Paper 1.4

Equity Exposure in Wet Gas Allocation Metering

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EQUITY EXPOSURE IN WET GAS VENTURI ALLOCATION METERING

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1. Introduction

Wet gas metering is becoming increasingly important in the development of marginal gas fields. Many of these gas fields are only economically viable if they can be tied back to existing platform infrastructure, reducing the capital expenditure required by significant margins. In such cases, several fields are often tied back to common facilities requiring each unprocessed stream to be metered before co-mingling.

Furthermore, there are now several instances in the North Sea of allocation “by difference”, where one field is allocated on the basis that it has no dedicated metering itself, and instead its production is determined from the total production from all fields involved (from fiscal meters) less the other field(s) involved, each of which have their own metering. This approach means that the field being allocated by difference essentially carries the combined uncertainty from the other field(s).

There are two principal approaches to wet gas metering. The first is to use a dedicated wet gas meter which has been designed to measure the flow rates of both the liquid and gas phases. The second is to use a standard dry gas meter and apply corrections to the measurements based on knowledge of how the meter in question is affected by the presence of a liquid phase in the gas stream. The second method requires prior knowledge of the liquid flow to correct for the gas flow.

When the liquid fraction in the gas stream is small, or relatively steady, it can be possible to apply the second method. In many North Sea gas fields it is now common to have additional tie-back fields being brought in to existing platforms, with the associated requirement for wet gas metering for allocation purposes. In such situations the wet gas Venturi meter is often selected for this duty.

This paper looks at the suitability of using of Venturi meters in wet gas, summarising the data collected over recent years, and discusses the uncertainties that can be expected with this method. The paper also looks at some of the factors that influence Venturi performance in wet gas and demonstrates the possible impact of measurement accuracy.

The second part of this paper looks at the impact of wet gas Venturi uncertainty on an allocation by difference system. A case study is presented that illustrates an example of the level of equity exposure in the “by difference” field as a result of the wet gas Venturi uncertainties in the other fields. The influence of key factors is also shown.

2. Venturi meters in wet gas flow

Venturi meters have become increasingly popular in the measurement of wet gas flows, particularly for allocation purposes and well management. Venturi meters are less susceptible to damage from liquid slugs than orifice plates and due to the convergent inlet section, the hold up of liquid is less pronounced than in an orifice plate.

When Venturi meters, or any other differential pressure meters, are used in wet gas flow the measured differential pressure is higher than it would be if the gas phase were flowing alone. It is believed that this is due to two main reasons. Firstly, the liquid occupies a volume in the pipe, causing the gas to flow at a higher velocity than it would on its own, and secondly there are additional energy losses at the gas liquid interface(s) as the gas drives the liquid along the pipe. The exact amount of additional pressure loss will depend on several parameters, including the amount of liquid present, pressure, gas velocity, liquid density, viscosity and surface tension, and the flow regime in the pipe (stratified or annular mist). This additional pressure drop produces an overreading in the apparent gas mass flowrate, compared with what would be measured without any liquid present. This difference must be corrected for using some form of overreading correlation. The following sections provide a summary of the available test data and any associated correction factors.

2.1. Early Orifice Plate work

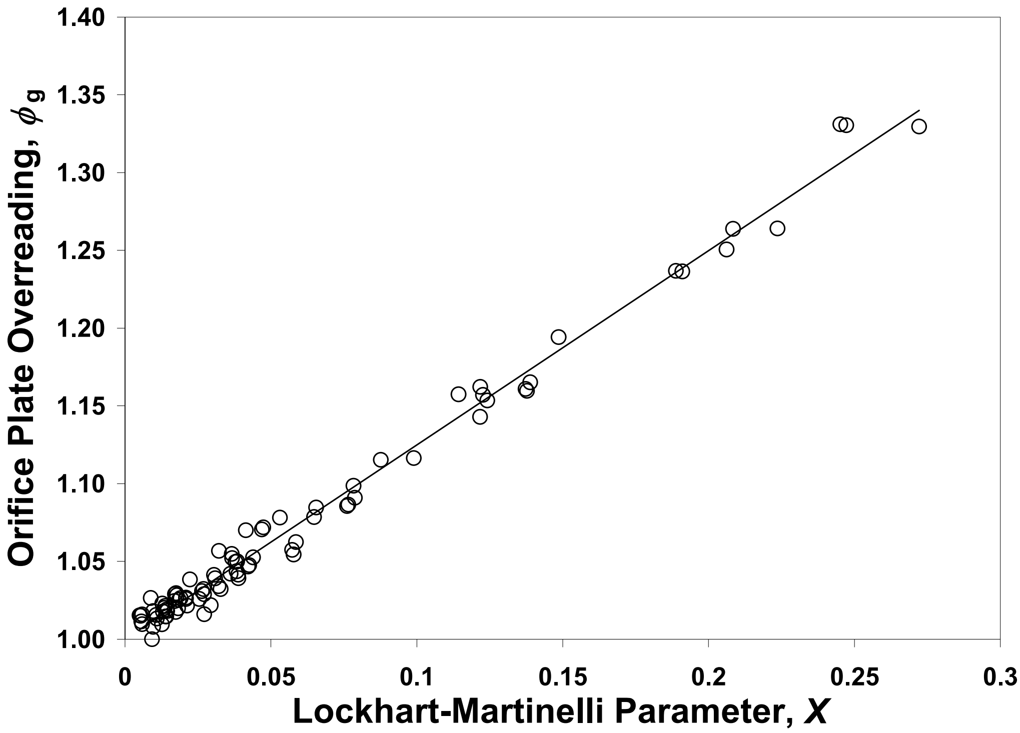

Figure 1. Murdock's Orifice plate wet gas data.

The first significant development was based on tests conducted by Murdock [1] on orifice plates, shown in Figure 1, resulting in the well-known correction factor:

$$m_{g_{(actual)}} = \frac{m_{g_{(tp)}}}{1+1.26X} \tag{1}$$

where $m_{g(actual)}$ is the corrected gas mass flowrate, $m_{(tp)}$ is the apparent gas mass flowrate determined from the two-phase measured differential pressure and *X* is the "modified" Lockhart-Martinelli, defined as:

$$X = \frac{m_l}{m_g}\sqrt{\frac{\rho_g}{\rho_l}} \tag{2}$$

where m_l and m_g are the liquid and gas mass flowrates, and ρ_l and ρ_g are the liquid and gas densities. The apparent gas mass flowrate is given by:

$$m_{g(tp)} = CE\varepsilon A_d \sqrt{2\rho_g \Delta p_{(tp)}} \tag{3}$$

where E is the velocity of approach factor $\left(1/\sqrt{1-\beta^4}\right)$, ε is the gas expansibility factor, A_d is the throat area and $\Delta p_{(tp)}$ is the measured two-phase differential pressure.

Chisholm [2] later published another correlation, again based on orifice plate data. Significantly, however, Chisholm subsequently published a research note [3] that modified his correlation to include a dependence on the gas pressure.

