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BP MULTIPHASE METER TEST EXPERIENCE

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SUMMARY

The paper summarises test data obtained for the BP-developed multiphase metering system. The eight-year test programme included a rigorous and comprehensive flow loop investigation using an independent multiphase flow meter test facility and field tests at Wytch Farm, England and Prudhoe Bay, Alaska.

The paper highlights key findings along the development path which have enabled the system to evolve. Latest field test data from Prudhoe Bay demonstrate a measurement capability of comparable accuracy to a reliable test separator reference. Calibration for this was on a simple basis using water as the flowing medium.

The Alaskan data cover the most difficult of multiphase flow conditions, involving gassy flows exhibiting violent slugging and annular regimes. Gas volume fraction ranged from 62% to 95% and fluid pressure varied from 200 psig to 2300 psig. In combination with the previous testing, the trial gave confidence in reliability and demonstrated resilience of the calibration.

NOTATION

GOR	Gas/oil ratio
GVF	Gas volume fraction (%)
ρ_g	Gas phase density
ρ_{mix}	Total stream mixture density
ρ_o	Oil phase density
ρ_w	Water phase density
V	Instantaneous total volume flow rate
V_g	Instantaneous gas volume flow rate
V_o	Instantaneous oil volume flow rate
V_w	Instantaneous water volume flow rate
WC	Water cut (fraction)

1 INTRODUCTION

Multiphase flow metering offers the potential for significant savings in capital expenditure in the development of oil fields. Several multiphase metering techniques are under development with the principal aim of replacing the conventional test separator and its associated piping and systems for reservoir management and well allocation flow measurements. A successful multiphase meter is expected to give significant improvements in operational efficiency and reduction in maintenance burden compared to conventional separation systems, with further savings in costs and a potential enhancement of production revenues.

The development of metering hardware beyond the basic phase separation and measurement approach is hampered by the complex nature of multiphase flows. The tendency of the phases to segregate results in generally non-reproducible, unsteady spatial distributions of the phases, which flow at different bulk velocities from each other and exhibit highly unsteady non-uniform velocity profiles. This complex behaviour is often over-simplistically described as the term "slip".

The BP-developed multiphase metering system is based on fundamental principles which overcome these inherent difficulties in measuring unprocessed multiphase streams. The philosophy of this measurement technique is to produce repeatable measurement response to oil, water and gas flow rates such that calibration is possible and is, indeed, meaningful in that it applies universally to subsequent applications in the field.

At the heart of the technique is a positive displacement meter. The development of this meter and, in particular, the principle of the flow constraining influence of its mechanical elements, was described in (1). It is combined with a gamma densitometer which measures mixture density and, as such, can measure the total stream mass flow rate. However, its intended use, as a system, is to measure the flow rates of oil, water and gas. For this purpose, it uses an additional measurement of water cut.

An account of the field testing at Wytch Farm and some of the laboratory flow loop results was reported earlier (1,2). This work facilitated the development of field prototypes of the positive displacement meter and a separate phase fraction measurement cell from which the water cut could be derived. The work exposed deficiencies in the system, particularly with regard to a characteristic but test-site dependent bias error, but also demonstrated a high degree of confidence in mechanical reliability. It showed that measurement accuracy suitable for well testing could be achieved and improvements to effect this were identified.

Following the Wytch Farm trial, the bias measurement error was investigated at BP Research. Subsequently, the opportunity arose to test the system at the Prudhoe Bay oil field which offered a significant extension in the range of flow conditions compared to the previous test facilities in Europe. This trial allowed further investigations of the shortcomings already identified and the chance to test design modifications to address these.

This paper presents significant findings from the overall test programme on the prototype multiphase meter system and the latest results from the testing at Prudhoe Bay. The data show that the principles of the metering technique work in practice.

2 MULTIPHASE METER SYSTEM

The positive displacement meter is shown installed at the Prudhoe Bay test site in Figure 1, with a phase fraction cell situated downstream in the background. Both devices have been described in the previous references (1,2). These prototypes were 4" designs, suitable for ANSI Cl 1500 service as at the Prudhoe Bay test location.

The system uses a novel combination of a fast response (0.1 secs) gamma densitometer with the positive displacement meter. The gamma beam senses across maximum cross-sectional coverage of the multiphase mixture within a specially shaped chamber which is located integrally within the swept volume elements. This ensures that mixture density and total stream volume flow rate are measured simultaneously at a point where the phases are constrained to move at a single velocity. The fast response of the densitometer was selected on the basis of BP experience of tracking multiphase flows using nucleonic gauges.

The instantaneous oil, water and gas volume flow rates at meter pressure and temperature are derived from the following three equations. These can be deduced from simple summations relating total mass and volumetric flow rates to the phase flow rates and densities and from the equation defining the water cut. The relationships rely on the assumption of zero phase slip at the measurement point, as ensured by the integrated positive displacement - gamma densitometer system:

$$V_o = \frac{V.(\rho_{mix} - \rho_g).(1 - WC)}{WC.(\rho_w - \rho_o) + (\rho_o - \rho_g)} \quad \text{..................(1)}$$

$$V_w = \frac{V.(\rho_{mix} - \rho_g).WC}{WC.(\rho_w - \rho_o) + (\rho_o - \rho_g)} \quad \text{..................(2)}$$

$$V_g = V - \frac{V.(\rho_{mix} - \rho_g)}{WC.(\rho_w - \rho_o) + (\rho_o - \rho_g)} \quad \text{...........(3)}$$

The water cut is derived by a second sensing means, such as a phase fraction measurement device, as in the example of Figure 1.

