Correction of Gas Humidity Flow in a Natural Gases Drying Plant

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A mathematical correlation has been established in order to find out the water content present in natural gases. It is based on the most modern approaches of this field upgraded with new correlations which enable a sensible approach between the physical and the mathematical pattern. This correlation has caused the determination of the natural gas flow rate correction coefficient. This coefficient, at his turn, is calculated due to the water vapours presence and it is also checked due to the real measurements in an experimental pilot unit especially designed for the industrial drying gases plant by using molecular sieves.

Keywords: humidity, gas mixture, drying plant, correction factor

Finding out the water content in the natural gases mixture is an actual issue of a paramount importance for dimensioning units and plants that work by using gases hydrocarbon mixtures with vapour water content. Also for designing the gas well equipment and the surface equipment for gas collecting, for designing of the compressor station units and of the gases drying plant, for the correction of natural gases yields in the oil and gas industry.

A complex correlation in order to determine the water vapour content in the natural gases is described [2]. Taking into account the information and data established there, a correction of the calculated gas volume coefficient has been estimated in the presence of the water in the measurement fluid.

The correlation is based on the most modern approaches in the field, approaches that are up-graded with new correlation which are able to establish a sensible approach between the physical and the mathematical pattern.

The aim of present paper is to check the result and the calculus precision due to the correlation usage in determining the water vapour content in the natural gases mixtures.

The calculated results have been compared with the experimental values recorded in the pilot unit of natural gases drying industrial plant [6].

Experimental part

In order the find out the water vapour condense point (water dew point) of the natural gases and of their humidity for both all the inlet and outlet commercial points between the gas industrial producers and their delivery and for others points of the gas shipping and delivering, we normally use Cermax IS hygrometers [3, 6, 11]. This hygrometer works on the principle of water vapour adsorption in porous non-conductive layer, situated between two conductive layers (ceramics sensor of capacitive kind). The water vapours enter in the sensor's dielectric and modify the sensor's capacity due to water content adsorption of the gases.

The gas dryer process in the experimental pilot unit

The undergone experiments in the pilot unit have been designed to follow two procedures:

- there have been measured, in first procedure, the absolute humidity or the water content in the natural gases and the dew point temperature in the drying plant inlet or, respectively, drying plant outlet in the point of gases delivery-receipt to the gases transport company [6, 9];
- during the second procedure, the gases drying plant has been by-passed, the absolute humidity and dew point temperature have been measured in the same point where the first measurements of firs procedure have already been accomplished.

There have been simultaneously sampled five measurements for each procedure in order to increase the calculus accuracy. The second procedures task was to check the measured values of the absolute humidity and of the dew point in the different points regarded in the place and the distance within the gases drying plant.

The calculus method

A mathematical correlation based on correlation has been used by J. M. Campbell [3] taking into consideration the water vapour content due the gas hydrocarbons mixture and the presence of other gases (carbon dioxide and/or hydrogen sulphide). It was added a correction factor due to the mineralized degree of the water vapours and due to the saturation pressure of the water vapours in the gases, as follows [6]:

$$U_s = \left(U_{sH} \cdot y_H + U_{sCO2} \cdot y_{CO2} + U_{sH2S} \cdot y_{H2S}\right) \cdot f_{sal} \qquad (1)$$

where U_s represents the absolute humidity or the saturation humidity of the natural gases mixture (hydrocarbons, gas impurities, mineralized water vapours); U_{sH} – water vapour content retained by gaseous hydrocarbons; U_{sCO2}, U_{sH2S} – water vapour content retained by carbon dioxide or by hydrogen sulphide; y_H, y_{CO2}, y_{H2S} – the molar fraction of the gaseous hydrocarbons, carbon dioxide and hydrogen sulphide respectively; f_{sal} – the correction factor due to the water vapour salinity.

The water vapour content retained by the gaseous hydrocarbons was calculated in the following formula [1, 6]:

$$U_{sH} = \frac{D}{p} + G \qquad (2)$$

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where p represents the static pressure of the gases mixture in the measurement point (bar).