2.2. Venturi data

The most significant advance since Murdock and Chisholm comes from the work of de Leeuw [4], as this work was the first to be based exclusively on wet gas Venturi data. de Leeuw confirmed that the over-reading was dependent on the gas pressure (density), and that the over-reading decreased with increasing pressure. The most significant aspect of de Leeuw's work was the discovery that the over-reading was also dependent on the gas velocity or Froude number, Fr_g. de Leeuw took this into account when developing his correlation, which is expressed as:

$$\sqrt{\frac{\Delta p_{(tp)}}{\Delta p_g}} = \sqrt{1 + CX + X^2} \tag{4}$$

where

$$C = \left(\frac{\rho_l}{\rho_g}\right)^n + \left(\frac{\rho_g}{\rho_l}\right)^n \text{ and}$$
$$n = 0.606\left(1 - e^{-0.746 Fr_g}\right) \quad \text{for } Fr_g \ge 1.5$$
$$n = 0.41 \quad \text{for } 0.5 \le Fr_g \le 1.5$$

de Leeuw's work used a 4-inch β = 0.4 Venturi using nitrogen and diesel oil as the test fluids.

Steven's work [5] used tested a 6-inch β = 0.55 Venturi. These tests were one of the first wet gas tests carried out on the NEL Wet Gas Facility following commissioning in 1999. This facility has been modified since to increase the available gas and liquid flow slightly from what was available for Steven [5]. Steven tested this Venturi at 20 bar, 40 bar and 60 bar at gas flowrates between 400 m^3/hr and 1000 m^3/hr, with liquid volume fractions between 0.1% and 5%. Steven's results confirmed de Leeuw's findings that the over-reading was dependent on Fr_g as well as pressure.

Stewart et al. [6] reported on more recent and wide ranging wet gas Venturi tests. Three 4-inch Venturis with beta values of 0.4, 0.6 and 0.75 were tested in wet gas at three pressures (15, 30, 60 bar) across a range of gas velocities and liquid fractions. The results showed once again that the over-reading increases with increasing gas velocity and decreases with increasing pressure. The significant discovery in these tests was, however, the fact that the over-reading was also significantly dependant on beta value, with higher beta values resulting in a lower over-reading. This was significant given that the widely used de Leeuw correction factor was developed using Venturis with beta values of 0.4, towards the lower end of the range commonly used. Figs. 2, 3 and 4 show examples of the trends in over-reading with gas velocity, pressure and beta value respectively.

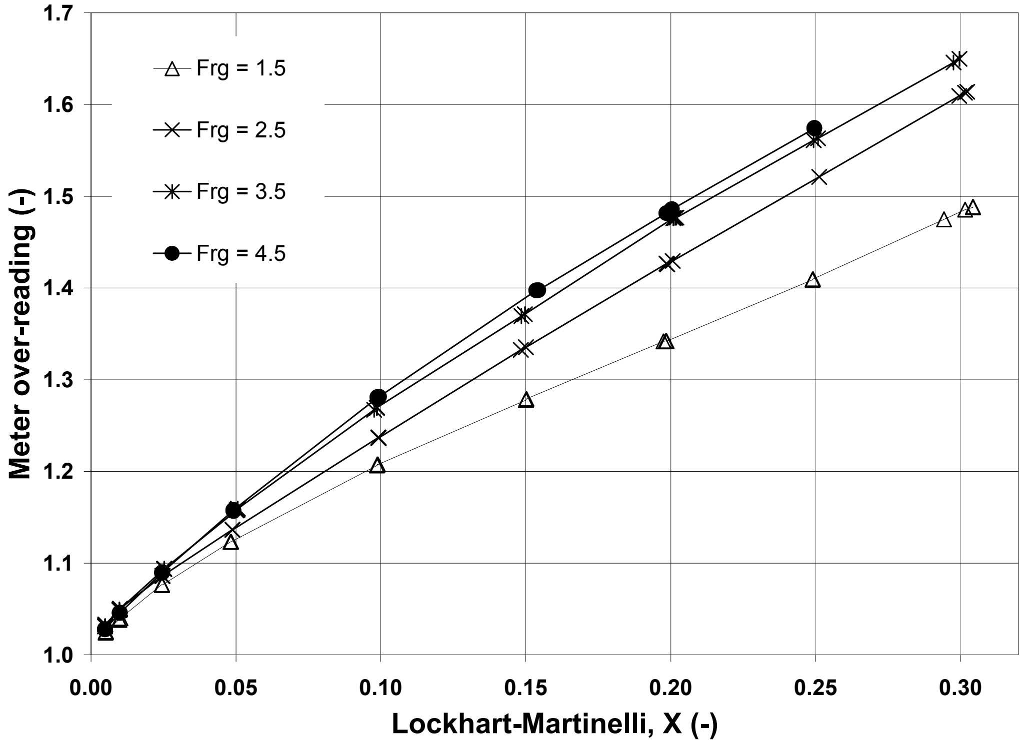

Figure 2. NEL wet gas Venturi data, showing effect of gas velocity on over-reading.

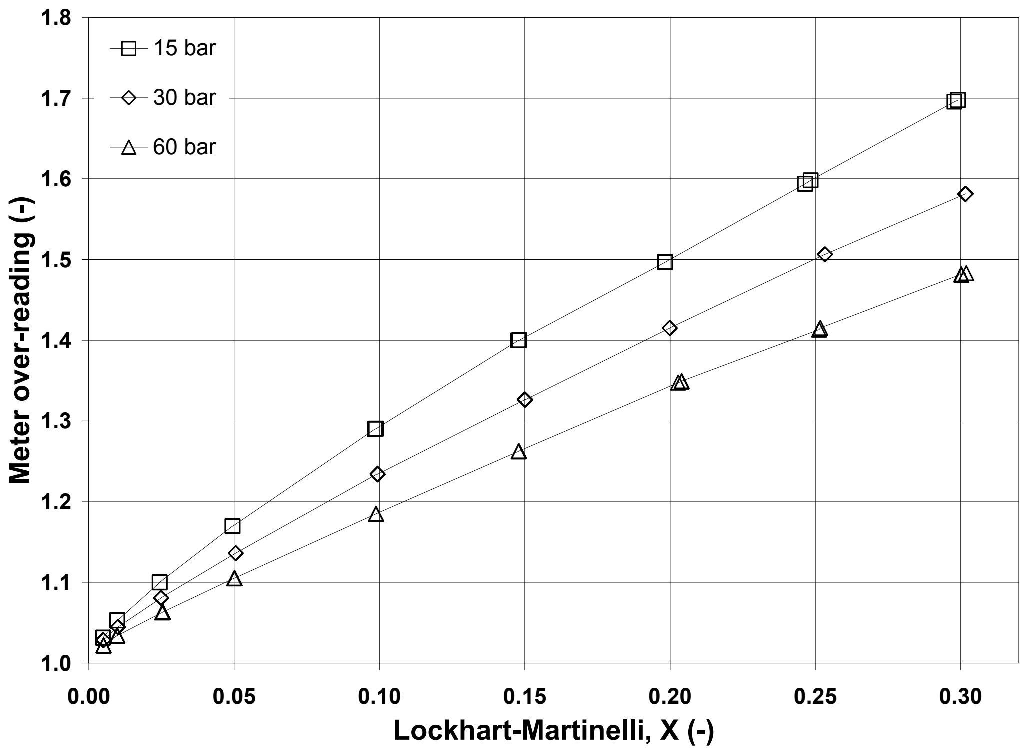

Figure 3. NEL wet gas Venturi data, showing effect of pressure on over-reading.

