

Influence of Natural Gas Composition on Gas Flow Measurement using Cylindrical Beans

FLORINEL DINU^{1*}, ION PANA², IULIANA GHETIU¹, MIHAELA NEAGU³

¹Petroleum– Gas University of Ploiesti, Faculty of Petroleum and Gas Engineering, Department of Wells Drilling, Hydrocarbon Extraction and Transportation, 39 Bucuresti Blvd., 100680, Ploiesti, Romania

²Petroleum – Gas University of Ploiesti, Faculty of Mechanical and Electrical Engineering, Department of Mechanical Engineering, 39 Bucuresti Blvd., 100680, Ploiesti, Romania

³Petroleum and Gas University of Ploiesti, Faculty of Petroleum Refining and Petrochemistry, Department of Petroleum Refining and Environmental Protection Engineering, 39 Bucuresti Blvd., 100680, Ploiesti, Romania

This paper proposes a mathematical model in which will be used both the classical equations and the modern mathematical correlations appeared in the literature concerning the determination of the physico-chemical parameters of the gas mixtures. All these are aimed to develop a modern methodology and a computer model, to design and sizing properly and fast of the calibrated orifice diameter of the cylindrical beans, commonly used in the natural gas producing companies. The results of the calculation achieved on the basis of the developed model lead to an error of 3.12 %, compared with the experimental results.

Keywords: gas flow measurement, natural gas composition, cylindrical beans

The fixing of the operating system of a gas well consists in the adjusting of the pressure and the flow, by a suitable choice of the diameter of the adjustable bean and / or by the mounting of a fixed bean to the outlet of the christmas tree or of the feed pipe, near the well [1, 2]. At the passage of gas through the bean orifice, there can be two types of flow regimes: the sonic flow regime (critical) or the subsonic flow regime (non-critical) [3-7]. The sonic flow regime is achieved when at the passing of the gas through the bean, it reaches a value of the rate of velocity of the gas equal to the velocity of sound in gas (the velocity of the sound in the natural gas is 400 m/s). In the critical flow regime, the pressure ratio values (downstream pressure of the bean P_2 on P_1 upstream pressure of the bean), is

$\frac{P_2}{P_1} \leq 0.552$. In this case, the backpressure in the feed

pipe does not affect the flow of gases, the gas well behaving as it delivers into the atmosphere. The subsonic flow regime is achieved when the gases (passing through the orifice of the bean) flow at a velocity less than the velocity of the sound in gas. In this case, the flow rate of the gas well decreases with the increasing of the backpressure in the feed pipe. This situation entails the increasing of the pressure in the entire network of pipes, which results in the decreasing of the flow rate of all extraction wells. In this case, the value of pressure ratio is

between $1 \geq \frac{P_2}{P_1} > 0.552$. The gas flow passing through the bean of the christmas tree is calculated by the formula:

$$Q = \frac{21800 \cdot \mu \cdot d^2}{\sqrt{\delta}} \cdot \frac{P_1 \cdot \varphi}{\sqrt{T_1 \cdot Z_1}}, \quad (1)$$

where δ is the relative density of methane. Only in this situation it applies the equation:

$$C_1 = \frac{21800 \cdot \mu \cdot d^2}{\sqrt{\delta}} = \frac{21800 \cdot 0.95 \cdot d^2}{\sqrt{0.554}} = 27925 \cdot d^2 \quad (2)$$

where C_2 is the flow coefficient of a cylindrical calibrated bean. In (1) we denote by φ the function that expresses the relationship between the flow rate Q and the pressure ratio β :

$$\varphi = \{ [4.4 \sqrt{(P_2/P_1)^{1.54} - (P_2/P_1)^{1.77}}] \cdot \beta = P_2/P_1 \in (0; 0.552) \} \cdot \beta = P_2/P_1 \in (0.552) \quad (3)$$

where:

