Wet Gas Metering with Venturi meters in the upstream area : Further results for the correction factor.

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Abstract : Since a few years now, the need for accurate and reliable on line metering of wet gas is arising for fiscal and allocation purposes when different partners share subsea or topside installations. TOTALFINAELF, Gaz de France and ONERA have been collaborating on that topic for 4 years. Basic researches were performed on a Venturi meter in order to improve the knowledge of the flow phenomena which take place between the upstream and downstream taps. This paper described the analysis of results obtained at atmospheric pressure which point out the influence of the flow patterns on the metering accuracy. From these results a first law is deduced which takes into account the size of the droplets and the distribution of the liquid phase between mist and annular.

1 Introduction

In a previous paper [1], we defined the applications of the wet gas metering and their accuracy requirements. This presentation showed that a need for a direct two phase flow metering exists in order to reduce the costs of production and/or to be applied for high water depth subsea applications. In parallel, this analysis indicated that the new equipments should be designed to be reliable, tractable and that, in some domains (allocation, subsea metering), their accuracy on gas flowrate would be around 5% and in some cases as low as 1.5%.

In the last decade, a lot of meters already used for dry gas like vortex meters, ultrasonic systems and differential pressure systems have been tested and used in wet gas environments. Today Venturi meters are evaluated in more details because the technology has been already used for topside and subsea applications.

In this paper, we present the new results obtained by ONERA , TOTALFINAELF and GDF on the metering of wet gas with a Venturi meter. We analyse the influence of the two phase flow characteristics on the correction factor used to deduce the true gas flow rate from the ΔP measurements.

2 Flow rate measurement of a wet gas by means of a Venturi meter.

For the measurement of two-phase flows by means of Venturi systems, the main approach is to define a correction factor depending on the flow characteristics in order to calculate the actual flow rate of gas and liquid in the pipe. These corrections use empirical correlations derived from orifice or Venturi measurements.

If ΔP_t is the actual differential pressure measured on the flow meter with a two-phase flow, then the total mass flow rate Q_{mt} will be :

$$Q_{mt} = C_D \frac{\pi d^2}{4} \varepsilon \frac{1}{\sqrt{1-\beta^4}} \sqrt{2\rho_t \Delta P_t} = Z\sqrt{2\rho_t \Delta P_t}$$

The apparent mass flow rate of gas will be :

$$Q_{mgs} = Z\sqrt{2\rho_g \Delta P_t}$$

In fact, the actual mass flow rates of gas are :

$$Q_{mg} = Z\sqrt{2\rho_g \Delta P_g} = x \cdot Q_{mt}$$

Thus, we can define the multipliers :

$$\Phi_g = \frac{Q_{mgs}}{Q_{mg}} = \sqrt{\frac{\Delta P_t}{\Delta P_g}} \text{ i.e } Q_{mg} = \frac{Q_{mgs}}{\Phi_g}$$

Different correlations can be found in the literature. For an orifice plate in a horizontal pipe, Murdock[2] obtained the following correlation :

$$\Phi_g = 1.26X + 1$$

where X is the Lockhart-Martinelli parameter defined by :

$$X = \frac{\Phi_g}{\Phi_l} = \frac{1-x}{x}\sqrt{\frac{\rho_g}{\rho_l}}$$

In this expression, the mass flow ratio *x* is defined by :

$$x = \frac{Q_{mg}}{Q_{mg} + Q_{ml}}$$

Chisholm[3] gives another expression obtained from wet steam measurements with orifice :

$$\Phi_g^2 = 1 + 2.66X + X^2$$

More recently, De Leeuw[4] has developed a new expression from the analysis of a data base collected in full-scale multiphase flow test facility with Venturi meters. In these tests, the pressure varied from 15 bar to 90 bar and the Gas Volume Fraction from 90% to 100%. In theses conditions, the Lockhart-Martinelli parameter varies from 0 to 0.3. He observed that the correlation depends on the Froude number Fr_g (= $\frac{U_g}{\sqrt{gD}}\sqrt{\frac{\rho_g}{\rho_l - \rho_g}}$) and he proposed the following expression for the multiplier parameter, derived from the Chisholm expression.

$$\Phi_g^{\,2} = 1 + C \cdot X + X^2$$

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

In this expression:

$$n = 0.41 \text{ for Froude number between } 0.5 \text{ to } 1.5$$

$$n = 0.606 \cdot \left(1 - e^{0.746 Fr_g}\right) \text{for Froude number above } 1.5$$

In these different expressions, the flow patterns upstream of the meter is only indirectly taken into account in the De Leeuw correlation through the Froude number variations.

