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ASSESSMENT OF MULTIPHASE FLOWMETER PERFORMANCE

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1 INTRODUCTION

The objectives of the Multiflow JIP run by NEL on behalf of Amerada Hess, Brasoil, BP, Exxon, Mobil, Schlumberger and Shell Expro were to characterise the performance of commercially available multiphase flowmeters on a single test bed facility with high quality reference flow rate measurement systems. The results from the project will be used by the sponsoring organisations as benchmark performance data for the selected meters to focus the implementation of multiphase metering strategies in new field developments. Data generated by this project has been utilised by these organisations to assess the likely effectiveness of the meter technology in the field and to assess the performance of the multiphase meter vendors in terms of technical back-up and response to problems with the instrumentation.

The multiphase test facilities at NEL were utilised for the evaluation of the meters, rather than field test data, due to the greater accuracy of the reference flow rate measurements for oil, water and gas. These approach the accuracy attainable with single-phase flow measurements. In addition the use of a laboratory test facility enabled meter performance to be evaluated quickly over a wide range of conditions at a relatively low cost. The evaluation matrix covered 0 to 100% water cut and 0 to 98% gas volume fraction (GVF) over a wide range of flow velocities. An additional benefit was to obtain data for each meter from the same traceable source.

To ensure that the evaluations were as representative as possible of likely field conditions the test fluids used were stabilised Forties blend crude oil, simulated produced water and nitrogen. To establish the effect of changes in water properties on the meter performance, two different concentrations of simulated produced water were used in each case. The concentrations were representative of the mass absorption and density of sea-water and brine, the conductivity of the second solution was approximately twice that of the first. The performance of the multiphase flowmeters was assessed in terms of percentage error relative to the reference oil, water and gas volumetric flow rates and the absolute error relative to the GVF and water cut. In addition to the evaluation of basic accuracy a number of reproducibility tests were run to define the capability of each instrument to return to a previously experienced flow condition and repeat the measurement to within similar levels of accuracy.

The multiphase flowmeters tested at NEL during Multiflow I were the Agar MPFM-301, the Fluenta MPFM 1900VI, the Framo MFM and the MFI LP meters. The bore diameter of the instruments was between 50 mm and 100 mm. These instruments utilised a variety of techniques[1] to measure a number of different parameters associated with oil/water/gas mixtures, such as bulk density, dielectric constant and mixture velocity. These parameters were then combined to derive the phase flow rates, the water cut and the GVF. All the meters made use of either an intrusive device or some configuration of the pipework upstream of the meter to condition the flow prior to the measurement section. Another feature common to each meter was the use of a differential pressure measurement device at some part of the envelope.

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The second stage of the Multiflow project commenced in September 1996 with completion planned for mid-1998. The main objectives for this project are to complete a further four benchmark multiphase flowmeter evaluations using the same experimental facilities as used in the initial stage of the project and to collate the data from these evaluations and the preceding stage into a single database from which the project sponsors can readily access information to assist in specifying the most suitable meters for particular installations.

The evaluation programme for Multiflow 2 has also been extended to include a second crude oil, in addition to the original Forties blend. These additional tests reflect the concern of the project sponsors that changes in the crude oil properties may influence the ability of multiphase flowmeters to perform accurate measurements. The second oil will be of higher viscosity and density, around API 26. The test matrices from the initial stage will be utilised in the second stage to allow direct comparison of the new data with the benchmark evaluations already collected.

The multiphase flowmeters for evaluation under the Multiflow 2 project will be selected from the Kongsberg MCF351, the MFI Full Range, the CSIRO MFM, the ISA multiphase flowmeter, the Petroleum Software and the Mixmeter projects. The Kongsberg MCF351 utilises intrusive capacitive and resistance sensors to measure water cut and GVF in the multiphase flow, propagation velocity of features is gained by cross-correlation with gas and liquid velocities derived from models. The MFI Full Range meter measures water cut and GVF with microwaves and gamma radiation attenuation, velocity measurement is by cross-correlation. The CSIRO MFM derives phase fractions from dual-energy gamma radiation attenuation, velocity measurement is from cross-correlation of flow features. The ISA meter is essentially a positive displacement meter which can be linked to a phase fraction meter to derive phase flow rates. Petroleum Software have linked a number of instruments which measure pressure drop, capacitance and resistance to a neural network which predicts the individual phase flow rates. The Mixmeter depends on differential absorption of dual-energy gamma radiation and cross-correlation of flow features. The final selection of test meters will be decided by the project sponsors and preference will be given to the most commercially advanced instruments.