- Q – the volumetric flow rate of gas in Nm^3/day ;
- μ – the flow coefficient of the bean which belongs to the interval $[0.94; 0.96]$;
- d – the diameter of the bean hole in mm;
- P_1 – the absolute pressure of the gas at the entrance into the bean, in bar;
- P_2 – the absolute pressure of the gas at the outlet of the bean in bar;
- δ – the relative density of the gas;
- T_1 – the absolute temperature of the gas at the entrance into the bean, in K;
- Z_1 – the compressibility factor of the gas at the entrance into the bean. We make the following notations:

$$\sqrt{K_1} = \frac{1}{\sqrt{T_1 \cdot Z_1}} = \frac{\sqrt{K}}{\sqrt{T_1}}, \quad (4)$$

$$\sqrt{K} = \frac{1}{\sqrt{Z_1}} \quad (5)$$

For a quick calculation, in the case of the cylindrical calibrated beans, it is used the diagram from the figure 1. With the previous observations, the determination of methane flow passing through the cylindrical bean (Lapuk) is done with the relationship [7]:

$$Q = C_1 \cdot P_1 \cdot \varphi \cdot \sqrt{K_1} \quad (6)$$

In the case of the gas mixtures with relative densities different from that of methane, the expression of calculus for the flow rate of the gas will be likewise of the form (6)

* email: flgdinu@upg-ploiesti.ro; Tel.: 0721213200

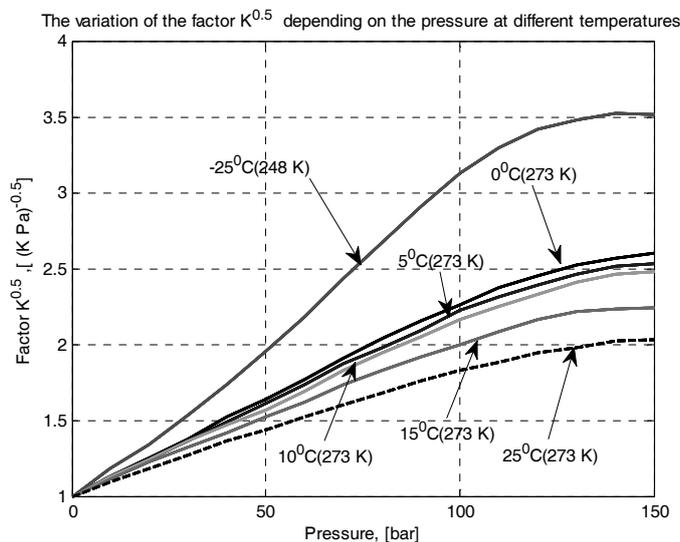


Fig. 1. The variation of the factor \sqrt{K} on the basis of the pressure and temperature [1]

Material	Diameter d , mm																			
Solid steel bean	2.5	3	3.5	4	4.5	5	5.5	6	6.5	7	8	9	10	11	12	13	14	15	16	
	18	20	22	25																
Mineral - ceramic	2	2.5	3	3.5	4	4.5	5	5.5	6	6.5	7	8	9	10	11	12	13	14		
	15	16	17	18																

Table 1
DIMENSIONS OF THE FIXED STANDARD CYLINDRICAL BEANS

in which Z , is the compressibility factor of the gas mixture, calculated in the conditions of pressure and temperature at the input of the fixed cylindrical bean [8, 9]. The compressibility factor may be calculated with the methods: Standing-Katz; Dranchuk, Purvis and Robinson; CNGA California Natural Gas Association method [10-13] and with other two standardized methods [14-17]. The beans can be: fixed with a constant flow area or variable with an adjustable cross section of the flow. According to the location of the fixed beans, they can be: the surface beans or the bottom beans (which is not the subject of our study) [1,16]. The fixed surface bean is usually in the shape of a truncated cone with a taper of 1/6 (as shown in fig. 2) and a central orifice of a constant diameter d (calibrated hole). The bean is mounted in a device named port bean,

and it is constructed of solid steel or mineral - ceramic sintered materials, figure 3. In the table 1 are presented the diameters at which are constructed the fixed surface beans.

Experimental part

To test the computer model it has been used the actual data taken from the current extraction wells that produce in the groups located at a structure of a producer from Romania. The data used are the chromatographic analysis of the gas mixtures (table 2), the parameters of operation of the extraction wells 1, 2 and 3, located on this structure (table 3) columns 1-5.

