BULETINUL Universităţii Petrol – Gaze din Ploieşti	Vol. LXII No. 3B/2010	81 - 88	Seria Tehnică

Increasing the Flow Gas Calculation Accuracy Flowing Through Fixed Cylindrical Nozzles

Florinel Dinu, Mihail-Valentin Batistatu

Universitatea Petrol – Gaze din Ploieşti, Bd. Bucureşti 39, Ploieşti
e-mail: flgdinu@upg-ploiesti.ro

Abstract

The paper presents a new mathematical model which uses both classical equation and the latest mathematical correlations occurring in the literature regarding the determination of the physical-chemical parameter of gas and also a computer model based on the algorithm performance previously developed on the mathematical algorithm has been developed, in order to design and accurately and rapidly size the fixed nozzles with cylindrical diameter. The accuracy of proposed modern technology design is to increase the accuracy of calculating productivity gas wells in a much shorter time. However, the paper seeks to realise a specialisation program with the practical and economic impact in an important area of gas extraction industry.

Key words: *mathematical correlation, nozzles, gas well, flow gas calculation.*

Introduction

Establishment of an operating system of gas wells is to regulate pressure, respectively the flow gas of well, by appropriate choice of adjustable diameter orifice nozzle or fixed nozzle assembly out of the Christmas tree or the supply pipeline, near well. The gas passing through the nozzle orifice can be two types of flows: sonic or subsonic regime [3, 4, 6, 7].

Fixed nozzles have constant cross section and adjustable nozzles have variable cross section. After their location the fixed nozzles can be: the surface or bottom nozzles. The gas passing through the nozzles, by reducing the flow section, causing an increase of speed and also a decrease of gas pressure, whose value is determined by the diameter of the nozzle. Gas flow produced by the well is calculated with the relationship will continue in this paper.

Determination of gas flow passing through the nozzle of the swivel flow head

The gas flow passing through the swivel head nozzle is calculated using the relation:

$$Q = 95900 \cdot \mu \cdot d^2 \cdot p_1 \cdot \sqrt{\frac{\left(\frac{p_2}{p_1}\right)^{1,54} - \left(\frac{p_2}{p_1}\right)^{1,77}}{\delta \cdot T_1 \cdot Z_1}}\,, \qquad (1)$$

where: Q is the gas flow, in m^3N/day; μ - efficiency coefficient of the pipeline, usually about 0,95; d – diameter of the bean hole, in mm; p_1 – gas pressure into the bean, in bar p_2 – gas pressure out of the bean, in bar; δ – relative density of gas to the air; T_1 – absolute temperature of the gas into the bean, in K; Z_1 – gas compressibility factor [5, 6].

The above relation may be rewritten as:

$$Q = 95900 \cdot \mu \cdot d^2 \cdot p_1 \cdot \sqrt{\frac{\left(\frac{p_2}{p_1}\right)^{1,54} - \left(\frac{p_2}{p_1}\right)^{1,77}}{\delta \cdot T_1 \cdot Z_1}} = \frac{21800 \cdot \mu \cdot d^2}{\sqrt{\delta}} \cdot \frac{p_1 \cdot \varphi}{\sqrt{T_1 \cdot Z_1}}, \tag{2}$$

where the value of the *relative density for methane* is $\delta = 0,554$. In this case only the following equation is valid:

$$\frac{21800 \cdot \mu \cdot d^2}{\sqrt{\delta}} = \frac{21800 \cdot 0,95 \cdot d^2}{\sqrt{0,554}} = 27925 \cdot d^2 \tag{3}$$

At the same time, the following notations for the below factors have to be used:

$$\varphi = 4,4 \cdot \sqrt{\left(\frac{p_2}{p_1}\right)^{1,54} - \left(\frac{p_2}{p_1}\right)^{1,77}} \tag{4}$$

In the case of *calibrated cylindrical nozzles*, the mathematical relation below is used for the determination of the expression $\sqrt{K}$:

$$\sqrt{K} = \frac{1}{\sqrt{Z_1}} \tag{5}$$

For determining the *methane gas flow* the passes through the *calibrated cylindrical nozzle (Lapuk)* the following relation is used:

$$Q = C_2 \cdot p_1 \cdot \sqrt{K}\ , \tag{6}$$

where C_2 is a coefficient for calibrated cylindrical nozzles whose values are calculated and shown in the literature.

