Paper 6

Suitability of Dry Gas Metering Technology for Wet Gas Metering

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SUITABILITY OF DRY GAS METER TECHNOLOGY FOR WET GAS METERING

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1 INTRODUCTION

Wet gas metering is being used increasingly in economically marginal fields, reducing the capital costs by allowing several small fields to share common platform infrastructure. The development of reliable wet gas meters is a key requirement in the oil and gas industry at present. Such meters should be able to measure both the gas and liquid flowrates if desired. However, in some cases the liquid flowrate is not important, requiring only the gas flowrate to be measured accurately.

If the liquid flowrate is reasonably steady, and can be determined by other means, i.e. tracer technique or periodic sampling, then a standard single phase gas meter, whose response to the presence of liquid is known, can be used with a correction applied to the reading to account for the liquid.

In some other situations, unexpected well conditions can result in a higher liquid loading in the gas stream causing nominally dry gas meters to be exposed to liquids. In this case it is important for the operator to be able to establish the error in gas measurement, particularly if the meter is used for allocation purposes.

This paper analyses the performance of three types of non-Δp meter, namely a turbine meter, a Coriolis meter and a vortex meter. Test data taken at NEL, during the 1999-2002 DTI Flow Programme, is analysed and compared with any previous data available. It is understood that some of these meter types may not be intentionally applied in a wet gas situation, however, it is important to know how they are affected by the presence of liquid in case they are subjected to wet gas flow unexpectedly.

2 METER OPERATING PRINCIPLES

The three meter types considered have very different operating principles and could therefore not be expected to behave in the same manner in wet gas flow. These principles are described below:

2.1 Turbine

A Gas Turbine meter operates by accelerating the flowing fluid past a centrally located hub onto a low friction rotor containing a set number of blades inclined at an angle to the flow. The accelerated flow causes the rotor to rotate and the passage of each blade past a magnetic pickup coil then generates a voltage pulse that can be amplified and squared off. The flowrate of the fluid through the meter is then related to the pulse output frequency via the determination of a meter factor, generally from calibration under controlled conditions.

The effect of wet gas flow on such a meter was initially difficult to predict, but would probably be concerned with the effect of the liquid droplets or liquid stream on the blades. In the tests at NEL a 6-inch Instromet meter (model G-650, type SM-RI-E) was used.

2.2 Coriolis meter

There are many different designs of Coriolis meter, but generally all operate on the same principal. The fluid passes through a flow tube(s) that is oscillated in a direction tangential to the flow. The forces generated cause the tube(s) to twist in shape, and it is this twist which is used to determine the flowrate. The forces generated are proportional to the mass flow passing through the tube(s). In twin tube meters, the tubes oscillate against one another, whereas in single tube meters the tube oscillates against an internal reference, sometimes the meter body.

As these meters measure mass flow directly it was uncertain whether or not they would measure the total mass flow of the wet gas stream, regardless of phase, and whether this would be affected by flow regime (stratified or annular/mist). Anecdotal evidence has also suggested that the tube vibration can stall in two-phase flow due to the density difference between the gas and liquid and the difficulty in controlling the tube vibration. In the NEL tests a 4-inch Endress and Hauser meter Promass 63F meter was used, which is a twin tube meter with a slight bend in the tubes.

2.3 Vortex meter

A Vortex meter operates by placing a (generally) triangular bluff body into a flow that generates a stream of vortices off its leading edges. The frequency of the production of these vortices is linearly related to the fluid velocity. Sensors downstream of the bluff body are used to measure the vortex frequency and consequently the flowrate.

In wet gas it was expected that this meter would be affected by the blockage factor introduced by the liquid, in that the liquid presence leaves less flow area for the gas, which therefore flows faster causing the meter to over-read the gas flowrate. The expected influence of the liquid on the vortex generation was unclear. In the tests at NEL a 4-inch Fisher-Rosemount 8800A Vortex meter was used.

3 Meter Behaviour in Wet-Gas

The NEL tests were conducted on NEL's high pressure wet gas test facility, described in detail elsewhere [1]. This facility operates at pressures up to 60 bar, with gas flowrates up to 1000 m^3/hr in wet gas mode, and liquid volume fractions up to 5%, with higher fractions achievable at low gas flowrates. The facility uses nitrogen for the gas phase and a kerosene substitute for the liquid phase. These have been selected to provide a balance between representative test fluids and high accuracy, traceable reference metering. There is no phase transfer between the fluids and therefore complicated PVT models are not required to determine the reference flowrates of each phase at the test meter.

3.1 Turbine

The turbine meter was initially calibrated in dry gas at 20 barg, 40 barg, and 60 barg. This gave a baseline calibration curve across a range of Reynolds from 1 x 10^6 to 9 × 10^6 against which the wet gas tests could be compared. The dry gas results are shown below in Fig. 1.

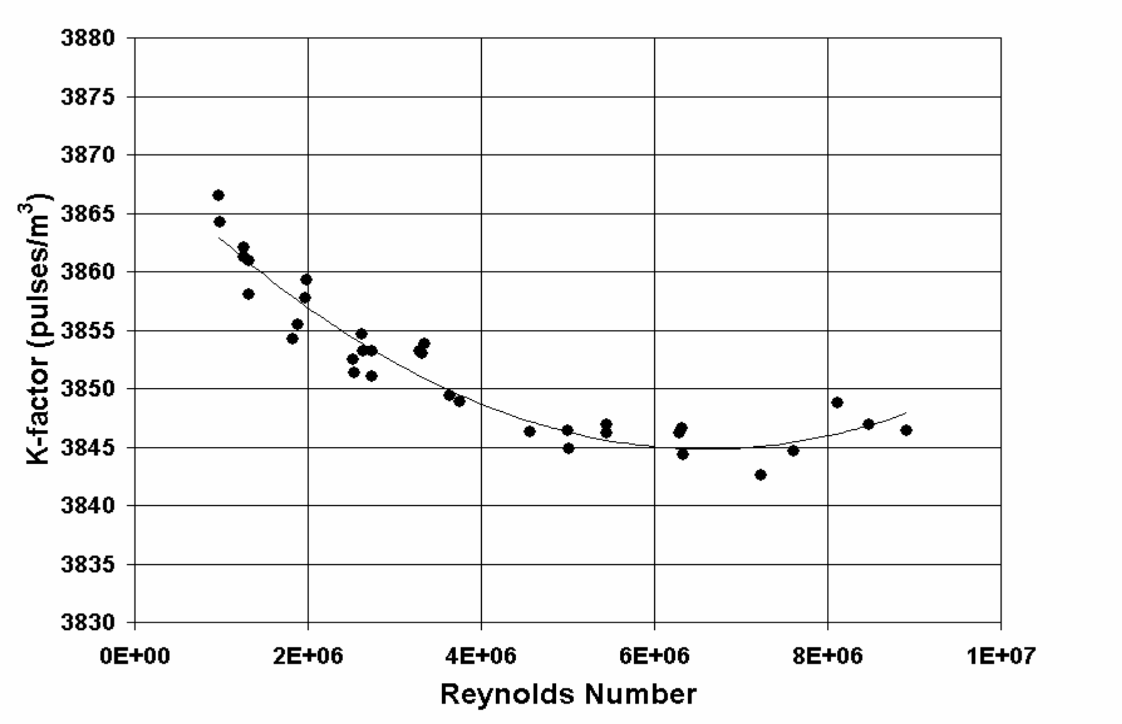

Fig. 1. Dry gas calibration of 6-inch turbine meter.

