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WET GAS METERING IN THE UPSTREAM AREA : NEEDS, APPLICATIONS & DEVELOPMENTS

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1 INTRODUCTION

Direct measurement of flow rates in multiphase flows (liquids and gas) without separation is possible in the oil & gas production upstream area. The concept is now considered by operators in most developments of oil and gas fields and it has been demonstrated that when correctly designed and operated it brings some significant benefits both on investments and operations to the users.

“Liquid multiphase techniques“ have been developed with reasonable success for high liquid content flows where there is generally more liquid than gas in mass and consequently where the dollar value of oil is higher than that of gas, this has resulted in numerous meters only suitable for high liquid content and low gas fractions (< 90% vol/vol).

On the gas side i.e. for multiphase streams with high gas fractions (wet gas domain), a significant number of applications have been identified which are not covered satisfactorily for existing and future prospects.

For a number of years Elf (now TotalFinaElf) and Gaz de France have identified wet gas metering as a key point and are trying to improve metering in high gas fractions and wet gas conditions for existing applications and future needs through development & test programs.

This paper describes production needs, existing applications, state-of-art and work carried out on Venturi meters in two phase flows.

This is one of the first attempts to correlate Venturi flow meter behaviour with flow pattern characteristics (liquid content, annular/mist ratio, droplet size, droplet slip ratio).

2 FROM WET GAS METERING TO MULTIPHASE METERING?

Wet gas is defined by Reservoir Engineers as gas which produces liquid at surface conditions without producing liquid in the reservoir. So wet gas at metering conditions can be humid gas, gas at the dew point or gas with a small amount of liquid for instance less than 1% in volume or some barrels/MSCF.

There is also an ISO definition from ISO : DIS 14532 (ISO TC 193 Natural Gas) which stipulates that wet gas is gas with inclusion of components like water vapour, free water and/or liquid hydrocarbons. ISO does not mention any limit for liquid content.

But today the measurement people have extended wet gas metering domain to gas metering in presence of higher liquid content up to 10% in volume and 50% in mass, as this is the case with gas condensate fields and are also interested in liquid content measurement itself. In that case, it is clear that we have separate gas and liquid phases.

Consequently wet gas metering applies to high gas fraction multiphase flows with significant amounts of liquid.

Wet gas metering terminology also indicates that the component to be measured specifically is the gas phase because gas value of the stream is significant though this does not mean that liquid is not valuable.

To sum up, it is proposed to define wet gas as a gas phase with liquid inside and to use wet gas metering or wet gas multiphase metering terminology depending if we are interested only in gas metering or, on gas and liquid which is the case in high gas fraction multiphase streams.

3 WHERE DO WE HAVE TO APPLY WET GAS METERING?

Wet gas metering is applicable in production upstream area for :

1. Reservoir monitoring on individual wells or in place of test separators

- Allocation on individual wells or flowlines
- Production optimisation through well flowrates monitoring (gas lift wells are not considered) and improved separated gas measurements)
- Flow assurance especially in subsea applications.

in the following developments :

- Wet gas fields in which liquid content at surface conditions is rather small (1% or less) ; WLR can vary in the whole range 0 to 100%.
- Gas condensate fields which give liquid at reservoir conditions and which can produce a significant amount of hydrocarbon liquid at surface conditions : GVF up to 96% or higher.
- Very high GOR fields (HP/HT) with GVF at metering conditions ranging from 90% to 99.9%.
- Associated gas metering in oil fields.
- Density of phases in case of compositional monitoring.

4 WHAT DO WE NEED?

Required information will depend particularly on the applications but could include :

- Only a gas flowrate measurement in volume or mass
- Specific parameters like water content and/or water flow rate
- Liquid and gas flowrates
- Three phase measurement with gas, water & condensate flowrates in liquid and mass.

The accuracy should be similar to well test separator for well testing applications. (+/-10%) and at least 5% (1% could be a target) on gas and sometimes on hydrocarbon condensate for allocation. Figures around 20% or more could be acceptable for flow assurance.