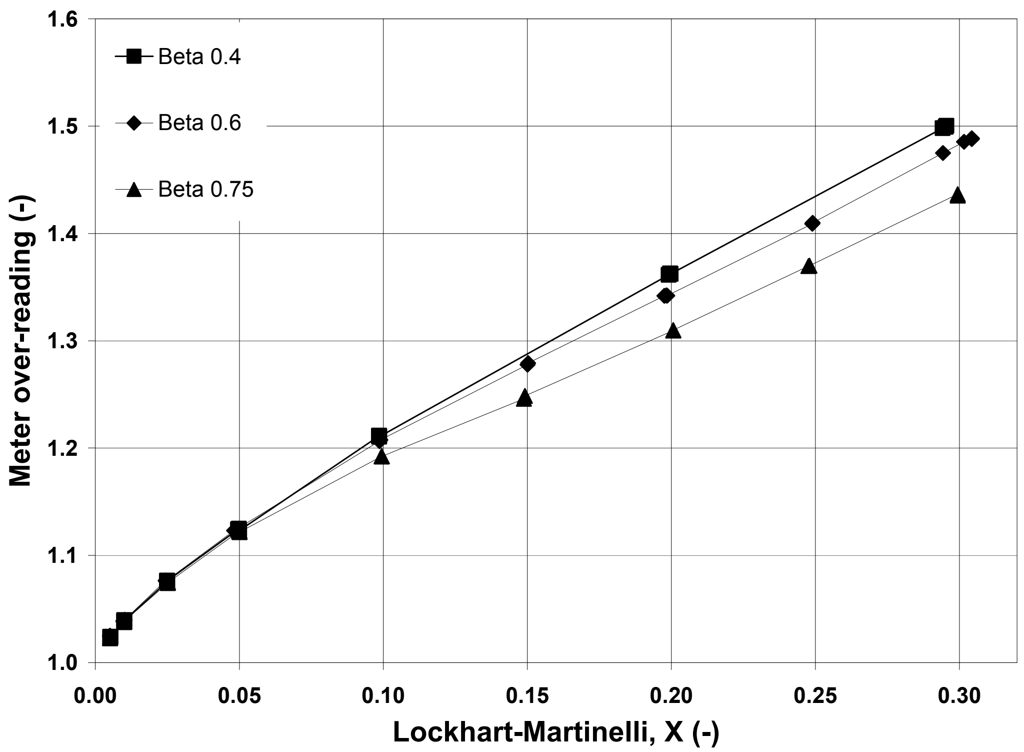

Figure 4. NEL wet gas Venturi data, showing effect of beta value on over-reading.

3. Potential uncertainty in corrected wet gas Venturi measurements

Using a wet gas Venturi in practice requires the following information:

- Dry gas meter calibration (to determine C_d)
- Knowledge of the liquid flowrate or fraction
- Correction factor to account for liquid presence

All three of these pieces of information can have an effect on the measurement uncertainty. This section briefly addresses each of them in turn to determine which effect(s) are most significant.

3.1. Dry gas calibration

In order to perform the basic flow measurement calculation it is necessary to know the meter discharge coefficient, C_d. This is normally close to unity, although the actual value can be out by up to 2% or 3%, depending on parameters such as meter and differential pressure tapping geometry and impulse line length and diameter.

However, when the meter is calibrated, any imperfections in manufacturing or installation are essentially calibrated out and the resulting uncertainty is that of the calibration reference standard used. This would normally be expected to be of the order of 0.3% to 0.5%.

If the circumstances, i.e. timescales or budgets, dictate that the meter will not or cannot be calibrated then the uncertainty in the assumed discharge coefficient can be significantly higher than this number, more in line with the potential range of values indicated above, giving a potential uncertainty of 2% or 3%.

Depending on the required uncertainty and the amount of liquid present, the uncertainty in discharge coefficient may or may not be important.

3.2. Liquid flowrate or fraction

To apply the wet gas correction to the apparent measured flowrate, it is necessary to have a measure of the actual liquid flowrate or liquid fraction. This can be achieved by a number of means, such as tracer measurements, sampling, routing through test separator, etc.

There are two main potential areas of uncertainty associated with the liquid measurement. The first is the actual uncertainty in the measurement itself and how this impacts on the wet gas correction factor. The second is due to the fact that normally the liquid measurement will not be continuous and will only be a succession of “spot” values, i.e. once per week or month, and therefore the liquid rate may change between measurements. These two areas of uncertainty are discussed further below in turn.

The impact of uncertainty in the liquid measurement can be analysed by referring to Fig. A.2, with two main apparent considerations. Firstly, it can be seen that a given uncertainty in the liquid measurement will result in a relatively lower uncertainty in the correction factor. Secondly, it is clear that the higher the liquid fraction in the gas stream the higher the correction factor (and hence higher the impact of a given uncertainty in liquid measurement). The resulting uncertainties can be illustrated by way of example. Consider the following scenario with an example gas field:

- Production rate: 100 mmscfd
- Gas density: 60 kg/m^3 (approx. 80 bar)
- Liquid density: 750 kg/m^3
- Meter size: 6-inch
- Flow velocity: 23 m/s

If we assume that the de Leeuw correction is applied then we can calculate the predicted over-reading correction for different liquid volume fractions (LVFs). Table 1 below shows the correction factors for three LVFs, a low, medium and high liquid loading, 0.25%, 1.0% and 2.5% respectively.

If the liquid measurement is in error, this effectively gives a false value of Lockhart-Martinelli and consequently an incorrect correction factor. Table 1 also shows the resulting error in the corrected gas flowrate if the liquid measurement is in error by 20%.

Table 1. Resulting gas error form liquid measurement error.

LVF (%)	Lockhart-Martinelli value, X	Over-reading (%)	Error in gas flowrate from 20% liquid flow error
0.25	0.009	2.1	0.4
1.0	0.036	8.2	1.4
2.5	0.091	19.9	3.0

It can be seen that the corrected gas flowrate is relatively insensitive to errors in the liquid flow determination. Even with a liquid loading of 2.5% by volume, with an associated over-reading of 20%, the error introduced by using the wrong correction factor as a result of a 20% error in liquid flowrate is 3.0%. At a lower LVF of 1.0% this additional error reduces to 1.4%, and at 0.25% falls to 0.5%. These values are relatively small when considered in light of the magnitude of the correction itself.

