BULETINUL Universităţii Petrol – Gaze din Ploieşti	Vol. LXII No. 1/2010	1 - 8	Seria Tehnică

Design of a Gas Feeding Pipeline for the Filiaşi – Strehaia – Drobeta Turnu Severin Area

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Abstract

This paper deals with several problems specific to the design of the natural gas transporting pipelines, with immediate practicability to the branched-type fluid transporting pipelines. The method of determining maximum operating pressure and wall thickness for steel-made pipelines described here is illustrated by a case study performed for feeding with natural gas an area exhibiting a significant energy deficit from Romania.

Key words: *natural gas, pipeline, branched-type pipeline, maximum pressure, flow rate.*

Considerations on the Design of Fluid Transporting Pipelines

Several approaches for designing steel pipelines used for oil or gas transporting are presented in the literature [1, 2]. The most appropriate calculation method for a specific case must be selected according to: the transporting system involved, the planner, the number of preset variables, the available pipe types and equipment, as well as the cost of the project. In selecting the optimal solution both the investment and operating-maintenance expenses have to be considered. It was frequently proved that a project involving fewer investments may be significantly more costly in the operational phase.

An important parameter in designing a gas transporting pipeline is the maximum pressure at which it can operate, for preset values of the inner diameter, pipe grade and specific weight. The maximum operating pressure determines the amount of gas the pipeline can carry, when the other parameters are fixed, in accordance with the physical and chemical properties of the steel used for manufacturing the pipes.

Many of the steel-made pipelines, used in the oil and gas industry all around the world, are manufactured according to the API (American Petroleum Institute) standards. The basic variant of these specifications are the API Spec 5L.

The steel pipelines are made of separate pieces of pipe assembled by welding. The maximum operating pressure for these pipelines may be established by using the tangential stress formula for thin wall pipes written, in the general case, as

$$\sigma_t = \frac{p\,D}{2\delta} \tag{1}$$

and extended for steel pipes under the form

$$\sigma_t = \frac{p\,D}{2\delta}\frac{1}{c_c\,c_l\,c_t}\ , \tag{2}$$

yielding the pressure expression

$$p = \frac{2\sigma_t\,\delta}{D}c_c\,c_l\,c_t\ , \tag{3}$$

where the pipe thickness is

$$\delta = \frac{D-d}{2}\ , \tag{4}$$

D, d are the external and internal pipe diameters, respectively, c_c – design coefficient accounting for the type of construction, c_l – longitudinal link coefficient, and c_t – working temperature coefficient.

Equation (3) may be used to calculate the pipe wall thickness necessary for preset values of operating pressure and pipe size.

The values of the c_c coefficient are given by the U.S. standard B31.8 (Code for Pressure Piping, Gas Transmission and Distribution Piping Systems), for four ranges as follows:

1. constructive type A, afferent to class 1 of locations, including desert, mountain, farm and other similar areas, for which a $c_c = 0.72$ value is attributed;
2. constructive type B, corresponding to class 2 of locations which include fan-type domains around towns, farms or industrial areas, with a specified density of population, where $c_c = 0.60$;
3. constructive type C, with class 3 of locations, including areas for residential or commercial purposes, with specified building density and type; in this case, $c_c = 0.5$;
4. constructive type D, afferent to class 4 of locations, involving domains in which buildings with many floors prevail, in presence of heavy or dense traffic, or where many other underground utilities exist; the constructive coefficient for this case is $c_c = 0.40$.

The purpose of the c_c coefficient is to reduce the admissible operating pressure of a pipe of given size, weight, and grade, as the area becomes more populated and the effect of pipe failure is more severe.

The longitudinal link coefficient c_l varies according to pipe's manufacturing method between 0.6 and 1, while the temperature coefficient c_t ranges from 1, when the operating temperature is less or equal to 121 °C, to 0.87 when the temperature equals 232 °C.

