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Hydraulic Analysis and Performance Evaluation of Ring Gas Distribution Networks

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Abstract. *This article considers the methodology of hydraulic calculation of ring gas distribution systems on the example of a network with one supply and one withdrawal node. In the course of the analysis the advantages of the ring structure over the beam structure are revealed, the regularities of pressure and gas flow distribution are substantiated, and the methods of calculation of looped sections of main gas pipelines are considered. Particular attention is paid to the situation where the ring network includes a single feeder node and a limited number of withdrawal nodes. The analysis concludes with a discussion of a computational experiment.*

Keywords: *Hydraulic calculation, annular and radiant network, gas pipeline, node, supply, withdrawal, looping, computational experiment.*

For hydraulic calculation of the static state of a separate section of the gas pipeline network, if the difference in level height of the gas pipeline axis is not significant (<200 м), a system of quasi-one-dimensional equations of conservation of momentum and mass of gas, as well as the equation of state of real gas is used [1]:

$$\begin{cases} \frac{dP}{dx} + \frac{\lambda \rho w|w|}{2D} = 0 \\ \rho w F = const \\ P = Z\rho RT \end{cases} \qquad (1)$$

The first equation of this system expresses the law of conservation of gas momentum, according to which the pressure drop along the flow direction is due to overcoming the frictional resistance force. The second equation expresses the law of conservation of mass of transported gas: the mass flow rate of gas M (kg/hour) remains constant along the length of a separately taken elementary section of the network. In the paper, to facilitate the application of the resulting formulas in practice, the commercial flow rate Q (nm^3/hour) is used - the volumetric flow rate of gas reduced to normal condition. The third equation is the equation of the state of real gas taking into account the coefficient Z of its supercompressibility.

The pressure P, density ρ and velocity w of the gas are taken as average integral values of the pipeline cross-section and vary along the length of the section. Diameter D, cross-sectional area $S = \frac{\pi D^2}{4}$, and resistance coefficient λ take fixed values for an individual linear section of the network. The temperature T, gas constant R and supercompressibility coefficient Z of the transported gas are assumed to be constant throughout the entire pipeline network. Moreover, if the static gas pressure is less than 1.2 MPa (e.g. in a gas distribution network), the value of the coefficient Z is assumed to be 1. For larger pressure values, the value of Z can be found from the solution of the Redlich-Kwong equation for the average pressure value on the section or in the network [2].

System (1) has a solution of the form

$$P_K^2 = P_H^2 - blQ^2, \quad (2)$$

where P_H, P_K - pressure values at the beginning and end of the section according to the flow direction; l - length of the section. Constant

$$b = \frac{16\lambda p_{ct}^2 T}{\pi^2 D^5 ZRT_{ct}^2} = const \quad (3)$$

in formula 2 takes into account the hydraulic parameters of the gas pipeline (diameter and resistance coefficient) and thermodynamic parameters of the transported gas (standard temperature, pressures and gas temperature) [3].

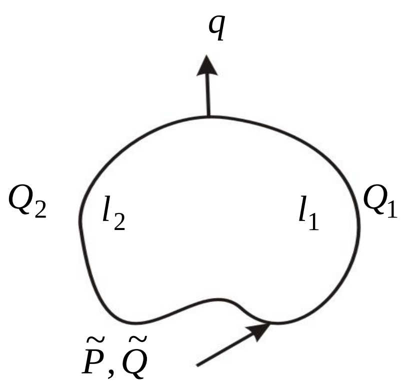

Fig. 1. Schematic diagram of a ring network with gas withdrawal and supply

When analyzing the advantages of a ring network, we will limit ourselves to the consideration of the simplest looped network with the same diameter D and resistance coefficient λ , when the ring has one gas inlet and outlet point each.

Suppose that gas delivery to the consumer is made along the arcs of the ring with lengths l_1 and l_2 , with $l_1 < l_2$ (Fig. 1).

On the basis of Kirchhoff's first law at the points of gas extraction and gas supply:

$$\begin{cases} q = Q_1 + Q_2, \\ \tilde{Q} = Q_1 + Q_2. \end{cases}$$

Here Q_1 and Q_2 are volumetric (commercial) gas flow rates along the first and second arcs of the ring, reduced to normal conditions. If the condition $q = \tilde{Q}$ is fulfilled, the solution of the problem does not depend on time, because gas does not accumulate and does not decrease in the network with the lapse of time.

