Flow and energy quantification impacts using a method out of recommended interval for determining physicochemical properties of the Gas.

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Abstract

The present study pretends to highlight the influence of physicochemical parameters such as compressibility and heat power in the volume and energy quantification, considering cases when the variable (Z) is calculated from a method outside the intervals (composition) recommended for its application (Gross method), for the study of this presented case, the flow conditions have a compressibility factor of 0.89928 with the Gross 1 method and 0.90702 with the Detailed method, these values have an influence on the determination of the adjusted heat value (ratio heat value and compressibility), obtaining a real net heat value of 39,150 MJ/m^3 @ Z (Gross 1) and 38,816 MJ/m^3 @ Z (Detail).

It is possible to analyze how compressibility directly influences the flow determination, which can be considered when there's changes in the composition aand the necessary controls are not analyzed or established to monitor if changes are required in the models used in the computer flow.

The study of this type of errors that the measurement systems area of CIATEQ A.C. has been able to detect over the years, in different projects of advice or support to the industry, allow to determine the impact that these represent and the economic losses that can be suppose one of the cases mentioned here.

1. Introduction.

The challenges in the natural gas measurement that is transported through pipes include the compression of the fluid at a different pressure and temperature values. The interest of compensation for the compressibility factor (z) in the natural gas measurement is derived from the volume and energy calculations that can be reported [1].

The electronic measurement system used for this study is composed of an ultrasonic flow meter, pressure element, temperature and a flow computer that also receives the online composition of a C9 chromatograph. The computer is configured with latest version of the equations of the AGA Report 7[2] and with the AGA Report 8 model for the calculation of compressibility by the Gross method or Gross 1.

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[1] KEVIN CLARK. (2015). COMPENSATING FOR COMPRESSIBILITY IN MEASURING GAS FLOW. 2018, de FLOW CONTROL Sitio web: https://www.flowcontrolnetwork.com/compensating-for-compressibility-in-measuring-gas-flow/
[2] A. G. Association, *AGA Report No 7, Measurement of Natural Gas by Turbine Meters,* 2006.

2. Impact of the Compressibility Factor.

this analysis considered two of the three methods established in the AGA Report No. 8 (Detailed, Gross 1)[3], an estimated composition (table 1) is used for possible values that can be found in the measurement systems evaluations, where the approximate location is reserved, owners and / or suppliers because of the subject of confidentiality to the contracts with CIATEQ A.C.

Table 1. Natural gas compositions used for the analysis.

Component	%mol
CH_4	83.101
C_2H_6	3.47
C_3H_8	3.427
n-C_4H_{10}	0.934
i-C_4H_{10}	0.242
n-C_5H_{12}	0.223
i-C_5H_{12}	0.464
C_6H_{14}	0.157
C_7H_{16}	0.008
C_8H_{18}	0.002
C_9H_{20}	0.001
CO_2	0.156
N	7.815

The composition indicated in table 1, meets the acceptance criteria of resolution RES / 596/2014 that updates the intervals indicated in the Mexican standard NOM-001-SECRE-2010[4], so it could be used in industrial processes in Mexico, allowing the analysis of how important is the knowledge of the intervals indicated at the international standards without demote the national ones and indicate the possible errors that are incurred.

The AGA report 8, recommends the use of the gross method (1 and 2) for conditions from 0 ° C to 55 ° C (32 ° F to 131 ° F) and up to 8.3 MPa (1203.81 PSI), also the compositions at normal range indicated in table 1 of AGA report. According to these established parameters is observed that the Butane proportion (C4H10) and pentane (C5H12) exceeds the limits of the Normal Interval (table 1 of the AGA Report 8), which establishes a limit of 1% of butanes and 0.3% pentanes of the total mixture; In addition, according to the AGA 8 report in its section 1.5.2 for the uncertainty of the Gross method, is established that "the equation is not designed and should not be used outside these limits".

