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Field Testing of the Multi-Fluid LP Multiphase Meter

by

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INTRODUCTION

This report describes the results of the first successful offshore field test of a complete multiphase meter for measuring the production rates of oil, water, and gas flowing from live oil wells. The test was sponsored by Saga Petroleum and carried out by Statoil on the Gullfaks B Platform in the Norwegian sector of the North Sea. The multiphase meter was developed and supplied by Multi-Fluid.

Many efforts are underway in the world to develop and prove multiphase meters. In Norway alone, there are four large independent efforts to develop a meter. In February of 1992, Saga Petroleum purchased the first prototype of a new multiphase meter from Multi-Fluid for testing on live wells in the North Sea. The meter was installed in November 1992 on the Gullfaks B platform by Statoil and the field tests of the meter started in December. The results so far are very promising.

THE MULTIPHASE METER

The meter being tested by Saga and Statoil is a 4 inch, ANSI Class 600 LP Meter supplied by Multi-Fluid. It is a full-bore instrument measuring 66.7 cm in length and has no moving parts. Unlike some 'multiphase' meters under development, this meter measures the complete production stream without using separation to partially or completely separate the gas from the liquid for measurement purposes. The meter spool piece was fabricated in 316L stainless steel and weighs approximately 100 kg.

The complete multiphase meter consists of two separate meters. It has a composition meter for measuring the instantaneous volume or mass fractions of oil, water, and gas in the sensor. The meter also contains a velocity meter for determining how fast the mixture is flowing through the sensor. Combining the outputs makes it possible to calculate the instantaneous volume or mass production rates of the separate components in the flow stream. Figure 1 is diagram of the LP Meter.

The measurement principle of the composition meter is to determine the composition of a well stream by measuring its density and its dielectric properties (permittivity and conductivity). Mixture density is measured using a conventional single source gamma-ray densitometer which mounted directly on the sensor spool piece. Mixture dielectric properties are quite sensitive to the water content while mixture density is most affected by the gas. The complimentary nature of these measurements is well known. Multi-Fluid is not the alone in using this combination as the basis of a multiphase composition meter. What sets the LP Meter apart, however, is the method used to measure the dielectric properties of the mixture.

The measurement method used in the LP Meter is the 'resonant cavity' method. It is one of the oldest methods of measuring dielectric properties of low conductivity materials at high frequency and it is still the most accurate. It is almost exclusively a laboratory method, however.

A resonant cavity is an electrically closed structure inside which electromagnetic waves will resonate at characteristic frequencies related to the geometry of the cavity and the dielectric constant of the medium in the cavity. Electromagnetic waves injected into a cavity reflect back and forth inside it, until the energy is dissipated. If the wavelength of the waves match the geometry of the box in a well defined manner, then the waves will reflect back and forth in phase with one another generating a high energy standing wave. Electrically the response of a resonant cavity is illustrated in Figure 2. The response is characterized by sharp easily identified output power peaks at characteristic frequencies. By analogy, a resonant cavity works with electromagnetic waves in the same manner as violin strings work with mechanical waves. A violin string resonates, producing sound, at characteristic fixed pitches related to the length of the string.

To measure the dielectric constant of a material using the resonant cavity method, one simply takes a closed metal box, fills the box with the material, then measures the characteristic frequency or frequencies at which the box resonates. Comparing the characteristic frequencies of the box when filled with the material to the frequencies when the box is empty gives one a direct and unambiguous measure of the dielectric constant of the material. In addition, measuring the width of the frequency peaks determines the conductivity of the material. The advantages of the method are 1) no sensitivity to drift in electronics, 2) nearly complete isolation of the measurement electronics from the measurement system, 3) high sensitivity because frequency can be measured with high precision, and 4) direct measurement of the dielectric constant of the desired material in the measurement cell without the perturbing effects of other materials used to build the cell. The measurement is virtually digital in nature.

Multi-Fluid's contribution to the resonant cavity method is to devise a means of building a cavity which is physically open so that a continuous flow of material can pass through, yet is remains electrically closed so that it will resonate. In this manner, the method can be usefully applied in industrial applications such as multiphase metering. Custom microwave electronics and software have been designed to make the process of finding and tracking the resonant peak automatic and extremely fast. The LP Meter has all of the inherent measurement advantages of the resonant cavity method that are realized in the laboratory.

The velocity meter determines the flow rate using cross-correlation techniques. More specifically, the velocity meter makes very rapid microwave dielectric measurements in two separate resonant cavities separated by a known distance in the pipe. By statistically analyzing the signals from each of the measurement sections using cross-correlation techniques, it is possible to determine the average time it takes the material to flow from the first measurement section to the second. Given the transit time and the spacing between the measurement sections, one can determine the velocity. The LP Velocity Meter benefits from the natural amplification of signals in the resonant cavities. Even very slight fluctuations in composition can be correlated to measure velocity with the meter. This means the meter still be used in applications with little to no water and virtually no gas, unlike other meters which implement cross-correlation methods.