3 Study methodology

The level of uncertainty associated with the use of wrong correction factors lead us to develop some knowledge and understanding of Venturi behaviour in presence of different flow patterns [1].

Experiments and numerical simulations have been developed with ONERA to determine influence of the flow pattern characteristics (liquid phase distribution, droplet size, liquid film thickness) on metering errors and available correlation.

The work is organised in three steps :

- Low pressure investigations (experiments + simulation)
- Extrapolation to field conditions by simulation
- Validation of simulation results through tests on an industrial site or on high pressure loops.

The first step that is useful is to perform a detailed analysis of the phenomena with a precise measurement of the flow characteristics. In parallel, these experimental results allow validation of the flow simulation approach.

In the second step, the numerical approach allows the prediction of the behaviour of the meter submitted to the actual flow conditions.

In the last step, tests performed in high pressure conditions validate the results obtained during the second step.

In this paper we present the on going work performed from the experimental and numerical approaches at low pressure.

4 Experimental set up and flow conditions

4.1 ONERA wet gas loop

The wet gas tests are carried out on the ONERA experimental flow loop[5].The gas flow (air) is produced by means of high pressure tanks. The gas flow rate is controlled by a sonic nozzle located upstream the test section. It varies from 0 to 650 Nm^3/h. The mass flow rate of liquid (water) can be varied from 0 to 250 l/h. This loop can be used from atmospheric pressure to 5 bar.

The flow loop is composed of:

- an horizontal section (25 pipe diameters (D = 100 mm) long),
- a flow conditioner,
- a liquid injector which can produce different types of two-phase flows,
- a test section where the device under test (venturi meter or other systems) is located
- a separator to recover the liquid.

The test section can be placed following three different pipe work orientations, i.e. horizontal, vertical upwards or vertical downwards.

A Venturi meter with a beta ratio equal to 0.6 has been tested. The upstream internal diameter is equal to 100 mm. Two models have been designed, one in metal for pressure measurements, and the other in Perspex for flow visualisation or optical measurements.

4.2 Flow pattern

Several flow configuration and flow rates can be used to vary the liquid fraction, the density ratio, the droplet size and the ratio droplet/film.

The two first parameters are fixed either by controlling & measuring individual flow rates of gas and liquid or by controlling the pressure.

Flow pattern morphology is measured in situ upstream the meter under test on the ONERA gas loop. The main flow characteristics are size and velocity distribution of droplets, liquid flow rate and repartition between dispersed and annular flow.

The repartition factor f (f = mass of liquid droplets/mass of liquid) is determined from the simultaneous measurement of liquid mass flow rate injected in the pipe and liquid mass flow rate flowing on the wall.

For the disperse phase, the measurements are performed with a granulometer based on the Phase Doppler Analysis (Aerometrics) which provides at different points, the histograms of velocity and droplet size. In our case, the measurements are performed at 22 points located on two orthogonal diameters (horizontal and vertical respectively). From this size histogram, it is possible to calculate some average values. For the droplet size distribution, different averaged diameters can be deduced representative of surface exchange, mass interaction etc… In our case, we use a d_{30} mean diameter defined as follows :

$$d_{30} = \left(\frac{1}{N} \sum_{i=1}^{N} d_i^3 \right)^{\frac{1}{3}}$$

where d_i corresponds to the diameter of the individual droplets.

For this study, the flow characterisation has been performed for three gas loop arrangements which permit to obtain, for the same gas and liquid mass flow rate, different flow characteristics.

