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Two-Phase Effects on Single-Phase Flowmeters

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Summary

The effect of gas entrainment in oil on the performance of a range of single-phase flowmeters has been investigated experimentally using the national standard flow calibration facilities at NEL. The flowmeters tested were 4 inch positive displacement, venturi, helicoidal and flat-bladed turbine meters and a 2 inch U-tube and a 1.5 inch straight tube coriolis meters. The flowmeters were tested in oil flow with gas fractions up to 15% by volume.

The volume flowrate and gas fraction determine the flow regime. This affects the flowmeter response. At low flowrates (up to 20 l/s), slug flow was the dominant flow regime and most of the flowmeters estimated the total volume flowrate to within ±10%. The higher flow rates produced either separated or mixed bubble flow regimes depending upon the gas fraction. At low gas fractions, the positive displacement and venturi flowmeters estimated the total flowrate to within ±2%. Over 9% gas fraction, there was an improvement to the response from some of the flowmeters with increasing gas fractions. This was thought to be due to the flow regime becoming more homogeneous.

Introduction

A large range of measuring techniques exist for the determination of single-phase flowrates. Many single phase flowmeters have been developed which can measure liquid flowrates to an accuracy within ±0.2% over the operating range of the meter under design conditions. The uncertainty increases if a second phase or component is present.

Second-phase components emanate in single-phase flows from a variety of different sources including, leaking pump seals, the evolution of gases from volatile liquids at pressure losses (e.g. bends, expansion zones etc.), or from carry-over from liquid separators or hydrocyclones.

The aim of this work is to quantify the effect of second-phase fluid components on a range of single phase flowmeters and, as a consequence, identify which generic types of single-phase flowmeter are most suitable in these applications. The generic groups of flowmeters were turbine, helicoidal turbine, straight-tube and U-tube coriolis, venturi, vortex shedding and positive displacement.

The effect on the flowmeter performance of gas breakout and water-in-oil/oil-in-water carry over will be quantified to demonstrate meter effectiveness with two component flows. These tests will provide evidence of the suitability of a flowmeter for difficult, two-component applications. Comparisons will be made between generic type and size of flowmeter.

The conditions under which the flowmeters have been tested are as follows:

a) Oil (viscosity = 10cSt) with gas fractions up to 15% by volume, simulating gas breakout or entrainment;
b) Water with oil fractions up to 15% by volume;
c) Oil (viscosity = 10cSt) with water fractions up to 15% by volume.

This paper presents some of the results from group a) above, oil with gas fractions up to 15% by volume.

Experimental

Measurements have been made on six single-phase flowmeters: 1.5 inch straight tube coriolis; 2 inch U-tube coriolis; 4 inch flat-bladed and helical turbine meters; 4 inch venturi and positive displacement flowmeters.

The meters were installed into the oil flowmeter calibration facilities at NEL in groups of three and a fourth flowmeter was used as a reference meter. A schematic of the experimental arrangement is shown in Figure 1. Velocite oil was used as the main fluid. The oil temperature was raised to 50°C to maintain a viscosity of 10cSt.