Some of the important meter specifications are listed in Table 1.

LIMITATIONS OF THE METER

The LP Multiphase Meter tested at Gullfaks has some limitations.

1) It is not able to measure production streams where the water is the continuous phase of the liquid. This is inherent to the resonant cavity method. When the conductivity of a material is too high, the cavity cannot resonate. In practice, this limits the usage of the meter to applications with water / oil ratios not much greater than 1. However, the meter is designed to function during water continuous slugs.

2) The first generation velocity meter is designed for bubble flow conditions only where the velocity exceeds about 2 meters per second. The first meter is specifically not designed for more difficult flow regimes such as plug, slug, or stratified flow. The complex slip flow conditions of these latter flow regimes pose greater difficulties for cross-correlation techniques. Multi-Fluid recommends that the meter be installed just after a static mixer with flow directed vertically upward. In this configuration, the mixer can break up most

annular or stratified flow conditions for the short distance necessary to perform the measurements. After more field experience is gained with the first generation LP Meter and specifically after cross-correlation techniques prove viable for bubble flow, Multi-Fluid will extend the measurement range of the velocity meter toward more difficult flow regimes.

3) The meter is intrusive, though it has virtually no pressure drop. It cannot be pigged. Another version of the meter, which has not been fully developed is non-intrusive. This version of the meter may be particularly suitable for subsea applications.

Multi-Fluid recognizes that this first meter is limited. Many applications for multiphase meters will require the capability of measuring higher water contents. Statoil and Saga together with British Petroleum Norway, Elf Aquitaine Norge, Phillips Petroleum Norway, and Total Norge have been sponsoring Multi-Fluid to develop a second multiphase meter capable of measuring 0 - 100% water. This second multiphase meter is based on very similar technical principles as used by the LP Meter. It will begin field trials later this year.

After years of effort and substantial research expenditures, the first generation of multiphase meters are moving toward implementation in the field. Nevertheless, it is becoming increasingly clear to those involved in the development of multiphase measurement devices that no single instrument will be capable of accurately measuring all possible multiphase flow streams with the accuracy and reliability required by users. Instead, different meters will serve different applications. The LP Multiphase Meter should be quite suitable for new fields where the water content is not high. It is also well suited for production logging of new wells.

THE TEST SET-UP

The meter is being tested on the Gullfaks B platform in the North Sea. It has been installed in a 4 inch bypass loop connected to the 8" test line running from the test manifold to the test separator. The meter is installed in a vertical line with flow directed upward. Twelve different wells are available for testing at the Gullfaks test site. The water/oil ratios vary from near zero to over 3. GOR's are typically 50 - 70 Sm^3/Sm^3. Eight different wells have been tested during the trials performed so far. The temperature and pressure at test conditions were about 65°C and 76 bar. The velocities on the tested wells varied from about 2 m/sec up to about 7.5 m/sec. The flow regime for these tests was uniformly bubble flow even though most wells produced between 30 and 50% gas by volume at test conditions.

The test separator itself is a very large three phase separator measuring some 15 meters in length and 3.5 meters in diameter. Because of its size, the separator is very efficient at separating the oil, water, and gas phases. Typically, the residual water content of the oil line is less that 0.5% and the oil in the water line is less than 0.1%. Consequently, the reference measurements made with the test separator are more accurate than would usually be expected with such a setup.

The instrumentation on the test separator consists of an orifice meter on the gas line and turbine meters on the oil and water lines. Figure 2 shows the test set-up. The accuracy of the liquid reference meters are estimated to be within ±2% of reading and the gas reference within ±5%. The test separator readings were totalized at 10 and 30 minute intervals to give volume production rates for oil, water, and gas. From the individual production rates, the average oil, water, and gas volume fractions and flow velocities were calculated for each test period to compare to the meter readings. The velocity reference was calculated by taking the sum of the production rates for the three components and dividing by the cross sectional area of the meter - Velocity $= \Sigma Q_i$ / Area. **This calculation assumes no slip flow between the different phases.** The composition reference was calculated similarly - Volume Fraction$_i$ = $Q_i / \Sigma Q_i$, again assuming no slip flow.

The meter was calibrated for the Gullfaks B tests in about 10 minutes. First, the gamma densitometer was calibrated in air at atmospheric conditions prior to pressurizing the bypass loop. Second, the estimated oil and gas densities at process conditions were keyed into the instrument. The values used were 815 and 53 kg/m^3 respectively. Finally, the approximate density of the water (980 kg/m^3) and its conductivity (60 mS/cm) were keyed into the meter. This completed the calibration process. No specific on-site dielectric or density measurements of the constituent oil, water, and gas components were necessary. Moreover, no attempt was made to differentiate between the oil, water, and gas in the different wells tested. The same values were used throughout. The simple calibration process is one of the attractive features of the meter.

Results from the meter were logged every 10 seconds, though its actual data output rate was more than once a second. The values were integrated for 10 and 30 minute intervals timed to match the measurement intervals from the test separator. These data sets were compared to determine how the meter was performing.

