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MULTIPHASE FLOWMETER PERFORMANCES UNDER SIMULATED CONDITIONS

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CHARACTERISATION OF THE PERFORMANCE OF MULTIPHASE FLOWMETERS: THE MULTIFLOW JIP

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SUMMARY

Multiphase flowmeters have been the subject of several individual laboratory and field trials, generally conducted to suit the requirements of a single organisation. Under the Multiflow JIP at NEL several commercially available multiphase flowmeters have been tested under a common test matrix designed to reflect the actual needs of oil companies. The test matrix was designed by NEL after consultation with the project sponsors and reflects the bias of fields to high GLR. Where appropriate to the meter technology the test matrix included the full range of water contents anticipated in the field.

The evaluations of the test meters were carried out on the NEL multiphase calibration facility using stabilised Forties blend crude and simulated produced water at two different salt concentrations. The performance of the meters under evaluation is described in terms of the percentage error relative to the reference phase flow rates, and the capability of the meters to meet the manufacturers specification.

1 INTRODUCTION

The objectives of the Multiflow project were to define a common evaluation envelope and to evaluate four multiphase flowmeters at these conditions. The evaluation matrix was designed to satisfy the needs of each of the sponsoring companies both in terms of determining the performance of the selected multiphase flowmeters at conditions near to those anticipated in the field and to assess the repeatability of each flowmeter by measuring the performance of the meters at the same conditions a number of times during the evaluation. The test matrix was designed by NEL after consultation with the project sponsors and reflects the bias of fields to high GLR. Where appropriate to the meter technology the test matrix included the full range of water contents anticipated in the field.

To simulate the type of installation expected in the field the vendor companies were invited to set-up their instruments in the NEL facility, but once the process was completed and the flowmeter was handed over no further alterations to the meter set-up were permitted unless a fault or breakdown occurred.

A significant aspect of the project was the request of the sponsors for NEL to monitor and report on the performance of the multiphase flowmeter vendors in terms of product support and response to problems encountered during the evaluation. Comments were also sought by the sponsors on the applicability of the various technologies to field and subsea environments.

Fluids as close as possible to field conditions were used during the evaluation, a mixture of topped Forties crude and kerosene, and simulated brine formed the liquid phase, nitrogen was used to simulate the gas phase for safety reasons. The effect of changes in density and salinity of the brine was also examined by repeating part of the matrix using a water solution of higher salt concentration.

2 FACILITIES

The multiphase flow loop at NEL was used to carry out all the evaluations. The Multiphase National Standard Facility at NEL is based around a three-phase separator. This vessel contains the working inventory of oil and water in separate compartments. Each liquid phase is drawn from its separator compartment by a variable speed pump and passed, via the primary reference flowmeter skids, to the mixing section. The gas phase is passed from the supply to the mixing section via a reference meter skid. At the mixing section the water and oil are commingled and the gas phase is injected a short distance downstream. The multiphase mixture then enters the test section, which can be up to 60 m in horizontal length or 10 m in vertical height. A schematic of the facility is shown in Figure 1. For these evaluations the multiphase flowmeters were connected into the facility test section approximately 50 m downstream of the mixing section. After the test section the mixture returns to the separator, where the gas phase is exhausted to atmosphere and the water and oil are separated by gravity.

Some carry-over from the separator is inevitable and both the oil and water feeds from the separator are fast-loop sampled to measure the composition of each process stream. Conditioning circuits allow operation of the facility at a temperature between 10°C and 50°C, to within 1°C and the operating pressure may be up to 10 bar gauge. Temperature and pressure are also measured at several points in the test section, at the oil/water monitors and at the reference meters and mixing sections.

A programmable logic controller (PLC) controlled the facility operation and data acquisition from all the field instruments. The outputs from the multiphase meter under test were also connected into the PLC and logged simultaneously with the facility field instrumentation. All measurements were automatically corrected for temperature and pressure, the reference liquid flow rates were also corrected for the carry-over in the process streams. All the instruments were regularly calibrated to local secondary standards, and density curves for the liquid phases were measured before each evaluation commenced.

