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The Influence of Temperature upon the Precision of Measuring Fluid Flows

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Abstract

The paper tackles some issues regarding the influence of the temperature of fluids transported through pipelines, upon the precision of the measured flow using common devices. A case study has been made regarding this issue, at S.R.M. Arad 1, the results being shown in tabulate form.

Key words: *measuring, natural gases, fluid flow.*

Introduction

The study of temperature's influence upon the precision of measuring fluid flows in general, and especially of natural gases, is of great importance in the relation supplier – consumer in order to perform invoicing correctly.

This problem occurs especially during the cold periods when, in order to achieve the transportation conditions of natural gases and of viscous and/or congealable oil products, these must be warmed up.

As far as natural gases are concerned, the problem is highly important, because of the fact that in the flow adjustment and measuring installations there takes place a major cooling of the gases. That is the reason why, in order to avoid the occurrence of cryohydrates and the forming of cryohydrate plugs that may clog the flow section, the natural gases are warmed before entering the adjustment and measuring station for the quantities delivered to consumers.

Out of practical data, there has been noticed that natural gases are warmed before entering the adjustment and measuring station at temperatures between 8 ÷ 28 [^{o}C].

Measurement of Fluid Flows by Using Diaphragms

The procedure of measuring fluid flows with diaphragms (ISO 5167 – 1) is highly applicable in fluid transportation and, especially, in the transportation of natural gases by pipelines.

In case of using diaphragms, the flow is established based on the pressure difference between the upstream and downstream of the diaphragm, according to the thermo and hydrodynamic properties of the fluid and to the operating conditions of the diaphragm (the primary element. The primary element used is geometrically symmetrical to one that was the object of a direct standardization beforehand and is used in the same conditions.

The weight rate is correlated to the differential pressure within the uncertainty limits set up in ISO 5167 and can be established with one of the following formulae:

$$q_{ms} = \frac{C}{\sqrt{1-\beta^4}} \varepsilon_1 \frac{\pi}{4} d^2 \sqrt{2\Delta p \rho_1}\ , \tag{1}$$

$$q_m = \frac{C}{\sqrt{1-\beta^4}} \varepsilon_2 \frac{\pi}{4} d^2 \sqrt{2\Delta p \rho_2}\ , \tag{2}$$

where index 1 refers to the upstream and index 2 refers to downstream of the primary element.

In these expressions $1 / \sqrt{1-\beta^4}$ is called the approach speed coefficient and $C / \sqrt{1-\beta^4}$ is called discharge coefficient. From the two relations, there results

$$\varepsilon_2 = \varepsilon_1 \sqrt{1 + \frac{\Delta p}{p_2}} \tag{3}$$

The volumetric flow results from the weight rate

$$q_v = \frac{q_m}{\rho} \tag{4}$$

In the above relations, there were noted: ρ - the fluid density, kg/m^3, d - the diameter of the squeeze section, m, C - discharge coefficient and ε - the expansion coefficient.

The discharge coefficient, C, in case of an incompressible liquid, is given by:

$$C = \frac{q_m \sqrt{1-\beta^4}}{\frac{\pi}{4} d^2 \sqrt{2\Delta p \rho_1}}\ . \tag{5}$$

The standardization of a primary element with the help of incompressible liquids leads to the conclusion that this discharge coefficient depend only on the Reynolds criterion (Re), in a given installation.

The value of coefficient C, for different installations, is the same if the installations are geometrically similar and the values of the Reynolds criterion are identical.

The calculations of the expression of coefficient C in ISO 5167-1 are based on experimental determinations.

The expansion coefficient, ε, takes into consideration the compressibility of the fluid, whose flow is measured.

Out of the above-mentioned relations, the calculation expression of this coefficient is:

$$\varepsilon = \frac{q_m \sqrt{1-\beta^4}}{\frac{\pi}{4} d^2 C \sqrt{2\Delta p \rho_1}} \tag{6}$$

The direct standardization of a primary element for a compressible fluid (gas) indicates the fact that the ratio

$$\frac{q_m\sqrt{1-\beta^4}}{\frac{\pi}{4}d^2\sqrt{2\Delta p\rho_1}} \tag{7}$$

depends on the value of the Reynolds criterion, on the ratio of the pressures in the upstream and downstream and on the adiabatic exponent (isentropic) of the gas.