The meter was subsequently tested in wet gas at 60 barg. Four sets of tests were carried out across the gas flow range 200 to 1000 m^3/hr. In the first set of tests, the liquid flowrate was held constant at 0.045 l/s, ie the minimum liquid rate that could be injected in the NEL wet gas facility. This flowrate corresponds to a liquid mass fraction (LMF) of 0.93% at the lowest gas flowrate and 0.18% at the highest gas flowrate. The next three tests were carried out with liquid mass fractions of 0.5%, 1.0% and 2.0%.

To keep these liquid contents in perspective, the generally accepted definition of 'wet gas' allows LMFs of 50% or more, considerably larger than were used here. These were not used for two reasons, namely that there was no particular relevance to actual field operating conditions, as a turbine meter is unlikely to be used intentionally under such conditions and also that it was felt that damage to the meter would have been certain to occur.

The results from the wet gas tests are shown in Fig 2. In the following discussion no attempt is made to interpret the results obtained from the point of view of the flow behaviour within the turbine meter itself, as this would be somewhat speculative in nature. Acceleration of the gas within the meter (due to the presence of the annular space directly upstream of the rotor) will likely cause a local shift in the flow pattern. The area available for flow in a typical meter is less than half of the cross sectional area in the upstream pipe. It is not clear however that sufficient time would be available within the upstream section of the meter to fully accelerate any liquid droplets present to the gas velocity at the rotor. The gas acceleration would also cause a partial thinning of the film at the pipe wall combined with an increase in liquid entrainment. It is uncertain as to what effect, if any, the entry vanes of the meter would have on the liquid passing into the meter.

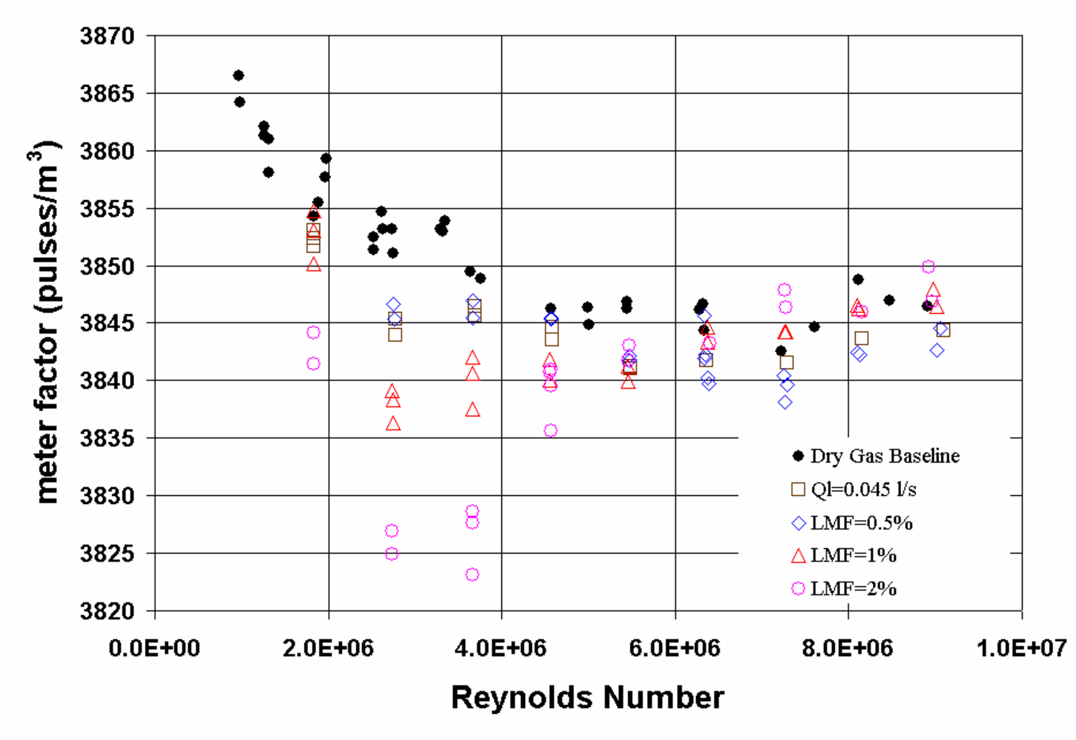

Fig. 2. Wet gas test results from 6-inch turbine meter are different liquid rates

The data shown in Fig. 2 can be divided into approximately three regions according to the type of wet gas flow. “Region 1” is actually only a single test point, at the minimum Reynolds number value of approximately 1.8 x 10^6, at which the flow is completely stratified. The maximum measured shift is -0.38% at an LMF of 2%, while at lower LMFs the shift is closer to -0.15%. The main influence on the turbine meter in this flow regime is the drag effect of the blades having to pass through a small layer of liquid running along the base of the pipe. This will have a decelerating effect on the turbine rotor, and will decrease the measured frequency compared with the dry gas flow.

“Region 2” covers the Reynolds number range 2.7 × 10^6 to approximately 5.4 × 10^6. Over this range the stratified flow becomes transitional (towards annular mist flow) in nature with jets (ie local concentrations of liquid flow) of liquid being partially suspended in the gas flow, plus a shift in the concentration of the annular-mist nature of the flow. These flow patterns were observed directly within the pipeline using the subsea camera fitted to a specially modified pipe spool. The trend in the data indicates that the shift away from the baseline data increases quite significantly with increasing LMF. The maximum shift measured was of the order -0.75% at a Reynolds number of 2.7 × 10^6.

As the Reynolds number increases above 5.4×10^6, the flow pattern gradually becomes dominated by the annular-mist regime, and all visible traces of liquid jets in the flow disappear. It is suspected that the liquid jets have a more significant effect on the deceleration of the turbine rotor than stratified flow due to the fact that they occur in a random manner over a wider cross-section of the pipe, and interact with a larger blade surface area than stratified flow.