3 MULTIFLOW RESULTS

The four multiphase flowmeters were independently evaluated against reference standard single-phase flow measurements, compensated to test section conditions, over a common evaluation matrix. The results from these evaluations indicated the performance of each meter against the accuracy specification claimed by each manufacturer. It is important to consider the results obtained in the light of the complexity of both the multiphase flow structure and number of measurements being made to infer the resultant phase flow rates. Effectively the measurements were tested over a turn-down ratio approaching 100:1 for each of three phases, and the same degree of absolute accuracy cannot be expected when deriving a small quantity by difference of two much larger quantities as can be achieved by direct measurement. Similarly, the flow rate errors are presented in terms of relative error to the reference phase flow rate, and here the relative error will always increase in significance as the magnitude of the quantity decreases relative to it's maxima.

The performance of the meters was assessed in terms of two-phase (gas/liquid) and multiphase (oil/water/gas) flow instruments. In general, the results for total liquid flow rate indicated predictions within ±10% of the reference flow rate over most of the evaluation matrix. For each of the meters there were small localised zones where measurements were found to be less accurate, the location of these zones varied between the meters. The boundaries within which the performance of the meter was within ±10% relative error of the reference are marked on Figure 1.

The gas flow rate predictions were also within ±10% over large regions of the evaluation matrix for each instrument, Figure 2. Local zones of reduced accuracy existed for each meter and covered larger areas of the evaluation matrix than for the liquid flow rates. These zones were, in part, linked to changes in the multiphase flow structure and local gas/liquid distribution. The existence of these zones indicate underlying weaknesses in some of the flow models used in the various instruments, or the inability of flow conditioners to produce consistent downstream conditions as the upstream flow pattern changed.

Each of the multiphase flowmeters evaluated exhibited a performance of better than ±10% relative error for some of the phase flow rates at some of the test matrix conditions. Because of the nature of the measurements the most accurate measure of phase flow rates tended to be at conditions where a relatively high proportion of that phase was present.

For example, the test meters were capable of measuring the oil flow rate to within ±10% relative for most conditions where the water cut was less than 50%, Figure 3. Water flow rate measurements were generally within a similar accuracy once the water cut exceeded 20%, Figure 4.

The data have also been shown on plots of superficial gas and liquid velocity to highlight regions of good and poor performance. The enclosed zones on Figures 5-8 again denote regions within which errors of less than ±10% can generally be expected to occur, this information must also be read in conjunction with the data detailed on the water cut vs. GVF plots to determine the likely performance at a given condition. Flow pattern boundaries for vertical air/water flows[2] have been overlaid on the plots to illustrate any linkage to flow patterns. Vertical flow pattern boundaries have been used as the majority of the instruments utilise a conditioner prior to vertical up-flow at the measurement section. The differences between Figures 5, and Figures 7 and 8, show that the proximity of the bubble/churn transition boundary may affect the ability of some instruments to distinguish between oil and water, whilst still being capable of more accurate measurement of total liquid flow rate.

In each meter the oil and water flow rates were derived by combining the total liquid flow rate measurement with a measure of the water cut in the liquid phase. It was immediately apparent that, as the total liquid flow measurement was generally within ±10%, the increased uncertainty at some conditions for the oil and water flow rate measurement was caused by larger uncertainty in the water cut measurement. On close examination of the data for the individual instruments it was seen that for increasing GVF the magnitude of the error in the water cut measurement generally increased, Figure 9. For some of the multiphase flowmeters the measurement of the water cut was also affected by the water cut in the flow.

From the data generated during the evaluations it can be seen that multiphase flowmeters are capable of providing the measurement accuracy required for practical applications over some part of the full range of multiphase flows, equally it is apparent that further advances are required before any meter can be claimed to fulfil the complete requirements of the operators. At present the main areas where further improvements are required are at above 85-90% GVF and for flows which are water continuous.