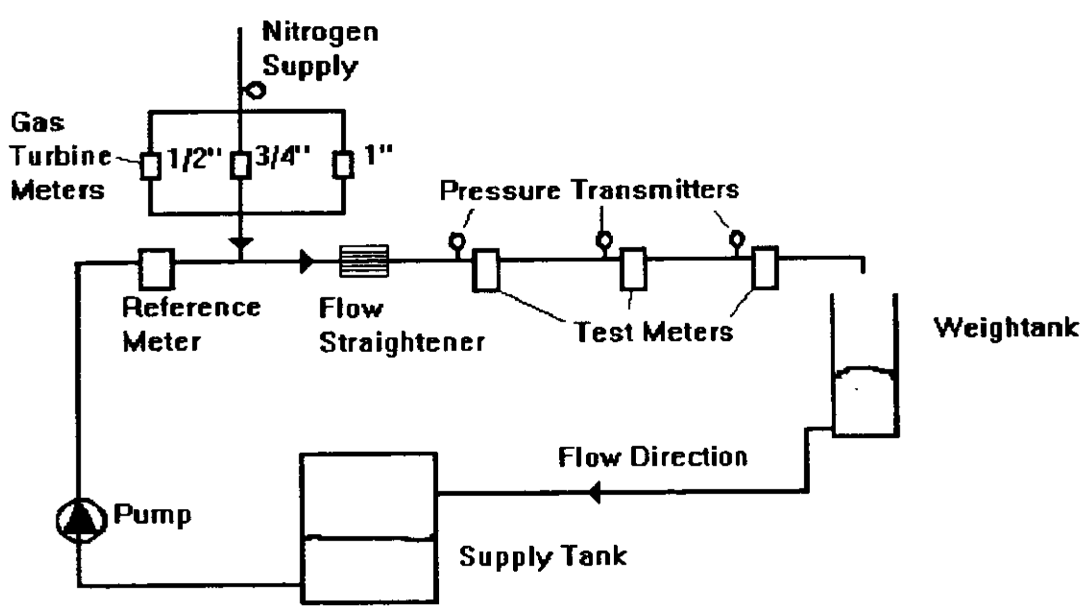

Figure 1 Schematic of the Experimental Set-up

The four meters were initially calibrated against a weightank. The calibration resulted in a single-phase characteristic equation for each meter, expressing volumetric flowrate as a function of pulse frequency or current output. The tests with gas entrainment were performed using the reference meter to measure the oil flowrate.

Gas turbine meters were used to measure the gas flowrate. Nitrogen gas was injected downstream of the oil reference flowmeter and the nitrogen-oil mixture passed through a tube bundle flow conditioner before entering the test section. The two-phase flow was allowed to develop for 30 pipe diameters before entering each meter under test. The static pressure was measured at the gas turbine meter and at each of the test meters.

Tests were performed with gas fractions of 3%, 6%, 9%, 12% and 15% with oil flowrates from 4 to 50 l/s. The test meter output at each of these gas fractions was compared with the sum of the oil and gas reference meter outputs.

Discussion of Results

Figures 2 to 7 show the results of the gas in oil tests for the flat-bladed turbine meter, helicoidal turbine meter, positive displacement meter, venturi, straight tube and U-tube coriolis meters respectively.