The D and G variables are calculated with the following formulae:

$$D = p_a^t \cdot \frac{p_{st} \cdot g \cdot M_a}{Z_{st}^{ag} \cdot R \cdot T_{st}} \tag{3}$$

$$G = 10^{-\frac{3083,86}{1,8 \cdot T} + 6,6945} \tag{4}$$

where:

p_a^t - water vapour pressure at the mixture gases temperature in the measurement point (Pa);

M_a - molar mass of the water (kg/kmol);

g - gravitational acceleration (m/s^2);

R - universal constant of gases (J/kmol K);

T - gas mixture temperature in the measurement point (K);

p_{st}, T_{st} are the standard pressure and temperature condition (p_{st} = 1 bar, T_{st} = 288.7 K).

The compressibility factor of the wet gases for standard condition Z_{st}^{ag} ,, is determined by using the formula [5]:

$$Z_{st}^{ag} = \frac{p_{st} - p_a^t}{p_{st}} \cdot Z_{st}^{g} + \frac{p_a^t}{p_{st}} \cdot Z_{st}^{a} \tag{5}$$

where:

Z_{st}^{g} - compressibility factor of the dry gas ;

Z_{st}^{a} - compressibility factor of the water vapour.

In order to determine the saturation pressure of the water vapours in gases due to the system temperature, the proposed correlation in this paper is of a polynomial type:

$$p_a^t = a + b \cdot t + c \cdot t^2 + d \cdot t^3 + e \cdot t^4 + f \cdot t^5 \tag{6}$$

where:

t is temperature of the gases mixture in the measurement point (°C);

the $a..f$ constants have got the following values: a=612.78; b=43.527; c=1.4999; d=0.0247; e=0.0003; f=0.000003.

CO_2 and H_2S influence upon the water vapours in the gases mixture U_{sCO2} and U_{sH2S} is graphically determined by using the J.M. Campbell diagrams [2], represented in figures 1 and 2.

As one easily notice, in number (1) formula, the water vapour content in this study is correlated with a correction factor due to the water salinity that got the following cubic equation:

$$f_{sal} = a + b \cdot S + c \cdot S^2 + d \cdot S^3 \tag{7}$$

where :

S – the water salinity (g/L);

$a..d$ - constants have the following values: a=1.000; b = - 0.0023923719; c=1.9253922·10^{-5}; d=- 3.3755886·10^{-7}.

Due the fact that, practically speaking, the natural gases aren't perfectly dried, not even after performing a drying process the determined value for U_s will be correlated with the following formula:

$$U_{sc} = U_s - U_{ad} \tag{8}$$

where:

U_{sc} is the corrected value of the water vapour content in natural gases;

U_{ad} – the admissible gas humidity allowed in the transport gas pipes imposed by American Technical Norms and Regulations, is of 0,118 g water/ Nm^3 gas.

The Romanian standards do not stipulate the same correction, but they enforce the dew point temperature of the natural gases below -15°C during the commercial transactions.