Equipment should be designed to be reliable, traceable and applicable to both topside and subsea applications, especially high water depth. Maintainability and operability shall be considered and will be a selection criteria.

5 APPLICATION EXAMPLES

Gas Condensate Well Testing

The Table 1 illustrates typical process data for an offshore well testing application at 100°C and 150 bar a

Table 1 - Gas condensate process data

	Start of life	Mid life	End of life
Gas flowrate MM Sm^3	0.5	1,3	0.8
Oil flowrate m^3	1830	900	200
WLR	0%	7%	64%
GVF	65%	90%	94%
Pressure bar a	150	150	150

The accuracy on gas, liquid and WLR shall be comparable with well test separator. Ideally, additional systems bringing complexity shall be avoided. Flowrates shall be given in volumes and in some cases mass flowrates and phase density will be required.

Field Production Allocation

The Table 2 gives example of process data related to wet gas fields production.

Table 2 - Wet gas field data

	Start of life	End of life
Number of fields	3	3
Gas flowrate $MMSm^3$	1.65	0.5
Water content	10 $m^3/MMSm^3$	70 $m^3/MMSm^3$
Condensate	10 $m^3/MMSm^3$	10 $m^3/MMSm^3$
Pressure	250	100

Measurement accuracy requirements can be as low as 1.5% on gas volumes

High Water Depth Subsea Applications

The development of deeper gas reserves in fields more and more distant from existing facilities, leads to the conception of longer sub-sea tieback where more and more wells or even fields are connected to a single flow-line. A solution is to have a wet gas meter installed on each wellhead of on a sub-sea manifold (water depth can be around 2000 m or more) for a group of wells. This is a typical application case for a subsea wet gas multiphase metering system. Meter will be installed downstream the choke prior to commingling. The resulting flow will be exported through a subsea line toward the processing platform.

The meter will be used for :

- Fiscal Metering for gas and condensate allocation
- Monitoring of well behaviour for reservoir monitoring
- Monitoring of water production in order to optimise methanol inhibition and prevent expensive blockages.

Typical required accuracy targets are :

- +/-5% on gas flowrates
- between 10% and +/-20% on total liquid fractions
- +/-20% relative on WLR.

6 AVAILABLE TECHNIQUES

Multiphase Metering Techniques

Measurement of multiphase flows without separation or with partial separation is now possible in oil & gas production. The technology is accepted by operators and when correctly designed and operated it brings to users some significant benefits both on investments and operations.

Multiphase techniques have been developed with a reasonable success for high liquid content flows where there is generally more liquid than gas in mass and consequently where the dollar value of oil is higher than that of gas.

This has resulted in numerous meters but only suitable for high liquid content (GVF < 90% vol/vol). When used at higher GVF (95%), most of the systems do not give liquid content and gas flowrate is not very accurate.

Wet Gas Meters

A lot of meters already used for dry gas have been used in wet gas environments like vortex meters, ultrasonic systems and differential pressure systems. Reliability and performance of Venturi meters and ultrasonic meters for wet gas metering is investigated.

Today Venturi meters are evaluated in more detail because the technology has been already used for topside and subsea applications.

One limitation of wet gas meters is that until now they have been designed to give the gas flowrate without measuring the liquid content. This is only acceptable if the liquid content is known or/and if it does not influence the meter. This has resulted in a new interest in liquid measurements from manufacturers.