A pressure transmitter mounted at a side tapping into the central densitometer chamber of the positive displacement meter gives the pressure at the multiphase flow measurement point. The line temperature may be measured by a transmitter located in piping close to the multiphase meter. These readings are used to derive the single phase fluid densities which appear in the above equations.

Volume formation factors for the oil, water and gas and solution GOR may also be computed from the measured pressure and temperature at the multiphase meter to convert the line phase flow rates to stock tank quantities. The instantaneous phase flow rates are typically sampled at 0.1 second interval and integrated over the well testing period (which can be for many hours) to derive average flow rates.

3 TEST EXPERIENCE

The following account presents measurement data taken during the course of the entire test programme to establish the principles of the multiphase metering system and validate the associated calibration methods.

The analysis of measurement errors is used to assess the performance of the separate components as well as the phase flow rate measurement accuracy of the combined multiphase meter system.

Specifically, the positive displacement meter is evaluated in terms of relative error in total volume flow rate measurement.

The mixture densitometer reading and, in particular, adherence to the no-slip principle are assessed by the relative error in total mass flow rate measurement. This must account for any total volumetric error characteristic of the positive displacement element which contributes within the product of density x volume.

The means of measuring the water cut required by the system has also been evaluated.

Finally, relative errors in individual phase flow rate measurements are presented to analyse the accuracy of the multiphase meter system as a whole.

3.1 Error Definition

Here, the test data are plotted as measurement errors as determined by the difference between multiphase meter reading and reference reading of average flow rate. These errors are defined in "relative" terms; that is, they are expressed as a percentage of actual reading or flow rate (not as a percentage of full scale reading). (Note that, in the analysis of errors in individual phase flow rate measurement that follows, the term relative means percentage of actual phase flow rate and **not** of actual total stream flow rate).

3.2 Volumetric Evaluation

The purpose of this part of the analysis is to assess the accuracy and repeatability of the positive displacement element of the multiphase measurement system.

The average total (oil + water + gas) swept volume measurement through the positive displacement meter is compared with the sum of the oil, water and gas single phase measurements by the reference metering system.

The results from the Prudhoe Bay tests are shown in Figure 2, together with those taken from earlier controlled flow loop tests conducted using the independent multiphase meter test facility. There, the single phase reference metering was calibrated to accurate traceable national standards.

The volumetric "K-Factor" curve of the multiphase meter used in this graph was established from the single phase water testing in the independent flow loop facility. The capability of the positive displacement meter, calibrated in this simple way, to repeat multiphase total swept volume measurements to within ± 5% relative is clearly demonstrated over a turn-down of 7:1.

Note that the flow loop tests covered pressures ranging 15 to 90 psig and involved the full range (0% to 100%) of gas volume fractions (GVFs) and flow regimes. The Prudhoe Bay data include points for pressure ranging from 200 psig to 2300 psig and were entirely in the most difficult high void fraction range of multiphase flows.

The repeatability of the data in Figure 2 between test sites and periods is especially noteworthy. It confirms insensitivity to multiphase flow pattern and conditions and how the positive displacement design is accurate for extremes of unsteadiness and low pressure gas (where fluid leakage past clearances is expected to be at its worst).

Further, through the test programme in Europe and Alaska, 12,000 run hours have accumulated using the prototype meter. Although the original internal bearing system has been modified at various stages to improve performance (resulting in a proven design run for 2000 hours at Prudhoe Bay in 1993) all other components were not changed. Thus, the data demonstrate the ruggedness and reliability of the meter and the resilience of its calibration curve.

Details of the Prudhoe Bay field trial given in (3) describe the reference metering system and procedures used to ensure good quality measurement data. Accurate and reliable reference metering was not available for the gas phase during the earlier trial at Wytch Farm to enable total volumetric accuracy assessments. This trial was primarily used during the development stages to evolve a rugged and reliable mechanical design.

During the Alaska trial in July 1993, for one particular well - H21, the meter exhibited apparently high readings of total throughput. These tests were repeated in October 1993 with the same choke settings but the error data fell in with all the other points and the discrepancy was not repeated. The reason for the erroneous points is unknown but one possible cause can be identified.

A clear possibility is that the gas reference (a turbine meter with no direct means of calibration checking) was in some way affected for this particular well (e.g. liquid carry-over at the separator gas outlet). The same tests do not exhibit corresponding errors in total mass measurement (see next section). The mass comparison is primarily influenced by the liquid reference metering whereas the total volume analysis is particularly sensitive to the gas reference owing to the high gas volume fraction of the well streams at Prudhoe Bay. Any error effect attributable to the multiphase meter could be expected to manifest itself in both the total volumetric and mass analyses.

Immediate repeat measurements of wells tested confirmed the errant data for H21 in July 1993. By October that year, the water cut of this well had risen from 65% in July to 77%, possibly further away from inversion-point emulsion viscosity effects which could have existed in July and affected separator performance.

The overall good and repeatable agreement between the multiphase meter measurements of total volume flow rate and the reference derived values throughout the tests confirms a high degree of confidence, not only in the multiphase positive displacement meter, but also in the reference metering systems. This confidence extends to the fluid property equations used to compensate for differences in pressure and temperature between test section and reference.

