THE PERFORMANCE OF A MULTI-PATH ULTRASONIC METER WITH WET GAS

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Due to increasing economic pressures in natural gas production, there is a recognized demand for flow meters that are able to measure when a significant quantity of liquid is present in gas flows. The key issues are that the liquid quantity is often unknown and its presence can affect the operation of traditional dry gas meters making the gas flow readings inaccurate. A number of techniques are emerging for the measurement of wet gas flows. The one considered here is the multi-path ultrasonic meter.

A JIP (Joint Industrial Project) was set up with participation from British Gas, British Petroleum, Conoco, Elf, Philips, Statoil and Daniel to investigate the performance of a six-inch 4-path Daniel SeniorSonic meter in wet gas service. This JIP was a continuation of the Ultraflow project, results of which were reported at previous NSFMW meetings [1 & 2].

Tests were conducted at CEESI (USA) with natural gas/decane and natural gas/Texsolve, and at NEL (UK) with Nitrogen/Kerosene to simulate the two-phase flow. The test matrix tried to cover pressures ranging from 25 to 75 bar, velocities from 2 to 20 m/s, and liquid volume fractions (LVF) from 0.1 to 5%. In practice, it was difficult to achieve this operating range. Ultrasonic wave propagation effects were observed on several meter diagnostic parameters, and the challenge is to find a simple correlation between these diagnostic parameters, pressure, velocity and LVF.

Results from CEESI and NEL tests are compared to some taken at Bacton with a natural gas/condensate flow coming straight from the North Sea, and to tests at Low Thornley with a 4-inch 2-path meter. This diverse testing tends to illustrate the complexity of the two-phase flow/ultrasonic meter interaction, and the difficulty of realizing a universal two-phase flow meter.

1 INTRODUCTION

Wet gas metering is a key enabling technology in the exploitation of marginal oil fields. The use of ultrasonic flow measurement technology has advanced significantly in recent years and is moving towards widespread acceptance for allocation and custody transfer metering duties. The ability of ultrasonic flowmeters to measure total volumetric flowrate in wet gas conditions has been demonstrated over a range of conditions. This work is aimed at further development to allow measurement of both liquid and gas flowrates.

This report describes the testing of a 6-inch ultrasonic meter (USM), calibrated in the NEL wet gas facility in order to generate characteristic data for the development of a two-phase meter. Results are presented for pressures of 25, 50, and 60bar gauge, covering a liquid volume fraction (LVF) range of 0.1 to 5%, with average gas velocities of 2-18m/s through the meter. The results of the wet gas tests are compared with baseline results obtained in dry gas conditions to obtain the relative error.

Similar tests were performed on the same 6-inch USM in the CEESI Colorado wet gas facility.

2 THE NEL WET-GAS TEST FACILITY

Figure 1 details the high-pressure wet gas facility at NEL. Before testing, the loop is pressurised to a maximum of 60 bar using high-pressure nitrogen packs located outside the building. The gas flow is produced by a 250 kW blower, capable of delivering volumetric flow rates of 120-1200 m^3/h at line-pressures of between 0.5 and 62 bar gauge. A 6-inch, high-precision turbine meter is used to measure the reference dry gas flow rate.

The liquid (kerosene) is injected into the stream via an injector nozzle placed on the axis of the pipe, facing downstream. A 130 kW pump is used to deliver liquid to the nozzle at up to 80 m^3/h. The flow rate through the nozzle is controlled via a 2-inch, class 900 ball valve, which is welded onto the side of the injection spool. The flow rate of the liquid is measured by one of 3 liquid turbine meters, located within ½-inch, 1-inch and 3-inch diameter lines. These meters have been calibrated in the range 0.1 - 140 m^3/h, to an uncertainty of 0.16% on flow rate. For the upper range of the flow rate, the 3-inch line is used, while the required turndown ratio is achieved using the ½-inch and 1-inch bypass lines accordingly.