Mathematical correlations needed for drawing up the model

Drawing up the computer model requires a fluent mathematical algorithm which should not depend on the reading or using the diagrams and the data tables. For this reason, the paper to model as accurate as possible the function φ, the coefficient $\sqrt{K}$ and the coefficient c_{stas} – for the cylindrical nozzle, which directly interferes in the flow relation, finally leading to a better accuracy of the computer program and the execution speed [1, 2, 3].

The following mathematical correlations of the elaborated ones are shown below:

a. Determination of *function φ* for the subsonic flowing domain, that is $p_2/p_1 > 0,552$,

- the pressure ration is *Reg*, so:

$$Reg = \frac{p_2}{p_1} \tag{7}$$

$$\begin{aligned}
\phi := & -44505.58\mathbf{Reg}^{19} + 94200.461\mathbf{Reg}^{18} + 35096.605\mathbf{Reg}^{17} + (-112126.89)\cdot\mathbf{Reg}^{16} \ldots \\
& + (-110932.31)\cdot\mathbf{Reg}^{15} + (101233.1)\mathbf{Reg}^{14} + (94279.834)\cdot\mathbf{Reg}^{13} + \mathbf{91264.443}\,\mathbf{Reg}^{12} \ldots \\
& + (-103764.8)\cdot\mathbf{Reg}^{11} + (-197550.87)\cdot\mathbf{Reg}^{10} + 64582.568\mathbf{Reg}^{9} + 142687.8\mathbf{Reg}^{8} + 45472.04\mathbf{Reg}^{7} \ldots \\
& + (-107515.79)\cdot\mathbf{Reg}^{6} + (-52688.234)\cdot\mathbf{Reg}^{5} + 49952.64\mathbf{Reg}^{4} + 54858.431\mathbf{Reg}^{3} \ldots \\
& + (-65157.503)\cdot\mathbf{Reg}^{2} + 23614.941\mathbf{Reg} - 3000.806
\end{aligned}$$

b. Calibrated fixed cylindrical nozzles. Determination of $\sqrt{K}$ coefficient – when the composition of the gaseous mixture is not known:

- for temperature t_1 = -25 ºC, the variation equation of $\sqrt{K}$ depending on pressure $x = p_1$ is:

$$\mathbf{K_{min25}} := \left[(-3.6577781)\cdot 10^{-10}\right]\cdot \mathbf{x}^4 + (-1.3009868)\left(10^{-8}\right)\cdot \mathbf{x}^3 + 1.2168986\left(10^{-5}\right)\cdot \mathbf{x}^2 \ldots + 0.0013721977\cdot \mathbf{x} + 1.0012416$$

- for temperature t_1 = -0 ºC, the variation equation of $\sqrt{K}$ depending on pressure $x = p_1$ is:

$$\mathbf{K_0} := \left[(-8.5377471)\cdot 10^{-11}\right]\cdot \mathbf{x}^4 + (-1.0260644)\left(10^{-8}\right)\cdot \mathbf{x}^3 + 2.6440154\left(10^{-6}\right)\cdot \mathbf{x}^2 \ldots + 0.0011939383\cdot \mathbf{x} + 0.99963673$$

- for temperature t_1 = 5 ºC, the variation equation of $\sqrt{K}$ depending on pressure $x = p_1$ is:

$$\mathbf{K_5} := \left[(-1.4015986)\cdot 10^{-10}\right]\cdot \mathbf{x}^4 + (8.8359497)\left(10^{-9}\right)\cdot \mathbf{x}^3 + 8.018801\left(10^{-7}\right)\cdot \mathbf{x}^2 \ldots + 0.0011890234\cdot \mathbf{x} + 0.99968769$$

- for temperature t_1 = 10 ºC, the variation equation of $\sqrt{K}$ depending on pressure $x = p_1$ is:

$$\mathbf{K_{10}} := \left[(-1.8082554)\cdot 10^{-10}\right]\cdot \mathbf{x}^4 + (2.3202672)\left(10^{-8}\right)\cdot \mathbf{x}^3 + (-4.7939006)\left(10^{-7}\right)\cdot \mathbf{x}^2 \ldots + 0.0011562195\cdot \mathbf{x} + 0.999735539$$