3.3 Total Mass Evaluation

All the test data, excluding Alaskan tests conducted in 1993, are plotted in Figure 3. The characteristic 'U' shaped bias error as a function of void fraction has been reported previously (1). The bias appears to be test site specific, the data otherwise exhibiting repeatability to within ±5% about the offset over most of the GVF range. Although plotted against GVF, they represent a number of different wells, flow rates, wide ranging pressures and water cuts and the full range of multiphase flow regimes.

Between the testing at the independent facility in 1990 and the two-year programme at Prudhoe Bay commencing in 1992, the mass bias characteristic was investigated during two-phase (air-water) flow loop tests at BP Research in 1991. Specifically, the geometry of the central section of the positive displacement meter was temporarily modified to investigate variations in the flow path through the gamma beam of the density gauge. From the analysis of the positive displacement meter total volume flow rate results, it was clear that the mass biasing error was primarily associated with the mixture density measurement.

Subsequently, in 1992, other work published in the literature (4) and an analysis by the supplier of the nucleonic densitometer highlighted a theoretical source of error exhibiting a 'U' shaped bias characteristic when plotted against GVF similar to the observed test results.

This evidence and observations arising from the air-water experiments identified a potential significant source of biasing of the mixture density measurement associated with the packaging and swirling actions of the positive displacement meter. Although constraining the level of phase slip, it is believed that the rotor action segregates the gas and liquid phases within the positive displacement chambers to produce perturbations in multiphase composition at the gamma beam. The frequency of these is related to rotor speed and is significantly higher than the response capability of the current detector technology. Coupled with the logarithmic characteristic of the density gauge, the averaging of photon counts can introduce a bias.

The theoretical work used modelling of compositional fluctuation amplitude to study this biasing effect. In practice, the amplitude of compositional fluctuations within the positive displacement meter, unlike the "packaging" frequency, is unknown. It depends on several variables of the flow stream, such as flow regime, composition and phase distribution pattern (and fluctuation of these) at entry to the meter and fluid properties such as gas density and liquid viscosity. All these factors vary between installations, which is one explanation for the site-specific nature of the biasing seen in Figure 3.

On the basis of the experiments conducted at BP Research, the path length of the gamma beam within the flow stream was reduced. This was intended to produce a more linear response characteristic of the densitometer in order to minimise the biasing effect. The modification of the flow cross-section was also intended to address a suspicion of localised phase segregation and slippage effects at the gamma beam. These aspects are described in more detail in (3).

Following the 1992 tests at Prudhoe Bay, the meter was returned to the UK in order to implement the design change. A number of well tests were then conducted at Prudhoe Bay following re-commissioning of the modified meter in 1993. The resulting total mass flow measurement error data are plotted in Figure 4 for comparison with the 1992 results.

As these data show, significant improvement in the performance of the multiphase meter resulted from the alterations to the gamma beam chamber. The data indicate that the characteristic bias error of the gamma densitometer system has apparently been fully eliminated.

(Note: ten percent of the bulk 15% negative error observed in Figure 3 for the Alaskan data is attributed to the gamma densitometer measurement. The remaining -5% is attributable to the use of a constant volumetric K-factor deduced from an original positive displacement meter calibration using a refined oil. For the Prudhoe Bay flows, this gives a 5% under-read on average compared to the calibration curve for tap water. This was not corrected in Figure 3 so as to give a consistent comparison with the earlier data from the field trials at Wytch Farm and air-water laboratory tests. These used the oil calibration factor and are subject to varying volumetric deviation from the water based calibration. The applicability of the water K-factor curve was demonstrated in the previous section and has been used in plotting Figure 4. Calibration philosophy is discussed in more detail in (5)).

The multiphase metering system is scheduled for testing as part of the UK National Engineering Laboratory "Multiflow" joint industry programme to independently evaluate multiphase meters. These tests will enable a check for elimination of the 'U' bias characteristic over the full range of gas void fraction.

3.4 Water Cut Measurement

The water cut measurement required within the BP multiphase metering system can be provided from a choice of measurement means. These range from full-bore phase fraction cells (BP has been involved in the development of alternative devices as part of its overall multiphase meter technology programme (2, 6)) to sampling methods.

For accurate results using any of these methods, the oil and water phases should ideally be well mixed together in the flow stream. This ensures representivity for sensors using only a sample or close adherence to mixture field models where, for example, full-bore dielectric techniques are used. Equally important, it ensures the absence of slip between the oil and water phases so that their quantity ratio is represented by the water cut deduced, even if the gas phase slips relative to the liquid phases within the sensing zone. For certain multiphase flow regimes, the shearing actions between the gas and liquid phases can ensure that this is the case. Fluid sample data obtained during the independent flow loop testing of the BP multiphase meter on oil, water and gas show how the internals of the positive displacement meter ensure thorough mixing of the oil and water across the full range of flow regimes.

During these flow loop tests, manual fluid samples were drawn from a side-tapping located on the multiphase meter body at the gamma beam section. This was achieved by means of a simple ball valve arrangement from which fluid could be momentarily drained during the course of testing. Table 1 compares water cuts derived from 250 ml graduated jars, once the sample liquids had stratified, with reference values determined from the accurately measured single phase flow rates at entry to the flow loop.

The agreement between the sample and reference water cuts is good. The observed deviations would be acceptable for practical oil field well test use. The tests shown cover a wide range of gas void fractions, regimes and flow rates and oil-continuous and water-continuous emulsions. Such agreement could only be achieved with thorough mixing of the oil and water phases, especially given the unsophisticated nature of the manual sample measurements.

On the basis of this evidence, it is concluded that the various water cut measurement techniques can be used provided the fluids are sensed or sampled in close proximity downstream of the multiphase meter.

