Comparative study between the use of standards and contractual conditions in the metering of natural gas orifice flow meter

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Résumé

The present study has for essential purpose, the evaluation of the difference between the use of the standard (1atm, 15°C) and contractual (1bar, 15°C) conditions by referring to existing standards in the field of the gas metering, in this particular case standard ISO 6976 for the calculation of the Heating Value, the Density and the Wobbe index as well as standard ISO 5167 for the measure of the flow of the fluids by means of orifice plate devices. The study in question, based itself on the measure of flow by means of the orifice plate flow meter as well as the measure of the energy delivered by the same quantity, the obtained results allowed to define the advantages and the inconveniences of the use of the contractual and standard reference conditions implemented in the metering systems.

I- Introduction

Determination of the quantities of gas in metering skid appeal at the same time the direct measure of parameters (pressure, temperature, density, composition) and the calculations realized from algebraic expressions which bring in characteristic values of the gas [1].

In the transactional metering of the natural gas, we estimate the quantities delivered to the customers by their energy value, while the flows are generally expressed in volume on reference conditions. The choice of the latter echoes directly on the calculation of the quantity and the quality of the product, and consequently, on the energy balance of the quantities transported.

II-Determination of the quantity

For the measure of the quantity of the gas, we shall use a flange taps orifice plate flow meter, The metering skid, the measure and the calculation of the quantity of the gas are designed according to the standard ISO 5167-2003.

II-1-Calculation of the flow by orifice plate

La The measure of the flow of the gas involves a physical coupling between a measuring instrument and an observed phenomenon, in the case of orifice plate flow meters, this coupling is realized by perturbing the flow by a leaky plate of a circular opening centered on the axis of the conduct, to create a value function of the mass flow which is measurable industrially. The intensity of the disturbance is characterized by the differential pressure between the upstream and the downstream of the diaphragm, and it depends of [2]:

- Geometrical characteristics of the system;
- Thermodynamic values, pressure, temperature, density of the gas;
- The mass flow;
- The profile of speed in the upstream of the disruptive element.

The differential pressure and the first two points above are measurable values; the third point is the looked value.

The influence of the fourth point being very difficult to quantify, we try to control it. For that purpose, whatever is the installation, the objective will be to have at the level of the diaphragm an established turbulent profile of speed [2].

Whatever is the pressure differential device used, the practical formula of calculation of the flow is the following one [3]:

$$q_m = \frac{C}{\sqrt{1-\beta^4}} \varepsilon \frac{\pi}{4} d^2 \sqrt{2\Delta p \rho} \qquad (1)$$

The flow rate in volume in the reference conditions is calculated from the following equation:

$$q_v = \frac{q_m}{\rho} \qquad (2)$$

Where:
ρ is the density of the gas in the operating conditions.

From the equation (1), we deduct that the flow rate depends on the Discharge Coefficient C, the ratio of orifice diameter to pipe diameter ß, the Coefficient of relaxation e, the diameter of the hole, the differential pressure ΔP and the density ρ.

III-Determination of the Quality

The chemical composition of the gas is determined by chromatography.
On the basis of the normalized composition of the natural gas, the calorific value, the density and the relative density are calculated according to ISO 6976 standard.
The calculation of the compressibility factor is calculated according to the standards MGERG 88, AGA8 either ISO 6976.

III-1-Determination of the Compression Factor

It is the ratio of the real volume of a defined mass of gas, in a specified temperature and under a specified pressure, in its volume in the same conditions, calculated from the ideal gas law.

The formula used in ISO 6976 standard, for the calculation of the Compressibility factor of a gas mixture in the reference conditions is [4]:

$$Z_{mix}(t_2, p_2) = 1 - \left[\sum_{i=1}^{n} X_i \cdot \sqrt{b_i} \right]^2 \qquad (3)$$

Where:

X_i : Mole Fraction of component i ;
b_i : Summation Factors;
n : Number of gas components.

Table 1 gives the compressibility factor of principal gas constituents, according to ISO 6976 standard [4]:

Components	Compression Factor 1 ,01325 bar		Summation factor b	
	273,15	*288,15*	*273,15*	*288,15*
He	*1,005*	*1,005*	*0,0006*	*0,0002*
N2	*0,9995*	*0,9997*	*0,0224*	*0,0173*
CO2	*0,9933*	*0,9944*	*0,0819*	*0,0748*
C1	*0,9976*	*0,9980*	*0,049*	*0.0447*
C2	*0,9900*	*0,9915*	*0,100*	*0,0922*
C3	*0,9789*	*0,9821*	*0,1453*	*0,1338*
i-C4	*0,958*	*0,968*	*0,2049*	*0,1789*
n-C4	*0,9572*	*0,965*	*0,2069*	*0,1871*
i-C5	*0,937*	*0,955*	*0,2510*	*0,2280*
n-C5	*0,918*	*0,937*	*0,2864*	*0,2510*
C6+	*0,892*	*0,913*	*0,3286*	*0,2950*

Table 1. Compression Factor for natural gas Components

III-2-Heat Value Determination

It is the quantity of heat that would be released by the complete combustion of a specified quantity of gas in the air, of a way such as the pressure p_1 in which the reaction takes place remains constant and such as all the products of the combustion are returned to the same specified temperature t_1, such as that of bodies in reaction, all these products being in the gaseous state, except the water formed during the combustion, which is returned to the liquid state in the temperature t_1 [4].