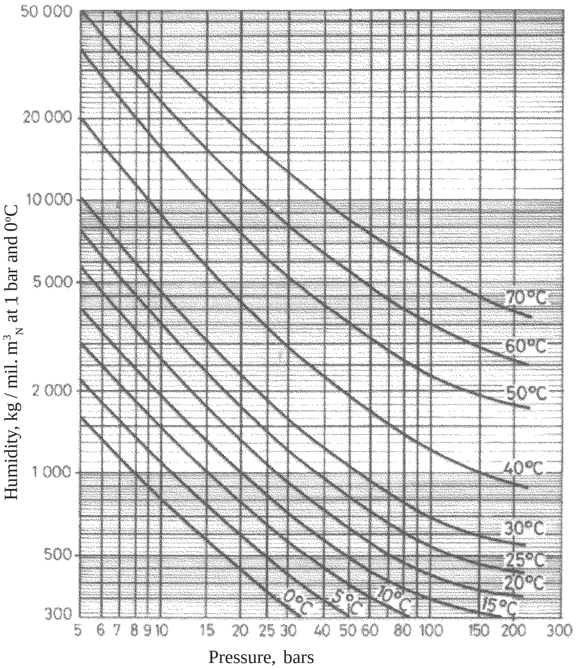

Fig. 1.Carbon dioxide influence upon the vapour content of the natural gases

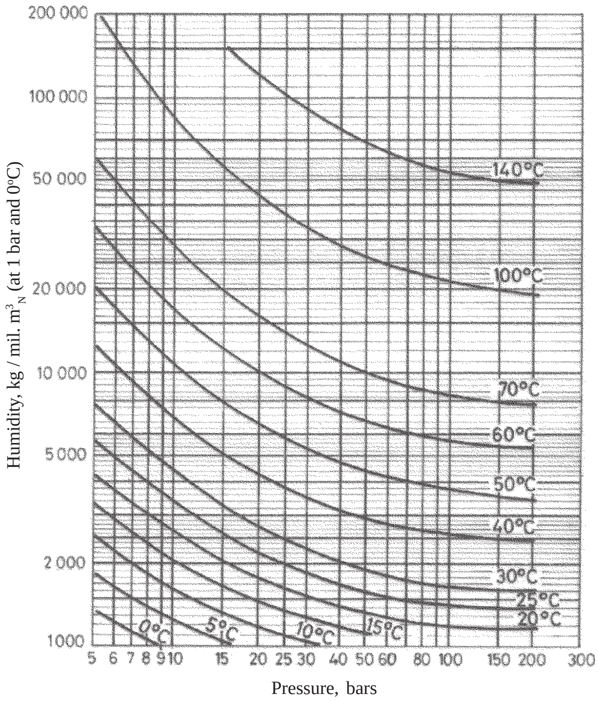

Fig. 2.Hydrogen sulphide influence upon the vapour content of the natural gases

The suggested factor proposed here in order to correct the dry gas flow rate calculated in the presence of the water vapour is described in the following formula:

- for the standard pressure and temperature conditions, U_{sS}, in kg/m^3:

$$U_{sS} = U_s \tag{9}$$

$$f_c = 1 - \frac{R \cdot T_S}{M_a \cdot p_S} \cdot U_{sS} \tag{10}$$

or

$$f_c = 1 - c_{dS} \cdot U_{sS}\,, \tag{11}$$

where the dimensional constant c_{ds} = 1.31246 m^3/kg (gas/ water)

Table 1
MEASURED AND CALCULATED PARAMETERS OF THE DRYING GASES PLANT
FOR VARIANT NUMBER I

Number of recordings			1	2	3	4	5
Wet gases inlet	p -barg		33.69	33.7	33.69	33.68	33.68
	T - °C		14.64	14.69	14.73	14.74	14.84
	Δp - mm col. H_2O		1923.68	1938	1921.03	1932.5	1922.96
	Q_i - m^3/zi		827860	832560	831290	832700	831610
	Measured	T_R - °C	15,3				
		U_{am} - g/ Nm^3	U_{am}=0.43 f_c=0.99947	$U_{acD\text{-}G}$ = 0.530 $f_{cD\text{-}G}$= 0.99934			
	Calculated	U_{ac} - g / Nm^3	0.513	0.515	0.516	0.516	0.520
		fcc	0.99936	0.99936	0.99936	0.99936	0.99935
Dry gases outlet	p -barg		33.14	33.15	33.14	33.14	33.14
	T - °C		15.01	14.65	14.51	15.04	14.69
	Δp - mm col. H_2O		1971.5	1984.9	2001	1998.8	1998.7
	Q_i - m^3/zi		832670	835500	833570	833800	835200
	Measured	T_R - °C	-30.9				
		U_{am} - g/ Nm^3	U_{am} = 0.01 f_{cm} =0.99999				
	Calculated	U_{ac} - g/ Nm^3	0.016				
		fcc	0.99998				