This aspect of the system was investigated further at Prudhoe Bay using the phase fraction cell shown in Figure 1. Specifically, a method of dynamically tracking the water cut in the high GVF streams was tested. Limited data were obtained (before a fault occurred with the fraction cell) which show that water cut can be measured accurately downstream of the positive displacement meter in high gas content multiphase streams. The tracking technique and the results are described in (3).

At this stage, practical sensor techniques giving accurate water cut measurement for oilfield multiphase streams have not been fully established, especially for high water cuts (near oil-water inversion point and water-continuous conditions). BP is still involved in joint-industry programmes to evaluate emerging technology.

3.5 Multiphase Measurement Evaluation

The results presented in the preceding sections have allowed the evolution of an understanding of the behaviour of multiphase flow through the multiphase metering system and its influence on sensor measurements. By analysing the measurement components separately, error sources have been isolated and practical calibration methods have been established. Latest understanding culminated in a final design of meter tested at Prudhoe Bay in 1993.

For the purpose of assessing the central multiphase flow measurement system in terms of its accuracy in measuring the phase flow rates, the latest Prudhoe Bay test data have been analysed using the water cut reading deduced from the test separator reference system. This allows an examination of the accuracy of oil, water and gas flow rates derived from the total volume and mixture density readings of the multiphase meter, given an accurate reading of water cut.

The 1993 test results have been analysed following the successful elimination of the bias error previously associated with the gamma densitometer as described in the section on total mass analysis.

The relative error data for oil, water and gas flow rates are plotted against reference total volume flow rate in Figures 5a, 5b and 5c respectively.

In Figure 5a, the relative errors show a scatter band achieving the ±5% level. This is a range quoted for multiphase meters intended to replace the test separator as a means of well testing and allocation measurement. In fact, the errors seen in Figure 5a are within the uncertainty levels associated with the reference metering system, which thus limits the capability to judge the multiphase meter beyond the scatter band observed.

Similarly, the error data for the water flow rate measurement, Figure 5b, on the whole exhibit a ±5% scatter, although a few points deviate significantly from this level. These outlying points represent low water cut wells (1% and less). They arise since the water flow rate is a small quantity in the total multiphase stream and its measurement is prone to magnification of error sources. This can occur even though the reference water cut has been used in the breakdown of the phase flow rates because of small errors in the other sensor readings on which the water flow rate depends. Also, the conversion of the reference water cut at test separator pressure and temperature to an in-situ value at multiphase meter conditions is susceptible to errors in oil and water formation volume factor calculations.

The gas phase flow rate error data plotted in Figure 5c largely comply with the ±5% band, within the uncertainties of the reference system. The outlying high readings all reflect the apparently high total volumetric readings observed in July 1993 when testing well H21. With the high gas volume fraction of the Prudhoe Bay well streams (62% to 95%) the error behaviour in gas phase flow rate measurement is mainly dependent on the accuracy of the total volumetric reading. (The liquid error data in multiphase flow measurement in general more closely mimic the corresponding total mass data). The high volumetric readings for H21 in July 1993 have already been discussed.

In all three graphs, the repeatability of the tests between July and October 1993 should be noted. Any remaining bias levels and uncertainty levels are within the uncertainties of the reference measurement system and a deeper investigation of error patterns is considered to be not worthwhile.

These data confirm that, given an accurate measurement of water cut, the positive displacement multiphase flow meter system can measure the flow rates of oil, water and gas to an accuracy comparable to a test separator system. At Prudhoe Bay, this has been achieved under the most arduous multiphase flow conditions, particularly in terms of gas voidage. The high volumetric gas contents make the measurement of the liquid phases particularly susceptible to error.

3.6 Calibration and Use in Practice

In order to obtain the above results, the gamma densitometer (a standard Cs-137 system) was laboratory calibrated by filling the meter with mains water and recording the detector reading and then repeating this measurement with the meter drained (giving a density reference from air at atmospheric pressure). Thus, including the water based calibration for the positive displacement meter K-Factor (section 3.2), the basic multiphase meter can be calibrated on a simple and practical basis.

Prior to safe-out procedures and pressurisation of the meter at the start of the field trials, it was a simple matter to check the "empty" air densitometry reading in-situ. The basic calibration of the densitometer unit mounted on the prototype meter for field and independent loop testing was first established in March 1990 (using air and tap water). The detector calibration count readings have been repeatable to within ±0.5% up to and including the last checks at Prudhoe Bay on all occasions. These have included mounting and disassembly at the Wytch Farm oil field and the independent test loop site. No faults have arisen with the densitometer equipment throughout the trials programme.

During the test work, simple procedures were established which could form the basis of in-service calibration checking. These can be applied to the mixture property sensing devices such as the densitometer and water cut sensors, where these are mounted vertically and can be isolated in a by-pass piping arrangement. (The thrust bearing design of the BP multiphase meter positive displacement mechanism is such that it must be mounted for vertical down-flow).

The method basically consists of a series of repeat valve operations where, in by-pass mode, the sensor spool is filled with single phase fluid at line pressure and temperature. For example, in downflow, with the upstream isolation valve shut and the downstream valve open, the sensor fills with vapour phase. Conversely, it fills with liquid with the reverse valve configuration. A combination of repeat valve operations and settling periods ensures stratification with the phase interface levels clear of the sensing region. The presence of a single phase fluid is confirmed when repeatable readings are observed each time the measurement section is exposed to production at one end and then isolated.