Superior Calorific Value of the ideal gas on a volumetric basis for a temperature of combustion t_1, of a mixture of known composition measured in a temperature t_2 and under a pressure p_2 is calculated from the equation (4) [4]:

$$\tilde{H}°[(t_1), V(t_2, p_2)] = \sum_{i=1}^{n} X_i \cdot \tilde{H}°_i [t_1, V(t_2, p_2)] \qquad (4)$$

Where :

$\tilde{H}°_i[t_1, V(t_2, p_2)]$: is the Ideal Calorific Value on a volumetric basis of component i (either Superior or Inferior).

The real-gas calorific value on a volumetric basis, for a combustion temperature t_1, of a mixture of known composition, metered at a temperature t_2 and pressure p_2, is calculated from the equation (5) [4] :

$$\tilde{H}_{mix}[(t_1), V(t_2, p_2)] = \frac{\tilde{H}°_{mix}[t_1, (t_2, p_2)]}{Z_{mix}(t_2, p_2)} \qquad (5)$$

Where :

$\tilde{H}_{mix}[(t_1), V(t_2, p_2)]$: The real-gas Calorific Value on a volumetric basis of component i (either Superior or Inferior). ;
$Z_{mix}(t_2, p_2)$: is the compression factor at the metering reference conditions.

Table 2 gives the Superior Calorific values for eleven used components, in both conditions, standard and contractual.

Components	Superior Calorific Value (Kcal/Sm3)	Superior Calorific Value (Kcal/Cm3)
He	/	/
N2	/	/
CO2	/	/
C1	8912	9005,92
C2	15746	15781,54
C3	22688	22437,18
i-C4	29303	28995,89
n-C4	29745	29089,04
i-C5	37145	35674,02
n-C5	37496	35745,67
C6+	45217	42407,08

Table 2. Superior calorific values for the natural gas components

III-3- Determination of the Density

It is the mass of a sample of gas divided by its volume in specified conditions of pressure and temperature [4].

The density of the ideal gas depends upon its temperature t and pressure p, and is calculated from equation (6) [4]:

$$\rho°(t,p) = \left(\frac{p}{R.T}\right) \sum_{i=1}^{n} X_i.M_i \qquad (6)$$

Where :

R : (= 8,314510 J.mol^{-1}.K^{-1}) molar gas constant;
T : Absolute Temperature, in Kelvins ;
X_i : Mole Fraction of component i ;
M_i : Molar Mass of components i ;
n : Number of gas components.

Density of the real-gas is calculated from equation (7) [4]:

$$\rho(t,p) = \frac{\rho°(t,p)}{Z_{mix}(t,p)} \qquad (7)$$

$\rho°(t,p)$: The Density of the ideal gas ;
$Z_{mix}(t,p)$: Compression Factor of the gas mixture.

Table 3 gives densities for eleven used components, in both conditions, standard and contractual.

Components	Density (Kg/Sm3)	Density (Kg/Cm3)
He	0,1698	0,1671
N2	1,1852	1,1696
CO2	1,8703	1,8475
C1	0,6796	0,6709
C2	1,2813	1,2657
C3	1,8940	1,8742
i-C4	2,5049	2,5003
n-C4	2,5242	2,5111
i-C5	3,1695	3,1760
n-C5	3,1777	3,1918
C6+	3,8590	3,9097

Table 3. Densities for the natural gas components

III-4- Determination of the Relative Density

It is the quotient of the density of a gas by the density of the dry air of standard composition in the same specified conditions of pressure and temperature [4].

The term of ideal relative density applies when the gas and the air are considered as fluids which obey the law of ideal gases; the term of real relative density applies when the air and the gas are considered as real fluids [4].

The relative density of the ideal gas is independent of any reference state, and is calculated from the equation (8) [4]:

$$d° = \sum_{i=1}^{n} X_i . \frac{M_i}{M_{Air}} \qquad (8)$$

Where :

$d°$: is the relative Density of the ideal gas ;
M_i : Molar Mass of components i ;
M_{Air} : Molar Mass of the dry air of standard composition.

The relative density of the real gas is calculated from the equation (9) [4]:

$$d(t,p) = \frac{d°.Z_{Air}(t,p)}{Z_{mix}(t,p)} \qquad (9)$$

Where :

$d°(t,p)$: is the relative Density of the ideal gas ;

$Z_{mix}(t,p)$: Compression Factor of the gas ;
$Z_{Air}(t,p)$: Compression Factor of the dry air of standard composition.