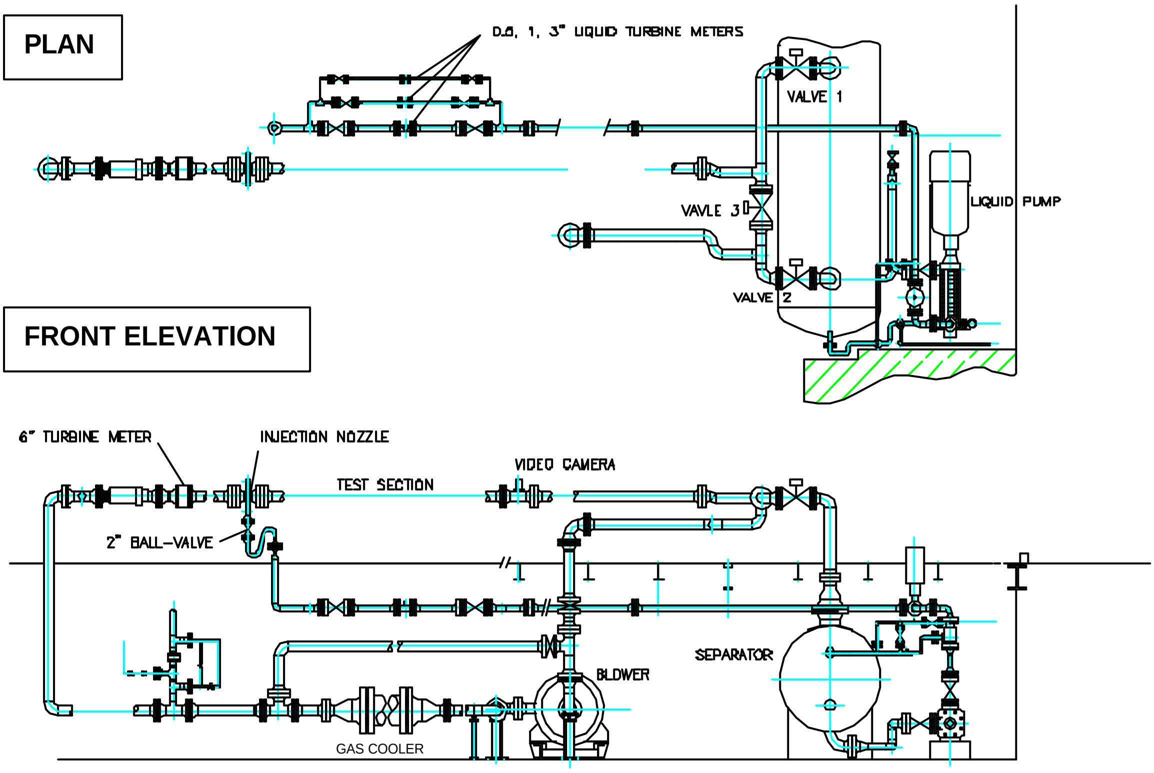

Figure 1. High Pressure Wet Gas Calibration Facility at NEL

3 THE CEESI TEST FACILITY

The test set-up at CEESI used natural gas that was re-circulated around the loop by four piston compressors with little provision for cooling. This meant that the gas in the loop got hot (95 -125°F) during test runs. The compressors were switched on and off to control gas velocity, with a bypass loop for fine control. At 25 bar, with the four available compressors working, the maximum gas velocity was 17.7 m/s. At 50 bar, Compressor 4 tripped out at any speed above 13 m/s, so that was the maximum velocity seen at 50 bar. At 75 bar, it was not possible to start the largest compressor, which limited the gas velocity to 6.6 m/s.

The liquids used were Decane and Texsolve, with a liquid injection system based on a diesel powered Triplex liquid pump. Unfortunately, this could not work at line pressure and a significant pressure cut was required on the liquid return pipe to the pump suction. During operation, problems occurred which were attributed to foaming liquid entering the Triplex pump, caused by out-gassing due to the pressure cut. The out-gassing gave problems in controlling the pressure, the gas flow, and liquid flow in the loop.

4 RESULTS OF METER PERFORMANCE

Dry gas calibrations at NEL and CEESI are shown in Figure 2. They were used as a baseline for determining wet gas errors. It is noticeable that the CEESI results are more erratic and scattered, no doubt due to the difficulty in controlling the rig and the suspected pulsation problems created by the reciprocating compressors.

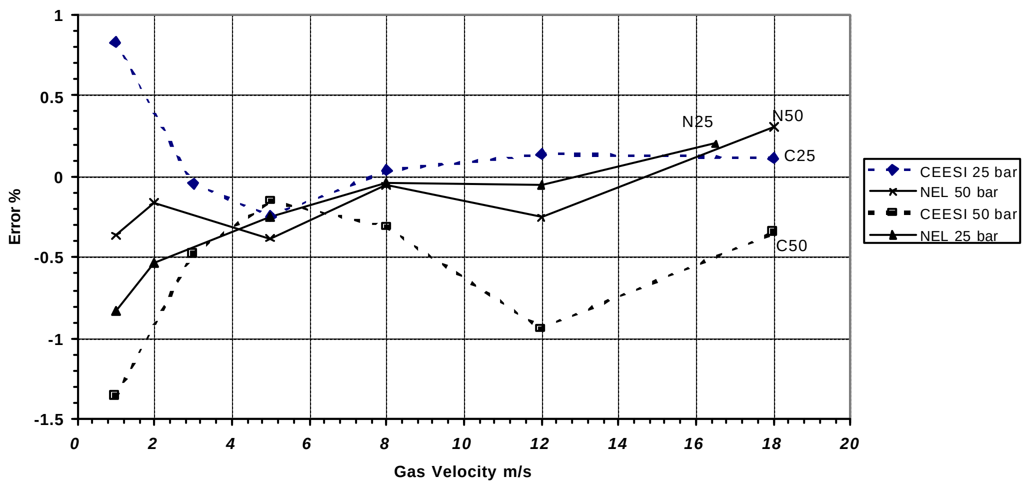

Figure 2. Dry Calibration at NEL and CEESI

Results of wet gas calibrations at NEL, with pressures of 25 and 60 bar, are shown in Figures 3 & 4.

Errors decrease as both the velocity and pressure increase. The pressure increase gives rise to a density increase of the gas, increasing buoyancy of the liquid as well as the momentum transfer from the gas to the liquid. Due to power limitations, a velocity of 18 m/s was the maximum achievable rate at NEL. At this rate the maximum LVF was 2%; at lower velocities higher LVF could be achieved. Planned improvements to the NEL facility this year should result in a moderate extension of this operating range.