For this reason, it was analysis the difference between a "recommended" method (detailed) and one outside the parameters recommended by that standard (Gross 1) at different temperature and pressure conditions, to show the impact on the volume measure. The results of the analysis are shown in figure 1.

[3] A. G. Association, *AGA Report No 8, Compressibility Factors of Natural Gas and Other Related Hydrocarbon Gases,* 1994.
[4] C. R. d. Energía, *NORMA Oficial Mexicana NOM-001-SECRE-2010, Especificaciones del gas natural (cancela y sustituye a la NOM-001-SECRE-2003, Calidad del gas natural y la NOM-EM-002-SECRE-2009, Calidad del gas natural durante el periodo de emergencia severa),* México: DIARIO OFICIAL, 2010.

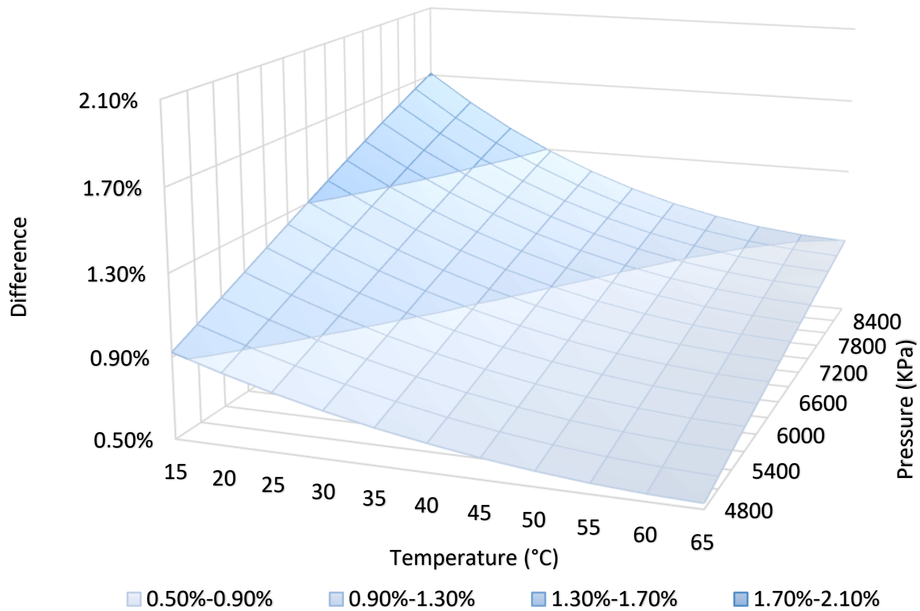

Fig. 1. Method Gross 1 difference

Figure 1 shows how the difference increases as the pressure increases and decreases as the temperature increases, however, the minimum values have a difference above 0.5%, which is a significant value if we consider that the range of the detailed method on this conditions is 0.1%.

The flow data used for the analysis are:

• Temperature: 24.70 ° C (24.7)
• Pressure: 5.1647 MPa (749.07 PSI)
• Uncorrected volume: 33130.71 m3 / d (1.17 MMCF / D)
• Base temperature: 20 ° C (68 ° F)
• Base pressure: 101,325 KPa (14,696 PSI)

The obtained compressibility results under these conditions are:

Tabla 2. Compressibility Factors

Method	Compressibility Factor Z (dimensionless) @flow	Compressibility Factor Z (dimensionless) @base
Gross 1	0.89928	0.99782
Detail	0.90702	0.99798

The difference on the Gross 1 method (outside the recommended composition parameters) respect to the detailed method is 0.85% at flow conditions; using both factors for volume correction for base conditions using the AGA Report 7 equation, the volumetric flow is obtained:

$$Q_B = Q_f\left(\frac{P_f}{P_b}\right)\left(\frac{T_b}{T_f}\right)\left(\frac{Z_b}{Z_f}\right)$$

Table 3. Results of Volumetric Flow quantification.