Liquid Content and WLR Determination

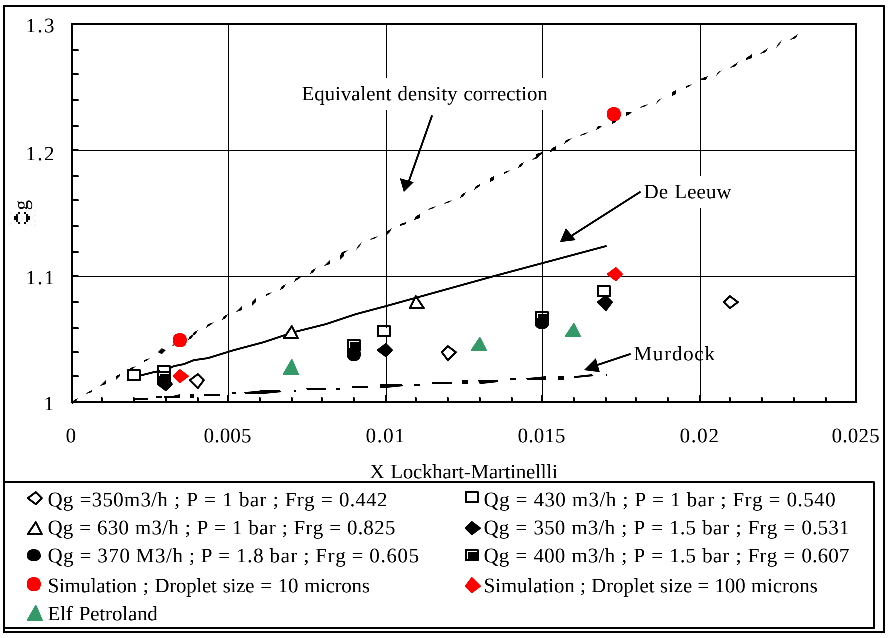
A number of techniques (sampling, optical particle analysis, tracers, gamma ray absorption, ultrasonic systems, electrical measurements, pressure drop measurements, tomography) can be candidates for liquid and water fractions measurements in high gas fraction flows. But no proven technique is really available on the market for upstream needs.

7 VENTURI BASED APPLICATIONS

Venturi meters are used for wet gas flows measurements of individual well productions for fiscal allocation. Apparent gas flowrate is corrected to give true gas flow rate by using a correction factor Φ_g

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

Φ_g modellisation by using a Murdock equation $\Phi_g = MX + 1$ does not apply (Figure 1). Periodic calibration has shown that the coefficient M could vary between 3.78 and 5.20 instead of 1.26 which is the expected one. This has been confirmed also by laboratory measurements [1].



8 VENTURI PERFORMANCE IN WET GAS

The high 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, 2].

Study methodology

Experiments and numerical simulations has 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 Section we present the experimental and numerical approaches used during this study.

ONERA Wet Gas Loop

The wet gas tests are carried out at low pressure on the ONERA experimental flow loop [1]. 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, and
- 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.

Tested Venturi

A Venturi meter with a beta ratio equal to 0.6.has been tested. The upstream internal diameter is equal to 138 mm and the throat diameter to 101.1 mm. Two models have been designed, one in metal for pressure measurements, and the other in perspex for flow visualisation or optical measurements.

Test Conditions

The results presented in this paper are obtained for two pressure values (1 bar and 1.5 bar) and gas flow rates between 350 m^3/h and 630 m^3/h. In these conditions the gas Froude number varies from 0.442 to 0.825. The liquid flow rate ranges from 0. To 250 l/h.

Flow Pattern Control & Measurements

Several flow configuration and flowrates 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.

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

In Figure 2 we plot the variation range of our installation in term of droplet size and *f* factor. For the diameter, the value plotted correspond to an averaged value obtained through the pipe section.

