FLOW MEASUREMENT GUIDANCE NOTE NO. 40

The Evaluation of Wet Gas Metering Technologies for Offshore Applications: Part 1 - Differential Pressure Meters

February 2003

1 Introduction

Differential pressure (Δp) meters are often used in environments where a small but significant quantity of liquid is present in a gas flow.

Examples are:

Often several small fields are tied back to a single platform, requiring each unprocessed stream to be metered prior to commingling. If the liquid content is small, standard differential pressure meters are often used for this and a correction applied.

On an offshore platform where the flowrate is higher than the original design flow, the gas output may contain some oil and/or water due to incomplete separation.

A steam line where a higher than expected pressure drop occurs leading to condensation in the line.

Δp meters can also be used for well testing in high gas-fraction wells, reducing capital expenditure and offering improved flexibility and reduced turnaround times.

This Guidance Note provides information on the use of Δp meters (specifically the orifice plate, Venturi and V-Cone meter) in wet gas conditions, based on past work and also recent wet gas tests undertaken as part of a project in the 1999-2002 DTI Flow Programme. More detail on the recent NEL tests can be obtained from reference [1].

2 Fundamental Meter Behaviour in Wet Gas

In general, the fundamental response of a Δp meter to a liquid presence in a gas flow is to overread the gas mass flowrate. This is caused by two things: (1) the direct blockage of the pipe area by the liquid (both upstream and at the throat) causing the gas velocity to increase and (2) the additional energy loss incurred by the gas phase as it accelerates the liquid through the meter. These two effects combine to produce a higher Δp and a meter reading in excess of that which would be produced if the gas phase flowed alone, i.e. an overreading (ϕ_g).

The effect of liquid presence is not the same for the three meter types considered in this note. The overreading is known to be affected by several parameters, namely:

- Liquid fraction (expressed as Lockhart-Martinelli parameter, X)
- Pressure
- Gas velocity (expressed as Froude number)
- Meter β (value)

The liquid fraction is commonly expressed as the Lockhart-Martinelli parameter, a dimensionless number expressed as:

$$X = \frac{m_l}{m_g}\sqrt{\frac{\rho_g}{\rho_l}}$$

where m_g and m_l are the gas and liquid mass flowrates respectively [kg/s], and ρ_g and ρ_l are the gas and liquid densities respectively [kg/m^3].

The gas velocity is also expressed as a dimensionless number, known as the Froude number:

$$Fr_g = \frac{v_g}{\sqrt{gD}}\sqrt{\frac{\rho_g}{\rho_l - \rho_g}}$$

where v_g is the superficial gas velocity [m/s]

g is the gravitational constant [m/s^2]

D is the upstream pipe diameter [m]

It is also possible that the fluid properties such as liquid density, gas and liquid viscosity and liquid surface tension could influence the overreading, but at present there is insufficient data to determine this.

Examples of typical overreading behaviour for these meter types are shown in Figs. 1 to 3. The orifice plate data in Fig. 1 was taken from reference [2], while the Venturi and V-Cone data shown in Figs. 2 and 3 were taken from reference [1].

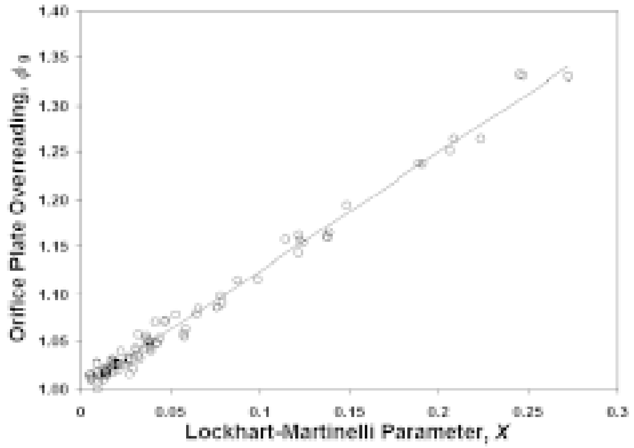

Fig. 1. Wet gas data from Murdock for orifice plate meters.

