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"Measuring the Flow of Wet Gas"

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MEASURING THE FLOW OF WET GAS

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SUMMARY

The capability to measure the flow of gas with entrained liquid can play an important role in the economic development of small fields in the North Sea. Such a capability enables separators to be omitted on small developments for which the separator was needed only to provide adequate gas quality for allocation meters. In a search for the best meter this paper presents a number of field tests of gas meters at a production location onshore in The Netherlands. Two aspects are considered, firstly the effect on meter accuracy of increasing quantities of entrained water, and secondly the spot measurement of the ratio of liquid to gas using a tracer technique.

Of the meters tested, the conventional venturi or orifice meter proved the most predictable. With these meters, the already published expressions of Chisholm or Murdock enable the meter reading to be accurately corrected for the effect of wetness. One class of meter for which the performance was not so good was that in which the gas velocity is measured. Tests with a vortex meter showed the wetness effect to be unpredictable because of slip between the liquid and gas.

No technique was found that was independent of the liquid-to-gas ratio. This prompted the development of simple non-nucleonic tracer methods to take spot measurements of the liquid and gas flow rates. The gas measurement has been completed and it gives a gas flow rate to within ±5% independently of the liquid content. The development of liquid tracer methods is still underway.

INTRODUCTION

Many offshore gas-field developments could be simplified if the flow measurements could be made before rather than after the produced liquids have been removed from the gas. This would enable the use of cheap satellite platforms without any separation facilities, it would remove any need to provide a test line to the mother platform for well testing and would enable the commingling of production from different fields before the gas is processed for sale.

There are two problems that stand in the way of this simplification of the measurement: there is no widely recognised technique for measuring gas flow accurately when entrained liquids are present and a method for quantifying the liquid production must be found in order to monitor the performance of the wells. This paper considers these two problems. It first reports on a series of tests on venturi and vortex meters that quantify the error and uncertainty which entrained liquid cause. It then describes the development of non-radioactive tracer methods for independently measuring the liquid and gas flow rates for well-testing purposes.

DIFFERENTIAL-PRESSURE-TYPE METERS

Literature survey

There have been many investigations into the measurement of gas and liquid flow through orifice-plate-type meters (see Ref. 1 for a comprehensive list). Most investigators have proposed their own expression to cover their range of experimental data, with little agreement between the different expressions proposed. However, the range of liquid/gas ratios found in most producing gas fields is limited to 500 m^3 of liquid to 10^6 normal m^3 of gas and, in this range, many of the proposed expressions predict the same effect.

The two most important expressions have been proposed by Murdock[2] and Chisholm[3 4]. Murdock's relationship can be written:

$$Q_g = \frac{Q_{tp}}{1 + 1.26 \, \frac{(1-x)}{x} \, \frac{C_g \epsilon_g}{C_l} \sqrt{\left(\frac{\rho_g}{\rho_l}\right)}} \tag{1}$$

while Chisholm's takes the form:

$$Q_g = \frac{Q_{tp}}{\sqrt{(1 + K/Y + 1/Y^2)}} \tag{2}$$

where $Y = \frac{x}{1-x} \sqrt{(\rho_l/\rho_g)}$ and $K = (\rho_l/\rho_g)^{1/4} + (\rho_g/\rho_l)^{1/4}$.

These two expressions are plotted in Fig. 1 for natural gas at 100 bar. The agreement between the two expressions is excellent despite them being of very different forms. However, the experimental data base used to derive these expressions does not cover natural gas at 100 bar; this result is an extrapolation from the original measurement.

Field measurements

To establish the validity of either Murdock's or Chisholm's expressions at flowline conditions, a set of field measurements were taken with a 100 mm venturi meter installed in a well flowline at a production station. The test facility (Fig. 2) was constructed between the test header and separator. Here, the gas was passed through a reference venturi flowmeter and then made wet by injecting water either through a wall tapping or through a spray in the centre of the pipe. The wet gas then flowed through the meter under test. The effect of the additional water on the meter under test could be determined by comparing the ratio of the readings of the test and reference meters with and without water injection.

All the instruments were connected to a data logger and each measurement consisted of the average of 10 individual readings over a period of about 15 seconds. The data logger took 1 second to scan all the instruments sequentially and 10 scans were taken for each measurement. Both the average and the standard deviation of the 10 readings were calculated for each instrument and if the standard deviation exceeded 1% for any of the instruments the run was rejected and repeated. The flows were calculated once from the average values.