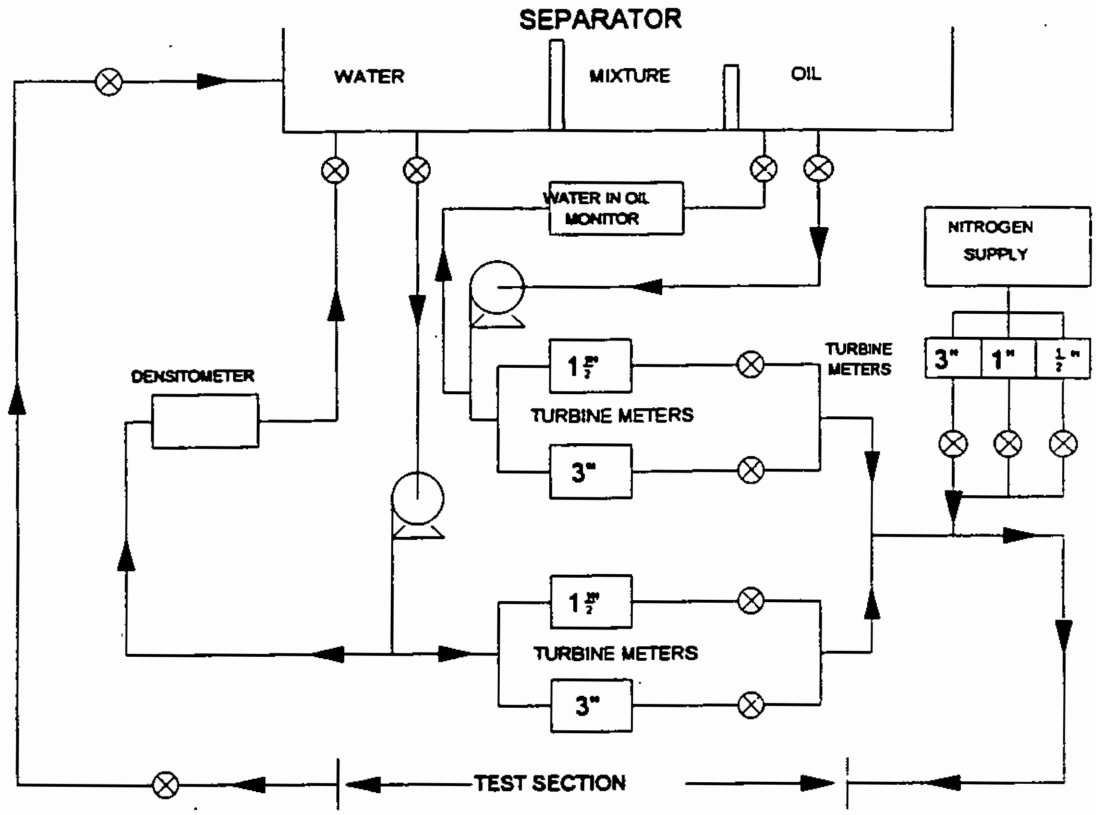

Figure 1: Schematic of NEL Multiphase National Standard Facility

The oil used during this evaluation was a mixture of stabilised Forties crude (flashpoint 60°C) and Exxsol D80 in a 70/30 ratio. The oil viscosity was 12.6 cSt at 18°C, density was 860.7 kg/m^3 at 20°C. Brine was simulated by the additional of Magnesium Sulphate ($MgSO_4$) salt to de-ionised water in two concentrations, these were 25g/l and 50g/l. The conductivity at 25°C of these solutions were 0.64 S/m and 1.05 S/m respectively, the density at 20°C was 1010.45 and 1018.4 kg/m^3 respectively. Nitrogen was used as the gas phase throughout.

The oil and water flow rates in the facility can be varied between 0.5 and 40 l/s of each phase, the maximum nitrogen mass flow rate is 0.5 kg/s. In a 100 mm test section the above flow rates can produce mixture velocities in the range 0.5 to 25 m/s at gas volume fractions in the range 1 to 99 per cent. The test section pressure can be maintained at up to 10 bar gauge, the fluid temperature may be varied in the range 5 to 50°C provided that the oil temperature does not increase to less than 20°C below the flashpoint.

All the reference flow data and process condition data is automatically logged at pre-set intervals to a time and date-stamped file. The test meter flow outputs were linked into the facility SCADA systems and were therefore logged simultaneously. Reduction of the data and comparison of the test instrument to the reference were conducted off-line.