Z Method	Volumetric Flow m^3/D (MMSCF/D)
Gross 1	1.8797 X10^6 (66.3817)
Detail	1.8639 X10^6 (65.8258)

As a result, the difference in volumetric flow is 0.844%, which means that the difference of the determination of compressibility influences on the base conditions correction. Analyzing these results according to those obtained for this composition in Figure 1, a system with pressures greater than 7.8MPa could reach deviations of the order of 1.7%

3. Heat Value

Natural gas is a high-value fuel whose use has been widespread in the industry, in transportation systems, thanks to its friendliness with the environment and the advantages that represents for those who use it, however, what happens when the gas is not treated in the right way?, for example, when it is treated as an ideal or real gas, or the physicochemical properties are determined wrongly, what is the influence it has on the flow measurement?

In the case of determination of the volumetric calorific value, when this is calculated as ideal or real, between both values there will be a variation, which will be reflected in multiple aspects.

Based on evaluations made at multiples gas measurement points, two patterns of errors constantly appears which, even though they may seem little relevant, could have long term repercussions in aspects such as energy or monetary quantification.

The first case of study is attributed to the concept of an ideal or real gas, sometimes it is excluded that gas measurement points are operated at high pressure and temperature conditions and as a consequence of this behavior it differs from an ideal gas.

Currently in Mexico regulations on the measurement of hydrocarbons and standards such as NOM-001-SECRE-2010 [NOM 001], suggest using the equations of ISO 6976 [5] for the measure of heat value. Table 4 shows the equations proposed in ISO 6976.

Table 4. Heat Value equations ISO 6976

Ideal Gas Gross Heat Value	Real Gas Gross Heat Value
$(H_v)^\circ_G\ (t_1; t_2, p_2) = \dfrac{(H_c)^\circ_G(t_1)}{V^\circ}$ $V^\circ = R.T_2/p_2$	$(H_v)_G\ (t_1; t_2, p_2) = \dfrac{(H_c)^\circ_G(t_1)}{V^\circ}$ $V^\circ = Z(p_2, t_2).R.T_2/p_2$
Ideal Gas Net Heat Value	**Real Gas Net Heat Value**
$(H_v)^\circ_N\ (t_1; t_2, p_2) = \dfrac{(H_c)^\circ_N(t_1)}{V^\circ}$ $V^\circ = R.T_2/p_2$	$(H_v)_N\ (t_1; t_2, p_2) = \dfrac{(H_c)^\circ_N(t_1)}{V^\circ}$ $V^\circ = Z(p_2, t_2).R.T_2/p_2$

Donde:

$(H_v)^\circ_G\ (t_1; t_2, p_2)$ is the ideal-gas gross volume-basic calorific value of the mixture.
$(H_v)_G\ (t_1; t_2, p_2)$ is the real-gas gross volume-basic calorific value of the mixture.

[5] I. STANDARD, *ISO 6976-1995, Natural Gas - Calculation of calorific values, density, relativy density and Wobbe index from composition,* ISO INTERNATIONAL STANDARD, 1995.

$(H_v)^{\circ}_{N}\ (t_1; t_2, p_2)$ is the ideal-gas net volume-basic calorific value of the mixture.
$(H_v)_N\ (t_1; t_2, p_2)$ is the real-gas net volume-basic calorific value of the mixture.
$(H_c)^{\circ}_{G}(t_1)$ is the ideal-gas gross molar-basic calorific value of the mixture.
$(H_c)^{\circ}_{N}(t_1)$ is the real-gas net molar-basic calorific value of the mixture.
$V^{\circ} = R.T_2/p_2$ is the ideal molar volume of the mixture.
T_2 is the absolute temperature.
$Z(p_2, t_2)$ is the compression factor.

