Comparative Analysis of different transactional gas metering systems used by Sonatrach and its partners

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Abstract

Since their first appearance, the gas metering systems have not ceased to progress. This evolution is principally used to resolve the issues in the gas industry particularly when the metering is intended to make the business transaction between two different partners which exactly is the case of the state Algerian company of oil and gas (Sonatrach) with its associates (the Foreign oil and gas companies). Therefore, the national company has launched a study to choose the right device regarding the transactional marketing standards. Indeed, several national organizations have been involved, such as the ONML (National Office of Legal Metrology) and the customs services. For different reasons like the fields weather conditions, the oil quality and different partner's nationalities it is not easy to choose one gas metering system which is very suitable. Sonatrach and its partners produce hydrocarbons using different types of gas meters as the orifice flow meter; turbine flow meter and ultrasonic flow meter. The nature of the product, the measured flow, the wanted measurement precision, the installation conditions are considered as the parameters that help us to choose a suitable gas metering system to make the right transaction marketing for Sonatrach and its partners in Algeria. Another way, the wide range of operating conditions over the period of oil wells combined with the dynamic three-phase flow cross section make it hard for one single technology to solve this problem. A multi-technology solution combined with smart data analytics is an option has being explored for providing reliable multiphase flow rates to the operator.

Keywords: gas, metering system; transactional; Sonatrach; multiphase flow.

1 Introduction

Transporting an industrial gas in pipes and measuring its flow are common operations of production and marketing done by Sonatrach and its partners. There exist different types of industrial gases which are corrosive or erosive and its nature can be changed by a matter of composition or parameters (temperature, pressure or velocity), therefore measuring an exact quantity of gas by flowmeter become so challenging [1].

A flowmeter is a device used for measuring or monitoring volumetric or mass flow rates of liquids and/or gas while they are transported through a pipe. Various flow meters exist in the commercial market today for both single phase and multiphase flow applications [2]. A single phase meter is used when the transport pipe is known to carry only one phase, either liquid or gas, whereas a multiphase flow meter is used when multiple phases, like liquid and gas or different gas are simultaneously transported through the pipe.

2 Different gas metering systems used by Sonatrach

There are different makers of metering system like; DANIEL, MECI, and KHRONE…etc. Each type of them has different technologies used according to the nature of flow (high flow, low flow…,). However, the most used gas flow meters at Sonatrach and its partners to make transactional deal of different types of gas are:

- Orifice flow meter ;
- Turbine flow meter ;
- Ultrasonic flow meter.

2.1 Orifice gas flow metering system

The running principle is based on a static disrupter system consisting of a throttle or orifice causing a pressure drop whose value is a function of the flow rate and thermodynamic properties of the gas to be measured (Figure 1) [4].

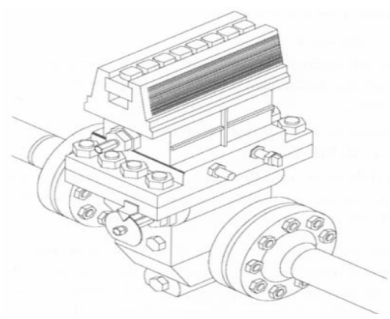


Figure 1 : Orifice gas flow meter [4].

Theoretically, the mass flow Q_m measured by the orifice flow meter is obtained by the following equation [7]:

$$Q_m = \frac{c}{\sqrt{1-\beta^4}} \cdot \varepsilon \cdot \frac{\pi}{4} \cdot d^2 \cdot \sqrt{2 \cdot DP \cdot \rho} \quad (1)$$

being c the coefficient of discharge; d is the internal orifice diameter; β is the diameter ratio of orifice to pipe diameter and finally ε is the expansibility factor, also called expansion factor [7].

2.2 Turbine gas flow metering system

The operation principle is based on turbine rotation speed inside this device, where a free axis of rotation carries a turbine spiral for gas that is placed in the middle of the pipe where the flow should be measured. Under the action of pressure forces on blades, the propeller of the turbine starts rotating with a speed that depends on the flowrate ω [5].

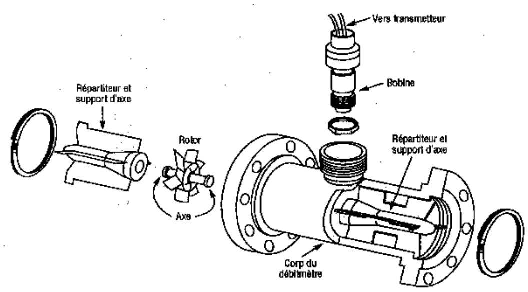


Figure 2: Description of the turbine gas flow meter [4].