THE RESULTS

The meter was tested at periodic intervals from December 1992 to July 1993. Between test periods, the bypass loop was closed off. Thus the meter has not been exposed to been in continuous service for the whole 10 months of the test period. Results from several different test periods will be discussed and compared. Composition and Velocity Meter results will be assessed separately to better focus attention on the strengths and weaknesses of the first generation meter.

Composition Meter Results - The composition meter has performed exceptionally well during the tests. Figure 4 shows the results of tests in December 1992 and in July 1993. The meter and the test separator data are presented in terms of percent by volume for each of the components at process conditions for representative periods. In addition to the oil, water, and gas percentages, volume percent hydrocarbon is also shown. This is equal to the sum of the oil and gas contributions. This value is considered to be more valuable by many field engineers when looking at data for high pressure and temperature fluids. The percent error represents the difference in absolute percentage terms between the meter readings and the readings from the test separator.

The results for the three wells tested in December were very good. Well B11 was water continuous, so the meter did not function as expected. For the other wells, B17, B20 and B21, the meter was within ±1.1% of the reference for all components. The test on well B21 was repeated on two separate days with equally good results.

The meter was tested again in March of 1993 and again in July 1993. The results for the five wells tested in July are summarized in Figure 4 as well. For three of the five wells, B2, B10, and B20, the meter was well within ±1% for all components. On the remaining two wells, B9 and B25, three of the six of the readings were between ±2 and ±3% off as compared to the reference; one excessive error each for oil, water, and gas. The %

hydrocarbon error only exceeded ±2% in one case. In all the results are very promising for a first test.

While Figure 4 illustrates the performance of the composition meter over long periods, it does not illustrate the relative quality of the meter's performance for real-time measurements when compared to the test separator. The test separator required about 30 minutes to stabilize after the test well was changed. The composition meter, on the other hand, reacted instantly to each new well. Moreover, the composition meter readings changed very little during the course of a well test cycle. They were generally stable to better than 1.5%. Figure 4a) shows the composition meter readings and the measured values from the test separator compared at 30 minute intervals for well B21. Note, that even with a 30 minute integration time, the results form the test separator are not nearly as stable as those of the meter. It became quite clear during the test that the composition meter gave very accurate, reliable and fast trend information about the production of individual wells. Figure 4b) shows a typical real-time data log from the meter over a 30 minute interval.

Velocity Meter Results - The results from the Velocity Meter are shown in Figure 6. The well tests shown are for the same set of wells as described for the Composition Meter. In general, they are not as good as with the composition meter, but still encouraging. As Figure 6 shows, the velocity meter is reading consistently high in all test. The velocity errors range from +4.5% and +7.4% on the low end and +11.3% and +13.2% at the high end. A simple reduction of the readings by 10% would put the velocity meter within its specified accuracy of ±5%. During the whole of the test period, the velocity meter has performed quite consistently, but biased to the high side.

Figure 7a) shows the measured velocities compared to to the corresponding results from the test separator on well B21 at 30 minute intervals. As with the Composition Meter, the Velocity Meter results trend nicely with the test separator, but are less erratic when looked at over this time scale. Figure 7b) shows a typical real-time output from the meter over a 30 minute interval. The spike in the results is caused by software imperfection in the first meter. When the meter measured erratic velocities for a long enough period of time, the zero velocity routine was be enabled improperly resulting in the spike in the reading to 0 m/sec. The logging software which would totalize the results from the velocity meter was programmed to override these spikes. Thus, they did not effect the results in most cases. It is hoped that this flaw has since been corrected in the meter.

MultiRate Test - In March of 1993 (and again in July) the meter was tested at several flow rates on a single well to determine the consistency of the Composition and Velocity Meters respectively under the different conditions. The test was performed on well B21. The flow velocities tested were 2.3, 3.4, and 5.3 m/sec respectively. Figure 8 shows the production rates for oil and gas as measured by the LP Meter and from the test separator respectively. The results are consistent with the others obtained with the meter. The Velocity Meter read consistently high. The flow rates measured by the meter were uniformly higher than measured with the separator. The Composition Meter tracked quite well during the test as is evidenced by the match in relative flow rate errors for the oil and the gas. In all, the multiflow rate tests have demonstrated that them meter does not perform oddly when the flow rates are varied.

DISCUSSION

Composition Meter - The LP Composition Meter has performed to everyone's satisfaction. This is not to say that there is not room for improvement. Some of the results in July exceed the accuracy specifications of the meter. There are three likely sources of error. They will be investigated more carefully in future tests if possible.