- for temperature t_1 = 15 ºC, the variation equation of $\sqrt{K}$ depending on pressure $x = p_1$ is:

$$\mathbf{K_{15}} := \left[(-1.6850614)\cdot 10^{-10}\right]\cdot \mathbf{x}^4 + (2.1685214)\left(10^{-8}\right)\cdot \mathbf{x}^3 + (-9.94118701)\left(10^{-7}\right)\cdot \mathbf{x}^2 \ldots + 0.0010575399\cdot \mathbf{x} + 1.0000256$$

- for temperature t_1 = 25 ºC, the variation equation of $\sqrt{K}$ depending on pressure $x = p_1$ is:

$$\mathbf{K_{25}} := \left[(-1.3744344)\cdot 10^{-10}\right]\cdot \mathbf{x}^4 + (2.3427536)\left(10^{-8}\right)\cdot \mathbf{x}^3 + (-2.1605243)\left(10^{-6}\right)\cdot \mathbf{x}^2 \ldots + 0.0009502041\cdot \mathbf{x} + 0.99996886$$

The standardized value of coefficient c_{stas} is calculated, depending on the standardized diameter of the cylindrical nozzle:

- for the standardized diameter of the nozzle $d_{STAS} \leq$ *18 mm* the below relation is used:

$$\begin{aligned}\mathbf{c_{stas1}} := {} & (3.3546763)\cdot\left(10^{-9}\right)\cdot \mathbf{d_{dSTASA}}^{10} + (-6.5627593)\cdot\left(10^{-7}\right)\cdot \mathbf{d_{dSTASA}}^{9} \ldots \\ & + (5.5101349)\cdot\left(10^{-5}\right)\cdot \mathbf{d_{dSTASA}}^{8} + (-0.0026016313)\cdot \mathbf{d_{dSTASA}}^{7} + (0.076065351)\cdot \mathbf{d_{dSTASA}}^{6} \ldots \\ & + (-1.4297252)\cdot \mathbf{d_{dSTASA}}^{5} + 17.36674\cdot \mathbf{d_{dSTASA}}^{4} \ldots \\ & + (-133.46689)\cdot \mathbf{d_{dSTASA}}^{3} + 630.7519\cdot \mathbf{d_{dSTASA}}^{2} + (-1534.8086)\cdot \mathbf{d_{dSTASA}} + 1562.733\end{aligned}$$

- for the standardized diameter of the nozzle $d_{STAS} >$ *18 mm* the below equation is used:

$$\begin{aligned}\mathbf{c_{stas2}} := {} & (4.2375984)\cdot\left(10^{-9}\right)\cdot \mathbf{d_{dSTASA}}^{10} + (-8.2000076)\cdot\left(10^{-7}\right)\cdot \mathbf{d_{dSTASA}}^{9} \ldots \\ & + (6.8201383)\cdot\left(10^{-5}\right)\cdot \mathbf{d_{dSTASA}}^{8} + (-0.0031941994)\cdot \mathbf{d_{dSTASA}}^{7} + (0.092748694)\cdot \mathbf{d_{dSTASA}}^{6} \ldots \\ & + (-1.7331612)\cdot \mathbf{d_{dSTASA}}^{5} + 20.95024\cdot \mathbf{d_{dSTASA}}^{4} \ldots \\ & + (-160.37796)\cdot \mathbf{d_{dSTASA}}^{3} + 752.70958\cdot \mathbf{d_{dSTASA}}^{2} + (-1833.7103)\cdot \mathbf{d_{dSTASA}} + 1862.0298\end{aligned}$$

The computer-based simulation model of gas flow through nozzles

The following two situations have been checked within the computer-based simulation model:

1. To calculate the *fixed nozzle diameter* for an imposed gas flow;

2. To calculate *the gas flow,* respectively the well production, imposing various diameters of calibrated orifices of the fixed cylindrical nozzles that are to be assembled in the swivel flow head of a gas well.