Venturi test results

Test runs were made at pressures between 80 and 100 bar and at at various gas flow rates between 50 000 and 200 000 normal m^3/day. The actual conditions for each test run are given in Table 1. Typically, 10 liquid flow rates were used in each test run. For the majority of the tests, eight measurements were taken at each injection flow rate, four with the water injected through the spray nozzle at the pipe centre and four with the water injected at the wall tapping. This enabled any mixing effect to be identified.

The effect of the injected water for the whole series of tests is shown in Fig. 3, in which the ratio of the test venturi reading and the reference venturi reading is plotted against wetness fraction. Each point in the figure is the average of four measurements with water injected either through the the spray nozzle or through the wall tapping. The effect of adding water can be seen to be linear over this range with a slope slightly greater than that predicted by Murdock or Chisholm. (The small zero shift is due to small differences between the test and reference venturis.) It can also be seen from this figure that there is no difference between the methods of water injection and hence the way in which the liquid is distributed in the pipe. The actual flow conditions have no effect. Details of individual test runs are discussed more fully in ref. 5.

These results confirm that the expressions of either Murdock or Chisholm can be used for correcting venturi meters for the effect of liquid entrainment at typical gas-well flowline conditions. Others (see ref. 1) have shown that there is no difference between the effect of water or condensate (other than the density dependence shown in equations (1) and (2)), that the size of the meter has no effect and that the expressions can be used up to 64 bar. It is, therefore, reasonable to say that the expressions are valid for any differential pressure meter (except the elbow meter) at any pressure up to 100 bar.

VORTEX METERS

The vortex meter is one candidate from a group of meters in which the fundamental measurement is one of gas velocity. It would be expected that the addition of small amounts of liquid would not effect the velocity of the gas and hence would not affect the reading of a vortex meter. This is not the case. Two sets of tests were carried out on the vortex meter, one in the same test facilities that were used for the venturi meter tests and one in the KSEPL multiphase test loop (Fig. 4).

Vortex meter - field test results

Figure 5 shows the results of four test runs in the field test facilities. It can be seen that, in contrast with the venturi meter, the vortex meter overreading is dependent on gas flow rate. The test run at 130 000 normal m^3/day also showed two distinct behaviours (lines 130 A and 130 B), one for liquid-to-gas ratios below 100 m^3/million normal m^3 and one for ratios above. There is no apparent explanation for the differences and the behaviour was not encountered at a later date.

The explanation for the increases in reading and the apparent variation with gas flow rate is found by considering the cross-sectional areas in the pipe taken up by the liquid and the gas. The vortex meter in gas service is a velocity-measuring device. It is reasonable to suppose that the increase in reading is due to an increase in gas velocity and that this is due to the reduction in cross-sectional area available for the gas because some of the pipe's cross-section is 'blocked' by the liquid. The area blocked is a minimum when the liquid and gas are travelling at the same velocity, i.e. no slip, and in this case the ratio of areas for liquid and gas is the same as the ratio of liquid/gas volumetric flow rates at actual flowing conditions. In practice, there is slip between the liquid and gas, the liquid travels more slowly than the gas. This results in a buildup of liquid in the pipe and this liquid holdup means that less area is available for the gas. As a result, the gas velocity increases by a factor greater than the ratio of the liquid/gas flow rates.

The actual areas taken up by the gas and the liquid are difficult to predict. At normal gas pipeline velocities the liquid travels either as a small film around the circumference of the pipe or as a rivulet in the bottom of the pipe if mounted horizontally. The thickness of the film or rivulet depends on the relative velocity of the liquid and the gas in the pipe, which in turn depends upon the pipe geometry and the gas and liquid flow rates and properties. For the 75mm line tested, it required a rivulet of only 1.6 mm depth or a film of only 0.9 mm thick to give an increase in gas flow rate of 5%.

Laboratory tests

The laboratory tests evaluated the vortex meter with air/water mixtures at nominally atmospheric pressure. The intention was to confirm that slip between the liquid and gas was the cause of the overreading and to see whether it could be reduced by mounting the meter in a vertical run with the flow down. Immediately upstream of the meter a transparent section of pipe was fitted so that the actual air/liquid distribution in the vortex meter could be seen.