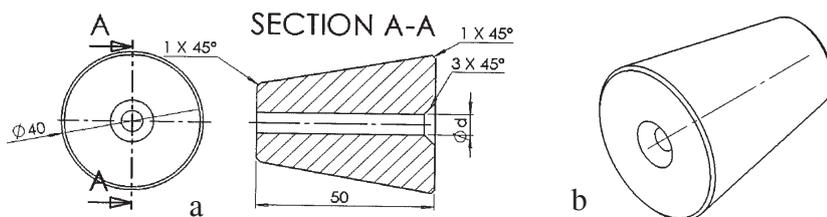


Fig. 2. Standard fixed cylindrical bean: a) a section through the bean, b) the three-dimensional model

Compound	Molar Percentage, % mol
Methane	99.4858
Ethane	0.1420
Propane	0.0249
i-Butane	0.0072
n-Butane	0.0030
i-Pentane	0.0019
n-Pentane	0.0009
n-Hexane	0.0015
n-Heptane	0.0007
n-Octane	0.0005
Nitrogen	0.2818
Oxygen	0.0040
Carbon dioxide	0.0460

Table 2
COMPOSITION AND SOME PHYSICAL PROPERTIES OF THE GAS MIXTURE FROM THE EXTRACTION WELLS

Relative density at 0 °C	0.557769
Relative density at 15° C	0.557638
Dynamic viscosity at 15 °C, Pa·s	0.0107

WELL	BEAN	P_1	P_2	t_1	Q_{con}	Q_A	ε_A	Q_B	ε_B	Q_{sim}	ε_{sim}	BEAN _{sim}
		m	bar	bar	°C	Nm ³ /day	Nm ³ /day	%	Nm ³ /day	%	Nm ³ /day	
0	1	2	3	4	5	6	7	8	9	10	11	12
1	7	57.3	19.2	28.3	43,260	42,810	1.04	42,997	0.60	37,460	13.40	6.5
1	7	56.7	22.2	19	34,930	34,150	2.23	34,220	2.03	29,270	16.20	6.5
1	7	56.8	22.4	20	34,785	34,130	1.88	34,270	1.48	29,270	15.85	6.5
1	7	56.4	19.9	13	35,276	34,820	1.29	34,980	0.83	29,770	15.60	6.5
2	6	60.3	20.2	25.9	32,810	33,000	0.59	33,115	0.92	28,510	13.08	6.0
2	6	58.5	22.3	21	36,810	37,100	0.78	37,110	0.81	31,000	15.78	6.0
2	6	57.5	19.9	21.5	35,970	36,220	0.69	36,280	0.86	30,350	15.62	6.0
3	6	50.0	19.2	23.4	25,180	27,626	9.71	27,707	10.03	23,962	4.83	5.5
3	6	48.5	22.3	22.5	30,340	32,500	7.11	33,110	9.12	25,560	15.75	5.5
3	6	49.3	19.9	21.7	31,450	33,660	7.02	33,430	6.29	26,540	15.61	5.5
Average error, (%)							3.05		3.12		14.21	

Table 3
COMPARATIVE CALCULATION OF
NATURAL GAS PRODUCTION IN
THE ANALYZED STRUCTURE

The meanings of the parameters denoted in the table 3 are: *BEAN* the diameter of the calibrated orifice of the cylindrical fixed bean, existing at the well, mm; P_1, P_2 – the absolute pressure at the inlet/outlet of the cylindrical beam in bar; t_1 – the temperature of the gas at the inlet of the cylindrical beam in °C; Q_{con} – the gas flow registered at the measure panel in Nm³/day; Q_A, Q_B – the gas flow rate determined with the computer model developed for the cylindrical fixed bean: on the methane well (index A) or on a well that produces a gas mixture (index B), Nm³/day; $\varepsilon_A, \varepsilon_B$ – the error corresponding to the variants A, B in %; Q_{sim} – the gas flow calculated with the process simulator, Nm³/day; ε_{sim} – the error corresponding to the simulator calculus, %; *BEAN_{sim}* – the diameter of the calibrated orifice of the cylindrical fixed bean (calculated with the methodology proposed by the authors for the cylindrical beans) corresponding to the gas flow rate calculated with the process simulator, in mm.

Results and discussions

The gas flow expressed by the equation (6) is calculated for the standardized cylindrical beans with the relationship (7):

$$Q = \{ \cdot [C_{1,2} \sqrt{(P_{1,2} (P_{1,1} - P_{1,2}))}], \beta = P_{1,2}/P_{1,1} \in [0.552, 0.8] @ C_{1,2} \cdot P_{1,1}, \beta = P_{1,2}/P_{1,1} \in [0; +0.552] \cdot \}. \quad (7)$$

where C_2 is the flow coefficient of the fixed standardized bean. The values of the coefficient C_2 are given in the table 4 for a gas with the relative density $\delta = 0.6$ and the temperature of $T = 288$ K. If the gas mixture has a different relative density (as against of the air) δ and another absolute temperature T , then the flow rate is calculated with the formula:

$$Q = \{ \cdot [C_{1,3} \sqrt{(P_{1,2} (P_{1,1} - P_{1,2}))}], \beta = P_{1,2}/P_{1,1} \in [0.552, 0.8] @ C_{1,3} \cdot P_{1,1}, \beta = P_{1,2}/P_{1,1} \in [0; +0.552] \cdot \}. \quad (8)$$

where the flow coefficient C_3 valid for the standard fixed beans (fig.1) is given by the relation:

$$C_3 = \frac{13.152 \cdot C_2}{\sqrt{\delta \cdot T}} \quad (9)$$

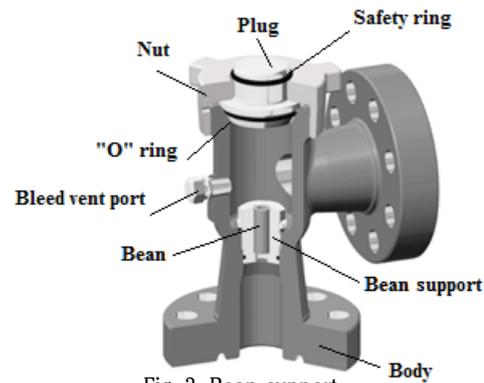


Fig. 3. Bean support.

The calculus relations of the gas flow flowing through the bean of the christmas tree of a gas well shown in the several papers published in the literature, are based on a series of correlations established between the physical and chemical parameters of the gases which characterize this process [8, 16-19]. If the determination of these parameters is correct and accurate, the calculus of the gas flow rate has a higher degree of accuracy.

In the following, we will present some mathematical correlations involved in the relationships of calculus of gas flow, selected on the degree of accuracy, in order to achieve the proposed computer model and the best correlations describing the variations of the physico - chemical parameters of the gas compared to the actual results of the laboratory experiments. The achievement of a computer model requires a fluent mathematical algorithm which does not depend on the reading or the using of the charts and the data tables. For this reason, the paper presents new mathematical correlations to accurately model the function φ , the standardized coefficient C_2 which occurs in the flow relationship, ultimately leading to a greater accuracy of the software. The mathematical correlations developed are:

- The determination of the function φ (of the argument
- for the subsonic flow domain ($\beta = \frac{P_2}{P_1} > 0.552$)

Diameter of the bean d , mm	Flow coefficient, C_2 Nm ³ /day · bar	Diameter of the bean d , mm	Flow coefficient, C_2 Nm ³ /day · bar
2.5	83.2	9	1216
3.0	127.3	10	1479
3.5	162.2	11	1698
4.0	211.3	12	1995
4.5	275.4	13	2630
5.0	346.7	14	3020
5.5	421.7	16	4074
6.0	512.9	18	5248
6.5	616.6	20	6761
7.0	716.1	22	8710
8.0	955.0	25	12735

Table 4
VALUES OF THE FLOW COEFFICIENT C_2 OF THE STANDARDIZED CYLINDRICAL BEANS (FOR A GAS WITH THE RELATIVE DENSITY $\delta = 0.6$ AND THE TEMPERATURE OF $T = 288$ K)

$$\varphi = \sum_{i=0}^{19} a_i \beta^i \quad (10)$$

where the values of coefficients of the polynomial a_i expressing the function φ are given in the table 5.

b. The determination of the coefficient $\sqrt{K_t}$ (fig. 1 for different temperatures t) for the fixed calibrated cylindrical beans, in the case when it is not known the composition of the gas mixture, considering 100 % methane (case A):

$$\sqrt{K_t} = \sum_{i=0}^5 b_i P_1^i \quad (11)$$

where the values of the coefficients involved in the expression of factor $\sqrt{K_t}$ are shown in the table 6, the pressure P_1 is expressed in bar.

c. The determination of the standardized value of the coefficient C_{2st} function on the standardized diameter of the cylindrical bean d_{st} :

$$C_{2st} = \sum_{i=0}^{10} c_i d_{st}^i \quad (12)$$

where the values of the coefficients involved in the expression of C_{2st} are given in the table 7, the diameter d_{st} is expressed in cm. The extraction wells located on analyzed structure due to the high levels of the system operating parameters (flow and pressure) are equipped with fixed cylindrical beans, ensuring good operation of the gas wells.