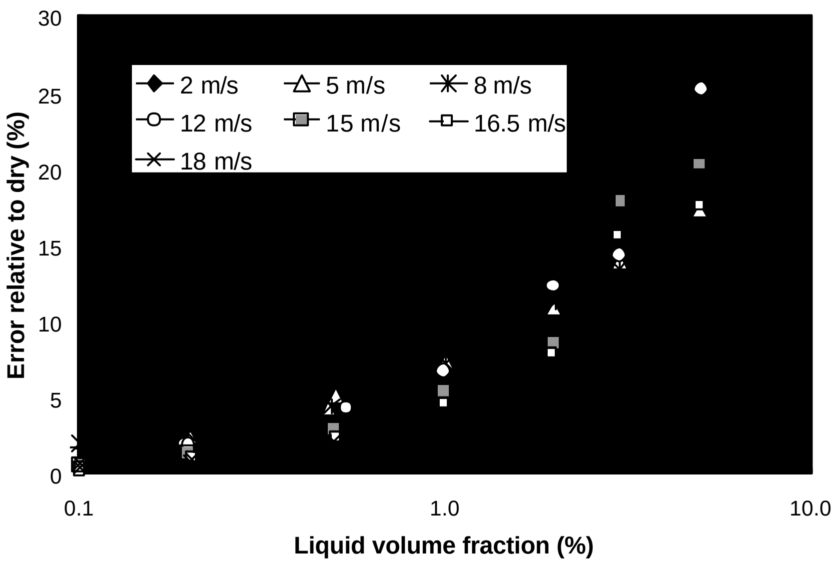

Figure 3. Error Relative to Dry Gas at 25 Bar Gauge at NEL

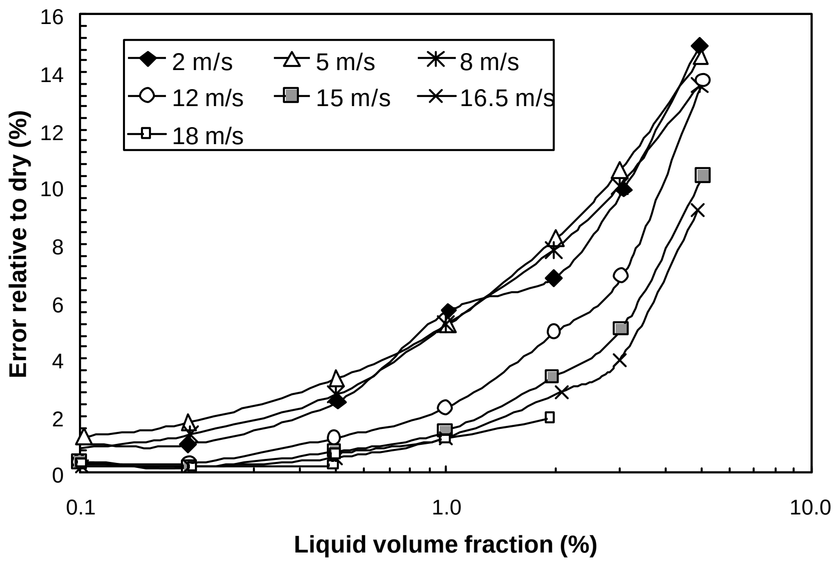

Figure 4. Error Relative to Dry Gas at 60 Bar Gauge at NEL

Ultimately, with sufficient gas density and velocity, the liquid will be carried as a mist at the same velocity as the gas with virtually no liquid wetting the pipe wall. This can be described as a 'total mist' condition. When this happens, the error (in gas measurement) will equal the LVF because the ultrasonic meter is volumetric, measuring the total volume flow. If the error is larger than the LVF, then the liquid is travelling slower than the gas and occupying more area (liquid hold-up). We can use the error curves to find:

Liquid Velocity = Gas Velocity * LVF / Error

Figure 5 shows results from NEL and CEESI together with comparisons from Low Thornley (LT) and the same 4-inch meter use for preliminary tests at NEL (designated NEL1).

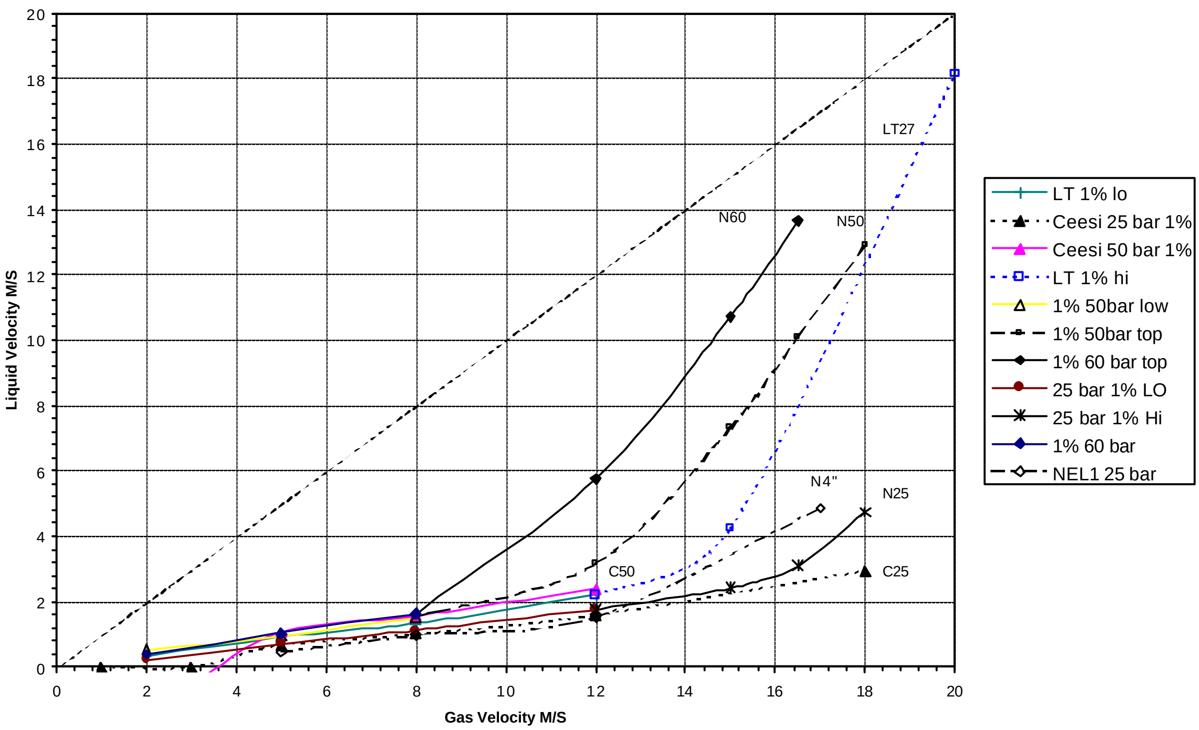

Figure 5. Liquid Velocity Calculated from Error, LVF and Gas Velocity

The curves split approximately into two parts: linear at low gas flows and quadratic at higher flows. The linear part corresponds to stratified flow, where the liquid is running along the bottom of the horizontal pipe, and increasing the gas velocity gives a proportional increase in the liquid velocity. The quadratic part occurs at higher flows (8 to 10 m/s) and higher pressure (50 to 60 bar), corresponding to annular/mist flow where more and more liquid is entrained until ultimately it all acquires the gas velocity (shown by the line of unit slope).

It is noticeable that the tests at CEESI were all in the stratified flow region, due to the pressure and flow limitations. This led to further work being undertaken at NEL facility, which did manage to get into the annular/mist region.

5 COMPARATIVE TESTS AT NEL AND LOW THORNLEY

Initial tests were carried out in the facility at NEL on a 4-inch dual-path meter. This meter had previously been tested at the Low Thornley test site using natural gas and condensate. This allowed comparison of the results to establish if the NEL test fluids would cause the magnitude of the errors to be different. Although the exact test conditions were not matched, the same test pressure was used and broadly the same range of LVF and gas velocity were covered.

Before these results are presented it is worth considering the uncertainty in the calculated error values. The instruments on the test facilities are normally fully traceable and data is acquired at a high rate and with sufficient resolution for the uncertainty to be small relative to the errors due to the presence of liquid. However, the data from the meter was acquired over a serial link using a standalone PC. The data was transferred approximately once ever thirty seconds with the result that relatively few flowrate samples are taken.

The results in Figure 6 show that the error values obtained on the NEL facility are reproducible to within about 1%. This is comparable with the uncertainty in the indicated flow rate as estimated from the standard deviation of the USM output (as shown by the error bars for test series 3). Considering the various sources of uncertainty, it is not hard to imagine that the derived error could differ by one and two percent between Low Thornley and NEL due to uncertainty alone.