Another effect of the entrained liquid is the increased random scatter observed in the meter factor. This is most apparent at $Re = 3.6 \times 10^6$ and 4.5×10^6 where the maximum size of the band is around 0.15%, compared to less than 0.1% at most other flowrates. The increase in scatter at these Reynolds numbers can most likely be attributed to the fluctuating nature of the observed liquid jets as the gas attempts to suspend the bulk of the liquid in the main flow. It is possible that these jets could either accelerate or decelerate the turbine rotor, producing a wider range of measured frequencies.

"Region 3" covers the Reynolds number range 5.4×10^6 to 9×10^6. At these flowrates only mist flow is observed with the camera, although the flow will still be of the annular-mist type. As the gas velocity increases, so the mean droplet diameter decreases, thereby ensuring that the droplets are more likely to remain completely suspended in the gas flow while moving at a significant fraction of the gas velocity. The observed shift in the meter factor decreases to within the measured band of the dry gas baseline curve for the two largest LMFs used. However, it is not clear why this should happen when at lower liquid contents there is a noticeable difference between the dry and wet gas data at the high gas flowrates. Perhaps at the higher liquid/gas mass ratios some component of the liquid droplet momentum is transferred to the turbine rotor, in effect increasing the measured frequency and therefore the meter factor.

The suggestion from the NEL data at the LMFs of 1% and 2% is that bulk mist flow does not appear to have a major effect on the behaviour of the meter. An increased distribution of the liquid throughout the pipe appears to effectively reduce the impact of the liquid on the meter performance. As the liquid droplets are travelling much closer to the superficial gas velocity then the meter appears to behave as if it is just measuring a less stable gas flow.

Fig. 2 also indicates that at the smallest liquid injection rates used, the liquid presence only reduces the measured turbine frequency by between 0.1% and 0.2% across the entire Reynolds number range tested, from stratified through to annular-mist flow conditions. The reason for this difference, which is contrary to the behaviour observed at higher liquid contents, is not known.

3.1.1 Comparison with previous work

The results of Jones and Ting [2], taken at CEESI using a different 6-inch meter, are reproduced in Fig. 3. It is apparent from comparison with Fig. 2 that the NEL results are clearly different to those obtained at CEESI. In the work of Jones and Ting the shift in the meter factor occurs above a pipe Reynolds number of 5×10^6, whereas in the NEL work the main shifts in the data are all below a Reynolds number of 5×10^6. Considering that the two LMFs used in the CEESI tests were quite small relative to values used at NEL, it is perhaps surprising that a shift of as much as -0.3% was obtained at CEESI. A suitable explanation for the differences in the two data sets is not obvious.

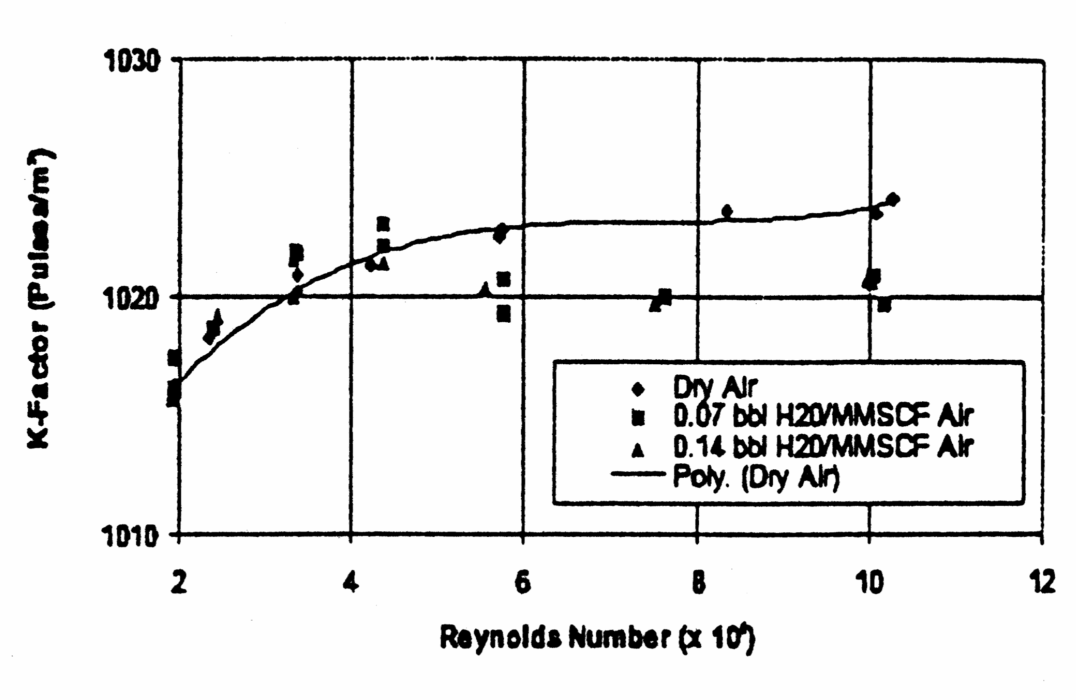

Fig. 3. Reproduction of Jones and Ting's results

3.1.2 Conclusions

A 6-inch turbine meter was tested in wet gas across a range of gas flow rates from 200 m^3/hr to 1000 m^3/hr, corresponding to a Reynolds number range of approximately 2×10^6 to 9×10^6. Four sets of tests were carried out, one with a constant liquid flowrate of 0.045 l/s, the other with constant LMFs of 0.5%, 1.0% and 2.0%.

The presence of even these small quantities of liquid produced a significant effect on the turbine meter at Reynolds numbers below 5×10^6. The maximum shift in observed meter factor was -0.75% at 2% LMF. At higher Reynolds number the liquid appeared to have little effect on the meter.

These results do not agree with the only previously published data on turbines in wet gas, albeit on a different meter. In this previous work, the most significant effect was at Reynolds numbers above 5×10^6. Additional testing, preferably on more than one model of turbine meter would be required to allow a better examination of turbine meters in wet gas flow.

3.2 Coriolis meter

The Coriolis meter was initially tested in dry gas at pressures of 15 bar, 30 bar, 45 bar and 60 bar, again to provide a dry gas baseline performance against which the wet gas results could be compared. The dry gas results are shown below in Fig. 4 below.