To calculate the flow rate for a long gas transporting pipeline (for which the minor head losses and the kinetic energy term are negligible), the energy conservation, continuity, and state equations are written as

$$\frac{\mathrm{d}p}{\rho} + v\,\mathrm{d}v + \frac{\lambda}{d}\frac{v^2}{2}\mathrm{d}x = 0\ , \tag{5}$$

$$M = \rho\,v\,A = \text{const.}\ , \tag{6}$$

$$\frac{p}{\rho} = \frac{p_1}{\rho_1}\ , \tag{7}$$

and associated to the boundary conditions

$$p = p_1 \text{ at } x = 0\ , \tag{8}$$

$$p = p_2 \text{ at } x = l\ , \tag{9}$$

where

$$A = \frac{\pi d^2}{4} \tag{10}$$

is the cross-sectional area, ρ, v and p are the density, average velocity and pressure of gases at the distance x from the pipe inlet, M – the mass flow rate, d – the inner diameter, and λ – the friction factor.

By integrating equation (5) while neglecting the term $v\,\mathrm{d}v$ and eliminating, based on relationships (6) and (7), the velocity v and density ρ, the pressure expression is derived as

$$p^2 = p_1^2 - \left(\frac{M}{A}\right)^2 \frac{p_1}{\rho_1}\frac{\lambda}{d}x\,, \tag{11}$$

giving for the mass flow rate, after imposing the boundary condition (10), the equation

$$M = A\sqrt{\frac{\rho_1 d\left(p_1^2 - p_2^2\right)}{p_1 \lambda l}}\,, \tag{12}$$

which can be set in terms of volume flow rate in normal state conditions (p_0, T_0) as

$$Q_0 = \frac{M}{\rho_0} = \frac{A}{\rho_0}\sqrt{\frac{\rho_1 d\left(p_1^2 - p_2^2\right)}{p_1 \lambda l}}\,. \tag{13}$$

Using the equation of state for real gases written under the form

$$\frac{\rho_1}{p_1} = \frac{1}{Z}\frac{T_0}{T}\frac{\rho_0}{p_0}\,, \tag{14}$$

relationship (13) becomes

$$Q_0 = A\sqrt{\frac{T_0 d\left(p_1^2 - p_2^2\right)}{Z T \lambda \rho_0 p_0 l}}\,, \tag{15}$$

and then, based on the equation of state written for air in normal conditions as

$$\frac{p_0}{\rho_a} = R_a T_0\,, \tag{16}$$

where ρ_a, R_a are the density and gas constant for air, the gas volume rate becomes

$$Q_0 = \frac{A T_0 \sqrt{R_a}}{p_0}\sqrt{\frac{d\left(p_1^2 - p_2^2\right)}{Z \lambda \rho_r T l}}\,, \tag{17}$$

in which

$$\rho_r = \frac{\rho_0}{\rho_a} = \frac{R_a}{R} \tag{18}$$

is the relative density of gas against air.

The friction factor may be estimated with the Weymouth formula

$$\lambda = \frac{0{,}009407}{d^{1/3}}\,. \tag{19}$$

In the case of pipes in series, equation (17) written for the pipe j (where $j = 1, 2, \ldots, n$) becomes

$$Q_0 = K_j \sqrt{\frac{p_j^2 - p_{j+1}^2}{l_j}} \ , \tag{20}$$

where the flow rate modulus K_j has the expression

$$K_j = \frac{\pi T_0 \sqrt{R_a}}{4 p_0} \sqrt{\frac{d_j^5}{\rho_r Z \lambda T}} \ . \tag{21}$$

For the pipes in parallel, the equation

$$Q_0 = \sqrt{p_1^2 - p_2^2} \sum_{j=1}^{n} \frac{K_j}{\sqrt{l_j}} \ . \tag{22}$$

is to be used.

The branched pipelines, characterized by nodal gas inputs and outputs, can be treated in two different versions [5, 6].

In the first version, the diameter d is constant and equation (20) gives for the flow rate of a sector of pipe the relationship

$$Q_j = K_j \sqrt{\frac{p_j^2 - p_{j+1}^2}{l_j}} \ , \tag{23}$$

where the flow rate modulus K_j is expressed by formula (21).