- The oil and gas densities of the different wells are not likely to be equal. The variation was not taken into account when the meter was calibrated, however. Errors are likely to appear as a result. When the results are look at in mass terms instead of volume terms, however, the errors should be less. The instrumentation on the test separator at Gullfaks is being upgraded such that reference data will be available expressed in mass terms. Individual component masses will also be available at test conditions for calibration purposes.
- The first generation meter was not programmed to adjust the calibrated densities of oil and gas as the temperature and pressure conditions vary. During the many tests, temperature varied approximately between 49°C and 68°C. This is certainly enough variation to call into question the fixed density calibration used in the meter. A software update will address this problem in upcoming tests.
- The meter was calibrated with a constant water density and conductivity. As with the oil and gas density, it is not likely that the water was the same in each well. This too will be investigated more thoroughly in future tests.

Velocity Meter - The Velocity Meter results while consistent and encouraging. But, where is the offset in the results coming from? At the moment no satisfactory answer has been found. The meter at Gullfaks is one of only two LP Multiphase Meters that have been built. Neither of them is available to Multi-Fluid for additional testing to try to find the source of the error. It is hoped that the Gullfaks meter can be returned to Multi-Fluid at some point in the future for a thorough investigation.

- The most obvious explanation is slip flow - the gas is moving faster than the liquid. If this were the case, however, then it is difficult to explain the excellent composition meter results. If significant slip flow were present in the different wells, then the composition reference values calculated from the separator results would overestimate the gas significantly and underestimate the liquid components. This was not observed.
- The meter was not calibrated properly. This is a plausible explanation, but one which cannot be explored until the meter can be looked at again.
- The flow profile of live wells is flatter than it was for the low pressure fluids used to calibrated the meter. This would account for the offset in the velocity results, but it is difficult to test this possibility with multiphase flows.

CONCLUSIONS

This test represents the world's first successful offshore test of a complete multiphase meter on live wells. The meter did not perform perfectly - there is still an outstanding question about the offset in the velocity readings. The composition meter performed especially well, however. The specifications of ±2% accuracy for the composition meter seem supported by the results. When the results of the composition and velocity meters are combined to calculate production rates in terms of produced volume per unit time for each component, the results were consistently high by about 10% ± 3%. The error is directly attributable to the high velocity readings. 10% is the target accuracy for the first generation of multiphase meters to be used for allocation purposes. The Multi-Fluid LP Meter appears capable of achieving this target when the velocity measurement is corrected.

Looking ahead to field implementation, certain important options appear readily achievable with this technology.

1) The meter is a compact self-contained unit. It has low power and communication requirements. It should, therefore, be readily implemented as a subsea device. Engineering a marinized version of the meter should be underway soon.

2) Another important possibility with this technology is pre-choke installation. Most difficulties with multiphase measurement are associated with high gas fractions and complex flow regimes. One can take advantage of the higher operating pressures before the choke to alleviate these problems somewhat. Higher pressure means lower gas fractions and more nearly equal liquid and gas densities. The LP Multiphase Meter can quite easily be designed for very high pressure. This will give engineers the option to install the meter before the choke to improve their measurements.