The equation that can calculate the flow of gas in this flowmeter is for the ideal case:

$$Q = \frac{r \cdot S \cdot \omega_i}{\tan \beta} \quad (2)$$

Where β is the angle between the flow direction and the turbine blades and r is the root mean square of the inner and outer radii of the blades from the turbine axis (parallel to flow), ω_i is the ideal angular velocity and *S* is the flow area [8].

2.3 Ultrasonic gas flow metering

The working principle is based on the use of acoustic waves to measure the flow velocity. A transmitter issues ultrasonic wave through the gas to be measured on a receiver placed diametrically opposite to the transmitter (Figure 3).

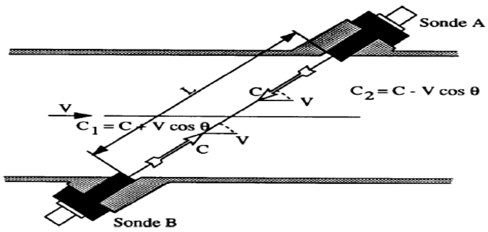


Figure 3: Ultrasonic gas flow meter [4].

The equation which calculates the flow of gas in the ultrasonic gas flow meter is:

$$Q = \frac{\pi D^2}{4} \cdot \frac{L^2}{2d} \cdot \frac{\Delta T}{T_{AB} \cdot T_{BA}} \cdot \frac{1}{K_H} \quad (3)$$

Where D is pipe diameter, L is the distance between the emitter and the receiver; $d=L.\cos\theta$ and K_H a calibration constant. T_{AB}, T_{BA} are the sound transit times, AB and BA respectively and ΔT is the difference between both transit times [8].

3 Modeling and simulation of gas flow metering systems considering operational conditions

For our studies, we will consider a specific gas from a field in the south of Algeria with operational conditions and we will test all the technologies seen above.

3.1 Orifice gas flow meter

The aim of this simulation is the calculation of the mass flow for the gas regarding the variation of pressure drop. Therefore, we used pressure loss values (DP) from 0.2 bars to 0.9 bars. Figure 4 displays the simulation results.

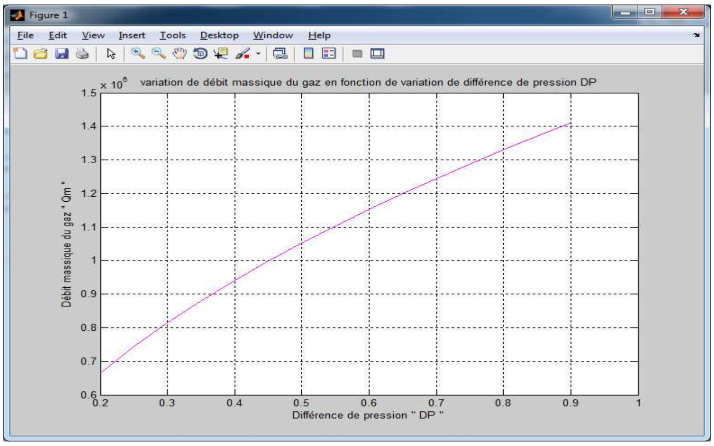


Figure 4: Simulation Results of pressure drop versus flow measurement using an orifice system.

From the result, we observe that the mass flow "Qm" varies proportionally with the pressure drop "DP".

3.2 Turbine gas flow meter

We simulate the volumetric flow of natural gas according to the pipe diameter D. Indeed, this simulation is to vary the value of driving diameter to get the mass flow rates which corresponds to different values of the pipe nominal diameter. Using the operational conditions, we obtain the simulation results here under:

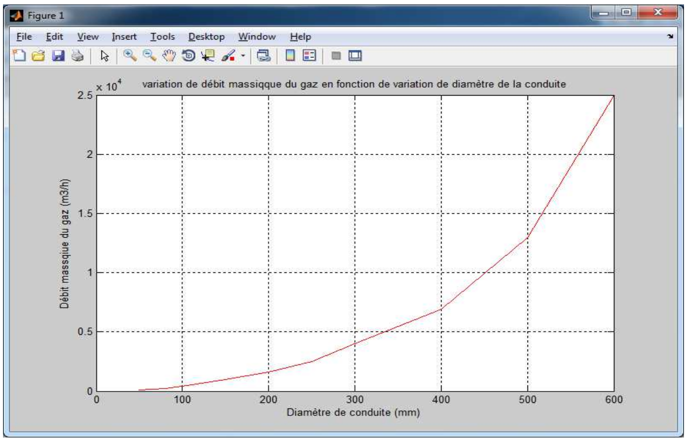


Figure 5: The mass flow rate versus the pipe diameter.