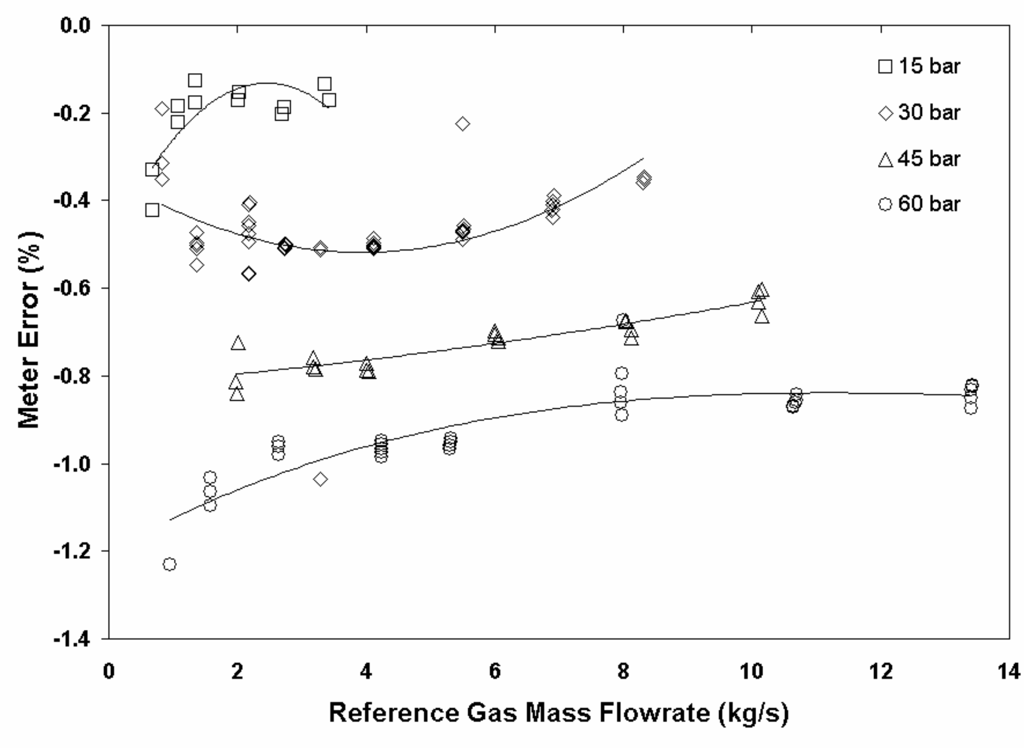

Fig. 4. Dry gas results from 4-inch Coriolis meter

It is clear that the error becomes increasingly negative with increasing pressure, however it should be notes that these results are the uncorrected results from the meter. When the standard manufacturer's pressure correction is applied the results mostly fall within the 0.5% error band. For the wet gas testing purposes, however, this correction was not made as the tests were intended to compare wet against dry baseline. The meter was subsequently tested in wet gas across the following range of conditions:

Table 1. Test envelope for Coriolis meter

Pressure (bar)	SGV (m/s)	Mass flow (kg/s)	Max LVF (%)	Max *X* (-)
30	5	1.4	5.0	0.24
	8	2.2	5.0	0.24
	10	2.7	5.0	0.24
	15	4.1	5.0	0.24
	20	5.5	3.8	0.18
	25	6.9	2.5	0.12
60	5	2.7	5.0	0.18
	8	4.2	5.0	0.18
	10	5.3	5.0	0.18
	15	8.0	5.0	0.18
	20	10.7	3.8	0.13
	25	13.4	2.5	0.08

Fig. 5 shows the results from the wet gas tests at 30 barg, in terms of gas mass flow error against reference gas mass flow, ordered by liquid content. It is clear that the liquid presence significantly affects the meter's performance.

At the lowest liquid volume fraction tested, 0.1% (X = 0.005), the meter error is -10% at the lowest flowrate tested, just over 2 kg/s, reducing to -3% at 4 kg/s and then to -1% at 5.5 kg/s.

The errors at the lower flowrates seem particularly large considering how little liquid is present in the gas. However, the Froude numbers are Fr_g = 1.8, Fr_l = 0.01. When these are transposed onto a two-phase flow map it can be seen that the flow conditions are in the transition from stratified to annular/mist flow. Consequently much, or most, of the liquid would be travelling along the bottom of the pipe and meter. This could potentially affect the tube vibration more than at higher gas flowrates where most of the liquid is carried along in the bulk gas stream.

This argument does not seem to hold, however, for the subsequent data sets. There is a similar shape to the error curves at 0.25%, 0.5%, and 1.0% liquid volume fraction, although the absolute error becomes increasingly positive as the LVF increases within this range. Up to 1.0% LVF, the meter output is within ±10% with respect to the reference gas mass flowrate for all test points.

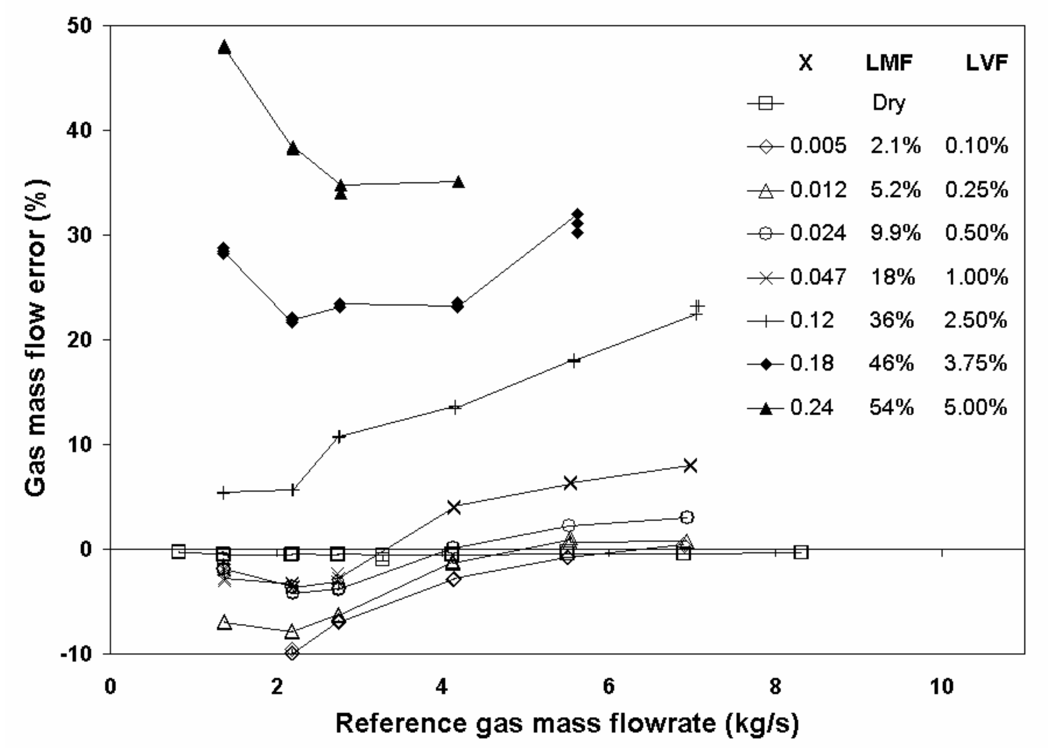

Fig. 5. Wet gas tests at 30 barg. Meter error vs gas mass flowrate.