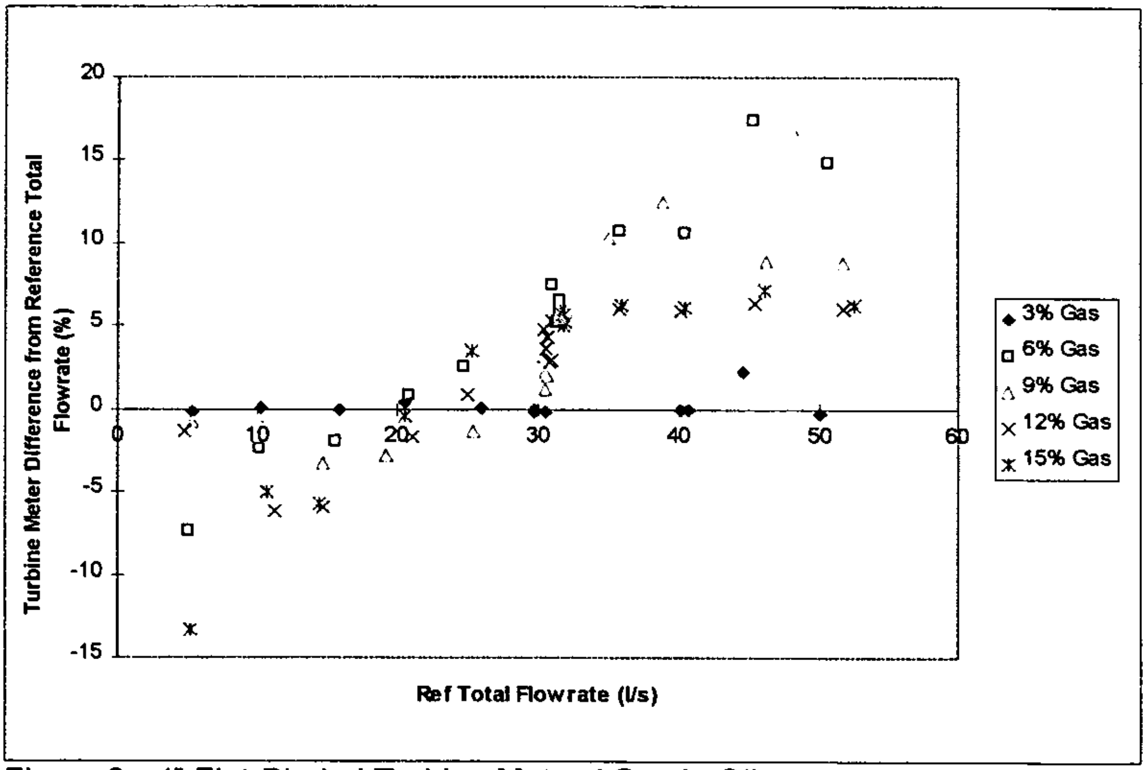

Figure 2 - 4" Flat-Bladed Turbine Meter / Gas in Oil

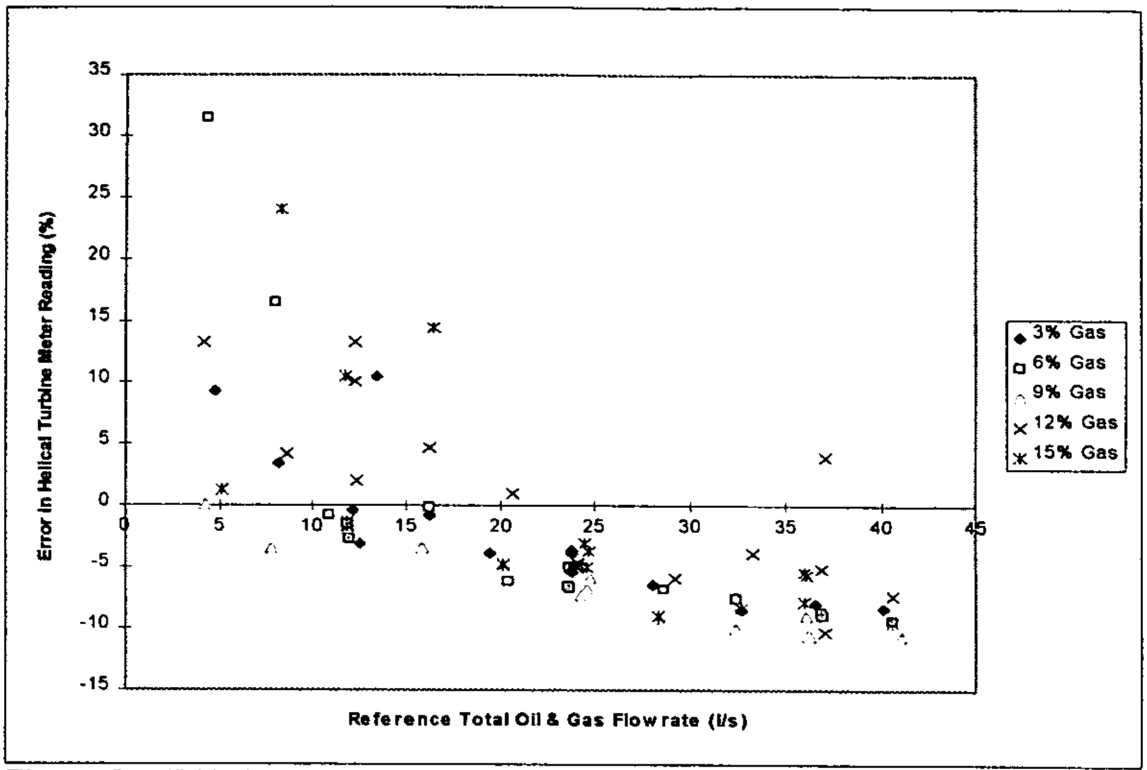

Figure 3 - 4" Helicoidal Turbine Meter / Gas in Oil

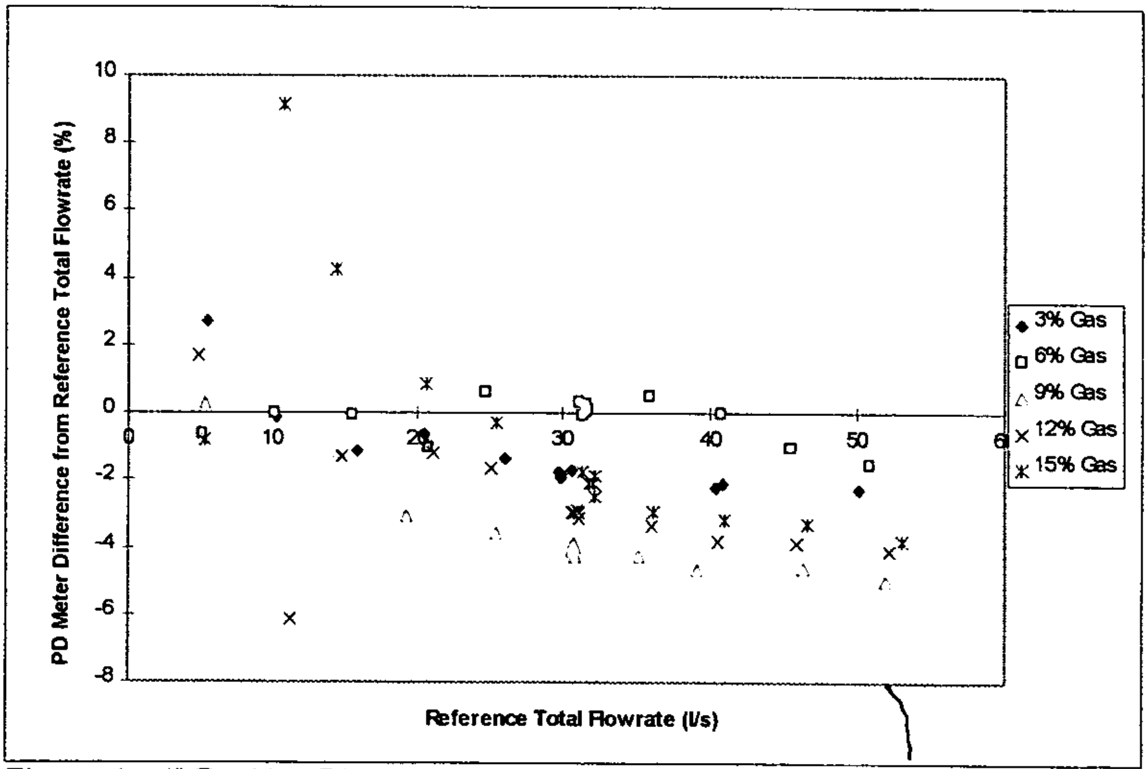