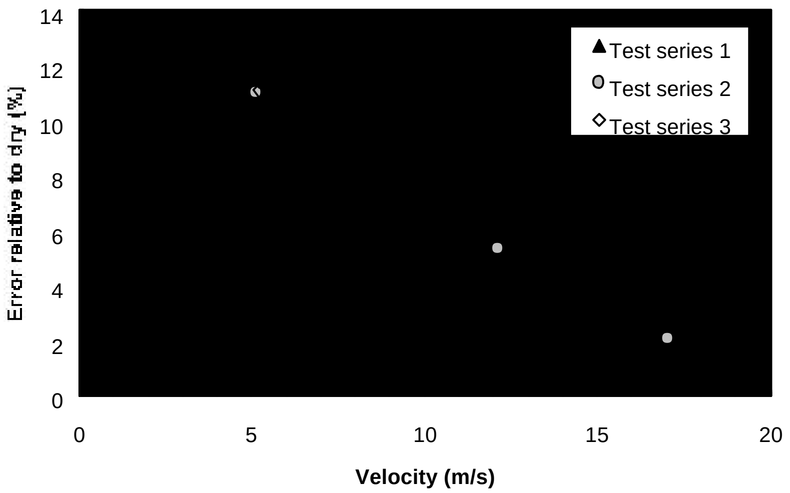

Figure 6. Test Results Reproduced at NEL at 2.7 m^3/hr Liquid Flowrate

Figures 7 to 10 show that the error values obtained at NEL generally agree with the Low Thornley results to within about 2%. A difference between the facilities is only clearly apparent in the 5 m/s data. At this lower velocity, different pipework installations in the two facilities could easily have an influence the liquid hold-up. It would appear that in terms of the overall performance of the meters, the nitrogen/kerosene fluids used by NEL produce very similar results to natural gas with condensate for the range of stratified and annual/mist conditions achieved in these two facilities.