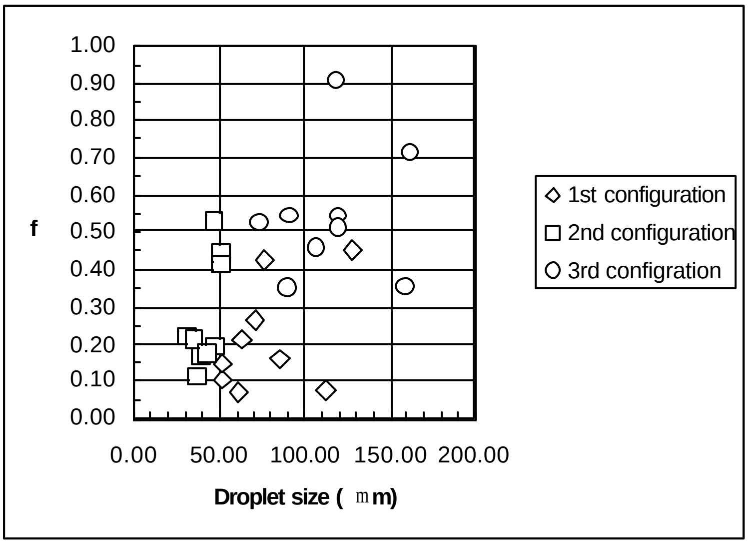


Figure 2 - Repartition factor f/droplet size map

Two Phase Mist Flow Characterisation

In Figures 3 & 4 we present an example of velocity and droplet size distribution obtained on the horizontal diameter for gas mass flow rate of 0.12 kg/s and different liquid mass flow rate. In Figure 3, we compared these results with a power law distribution valid for a fully developed flow. We can observe that, in this case, the flow is symmetric and that the velocity distribution follows the fully developed conditions.