Horizontal tests

Two sets of test runs were made in the horizontal section. Initially the meter was installed in an almost identical manner to the field tests (Fig. 2) and it showed a similar behaviour. The results for this installation are given in Fig. 6. They show that the meter was affected by liquid in the same way as in the field tests although the magnitude of the effect is lower. The difference in magnitude is to be expected because the effect is dependent on the actual distribution of liquid and gas in the pipe and this depends on actual line conditions; the field trials were at a pressure of 80 bar whereas the laboratory tests were at atmospheric conditions. This means that for the same liquid-to-gas ratio at reference conditions, the ratio of liquid-to-gas flow rates at line conditions in the laboratory was one eightieth of that in the field tests. The effect of the liquid, however, was not one eightieth because the gas could not drive so much liquid through the pipe, since the density was also one eightieth. The resulting difference in velocities between the gas and liquid (slip) was therefore greater in the laboratory than in the field. The two effects, less liquid but more slip, are in the opposite directions. These tend to cancel, giving an overall effect of similar magnitude in both the field and laboratory.

During these first tests the liquid was running in a rivulet along the bottom of the pipe for all but the highest gas flow rate. At the high gas flow rate the liquid spread up around the walls of the pipe to about half the pipe diameter.

A second set of tests were made with a simple liquid bypass around the vortex meter, Fig. 7. This sucessfully removed any effect of entrained liquid for the majority of the conditions, the results are shown in Fig. 8. The bypass was a tube running below the pipe and inserted into the bottom of the pipe by means of T-joints a short distance upstream and downstream of the meter. Its effect was to divert away from the meter the rivulet of liquid that was running along the bottom of the pipe. The liquid was driven through the bypass by the differential pressure across the vortex meter created by the bluff body. The distance of the bypass below the main line was sufficient to ensure that this same differential pressure could not empty it of liquid. This ensured that no gas could go through the bypass once it had become full of liquid. This was completely successful as long as the liquid ran only along the bottom of the pipe. At high liquid-to-gas ratios and high gas flow rates when the liquid was seen to be transported partially along the pipe walls, the bypass only partly reduced the problem. This confirms that the meter overreading was due to liquid holdup in the meter.

Vertical tests

The attempt to reduce the effect of the slip between the liquid and gas by installing the vortex meter in a vertical section was unsuccessful because the liquid distributed itself around the walls of the pipe and, because of this contact, it was slowed down considerably. An attempt was made to inject the liquid in the pipe centre but the liquid had still distributed itself on the walls by the time it passed through the meter only 1.5 m downstream.

A vertical installation, therefore, is not a practical way of reducing the effect of entrained liquid on a gas vortex meter.

TRACER METHODS

The tracer measurement methods have two purposes: firstly they provide a way of carrying out a well test with no test separator, and secondly, they provide a method of measuring the actual liquid/gas ratio so that venturi meters can be corrected for the effect of wetness. Separate methods are required for the liquid and gas phases and both methods will be described, although only the gas method has been tried in the field. The liquid tracer method is currently under development.

Gas tracer method

The main objective of the method is that it must measure gas flow in a well flowline to ±5% at pressures between 65 and 150 bar independently of any produced liquids up to a liquid/gas ratio of 500 $m^3/10^6$ normal m^3. It has to be simple enough to be carried out by operators without any special training, it has to be portable and not require special equipment to be permanently installed at the measurement location. A tracer dilution technique using a non-radioactive tracer was chosen because it is operationally simple and requires no special facilities in the field.

The tracer has to be in gaseous form, must not react with the natural gas, the produced liquids or the pipe walls, and it must not be present in the produced gas. Ideally, it should remain entirely in the gas phase and not partially partition into the liquids. A noble gas satisfies the chemical requirements and neon was chosen because it is not present in natural gas yet is freely available. The drawback of a noble gas is that the required analysis technique is complex because the gas is chemically inert.

The method chosen generally follows the ISO recommended procedure[4]. In this, a chemical tracer is injected at a known flow rate into the gas stream. At some point downstream, at a distance sufficient for the tracer to be mixed uniformly, the stream is sampled. The gas flow rate is calculated from the concentration of the tracer in the sample and the tracer injection rate. The technique is shown schematically in Fig. 9.