From our simulation results, we see that the mass flow rate increases with the increase of the pipe diameter. That means, the pipe diameter has an evident impact on the flow measurement. Consequently, the variation of the flow measurement is related directly to the turbine rotation speed inside the pipe and its diameter.

a. Ultrasonic gas flow meter

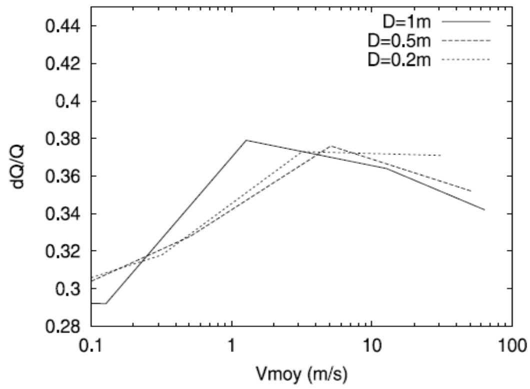


Figure 6: Relative uncertainty of flow measurement (dQ/ Q) versus average gas velocity (Vmean).

It is seen from the graph above that the shape of the curve goes up and it downs up, reflecting the uncertainty created by the flow calculation increases relative to the average gas velocity. The main factor which has a big impact on the flow of gas in industry generally and the case of Sonatrach especially, it's the precision of measurement by using one type between different flow meters because it is considered as the first device which is installed in the field to measure the gas flow in the pipe. Therefore, we have to take care of different coefficients involved with this device, so the pressure difference inside the pipe is considered as the principal coefficient which changes the measurement precision of the flow especially in the case of gas because of its compressibility.

4 Multiphase Flow Metering Techniques

4.1 Density Measurement

In principle, the density of a fluid flowing in a horizontal pipe could be determined directly from the weight of a section of the pipe. It may be possible to measure the weight of fluid in a horizontal section of the pipe by using the elasticity of the pipe as a spring balance and measuring the deflection.

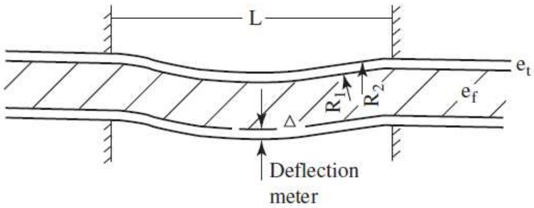


Figure 7: Principle of the weighing of pipe measurement [6].

The figure (7) shows a horizontal pipe of radii R1 and R2 and a length L supported rigidly at its ends. Under the combined weight of the pipe and its fluid contents, Δ is the deflection at the centre of the span that is given by:

$$\Delta = \frac{1}{384}\frac{WL^3}{EI} \qquad (4)$$

Where E is the modulus of elasticity of the pipe material, N/m^2; I is the moment of inertia, m^4:

$$I = \frac{\pi}{2}(R_2^4 - R_1^4) \qquad (5)$$

The total weight is given by:

$$W = \left\{\pi(R_2^2 - R_1^2)\rho_p g + \pi R_1^2 \rho_f g\right\}(L.N) \qquad (6)$$

Where ρ_p is the density of pipe material [kg/m^3] and ρ_f the density of fluid, [kg/m^3].

$$\Delta = \frac{1}{384}\frac{\{\pi(R_2^2 - R_1^4)\rho_p g + \pi R_1^2 \rho_f g\}L^4}{1/2E(R_2^4 - R_1^4)} \ (m) \qquad (7)$$

4.2 Velocity Measurement

4.2.1 Turbine flow meters

Turbine flow meters are frequently used in the measurement of single-phase flow rates. In principle, the turbine meter operates simply as a hydraulic turbine. It is essentially a device, which rotates as the fluid flows through the turbine blades; the rotational speed of the blades is related to the volumetric flow rate.

a) Equations

In a single-phase flow, the mass flux G is related to the speed of rotation of the turbine meter n and the fluid density ρ in the following way:

$$kv_T = kn\rho \qquad (8)$$

In the volumetric model, k is assumed to be a constant over a wide range of Reynold's numbers. The product $n*\rho$ is often designated as the turbine velocity v_T. There are several models describing the turbine velocity, v_T in a two phase flow.