The arrangement of the pressure intake ports according to ISO 5167-1 allows the calculation of the discharge coefficient, C, with the relation Reader–Harris/Gallagher, whose expression is:

$$\begin{aligned} C = {} & 0{,}5961 + 0{,}0261\beta^2 - 0{,}216\beta^8 + 0{,}000521\left(\frac{10^6\beta}{Re_D}\right)^{0{,}7} + (0{,}0188 + 0{,}0063A)\beta^{3{,}5}\left(\frac{10^6}{Re_D}\right)^{0{,}3} + \\ & + (0{,}043 + 0{,}080e^{-10L_1} - 0{,}123e^{-7L_1})(1 - 0{,}11A)\frac{\beta^4}{1-\beta^4} - 0{,}031\left(M_2' - 0{,}8M_2'^{1{,}1}\right)\beta^{1{,}3} \end{aligned} \tag{8}$$

If D<71,12 mm (2,8 in), relation (8) is added the term:

$$0{,}11(0{,}75-\beta)\left(2{,}8-\frac{D}{25{,}4}\right) \tag{9}$$

In relations (8) and (9) there were noted:

$$\beta = \frac{d}{D} \tag{10}$$

d is the choke diameter and D being the inner diameter of the pipe in mm. Re_D – Reynolds criterion corresponding to diameter D.

$$A = \left(\frac{19000\beta}{Re_D}\right)^{0{,}8}, \tag{11}$$

$$M_2' = \frac{2L_2'}{1-\beta}, \tag{12}$$

$$L_1 = \frac{l_1}{D}, \tag{13}$$

$$L_2' = \frac{l_2'}{D}, \tag{14}$$

l_1 being the distance from the upstream pressure intake port to the "upper side" of the diaphragm, and l_2' being the distance from the “lower side” of the diaphragm to the upstream pressure intake port of the diaphragm. L_2 is the distance from the pressure intake port in the upstream of the diaphragm to the “upper side” of the diaphragm.

In order to arrange the pressure intake ports according to ISO 5167-1, relations (13) and (14) become:

$$L_1 = L'_2 = \frac{25{,}4}{D} \tag{15}$$

In case of using other arrangements of the pressure intake ports than those according to ISO 5167-1, relation (15) is no longer valid.

All the above-mentioned relations from (8) to (15) are valid only on the installing general conditions and within the use limits stipulated in ISO 5167-1.

For the arrangement of the pressure intake ports, the expansion coefficient ε_1 can be calculated with the following relation, if the use limits are those stipulated

$$\varepsilon_1 = 1 - \left(0{,}41 + 0.35\beta^4\right)\frac{\Delta p}{\kappa p_1}, \tag{16}$$

where k is the adiabatic exponent of the gas.

Relation (16) was applied for air, steam and methane, the results of the tests being published. For other gases, relation (16) has not been testes, but there is no objection regarding its use for any other gases and vapours whose adiabatic exponent is known. The only condition that relation (16) could be applied is the observance of the value of the primary element upstream and downstream pressure ratio of

$$\frac{p_2}{p_1} \geq 0{,}75.$$

Case Study Regarding the Influence of Temperature upon the Precision of Measuring Natural Gas Flows in S.R.M. Arad 1

Based on the above-mentioned information, using the methodology shown and implemented in the measurement system of natural gas flows in S.R.M. Arad 1, there were established the values of the flows and of the thermal energy of the natural gases for their various temperature values.

The calculation of the natural gas flow parameters is made according to ISO 5167 and ISO 1223-1,2,3.

Input data:

COMPRESIBILITY NORM: NX 19 changed
CALCULATION OPTION: ISO 5167
THERMAL RESISTANCE POSITION Pt 100: upstream/downstream
TYPE PRIMARY ELEMENT: Diaphragm with flange intake
CONSTANT VALUES:
ITA E-6
10,85 Pa*s
hi: 1,31
pb: 1,01325 bar
tb: 15 dgr C
Ro aerb: 1,22541 kg/mc
Gas pressure 3.8 bar
Differential pressure: 8000 Pa
Inner diameter of the pipe: D_0=301,3 mm

Orifice diameter of the deprimogene element: d_0=164,9 mm
ID E-6:12,00 1/dgr C
Id E-6: 16.00 1/dgr C
Relative density =0,5661;
Superior caloric power=37,88263 MJ/mc