For the two existing cases, the comparative calculation of the gas flow has been performed in two variants, which are:

- *variant A* is valid for *methane gas wells* which is named in the model „ *A – when the gas mixture composition is not taken into consideration”*;
- *variant B* is valid *for all natural gas wells* which is named in the model „ *B – when the gas mixture composition is taken into consideration*”.

For exemplifying the calculations, real data have been taken from the wells in the field cluster Bilciureşti within S.N.G.N. ROMGAZ S.A. subsidiary, which are shown below: the chromatographic analysis data sheet of the gases; the parameters of the exploration state of the production wells in Bilciureşti structure, respectively in the production clusters and temperature variation of gases on the route well-heater-nozzle for well 57 and 125 from the cluster 57. The compute-based models with complete data will be run fro well 57 in field cluster 57.

Testing in well conditions the computer-based design model

In order to test the computer-based design model of gas flow through nozzles in well conditions real data have been used taken from active production wells from Bilciureşti structure. At the same time, the wells are used for underground storage processes, the Bilciureşti deposit having the biggest storage capacity in Romania at present.

For exemplifying and checking the accuracy of the results obtained from the computer-based design model, two distinct cases are checked, that is:

Case 1. Checking production data registered by ROMGAZ Subsidiary on the parameters of exploration state of production wells placed on Bilciureşti structure in the field cluster 57, with results obtained from running the computer-based design model and the same time with the process simulator from the Petroleum Gas University of Ploieşti;

Case 2. Comparing results obtained from the computer-based design model and the process simulator of the University, for a surface unit whose construction is swivel flow head well 57 – heater – fixed nozzle – supply pipeline – separator, shown in detail in figure 1 and simplified for applying the process simulator in figure 2.

Case 1. Checking recorded production data with results obtained from running the computer-based design model

The checking of the recorded and reported production data regarding the exploration state parameters of production wells in field cluster 57 Bilciureşti with results obtained both from running the computer-based design model and the process simulator from the Petroleum Gas University of are synthetically shown in table *1.* The significations of the parameters noted in table *1* are: NOZZLE is the diameter of the orifice calibrated fixed nozzle existing in the well at the time the measurements were made; NOZZLE $_{\text{Cylinder}}$ – diameter of the calibrated orifice, in the hypothesis of using the fixed cylindrical nozzle in the computer-based design model; NOZZLE $_{\text{Simulator}}$ – the diameter of the calibrated orifice, in the hypothesis of using the fixed cylindrical nozzle with the process simulator; NOZZLE $_{\text{Equivalent Simulator}}$ – the diameter of the calibrated orifice fixed cylindrical nozzle equivalent to the calculated flow of gas with the process simulator; Q $_{\text{nozzle}}$ – the gas flow calculated by the Storage Subsidiary when the gas leaves the NOZZLE assembled on the well; Q $_{\text{counter}}$ – gas flow recorded on the counter panel; Q_{cylindA}, Q_{cylindB} – gas flow calculated by the computer-based model drawn up for the fixed

cylindrical nozzle on the methane gas well (variant A), respectively on a well that produces a mixture of natural gases (variant B); $Q_{g\ \mathrm{Simulator}}$ – gas flow calculated with the process simulator.
The comparative calculation results of the natural gas production wells, shown in table *1* was made in the hypothesis of using the diameters of fixed nozzle in the field (NOZZLE), for both the computer-based drawn up model and the process simulator.
The results show that the closest ones to the Q_{counter} proved to be those obtained from using the computer-based model drawn up for the fixed cylindrical nozzle assembled on the methane gas well (variant A). Due to the noticed differences, we have tried to calculate the diameter of the calibrated orifice of the *fixed cylindrical nozzle equivalent* to the calculated gas flow by using the process simulator NOZZLE $_{\mathrm{Equivalent\ Simulator}}$, imposing the flow values $Q_{g\ \mathrm{Simulator}}$. in the drawn up computer-based model.
Thus it can be noticed that, for the same imposed gas flow, the diameter of the calibrated orifice of the *fixed cylindrical nozzle equivalent to* NOZZLE $_{\mathrm{Equivalent\ Simulator}}$ has *lower* values compared to the diameter of the fixed nozzle assemble at the time the measurements were made in the Bilciureşti Store (NOZZLE). For this reason it can be noticed the fact that here are differences between the Romanian methodology of calculating the gas flow that passes through a fixed nozzle and the one existing within the process simulator.
For proving the accuracy of the calculations, the *e* calculation error has been used, defined by the following calculation relation:

$$e = \frac{\left| Q_{contor} - Q_{ccalculat\,mod\,el} \right|}{Q_{contor}} \cdot 100 \quad (\%) \qquad (8)$$