When the LVF was increased to 2.5%, the meter error with respect to the reference gas mass flow increased substantially, ranging from +5% at the lowest gas flowrate to +23% at the highest. The error increased almost linearly with gas flowrate. At 3.75% and 5.00% LVF the meter error with respect to the reference gas mass flowrate is over 20%

and 30% respectively. In both cases the error appears at first to decrease slightly before increasing again with increasing gas flowrate. It is clear that the larger liquid content has a significant effect on the performance of this Coriolis meter.

Fig. 6 shows the results from the wet gas tests at 60 barg, in terms of gas mass flow error against reference gas mass flow, ordered by liquid content. Once again, it is clear that the liquid presence significantly affects the meter's performance.

At all liquid fractions up to 2.5% LVF the error is negative, between -6% and -10% at the lowest gas flowrate. As the gas flowrate increases the errors move in the positive direction. For LVFs up to 0.5% the errors level off in the band ±2% at gas flowrates from 8 kg/s up to the maximum tested 13.4 kg/s, corresponding to SGVs of 15 m/s to 25 m/s.

At 1.0% LVF the meter error rises gradually to almost 5% at the highest gas flowrate, whilst at 2.5% LVF the error reaches over 14%. At 3.75% LVF the error starts at -1% at the lowest gas flowrate before climbing steeply to almost 20% at a gas flowrate of 10.7 kg/s (20 m/s). At the highest liquid fraction, 5.0% LVF, the error ranges from 8.5% at the lowest gas flowrate to almost 23% at a gas flowrate of 8 kg/s (15 m/s).

For the 30 barg results, the errors at the lower flowrates seem particularly large considering how little liquid is present in the gas. The earlier suggestion of a stratified flow regime seems unlikely at 60 barg as for the higher liquid contents the errors start low and become greater at higher gas flowrates, when more of the liquid will be suspended in the gas stream.

At higher liquid fractions, 2.5% and above, the errors at 60 bar are significantly smaller than those at 30 bar. This may well be explained by the reduction in density ratio between the two phases, as the liquid is more easily carried in the denser gas stream.

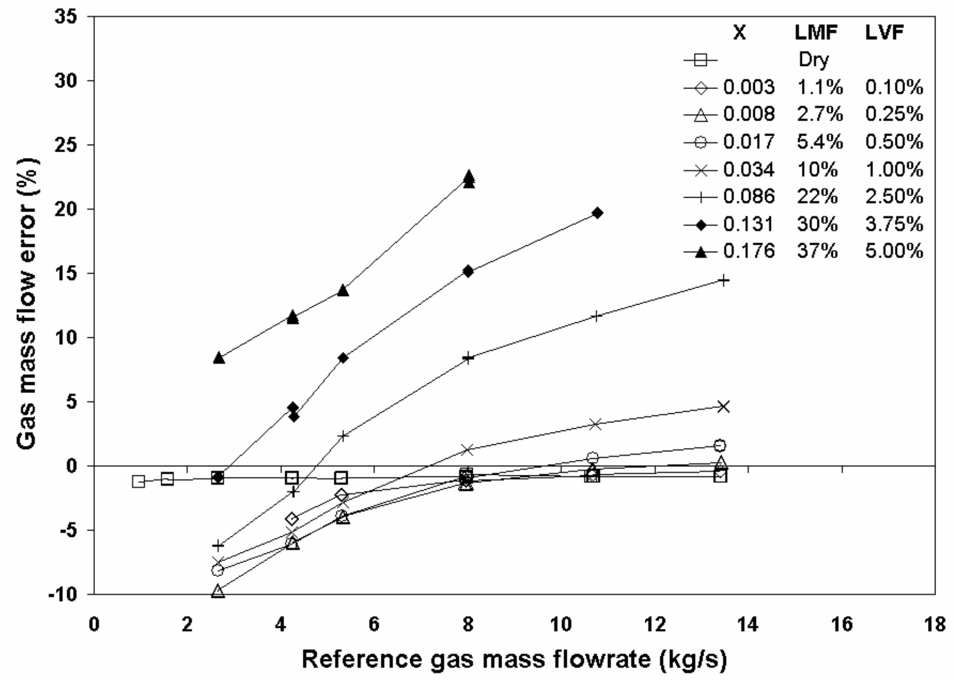

Fig. 6. Wet gas tests at 60 barg. Meter error vs gas mass flowrate.

For more analysis of the Coriolis results, the reader is directed to Ref [1]. At the time of writing, no other published data could be found to provide a comparison with the present results.

In conclusion, the meter exhibited significant errors in wet gas flow compared with both the dry gas reference mass flow and the total reference mass flow [1]. From these results it would appear that the Coriolis meter may be the most suitable type of meter for wet gas. However, many modern meters have the built in capability to sense the presence of liquid from the increased power drawn by the drive coils due to liquid damping and can stop measuring temporarily while liquid passes.

3.3 Vortex meter

The vortex meter was tested in a horizontal orientation in wet gas at three test pressures: 15 bar, 30 bar and 60 bar. The meter was tested across a range of gas and liquid flowrates to investigate the effect of liquid content and superficial gas velocity on the meter performance. The modified Lockhart-Martinelli parameter, X, and the gas densiometric Froude number, Fr_g, (both described in section 6) were also investigated.

The three test pressures chosen allowed the influence of the gas density on the meter performance to be checked. The overall test envelope is shown in Table 5.1, expressed by the superficial gas velocity (SGV), gas densiometric Froude number, Fr_g, and maximum achieved X value. The liquid volume fractions used at each superficial gas velocity were 0.1%, 0.25%, 0.5%, 1%, 2.5% and 5%.