Table 2
MEASURED AND CALCULATED PARAMETERS OF THE DRYING GASES PLANT
FOR VARIANT NUMBER II

Number of recordings			1	2	3	4	5
Wet gases inlet	p -barg		33.47	33.46	33.48	33.47	33.47
	T - °C		15.19	15.22	15.25	15.24	15.22
	Δp - mm col. H_2O		2007.34	1978.48	1968.27	1974.71	1951.06
	Q_i - m^3/zi		838160	835610	833670	833520	831860
	Measured	T_R - °C	14.3				
		U_{am} - g/ Nm^3	U_{am}=0.43 f_c=0.99947	$U_{acD\text{-}G}$ = 0.499 $f_{cD\text{-}G}$= 0.99938			
	Calculated	U_{ac} - g/ Nm^3	0.533	0.534	0.535	0.535	0.534
		fcc	0.99934	0.99934	0.99933	0.99933	0.99934
Wet gases outlet	p -barg		33.25	33.26	33.28	33.26	33.28
	T - °C		14.45	14.5	14.5	14.97	14.52
	Δp - mm col. H_2O		2026	1995	1979	2000	1981
	Q_i - m^3/zi		841680	838360	839870	836450	835380
	Measured	T_R - °C	14.3				
		U_{am} - g/ Nm^3	U_{am}=0.43 f_c=0.99947	$U_{acD\text{-}G}$ = 0.499 $f_{cD\text{-}G}$= 0.99938			
	Calculated	U_{ac} - g/ Nm^3	0.513	0.514	0.514	0.529	0.514
		fcc	0.99936	0.99936	0.99936	0.99934	0.99936

-for the normal pressure and temperature conditions U_{sN}, in kg/Nm^3:

$$U_{sN} = U_s \cdot \frac{T_S}{T_0} \tag{12}$$

$$f_c = 1 - c_{dN} \cdot U_{sN}\,, \tag{13}$$

and the dimensional constant c_{dN} = 1.24414 Nm^3/kg (gas/water)

In such a way, the corrected gas flow rate will be determined by using the formula:

$$Q_{corected} = fc \,.\, Q_{measured} \tag{14}$$

where the measured $Q_{measured}$ is wet gas flow rate measured in the receipt-delivery gases points.

Results and discussion

In tables 1 and 2 there is a comparison between the value got in the experimental measurements and those calculated by using those two procedures above mentioned [6].

The data analysis of tables 1 and 2 leads of the following considerations:

T_R dew point temperature and the absolute humidity of the wet gases flow U_{am} which feeds the drying plant have the following values:

- for the first version,
  T_R = 15.3°C and U_{am} = 0.43 g/m^3_N;
- for the second version,
  T_R = 14.3°C and U_{am} = 0.43 g/m^3_N.

One may notice that between these two experimental versions, the wet gases dew point temperature has varied only 1°C, which is an allowed difference in the dew point temperatures measurements, accomplished by using the Cermax hygrometer.

The high performance and accuracy of the measurement device for the dew point temperature and for the absolute humidity may be emphasized by the fact that is the second experimental version, the respective hygrometer has showed the same dew point temperature both for the wet gases inlet flow which has by-passed the drying plant (table 2).

The Gas Drying Plant using molecular sieves has allowed a high level of drying, the dew point temperature of the dry gases reaching a –30.9°C, and an absolute humidity of 0.01 water g/Nm^3 gases. So that, the gas drying plant using molecular sieves has depressed the gases dew point temperature from 15.3°C to – 30.9°C, and the absolute humidity had lowered from 0.43 water g/Nm^3 to 0.01 water g/Nm^2, which corresponds to gas drying degree equal to 97.67 %.

The undergone calculations due to the pilot unit measurements presented in tables 1 and 2 leads the following results:

-in the wet gases case, for the absolute humidity indicated by the hygrometer U_{am} = 0.43 g/Nm^3 to the dew point temperatures T_R = 15.3°C and respectively 14.3°C, the correction factor obtained with the proposed method is $f_{cD\text{-}G}$ = 0.99947;

-for the dew point temperature T_R = 15.3°C, the absolute humidity and the correction factor are $U_{acD\text{-}G}$ = 0.530 g/Nm^3 and $f_{cD\text{-}G}$=0.99934;

-for the dew point temperature T_R = 14.3°C, the absolute humidity and the correction factor are $U_{acD\text{-}G}$ =0.499 g/Nm^3 and $f_{cD\text{-}G}$ = 0.99938;

-in the dry gases case, for the absolute humidity indicated by hygrometer U_{am} = 0.01 g/Nm^3, to the dew point temperature T_R = -30.9 °C, result the correction factor value $f_{cD\text{-}G}$ = 0.99999;

-for the dew point temperature T_R = -30.9°C, the absolute humidity and the correction factor are $U_{acD\text{-}G}$ = 0.016 g/m^3_N and $f_{cD\text{-}G}$ = 0.99998.