Let's make formulas for calculating the pressure at the outlet point, assuming equal supply pressure : $\tilde{P}$

$$\begin{cases} P_{q(1)}^2 = \tilde{P}^2 - bQ_1^2 l_1, \\ P_{q(2)}^2 = \tilde{P}^2 - bQ_2^2 l_2. \end{cases}$$

In these equations it was assumed that at the point of branching the value of gas pressure is greater than at the point of merging of flows (withdrawal): $\tilde{P} > P_{q(1)}$ and $\tilde{P} > P_{q(2)}$. Moreover, according to the analog of Kirchhoff's second law, in the communicating sections of the arcs the pressure has no break, i.e. in the end nodes of both arcs the pressure has the same value $P_q = P_{q(1)} = P_{q(2)}$. In this connection from the last system we obtain

$$Q_1^2 l_1 = Q_2^2 l_2.$$

Since $Q_2 = \tilde{Q} - Q_1$, the quadratic equation with respect to Q_1 follows from this equality:

$$(l_1 - l_2)Q_1^2 + 2\tilde{Q}l_2Q_1 - \tilde{Q}^2l_2 = 0.$$

At hydraulic symmetry $(l_1 = l_2)$ the equation transforms into a linear equation, the only solution of which is

$$Q_1 = Q_2 = \tilde{Q}/2.$$

This is a special case of two parallel filaments, when the filaments have the same hydraulic indices. Since the lengths of the filaments are the same, the uniqueness of the solution is not in doubt.

Let us determine the area costs of Q_1 and Q_2 , when the arcs have different lengths (at). $l_1 < l_2$

Let's calculate the discriminant of the quadratic equation

$$\mathcal{D} = 4\tilde{Q}^2l_2^2 + 4Q^2l_2(l_1 - l_2) = 4\tilde{Q}^2l_1l_2 = \left(2\tilde{Q}\sqrt{l_1l_2}\right)^2$$

and determine the positive solution of the quadratic equation, which is the gas flow rate along the first arc of the ring

$$Q_1 = \frac{-2\tilde{Q}l_2 + 2\tilde{Q}\sqrt{l_1l_2}}{2(l_1 - l_2)} = \frac{\sqrt{l_1l_2} - l_2}{l_1 - l_2}\tilde{Q} = \frac{\sqrt{l_2}}{\sqrt{l_1} + \sqrt{l_2}}\tilde{Q}.$$

The corresponding gas flow rate on the second arc is

$$Q_2 = \tilde{Q} - Q_1 = \frac{\sqrt{l_1}}{\sqrt{l_1} + \sqrt{l_2}}\tilde{Q}.$$

According to these relationships, a larger volume of gas $(Q_1 > Q_2)$ is transported along the short arc and the pressure drop will be more intense (Fig. 2).

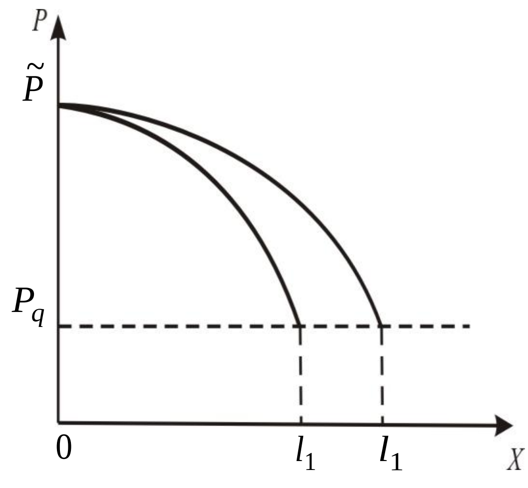

Figure 2. Pressure variation along the arc length of the annular gas pipeline according to the quadratic law of resistance

Suppose that the pressure values $\tilde{P}$ and P_q are set at the gas inlet and outlet points. Let us estimate the throughput (capacity) of the ring and its individual arc when the other arc is not functioning.

The capacities of individual arcs in a ring structure are as follows

$$Q_1 = \sqrt{\frac{\tilde{P}^2 - P_q^2}{b\,l_1}}\,,.Q_2 = Q_1\sqrt{l_1/l_2}$$

Then the total capacity of the ring is

$$Q_{(k)} = Q_1 + Q_2 = \sqrt{\frac{\tilde{P}^2 - P_q^2}{b\,l_1}}\left(1 + \frac{\sqrt{l_1}}{\sqrt{l_2}}\right) = \sqrt{\frac{\tilde{P}^2 - P_q^2}{b}}\,\frac{\sqrt{l_1} + \sqrt{l_2}}{\sqrt{l_1l_2}}$$

.