The volumetric flux or superficial velocity *j=Q/S* is the rate of volumetric flow divided by the pipe area and can be expressed as:

$$j = \alpha \upsilon_G + (1-\alpha)\upsilon_L$$

$$\upsilon_T = \alpha \upsilon_G + (1-\alpha)\upsilon_L \tag{9}$$

If Eq. (8) is to be used in a two-phase flow, the density ρ must be replaced by an equivalent two phase density. For the volumetric model, the homogeneous mixture density ρ_h is used:

$$\rho_h = \left(\frac{x}{\rho_G} + \frac{1-x}{\rho_L}\right) \tag{10}$$

Where x is the quality. The solution is of the form:

$$\frac{d}{dt}(\upsilon_L) = A(t)\upsilon_L - B(t)\upsilon_L - C(t)\upsilon_L.|\upsilon_L| + D(t) \tag{11}$$

Where A(t), B(t), C(t) and D(t) are complicated functions of fluid properties, time (t), rotor inertia and flow meter geometry and flow distribution. Eq. (11) can be integrated numerically for υ_L and the two-phase mass flux can be obtained from:

$$G = \rho_L(1-\alpha)\upsilon_L + \rho_V \alpha s \upsilon_L \tag{12}$$

Where G is the mass flux, ρ_L, ρ_V the liquid and vapour (gas) densities, respectively, α the cross sectional area void fraction and s the slip ratio.

b) Acoustic cross-correlation

Acoustic cross-correlation is a technique for determining the velocity of flow in a pipe by measuring the temporal fluctuations in the transmission of two axially spaced ultrasonic beams. It is based on the assumption that the fluctuations in the signals are caused by gas bubbles and turbulent eddies which travel down the pipe at the same velocity as the fluid. The signal at the downstream sensor at time t is therefore related to the signal at the upstream sensor recorded at an earlier time, $t - \tau_m$, where τ_m is the time taken for the fluid to traverse the distance, L, between the beams. The aim is to calculate τ_m and hence the velocity:

$$V = \frac{\mathrm{L}}{\tau_\mathrm{m}} \tag{13}$$

The mathematical procedure for calculating τ_m from the recorded fluctuating signals is called cross-correlation, described later.

The mathematical procedure used to determine the mean transit time of the fluid between the two acoustic beams, τ_m, is to calculate the cross-correlation function for the two signals. If y(t) is the downstream signal at time t and x(t-τ) the upstream signal at an earlier time t-τ, then the cross-correlation function is:

$$R_{xy} = \lim_{T\to\infty} \frac{1}{T} \int_0^T x(t-\tau) y(t) dt \quad (14)$$

This integral has a maximum value when $\tau = \tau_m$. The procedure is to vary t and find which value gives a maximum forR_{xy}. Having found τ_m by this means, the fluid velocity is given by:

$$V = \frac{L}{\tau_m} \quad (15)$$

L is the distance between the two beams.

4.2.2 Momentum Flux Measurement

a) Orifice flow meter

Various theoretical models have been proposed for the pressure drop of two-phase flow through an orifice. The models for two-phase flow encompass both incompressible flow, where the pressure drop across the orifice is small in relation to the total pressure, and compressible flow, where the pressure drop is large. As one would expect, the analysis of compressible flow is more complex.

Two-phase flow models are generally subdivided into two categories: homogeneous flow models and non-homogeneous (or separated) flow models.

As an example, the model of Chisholm in [6] will be used in what follows. This states that the ratio of the pressure drop for a mixture of gas and liquid, ΔP_{tp}, to the pressure drop if the liquid component alone were flowing, ΔP_L, is given by (Lockart-Marinelli correlation):

$$\frac{\Delta P_{tp}}{\Delta P_L} = 1 + \frac{C}{X} + \frac{1}{X^2} \quad (16)$$

Where X is defined as:

$$X = \left(\frac{\Delta P_L}{\Delta P_G}\right) = \frac{\dot{M}_L}{\dot{M}_G} (\frac{\rho_G}{\rho_L})^{1/2} \quad (17)$$

Where ΔP_G is the pressure drop if the gas component alone were flowing, and $\dot{M}_L$ is the liquid mass flow rate; $\dot{M}_G$ is the gas mass flow rate; ρ_L the liquid density; ρ_G the gas density.