3 TEST METERS

Several vendors were approached for loans of multiphase flowmeters for evaluation, on the basis that in return they would receive the evaluation data. The key criteria for selection of the meters was that they be commercially available instruments. On this basis the multiphase flowmeters chosen for evaluation were the Agar MPFM-301, the CSIRO MFM, the Fluenta MPFM 1900VI, the Framo MFM, the ISA ScrollFlo and the MFI LP meter. Four of these meters will be evaluated under the current phase of the Multiflow project, and the remainder will be included under the second phase (Multiflow 2). It is anticipated that as current developments become more mature they will also fulfil the requirements of the project, and will be included in the evaluations of Multiflow 2. Organisations which have already expressed interest in evaluation under the Multiflow 2 project include Mixmeter, Kongsberg and Jordan-Kent.

3.1 Agar MPFM-301

The flowmeter contains a rotary positive displacement flowmeter, modified for multiphase use, and two venturis in series in a vertically upward flow. An algorithm in the control computer derives the total, gas and liquid volume flow rates from these outputs. The water content of the flow is derived from the power absorbed by the process fluid from an in-line microwave monitor. The continuous liquid phase is detected by the phase shift between the transmitter and two differentially spaced aerials. The measurement of the liquid phase water cut can then be derived from the gas fraction and the microwave monitor output, individual oil, water and gas flow rates are then computed from these variables.

3.2 CSIRO MFM

This flowmeter uses the attenuation of gamma rays at two different energies to derive the oil, water and gas phase fractions. The mass absorption coefficients of oil and water vary as a function of gamma photon energy and the difference between the coefficients for oil and water is also a function of the photon energy. These differences can be utilised to measure the phase fractions. To maximise the transmission of the lower energy gamma rays the sources and detectors are arranged around a GRP pipe section. Velocity measurement is by cross-correlation of multiphase flow features, slugs and bubbles for example. Velocity and phase fractions are combined to give oil, water and gas flow rates.

3.3 Fluenta MPFM 1900VI

This meter uses several different sensors in combination. Capacitance and inductance sensors are used to measure bulk electrical properties of the flowing mixture in oil and water continuous flows respectively, and derive water cut from these measurements. A single energy gamma densitometer measures the average bulk density by attenuation of gamma photons. The phase fractions can then be extracted from this information. Velocity measurement is by a combination of cross-correlation of capacitance signals and venturi differential pressure in oil continuous flow and from the venturi differential pressure in water continuous flow. Velocity and phase fraction measurements are then combined to give phase flow rate information.

3.4 Framo MFM

A mixer is utilised to pre-condition the flow entering a venturimeter. The mixer consists of a large plenum chamber and piccolo tube. The piccolo tube penetrates the base of the plenum chamber and conducts the flow to the venturimeter, the aim being to draw the gas and liquid into the venturi at equal velocity. The differential pressure across the venturimeter is proportional to the total volume flow rate. A dual-energy gamma densitometer is mounted at the throat of the venturi and is used to derive phase fractions. The phase flow rates are then calculated from these and from the total flow rate.

3.5 ISA Multiphase Flowmeter

Essentially a positive displacement flowmeter this instrument contains two counter-rotating shafts. The shafts are machined to form a continuous constant volume cavity and the rotation imparted to the shafts by the fluid passing through the meter is proportional to the total volume flow rate. At the centre of the meter a single-energy gamma densitometer is mounted to measure the overall mixture density. If the water cut of the liquid phase is known then the phase flow rates can be determined from these measurements.

3.6 MFI LP Meter

Several elements are combined to measure the phase flow rates in oil continuous flow. The fraction sensor and venturimeter are mounted vertically above a static mixer. The fraction sensor contains a resonant cavity between two sets of microwave reflectors. Measurements of the RF frequency in the cavity are proportional to the water cut in the liquid phase. A single-energy gamma densitometer is used to measure the total mixture density and the gas fraction is derived from this measurement and the water cut. The total volume flow rate is gained from the differential pressure across the venturimeter, and the oil, water and gas flow rates are calculated from this and from the phase fractions.

4 RESULTS

The Multiflow project has been conducted on behalf of commercial sponsors. These sponsors do not wish to identify the evaluation results with particular instruments and so, for the purpose of discussion, the multiphase flowmeters have been identified by randomly selected letters. Manufacturers accuracy limits have also been removed to prevent identification.