Similarly, we obtain the throughput values for the case of functioning of the first arc only (failure of the second arc)

$$Q_{(1)} = \sqrt{\frac{\tilde{P}^2 - P_q^2}{b}}\,\frac{1}{\sqrt{l_1}}$$

and only the second arc (failure of the first arc)

$$Q_{(2)} = \sqrt{\frac{\tilde{P}^2 - P_q^2}{b}} \frac{1}{\sqrt{l_2}}.$$

By honorable division of expenses we obtain

$$Q_{(k)} : Q_{(1)} : Q_{(2)} = (\sqrt{l_1} + \sqrt{l_2}) : \sqrt{l_2} : \sqrt{l_1}.$$

The comparison shows that for fixed values of $\tilde{P}$ and P_q the performance advantage of the ring network is obvious. At $l_1 = l_2$ a case of hydraulic symmetry is formed.

Let us estimate the energy loss on transportation of a fixed gas flow rate through the ring and its individual arcs. In this case, the measure of energy loss is the statistical pressure drop.

According to the obtained formulas for the ring network

$$P_{2(k)}^2 = P_1^2 - b\tilde{Q}^2 \frac{l_1 l_2}{\left(\sqrt{l_1} + \sqrt{l_2}\right)^2}.$$

Accordingly, for its separately functioning arcs

$$P_{2(1)}^2 = P_1^2 - b\tilde{Q}^2 l_1$$

и

$$P_{2(2)}^2 = P_1^2 - b\tilde{Q}^2 l_2.$$

A comparison of the pressure values at the ends of individual arcs shows that a larger arc length results in a greater pressure loss. I.e. under the condition $l_1 < l_2$ the inequality $P_{2(1)} > P_{2(2)}$ takes place.

Under these assumptions, we compare the final pressure value in the ring $P_{2(k)}$ with $P_{2(1)}$, i.e. with the arc of lower pressure loss. The ratio of the pressure drop squared of these equalities is

$$\frac{l_1 l_2}{\left(\sqrt{l_1} + \sqrt{l_2}\right)^2} : l_1 = \frac{l_2}{\left(\sqrt{l_1} + \sqrt{l_2}\right)^2} = \frac{l_2}{l_2 + \left(2\sqrt{l_1 l_2} + l_1\right)}.$$

This fraction has a value that is less than one because of the positivity of the expression in the last bracket. Then the subtraction in $P_{2(k)}^2$ will be less than the subtraction in $P_{2(1)}^2$. Hence the inequalities

$$P_{2(k)}^2 > P_{2(1)} > P_{2(1)},$$

which is equivalent to writing

$$P_{2(k)} > P_{2(1)} > P_{2(2)}.$$

It follows that by using a ring gas supply structure, the loss of statistical pressure is reduced and consequently the operating costs are reduced.

We compare the accumulation abilities of the ring and its separately functioning arcs.

The mass accumulated in the gas pipeline section with length l and cross-sectional area F is determined by the formula

$$M_\Sigma = F\int_0^l \rho(x)dx.$$

It can be represented through the density of the gas in the standard condition ρ_{st} :

$$M_{\Sigma} = \rho_{st} V_{\Sigma},$$

where $V_{\Sigma} = V_{\Phi} \dfrac{P_{cp} T_{st}}{Z_{cp} P_{st} T_{cp}}$ - gas volume reduced to standard condition with T_{st}, P_{st}; $V_{\Phi} = Fl$ - physical volume of the gas pipeline section; Z_{cp}, P_{cp}, T_{cp} - average values of gas supercompressibility coefficient, static pressure and gas temperature for the considered gas pipeline.

Accordingly, the mass of accumulated gas in the pipeline section is determined by the product $V_{\Phi} P_{cp}$, since the other parameters in the formula are constant.

For the independently functioning first arc we have

$$(V_{\Phi} P_{cp})_1 = \frac{\pi D^2}{4} \int_0^{l_1} P(x)dx,$$

and for the longer one, the second one

$$(V_{\Phi} P_{cp})_2 = \frac{\pi D^2}{4} \int_0^{l_2} P(x)dx.$$

These formulas clearly demonstrate the relationships . $M_{\Sigma 2} > M_{\Sigma 1}$

We now compare the values of $V_{\Phi} P_{cp}$ for the ring and the separately functioning 2nd arc.