The comparison of the results obtained from the computer-based design model and the process simulator in the university, for a surface unit made up of swivel flow head – heater – fixed nozzle – supply pipeline – separator, according to figure 2, is synthetically shown in table 2. The calculations were made for all the wells existing in Bilciureşti storage facility. Having a great amount of data, after running the program, leads to a more accurate image of the total daily production.

Conclusions

From the interpretation of the results the following conclusions can be drawn:
1. The comparative results of the production calculation of natural gas wells, shown in table 1, were done in the hypothesis of using the diameters of fixed nozzle in existing in the field (NOZZLE), both for the drawn up computer-based model and the process simulator.
2. Significant differences can be noticed between the gas flow value recorded at the counter panel Q_{counter} considered as reference and the values of the flow calculated by the computer-based model drawn up for the convergent fixed nozzle, assembled at a methane gas well (variant A), respectively at a well producing a mixture of natural gases (variant B) and the gas flow calculated with the process simulator. The closest results compared to Q_{counter} were the ones obtained from using the computer-based model designed for the fixed cylindrical nozzle assembled to the methane gas well (variant A). Due to these important differences, our purpose was to calculate the diameter of the calibrated orificiu of the *fixed cylindrical nozzle equivalent* to the gas flow calculated with the process DUZA$_{\mathrm{Equivalent\ Simulator}}$, imposing the values of the flow $Q_{g\ \mathrm{Simulator}}$. in the computer-based design model.
Thus, it can be observed that, for the same imposed gas flow, the diameter of the calibrated orifice of the *equivalent fixed cylindrical nozzle* NOZZLE$_{\mathrm{Equivalent\ Simulator}}$ has *lower* values than the fixed nozzle diameter assembled at the time the measurements were made in Bilciureşti Storage facility (NOZZLE). For this reason, it can be notices that there are differences between the Romanian calculation methodology of the gas flow passing through a fixed nozzle and the existing methodology within the process simulator.