III-5- Determination of delivered Energy

The supplied energy is the product of the Calorific value and the flow crossing the pipe:

$$E = \widetilde{H}^0_{S\,mix}[(t_1), V(t_2, p_2)].q_v \qquad (10)$$

IV- Calculation Example

In our study case, we used Hassi R'mel gas, located about 580 Km south of Algiers, which is transported by pipeline to the north.

The gas metering station contains six (06) streams of 16" Sch XS.

Each stream makes cross a maximum flow rate of 369400 Sm³/h.

The minimal operating pressure and the maximal operating temperature are respectively:

P_{min} (barg)	70
T_{max} (°C)	55

IV-1- Calculation of Superior Calorific Value, Density, Relative Density and Compression Factor

Table 3 gives normalized composition of the used gas mixture:

Normalized Composition

Components	% Molar
He	0.18
N2	5,6100
CO2	0,2300
C1	82,6000
C2	7,6000
C3	2,3100
i-C4	0,3500
n-C4	0,6500
i-C5	0,1500
n-C5	0,1800
C6+	0,3200
Total	100

Table 4. Normalized Composition of natural gas mixture

The diverse physical properties of the natural gas mixture are calculated as follows:

The molar mass, the isentropic exponent and viscosity of the previous gas mixture are respectively: $M = 19,323$, $k(Cp/Cv) = 1,306$ and $v = 0,014$.

The compression factor of the gas mixture, calculated in accordance with ISO 6976 standard is : $Z_{mél}(1atm,15°C) = 0,99732$.

In accordance with equation (1) and using the table 3, the calculation of the Superior calorific value gives the following results:

$\widetilde{H}_{mix}$	9726,62	Kcal / Sm³
	9645,91	Kcal / Cm³

We note that the Superior Calorific Value, calculated at standard conditions is higher than that calculated at contractual conditions.

The calculation of the density at reference conditions, according to equations (6) and (7) gives the following results:

ρ	0,8194	Kg / Sm³
	0,8105	Kg / Cm³

Density at flow conditions is equal to $\rho(t,p) = 56,063$ Kg/m³.

In accordance with equations (8) and (9), the relative density is $d(t,p) = 0,6687$.

IV-2- Calculation of maximum flow rate

The parameters needed for calculating the stream's maximum flow rate are summarized in the following table:

Maximum Differential Pressure (mbar)	500
Stream Internal Diameter(mm)	381
Maximum Operating Temperature(°C)	55
Minimum Operating Pressure (bar g)	70
Isentropic Exponent	1,306
Density (Kg/m3)	56,0063
Viscosity (cP)	0,014
Orifice Diameter (mm)	258
Diameter ratio	0,677

The volumetric flow calculation is made according to equation (1), and gives the following:

$q_{v\text{-}max}$	369467,0475	Sm^3 / h
	374388,3120	Cm^3 / h

The volumetric flow rate calculated at the contractual conditions is greater than that calculated at standard conditions.

If we calculate the flow rate crossing the metering station, we obtain:

$q_{v\text{-}max}$	2216802,285	Sm^3 / h
	2246329,872	Cm^3 / h

We can deduce the maximum flow rate for a year, with an operating cycle of 330 days:

$q_{v\text{-}max}$	19419188017	$Sm^3 / year$
	19677849679	$Cm^3 / year$

Using the values obtained from the Superior Calorific Value and maximum flow rates, for a period of one year, we obtain the energy delivered to customers, according to equation (10):

E (1atm, 15°C)	749,49	MMBTU / year
E (1bar, 15°C)	753,17	MMBTU / year

The calculation gives a gain 3,681,131.29 MBTU / year using contractual conditions, which equates to 25,767,919.03 $ / year, with a price of 7 $/MBTU.

V- Conclusion :

In view of the above findings, we note that the Gross Calorific Value, calculated at standard conditions is higher than that calculated with the contractual conditions.
Also, the volumetric flow rate calculated with the contractual conditions is greater than that calculated under standard conditions.
We conclude that the use of contractual conditions (1bar, 15°C) makes a profit in the transactions with customers.

VI- References :

[1] Comité des Techniciens « Commercialisation des gaz naturels – Spécifications et Comptage », Chambre syndicale de la recherche et de la production du pétrole et du gaz naturel - 1990.

[2] Claude Doerflinger « Mesure des débits de gaz par voludéprimomètre à diaphragme », Association Technique de l'industrie du gaz en France, Juillet 1990.

[3] ISO 5167 « Measurement of fluid flow by means of pressure differential devices inserted in circular-cross section conduits running full », Second Edition – March 2003.

[4] ISO 6976 « Natural Gas – Calculation of calorific values, density, relative density and Wobbe index from composition », Second Edition 1995.