Relationship (23) gives by summation the equation

$$p_1^2 - p_{n+1}^2 = \frac{1}{K^2} \sum_{j=1}^{n} Q_j^2 \, l_j \ , \tag{24}$$

yielding

$$K = \sqrt{\frac{\sum_{j=1}^{n} Q_j^2 \, l_j}{p_1^2 - p_{n+1}^2}} \ , \tag{25}$$

from which, based on formula (21), the inner diameter d is obtained.

In the second version, when the diameter of the pipe varies in several steps, the linear relationship

$$p_j - p_{j+1} = \frac{l_j}{l} \left(p_1 - p_{n+1} \right) , \tag{26}$$

can be used, where the total length is

$$l = \sum_{j=1}^{n} l_j \ , \tag{27}$$

and then, from equation (23) written for each sector, the flow rate modulus is derived as

$$K_j = Q_j \sqrt{\frac{l_j}{p_j^2 - p_{j+1}^2}} \ , \tag{28}$$

and finally the diameter d_j of the sector is obtained.

General Aspects Concerning the Case Study

The goal of the case study presented here is the identification of technically and economically feasible solutions capable to ensure, on a medium and long term, the gas supply for the localities in the Mehedinți county, taking into account the deficit of natural gas furniture in that area. From a total of about 322,000 inhabitants, 144,000 live in the urban environment (Drobeta Turnu Severin, Strehaia, Orşova, Vânju Mare and Baia de Aramă towns), and the other 178,000 inhabitants are located in 59 communes. Moreover, the Strehaia – Turnu Severin area exhibits a significant deficit of energy resources.

Observing that this region is situated at the periphery of the National System of Natural Gas Transport (NSNGT), the following objectives must be carried out:

a) a natural gas transport pipeline which connect Drobeta Turnu Severin to the Natural Gas Transport System 2 from the Southern Oltenia;

b) a system of connected gas pipelines which feed the towns in the direction Strehaia – Drobeta Turnu Severin;

c) several gas regulation, measurement and delivery (RMD) stations at the inlet in the towns in which natural gas distribution networks will be established, intended to set specific parameters, measure and deliver the gas to the distribution company which will be set up in the area.

The actual purpose of this study is to establish:

1. the economic feasibility of the new natural gas transporting pipeline system;
2. the stages of investment effort correlated to the echeloned achievement of the gas transporting system in the area.

The geographical characteristics of the site, which is situated in the Dolj and Mehedinți counties, are: seismic area grade E, seismic coefficient K_s = 0.12; frost depth 0.9 m; average annual temperature ranging between 9.3 °C and 10 °C; the maximum temperature $T_{\max}$ = 48.5 °C, the minimum temperature $T_{\min}$ = –33 °C (in Strehaia); wavy land with benchmarks between +68 m and +373 m beyond sea level and annual precipitation amounts in the range (95…800) mm/year.

Estimating the Natural Gas Flow Rate Needed for the Filiaşi – Strehaia – Turnu Severin Area

For establishing the gas flow rate necessary for feeding the gas consumers in the area, several methods were used:

- the data delivered by the Mehedinți Regional Council based on the questionnaires issued by the designer;
- for the towns in which gas distribution networks will be set up, excepting Drobeta Turnu Severin, the gas consumption is defined by allocating a 1.67 m_N^3/hour for each household, and a 0.47 m_N^3/hour for each flat, as well as thermal power stations with 2.3 m_N^3/hour or 5 m_N^3/hour gas consumptions for the social and cultural objectives, as a function of the actual number of rooms;
- for Drobeta Turnu Severin, the gas rates allocated are: 1.67 m_N^3/hour/household, 0.47 m_N^3/hour/flat, thermal power stations with 5 m_N^3/hour or 10 m_N^3/hour gas consumptions for the social and cultural objectives, depending on their size, and a flow rate of 83.932 m_N^3/hour for industry, by applying a simultaneity coefficient of 0.7.