In Figure 1, we plot an example of droplet velocity profile obtained upstream of the Venturi meter. This profile is compared with a power law describing the velocity distribution in a fully developed turbulent pipe flow. We can observe that, in this case the flow is symmetric and that the droplet velocity profile follows quite well the fully developed conditions. Note that, in some configuration the accordance between the droplet velocity profile and the power law is not so good. In particular in some pipe configurations a flow asymmetry can be observed. Figure 2 shows the radial distribution of the droplets size for one flow case (Q_{vg} = 360 Nm3/h, Q_{vl} = 54 l/h).

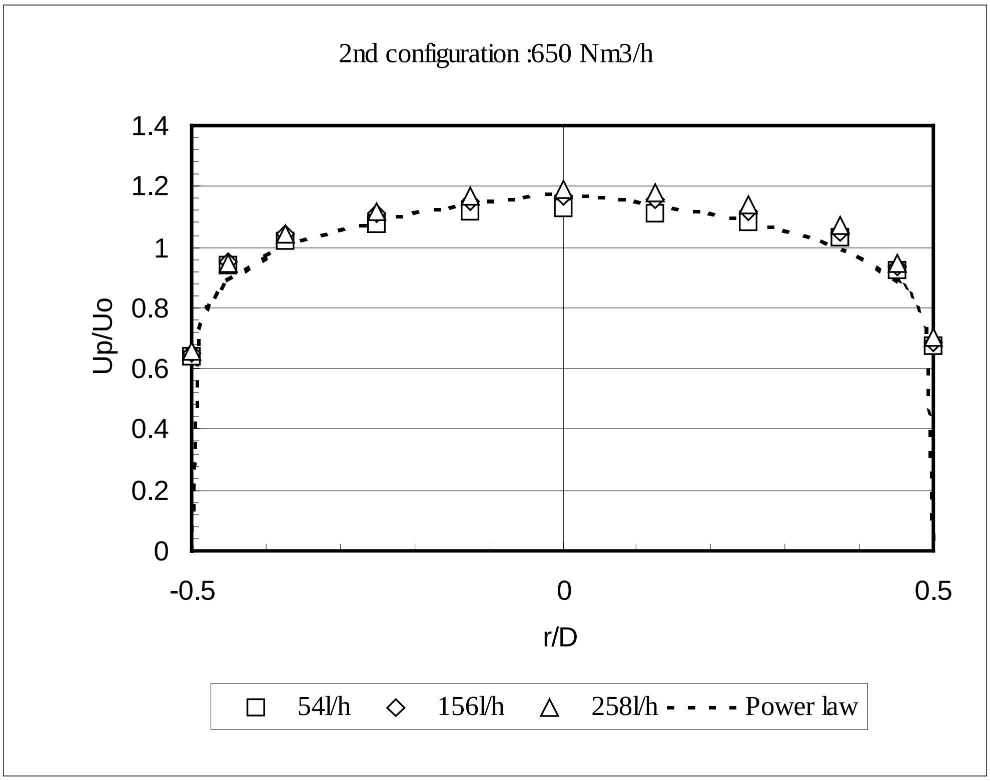

Figure 1 : Droplet velocity profile obtained for the second pipe arrangement.