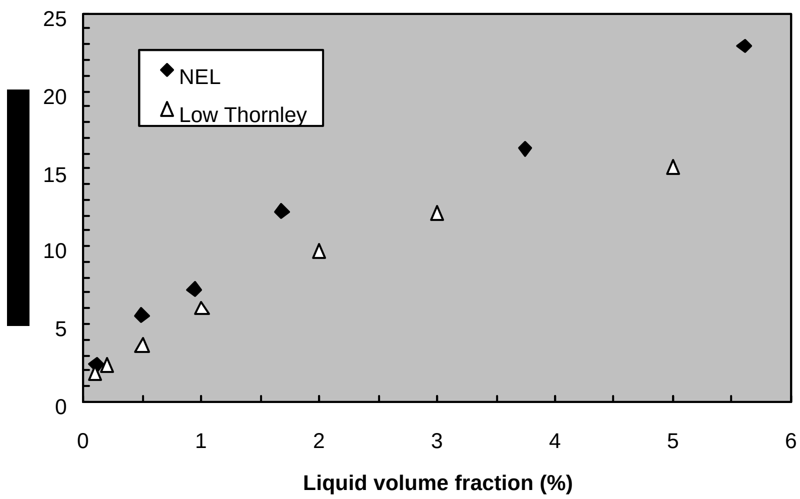

Figure 7. Comparison of Results at 5 m/s Gas Velocity

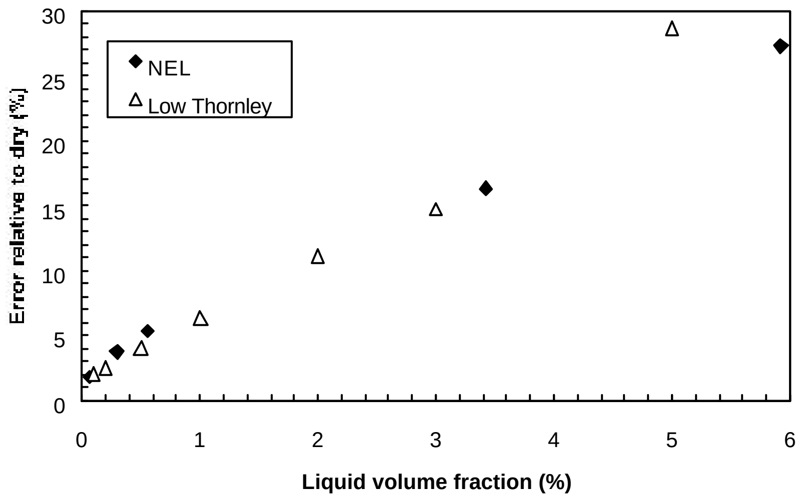

Figure 8. Comparison of Results at 8 m/s Gas Velocity

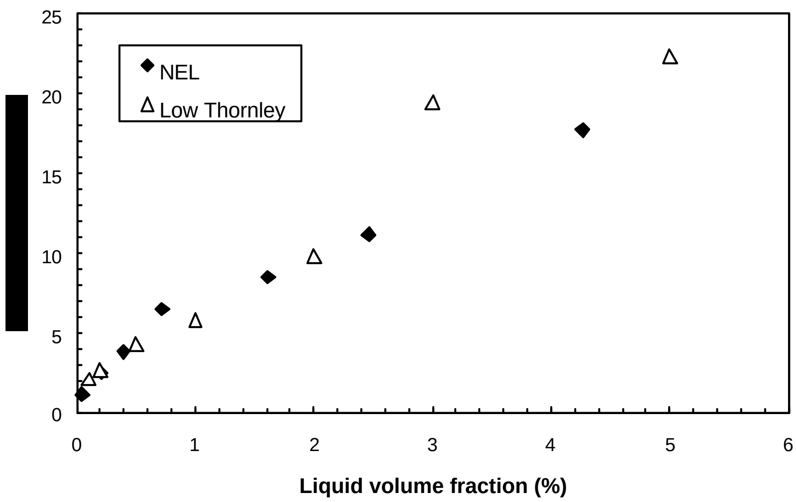

Figure 9. Comparison of Results at 12 m/s Gas Velocity

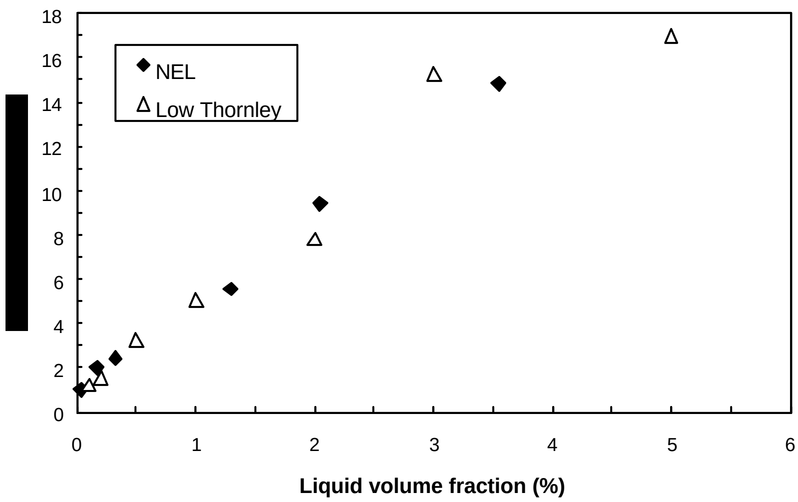

Figure 10. Comparison of Results at 15 m/s Gas Velocity

6 RESULTS FROM USM DIAGNOSTICS

The USM has many diagnostic functions aimed at ensuring consistent signal detection and accurate transit time measurement for the normal gas meter performance. Previous experience at Bacton and Low Thornley has shown that many of these are affected by liquid mist in the ultrasonic path. In particular, the following have shown dependence on LVF:

1. VOS (Velocity of Sound) is used to check for a sensible value (typically 400 m/s for natural gas) and that all four-path VOS values are the same within 1%. The presence of liquid mist reduces the VOS.
2. Gain is a measure of the attenuation of the signal. The transmitted signal has a fixed value dictated by intrinsic safety considerations. AGC (Automatic Gain Control) is applied to the received signal to give a constant amplitude for signal processing. AGC is used to compensate for changes in pressure and velocity. The presence of liquid mist increases the Gain.
3. StdDev (Standard Deviation) a single flow measurement point consists of a batch of 20 transit time measurements both upstream and downstream on all four chords, which allows statistical evaluation of StdDev. This is used to check the quality of the signal detection. The presence of liquid mist increases the StdDev.
4. S/N (Signal to Noise) is used as another check on the quality of the signal detection. Noise is defined as what is seen in front of the signal detection point. The presence of liquid mist generally decreases the S/N.

6.1 Velocity of Sound (VOS)

The change in VOS with LVF is small but very consistent and not affected by pressure or velocity. At NEL Chord D is at the top and Figure 11 shows a typical vertical mist gradient in the horizontal pipe due to gravity.