Table 1

No. Crt	THERMAL RESISTANCE Pt 100 - UPSTREAM				THERMAL RESISTANCE Pt 100 - DOWNSTREAM		
	Temp dgr C	Gas flow m^3_N/h	Gas flow kg/h	Energy MJ	Gas flow m^3_N/h	Gas flow kg/h	Energy MJ
1	-10	16818.9572	11667.38801	637146.3336	16795.6728	11651.2355	636264.2571
2	-9	16786.2979	11644.73207	635909.1112	16763.0694	11628.6183	635029.1545
3	-8	16753.8398	11622.21578	634679.5156	16730.6669	11606.1406	633801.6647
4	-7	16721.5811	11599.83775	633457.4702	16698.4634	11583.8009	632581.7114
5	-6	16689.5197	11577.5966	63 2242.8994	16666.4569	11561.5978	631369.2191
6	-5	16657.6536	11555.49096	631035.7287	16634.6453	11539.53	630164.1134
7	-4	16625.9809	11533.51948	629835.8845	16603.0268	11517.5961	628966.3208
8	-3	16594.4998	11511.68083	628643.2941	16571.5994	11495.7948	627775.7687
9	-2	16563.2081	11489.9737	627457.8858	16540.3613	11474.1247	626592.3856
10	-1	16532.1043	11468.39679	626279.589	16509.3105	11452.5846	625416.1008
11	0	16501.1863	11446.94883	625108.3336	16478.4452	11431.1733	624246.8443
12	1	16470.4523	11425.62855	623944.0508	16447.7637	11409.8894	623084.5474
13	2	16439.9006	11404.4347	622786.6722	16417.2641	11388.7317	621929.1419
14	3	16409.5294	11383.36604	621636.1305	16386.9446	11367.6989	620780.5605
15	4	16379.3369	11362.42137	620492.3593	16356.8035	11346.7899	619638.7367
16	5	16349.3214	11341.59947	619355.2927	16326.8391	11326.0034	618503.6047
17	6	16319.4811	11320.89915	618224.8657	16297.0496	11305.3383	617375.0996
18	7	16289.8145	11300.31924	617101.0141	16267.4333	11284.7933	616253.1573
19	8	16260.3197	11279.85858	615983.6745	16237.9886	11264.3674	615137.7141
20	9	16230.9952	11259.51601	614872.7838	16208.7138	11244.0593	614028.7074
21	10	16201.8392	11239.2904	613768.2801	16179.6072	11223.868	612926.075
22	11	16172.8502	11219.18063	612670.1019	16150.6674	11203.7923	611829.7555
23	12	16144.0267	11199.18557	611578.1885	16121.8925	11183.831	610739.6882
24	13	16115.3669	11179.30413	610492.4798	16093.2811	11163.9831	609655.8129
25	14	16086.8693	11159.53522	609412.9162	16064.8316	11144.2476	608578.0703
26	15	16058.5323	11139.87777	608339.4389	16036.5424	11124.6232	607506.4014
27	16	16030.3545	11120.3307	607271.9898	16008.412	11105.109	606440.748
28	17	16002.3343	11100.89296	606210.511	15980.4389	11085.704	605381.0523
29	18	15974.4673	11081.56147	605154.8346	15952.6051	11066.3956	604326.6364
30	19	15946.7422	11062.32841	604104.533	15924.9329	11047.1992	603278.3392
31	20	15919.1772	11043.20646	603060.2996	15897.4151	11028.11	602235.8948
32	21	15891.7653	11024.19068	602021.8637	15870.0494	11009.1263	601199.211
33	22	15864.5042	11005.27955	600989.1424	15842.834	10990.2469	600168.2202

There can be noticed a difference of the hourly flow as a result of the increase of the gases temperatures from 8 ˚C to 20 ˚C, usual values in practice of :$Q_{calc}= Q_{8}{}^{\circ}C- Q_{20}{}^{\circ}C=16260.3197$ Nm^3/h -15919.1772 Nm^3/h $=341,1425$ Nm^3/h, thus resulting a monthly difference of natural gases of :

$\Delta V_{monthly}=245.622,6\ N_m{}^3$/month, namely a flow variation of 2.14%

There can be calculated an increment of the measurement deviation according to temperature of about 0.2% to 1˚C.

There can be noticed that for a station with average flow delivered of 16.000 $N_m{}^3/h$ if the gases are warmed by 12˚C above the gas warming temperature considered to be sufficient, there occurs a monthly measurement deviation of 245.622 $N_m{}^3$, 2.14% respectively of the delivered natural gas quantity. This deviation increases proportional to the circulated flow and there are situations when the deviation can have absolute values that are 4-5 times higher.

Taking into consideration the energetic consumption required to increase the gas temperature, we consider that the uncontrolled increase of the natural gases leads to important economic losses.

Considering that the recommendation for the gas warming up is that the temperature value should be at least 10˚C above the dew-point temperature and the fact that, for the hereby case, this value is of about – 19 ˚C DP, we consider that the temperature of 8 ˚C is enough for the optimum operation of the adjustment and measurement system of station Arad 1.

During summer, when the circulated flows are low, their flow speed through the over ground installation of S.R.M. being low, there results a high thermal transmission from the environment to the gas in the pipe, a phenomenon that, for this situation also, results in a high natural gas temperature in the measurement area, with the same consequences in respect to the above-mentioned measurement deviations. Out of these reasons, we recommend thermal insulation of the over ground installation placed upstream of the test point.

Conclusions

Taking into consideration the necessity to guarantee a high level of precision when measuring the natural gas quantities, it is highly important to ensure an acceptable uncertainty for the measurement systems used. This is imposed by the high values of the transactions performed and fully accounts for the technical and economic efforts it involves.

There must be taken into account the implications the influence factors (e.g. temperature) have upon the measurement uncertainties, implications that may greatly exceed the effort to improve the performances of the measuring devices.

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Influența temperaturii asupra preciziei măsurării debitelor de fluide

Rezumat

În lucrarea sunt prezentate câteva probleme privind influența temperaturii fluidelor transportate prin conducte, asupra exactității debitului măsurat cu aparatele uzuale. Este realizat un studiu de caz privind această problemă, în cadrul S.R.M Arad 1, rezultatele fiind prezentate sub formă tabelară.