The equations of ISO 6976 are proposed to obtain the heat value of an ideal or real gas, this warns that, for any volumetric heat value, a correction of the real gas is required, which considers the difference of the real gas by the ideal volume, this correction cannot be treated as insignificant, this correction is made through the compressibility factor (Z), then examples related to Z and its effect on the heat value are presented; It should be notice that the compressibility determined by means of the models established in the AGA Report 8 (previously analyzed) were used in order to observe the impact they have not only on the determination of volumetric flow but also the impact on the determination of the Energy.

Table 5 and Figure 2 show the differences of the ideal heat value respect to the real value by correcting the ideal quality of the gases, for example, the difference between the ideal gross heat value with respect to the actual gross is of 4,358 MJ/m^3 using the compressibility obtained by the gross 1 method (Table 2), using the result by the detailed compressibility method, the difference is 3,943 MJ/m^3.

Table 5. Ideal and Real Gas Heat Value with different method of Z (Gross and detail method).

Compressibility Method (Z)	**Calorific value**	**Ideal MJ/m^3**	**Real MJ/m^3**	**Difference (Hv) Ideal & Real MJ/m^3**
(Gross 1)	(Hv) Gross	38.911	43.269	4.358
	(Hv) Net	35.207	39.150	3.989
(Detail)	(Hv) Gross	38.911	42.900	3.943
	(Hv) Net	35.207	38.816	3.609
Compressibility Method (Z)	**Calorific value**	**Ideal $BTU_{(IT)}/ft^3$**	**Real $BTU_{(IT)}/ft^3$**	**Difference (Hv) Ideal & Real $BTU_{(IT)}/ft^3$**
(Gross 1)	(Hv) Gross	1044.343	1161.310	116.967
	(Hv) Net	944.920	1050.752	107.057
(Detail)	(Hv) Gross	1044.343	1151.400	105.832
	(Hv) Net	944.920	1041.785	96.865

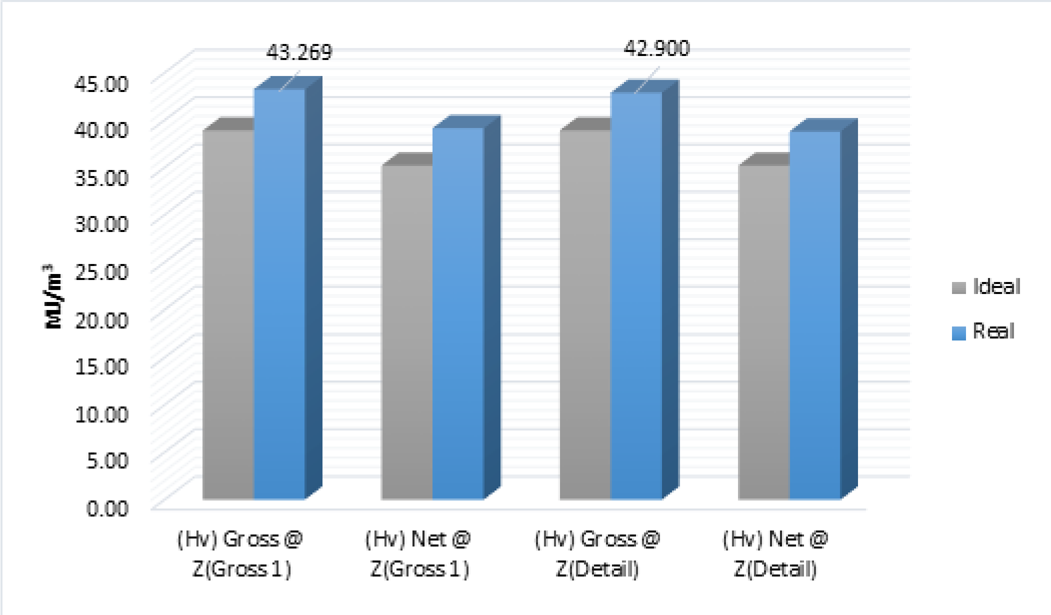

Fig. 2. Real and ideal gas Heat Value Difference.