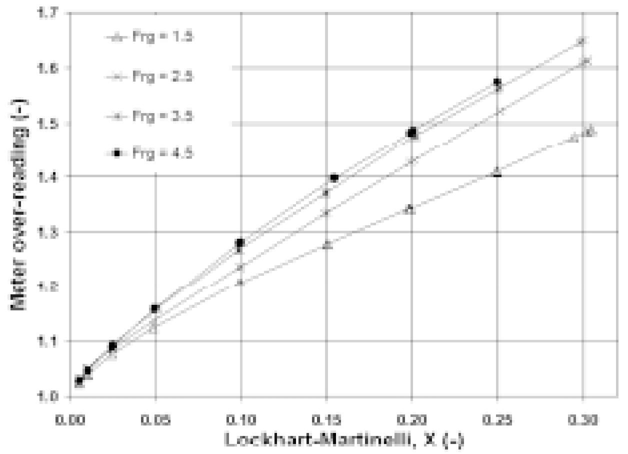

Fig. 2. Overreading of a 4-inch b = 0.6 Venturi meter at 30 barg at NEL.

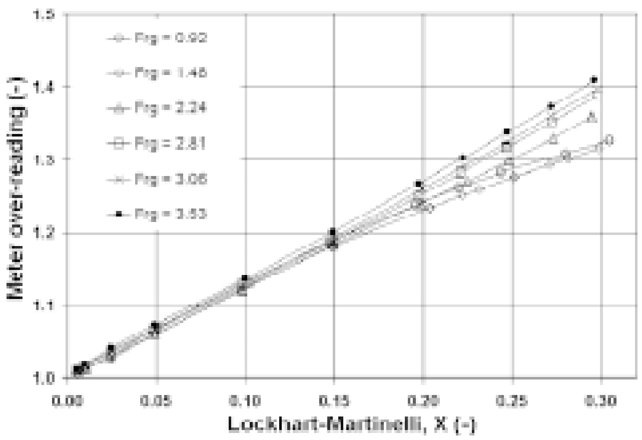

Fig. 3. Overreading of a 6-inch b = 0.75 V-Cone meter at 60 barg at NEL.

For orifice plate meters, the data of Murdock [2] suggests that a single equation can be used to represent the meter overreading across a range of pressures and gas and liquid flowrates, and this is how Murdock interpreted his data. However, it should be noted that there is significant scatter in the data, particularly at low X values. This may well indicate that an orifice plate meter overreading is also dependent on variables other than X. This requires further investigation.

For Venturi meters the data obtained at NEL [1] and that of de Leeuw [3,4] highlight a number of common trends that are not indicated by Murdock's data. These trends include a dependence of the overreading on gas pressure (essentially the gas/liquid density ratio), gas Froude number and the diameter ratio. The meter overreading increases with:

- increasing gas Froude number, Fr_g (velocity)
- decreasing pressure
- decreasing β value

Without correction the apparent gas mass flowrate could be up to 70% in error, as shown in Fig. 2.

De Leeuw [4] has stated that at high pressure the Venturi meter overreading tends toward a limit, at which the gas and liquid densities are equal. This claim follows from his use of the Chisholm correlation as the basis for his own. For Chisholm's correlation this apparent density limit has the effect of reducing the expression to $\phi_g = 1+X$, indicating that an overreading still exists. However, when the gas and liquid densities are the same (i.e. at the mixture critical point) the whole concept of an overreading breaks down, as the system has become a single phase, and the concept of separate phases is no longer valid.

For V-Cone meters the data obtained at NEL [1] forms a significant part of only two sets of tests conducted in wet gas on this proprietary meter type. The behaviour is similar in form to a Venturi, with the meter overreading being dependent on X, Fr_g and gas pressure. One difference though is the shape of the overreading curves, as shown in Fig. 3. The curves do not separate until a much larger value of X is reached, even at low Fr_g's. The reasons for this behaviour are not known, but may be related to the meter geometry and how this affects the liquid holdup within the meter body.