Figure 4 - 4" Positive Displacement / Gas in Oil

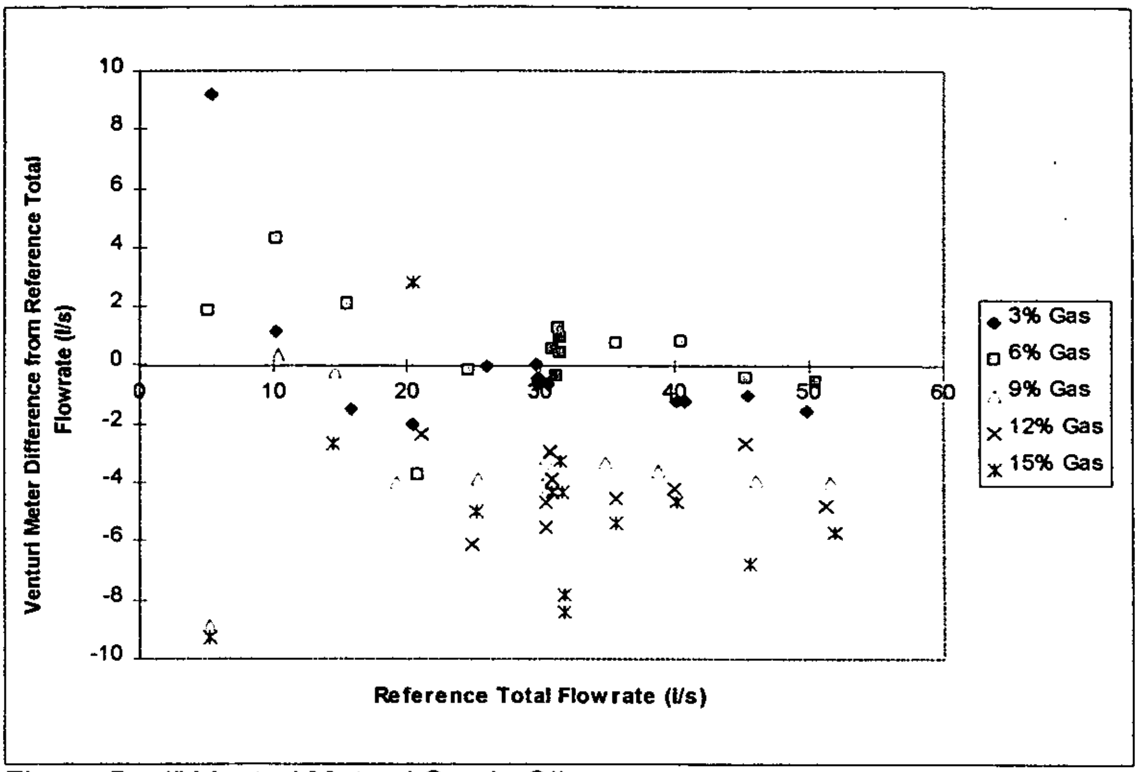

Figure 5 - 4" Venturi Meter / Gas in Oil

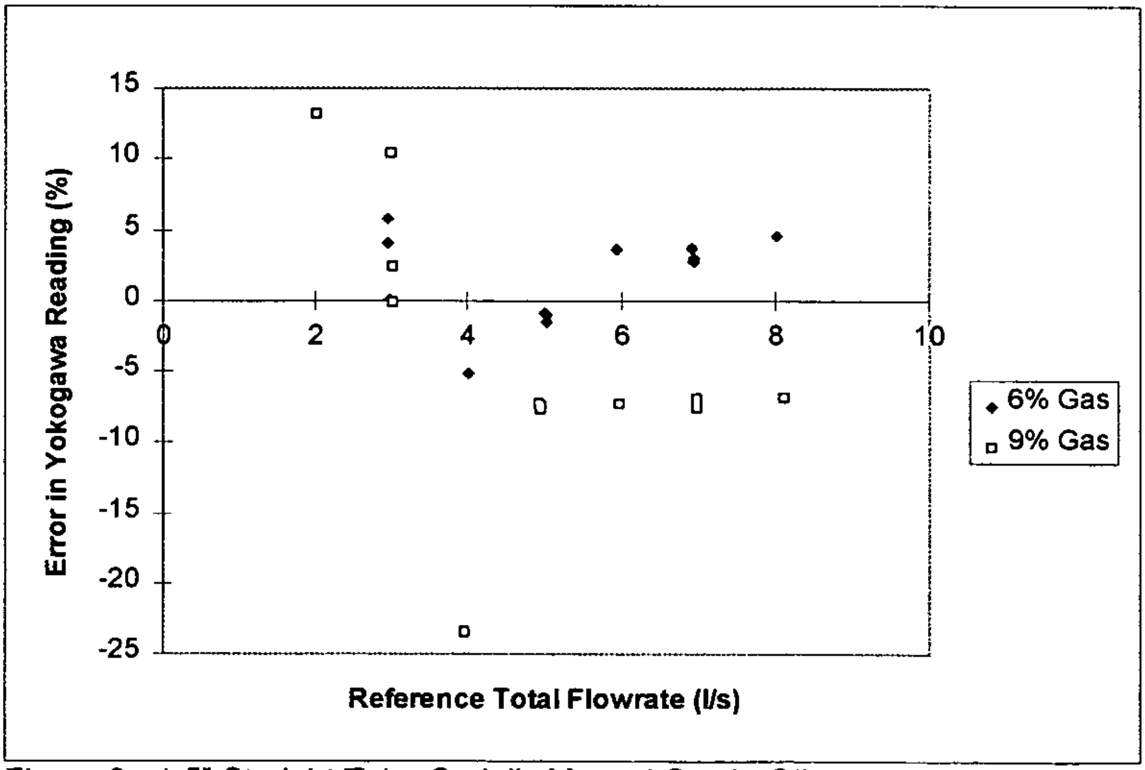

Figure 6 - 1.5" Straight Tube Coriolis Meter / Gas in Oil