Otherwise, Table 6 shows the differences comparison of the real heat value gross and net calculated by the two compressibility methods, in the case of the gross heat value the difference is 0.369 which is equivalent to a difference of 0.86 %, similar to the difference of the net heat value calculated from the two compressibility methods.

Table 6. Differences in the heat value by Z (Gross) & Z (Detail)

Real Heat Value	**(Hv) Real MJ/m^3**	**Difference Z (Gross) & Z (Detail) MJ/m^3**
(Hv) Gross @ Z (Gross method)	43.269	0.369
(Hv) Gross @ Z (Detail method)	42.900	
(Hv) Net @ Z (Gross method)	39.150	0.334
(Hv) Net @ Z (Detail method)	38.816	
(Hv)	**(Hv) Real** BTU$_{(IT)}$/ft^3	**Difference Z (Gross) & Z (Detail)** BTU$_{(IT)}$/ft^3
Gross @ Z (Gross method)	1161.310	9.910
Gross @ Z (Detail method)	1050.752	
Net @ Z (Gross method)	1151.400	8.967
Net @ Z (Detail method)	1041.785	

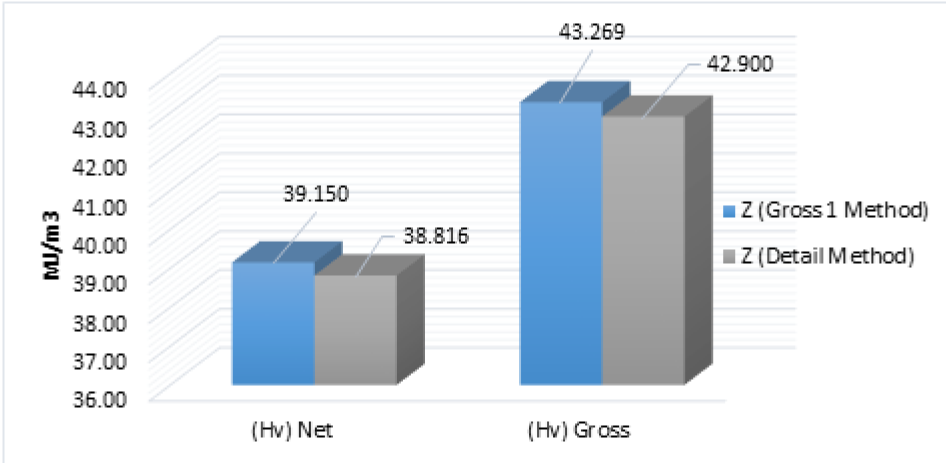

Fig. 3. Difference of the real heat value by Z effect (Gross and detail method).

The results shown above could be considered irrelevant, but if these values are transferred to economic aspects, these small differences could represent a disagreement between who provides and who receives the natural gas. This can be observed in the following analysis.

If, for example, following the whole process, the energy is estimated with the AGA 5 equation [6] from the volume calculated in table 3 and the actual gross heat value indicated in table 5, it is notice as the differences between the real and ideal methods they become representative with values of 8,192 X106 MJ / Day (with Z per method gross 1) and 7,435 X106 MJ / Day (with Z by Detailed method).

$$Energy = (Volume\ @P_{base}, T_{base}).(Volumetric\ Heat\ Value\ @P_{base}, T_{base})$$