Table 2. Test envelope for Vortex meter tests

Pressure	**SGV**	**Fr_g**	**Max X**	**Pressure**	**SGV**	**Fr_g**	**Max X**	**Pressure**	**SGV**	**Fr_g**	**Max X**
(barg)	**(m/s)**	**(-)**	**(-)**	**(barg)**	**(m/s)**	**(-)**	**(-)**	**(barg)**	**(m/s)**	**(-)**	**(-)**
15	3	0.47	0.163	30	3	0.67	0.244	60	3	0.95	0.174
	5	0.77	0.346		5	1.09	0.243		5	1.53	0.180
	10	1.54	0.341		10	2.2	0.244		10	3.13	0.178
	15	2.32	0.168		15	3.3	0.120		15	4.67	0.180
	20	3.09	0.065		20	4.4	0.047		20	6.3	0.085
	25	3.87	0.031		25	5.6	0.146		25	7.9	0.033
	30	4.69	0.033		30	6.7	0.024		30	9.5	0.033

The superficial gas velocities used in these tests were chosen to produce a range of flow patterns in the test line. These flow patterns ranged from wavy-stratified, through a transitional zone and into an annular-mist region. However, the static pressure in the line also influences the flow pattern, tending to shift it toward an annular-mist regime as pressure increases. In wavy-stratified flow conditions the liquid runs along the bottom of the pipe. The surface of the liquid is however quite turbulent with the presence of waves as well as an indistinct, mixed two-phase interface. The slip between gas and liquid in this regime is quite high, with the gas generally travelling much faster than the liquid.

As the gas velocity increases, so the flow pattern changes into a transitional form, with some liquid moving along the pipe bottom, some starting to spread out around the pipe wall and some being picked-up as droplets moving with the gas. At high gas velocities a large fraction of the liquid is suspended in the gas flow, with a continuous interchange between a liquid film at the wall and the gas core.

The combined dry and wet gas test results for the vortex meter, across the entire pressure range used, are shown in Figs. 7 to 9. The data is given in terms of the meter error and superficial gas velocity, as a function of the Lockhart Martinelli / liquid volume fraction (LVF). Figs. 7 to 9 highlight a number of points:

(a) As pressure increases, so the size of the error decreases, eg at 15 bar and 0.5% LVF there is a mean error of 10%, yet at 60 bar the error reduces to a mean value of 2.5%. This reduction is considered to be mainly due to a decrease in the liquid holdup level in the pipe at a fixed SGV.

(b) The meter error increases with increasing LVF at all pressures, however the higher the pressure the smaller the error increase, particularly up to an LVF of 1%.

(c) For some of the high LVFs the meter error behaves in an erratic fashion, with large fluctuations in the error from one SGV to another. The effect is most pronounced at 15 bar, and diminishes as the line pressure increases. An example of this is the 1% LVF data. At 15 bar there is a spread in the data of 20%, yet at 30 bar an average error of 10% was measured with a spread of approximately 5%. At 60 bar the error reduces to around 5% and is almost totally linear across the test SGV range.

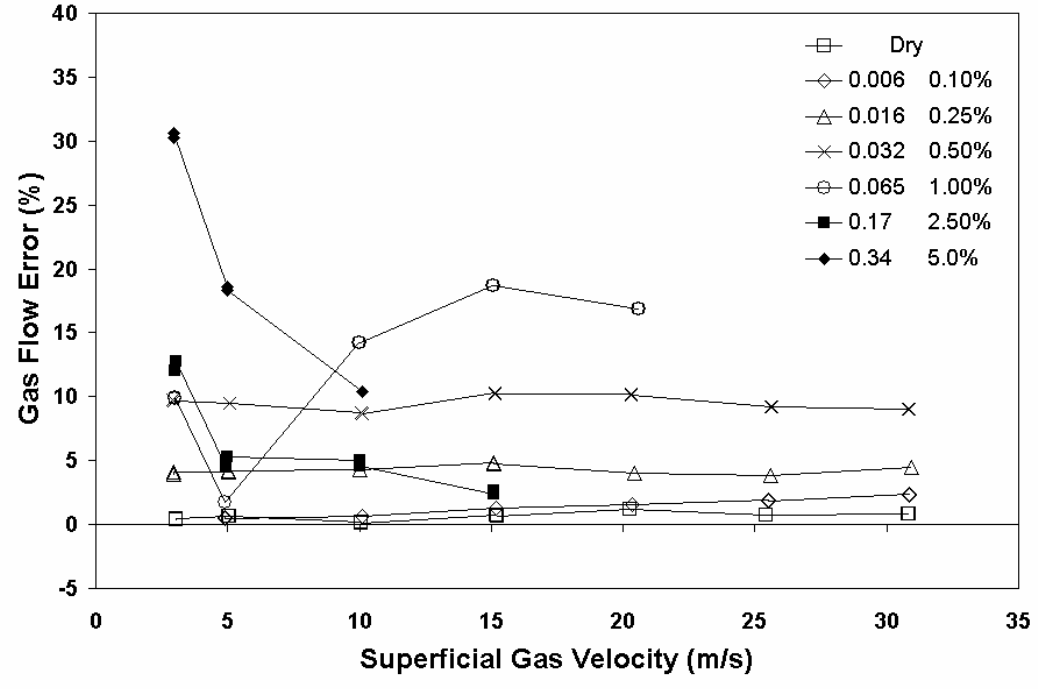

Fig. 7. Vortex meter wet gas results at 15 bar (ordered by X and LVF)

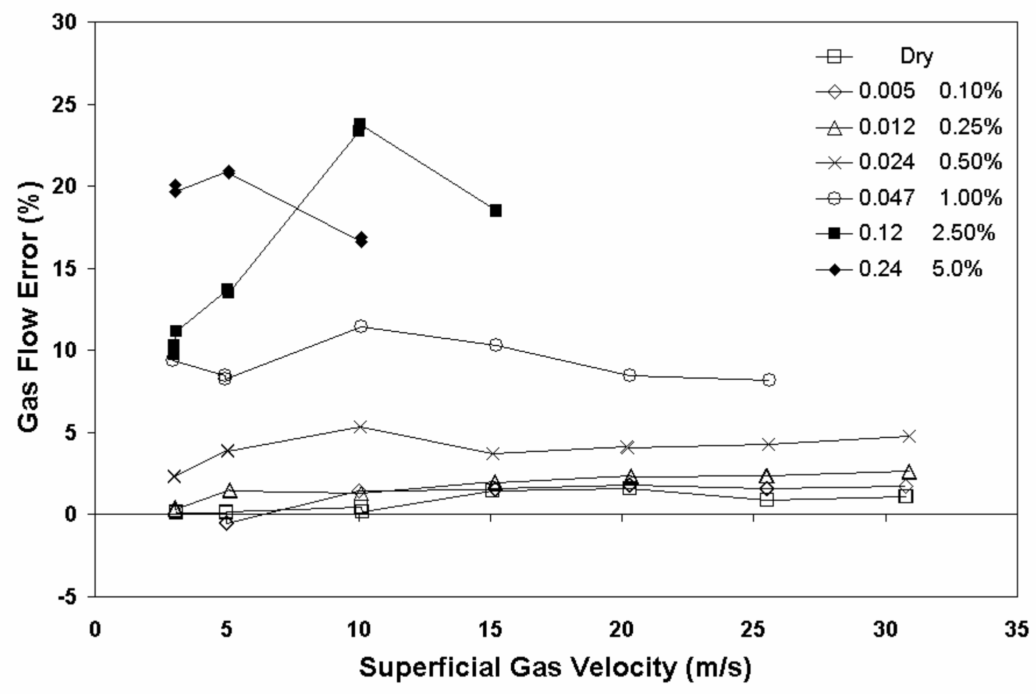

Fig. 8. Vortex meter wet gas results at 30 bar (ordered by X and LVF)