4 CONCLUSIONS

All the multiphase flowmeters tested under the Multiflow JIP were capable of providing phase flow rate measurements to within ±10% relative of the reference measurements for mixtures of crude oil, simulated brine and nitrogen gas over part of the evaluation matrix.

The regions over which the oil, water and gas flow rate measurements provided by the meters were within ±10% relative did not extend over the full matrix of conditions.

All the multiphase meters were capable of measurements within ±10% relative of the reference for gas and liquid flow rates over a wider extent of the evaluation matrix than for individual phase flow rates.

The performance of the multiphase meters was generally strongest in oil continuous flows and for GVF less than 90%. There is scope for improvement in these areas by further development or use of new technologies.

ACKNOWLEDGEMENTS

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2 McQuillen K.W. and Whalley P.B., Flow Patterns in Vertical Two-Phase Flow. I.J. Multiphase Flow, 1985. Vol. 11, No.2,pp.161-175.

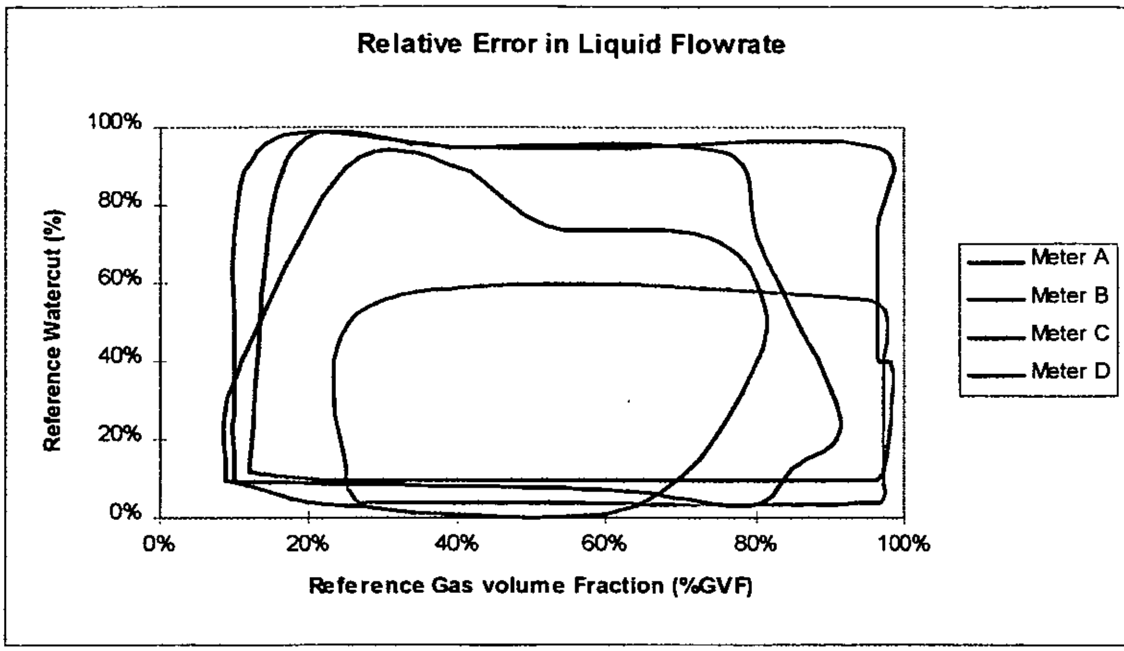

Figure 1: Liquid Flow Rate Prediction

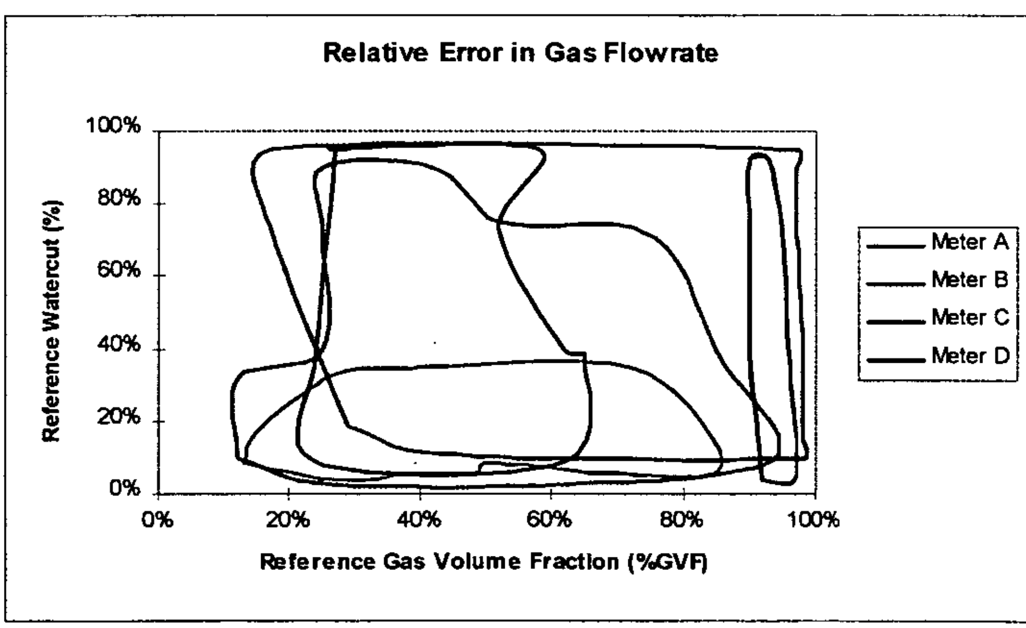