The Multi-Fluid LP Multiphase Meter

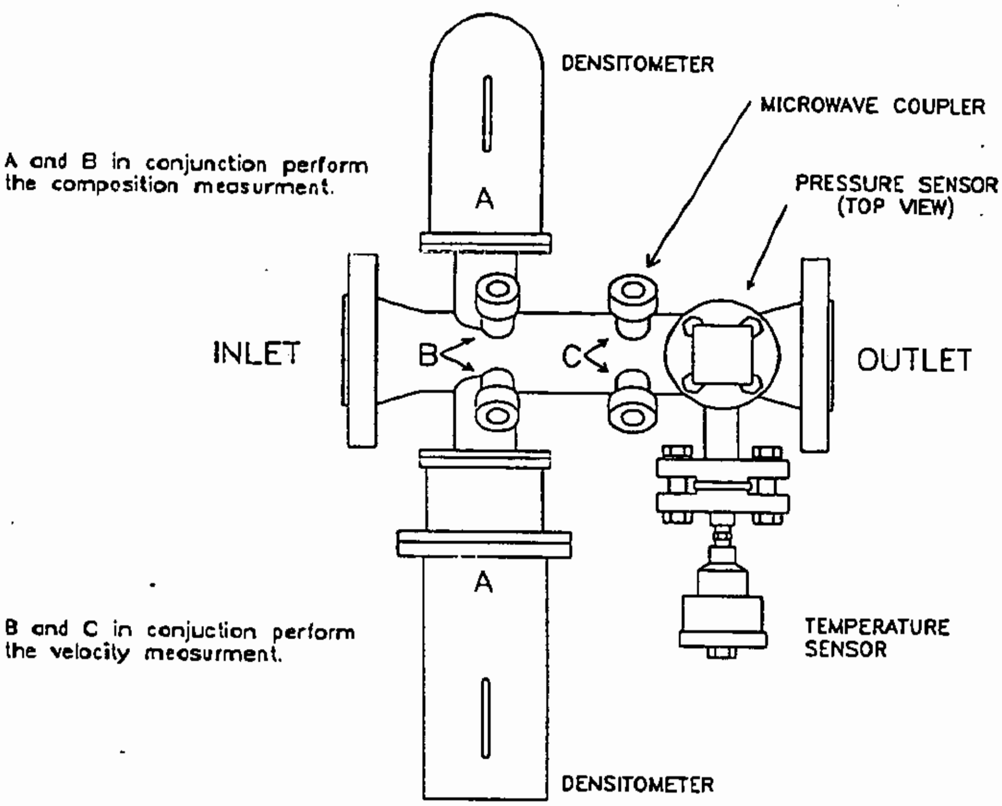

Figure 1

Typical Response of a Resonant Cavity

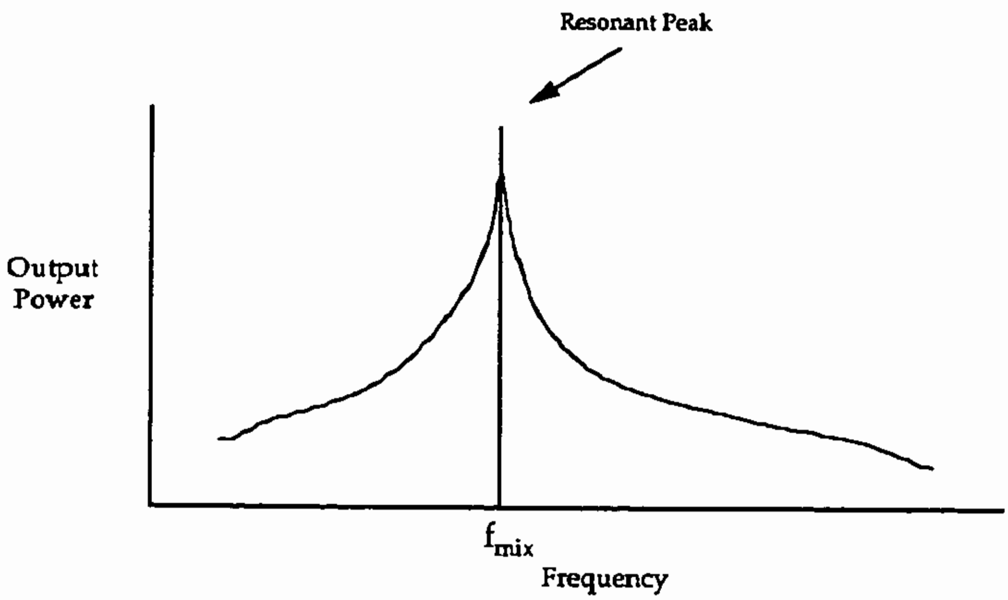

Figure 2

TEST FACILITIES

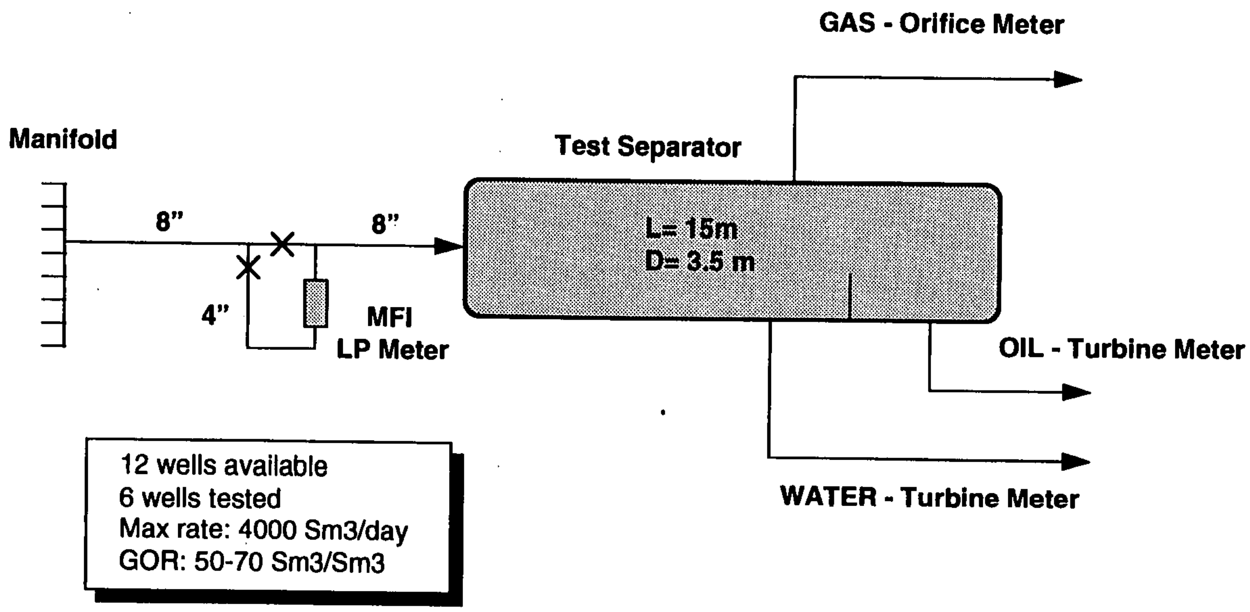

Figure 3

COMPOSITION METER TEST RESULTS

WELL NO.	DATE	TIME	TEST SEPARATOR				MULTIPHASE METER				PERCENT ERROR ABSOLUTE			
			Water %	Oil %	Gas %	HC %	Water %	Oil %	Gas %	HC %	Water %	Oil %	Gas %	HC %
December '92														
B11	18-Dec	11:00-15:00	65.2	22.4	12.4	34.8	No readings - Water continuous				-	-	-	-
B17	18-Dec	21:45-01:45	11.1	52.6	36.3	88.9	10.0	53.2	36.8	90.0	-1.1	0.6	0.5	1.1
B21	18-Dec	04:40-08:40	0.0	60.4	39.6	100.0	0.2	60.2	39.6	99.8	0.2	-0.2	0.0	-0.2