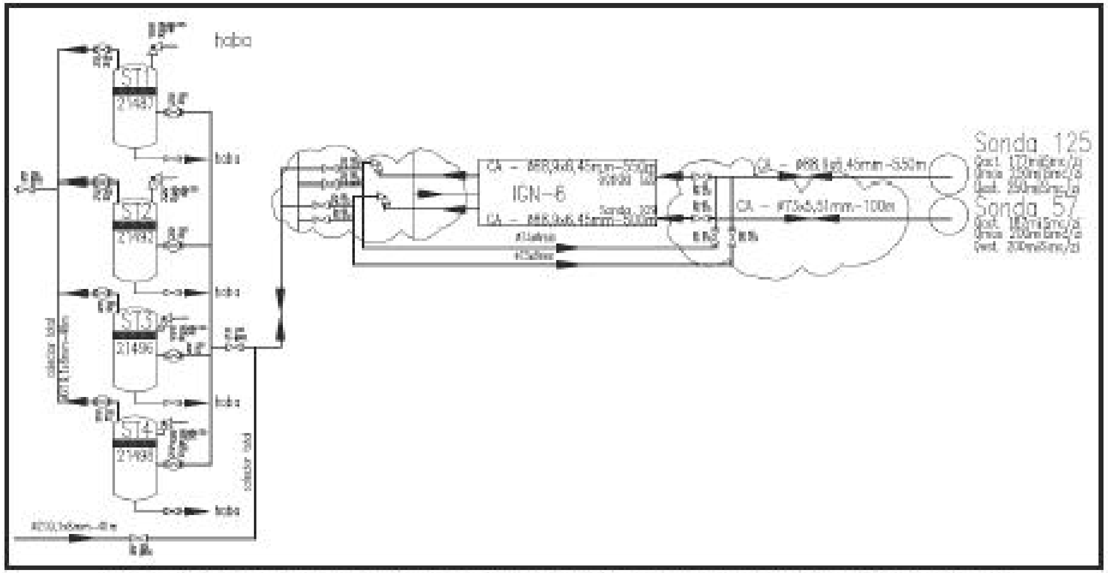
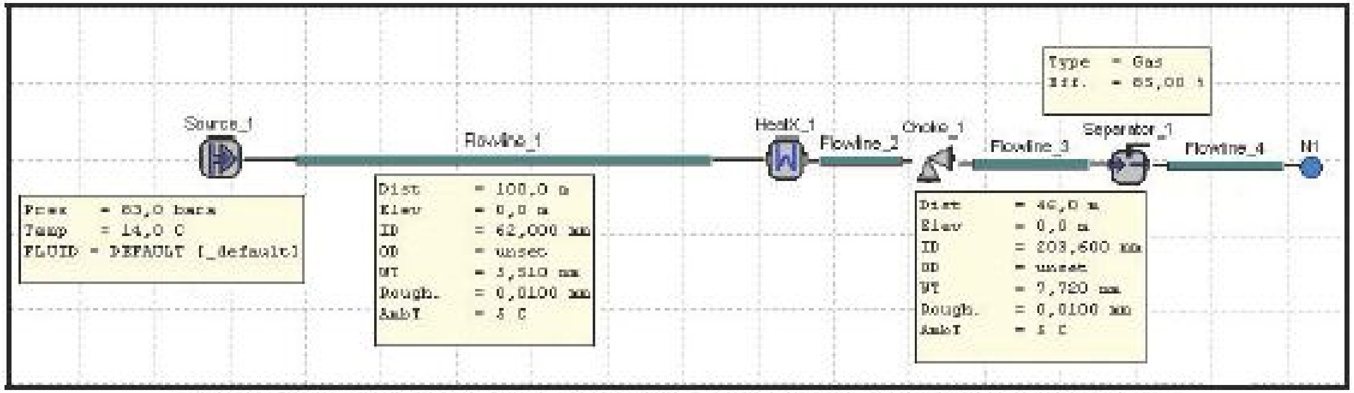


Fig. 1. Scheme of the technological flow of gas on the route swivel flow head wells 57 and 125 – heater – fixed nozzle – total separator within field cluster 57.



```
Pres   = 83,0 bara
Temp   = 14,0 C
FLUID = DEFAULT [_default]
```

```
Dist      = 100,0 m
Elev      = 0,0 m
ID        = 62,000 mm
OD        = unset
WT        = 3,510 mm
Rough.    = 0,0100 mm
AmbT      = 5 C
```

```
Type   = Gas
Eff.   = 85,00 %
```

```
Dist      = 46,0 m
Elev      = 0,0 m
ID        = 203,600 mm
OD        = unset
WT        = 7,720 mm
Rough.    = 0,0100 mm
AmbT      = 5 C
```

Fig. 2. Scheme - surface unit made up of swivel flow head wells 57 - aducție pipeline (100 m)- – heater – fixed nozzle – pipeline – total separator.

Table 1. Comparative calculation of natural gas production within field cluster 57

CLUSTER 57/ WELL	Existing NOZZLE	p_1	p_2	Q nozzle	Q counter	Prod. time	NOZZLE Cylind	$Q_{cylindA}$ nozzleRec	$Q_{cylindB}$ nozzleRec	NOZZLE Simulat	Q_E Simulator	NOZZLE Equivalent Simulator
	mm	bar	bar	thousands Nmc/day	thousands Nmc/day	Hours/day	mm	thousands Nmc/day	thousands Nmc/day	mm	thousands Nmc/day	mm
57	7	82	27	64	62	24	7	63361	63661	**7**	61088	**7**
102	16	60	27	245	238	24	16	242761	243754	**16**	219678	**15,5**
ET.107	10	88	27	137	133	24	10	139305	139986	**10**	135254	**10**
109	16	61	27	250	243	24	16	247041	248061	**16**	224380	**15,5**
115	15	59	27	211	205	24	15	209293	210141	**15**	188863	**14,5**
116	15	58	27	207	201	24	15	205550	206374	**15**	184707	**14,5**
117	17	56	27	269	262	24	17	255250	256252	**17**	226620	**16**
125	11	64	27	123	120	24	11	120770	121283	**11**	112556	**10,5**
131	14	62	27	193	188	24	14	191769	192566	**14**	157239	**13**
133	16	58.5	27	239	233	24	16	236354	237308	**16**	212490	**15**
138	14	70	27	220	214	24	14	218132	219097	**14**	203114	**13,5**
151	15	62	27	223	217	24	15	220561	221480	**15**	201201	**14,5**
155	7	80	27	62	60	24	7	61708	61996	**7**	59398	**7**
157	17	60	27	290	282	24	17	274526	275650	**17**	248160	**16**
158	16	60	27	245	238	24	16	242761	243754	**16**	219678	**15,5**
159	16	58	27	236	230	24	16	234223	235162	**16**	210153	**15**
				3214	**3126**			**3163.365**	**3176.525**		**2864.579**	