Another important point to note is the differences in the magnitude of meter overreadings. A Venturi meter produces the highest overreadings of the three meter types, with the V-Cone lower and orifice plate slightly lower again, although there is some overlap between the V-Cone and orifice plate data. If uncorrected, the Venturi meter could result in a slightly higher error than the other two. However, there is more wet gas data available for Venturis, giving higher confidence in the correction factors.

3 Available Wet Gas Correlations

Over the last forty years the experimental data used to generate the typical meter responses shown in Figs. 1 and 2 have been reduced to a number of correlations that apply over a wide range of operational conditions and for a number of fluid combinations.

For orifice plates the most common corrections are taken from Murdock [2] and Chisholm [5,6]. This work was based largely on steam/water flows. Murdock's correlation can be expressed as:

$$\phi_g = 1 + 1.26X$$

which implies that the overreading is dependent only on the Lockhart-Martinelli value (liquid fraction). Chisholm developed a new correlation to account for the effect of pressure:

$$\phi_g = \sqrt{1 + CX + X^2}$$

$$C = \left(\frac{\rho_l}{\rho_g}\right)^{0.25} + \left(\frac{\rho_g}{\rho_l}\right)^{0.25}$$

For Venturi meters the de Leeuw correlation [3,4] has become the most appropriate correction to apply. De Leeuw's work was based entirely on gas/condensate tests. The correlation is based on Chisholm's correlation but the "C" term has been modified to include a dependence on gas velocity:

$$C = \left(\frac{\rho_l}{\rho_g}\right)^{n} + \left(\frac{\rho_g}{\rho_l}\right)^{n}$$

$$n = 0.41 \qquad (0.5 \le Fr_g \le 1.5)$$

$$n = 0.606\left(1 - e^{-0.746 Fr_g}\right) \qquad (Fr_g > 1.5)$$

Steven has recently developed correlations for the V-Cone meter, based on the tests described in [1]. However, this is a limited data set and more experimental testing is required to confirm the behaviour of these meters over a wider range of sizes, diameter ratios and test conditions. The correlations can be found in reference [7].

4 Application of Wet gas correlations

It is clear from the data shown in Figs. 1, 2 and 3 that there is a large spread of overreading data between the three meter types discussed. The published data demonstrates that the overreading is also affected by variations in pressure, gas velocity and meter β value.

Consequently the use of any wet gas correction factor should be considered carefully. It is probable that applying any correction will result in a lower error than leaving the measurement uncorrected.

It is recommended that the flow conditions in the application being considered are compared with those used to derive the correlation to assess the suitability of the correlation and help provide an estimate of the expected residual uncertainty in the corrected gas flowrate.

One common misapplication of wet gas correction factors in the oil and gas industry is the use of Murdock's correlation for Venturi meters. This may introduce errors in excess of 10% or 20% if the liquid content is high (X>0.2).

The procedure used to correct the measured flowrate is shown schematically below:

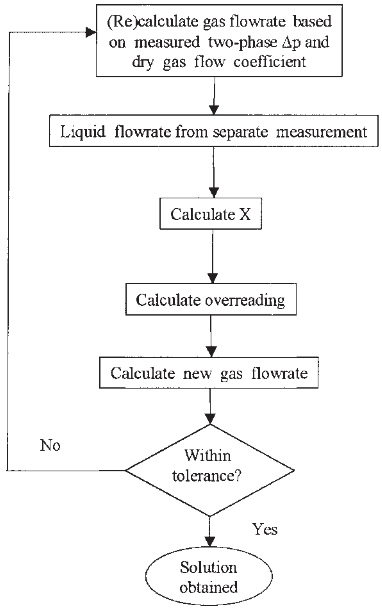

Fig. 4. Calculation procedure to determine dry gas flowrate.

One aspect of all the correlations available for use with single Δp meters is that the liquid fraction must be known. This means that currently the use of test separators, sampling techniques or tracer methods are necessary.