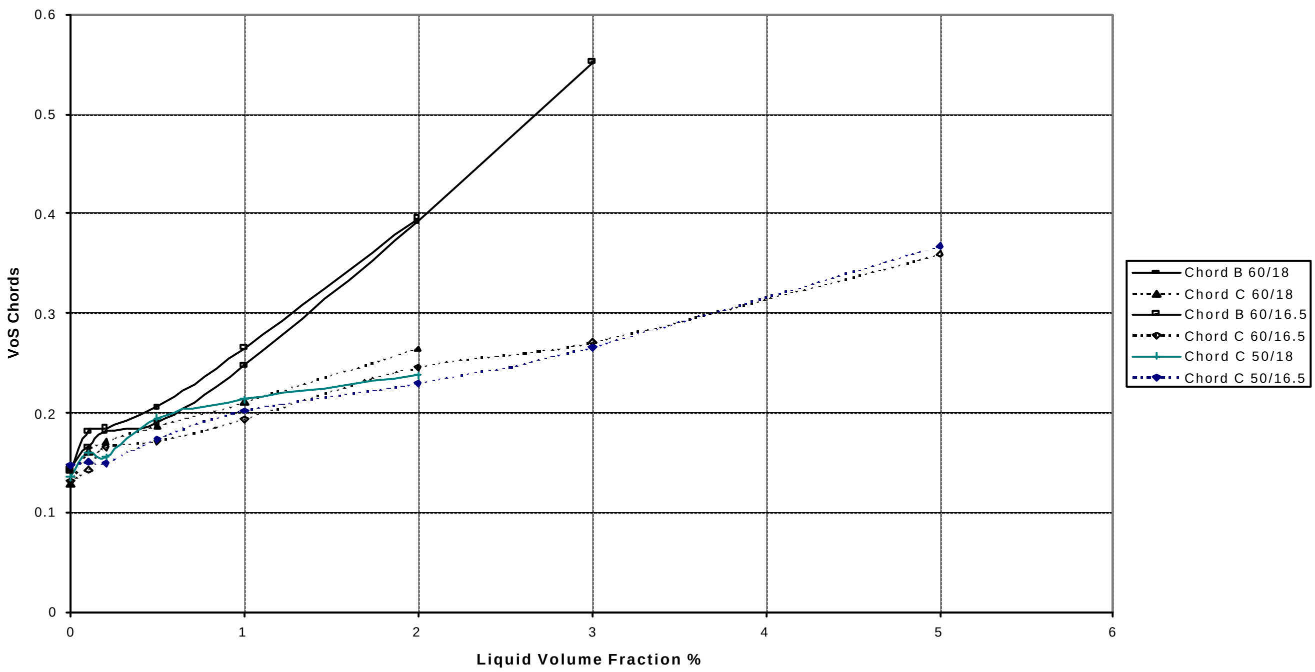

Figure 11. VOS – LVF for the Chords at NEL

6.2 Gain

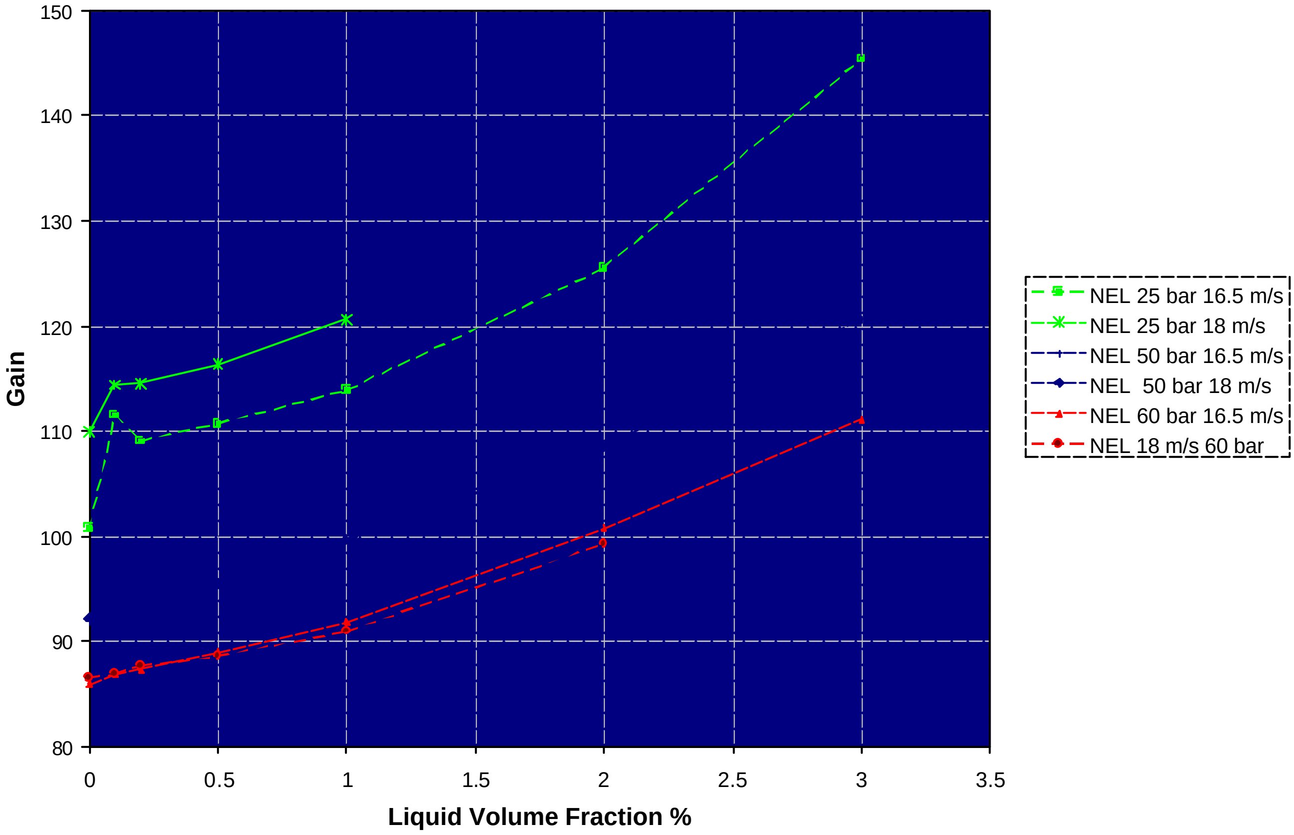

Figure 12. GAIN – LVF for the Meter at NEL

As can be seen from Figure 12, the Gain increases with LVF, as expected. The gain correlates strongly with pressure and weakly with velocity. The op-amp used for the AGC causes the gain to have a log scale where a difference of about 15 is a doubling. The effect of pressure is to increase the density and improve the impedance match between the transducer and gas. Thus, the doubling in pressure (from 25 to 50 bar) is seen to halve the gain.

In a horizontal pipe, the top chord (Chord D) will see very little mist and could be used as a reference to correct for the effects of pressure, temperature, composition, and velocity. This particular USM shows an anomaly between the response of the outer chords (A & D) and the inner chords (B & C), making it difficult to use Chord D as a reference.

6.3 Standard Deviation (StdDev)

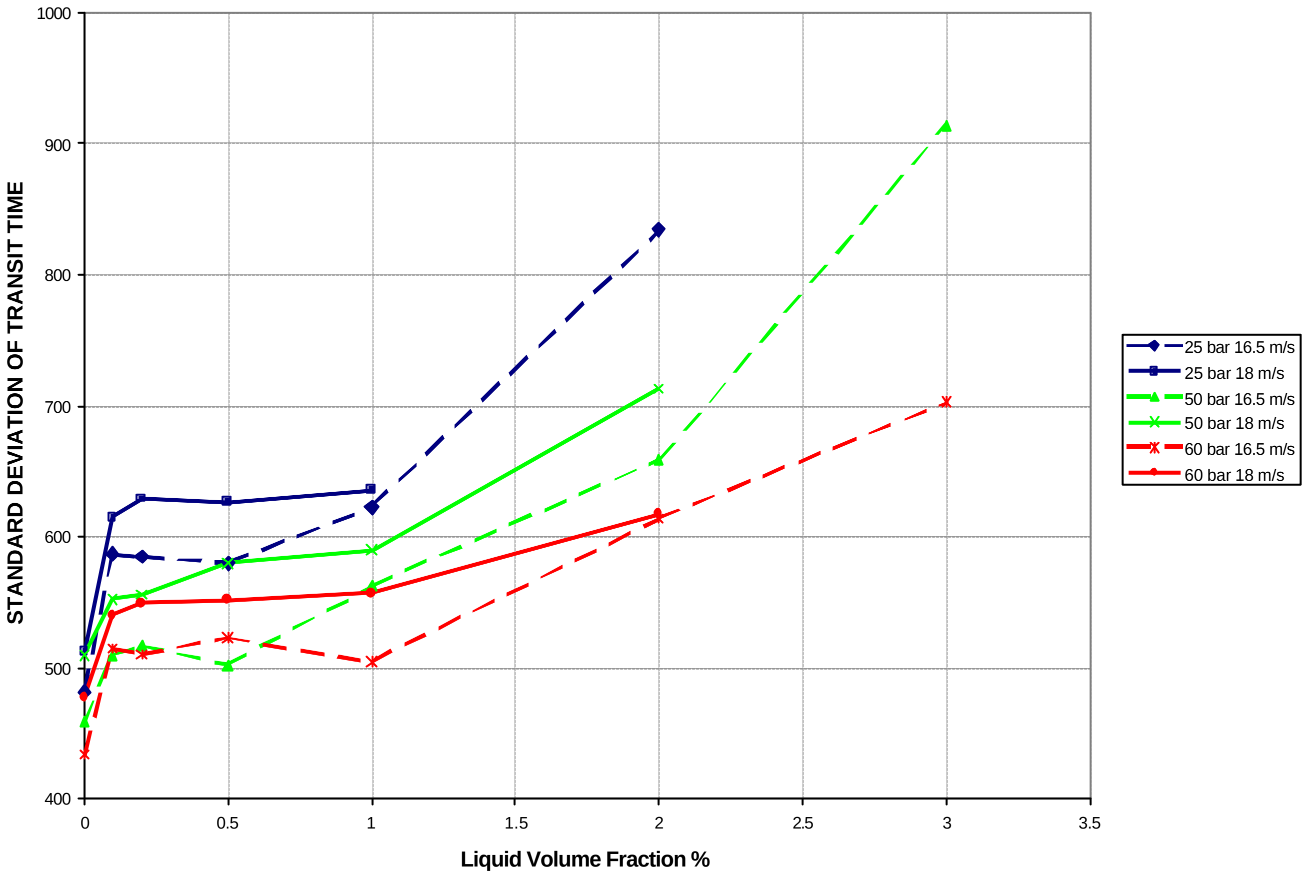

Figure 13. StdDev – LVF for the Meter at NEL

As can be seen from Figure 13 , the StdDev increases with LVF as expected, but there is also an effect of pressure and velocity, and the trends are not consistent.