The computer model developed (based on mathematical algorithm presented) is performed within

a_{19}	a_{18}	a_{17}	a_{16}	a_{15}
-44,505.58	94,200.461	35,096.605	-112,126.89	-110,932.31
a_{14}	a_{13}	a_{12}	a_{11}	a_{10}
101,233.10	94,279.834	91,264.443	-103,764.8	-197,550.87
a_9	a_8	a_7	a_6	a_5
64,582.568	142,687.8	45,472.04	-107,515.79	-52,688.234
a_4	a_3	a_2	a_1	a_0
49,952.641	54,858.431	-65,157.503	23,614.941	-3,000.806

Table 5
COEFFICIENTS OF THE POLYNOMIAL THAT EXPRESSES THE FUNCTION φ

t °C	b_4 bar ⁻⁴	b_3 bar ⁻³	b_2 bar ⁻²	b_1 bar ⁻¹	b_0 -
-25	$3.6577781 \cdot 10^{-10}$	$-1.3009868 \cdot 10^{-8}$	$1.2168986 \cdot 10^{-5}$	$0.13721977 \cdot 10^{-2}$	1.0012416
0	$-8.5377471 \cdot 10^{-11}$	$-1.0260644 \cdot 10^{-8}$	$2.6440154 \cdot 10^{-6}$	$0.11939383 \cdot 10^{-2}$	0.9993673
5	$-1.4015986 \cdot 10^{-10}$	$8.8359497 \cdot 10^{-9}$	$8.018801 \cdot 10^{-7}$	$0.11890234 \cdot 10^{-2}$	0.9996876
10	$-1.8082554 \cdot 10^{-10}$	$2.3202672 \cdot 10^{-8}$	$-4.7939006 \cdot 10^{-7}$	$0.11562195 \cdot 10^{-2}$	0.9997355
15	$-1.6850614 \cdot 10^{-10}$	$2.1685214 \cdot 10^{-8}$	$-9.94118701 \cdot 10^{-7}$	$0.1057539 \cdot 10^{-2}$	1.0000256
25	$-1.3744344 \cdot 10^{-10}$	$2.3427536 \cdot 10^{-8}$	$-2.1605243 \cdot 10^{-6}$	$0.95020411 \cdot 10^{-3}$	0.9999688

Table 6
VALUES OF THE COEFFICIENTS INVOLVED IN THE EXPRESSION OF $\sqrt{K_t}$ FROM RELATIONSHIP (11) FOR DIFFERENT TEMPERATURES t

$d_{st} \leq 1.8$ cm	c_{10}	c_9	c_8	c_7
	Nm ³ /zi·bar·cm ⁻¹⁰	Nm ³ /zi·bar·cm ⁻⁹	Nm ³ /zi·bar·cm ⁻⁸	Nm ³ /zi·bar·cm ⁻⁷
	$3.3546763 \cdot 10^{-9}$	$-6.5627593 \cdot 10^{-7}$	$5.5101349 \cdot 10^{-5}$	$-2.6016313 \cdot 10^{-4}$
	c_6	c_5	c_4	c_3
	Nm ³ /zi·bar·cm ⁻⁶	Nm ³ /zi·bar·cm ⁻⁵	Nm ³ /zi·bar·cm ⁻⁴	Nm ³ /zi·bar·cm ⁻³
	$7.6065351 \cdot 10^{-3}$	-1.4297252	17.366741	-133.46689
	c_2	c_1	c_0	
	Nm ³ /zi·bar·cm ⁻²	Nm ³ /zi·bar·cm ⁻¹	Nm ³ /zi·bar	
	630.75199	-1,534.8086	1,562.733	
$d_{st} > 1.8$ cm	c_{10}	c_9	c_8	c_7
	Nm ³ /zi·bar·cm ⁻¹⁰	Nm ³ /zi·bar·cm ⁻⁹	Nm ³ /zi·bar·cm ⁻⁸	Nm ³ /zi·bar·cm ⁻⁷
	$4.2375984 \cdot 10^{-9}$	$-8.2000076 \cdot 10^{-7}$	$6.8201383 \cdot 10^{-5}$	$-3.1941994 \cdot 10^{-4}$
	c_6	c_5	c_4	c_3
	Nm ³ /zi·bar·cm ⁻⁶	Nm ³ /zi·bar·cm ⁻⁵	Nm ³ /zi·bar·cm ⁻⁴	Nm ³ /zi·bar·cm ⁻³
	$9.2748694 \cdot 10^{-3}$	-1.733162	20.95024	-160.37796
	c_2	c_1	c_0	
	Nm ³ /zi·bar·cm ⁻²	Nm ³ /zi·bar·cm ⁻¹	Nm ³ /zi·bar	
	752.70958	-1,833.7103	1,862.0298	