The second issue of changing liquid flowrate or fraction between periodic tests or samples is more difficult to quantify. In general if the liquid rate varies between sample measurements then the gas accuracy can be affected in proportion to the variation of the liquid rate. It may be the case that any variations in liquid rate could cancel out over the time period in question, but it could also be the case that the liquid rate rises or falls gradually over the same period.

To assess the impact of this it would be necessary to try to determine the variation in liquid rate over a normal period by some method, such as:

1. Taking a series of measurements over a shorter period of time than would normally be undertaken. This may show that the well is stable and one can be confident in the validity of a periodic spot sample.

2. Using downstream information (i.e. separator liquid rates) to estimate variation. This could prove difficult as more than one stream may be combined prior to the separator and also the separator will average out the liquid flowrate to some degree.

3. Utilising a recovered pressure measurement on the Venturi meter. The involves measuring the differential pressure from the normal upstream tapping to the additional (3rd) tapping downstream of the Venturi meter. The ratio of this Δp measurement to the main Venturi Δp is sensitive to the liquid content in the gas stream, particularly at low liquid fractions, as shown in Figure 5. Once a periodic tracer measurement or sample has been taken, the Δp ratio should be monitored for possible changes in liquid content. Any significant change in the ratio would indicate that a new measurement is required.

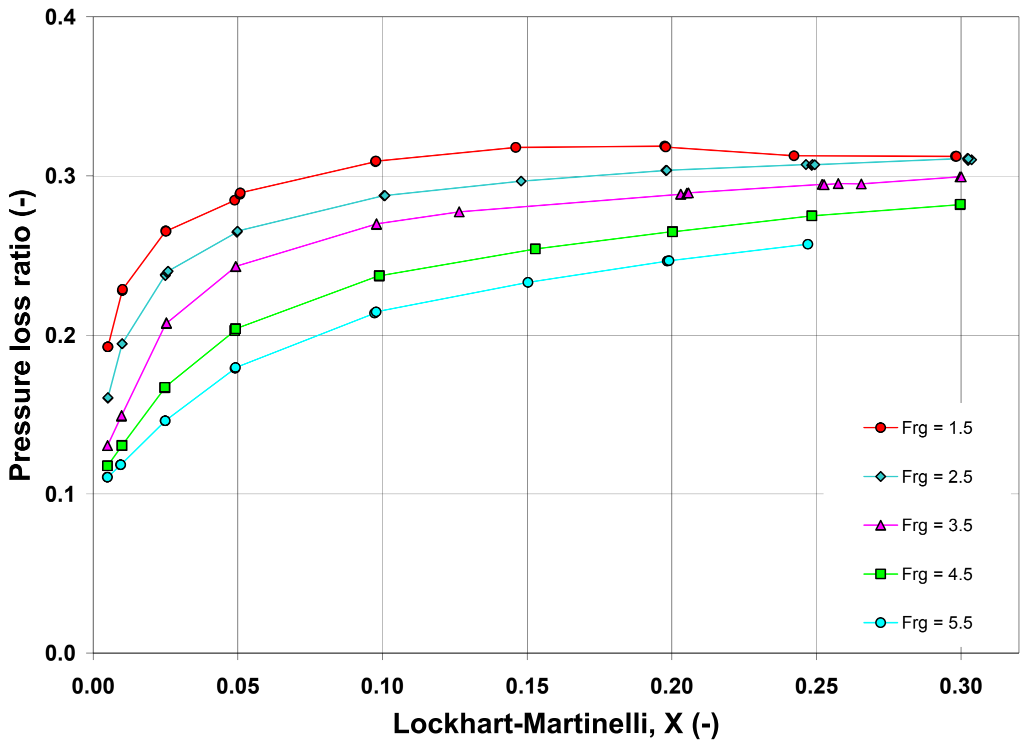

Figure 5. Example of pressure loss ratio ($\Delta p_2/\Delta p_1$) variation with liquid fraction and gas velocity.

3.3. Correction factor

In Section 2 the development of wet gas correlations, or correction factors, for Δp meters was discussed briefly. It was shown that the initial work done by Murdock [1] was based on orifice plate data, and consequently the well known Murdock correction factor, Eq. (1), is only suitable for orifice plates. The most suitable general correction factor available in the public domain is that developed by de Leeuw [4], given in Eq. (4). This equation is also sometimes referred to as a "modified Chisholm" correction factor.

Despite this fact, there are many cases where the Murdock correction has been used to correct wet gas Venturi meters. This has been done either through lack of awareness, lack of understanding of the difference between Murdock and de Leeuw, or even problems with flow computers implementing the de Leeuw correction, as it requires an iterative calculation.

It must be pointed out, however, that test data in Ref. [6] showed that the Venturi beta value also has a significant effect on the Venturi over-reading, and that using the de Leeuw correlation with high beta values (above 0.65 or 0.7) may result in increased errors in the corrected gas measurement.

Figure 6 shows an example of the difference between the correlations for a meter operating at the conditions given above in Section 3.2. It can be seen from Figure 6 that there is a significant difference between the two corrections factors. Table 2 shows the calculated additional error introduced by the incorrect use of the Murdock correction factor. Even at low liquid levels, with an LVF of 0.25% there is an additional 0.9% error in the corrected gas measurement. At higher liquid fractions, LVF = 2.5%, this increases to 7.3% error.