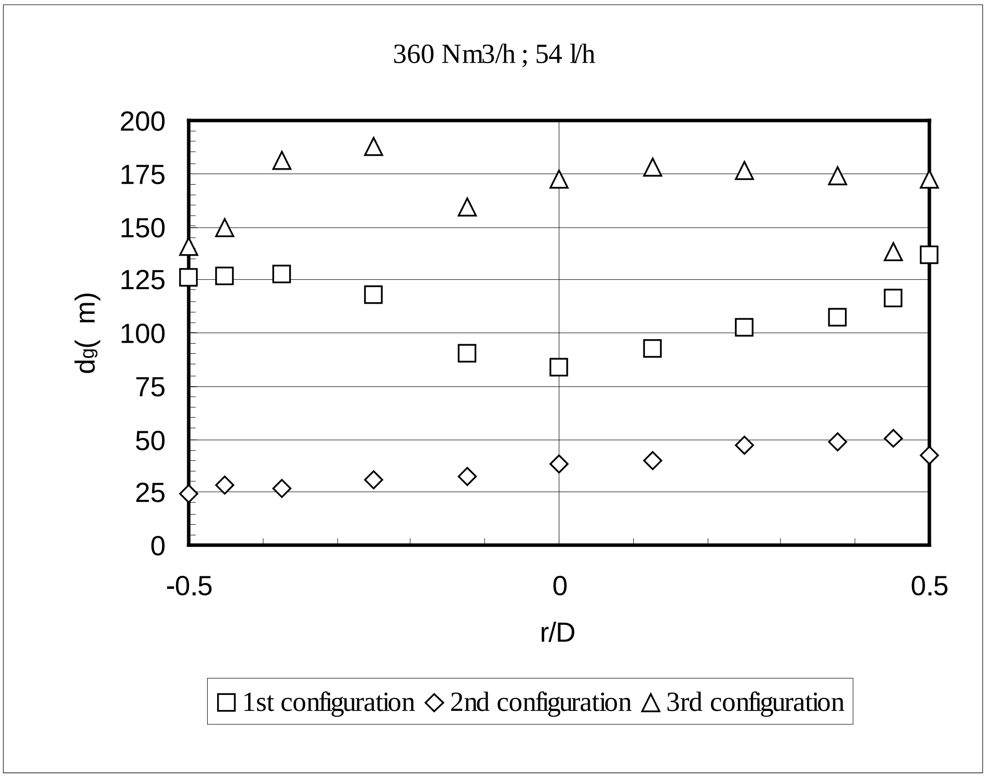

Figure 2 : Radial distribution of the droplet size obtained for different pipe arrangements.

In previous papers, we have noted that the momentum exchange between the droplets and the gas flow is defined by a non dimensional number, the Stoke number which compares the response time of the droplet τ_d with a characteristic time τ_g of the air flow.

$$Sto = \frac{\tau_d}{\tau_g}$$

If the droplets are only submitted to drag forces, their response time is :

$$\tau_d = \frac{\rho_l \cdot {d_d}^2}{18 \cdot \mu}$$

In our case the characteristic time of the flow corresponds to the time need for a gas parcel for flowing through one pipe diameter :

$$\tau_g = \frac{D}{U_0}$$

In figure 3, we plot the variation range of our installation in term of Stoke number and f factor.

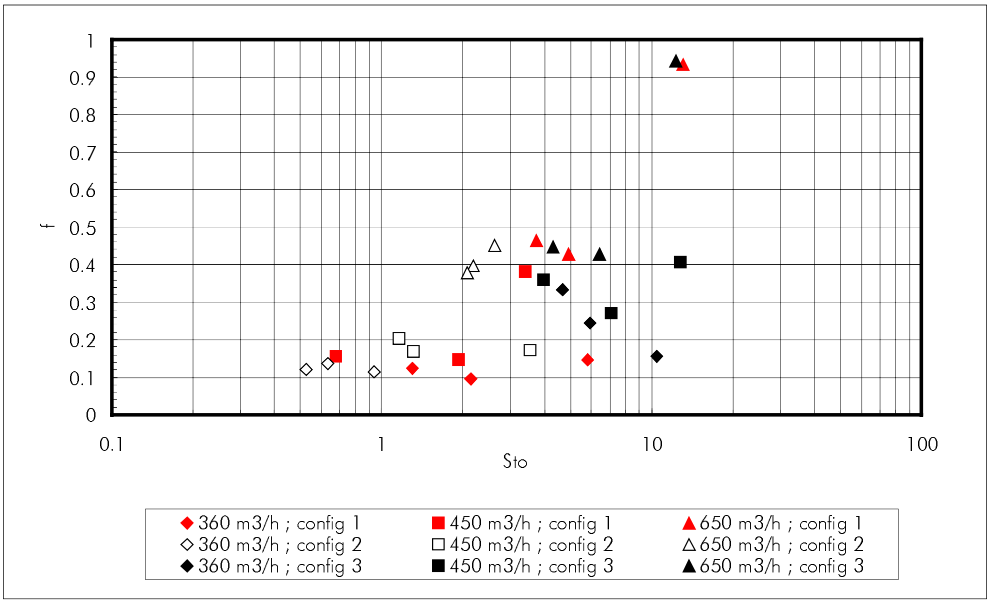

Figure 3 : Stoke number versus f factor obtained on the ONERA loop.