Table 7
VALUES OF THE COEFFICIENTS INVOLVED IN THE EXPRESSION OF C_{2st} FROM RELATIONSHIP (12)

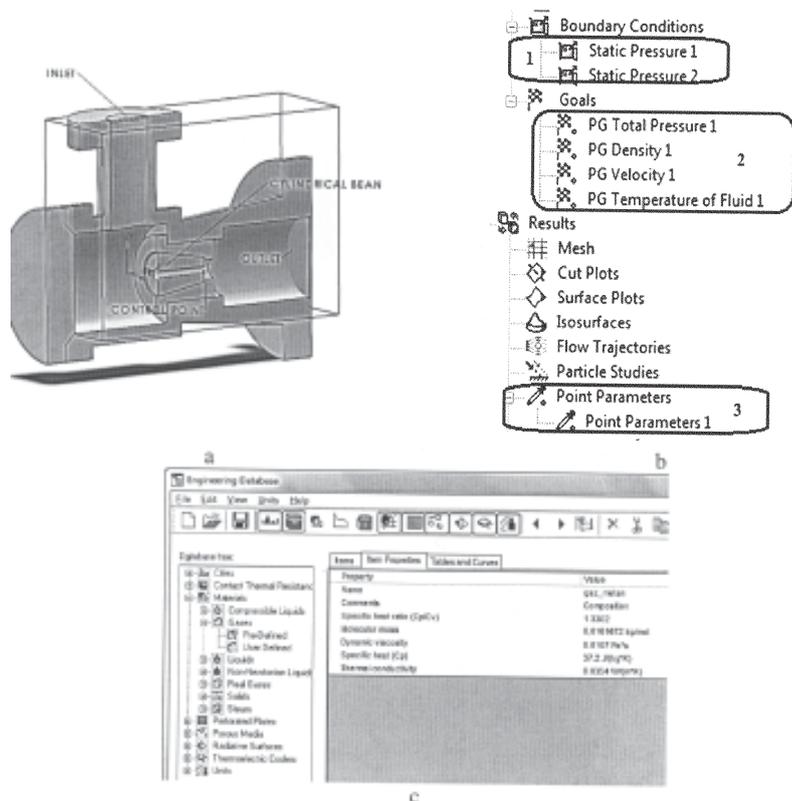


Fig. 4. The model of the bean in the program Solid Works/Flow Simulation: a) the section through the bean support; b) the elements of the simulation; c) the entering of the characteristics of the gas mixture according with the information from table 2

WELL	BEAN	v_g	ρ_g	Q_m	Q_{FS}	Q_{con}	ϵ_{FS}
-	mm	m/s	kg/m ³	kg/s	Nm ³ /day	Nm ³ /day	%
1	7	475.05	19.86	0.3631	43,751	43,260	1.13
1	7	468.68	20.3	0.3661	43,937	34,930	25.78
1	7	468.68	20.3	0.3661	43,937	34,785	26.30
1	7	471.36	20.1	0.3646	43,753	35,270	24.05
2	6	476.42	21.34	0.2875	34,638	32,810	5.57
2	6	473.81	23.81	0.3190	38,436	36,810	4.41
2	6	476.18	20.26	0.2728	32,732	35,970	9.00
3	6	473.68	17.59	0.2356	28,269	25,180	12.26
3	6	457.25	17.78	0.2299	27,583	30,340	9.08
3	6	467.03	17.63	0.2328	27,936	31,450	11.17
Average error, (%)							12.87

Table 8
ANALYSIS OF THE
PRODUCTION DATA USING
FLOW SIMULATION PROGRAM

the Mathcad 15 version, language which allows us to easily follow both the accuracy of the used calculus relations and the results obtained. In the computer simulation model developed it was intended to determine the diameter of the fixed cylindrical bean, for a gas flow required. We have achieved the calculation of the gas flow into two situations, namely:

- Version A is valid for methane wells, named the model "A (100 % methane)";
- Version B is valid for all natural gas wells, named the model "B - when it takes into account the composition of the gas mixture."

The comparison with the production data recorded was made with:

- the results obtained by the running of the computer design model developed;
- the process simulator data, existing at the Petroleum – Gas University of Ploiesti, developed by a company from domain;
- the finite element modeling of convergent bean, with the program Flow Simulation included in Solid Works.