This was initially attempted at Wytch Farm and then on several wells at Prudhoe Bay giving a range of fluid pressures and temperatures. Line density measurements for the oil and gas phases obtained from the densitometer of the BP multiphase meter are plotted in Figure 6 against reference values derived from site sample and PVT data. The agreement, generally within ± 6% relative, is within uncertainty figures quoted with the reference data.

At both sites, the procedure only required one or two iterations with the valving and took about half an hour. It was possible to isolate the oil, water and gas phases in turn to measure the density of each. In practice, the method could form an additional part of well testing procedure whereby sensor calibration could be checked when required.

Furthermore, the method provides a means of checking or directly measuring the phase densities used in equations (1) to (3) to derive the phase flow rates. These otherwise rely on equation-of-state calculations and sample data. It can be used in installations where the pipe section can be isolated and purged with service fluids to provide a more reliable reference fluid calibration if the properties of the injectant are accurately known.

(It should be noted that the exponent of the gamma beam decay law of the densitometer is a product comprising density (the measurand), path length and mass absorption coefficient. This coefficient depends, to a limited extent, on the atomic make-up of the attenuating medium, although it is particularly influenced by the presence of hydrogen. Using an average mixture or bulk value for the coefficient (as determined by calibration on air and water) can lead to ±2% error in density when reading at the extremes of 100% oil or 100% water. The effect can be corrected by an iterative procedure when the three phase flow rates (and hence there ratios) have been measured by the multiphase measurement system. This refinement was not made for the BP test programme but its inclusion in later versions of the system could improve even further on the flow rate error levels observed).

3.7 Pressure Drop

Through the course of the BP test programme, confidence has been established in the performance of the multiphase meter for an envelope of gas-liquid flow rates, see Figure 7. This envelope covers the full spectrum of flow regimes, from all liquid to annular flows. The pressure drop across the meter depends on where in this envelope it is operating and can fluctuate in intermittent flow regimes. Pressure loss also depends on fluid properties and the nature of the variation in its level during intermittent flows can depend on the behaviour of a particular well and the topography and components of the entire flowline. Maximum continuous and peak pressure differentials of 35 psi have been observed across, and tolerated by, the meter during extended periods of well testing. The meter has been subjected to violent surges continuously for several days during some well tests at Prudhoe Bay (cycling over seconds in some cases and tens of minutes in others).

4 CONCLUSIONS

The principles of the multiphase flow meter system developed by BP were adopted in order to overcome the complex and generally non-reproducible nature of multiphase flow streams. Key observations, arising out of an eight year test programme, have enabled these principles to be realised in practice. The test data, presented in this paper, show that flow rate measurements within ±5% relative error can be obtained on the basis of simple and practical calibration procedures. This level of scatter is within the uncertainties of the separate phase reference metering and meets the target level specified for well test and allocation purposes in order to replace the conventional test separator system. At the Prudhoe Bay oil field, this has been achieved under the most difficult multiphase flow conditions in terms of reliability and accuracy.

BP Exploration is now targeting specific application opportunities where multiphase metering will add value. In common with several other multiphase meter systems developed, the prototype BP system is a 3" to 4" nominal design and further experience will be required in order to confirm its capability for larger line sizes. Flow rate operating envelopes requiring larger designs have been identified in some applications. These cases include examples of total field production measurement for allocation. Furthermore, acceptable accuracy of water cut measurement has only been demonstrated for oil-continuous liquid conditions. The development of techniques for full-range (0-100%) water cut measurement continues.

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DISCLAIMER

The techniques and/or conclusions are those of the authors and may or may not be shared by the Prudhoe Bay Unit Working Interest Owners.

TABLE 1

TEST	TOTAL FLOW	GVF	REFERENCE WATER CUT	SAMPLE WATER CUT	DEVIATION WATER CUT
	m3/h	%	%	%	%
		< 45% WATER CUT (OIL CONT.)			
202	77.1	22.4	18.1	19.3	1.2
213	182.2	91.0	28.4	29.9	1.5
219	153.3	98.2	29.8	30.3	0.5
223	61.0	42.5	29.4	28.3	-1.1
224	122.9	52.4	29.4	29.5	0.1
225	58.9	61.3	29.0	28.8	-0.2
230	63.8	53.2	38.4	38.6	0.2
242	169.4	62.3	28.8	30.2	1.4
		>45% WATER CUT (WATER CONT.)			
210	173.4	58.8	65.6	65.5	-0.1
217	194.4	95.1	55.4	55.4	0.0
232	122.6	43.8	59.5	60.2	0.7
233	128.6	45.8	57.1	57.1	0.0
243	168.4	62.6	61.5	59.2	-2.3