Two aspects of the method proved problematic: the choice of injection flowmeter and the analysis technique. The flowmeter eventually chosen was a gas turbine meter (Fluid Dynamics Inc. type FTO-1/N1/Sa-GHC-5), after the failure of many other meters to retain their calibration. For the analysis two techniques were tried, both using chromatographs but with different detectors for different gas concentrations. At low concentrations of the tracer, 1 to 50 ppm by volume, a system with two columns and a microwave plasma detector was used. This achieved a standard deviation of about 1%. A simpler technique using a single column and a thermal conductivity detector achieved the same target for concentrations over 100 ppm.

Proving the technique was done in two phases, firstly in dry gas against a fiscal standard (±1%) dry gas measurement and secondly in wet gas, for which the effect of entrained water in the gas was evaluated. The results of three trials are shown in Fig. 10. By the third trial, results within ±5% were achieved. This third trial was also in wet gas with liquid/gas ratios between zero and 500 $m^3/10^6$ normal m^3. The method is shown to be independent of wetness fraction.

Liquid tracer method

The liquid tracer method follows very closely the principles of the gas tracer method. Again, the tracer has to be chosen for its abiltiy to remain entirely in the liquid and a suitable analysis technique has to be found. The main problem is that the liquid is made up of two liquids, produced water and condensate. A simple tracer that is suitable for both cannot be found so two tracers have to be used. The selection of a tracer for the condensate phase is still under discussion but glucose is an ideal tracer for water and simple analysers are available.

CONCLUSIONS

A venturi meter can be used to measure the flow of wet gas. The effect of entrained liquid is predictable and can be compensated for by using the expressions of either Murdock or Chisholm. Velocity-measuring meters cannot be used for wet gas measurements. They are affected unpredictably by slippage between the liquid and gas phases and this depends on the pipe geometry and the actual liquid and gas flow rates and properties.

Simple tracer methods can also be used to measure gas flow independently of liquid content to an accuracy adequate for well-monitoring purposes. It should also be possible to extend these tracer techniques to measure the liquid flow in a wet gas stream. This will enable a full well test to be carried out without a test separator.

NOMENCLATURE

Q_g	Flow of gas alone
Q_l	Flow of liquid alone
Q_{tp}	Flow calculated from the measured differential pressure and the dry gas density
x	Gas quality (ratio of mass of gas to mass of liquid)
C_g	Discharge coefficient for gas
ϵ_g	Expansion coefficient for gas
C_l	Discharge coefficient for liquid
ρ_g	Gas density
ρ_l	Liquid density

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3. Chisholm, D.: "Flow of incompressible two-phase mixtures through sharp edge orifices," Journal of Mechanical Engineering Science, Vol. 9 No. 1 1967
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6. ISO 4033-1980, International Organisation for Standardisation, 1980

Table 1. Venturi meter test run conditions

Nominal gas flow		Press.	Temp.	Maximum liquid/gas	
(m^3/day)*	(kg/s)	(bar)	(°C)	($m^3/10^6 m^3$)*	(actual %v)
180 000	1.7	82	40	100	0.8
150 000	1.4	83	38	100	0.8
95 000	0.9	85	39	240	2.0
56 000	0.5	86	32	150	1.3
75 000	0.7	98	42	400	3.8
108 000	1.0	97	43	180	1.7
72 000	0.7	80	35	365	3.1
180 000	1.7	78	38	100	0.8

* Volumes are at 1 bar and 0°C.