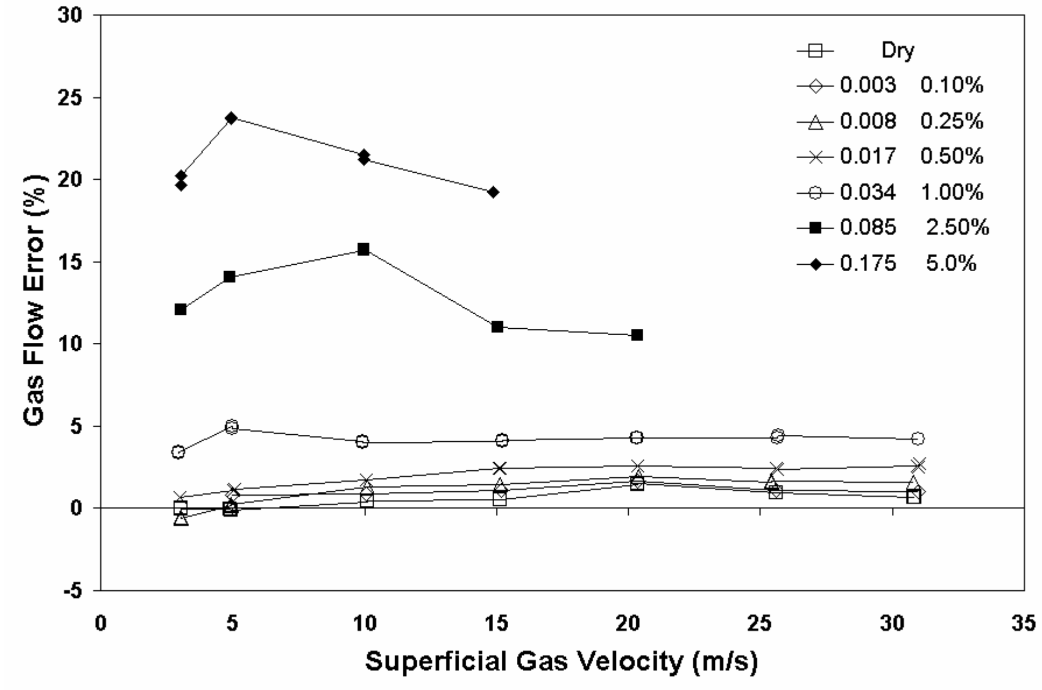

Fig. 9. Vortex meter wet gas results at 60 bar (ordered by X and LVF)

> The exact reason for the fluctuation in the high LVF errors at 15 barg is unknown, but it may possibly be connected to some interaction between the vortex shedding mechanism and the liquid fraction/flow regime. Most of the inconsistent behaviour occurs at the lower test velocities, where it is likely that a transitional flow pattern exists, even at 15 barg. Unfortunately it was not possible to test the meter at high SGVs and LVFs together, so it is not possible to determine if the errors would return to a stable level. However, some further repeat test runs conducted at the 'unstable' vortex-meter test points at 15 barg in fact produced almost the same error values as the original test runs, indicating a consistent behaviour in the meter performance. These repeat points are included in Fig. 7 as part of the overall data set.

In conclusion, the performance of the vortex meter shows more consistency than the Coriolis meter, particularly at lower LVFs. Here, the meter error is reasonable independent from the SGV and could be used to correct the meter with some confidence. At higher LVFs the meter performance becomes more erratic.

The liquid fraction at which the performance becomes unstable appears to be pressure dependent, being approximately 0.5% at 15 bar and 30 bar, but 1.0% at 60 bar. The absolute error for a given LVF also decreases with pressure. Both of these effects are consistent with the higher gas density at higher pressures resulting in a lower liquid hold-up in the pipe, and consequently less area reduction.

3.3.1 Comparison with previous work

In their 1989 paper [3] Nederveen et al describe some (rare) vortex meter wet gas test results, obtained as part of a wider test programme investigating wet gas flow measurement under actual field and laboratory conditions for NAM in the Netherlands. The vortex meter used had a nominal diameter of 75mm and tests were conducted at 80 bar and at two gas flowrates: 85,000 and 135,000 Nm^3/day. These correspond to superficial gas velocities of approximately 2.9 and 4.6 m/s respectively and gas Froude numbers of 0.81 and 1.29 respectively. These values put the tests in the region of the transitional boundary between stratified-wavy and annular-mist flow regimes. Water was injected into the natural gas flow line downstream of a reference Venturi meter and upstream of the vortex meter. Liquid contents (LGR=Liquid/Gas Mass Ratio) ranged from 0 to 300 m^3 liquid/10^6 Nm^3 gas (20 l/min maximum injected flowrate). This equates to a maximum liquid volume fraction of 2.56% at the minimum gas flowrate and 1.63% at the maximum gas flowrate.

The results of their tests are reproduced in Fig. 10 below. An increasing liquid content (at both gas flowrates) clearly increases the meter over-reading relative to the dry gas values, with a maximum shift in the meter reading of around 14% at the maximum SGV and LGR tested. The authors concluded that the meter over-reading was dependent mainly on the liquid flowrate, and that the magnitude of the change in the meter error depends on the slip rate between the gas and liquid phases. The authors also suggested that vortex meters were not suitable for measuring gas flows containing entrained liquids due to an inability to produce predictable readings.