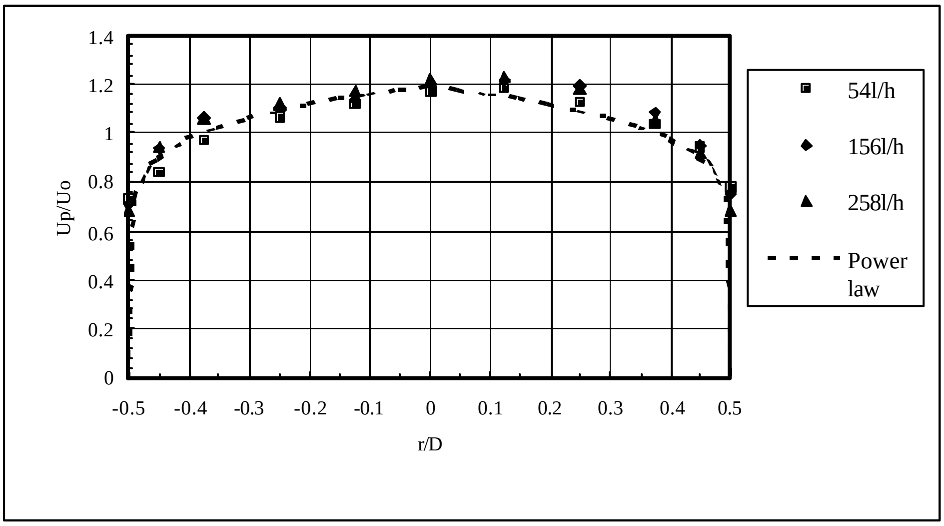


Figure 3 - Velocity & droplet size distribution upstream Venturi

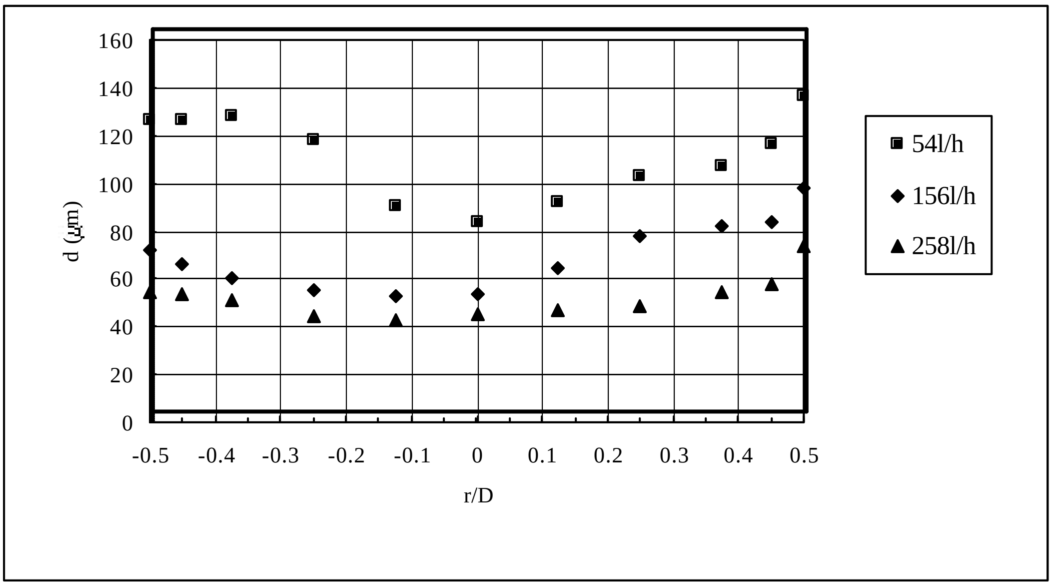


Figure 4 : Droplet velocity distribution upstream of the Venturi meter.
(P = 1 bar, Qmg = 0.12 kg/s)

Experimental Results

- **Correlations versus Lockhart Martinelli parameter**

All the results obtained during this study are plotted in Figure 5 in the form of $?_g$ distribution against the Lockhart Martinelli parameter. They are compared to the Murdock and DeLeeuw [3] correlation. In the latter, the variation of the Froude number taken into account in the experiments implies a unique curve correlation ($0.5<Fr_g<1.5$) which imposes a constant value of n in the De Leeuw correlation). Note that the Chisholm and Murdock correlations are equivalent.

Globally we can note that all the experimental results are located between the Murdock and De Leeuw correlations. We also observe that when the air flow rate increases, the result tends to the De Leeuw prediction.

When we look at the results obtained at atmospheric pressure for which the Froude number varies from 0.442 to 0.825, we observe that the slope of the correction curve increases with the gas Froude number. This tendency has been already noticed by De Leeuw.

Nevertheless, if we compare results obtained at two different pressures, this tendency is not verified. This discrepancy can be explained by a flow regime modification obtained during the tests. As a matter of fact, the first flow visualisations show that when the air flow rate increases, the number of droplets increases, that is to say that the flow tends to a dispersed flow regime. Thus, for the higher pressure the flow regime tends to an annular flow type whatever the flow rate.

This influence of the flow regime can also be deduced from the De Leeuw results from which we can note that the correction diminishes with the Froude number and that, in parallel, the flow changes from annular dispersed regime to stratified regime.

This explanation will be verified by a characterisation of the two-phase flow.

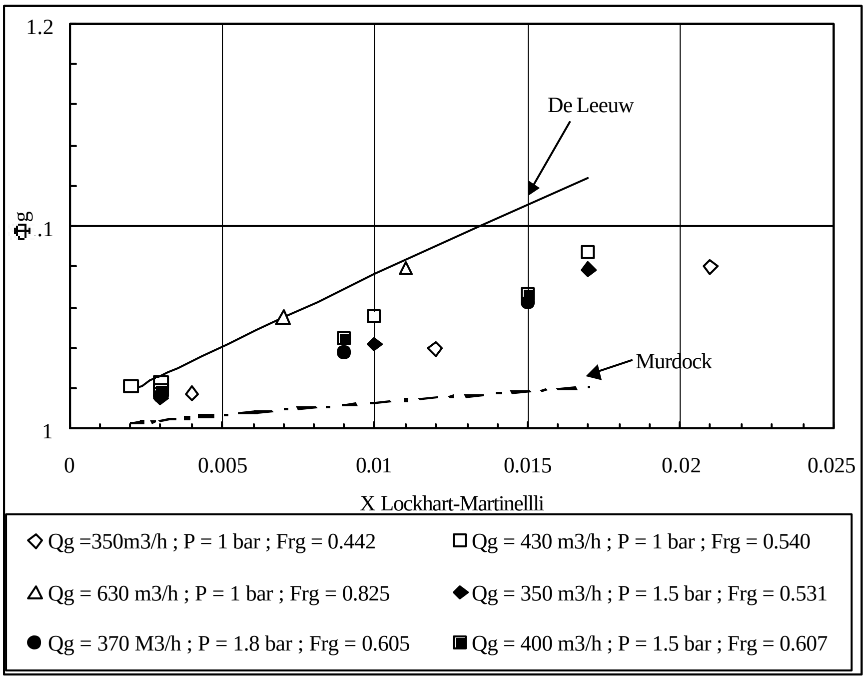


Figure 5 : Evolution of the ?g factor with the Lockhart Martinelli parameter

- **Sensitivity to droplets size and Stoke number**

Venturi over reading has been found sensitive to droplet size and Stoke number at a given liquid content.