Making allowance for the fact that gas consumption during winter is 2.5…2.8 times greater than the gas consumption in summer, the annual gas flow rate used to calculate the economical efficiency is defined as

$$Q_{yr} = Q_c\, t_1 + c_s\, Q_c\, t_2 \;, \tag{29}$$

where Q_{yr} is the annual gas flow rate, $\mathrm{m_N^3}$ /year, Q_c – the calculation gas flow rate, t_1 = 185 days 24 hours = 4,440 hours – the winter conventional duration, t_2 = 180 days · 24 hours = 4,320 hours – the summer conventional duration, and c_s = 0.7 – ratio of summer and winter gas consumptions.

The layout of the gas transporting pipeline, the towns included into the project and the positions of the RMD stations are plotted into the figure 1.

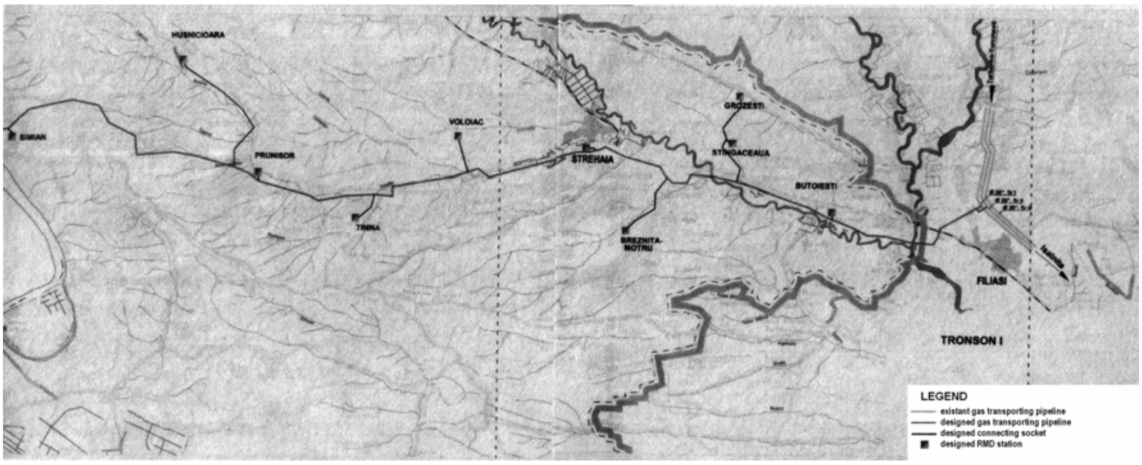

Fig. 1. Layout of the natural gas transporting system

Pipeline Design

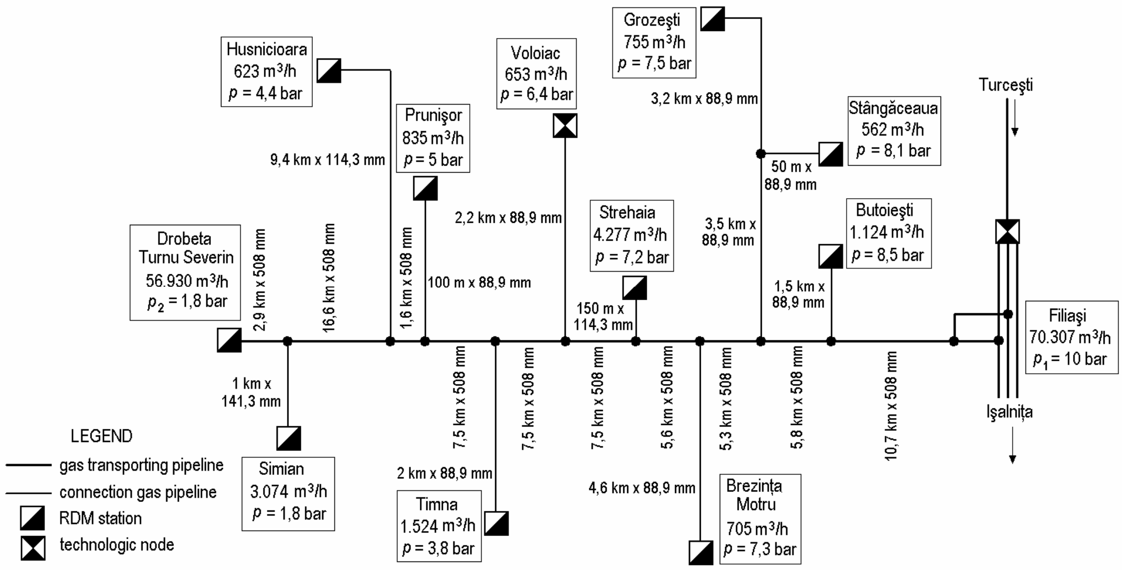

Fig. 2. Gas feeding diagram and calculated parameters

The gas transporting pipeline Filiaşi – Strehaia – Drobeta Turnu Severin, having a length of 73 km, has been designed according to the Departmental Normative [7], using the following parameters: Q_{max} = 90,000 m_N^3/hour, Q_{min} = 10,000 m_N^3/hour, maximum pressure at the point of linkage with the Turburea – Işalniţa pipeline p_{max} = 2.5 MPa. The inner diameter was calculated as $d = D_n$ = 500 mm and the pipe wall thickness was determined using equation (3).

The results of the calculations correlated to the gas feeding scheme of the towns involved (presented in figure 2) are listed in Table 1.