4.1 Analysis

All the results were analysed by a common process, although different vendors have chosen to express the maximum errors from the flowmeters in different ways, as a percentage error of the oil, water or gas phase flow rate. The results were compared with the reference measurements from the NEL facility, which are traceable to the UK National Standards for flow measurement and are calibrated at regular intervals. The uncertainty for the reference flow measurements are ±0.5% of reading for oil and water flow rate, and ± 1 to 1.5% of reading for gas flow rate. The errors from the reference phase flow rates were expressed as percentage error of phase flow rate:

$$\%Error = \frac{Q_{TEST} - Q_{NEL}}{Q_{NEL}} \times 100$$

The results, in terms of percentage error of reference phase flow rate were plotted against the gas and liquid superficial velocities (V_s) for each of the test meters. The superficial gas and liquid velocities are defined as the mean fluid velocity were the phase alone flowing in the test section.

$$V_s\_liquid = \frac{Q_{oil} + Q_{water}}{Area} \quad : \quad V_s\_gas = \frac{Q_{gas}}{Area}$$

Lines of constant gas volume fraction (GVF) are also shown on these graphs to assist in identifying regions of low and high GVF. Regions of low total flow rate correspond to low gas and liquid superficial velocities, similarly high flow rates correspond to high superficial velocities. The magnitude of the error from the reference has been illustrated at each evaluation point within a band of uncertainty i.e. between -10 and + 10 per cent.

4.2 Meter C

The results from the meter C test using brine solution 2 are shown in Figures C1, C2 and C3 for 10 per cent water cut

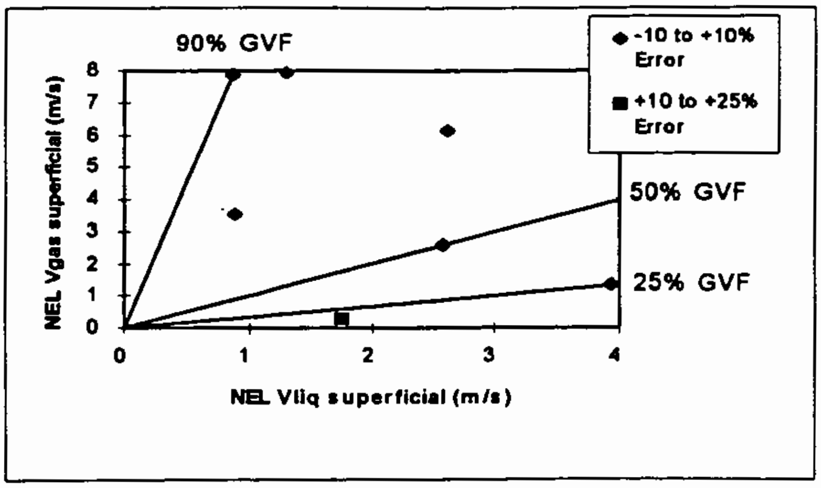

Figure C1: Oil phase flow rate errors at 10% water cut

The oil and gas phase flow rates were generally well predicted to within ±10 per cent of the reference phase flow rate at this condition, prediction of the water flow rate was less good with all the errors greater than ±10 per cent. There was some evidence of under-estimation of the gas phase flow rate at high GVF (see Fig. C3)