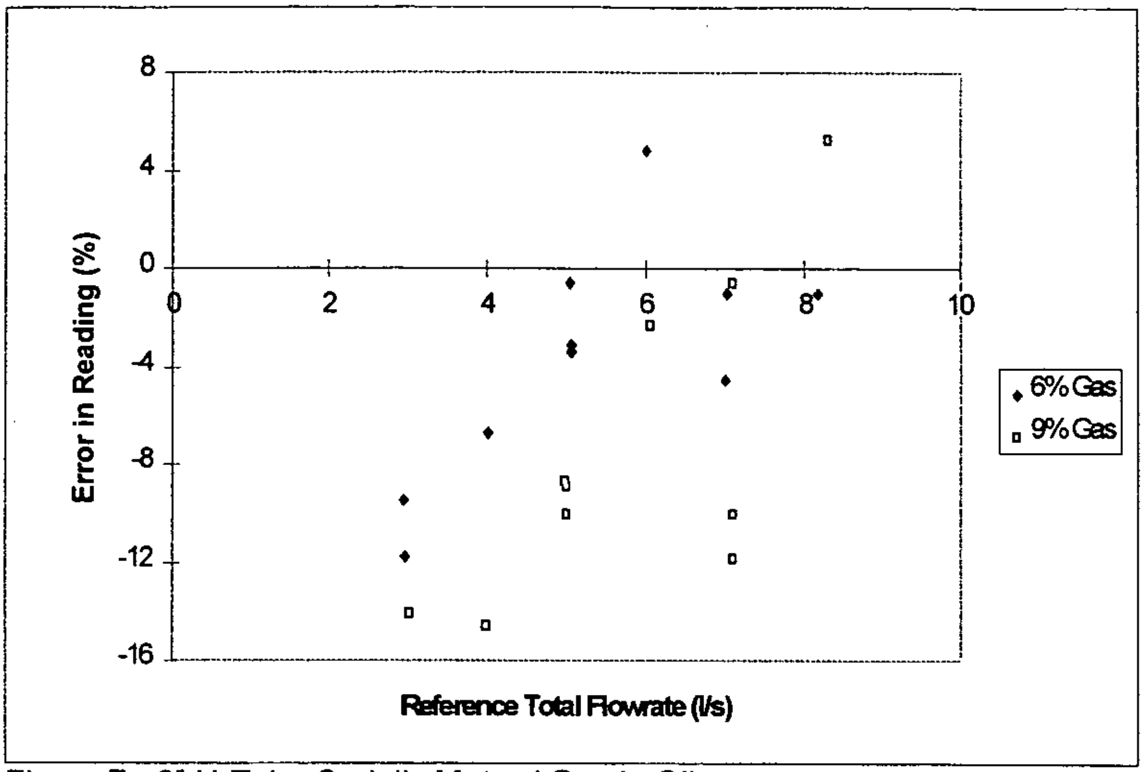

Figure 7 - 2" U-Tube Coriolis Meter / Gas in Oil

Flow visualisation of air in water (Mark et al 1989) and nitrogen in oil (Hall 1996) taken in 4 inch pipe have shown that at approximately 20 l/s there is a transition from slug flow to bubble flow. Figure 8 is adapted from data presented by Hall (1996) and shows the transition between the flow regimes. Some additional flow regimes are defined in Figure 9.