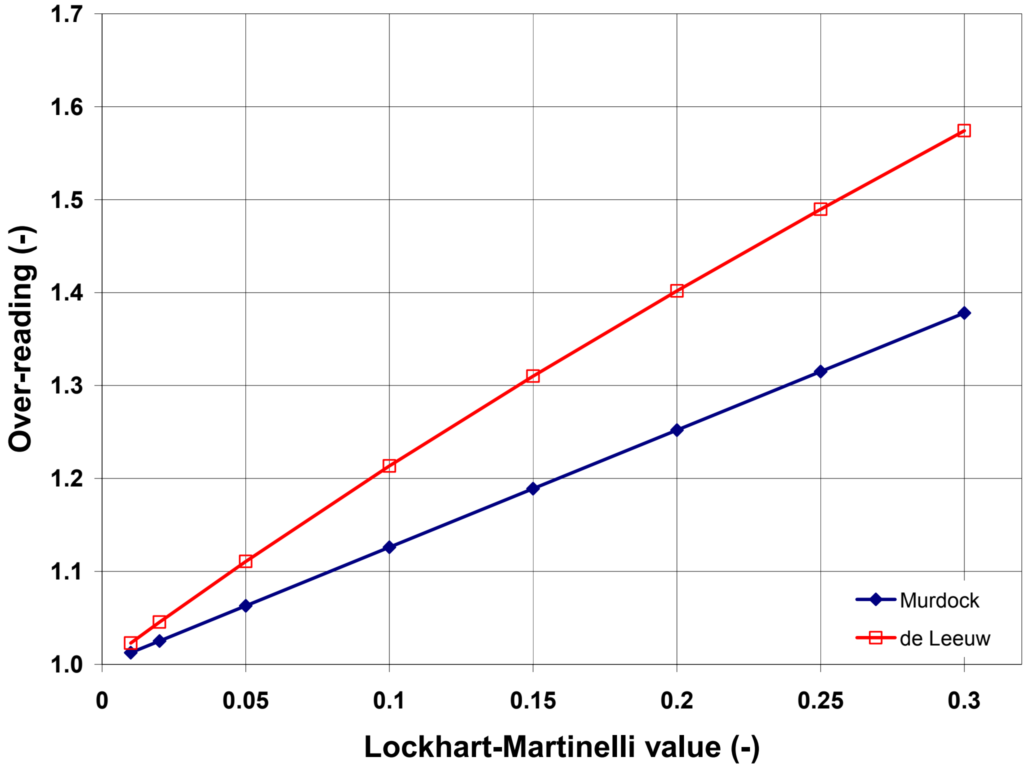

Figure 6. Example of difference between de Leeuw and Murdock correction factors.

On the basis of a gas price of 15 pence per therm, the associated financial value of the additional error is also given in Table 2.

It should also be pointed out that this error is not a “random” uncertainty in any way, but a systematic bias in the measurement, which if used in an allocation system will result in one party gaining by this amount and the other losing out by the same amount.

Table 2. Additional error resulting from incorrect use of Murdock correction factor with Venturi.

LVF (%)	Lockhart-Martinelli value, X	Additional error form Murdock (%)	Financial value of error per annum
0.25	0.009	0.9	£0.43 million
1.0	0.036	3.4	£1.6 million
2.5	0.091	7.3	£3.5 million

It is clear that the financial impact of using the wrong correction factor for a wet gas Venturi can be very significant.

4. Allocation by difference

With the increasing development of remote satellite fields that are tied back into existing platform infrastructure or subsea pipelines, the allocation of fluids to their respective fields is becoming increasingly complicated. Indeed there are now some situations where, after the new tie back is competed, the host platform or field does not have any dedicated metering of its own. For example an older field with single ownership where the metering is onshore, or where a new field is tied into an existing pipeline prior to the associated meter. The decision is normally taken to use this approach when the development of the new field(s) would not be economically viable if the existing infrastructure had to be substantially upgraded.

4.1. Example case study

To illustrate this approach an example of this approach is shown schematically in Fig. 7 below, with Field A having its gas metering at fiscal metering station F (after separation). There is a plan tp develop Field B as a satellite field and have it tied into Field A's production line. Field B will be measured unprocessed using a corrected wet gas Venturi meter prior to commingling.

The example will look at the basic method for evaluating the uncertainty in the Field A allocation, together with the key parameters that will affect the magnitude of this uncertainty, namely:

- Uncertainty in corrected WGV on Field B,
- Uncertainty in fiscal metering station F,
- Relative production rates from Fields A and B.

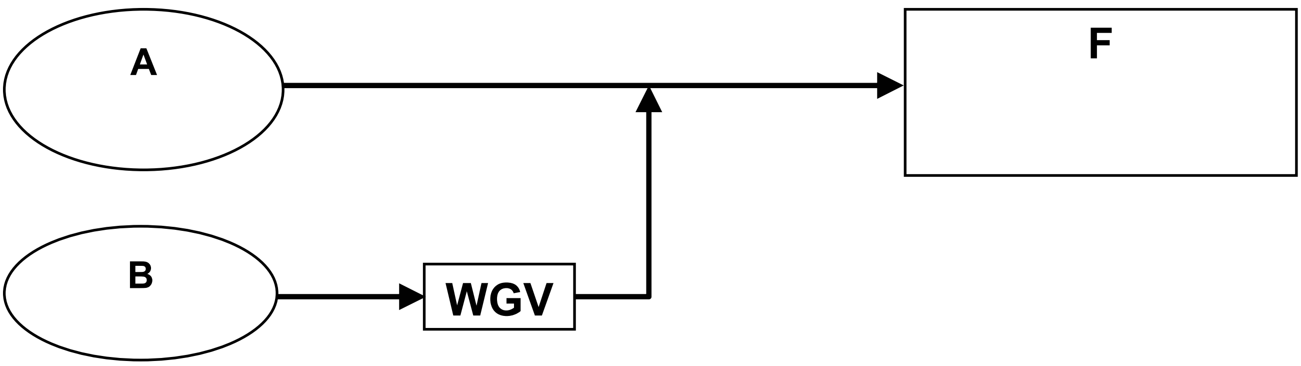

Fig. 7. Example of tie-back resulting in allocation by difference.

The allocation for Field B is taken directly from the WGV, with Field A being calculated from:

$$m_A = m_F - m_B \quad (5)$$

The resulting uncertainty in the allocation for field A is therefore calculated from the root sum square of the uncertainties in the measurements from F and B:

$$U_{m,A}^2 = U_{m,F}^2 + U_{m,B}^2 \quad (6)$$

where the uncertainties are in absolute units (i.e. mmscfd). It is clear therefore that the uncertainty in the Field A allocation depends on both Meter B and Meter F uncertainties and also on the actual production rates of Fields A and B.

It would be expected that the uncertainty in the wet gas Venturi would be higher than that of the fiscal metering station, and that as the liquid fraction from Field B increases the WGV uncertainty would increase. The de Leeuw correlation is quoted as having an uncertainty of +/- 2% on the corrected gas flowrate across a wide range of Lockhart-Martinelli values, however at very low Lockhart-Martinelli values, where the correction made to the measurement is for example 2%, it seems unlikely that the correlation should have an uncertainty as large as the correction itself. It would seem more appropriate to estimate the uncertainty as a given fraction of the correction made, subject to a maximum uncertainty of the published 2%.

For this example we will assume that the uncertainty in the correction is ½ of the correction made. For example, if the Venturi measurement is corrected by 1.2% using the de Leeuw correlation, then the additional uncertainty over and above the dry gas uncertainty would be 0.6%. This 0.6% would then be root sum squared with the dry gas uncertainty.