5 Influence of the two phase flow characteristics on the flow rate measurements

The raw data obtained during this study are plotted in Figure 4. We notice that, for a same flow condition, a variation of 5% of the effective correction factor has been measured between the different pipe arrangements. By comparing these results we observe that these variations depends on the gas mass flow rate. In particular, they become less important when the bulk velocity increases.

In order to interpret these results, it is necessary to take into account the corresponding variations of the *f* factor and the Stoke number. From this analysis, we deduce that the correction factor is higher when the amount of liquid flowing as droplets increases. At contrary, we observed that this factor augments when the Stoke number decreases. This tendency was yet obtained from flow simulation presented in a previous paper[5].

These conclusions are clearly illustrated by the Figure 5 where we plot the Φ_g factor with respect to the *f.X* product for different ranges of the Stoke number. In this figure, the *f.X* product is the Lockhart Martinelli coefficient calculated only on the liquid mass flow rate flowing as droplets. This figure shows that for Stoke number greater than 2, the correction factor is not greatly influence by this parameter.

In order to collapse these different curves, we looked for a relation which permits to describe these observations. In Figure 6, we compare the expression found to our experimental results. We can observe that most of the point follows the curve. Nevertheless the tendency obtained during this study must be confirmed. In particular the influence of the pressure must be taken into account.

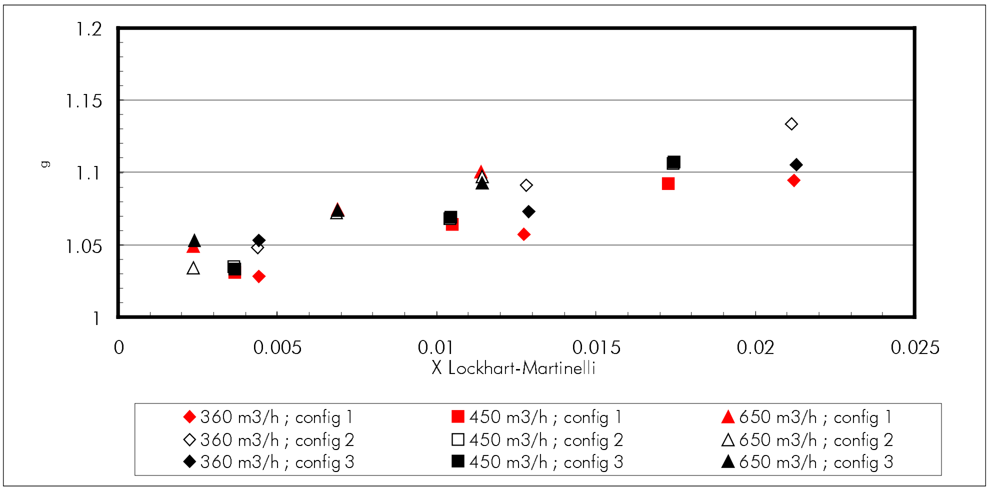

Figure 4 : Raw data obtained for the different flow cases

6 Conclusions

This paper presents the new results obtained on basic researches focussed on the influence of liquid phase on a Venturi meter. This work permits to link the flow characteristics to the ΔP variations observed on the meter.

In a first step, we analyse the inlet two phase flow in terms of droplet size and velocity and distribution of the liquid phase between the mist and annular regions. During these experiments, we modify the pipe arrangement in order to obtained for a same flow condition (mass flow rates of gas and liquid) different flow patterns (droplet size and liquid distribution).

In a second step, we measure for the different cases the ΔP variations induced by the liquid phase.

The analysis of these results shows that the ΔP variations are linked to the amount of liquid in the mist zone. In parallel, we notice that the influence of the droplet increases when their response time is low compared to a characteristic time of the gas flow. From these observations, we looked for an expression which takes into account the dynamic response of the droplet characterised by a Stoke number and the liquid distribution in the pipe. The mathematical expression obtained permits to collapse our results with an accuracy better than 2 % for most of the points. Nevertheless, it is deduced from a limited number of results obtained at the atmospheric pressure and it is now necessary to extend its validity domain to higher pressure.