Table 2. Comparative calculation of natural gas production for the whole deposit

WELL	FIELD CLUSTER	NOZZLE	p_1	p_2	Q nozzle	Q counter	Prod. time	NOZZLE Cylind	$Q_{cylindA}$ nozzleRec	$Q_{cylindB}$ nozzleRec	NOZZLE Simulat	$Q_{convergA}$ Simulator
		mm	bar	bar	thousands Nmc/day	thousands Nmc/day	h/day	mm	thousands Nmc/day	thousands Nmc/day	mm	thousands Nmc/day
TOTAL = 11616 (thousands Nmc/day)					**11937**	**11616**			**11736.728**	**11786.2**		**10686.3**

3. The best results regarding the accuracy of the calculation of the gas flow were obtained when using *fixed cylindrical nozzle*, which for the methane gas wells variant *A*, e = 1,04 %, and for the variant admitting gas mixture *B*, e = 1,47 %.
There can be noticed differences between the calculation methodology of the gas flow Q_{nozzle}, presently used in ROMGAZ (e = 2,76 %) and the computer-based design model drawn up in the present paper for the cylindrical nozzle whose calculation accuracy is e = 1,04 %.
This confirms our recommendation of using without any hesitation the computer-based model which was made and tested, as it offers increased accuracy to the production calculation for the entire Natural Gas Storage Subsidiary of Ploieşti.

References

1. Al-Blehed, M., Sayyouh, H. M., Desouky, M. *New approach estimates viscosity of natural gases*, Petroleum Engineer International, July, 1991;
2. Arnold, K., Stewart, M. *Design of Gas – Handling Systems and Facilities, Surface Production Operations*, Volume 2, Gulf Publishing Company, Houston, Texas, 1989;
3. Dinu, F., Grigore, V. *Calculul debitului de gaze în punctele de livrare pe baza diagramelor înregistrate cu contorul diferenţial*, Documentaţie nr. 2578/1998, beneficiar Schela de Producţie Berca;
4. Dinu, F. *Extracţia gazelor naturale*. Editura Universităţii din Ploieşti, 2000;
5. Katz, D. L., Lee, L. R. *Natural Gas Engineering, Production and Storage*. McGraw-Hill Chemical Engineering Series, 1990.
6. Puşcoiu, N. *Carnet tehnic gaze naturale*. Editura Tehnică, Bucureşti, 1994;
7. Soare, Al., Strătulă, C. *Transportul şi depozitarea fluidelor*, Vol. II, Editura Universităţii din Ploieşti, 2002.

Creşterea preciziei de calcul a debitului la curgerea gazelor prin duzele fixe cilindrice

Rezumat

În lucrare se prezintă un nou model matematic, în care se utilizează atât ecuaţiile clasice, cât şi cele mai moderne corelaţii matematice apărute în literatura de specialitate privind determinarea unor parametri fizico-chimici ai gazelor şi totodată, s-a realizat un model informatic performant bazat pe algoritmul matematic elaborat anterior, în vederea proiectării şi dimensionării corecte şi rapide a diametrului orificiului calibrat normalizat a duzelor fixe cilindrice. Acurateţea tehnicii moderne de proiectare propuse are ca scop creşterea precizie de calcul a productivităţii sondelor de gaze într-o perioadă de timp mult mai mică. Totodată, lucrarea îşi propune realizarea unei program de specialitate cu impact practic şi economic, într-un domeniu important al industriei extractive de gaze.