Taking into consideration the differences we have got when measuring the gases flow rate with those two flow meters, these measurement gauges error (1% maximum) and taking into consideration the fact that the correction factors for wet gases have a tendency to reach one unit (for example $f_{CD\text{-}G}$=0.99934, which corresponds to a water vapours content in the gases equal to 0.066% volume), there results the undoubted fact that the presence of the water vapour in gases cannot be noticed by the measurement gauges of the gases flow rates during their transportation.

Conclusions

The results we have achieved by using different methods and correlations there are in the measurements results undergone in real conditions, show the fact that differences are recorded and these differences are sometime significant ones. That is why the applicability domain knowledge for each method and correlation ever has provided the possibility of reaching as accurate results as possible.

A correction factor which taking into consideration the presence of CO_2 and H_2S in natural gases, the salinity of water in gases phase and also a polynomial equation for saturated pressure calculation depending on temperature were used.

On this base correlation has been established a correction of gas flow rate calculated due to the water vapour presence in the measured fluid and also, checked due to the real measurements in the experimental pilot unit especially designed within a drying gases industrial plant using the adsorption on molecular sieves.

Notations

p - statistic pressure in the gases measurement point (barg);

Δp- differential pressure in the gases measurement point (mm coll. H_2O);

Q_c- instantaneous gas flow rate (m^3/day);

T_R- dew point temperature measured with the CERMAX hygrometer (°C).

U_{am} - absolute humidity of the gas mixture measured with the CERMAX hygrometer (g/Nm^3);

U_{ac} - absolute humidity of the natural gas mixture calculated by using the proposed method for the pressure and the temperature conditions in the measurement point (g/Nm^3);

$U_{acD\text{-}G}$ - absolute humidity of the natural gas mixture calculated by using the proposed method and due to the measured T_R dew point temperature (g/Nm^3);

f_c - correction factor calculated due to U_{am} the measured absolute humidity;

f_{cc} - correction factor calculated due to the U_{ac} measured absolute humidity in conformity with the pressure and temperature conditions in the measurement point;

$f_{cD\text{-}G}$ - correction factor calculated in conformity with $U_{acD\text{-}G}$ the measured absolute humidity.

References

1.BUKACEK, R.F., Research Bulletin 8, Institute of Gas Technology, Chicago, USA, 1955

2.CAMPBELL, J. M., Gas Conditioning and Processing, 3rd Edition, Campbell Petroleum Series, Norman, Oklahoma, 1974

3.DINU, F., Extracţia gazelor naturale, Editura Universităţii "Petrol-Gaze" Ploieşti, 2000

4.HOBINCĂ, L., Revista Română de Petrol, **5**, nr. 3, 1998, p. 42

5.MILLER, R. W., Flow Measurement Engineering Handbook, 3rd Ed., McGrow-Hill, Boston, 1996

6.SOARE, AL., STRĂTULĂ, C., DINU, F., GRIGORE, V., OPREA, F., Studiul influenţei umidităţii gazelor naturale asupra corectitudinii măsurării cantităţilor acestora la staţiile de predare – primire şi a promovării şi implementării metodelor de corecţie, Contract nr. 22/2002, partea a II-a, U.P.G. Ploieşti, 2004

7.STRĂTULĂ, C., Purificarea gazelor, Editura Ştiinţifică şi Enciclopedică, Bucureşti, 1984

8.PETRE, M., STRĂTULĂ, C., Rev. Chim. (Bucureşti), **57**, nr. 12, 2006, p. 1114

9.STRĂTULĂ, C., OPREA, F., Rev. Chim. (Bucureşti), **54**, nr. 12, 2003, p. 988

10.TRENT, R. E., Dehydration with Molecular Sieves, Laurence Reid Gas Conditionong Conference, Norman, OK, 2001

11.OELLRICH, L.R., ALTHAUS, K., Relationship Between Water Content and Water Dew Point Keeping in Consideration the Gas Composition in the Field of Natural Gas, GERG Technical Monograph TM 14, Fortschritt-Berichte VDI, nr. 679, 2002

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