5 Direct Measurement of Wet Gas with Δp Meters

Over the last few years a number of approaches have been developed to directly determine the on-line gas and liquid flowrates in a wet gas stream.

In 1997 de Leeuw suggested the use of the overall pressure loss from a Venturi meter to allow the calculation of the relative pressure loss. This information could possibly be used to estimate the liquid and gas flowrates. It can be used to show when the liquid fraction in the line changes, as the overall pressure loss will change with changing liquid fraction.

The approach adopted by BG in the 1990s and developed further by Solartron ISA is the use of two Δp meters in series. This method is based on the fact that the two Δp meters have different overreading characteristics, and at the same conditions and flowrates, one will exhibit a higher overreading than the other. The difference in overreadings can then be used to determine the liquid content and hence both liquid and gas flowrates. The key to this approach is that there must be sufficient difference in the overreadings to allow discrimination between the meters.

FMC Energy Systems offer an extended-throat Venturi meter, with a throat approximately 12D in length. The Δp is measured across the convergent section of the Venturi and also along the length of the extended throat. These measurements are combined with a two-phase flow model to calculate the liquid and gas flowrates. This meter must be installed vertically.

Further alternative approaches exist, such as that from Agar Corporation, where two Venturis are combined with a Vortex meter. Three functions are produced that can be solved for all the unknowns in the system. The optimum installation is vertical, although it will operate horizontally.

TEA Sistemi have developed a wet gas meter based on isokinetic sampling of a vertically downward flow. It samples the two-phase fluid stream and separates the gas and liquid in a separation chamber. The liquid fraction in the sample is equal to that in the main fluid stream. The sample liquid flowrate is measured using a single-phase liquid meter, with the total liquid flowrate calculated from the area ratio of the pipe to the sample section. The gas rate is calculated using a multiphase nozzle and overreading corrections.

The uncertainties in all these approaches are dependent on many factors, and the reader is directed to the suppliers of these metering packages for this information. In general, however, most wet gas meters claim to measure the gas to 5% or better.

6 References

1 NEL Report No. 2002-100, Project FDMU07

2 Murdock, J.W., "Two-Phase Flow Measurement with Orifices", Journal of Basic Engineering, pp. 419-433, 1962.

3 De Leeuw, H., "Wet Gas Flow Measurement using a combination of Venturi meter and a tracer technique", North Sea Flow Measurement Workshop, Peebles, Scotland, Oct. 1994.

4 De Leeuw, H., "Liquid Correction of Venturi Meter Readings in Wet Gas Flow", North Sea Flow Measurement Workshop, Norway, Oct. 1997.

5 Chisholm, D., "Flow of Incompressible Two-Phase Mixtures through Sharp-Edged Orifices", Journal of Mechanical Engineering Science, 9, No. 1, 1967.

6 Chisholm, D., "Research Note: Two-Phase Flow through Sharp-Edged Orifices", Journal of Mechanical Engineering Science, 19, No. 3, 1977.

7 Stewart, D, et al., "Wet Gas Metering with V-Cone Meters", North Sea Flow Measurement Workshop, St Andrews, Oct. 2002.

Acknowledgement

The NEL work referred to in this Guidance Note was carried out as part of the 1999-2002 Flow Programme under the sponsorship of the DTI's National Measurement System Directorate.

Contact for Further Information

Further information can be obtained by contacting Dr David Stewart , NEL, East Kilbride, Glasgow G75 0QU, Tel: +44 (0) 1355 272927, Fax: +44 (0) 1355 272290, email: dgstewart@nel.uk

Guidance Notes

This series of Guidance Notes is designed to provide, in condensed form, information on flow measurement methods and equipment that has been generated as a result of Flow Programme work. In each case, the Guidance Note is based on the full project report, which is available from NEL
For a listing and copies of Guidance Notes, please contact
Susan Tough, Tel: +44 (0) 1355 272858, Fax: +44 (0) 1355 272626, e-mail: stough@nel.uk