The incomes which will recover the investment were determined using the tariffs provided by the ANRGN Order No. 594/7.08.2003, while applying the Discounted Cash Flow Method, and the resulted values are listed in Table 2.

Table 1. Calculated parameters of the gas feeding system

Segment	Q_0, m^3/hr.	l, km	p_1, MPa	p_2, MPa	v_{max}, m/s	Noise, dB	D, mm	δ, mm	Capac, m^3_{st}	Weight t
Filiaşi–Node 1	70307	10.7	1.00	0.90	10.4	45	508.0	10.1	21881	834.0
Node 1–RDM Butoeşti	1124	1.5	0.90	0.85	6.7	14	88.9	5.4	74	14.0
Node 1–Node 2	69183	5.8	0.90	0.85	10.8	46	508.0	10.1	10996	452.1
Node 2–Node 2'	1317	3.6	0.85	0.81	4.8	15	114.3	5.6	294	43.9
Node 2'–RDM Sting.	562	0.1	0.81	0.81	3.4	9	88.9	4.9	5	0.8
Sting.–RDM Grozeşti	755	3.2	0.81	0.75	5.1	11	88.9	5.4	142	30.0
Node 2–Node 3	68621	5.3	0.85	0.80	11.3	46	508.0	10.1	9495	413.1
Node 3–RDM Brezinţa	705	4.6	0.80	0.73	4.9	10	88.9	5.4	200	43.1
Node 3–Node 4	67916	5.6	0.80	0.74	12.0	46	508.0	10.1	9437	436.5
Node 4–RDM Strehaia	4277	0.15	0.74	0.72	17.1	29	114.3	5.6	11	1.8
Node 4–Node 5	63639	7.5	0.74	0.67	12.3	46	508.0	10.1	11692	584.6
Node 5–RDM Viloiac	653	2.2	0.67	0.64	5.1	10	88.9	5.4	83	20.6
Node 5–Node 6	62986	7.5	0.67	0.59	13.6	47	508.0	10.1	10589	584.6
Node 6–RDM Tâmna	1524	2.0	0.59	0.38	18.0	22	88.9	5.4	60	18.7
Node 6–Node 7	61462	7.5	0.59	0.51	15.1	47	508	10.1	9405	584.6
Node 7–RDM Prunişor	835	0.1	0.51	0.50	7.9	13	88.9	5.4	3	0.9
Node 7–Node 8	60627	1.6	0.51	0.49	15.4	48	508.0	10.1	1643	124.7
Node 8–RDM Husnic.	623	9.4	0.49	0.44	3.8	11	114.3	5.6	464	114.5
Node 8–Node 9	60004	16.6	0.49	0.24	26.4	53	508.0	10.1	15171	1293.9
Node 9–RDM Simian	3074	1.0	0.24	0.18	23.0	30	141.3	5.9	43	15.2
Node 9–Turnu Severin	56930	2.9	0.24	0.18	30.3	54	508.0	10.1	1734	226.0