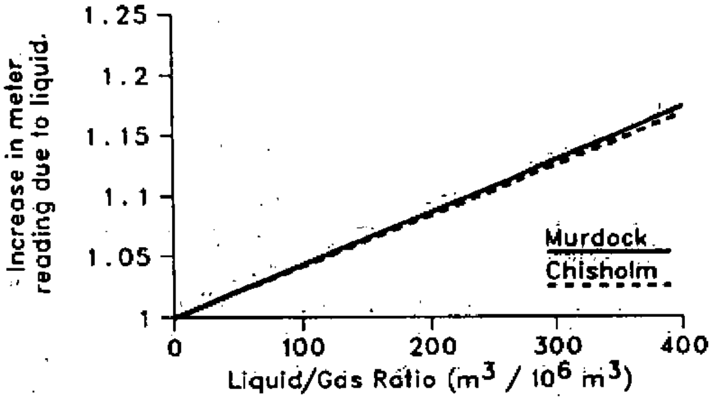


Fig. 1 Wet gas flow equations at 100 bar

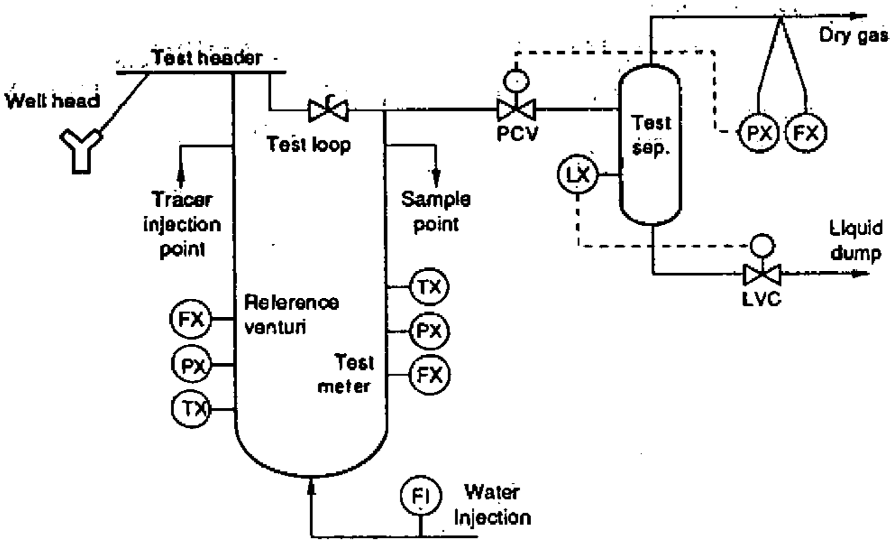