To investigate the influence of changes in the liquid fraction in Field B and the relative production rates of the two fields it is necessary to make some simplifying assumptions as follows:

- Fiscal metering station uncertainty - 0.75%
- Dry gas Venturi uncertainty - 0.75%

The production rate of the new field B will be assumed as a flat rate producer, at 50 mmscfd, in the first 3 years before declining to zero over the next two years. Two cases are shown for Field A, the first being a steady producing but declining field, and the second being a declining field with a seasonal production variation through the year. To analyse the effects of the relative productions rates in Fields A and B, the initial production rate of Field A will be taken as 100 or 50 mmscfd. These are shown in Figure 8 below:

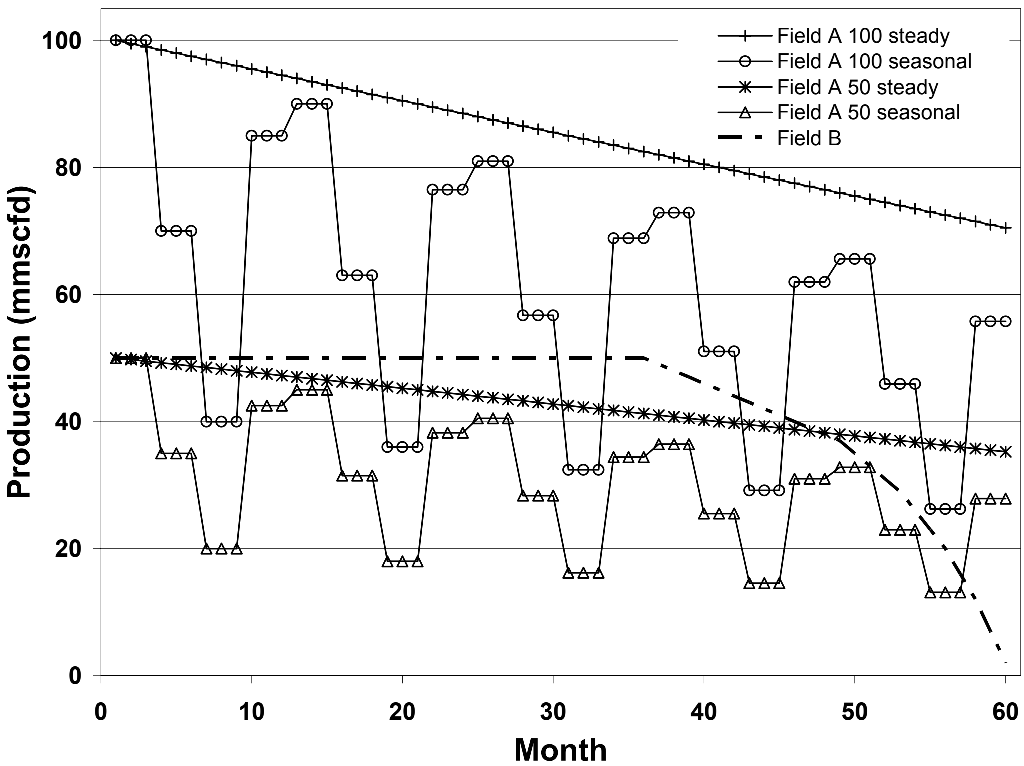

Fig. 8. Example production profiles for Field A (50/100 mmscfd, steady/seasonal, and Field B (50 mmscfd flat rate then declining).

4.2. Analysis of 100 mmscfd Field A profile

Taking the 100 mmscfd production profile for Field A means that Field B starts off at 50% of the production rate of A. If Field A has a steady but declining production, this ratio increases slowly through the first three years of Field B's life, before reducing once Field B production begins to decline sharply.

However if Field A has the seasonal production shown in Fig. 8, then the ratio between B and A is more complicated, varying through each year as A's production varies. In fact for three months each year (summer) Field B produces more than Field A, at least for the first four years, before Field B production declines in year 5.

The resulting uncertainty in Field A's allocation, calculated as shown in Section 4.1 above, is illustrated in Figs. 9 and 10 below, which show two cases for the liquid content of the Field B gas stream. Fig. 9 shows the low liquid case outlined previously (LVF = 0.25%, X = 0.009) and Fig. 10 shows the medium liquid case (LVF = 1.0%, X = 0.036).

When Field B is producing at the low liquid fraction, Fig. 9, the de Leeuw correction is just over 2%, with the additional uncertainty due to this taken as 1.0%. Accordingly, the uncertainty in Field A allocation starts at approximately 1.3%. With the steady declining Field A profile, the uncertainty rises only slightly to approximately 1.4% at the end of year three (where the ratio of B to A is at its highest), before dropping off to the base level of 0.75% as Field B production declines to zero.

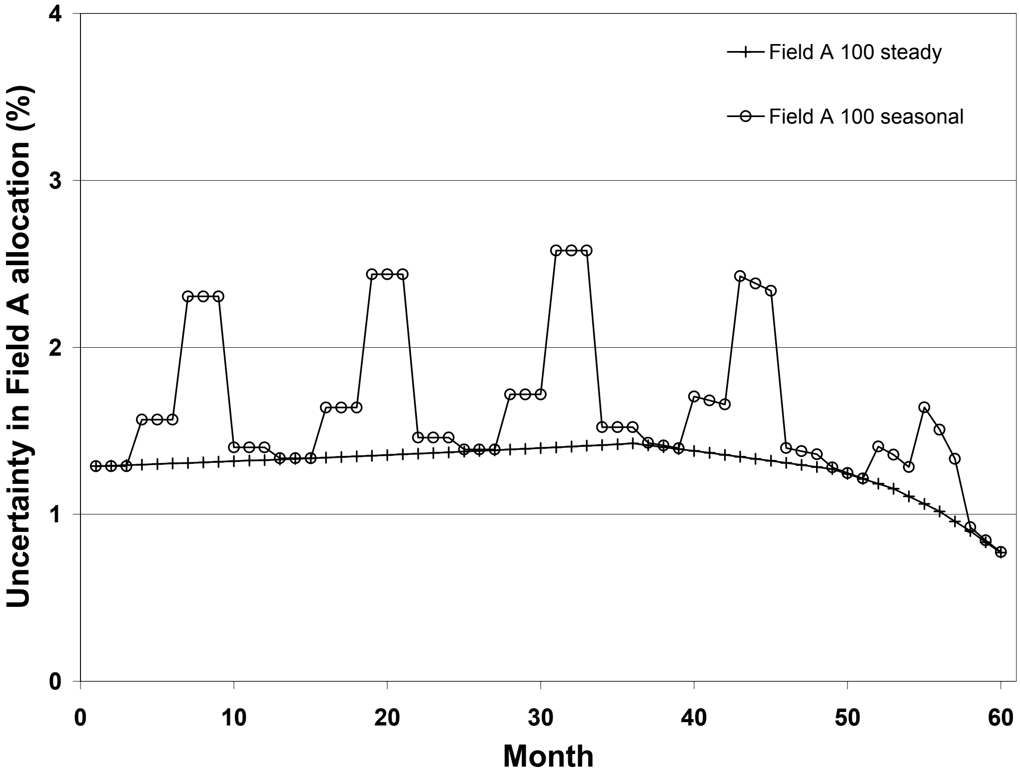

Fig. 9. Uncertainty in Field A allocation. Field B has X = 0.009.