B20	19-Dec	12:30-13:30	0.0	61.0	39.0	100.0	0.6	60.2	39.2	99.4	0.6	-0.8	0.2	-0.6
B21	19-Dec	04:10-11:10	0.0	60.3	39.7	100.0	0.0	59.9	40.1	100.0	0.0	-0.4	0.4	0.0
July '93														
B2	29-Jul	18:30-22:30	0.0	61.2	38.8	100.0	0.1	61.5	38.4	99.9	0.1	0.3	-0.4	-0.1
B9	30-Jul	15:00-17:00	24.6	43.9	31.6	75.5	22.1	45.8	32.1	77.9	-2.5	1.9	0.5	2.4
B10	30-Jul	1:00-5:00	8.9	52.8	38.3	91.1	9.3	52.5	38.2	90.7	0.4	-0.3	-0.1	-0.4
B21	30-Jul	11:30-12:30	1.5	58.7	39.8	98.5	2.2	58.4	39.5	97.9	0.7	-0.3	-0.3	-0.7
B25	30-Jul	10:00-14:00	0.0	51.6	48.4	100.0	0.0	48.9	51.1	100.0	0.0	-2.7	2.7	0.0

Figure 4

A Comparison of the Meter Readings for %Oil
with Those of the Test Separator for Well B21

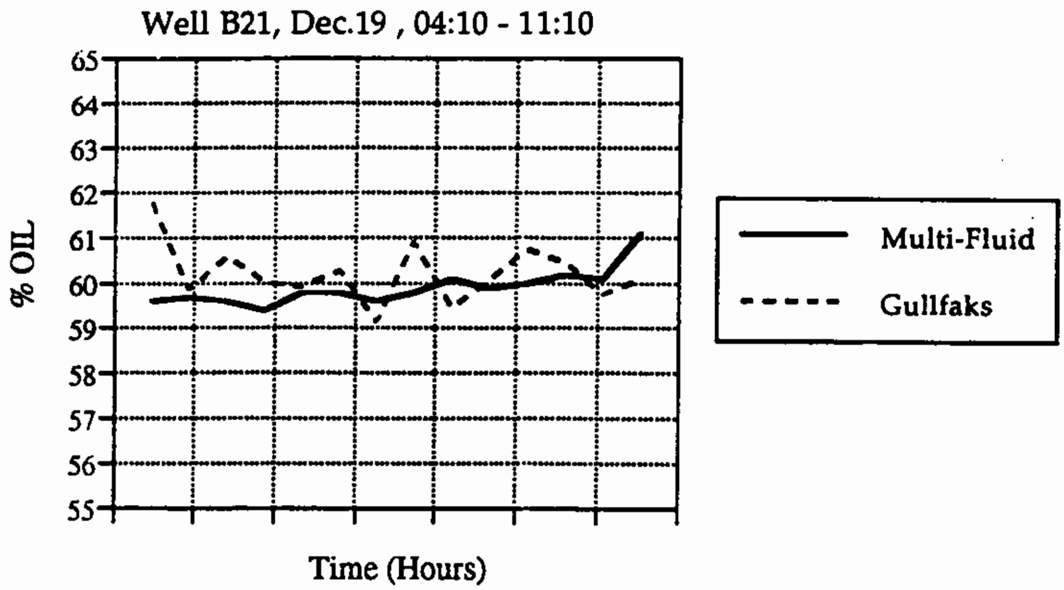

Figure 5a)