Fig. 2 Wet gas meter test facility

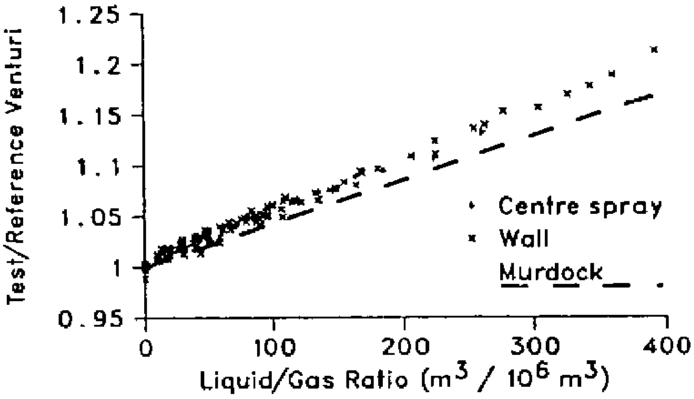
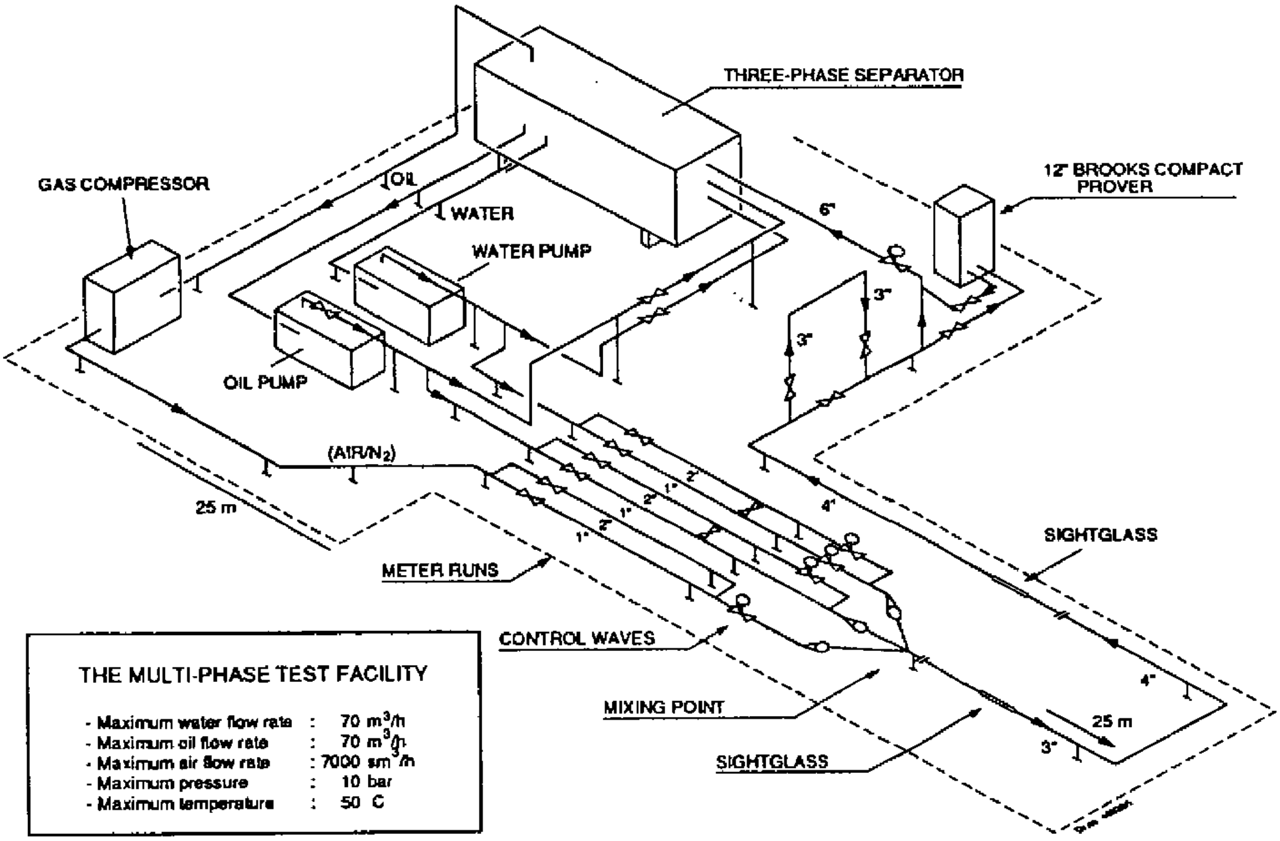