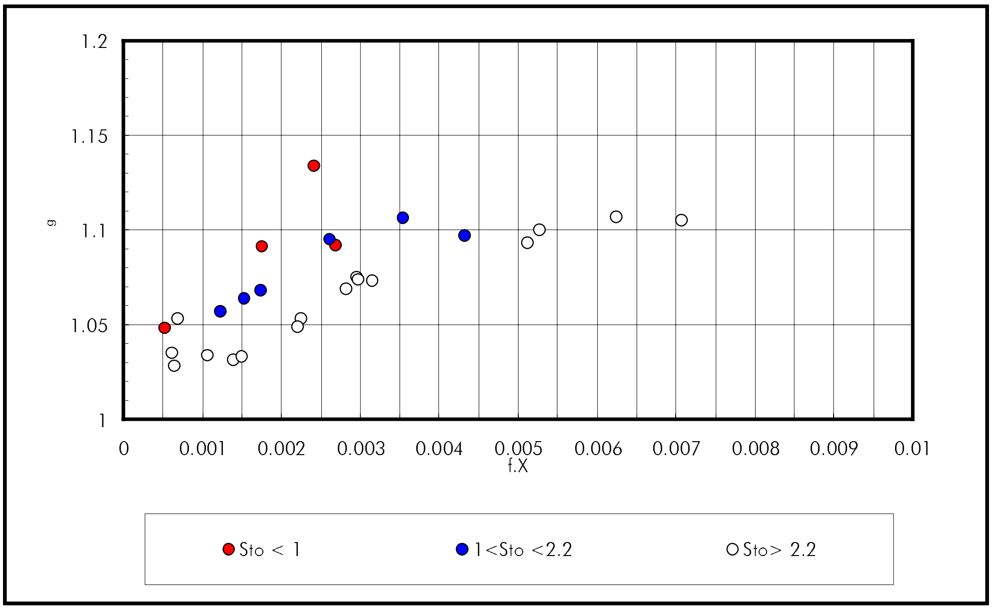

Figure 5 : Φ_g coefficient with respect to the X.f product. Influence of the Stoke number

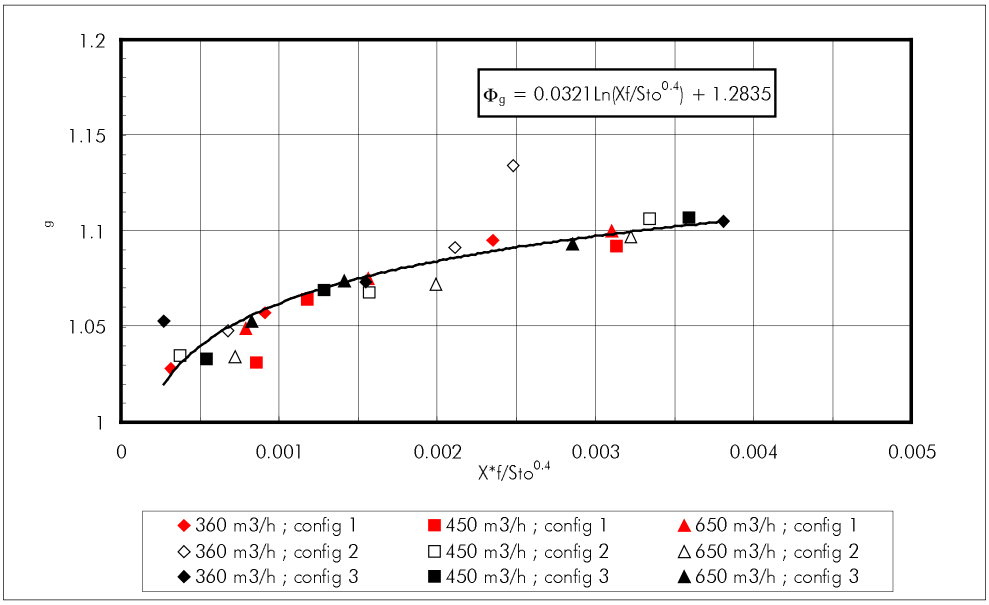

Figure 6 : New relation obtained from our experimental results

7 References

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