To determine the accuracy of the calculations, we used the calculation error [defined by the following relationship:

$$\epsilon = \frac{|Q_{con} - Q_{mod}|}{Q_{con}} \cdot 100 \quad (13)$$

where Q_{con} is the registered gas flow rate in the measurement panel; Q_{mod} – gas flow rate calculated using one of the previous models a-c. The results are summarized in the table 3.

Good results regarding the accuracy of the gas flow rate were obtained: variant A (methane), calculated error $\epsilon_A = 3.05\%$ and the variant B (considering the composition of the gas mixture), calculated error $\epsilon_B = 3.12\%$. The error corresponding to the gas flow rate calculated with the process simulator is $\epsilon_{sim} = 14.21\%$.

The verification of the model of calculation was done also, with the program SolidWorks, Flow Simulation module. For this it was developed the model of the bean figure 4,a and a flow study has been conducted with the following parameters: the static pressure P_1 and the absolute temperature T_1 at the input of the model; the static pressure P_2 and the absolute temperature T_2 (1) figure 4,b at the outlet of the model; the elements used to monitor the convergence of the study are placed in the center of symmetry of the outlet section of the bean: the total pressure, density, velocity, and temperature (2) figure 4,b; the values used for the calculation of the volumetric flow are evaluated in the center of symmetry of the bean exit, namely: the density of the gas mixture ρ_g and its velocity (3) v_g figure 4,b. With the values of ρ_g and v_g have been calculated the mass flow passing through the bean Q_m and the volumetric flow rate (calculated by the Flow

Simulation software) Q_{FS} expressed under normal conditions. In the simulation were used the actual data of the gas mixture according to the analysis bulletin of the table 2, figure 4.c. For the actual data from table 3 (columns 1-5), the results obtained are given in the table 8. There is a $\epsilon_{FS} = 12.87\%$ error of the method. It is noted that (as in the case of the simulator) the error is higher than at the analytical methods. The explanations for the differences between the results provided by the analytical methods proposed by the authors and the methods implemented into the simulator and in Solid Works / Flow Simulation are:

- the Flow Simulation program (Solid Works) is general (not specialized in certain applications). At the velocity rates of the gas which exceed the velocity of sound, the gas flow is almost constant [3-6]. The program does not take into account these practical issues and therefore those differences occur. The error is comparable with the simulator error.

- The simulator is specialized in petroleum applications where the modelling of beans as flow control elements is well done, so that errors are less 14.21 %. It must be noted, however, that the methodology used by program leads to errors three times higher than the actual proposed method.

Conclusions

1. The comparative results of the calculation of the production of the natural gas wells, as shown in the table 3 were made assuming fixed bean diameters used on the site (BEAN) for the computer model, process simulator and the Flow Simulation (program using the finite element method). To the extraction wells located on analyzed structure, the closest results to Q_{con} were found to be those obtained by the computer model developed for the fixed cylindrical bean, mounted to the gas well variant A, calculated error $\epsilon_A = 3.05\%$. Good results regarding the accuracy of the gas flow rate were obtained (for the fixed cylindrical bean) also for the variant B (considering the composition of the gas mixture), calculated error $\epsilon_B = 3.12\%$. For the extraction wells located on the analysed structure, there are significant differences between the values recorded of the gas flow on the measurement panel Q_{con} considered as reference and the calculated gas flow rate corresponding to the process simulator, the error calculated is $\epsilon_{sim} = 14.21\%$.

2. Because of these significant differences, we aimed to determine the diameter of the calibrated orifice of the cylindrical fixed bean corresponding to the gas flow Q_{sim} calculated with the process simulator BEAM_{sim}. By imposing the flow values of Q_{sim} into the design computer model developed, it appears that, for the same gas flow imposed, the calibrated orifice diameter of the fixed cylindrical equivalent bean has lower values compared with the fixed bean diameter mounted in the analysed group, corresponding to the wells 1 and 3. For this reason, it is concluded that there are differences between the Romanian method of calculating of the gas flow passing through the fixed cylindrical bean and methodology existing in the process simulator.

3. The using of the finite element method for the flow verification at cylindrical bean (at pressure drops, temperatures and geometry indicated in table 3) in the program SolidWorks, Flow Simulation module, indicates the gas flow values with an error of $\epsilon_{FS} = 12.87\%$. The error is more than three times higher compared to the error obtained using the methodology proposed by the authors. These errors are explained by the complexity of high-speed

flow phenomena that cannot be captured with a sufficient accuracy by the finite element analysis programs [20-24].