Figure 2: Gas Flow Rate Prediction

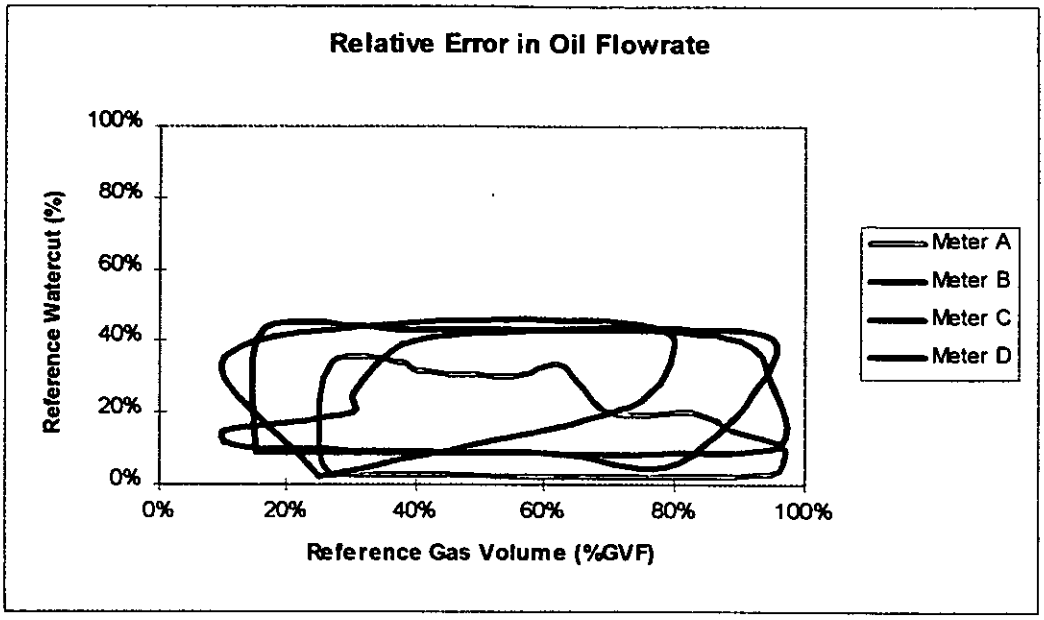

Figure 3: Oil Flow Rate Prediction

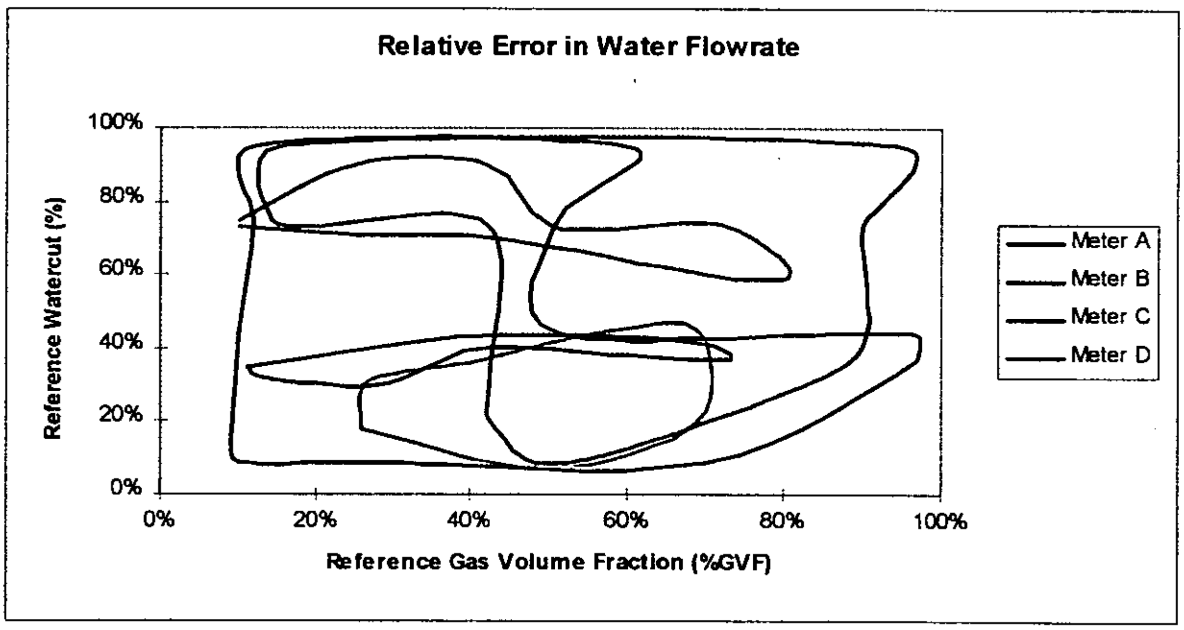

Figure 4: Water Flow Rate Prediction

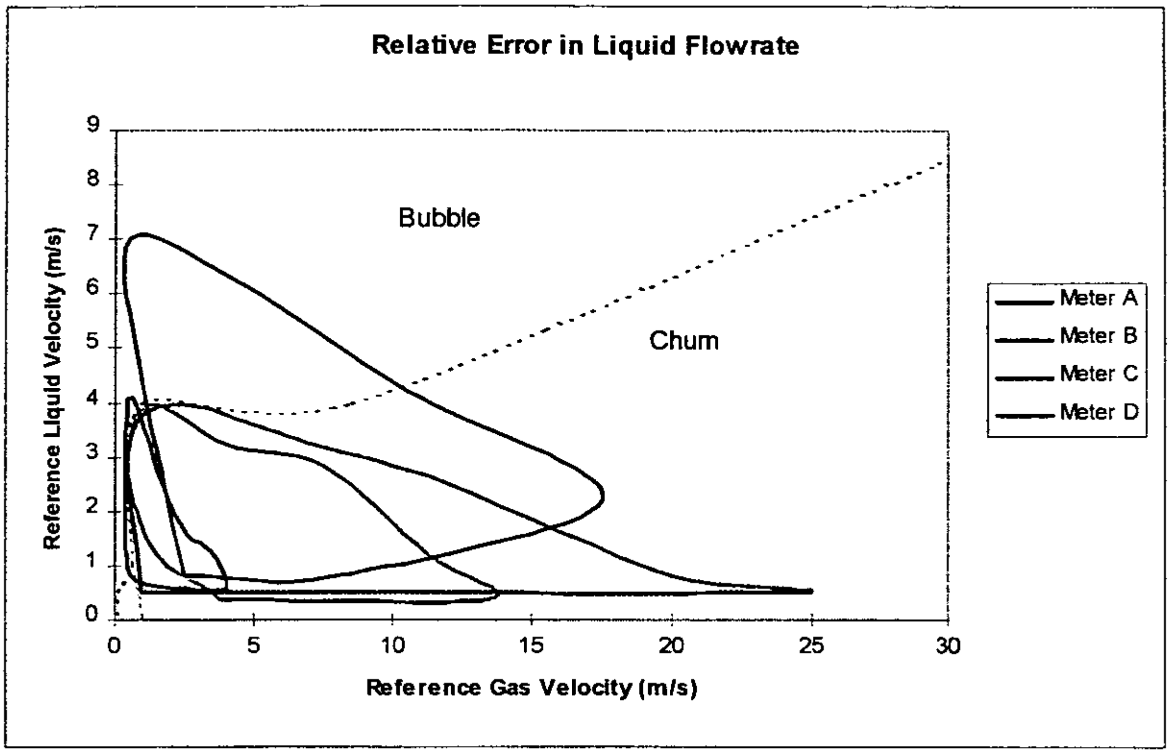

Figure 5: Liquid Flow Rate Error Plots

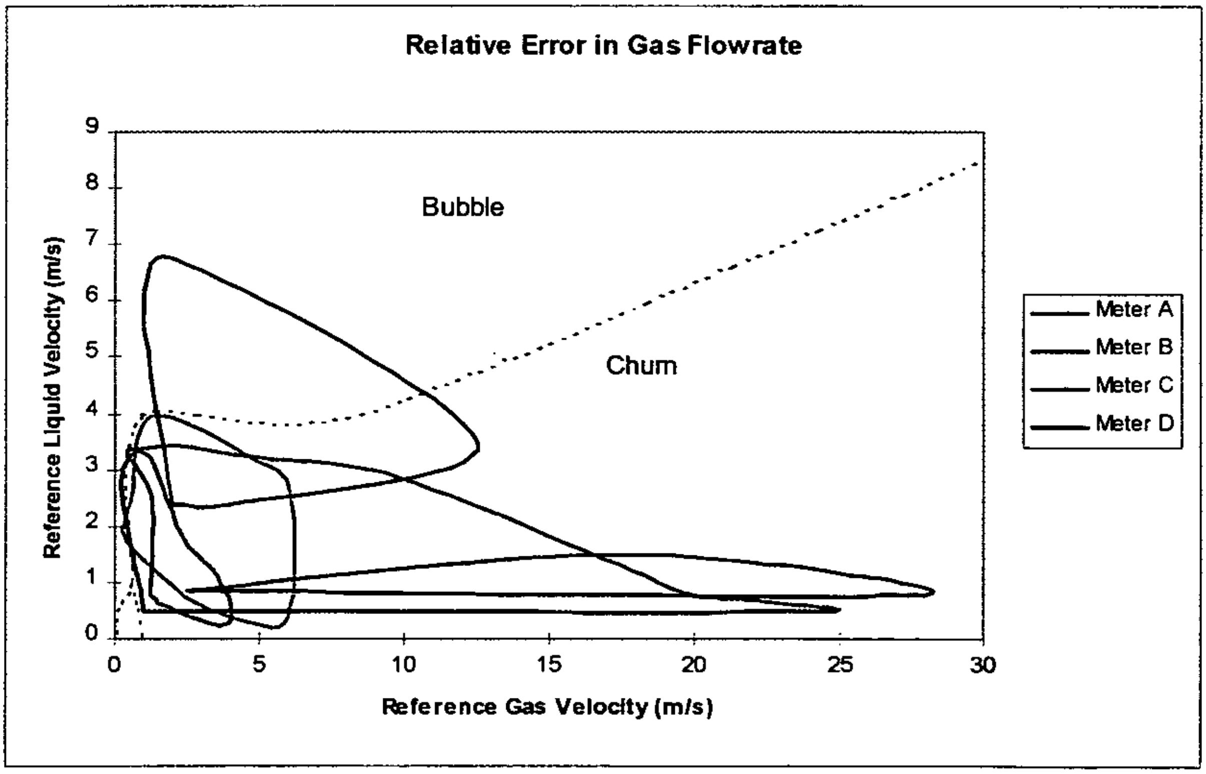