Fig. 3 Venturi trial result



THE MULTI-PHASE TEST FACILITY

- Maximum water flow rate : 70 m^3/h
- Maximum oil flow rate : 70 m^3/h
- Maximum air flow rate : 7000 sm^3/h
- Maximum pressure : 10 bar
- Maximum temperature : 50 C

Fig. 4 The KSEPL multi-phase test loop

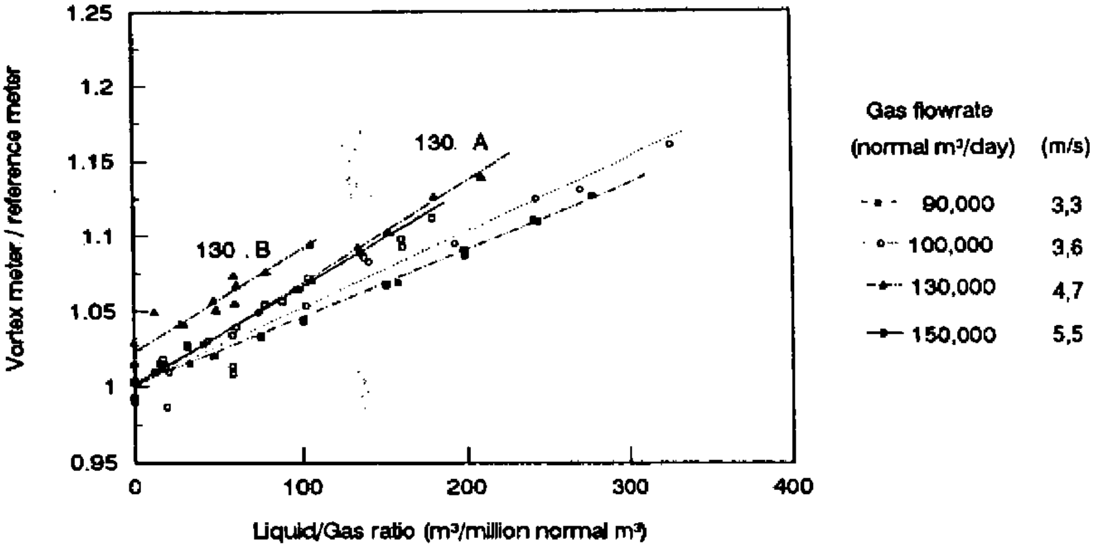


Fig. 5 Vortex meter field test results

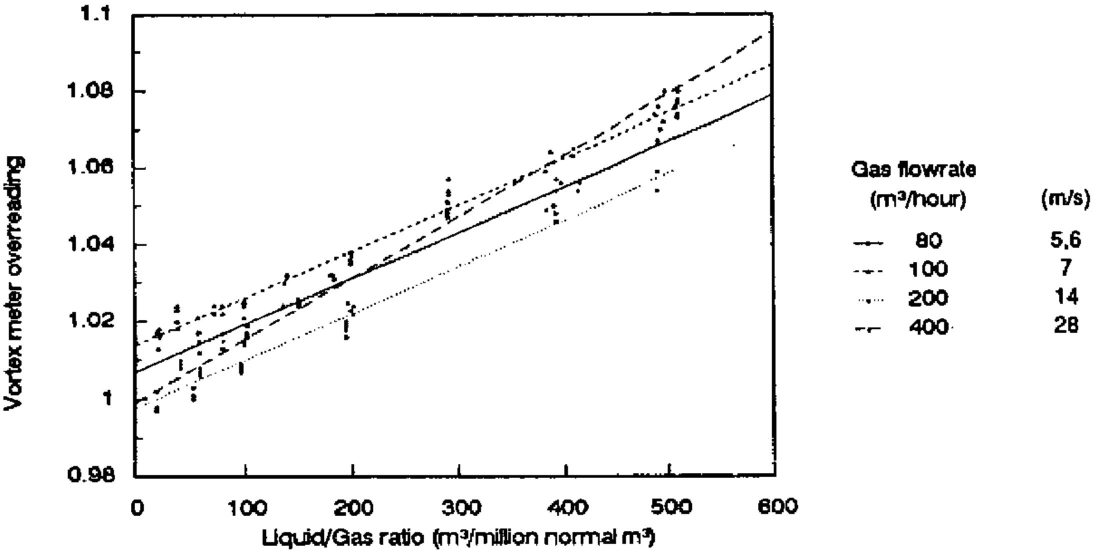