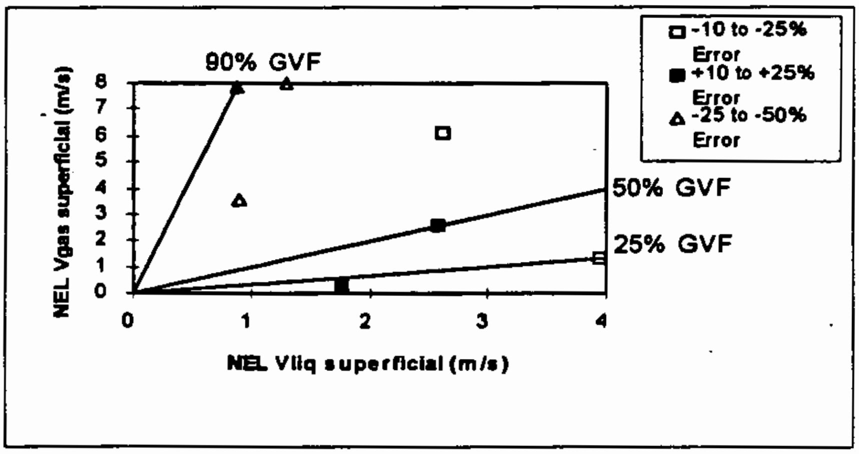

Figure C2: Water phase flow rate errors at 10% water cut

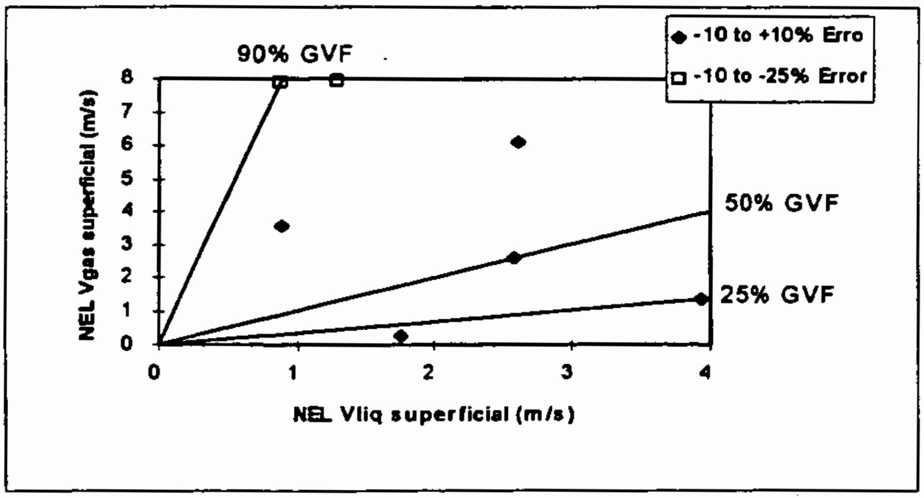

Figure C3: Gas phase flow rate errors at 10% water cut

Figures C4, C5 and C6 illustrate the results at brine solution 2 with 35 per cent water content.

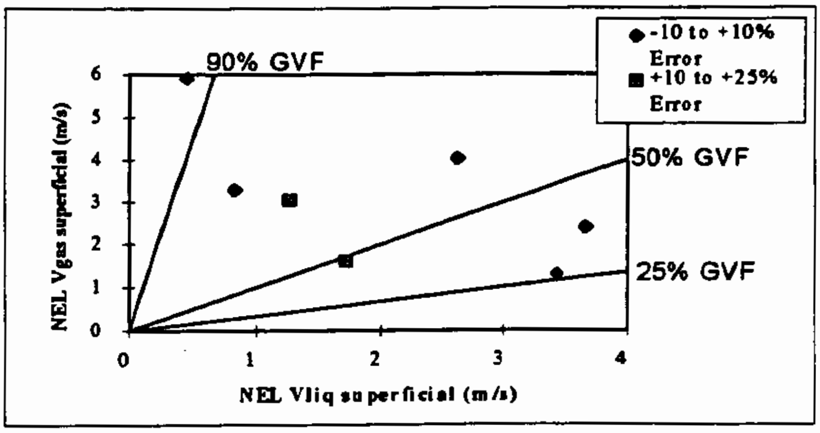

Figure C4: Oil phase flow rate errors at 35% water cut

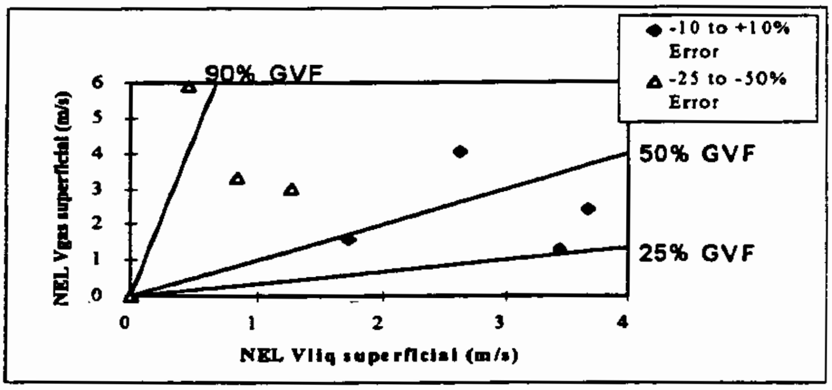

Figure C5: Water phase flow rate errors at 35% water cut

The majority of the oil and gas phase flow rates were well predicted to within ± 10 per cent of the reference condition. At the higher water cut the meter predictions were more accurate than at the 10 per cent water cut.