Real Time Composition Meter Output
for 30 minute interval on Well B10

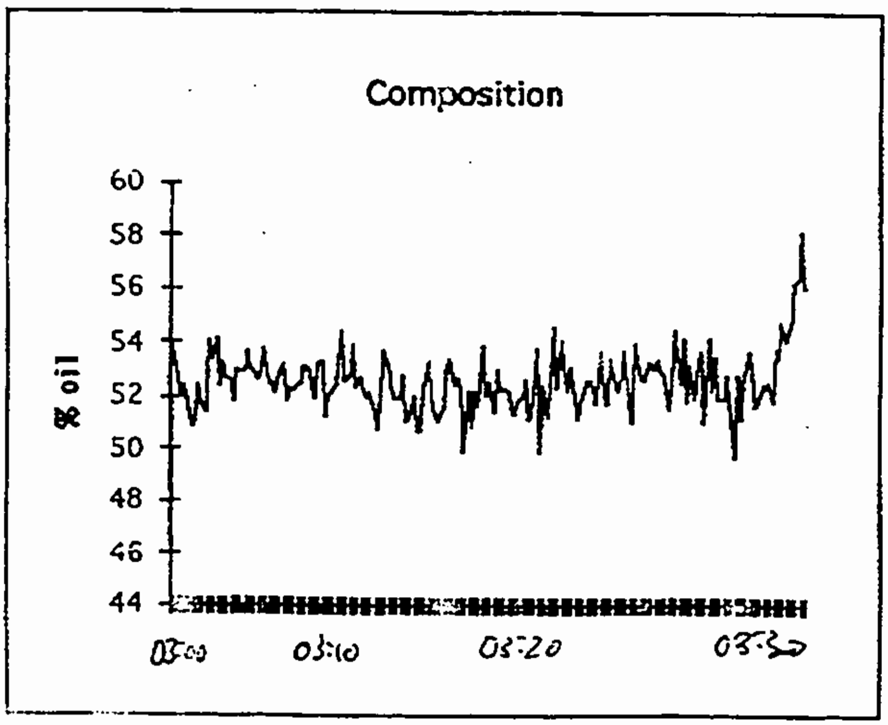

Figure 5b)

VELOCITY METER TEST RESULTS

WELL NO	DATE	TIME	TEST SEPARATOR (m/sec)	VELOCITY METER (m/sec)	PERCENT ERROR
			December '92		
B11	18-Dec	11:00-15:00		No readings Water Continuous	
B17	18-Dec	21:45-01:45	8.75	9.14	4.5%
B21	18-Dec	04:40-08:40	no data	2.88	-
B20	19-Dec	12:30-13:30	7.13	7.94	11.4%
B21	19-Dec	04:10-11:10	3.16	3.59	13.6%
			July '93		
B2	29-Jul	18:30-22:30	2.05	2.32	13.2%
B9	30-Jul	15:00-17:00	4.55	5.04	10.8%
B10	30-Jul	1:00-5:00	4.76	5.30	11.3%
B21	30-Jul	11:30-12:30	7.28	7.82	7.4%
B25	30-Jul	10:00-14:00	7.09	7.82	10.3%

Figure 6

A Comparison of the Meter Readings for Mixture Velocity with Those of the Test Separator for Well B21

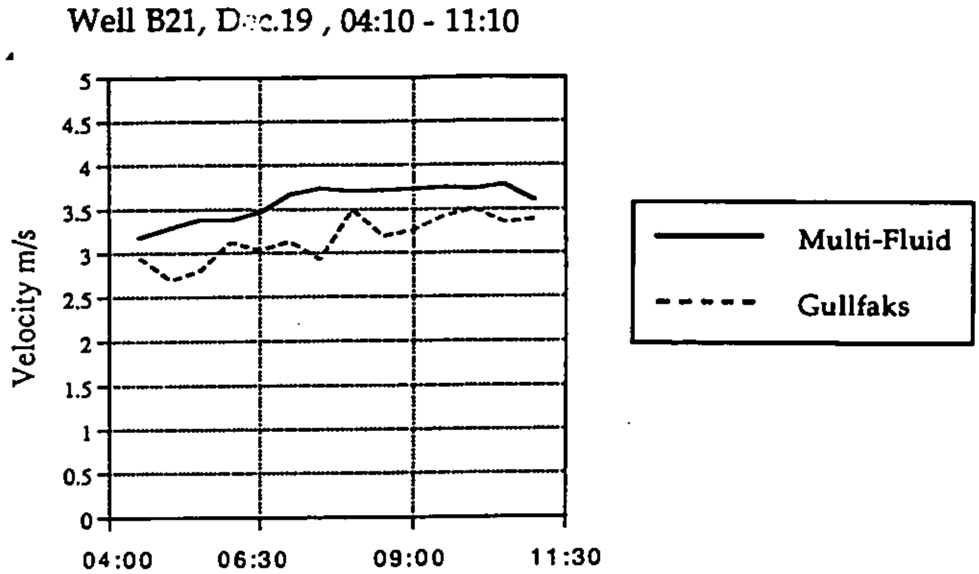

Figure 7a)