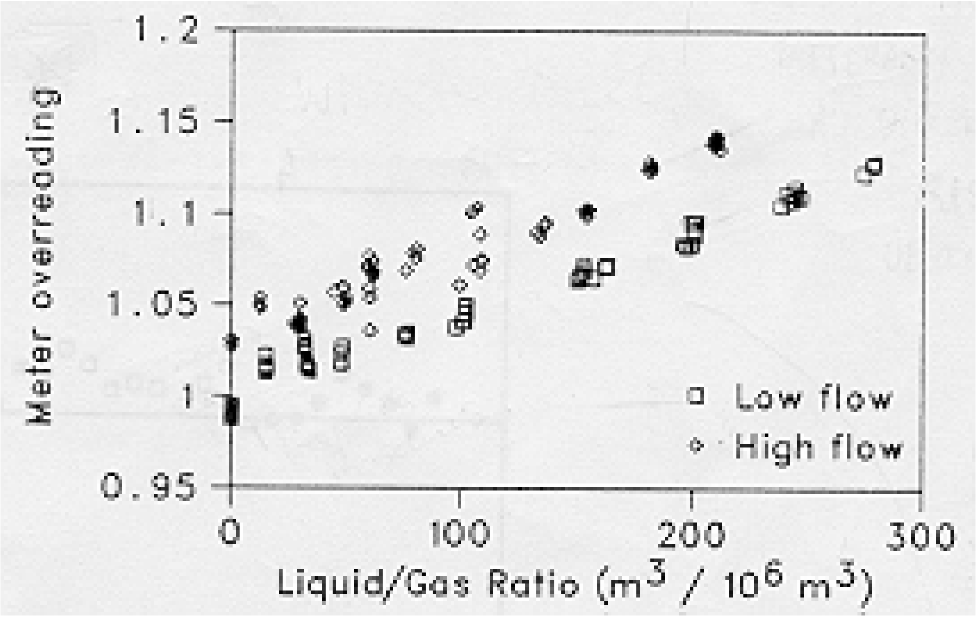

Fig. 10. Reproduction of results from Ref. [3].

The NEL results at 60bar (closest pressure to Ref. [3]) are presented in Fig. 11 below in a similar manner.

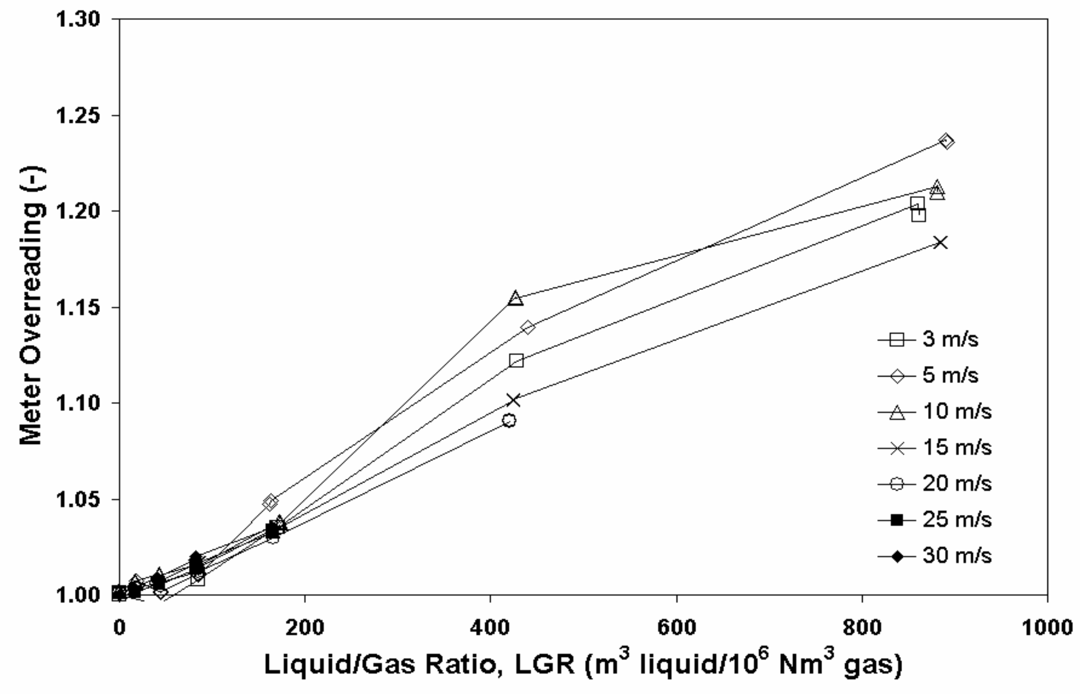

Fig. 11. NEL over-reading as a function of the LGR and SGV at 60 bar

The NEL results tend to agree qualitatively with the previously published data, however the absolute over-reading values are much lower for the NEL data at a given LGR. For example, at an LGR of 200 m^3 liquid/10^6 Nm^3 gas, the data of Nederveen et al suggest a meter over-reading range of between 9% and 14%. At the same LGR for the NEL data a meter over-reading of around 5% is produced - a significant difference. The larger slope of the over-reading curves of Nederveen et al may be due to a higher relative holdup of liquid in the test line. Nederveen et al did use water as the liquid phase in their tests, while at NEL a kerosene substitute was used. This results in a difference in liquid density of nearly 20%, which even at the higher test pressure of Nederveen et al appears likely to produce a difference in liquid holdup, however it would be unlikely to cause the difference in over-reading seen here.

Another point to note with respect to Fig. 10 is the separation in the over-readings at the two test gas flowrates used. At first glance it appears as if there is a gas flowrate effect. This is even stated by the authors. However, closer inspection of Fig. 10 shows that some dry gas points (ie LGR = 0) have been included. At the low gas test flowrate the over-reading is in fact slightly less than 1, while at the higher flowrate it is closer to 1.03 (a 3% shift). If the wet gas data were calculated relative to these dry gas values, then both data sets would collapse directly onto each other and it could be concluded that the gas flowrates used had no effect on the meter performance. This would then agree with the findings of the NEL tests. For more detailed comparison with previous data, the reader is directed to Ref. [1].

4 CONCLUSIONS

The testing conducted at NEL has shown that a turbine meter tested in wet gas flows up to 2% GMF measured the gas flow mostly to within 0.5% across a range of gas flowrates from 200 m^3/hr to 1000 m^3/hr. The meter performance appeared to be slightly affected by changes in the flow regime as the gas velocity increased. If a gas turbine meter was inadvertently subjected to small amounts of liquid, or the order tested at NEL, it would appear unlikely that large measurement errors would occur. However, the possibility of damage would always remain.

The Coriolis meter tests showed that this type of meter is not very predictable in wet gas flow. There was no obvious explanation for the trends displayed across the range of conditions tested. Based on these results, it would not be recommended to use a Coriolis meter where liquid may occur in the gas stream.

The vortex meter shows the most promise for use in wet gas streams. At lower LVFs the performance was reasonably repeatable. It was clear that the pressure has a significant effect on the measurement errors. It would appear that vortex meters could be used with care in gas streams with small amounts of liquid. The measurement uncertainty would be improved with prior testing to determine the likely errors.

5 REFERENCES

[1] NEL Report 2002-100.

[2] Jones, E.H. Jr. and Ting, V.C., “Wet Gas Metering Performance”, OMAE – Vol. V, Pipeline Technology, ASME 1996.

[3] Nederveen, N., Washington, G.V. and Batstra, F.H., “Wet Gas Flow Measurement”, SPE 19077, Presented at the SPE Gas Technology Symposium, Dallas, Texas, June 7-9, 1989.