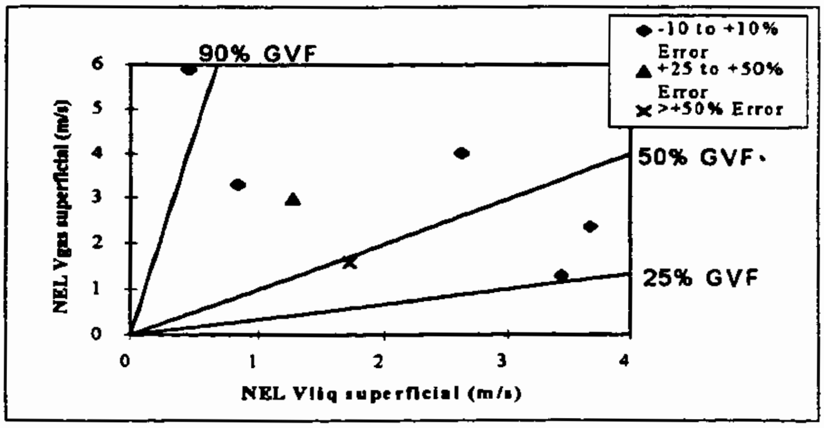

Figure C6: Gas phase flow rate errors at 35% water cut

For both water cut conditions the water flow rate was increasingly under-estimated as GVF increased, an indication that the accuracy of the water cut measurement was sensitive to GVF. The majority of the meter predictions which were within ±10 per cent of the reference were at liquid superficial velocity higher than 2 m/s. Below this level, and particularly with similarly low gas superficial velocity, greater errors wêre noted.

4.3 Meter Y

Data from this evaluation was unavailable at the time of writing but will be presented at the North Sea Workshop

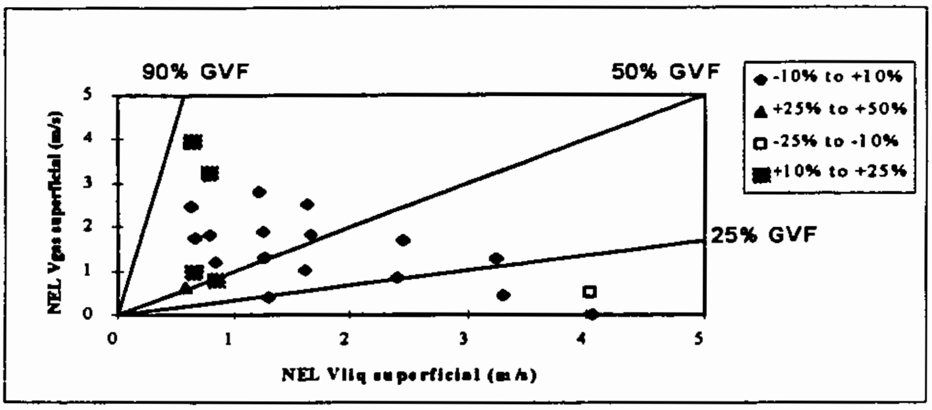

Figure N1: Oil phase flow rate errors at 40% water cut

4.4 Meter N

The results at 40% water cut for brine solution 1 are shown in Figures N1, N2 and N3.