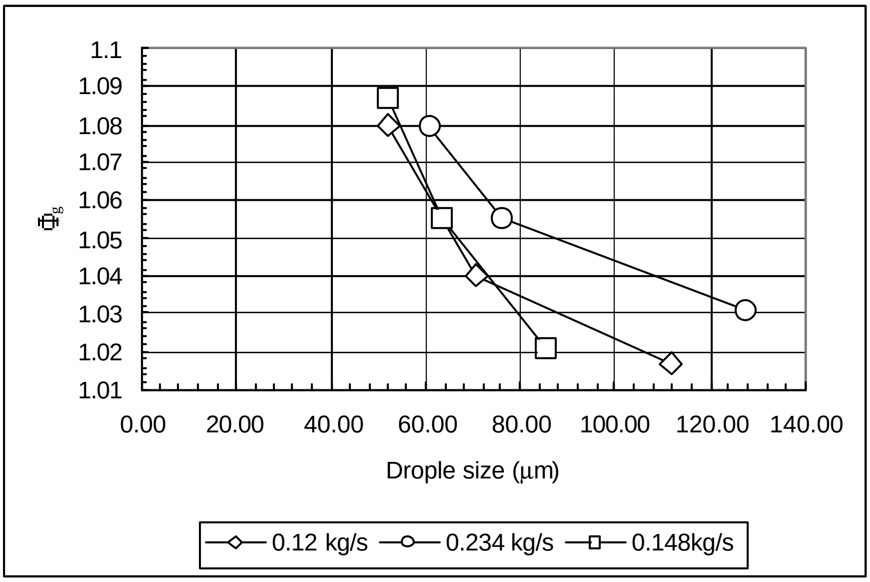


Figure 6 : Influence of the droplet size on the ?g factor for different gas mass flow rates

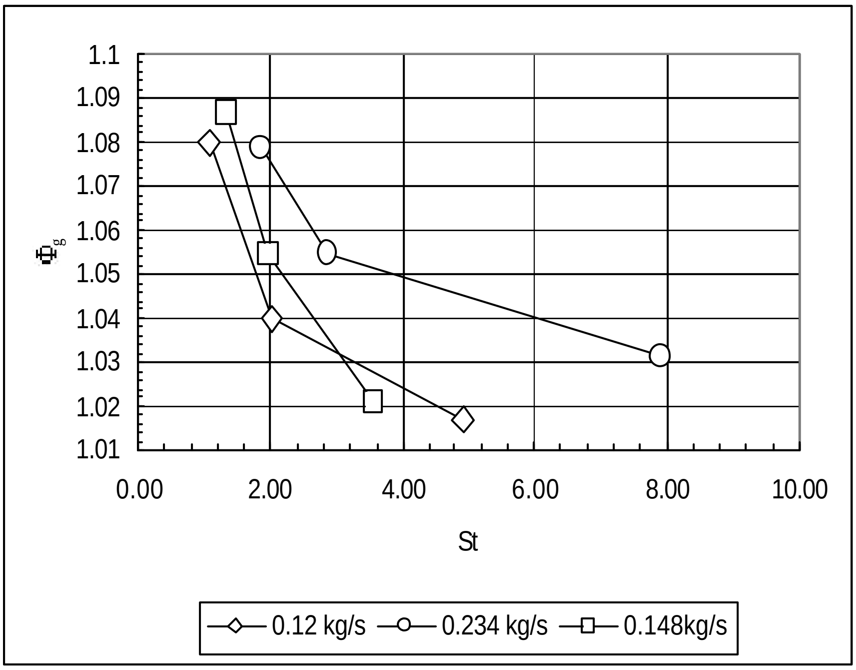


Figure 7 - Influence of the Stokes number on correction factor

- **Venturi Modelling in a Two Phase Flow**

For two phase flow measurements with differential devices, we have identified 4parameters which can be used to describe or modelise the Venturi behaviour in two phases flows. The first two are already used, the two others are new.