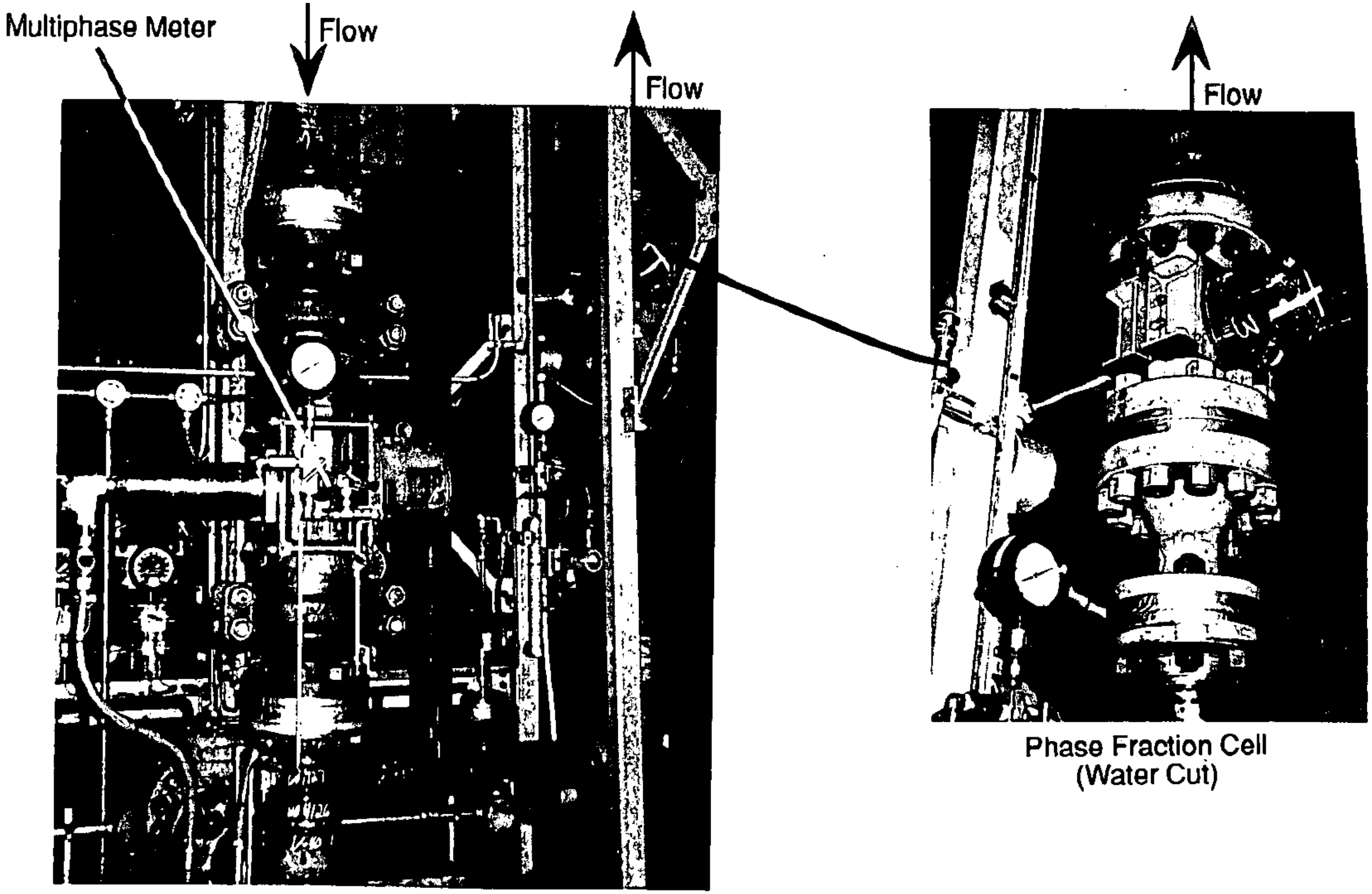


Figure 1. Test Multiphase Meter System

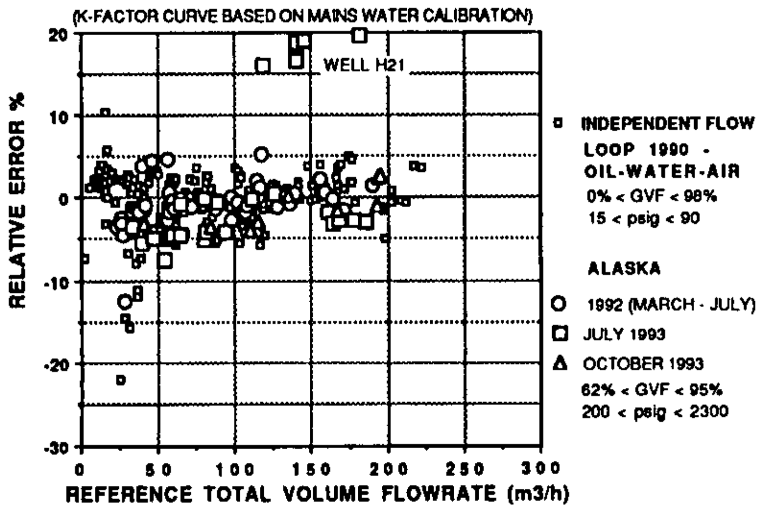


Figure 2. Volumetric Performance of Multiphase Flow Meter

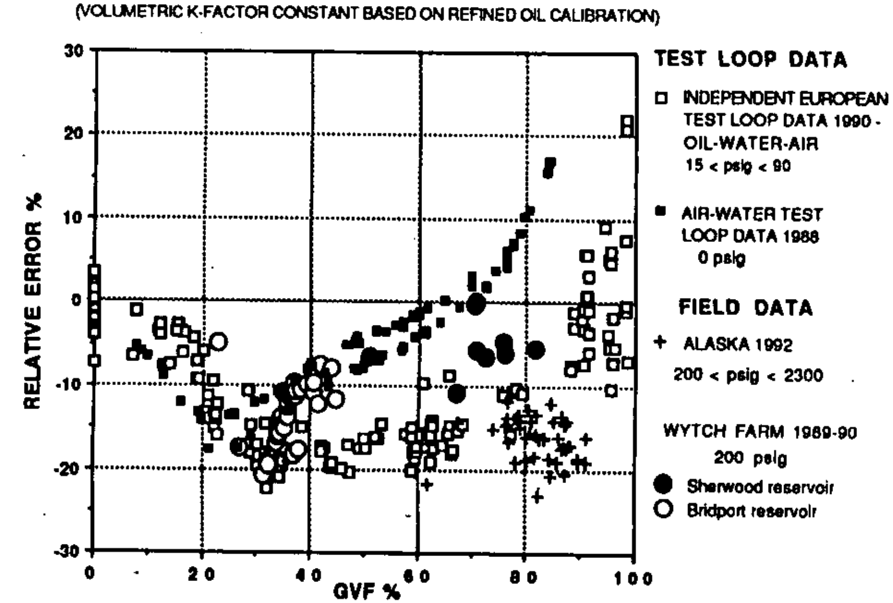