Table 2. Results of the economical analysis by the Discounted Cash Flow Method

Year	Invest-ment, euro	Gas flow, 10^6 m^3/yr	Gross pay, euro	Operation expenses, euro	Redemp-tion, euro	Net pay, euro	Cash flow, euro	PV, euro	NPV, euro
0	3645473	31,92	203245	440	199798		–3645473	–3645473	–3645473
1	6285586	451,22	2872671	1650	547373	2255	–6083532	–5632900	–9278373
2	943261	524,80	3341151	107522	616445	1742736	1346848	1154705	–8123668
3		524,80	3341151	108732	616445	1962888	2579333	2047558	–6076110
4		524.80	3341151	108732	616445	1961980	2578426	1895220	–4180890
5		524,80	3341151	108732	616445	1961980	2578426	1754833	–2426057
6		524,80	3341151	108732	543852	2016426	2560277	1613409	–812647
7		524,80	3341151	108732	418601	2110364	2528965	1475627	662979
8		524,80	3341151	108732	399748	2124503	2524252	1363775	2026754
9		524,80	3341151	108732	399748	2124503	2524252	1262754	3289508
10		524,80	3341151	108732	399748	2124503	2524252	1169217	4458725
11		524,80	3341151	108732	399748	2124503	2524252	1082608	5541333
12		524,80	3341151	108732	399748	2124503	2524252	1002415	6543748
13		524,80	3341151	108732	399738	2124511	2524249	928161	7471909
14		524,80	3341151	108732	399178	2124931	2524109	859361	8331270
15		524,80	3341151	108732	398063	2125767	2523830	795617	9126887
16		524,80	3341151	108732	397794	2125969	2523763	736662	9863549
17		524,80	3341151	108732	397710	2126032	2523742	682089	10545638
18		524,80	3341151	108732	360326	2154070	2514396	629225	11174863
19		524,80	3341151	108732	360326	2154070	2514396	582616	11757479
*		9404,74	59875491	1849326	8270389	37316494	34713014	11757479	

Conclusions

The selection of a design method for gas transporting pipelines among those presented in the literature depends on the planner, the number of preset variables, the available pipes and equipment, as well as the cost of the project.

The maximum operating pressure of a gas transporting pipeline, for pre-established values of diameter, pipe grade and specific weight, determines the gas flow rate the pipeline can transport, when the other parameters are fixed, in correlation with the physical and chemical properties of the pipe material.

The maximum operating pressure of a fluid transporting pipeline is determined on the basis of the tangential stresses afferent to thin plates, customized for thin-wall pipes.

By appealing to the methodology for determining gas flow rates afferent to gas feeding of the towns along the Filiaşi – Strehaia – Drobeta Turnu Severin pipeline layout, this conduit was treated as a constant-diameter branched pipeline, having known pressure values at the ends of each branch, which permits the calculation of flow modulus and inner diameter.

The Discounted Cash Flow Method was used to determine the recovery of the investment involved by the construction of the pipeline under study.

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Proiectarea unei conducte de alimentare cu gaze pentru zona Filiaşi – Strehaia – Drobeta Turnu Severin

Rezumat

Lucrarea tratează câteva probleme specifice proiectării conductelor de transport al gazelor naturale, cu aplicabilitate directă la cazul conductelor de transport cu ramificații. Procedeul de calcul al presiunii maxime de operare şi grosimii de perete a conductelor de transport confecționate din oțel descris în lucrare este ilustrat printr-un studiu de caz, realizat pentru alimentarea cu gaze naturale a unei zone cu deficit energetic semnificativ din România.