- **The first one is the mass fraction of liquid in the gas *x* defined as follows :**

$$x = \frac{Q_{mg}}{Q_{mTotal}}$$

- The second one is the Lockhart-Martinelli factor *X* which takes into account the density ratio between gas and liquid It appears in an explicit form in the different correlation of the literature and is defined as follows :

$$X = \frac{1-x}{x}\sqrt{\frac{r_g}{r_l}}$$

- A third one is related to the size of the droplets and the slip between droplets and gas. These two parameters are combined in an non dimensional number, the Stoke number (St). It is defined as the ratio between two characteristic times, the first t_d for the liquid phase and the second for the gas phase t_g.

$St = \frac{t_d}{t_g}$ where, $t_d = \frac{r_l d^2}{18 \cdot m_g}$ represents the response time of the droplets which have a diameter equal to *d* and $t_g = \frac{D}{U_o}$ the time need for a gas parcel for flowing through one pipe diameter.

If the Stoke number is much greater than 1, the droplets will not follow the gas phase accelerations or deceleration. At the other hand, for Stoke numbers much smaller than one, the droplet will ever follow the gas velocity variations.

- In the case of annular/disperse flow, an another parameter which will play a role in the flow metering is the amount of liquid phase which flows in the form of droplet with respect to the overall liquid flowrate. This repartition of the liquid phase can be characterised by a factor *f* defined as follows :

$$f = 1 - \frac{Q_m(film)}{Q_m(total)}$$

Influence of f is not considered in this paper.

9 HIGH PRESSURE VENTURI METERS TESTS

Tests of wet gas multiphase flow meter in conditions as close as possible of actual wellhead flowing conditions (pressure, flow-rate, liquid content, temperature) are planned on Venturi systems to collect data and to evaluate at pressures up to 240 bar a the behaviour of Venturi flow meters .

The test would be done both in dry gas and in three-phase flow conditions (Gas, Condensate and Water). Optionally , methanol will be added to the water phase.

10 IMPROVEMENT OF WET GAS METERS BASED ON VENTURI

From these first flow characterisations coupled with ΔP measurements, we can see that the correlation factors are affected, not only by the fraction of liquid in the gas, but also by the flow regime. To improve these measurements different strategies can be proposed. The first one consists in identifying the main parameters and trying to measure them in situ. The second strategy will be to impose a known two phase flow at the inlet of the Venturi meter by the use of a conditioner. At this time, the two solutions need research. For the first, the identification of the main parameters can be performed from basic and detailed experiments linked with flow simulations and high pressure tests . This work is being progressed in collaboration between TotalFinaElf, Gaz de France and ONERA. Furthermore, it is also necessary to improved the characterisation of the two phase flow in situ. New tools must be developed. Concerning the second strategy, it is necessary to developed new flow conditioners adapted to the two phase flow. Again, this work will need detailed experiments, flow simulations and validation tests.

11 CONCLUSIONS

Wet gas multiphase metering is still in its beginning or early stages. More and more applications have been identified for cost effective solutions for reservoir monitoring, gas & condensate allocation and there is definitely a need for reliable wet gas meters or wet gas multiphase meters.

Applications will be both on topside but also subsea with high water depths.

The gap between what has been called wet gas metering in the past and multiphase will be reduced for higher efficiency and better answer from manufacturer to user.

Venturi meters are and will be one of the alternative for gas and total flowrate measurements , some work has been started to improve their accuracy in two phases flows but a number of things still remain to be done.

For instance, work carried out by TotalFinaElf and Gaz de France has demonstrated that flow pattern or flow morphology has a big influence on accuracy and on correction to use. Some flow parameters for Venturi modelling have been identified.

Available results will allow to specify parameters to measure or to control these parameters through installation and to define models to apply to Venturi.

Additionally, there is and there will be a need for accurate liquid content and water cut measurements.

12 REFERENCES

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13 ACKNOWLEDGEMENTS

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