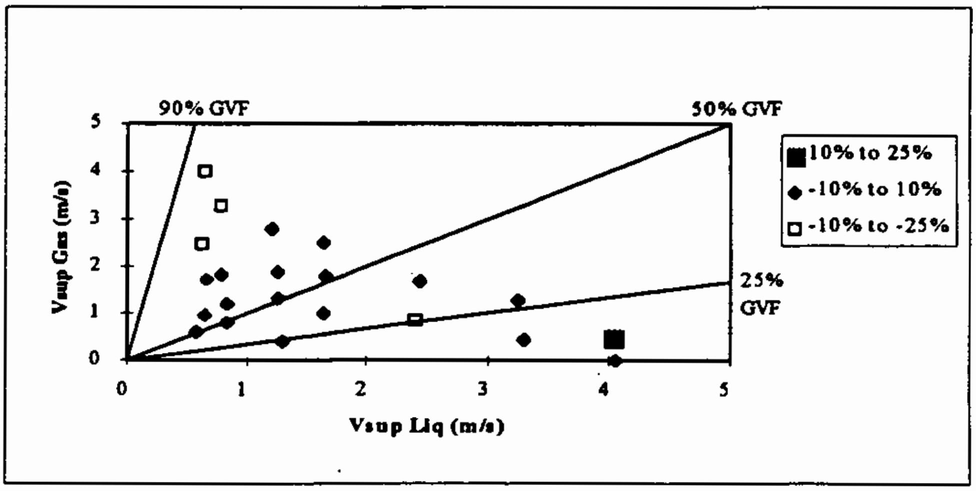

Figure N2: Water phase flow rate errors at 40% water cut

Most of the errors are within ±10 % of the reference phase flow rate. At high GVF and low liquid superficial velocity the oil flow rate was over-estimated and the water flow rate under-estimated, at these conditions an under-estimation of the water cut measurement was indicated The general trend is for water flow rate to be increasingly under-estimated as the GVF is increased. Gas flow rate was under-estimated at low gas and liquid flow rates.

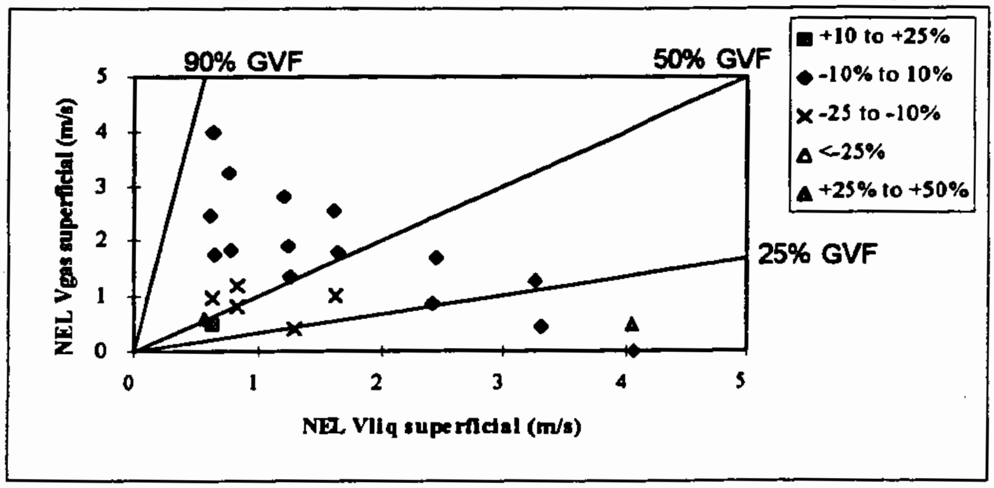

Figure N3: Gas phase flow rate errors at 40% water cut

The results at 75% water cut for brine solution 1 are shown in Figures N4, N5 and N6.

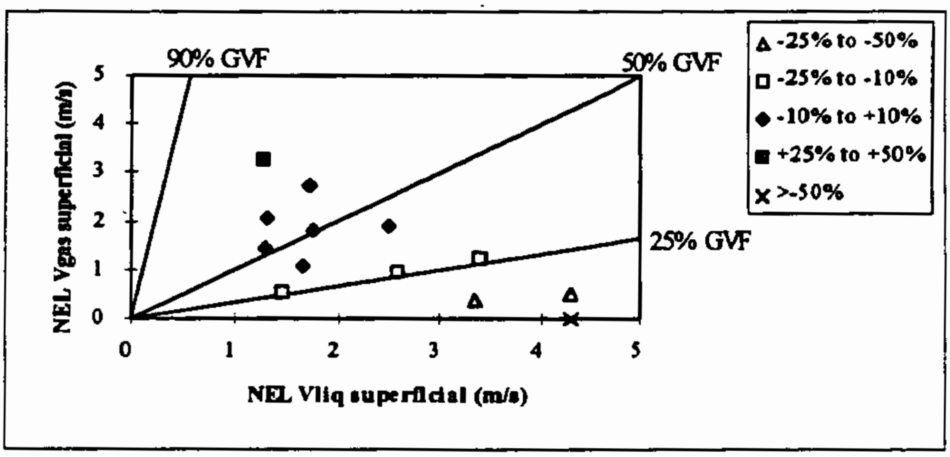

Figure N4: Oil phase flow rate errors at 75% water cut

Most of the errors are within ± 10% of the reference phase flow rate, the water flow rates were generally under-estimates within this region. The oil and gas flow rate errors were less than ±10% in the main, although the oil flow rate was under-estimated by up to 50% at low GVF for all flow rates and at low GVF the gas flow rate errors were large. The under-estimation of water content was not evident at high GVF for the 75% water cut, but the evaluation matrix did not include points above 70% GVF