Table 7. Comparison of energy using the value heat Ideal to real

	MJ/m^3	**Volume m^3/Day**	**Daily Energy MJ/Día**	**Difference Ideal & real MJ/Día**
$(H_v)^{\circ}_{G\ Ideal}$	38.911	1879721.470	73.14 X10^6	8.192 X10^6
$(H_v)_{G\ Real\ @\ Z\ (Gross\ method)}$	43.269		81.33 X10^6	
$(H_v)^{\circ}_{G\ Ideal}$	38.911	1863979.822	72.53 X10^6	7.435 X10^6
$(H_v)_{G\ Real\ @\ Z\ (Detail\ method)}$	42.900		79.96 X10^6	
	BTU/ft^3	**Volume MMSCFD**	**Daily Energy MMBTU$_{(IT)}$ /Día**	**Difference Ideal & real MMBTU$_{(IT)}$ /Día**
$(H_v)^{\circ}_{G\ Ideal}$	1044.343	66.38174	69.33 X10^3	7.76 X10^3
$(H_v)_{G\ Real\ @\ Z\ (Gross\ method)}$	1161.310		77.09 X10^3	
$(H_v)^{\circ}_{G\ Ideal}$	1044.343	65.82583	68.74 X10^3	7.05 X10^3
$(H_v)_{G\ Real\ @\ Z\ (Detail\ method)}$	1151.400		75.79 X10^3	

Finally, following the initial analysis, the comparison of the actual heat value obtained by means of the compressibility by the two methods made in this analysis (gross 1 and detailed), considering that one of them was implement outside the parameters of

[6] A. G. Association, *AGA Report No 5 Natural Gas Energy Measurement,* 2009.

composition recommended by the standard AGA report 8, the results show a difference of 1.369 X106 MJ / Day which represents a 1.71% difference between the two calculations, which is expected, given that the compressibility contributes a 0.85% difference to the calculated volume and 0.86% at the heat value.

Table 8. Comparison of the energy calculated using the heat value real calculated by the two compressibility methods.

	Daily Energy MJ/Día	**Difference MJ/Día**
$(H_v)_{G\ @\ Z\ (Gross\ method)}$	8.133E+07	1.369 X10^6
$(H_v)_{G\ @\ Z\ (Detail\ method)}$	7.996E+07	
	Daily Energy $MMBTU_{(IT)}$/Día	**Difference $MMBTU_{(IT)}$/Día**
$(H_v)_{G\ @\ Z\ (Gross\ method)}$	7.709E+04	1.30 X10^3
$(H_v)_{G\ @\ Z\ (Detail\ method)}$	7.579E+04	

4. Conclusions

According to the theoretical analysis applied, using a value of the compressibility factor outside the intervals recommended by the standards, can lead to a series of differences that, although they may seem minor, in the long term, represent a significant value that affects the results of the volumetric flow measurements, related physicochemical properties and energy, which transferred to economic aspects may represent disagreements between the distributor and its customers.

It should be notice that the results correspond only to the composition analyzed and that this type of result could be, cases that could be prevented with an adequate control and monitoring of the physicochemical properties of the natural gas used in the industry.

5. References.

[1] K. CLARK, "FLOW CONTROL," 14 january 2015. [Online]. Available: https://www.flowcontrolnetwork.com/compensating-for-compressibility-in-measuring-gas-flow/. [Accessed 2018].

[2] A. G. Association, *AGA Report No 7, Measurement of Natural Gas by Turbine Meters,* 2006.

[3] A. G. Association, *AGA Report No 8, Compressibility Factors of Natural Gas and Other Related Hydrocarbon Gases,* 1994.

[4] C. R. d. Energía, *NORMA Oficial Mexicana NOM-001-SECRE-2010, Especificaciones del gas natural (cancela y sustituye a la NOM-001-SECRE-2003, Calidad del gas natural y la NOM-EM-002-SECRE-2009, Calidad del gas natural durante el periodo de emergencia severa),* México: DIARIO OFICIAL, 2010.

[5] . STANDARD, *ISO 6976-1995, Natural Gas - Calculation of calorific values, density, relativy density and Wobbe index from composition,* ISO INTERNATIONAL STANDARD, 1995. A. G.

[6] IAssociation, *AGA Report No 5 Natural Gas Energy Measurement,* 2009.