Figure 6: Gas Flow Rate Error Plots

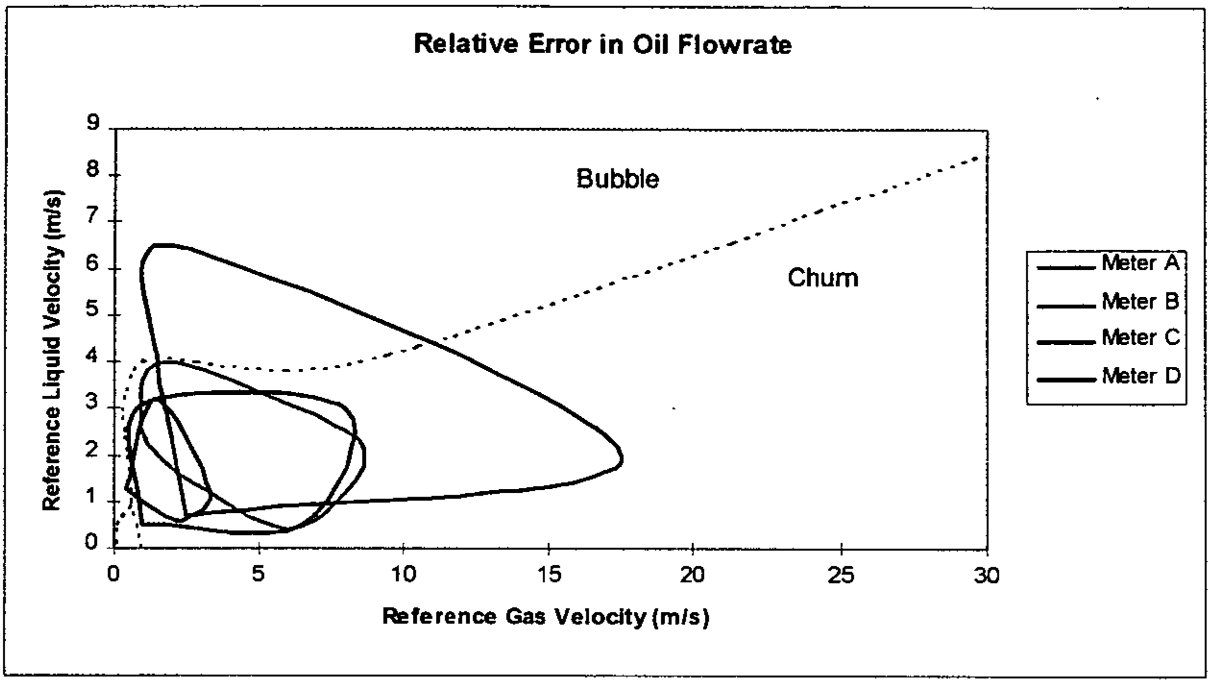

Figure 7: Oil Flow Rate Error Plots

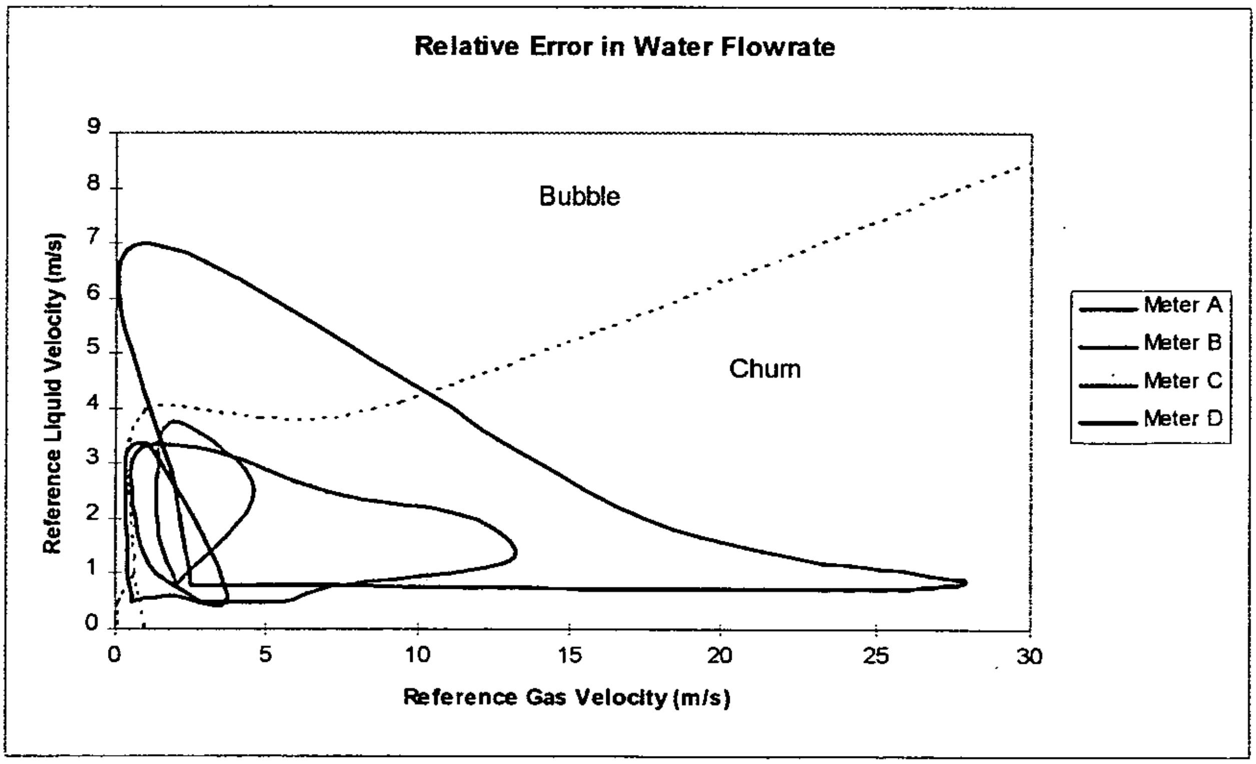

Figure 8: Water Flow Rate Error Plots

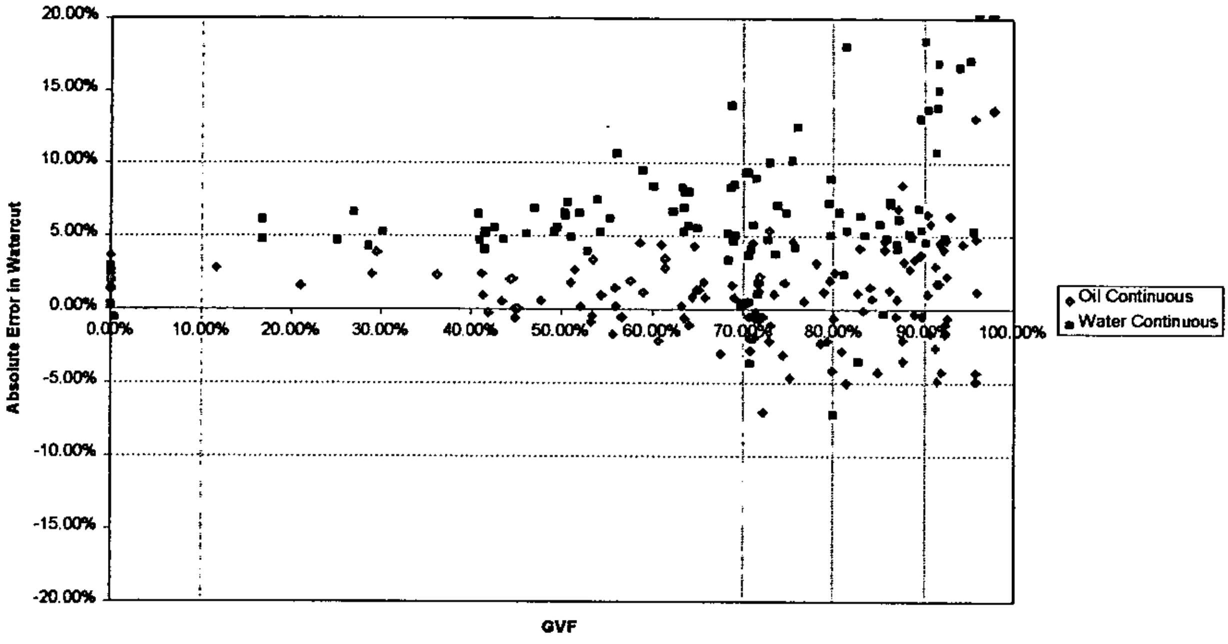

Figure 9: Influence of GVF on Watercut Error