The subject has also been discussed in other paper [25].

References

1. DINU, F., *Extracția gazelor naturale*, Editura Universității din Ploiesti, Ploiesti, 2000
2. ARNOLD, K., STEWART, M., *Design of Gas – Handling Systems and Facilities, Surface Production Operations*, Vol. 2, Gulf Publishing Company, Houston, Texas, 1989
3. LYONS, W. C. *Standard Handbook of Petroleum and Natural Gas Engineering*, Vol. 1, Boston, MA: Gulf Professional Publishing, an imprint of Butterworth-Heinemann, Houston, TX, 1996
4. MENON SH. *Gas Pipeline Hydraulics*, Taylor & Francis, London, 2005
5. OERTEL H., *Prandtl's Essentials of Fluid Mechanics. Applied Mathematical Sciences*, Second edition, Springer Verlag Inc., New York, 2004
6. PERRY R.H., GREEN D.W., *Perry's Chemical Engineer's Handbook on CD-ROM*, McGraw Hill Companies, 1999.
7. KATZ, D. L., LEE, L. R., *Natural Gas Engineering, Production and Storage*, McGraw-Hill Chemical Engineering Series, 1990
8. DINU, F., GRIGORE, V., *Calculul debitului de gaze în punctele de livrare pe baza diagramelor înregistrate cu contorul diferențial*, Documentație nr. 2578/1998, beneficiar Schela de Producție Berca
9. ***. *Măsurarea debitelor de gaz cu echipamente electronice, Curs perfecționare ALCONEX*, Bazna, februarie, 2002
10. DRANCHUCK, M. P., PURVIS, R. A., ROBINSON, D. B., *Computer Calculations of Natural Gas Compressibility Factors Using the Standing and Katz Correlation*, I. P. T. Series, Nr. IP 74-008, 1974
11. ***. *Les Techniques de Traitement sur les Champs*, Production Surface, Tome II, Institut Français du Pétrole, Paris, 1986
12. ***. *Aide – Mémoire de L'Industrie du Gaz*, France, 1990
13. ISO 12213-1:2006 Natural gas — Calculation of compression factor — Part 1: Introduction and guide lines
14. ISO 12213-1:2006 Natural gas — Calculation of compression factor — Part 2: calculation using molar composition
15. ISO 12213-1:2006 Natural gas — Calculation of compression factor — Part 3: Calculation using physical properties
16. PUȘCOIU, N., *Carnet tehnic gaze naturale*, Editura Tehnică, București, 1994
17. PATEL M. S., CHAUDHURI S., PIKAL. J. M., *Choked Flow and Importance of Mach I in Freeze – Drying Process Design*, Chemical Engineering Science, (journal home page: www.elsevier.com/locate/ces), **8**, 2010, p. 5716
18. TUDOR, I., DINU, F., ZECHERU, G., DRĂGHICI, G., RÂPEANU, R. G., LAA, I., ROSU, B., *Protecția anticorozivă și reabilitarea conductelor și rezervoarelor*, Editura Universității Petrol - Gaze din Ploiesti, Ploiesti, 2007
19. SOARE A., STRĂTULĂ C. *Transportul și depozitarea fluidelor*, vol. 2, Editura Universității din Ploiesti, Ploiesti, 2002
20. BS EN ISO 5167-1:2003 Measurement of fluid flow by means of pressure differential devices inserted in circular cross-section conduits running full — Part 1: General principles and Requirements
21. *** NF EN ISO 5167-2: 2003 Measurement of fluid flow by means of pressure differential devices inserted in circular-cross section conduits running full. Part 2: Orifice plates
22. *** NF EN ISO 5167-3: 2003 Measurement of fluid flow by means of pressure differential devices inserted in circular-cross section conduits running full, Part 3: Beans and Venturi beans
23. *** NF EN ISO 5167-3: 2003 Measurement of fluid flow by means of pressure differential devices inserted in circular cross-section conduits running full Part 4: Venturi tubes
24. NORSOK STANDARD I-204:2005 Fiscal measurement systems for hydrocarbon gas
25. DINU, FI., PANA, I., GHETIU, I., NEAGU, M., *Rev. Chim. (Bucharest)*, **64**, no. 10, 2013, p. 1177