The StdDev is a batch statistical property and only a few batches have been collected for each experimental point in the Flow, LVF, and Pressure matrix. In practice, it would be better to continuously update the StdDev (moving average) to avoid random fluctuations and small sampling problems.

Ideally, it should be possible to use the top chord to compensate for the pressure and velocity effects, but this method does not always work.

6.4 Signal to Noise (S/N)

As can be seen from Figure 14, the S/N basically decreases with LVF, but there is also an effect of pressure and velocity, and the trends are not consistent.

It is noticeable that, at low LVF, the S/N sometimes increases a little before decreasing as more liquid is added. Other anomalies have been noticed at very low LVF. These are thought to be associated with wetting the pipe walls and the possibility that the liquid could suppress turbulence in the gas flow.

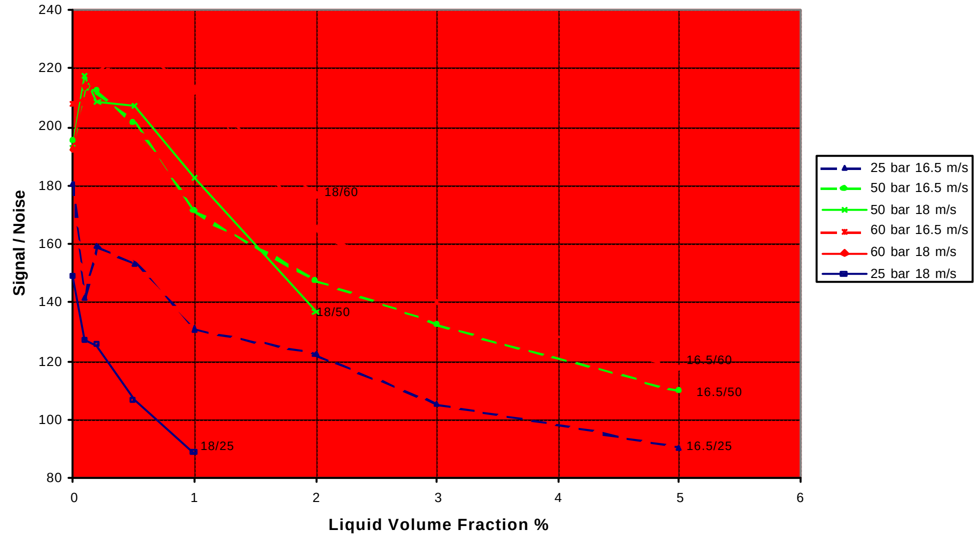

Figure 14. S/N – LVF for the Meter at NEL

7 COMPARISON WITH PREVIOUS TESTING

The past testing is summarized below:

1) *Bacton* 1994. 6-inch 4-path USM. Pressure of 60 bar. Natural gas and condensate at Shell Bacton terminal. Limited data from survival and recovery tests. Showed initial relationships between LVF and VOS, Gain ,& StdDev in mist flow (> 5 m/s).

2) *NEL* 1994. Same meter as Bacton. Pressure of 60 bar. Air and Water. Despite concerted attempts to produce mist flow it reverted to stratified flow. Demonstrating that the fluid properties are very important.

3) *Low Thornley* 1998. 4-inch 2-path USM due to limitations of site. Pressure of 27 bar. Natural Gas and condensate. Vertical and horizontal orientation. Mist flow only just achievable. Showed importance of pipe configuration. Vertical down flow flooded the transducer ports.

Together with the tests reported here, from NEL and CEESI, we have covered a wide range:

USM:	6-inch 4-path, 4-inch 2-path
Orientation:	Horizontal and vertical
Gas:	Air, nitrogen and natural gas
Liquid:	Water, condesate, Kerosene (Exxsolve), Texsolve and decane
Field:	Bacton and Low Thornley were once-through field tests
Lab:	NEL and CEESI are re-circulating lab tests
Pressure:	25 to 75 bar
Velocity:	1 to 18 m/s

Any individual test can be interpreted and a correlation found between LVF and VOS, Gain StdDev and S/N that can be used to determine the LFV. However, when looking at all the tests, it shows the difficulty of finding universal relationships between LVF and VOS, Gain StdDev, and S/N, that will be true for all cases. This is illustrated in Figures 15, 16, and 17.