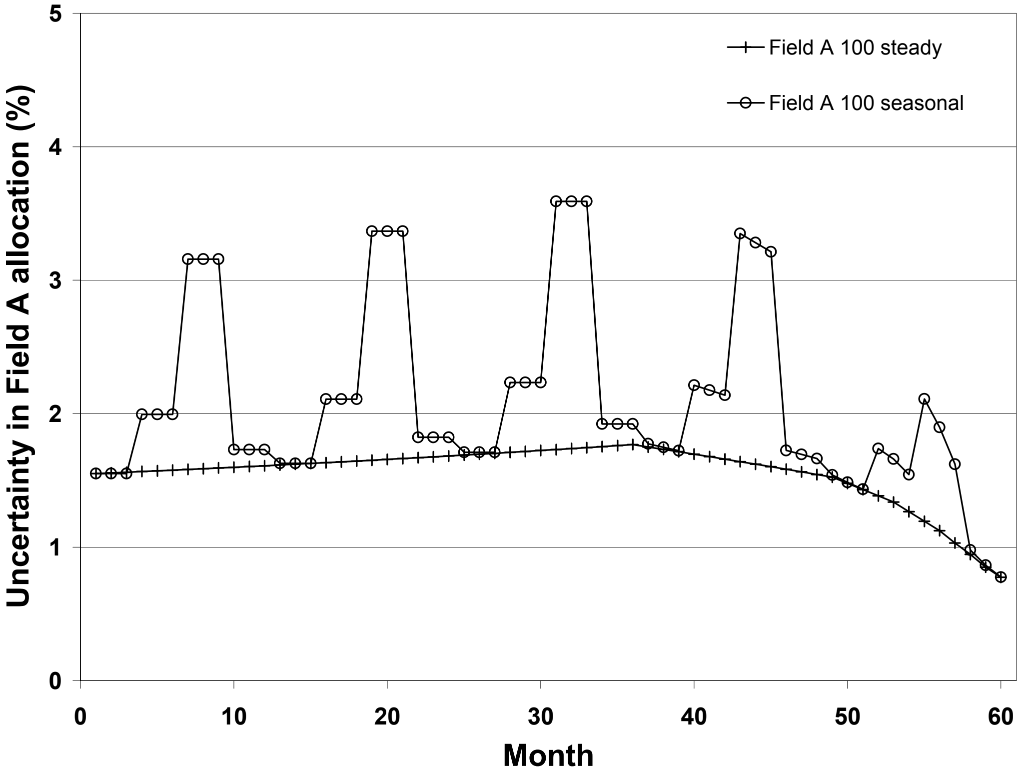

Fig. 10. Uncertainty in Field A allocation. Field B has X = 0.036.

With the seasonal Field A production profile, the uncertainty rises and falls cyclically each year, reaching a maximum uncertainty of between approximately 2.3% and 2.6%. Again, once the production in Field B declines the uncertainty in A reduces back to the base level of 0.75%.

The effect of an increase in the liquid fraction of Field B can be seen in Fig. 10, when Field B is producing with the medium liquid fraction. The LVF has increased to 1.0% (X = 0.036) with the de Leeuw correction almost 8%, however the uncertainty of the correction is taken as the published 2%. Accordingly, the uncertainty in Field A allocation starts at just over 1.5%. With the steady profile in Field A, the uncertainty in Field A allocation slowly rises to approximately 1.75% at the end of year three, before dropping back to the base level of 0.75%.

With the seasonal Field A production profile, the uncertainty rises and falls cyclically each year as in the low liquid level case, this time reaching a maximum uncertainty of between approximately 3.2% and 3.6%. Again, once the production in Field B declines the uncertainty in A reduces back to the base level of 0.75%.

It is clear that the increase in the liquid fraction of the gas stream from Field B has had an effect on the uncertainty in Field A allocation, due to the increase in the corrected gas measurement uncertainty from the Field B WGV. In the steady production case above the effect is small, approximately 0.25%, however in the seasonal production scenario the effect is more significant, increasing the maximum monthly uncertainty from 2.6% to 3.6%.

4.3. Analysis of 50 mmscfd Field A profile

It is clear from the seasonal production profile in Section 4.2 that the ratio of production from Fields A and B has a very large effect on the resulting uncertainty in the Field A allocation. It is worthwhile, therefore, to look at the effect of reducing the production rate of Field A, making Field B much more significant in comparison.

Taking the 50 mmscfd production profile for Field A means that Field B starts off at the same production rate of A. If Field A has a steady but declining production, this ratio increases slowly through the first three years of Field B's life, with B becoming slight larger than A, before reducing once Field B production begins to decline sharply.

With the seasonal profile used before for Field A, but at lower absolute rates, now starting at 50 mmscfd, Field B now has a higher production rate than A for the first four years, sometimes more than double, only becoming more equal in the final year of Field B's production life.

The resulting uncertainty in Field A's allocation, again calculated as shown in Section 4.1 above, is illustrated in Figs. 11 and 12 below, which show the same two cases outlined previously for the liquid content of the Field B gas stream. Fig. 11 shows the low liquid case (LVF = 0.25%, X = 0.009) and Fig. 12 shows the medium liquid case (LVF = 1.0%, X = 0.036).

When Field B is producing at the low liquid fraction, Fig. 11, the de Leeuw correction is just over 2%, with the additional uncertainty due to this taken as 1.0%. Accordingly, the uncertainty in Field A allocation starts at approximately 2.0%. This is significantly higher than with the 100 mmscfd Field A production rate.

With the steady declining Field A profile, the uncertainty rises only slightly to just over 2.2% at the end of year three (where the ratio of B to A is at its highest), before dropping off to the base level of 0.75% as Field B production declines to zero.