Real Time Velocity Meter Output for 30 minute interval on Well B10

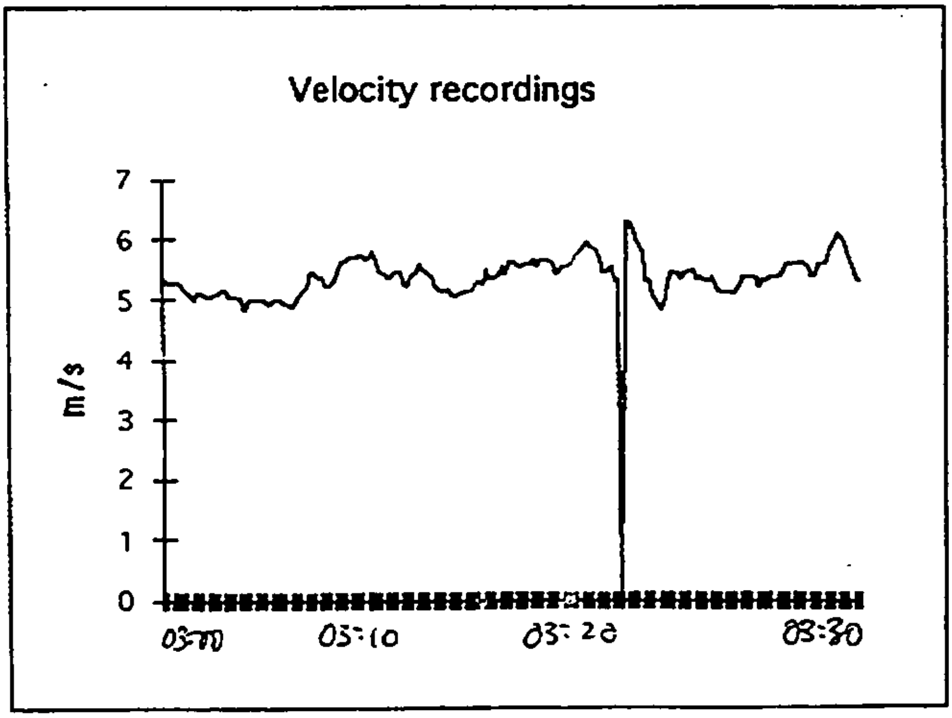

Figure 7b)

Gullfaks B - July 1993

Multirate test - Well B21

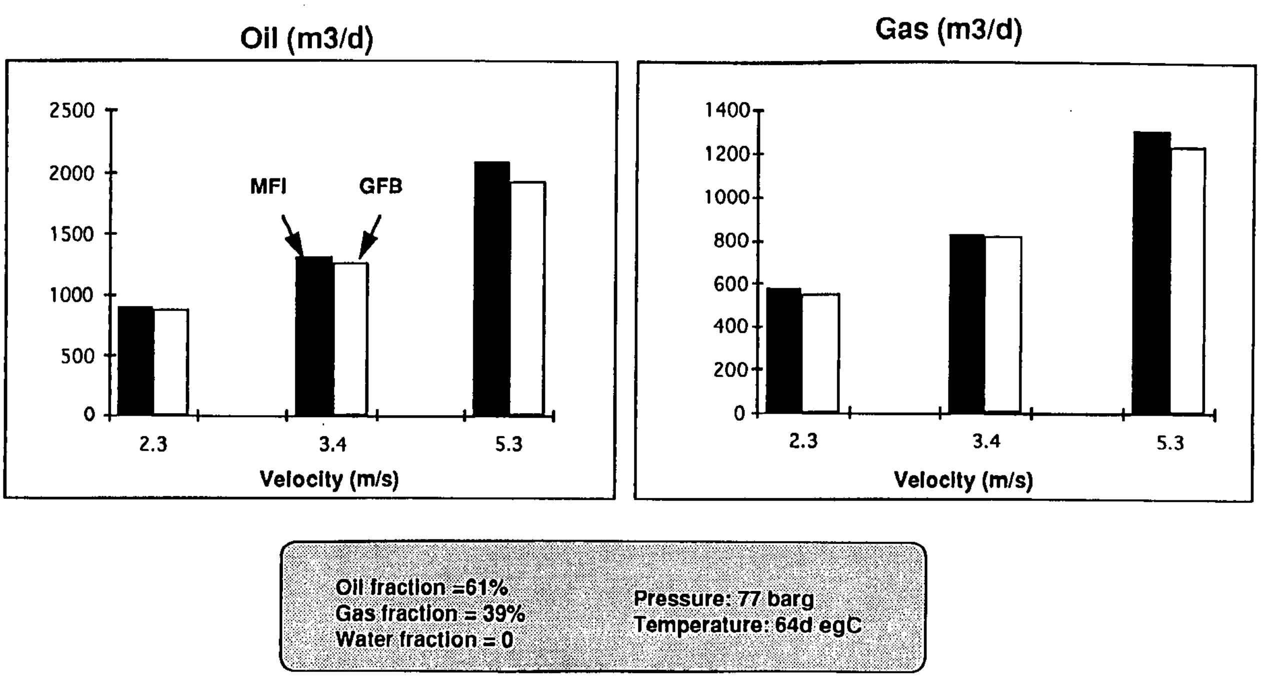

Figure 8

References

[1] Paper presented at the North Sea Flow Measurement Workshop, a workshop arranged by NFOGM & TUV-NEL

Note that this reference was not part of the original paper, but has been added subsequently to make the paper searchable in Google Scholar.