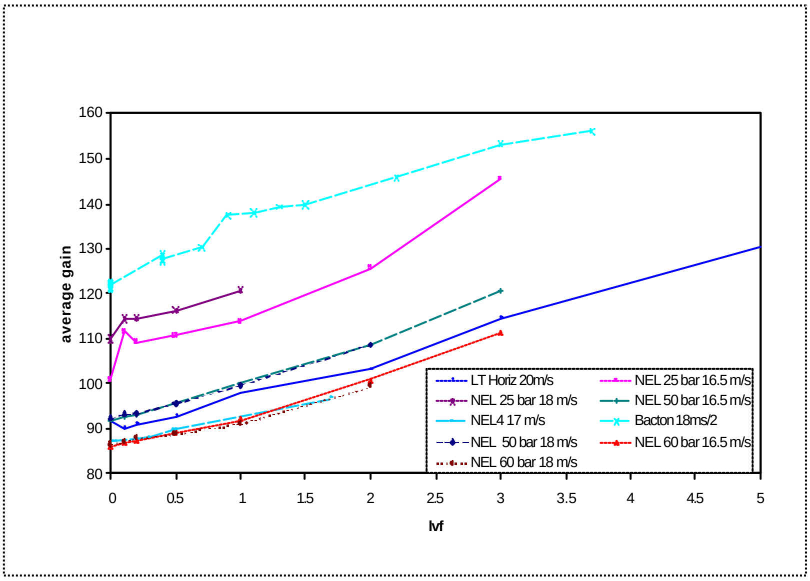

Figure 15. Comparison of LVF – Gain for Different Tests

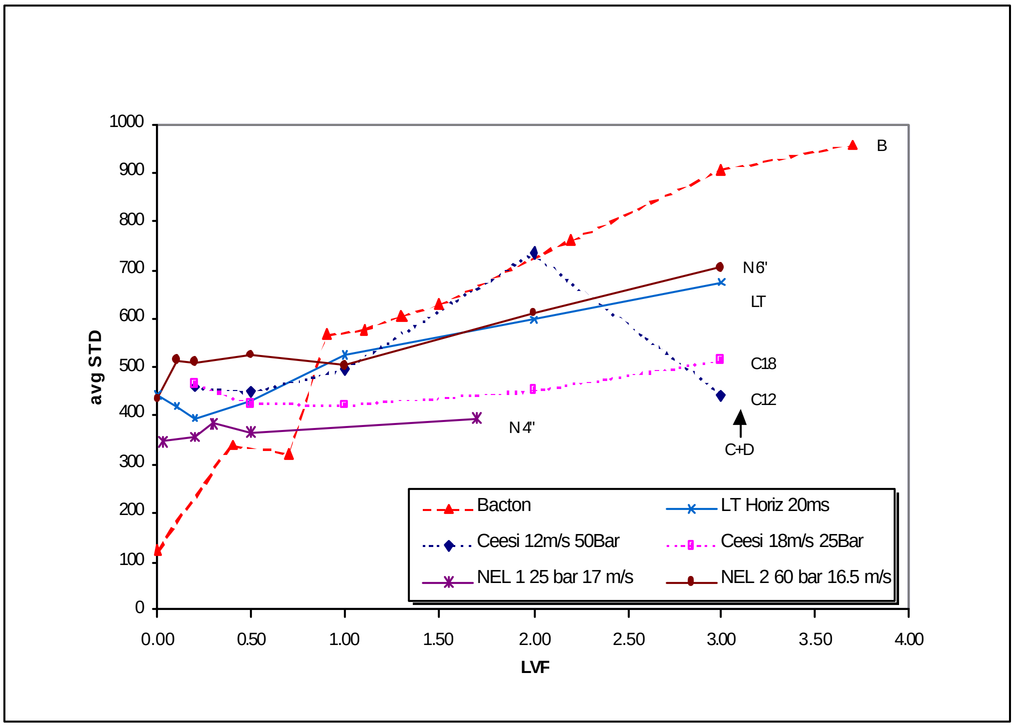

Figure 16. Comparison of LVF – StdDev for Different Tests

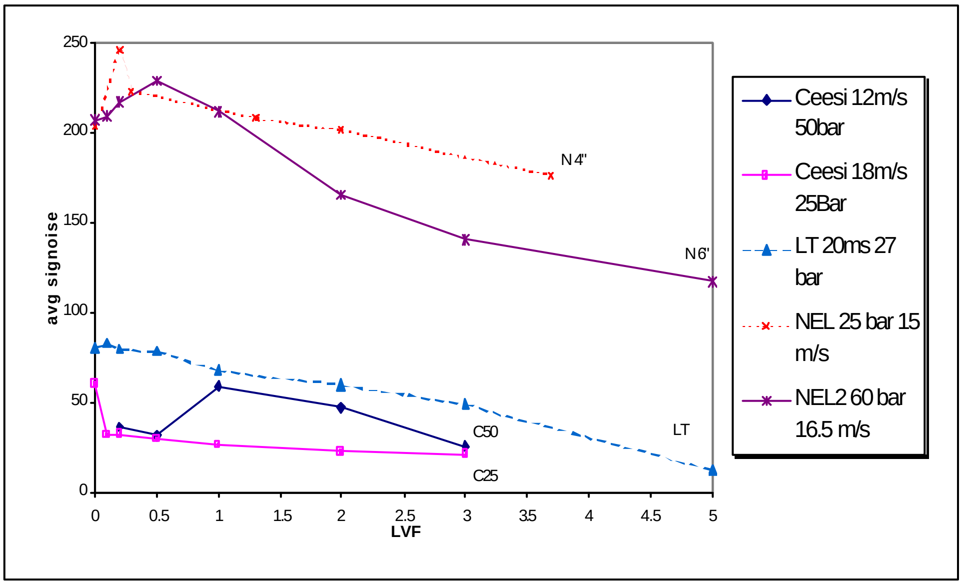

Figure 17. Comparison of LVF – S / N for Different Tests

Although the trends are fairly similar, actual magnitudes and slopes can vary. Some of this difference can be attributed to changes in pipe size, pressure and velocity, but other factors must be important. For example, we can consider liquid properties such as density, viscosity, and surface tension. Phase changes can occur with natural gas/condensate but not with other fluids. The Bacton results show that total mist flow will occur at high velocities in natural gas/condenstate systems (due to the lower surface tension of the liquid), while the other fluids more often give stratified and annular/mist conditions with more of the liquid traveling along the pipe wall. The results of the Low Thornley/NEL comparison show that there is reasonable agreement in the error results at velocities up to approximately 18 m/s. However, the error never reduced to equal the LVF, the conclusion being that total mist conditions were not achieved at NEL or Low Thornley. It is clear therefore that distribution of the liquid phase owing to the flow regime has a significant effect on the performance of ultrasonic meters in wet gas. It is also accepted that other factors such as the droplet size in the mist will affect interaction with the ultrasonic signals [3].

8 CONCLUSIONS

- The ultrasonic meter will work in a wet gas environment.
- The diagnostic functions can certainly detect the presence of liquid mist.
- For a given system, it is possible to correlate the LVF and diagnostic parameters so that they can be used to predict the LVF, but it is difficult to be universal.
- At present, each meter would require calibration in conditions similar to the application. This may demand the use of natural gas/condensate or more realistic substitute fluids.
- The general lack of wet gas test facilities makes further investigation difficult. This is particularly true when an extensive range of sizes, pressures, flowrates and fluids is required.
- In mist flow, a 1% LVF gives a 1% error in an USM, and in stratified flow about 5% error.
- If the liquid density is 20 times the gas density (liquid 800 kg/m^3, gas 40 kg/m^3) then 1% LVF is 20% by mass and a Venturi meter (responding to ρV^2) will give a 10% error.
- If it is difficult to achieve total mist flow in practice, it might be better to ensure lower gas velocities and design a meter suitable for stratified two-phase flow measurement.

REFERENCES

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