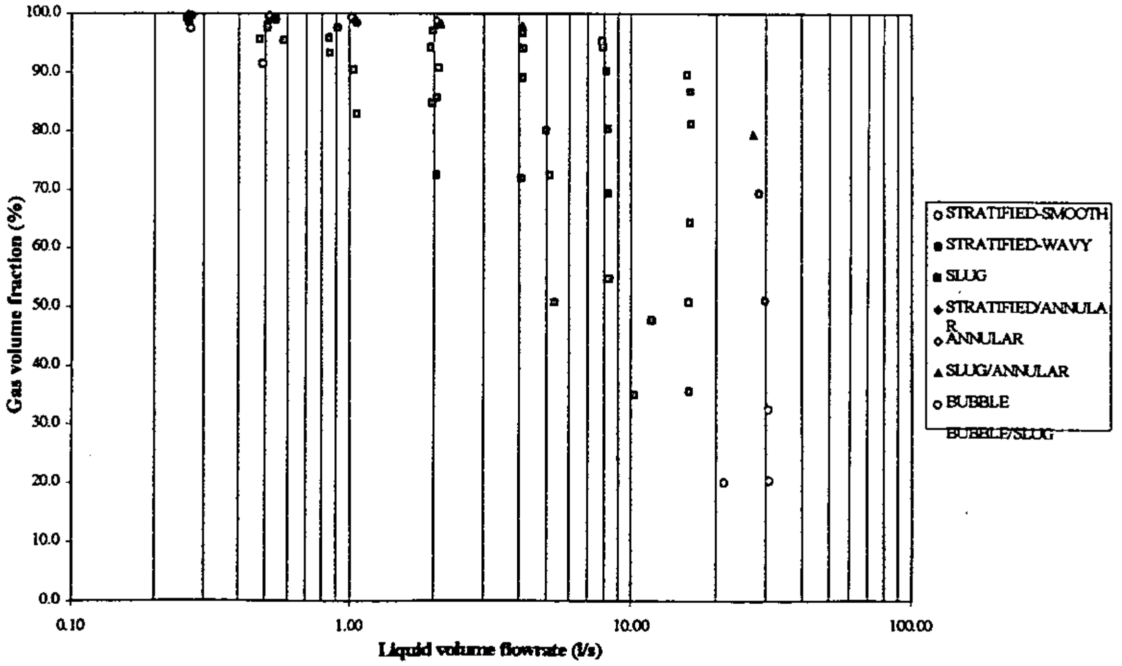

Figure 8 - Two-Phase Flow Patterns in 4" Test Section

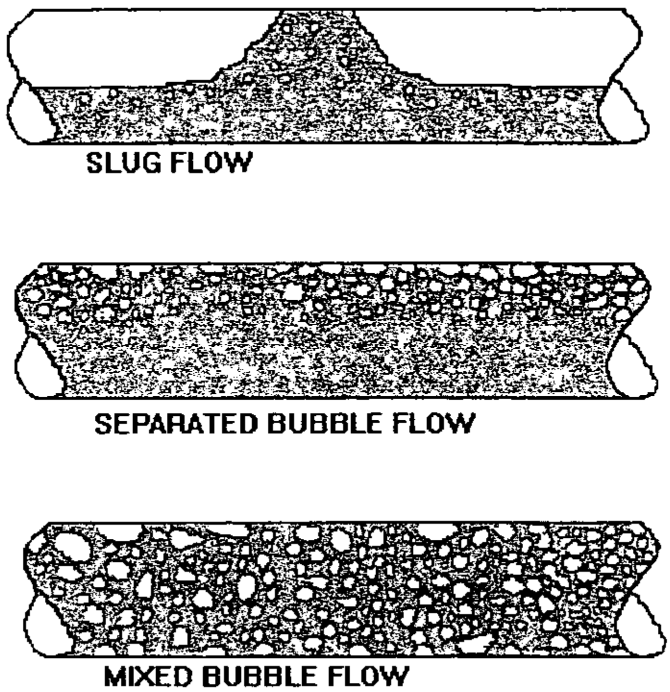

Figure 9 - Flow Regimes

The results presented in this paper from the 4 inch meters all show a transition at around 20 l/s. Additionally, there is a change in the trend of the results between gas fractions less than 9% and gas fractions greater than 9%. This may correspond to a change in the flow characteristic from separated bubble flow to mixed bubble flow.

The total volume flowrate and the gas void fraction each have an influence on the flow characteristics, these in turn have an effect on the flowmeter response. Each flowmeter responds in a different way depending upon its design.

The results from the flat-bladed turbine meter show that at flowrates less than 20 l/s the meter underestimates the total flow. This implies that during slug flow some of the gas is passing through the turbine meter blades without applying a driving torque. Over 30 l/s the turbine meter overestimated the total volumetric flowrate. Bubble flow is causing the blades to overspin.

These results show a marked difference from the measurements taken from the helicoidal turbine meter. Up to around 20 l/s the helicoidal turbine meter overestimates the total flowrate and above 20 l/s the meter underestimates the flowrate. The magnitude of the error is similar for the two turbine meters. Most of the points are within ±10% of the referenced total flow.

The results for the flat bladed turbine meter are in close agreement with previous experimental work performed by Mark et al (1989) on a flat bladed turbine meter in water flow with up to 12.5% air injection. An overestimation of the total volumetric flowrate was observed at flowrates over 20 l/s. The greater the gas fraction the greater the overestimation, but only up to a gas fraction of 10%. Greater than 10% the overestimation is reduced. This was also observed in the results presented here except that the maximum overestimation observed by the turbine meter was at a gas fraction of 6%. A similar trend was observed from the results of the helicoidal turbine meter. The largest error at high flowrates was for a gas fraction of 9%, the magnitude of the error decreased as the gas fraction increase to 15%.