The parameter C is dependent upon the slip ratio, s (s = velocity of gas/ velocity of liquid), that is:

$$C = \frac{1}{s} (\frac{\rho_L}{\rho_G})^{1/2} + s((\frac{\rho_G}{\rho_L})^{1/2} \quad (18)$$

In effect, C or s has to be determined by calibration under representative conditions.

a) Variable area orifice

The variable area orifice has an additional moving component which alters the area of the restriction, and hence the value of K, in such a way that the effective calibration produces a pressure drop proportional to velocity, not velocity squared, that is:

$$\Delta p \propto V \tag{19}$$

This effect is produced by having a moving core which penetrates a circular orifice plate and which can move axially in response to pressure acting against a spring. The main advantage of the variable area orifice is its linear characteristic and increased range, that is, it has as higher a turn down ratio than the standard orifice meter.

$$Q = AC_dC_a\sqrt{\frac{2\Delta p}{\rho}} \Rightarrow K_v = AC_dC_a\sqrt{\frac{2}{\rho_w}} \tag{20}$$

Where A is the total flow area, Ca the opening coefficient relating the flow area fraction and the valve opening, ρ the fluid density and ρ_w the water density.

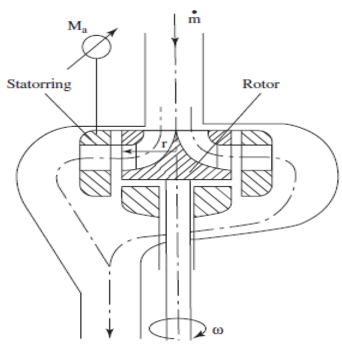
4.2.3 Momentum Flux Measurement

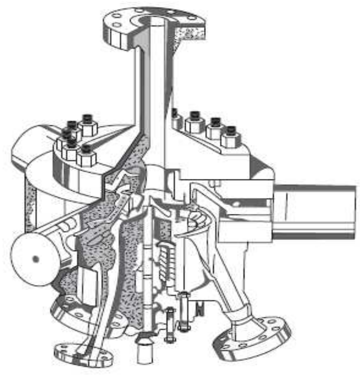
a) True mass flow meter

In principle, the true mass flow meter (TMFM) is a radial circulation pump. It consists of a rotor with an axial inlet and radial outlet, and a radial stator.

The two-phase fluid leaves the rotor, which is rotating at a constant angular velocity, with a defined swirl. In the stator the swirl is reduced to zero, producing a torque which can be related to the mass flow.

Figure 8 (a) gives a schematic view of the instrument and figure 8 (b) a perspective view of TMFM developed by Kernforschungszentrum Karlsruhe (KFK). The stator is suspended on three radials arranged bending springs. The elastic deformation of the springs is measured by strain.





(a) (b)

Figure 8: Schematic view of the TMFM [6].

A modified form of Euler's pump formula in the form determines the mass flow rate:

$$\dot{m} = \frac{KM_a}{r^2\omega} \quad (21)$$

Where Ma is the torque measured at the stator, r the radius of the rotor, ω the angular velocity and K a calibration factor.
The measuring principle is independent of the density and density distribution of the two-phase or multiphase flow because the fluid leaves the rotor at a uniform angular velocity. The rotor and stator are designed and manufactured with many narrow channels in them to guarantee an exact radial output flow direction of fluid direction under any operating condition. If the rotor diameter and angle of velocity are known, the torque on the stator, M_a is the only measured value. The calibration constant K takes into account any fluid leakage between the rotor and stator and small deviations of the fluid direction at the outlet [6].

5 Conclusion

The nature of the gas which is produced and transported, the type of the flow which is measured, the wanted measurement precision, the conditions of installation and of service are considered as the parameters which help us to choose a suitable gas metering system to make suitable transaction marketing for Sonatrach and its partners in Algeria.

With the technology development, the multiphase flow metering system progress systemically with the gas flow metering systems. This improvement helps evidently petroleum companies to resolve their needs in order to make a good transactional marketing of gas and liquids using the same device.

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