Fig. 6 Vortex meter laboratory results for horizontal installation

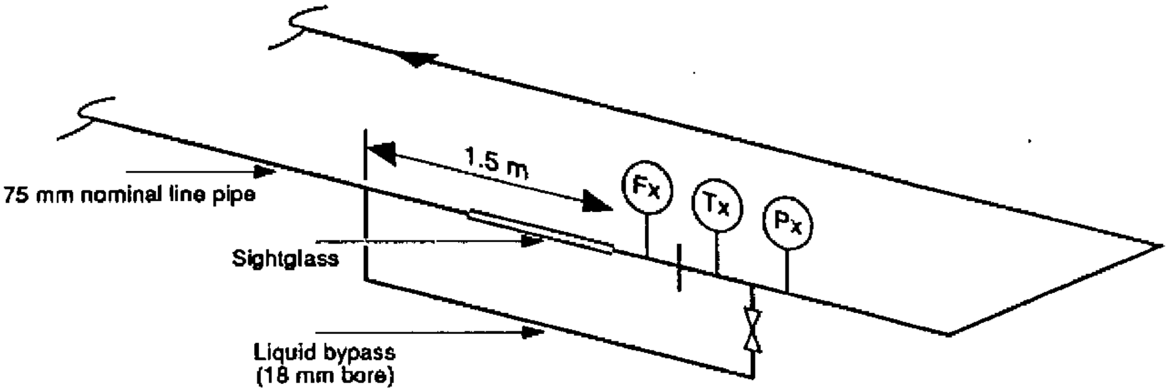


Fig. 7 Liquid bypass

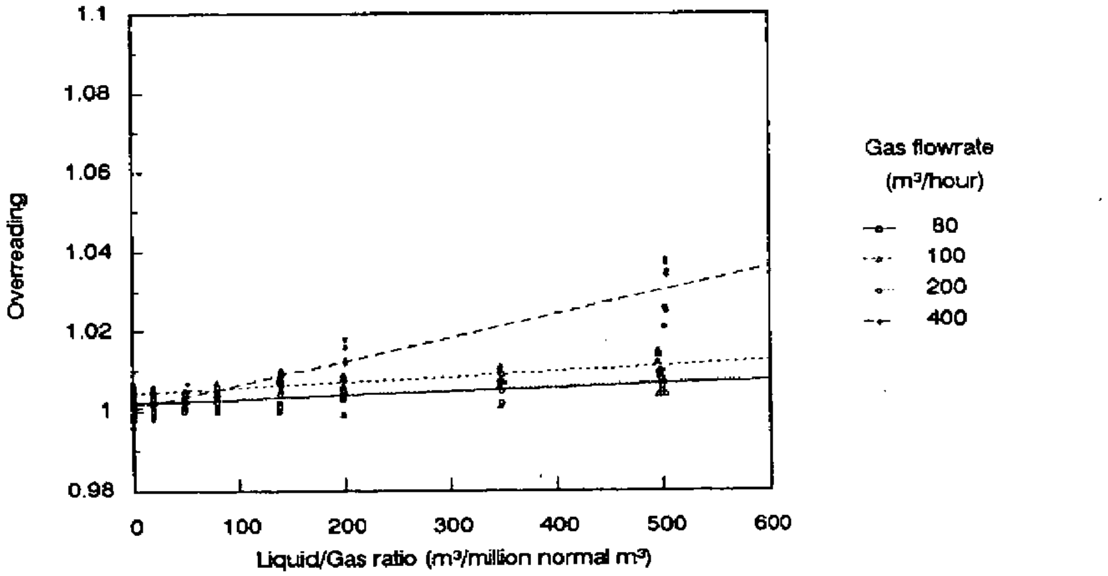


Fig. 8 Vortex meter results with liquid bypass

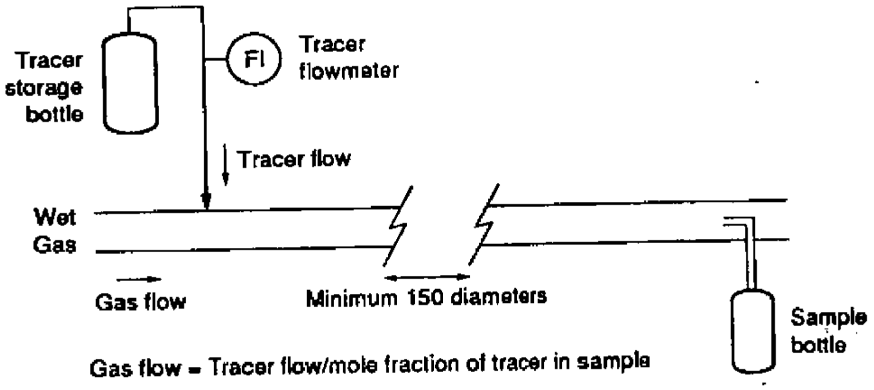


Fig. 9 Schematic of tracer technique

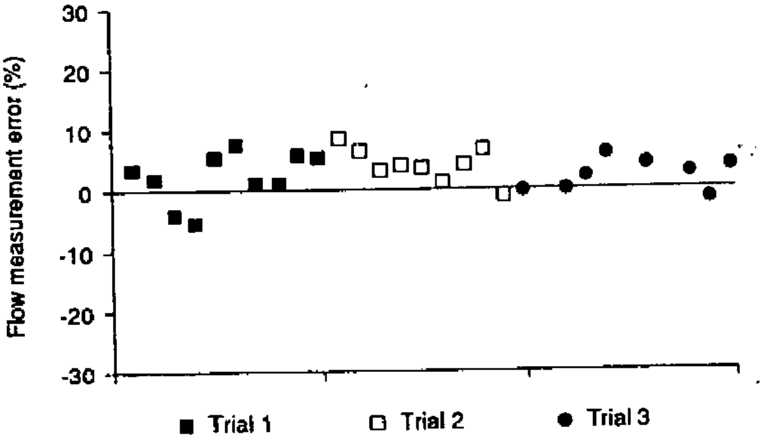


Fig. 10 Tracer trial results summary

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.