Figure 3. Total Mass Measurement Performance of Multiphase Meter

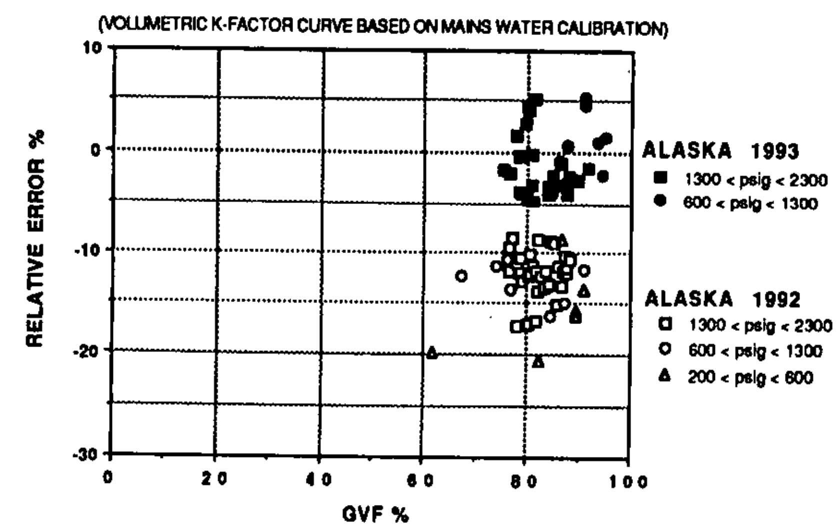


Figure 4. Total Mass Measurement Performance - Alaska

Figures 2, 3 and 4 taken from Reference 3.