The improved performance with increasing gas fraction over 6% (or 9% for the helicoidal turbine meter), may be due to improved mixing of the gas in the oil as the flow regime changed from separated bubble to mixed bubble flow. At low gas fractions the gas bubbles travel along the pipe near to the upper surface, but as the gas fraction increases, the bubbles mix throughout all of the oil.

The positive displacement meter generally underestimated the total flowrate over the entire flow range and at all gas fractions. The magnitude of the error is less than for the other meters in the tests at high gas fractions. Most of the points are in the range of -4% to 1% from the reference total flowrate. Above 20 l/s the measurements became more stable and repeatable. The magnitude of the error also decreased as the gas fraction increased from 9% to 15%.

The repeatability of the measurements from the venturi meter also improved above 20 l/s. The error in the venturi meter measurements for 3% and 6% gas fractions was within ±1% of the reference total flowrate. For gas fractions greater than 6% the venturi meter underpredicts the total volumetric flowrate. The errors in these measurements are between -6% and -2% from the reference flowrate at flowrates greater than 20 l/s. The venturi meter underestimates the total volume flowrate because the density of the oil-gas mixture reduces with increasing gas fraction while the value for the density in the calculation remains constant. The performance of the venturi meter deteriorated with increased gas fraction.

The coriolis meters were both tested on a 2 inch line. The U-tube meter was 2 inch and the straight tube meter was 1.5 inch. Tests were performed on a 4 inch straight tube coriolis meter but, with the exception of the calibration results, no stable measurement could be obtained.

Coriolis meters are mass flowmeters and so it would be expected that the total volume flowrate would be underpredicted by an amount corresponding to the gas fraction. Measurements could only be obtained for gas fractions of 6% and 9%. The U-tube coriolis showed a certain amount of linearity for high flow rates and 9% gas fraction. There were no other reliable trends from these meters. The coriolis meters did not give any results for gas fractions greater than 9%.

Conclusions

Six single phase flow meters have been tested in two-phase flow. The main fluid component was velocite oil at 50°C and the second component was nitrogen. Tests were performed at 3%, 6%, 9%, 12% and 15% gas fractions. The flow regime changed with total volume flow rate and gas fraction. At volume flowrates less than 20 l/s there was slug flow and above 20 l/s the flow was either separated bubble or mixed bubble depending upon the gas fraction. Each of these flow characteristics had a different influence on the meter performance depending upon the meter design. The scale of the uncertainty in the meter response at these gas fractions has been quantified and the generic type of flowmeters most suitable for these flow conditions have been identified.

At low flowrates most of the meters tested estimated the total volume flowrate to within ±10%. The venturi and positive displacement meters performed better than the other flowmeters at low gas fractions. They predicted the total volume flowrate to within ±2% for 3% and 6% gas fractions at flowrates greater than 20 l/s. At high gas fractions the positive displacement meter produced the lowest errors.

The repeatability of the measurements from the positive displacement and flat-bladed turbine meters improved for the higher flowrates with gas fractions greater than 9%. This may be due to the improved mixing of the oil and gas. The magnitude of the error decreased with increasing gas fractions over 9% for both of the turbine meters and for the positive displacement meter.

Different trends have been observed from each of the single-phase flowmeters with increasing total volume flowrate and with gas fraction. The performance of the flowmeters could be improved if correction factors were developed to represent the trends observed in these tests. Any improvements to the flowmeter estimations in two-phase flow first requires a knowledge of the flow characteristic in the pipe. Each flow characteristic requires separate modifications to be made to the single-phase characteristic equation for each meter to take the second component into consideration.

The flowmeters produced smoother curves that had good repeatability in the fully mixed bubble flow than in slug or separated bubble flow. Controlling the flow regime to a homogeneous flow over the flow range of the meters and at different gas fractions would provide the opportunity for the single-phase flowmeters to measure accurately the total volumetric flowrate. This would also require the use of another instrument, such as a gamma densitometer, to measure separately the gas fraction in the mixture.

Acknowledgement

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