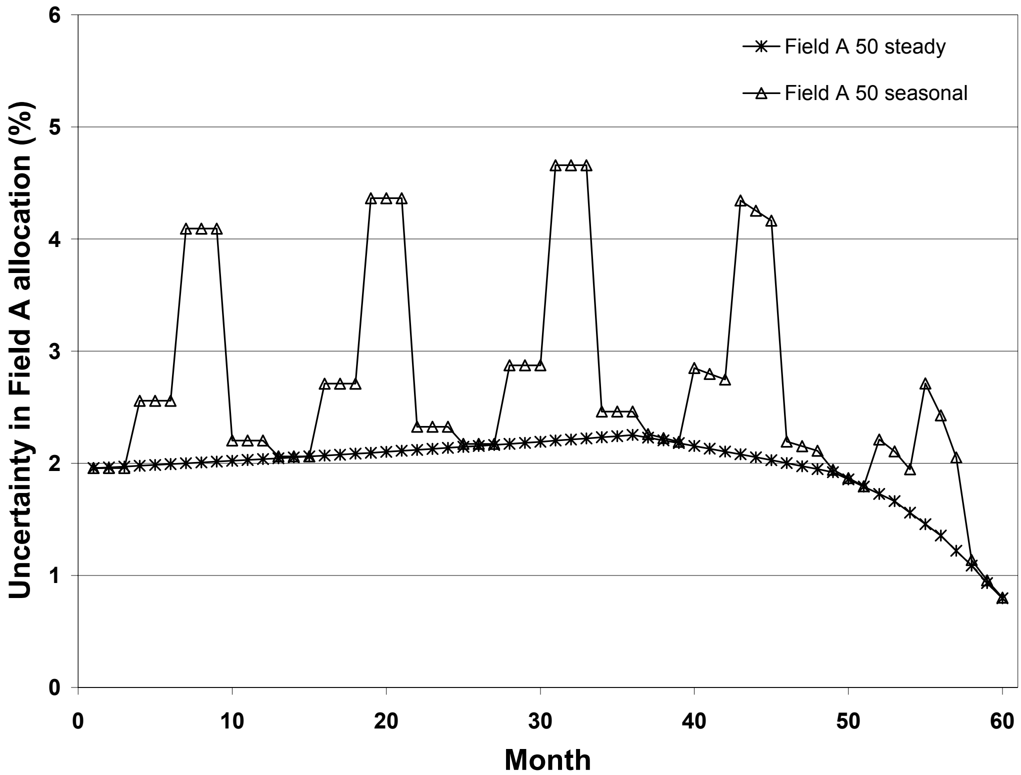

Fig. 11. Uncertainty in Field A allocation. Field B has X = 0.009.

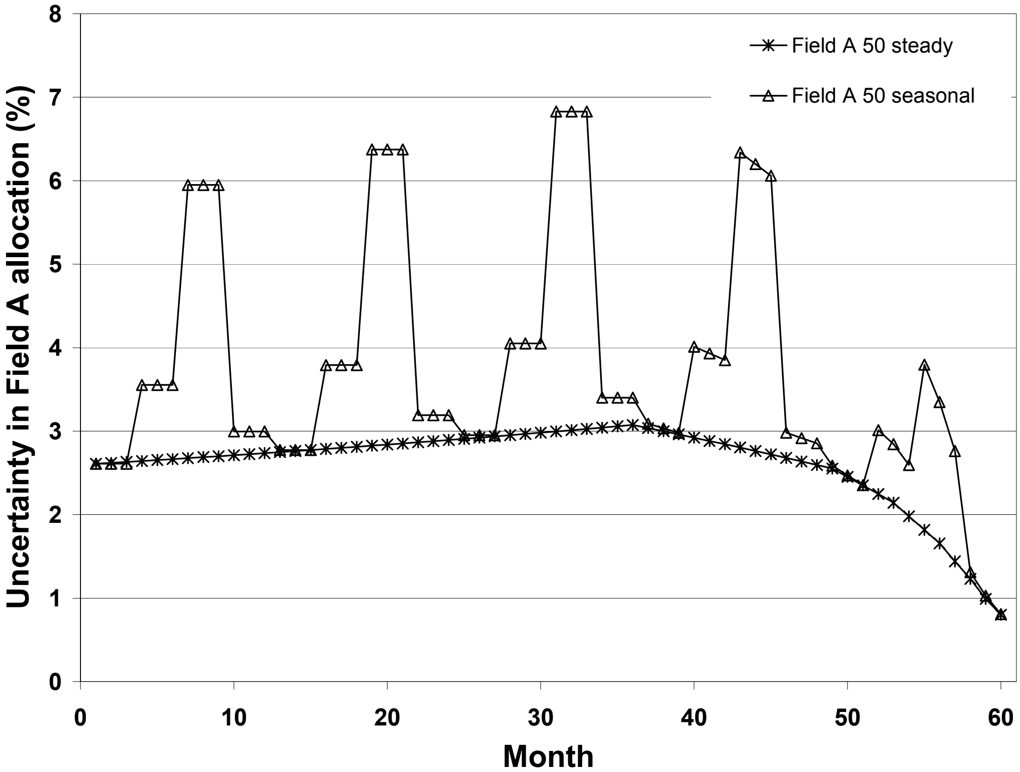

Fig. 12. Uncertainty in Field A allocation. Field B has X = 0.036.

With the seasonal Field A production profile, the uncertainty rises and falls cyclically each year, reaching a maximum uncertainty of between approximately 4.1% and 4.7%. Again, once the production in Field B declines the uncertainty in A reduces back to the base level of 0.75%.

The effect of an increase in the liquid fraction of Field B can be seen in Fig. 12, when Field B is producing with the medium liquid fraction. The de Leeuw correction and its uncertainty are as in Section 4.2. Accordingly, the uncertainty in Field A allocation starts at just over 2.6%. With the steady profile in Field A, the uncertainty in Field A allocation slowly rises to approximately 3.1% at the end of year three, before dropping back to the base level of 0.75%.

With the seasonal Field A production profile, the uncertainty rises and falls cyclically each year as in the low liquid level case, however this time the maximum uncertainty is between approximately 6.0% and 6.8%. Again, once the production in Field B declines the uncertainty in A reduces back to the base level of 0.75%.

It is clear again that the increase in liquid content in Field B has increased the uncertainty in the Field A allocation.

It is also clear that the change in the ratio between Field A and B production rates has had a significant effect in the uncertainty in the Field A allocation, as would be expected.

4.4. Correction factors – again!

The analysis of the uncertainty in Field A allocation for the simple example given above is based on the use of the de Leeuw correction factor, which is the most suitable correlation available for Venturi meters.

The use of the de Leeuw correction will have some uncertainty associated with it, however this will be significantly less than the potential error caused by not applying the correction at all. It should be stressed that the resultant corrected gas measurement has an ***uncertainty*** whereas the uncorrected measurement is known to be in error and would represent a ***bias*** in one direction (i.e. over-estimating the gas rate).

Earlier, in Section 3.3, the use of the Murdock correction factor was analysed to evaluate the difference between that and the de Leeuw correlation. It was shown that the Murdock correlation predicts too low an over-reading for Venturi meters and its use would therefore result in the wrong value for the corrected gas measurement.

Given that we know the Murdock correction to be wrong, when compared against the most suitable correlation available, de Leeuw, and also against the available test data, then its use would effectively result in an additional ***bias*** over and above the uncertainty that would be introduced by using the de Leeuw correlation.

In practical terms the Murdock correlation simply should not be used, however if it is then this additional bias should be added arithmetically to the uncertainty from the de Leeuw correlation at the same conditions.

5. Conclusions

The use of wet gas Venturi meters is becoming more widespread for allocation metering of new tie back developments. The main parameters affecting the performance of wet gas Venturis have been summarised and the correction factors available have been discussed and compared. It is clear that the use of the Murdock correlation is not appropriate to Venturi and should not be used.

An example of a system using allocation by difference to allocate to an older field left with no dedicated metering by the addition of a new tie back has been presented. A simple method for evaluating the uncertainty has been discussed along with an analysis of the key parameters that will affect the uncertainty.

Acknowledgments

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