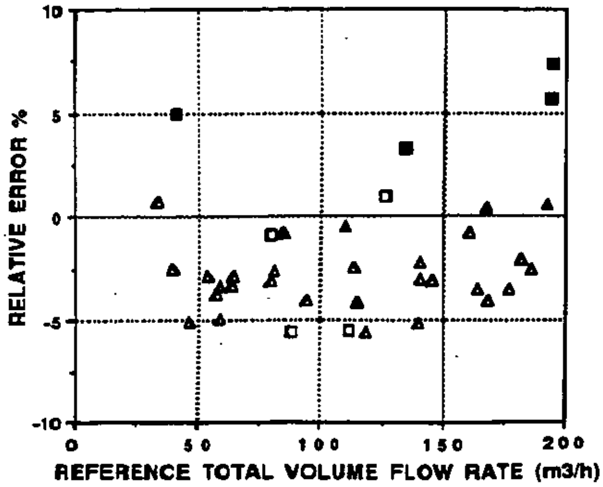


Figure 5a. Oil

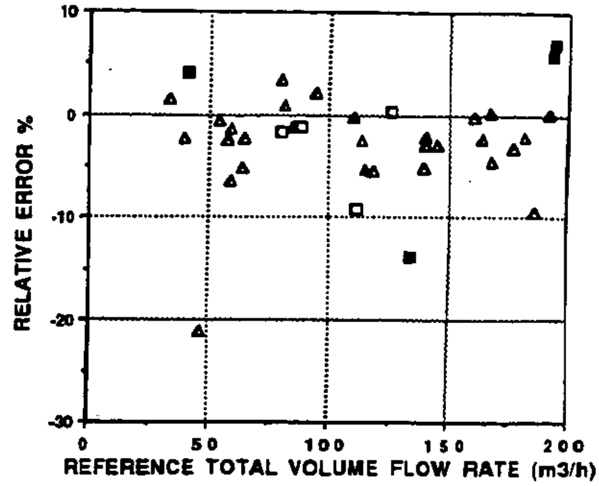


Figure 5b. Water

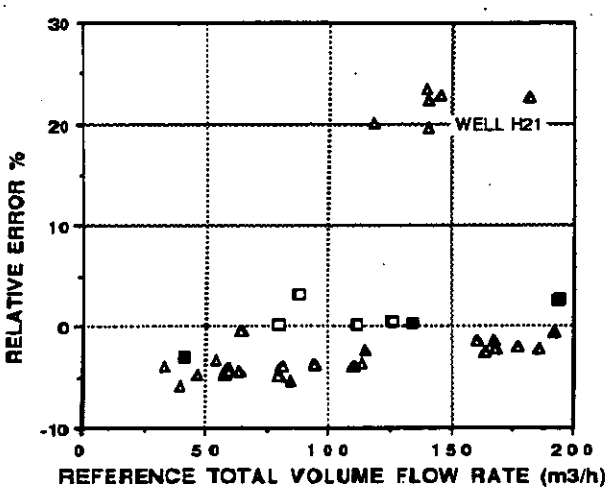


Figure 5c. Gas

JULY 1993
□ 600 < psig < 1300
△ 1300 < psig < 2300

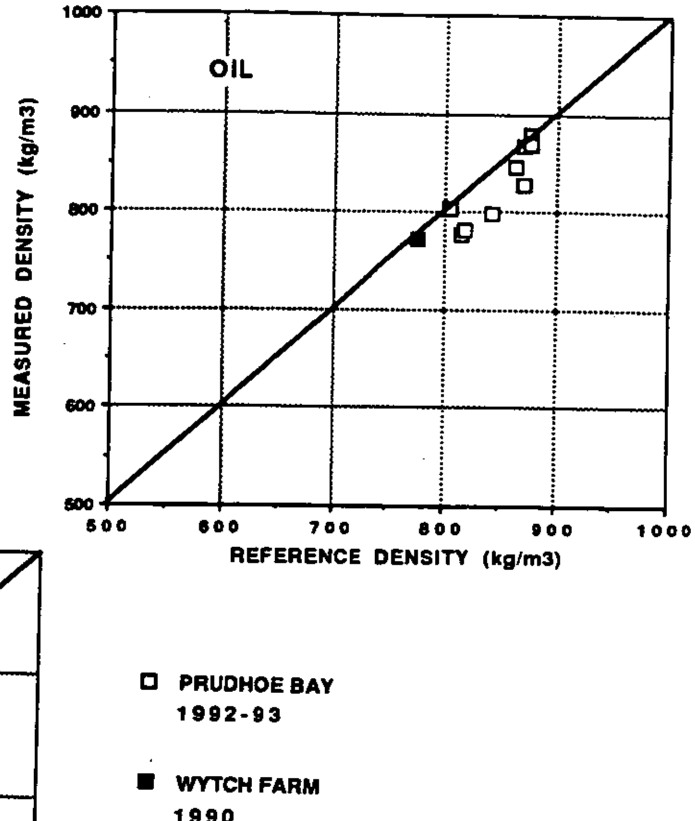
OCTOBER 1993
■ 600 < psig < 1300
▲ 1300 < psig < 2300

(75% < GVF < 95%)

(VOLUMETRIC K-FACTOR CURVE BASED ON MAINS WATER CALIBRATION)

Figure 5. Relative Error in Phase Flow Rate - Alaska

Figure 5 is taken from Reference 3.



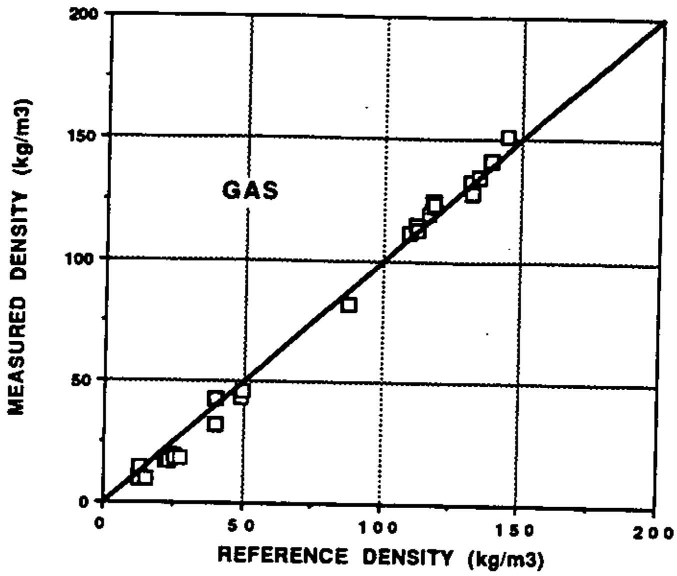


Figure 6. Single Phase Fluid Line Densities Multiphase Meter Densitometer

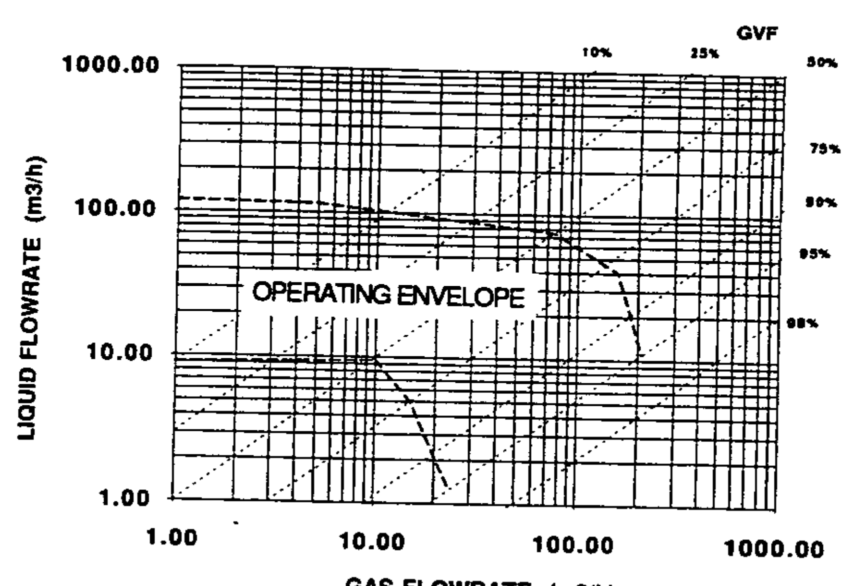


Figure 7. Operating Envelope of the BP Multiphase Meter