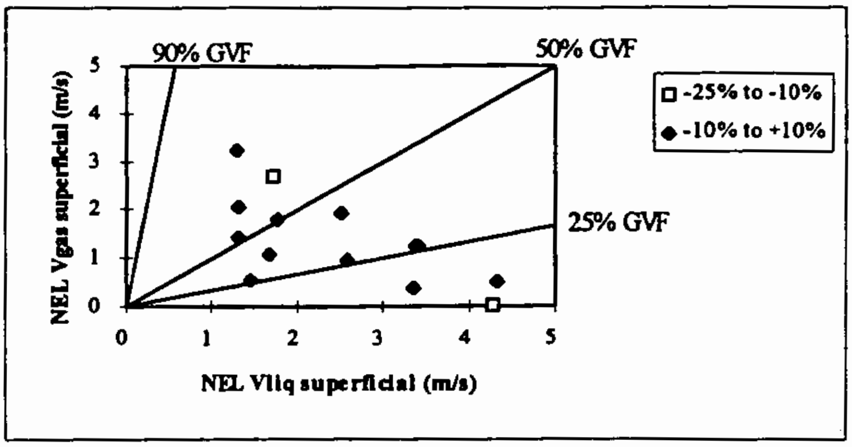

Figure N5: Water phase flow rate at 75% water cut

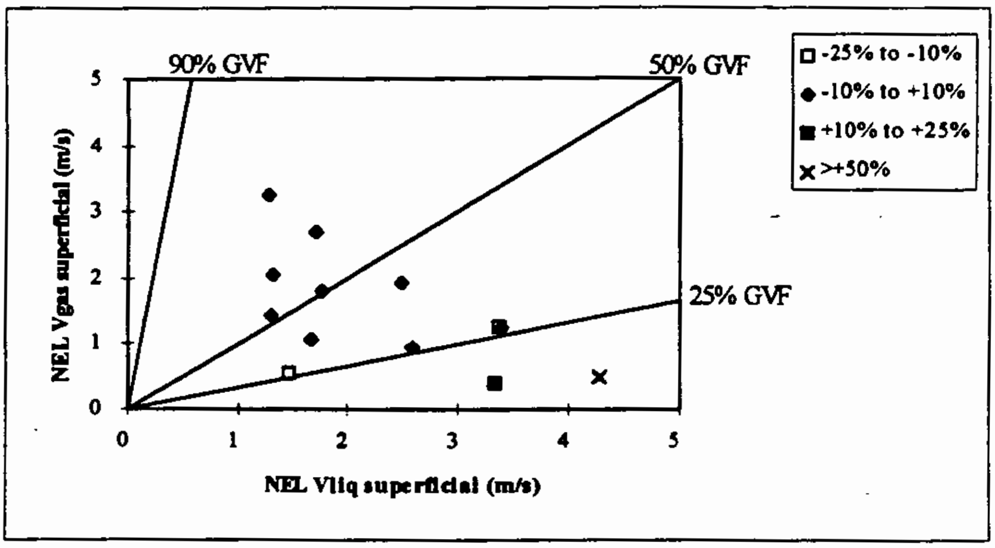

Figure N6: Gas phase flow rate errors at 75% water cut

5 CONCLUSIONS

The multiphase flowmeters evaluated to date have made use of a variety of different measurement techniques and have demonstrated that different approaches to the same fundamental problem can be equally effective.

Evaluation of the results from the meter tests has enabled the identification of regions of good and poor performance for each of the multiphase flowmeters and will help operators to select the appropriate technologies to meet the need of each field application

ACKNOWLEDGEMENTS

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Thanks also to all the manufacturers who have supported the JIP project by loan of equipment and support staff.

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.