By virtue of $l_1 + l_2 > l_2$ and, since the cross-sectional areas of the compared gas pipelines are the same, we have . $(V_{\Phi})_K > (V_{\Phi})_2$

The average value of the site pressure, under the quadratic law of resistance, is defined through the inlet ($\tilde{P}$) and outlet (P_q) pressures in the form [3]

$$P_{cp} = \frac{2}{3}\left(\tilde{P} + \frac{P_q^2}{\tilde{P} + P_q}\right).$$

To compare $(P_{cp})_K$ and $(P_{cp})_2$, let's make up the difference : $(P_{cp})_K - (P_{cp})_2$

$$(P_{cp})_{(k)} - (P_{cp})_{(2)} = \frac{2}{3}\left(\frac{P_{q(k)}^2}{\tilde{P} + P_{q(k)}} - \frac{P_{q(2)}^2}{\tilde{P} + P_{q(2)}}\right) =$$

$$= \frac{2}{3} \frac{\tilde{P}\left(P_{q(k)}^2 - P_{q(2)}^2\right) + P_{q(2)} P_{q(k)}\left(P_{q(k)} - P_{q(2)}\right)}{\left(\tilde{P} + P_{q(k)}\right)\left(\tilde{P} + P_{q(2)}\right)}.$$

Since the expressions in each of the brackets have positive values (the condition $P_{q(k)} > P_{q(2)}$ proved above), we obtain

$$(P_{cp})_K > (P_{cp})_2 .$$

On the basis of the theorem on inequalities with positive terms from inequalities $(V_{\Phi})_K > (V_{\Phi})_2$

and $\left(P_{cp}\right)_K > \left(P_{cp}\right)_2$ we obtain

$$\left(V_\Phi P_{cp}\right)_K > \left(V_\Phi P_{cp}\right)_2 .$$

Hence, taking into account $M_{\Sigma 2} > M_{\Sigma 1}$, the final estimate for accumulating abilities follows

$$\left(M_\Sigma\right)_K > \left(M_\Sigma\right)_2 > \left(M_\Sigma\right)_1 .$$

Thus, it was proved that the ring structure is also expedient from the point of view of the accumulation capacity of the network, which to a certain extent contributes to the smoothing of irregularities in gas consumption at high operating pressures in the network.

In the course of proving the advantages of the looped network in relation to the beam structure, we have obtained the formulas that are necessary to carry out hydraulic calculations in normal and emergency situations.

For completeness, we present formulas that take into account the different hydraulic indices of the arcs

$$Q_1 = \frac{\sqrt{b_2 l_2}}{\sqrt{b_1 l_1} + \sqrt{b_2 l_2}} \tilde{Q}, \quad Q_2 = \frac{\sqrt{b_1 l_1}}{\sqrt{b_1 l_1} + \sqrt{b_2 l_2}} \tilde{Q} ,. P_q = \sqrt{\tilde{P}^2 - b_1 Q_1^2 l_1}$$

If the lower limit of the permissible value P_{q*} of the pressure in the extraction unit is set, the value of the supply pressure is restricted from below to ensure a normal situation . $\tilde{P} > \tilde{P}_* = \sqrt{P_{q*}^2 + b_1 Q_1^2 l_1}$

Based on the obtained formulas, let us compare the main characteristics of the ring and beam networks:

Parameter	Ring network	Radial network
Performance	Higher due to alternative gas delivery routes	Limited to one direction of flow
Pressure losses	Below because of the possibility of redistributing the flow	Higher with increasing distance
Network flexibility	High, load shifting possible	Low, failure of one branch is critical
Stability of operation	Resistant to temporal irregularities in consumption	Possible sudden spikes in blood pressure
Gas accumulation	Large, which helps to smooth out flow variations	Smaller, does not compensate for peak loads

Thus, a ring network has advantages in terms of reliability, uniformity of pressure distribution and reduced operating costs.

The following conclusions can be drawn on the basis of the calculations performed:

1. The ring network outperforms the beam network in terms of performance, flexibility and resilience to abnormal situations.
2. Reduced pressure losses in the ring structure lead to reduced energy consumption.
3. The large storage capacity allows for smoothing out consumption peaks.

Thus, the use of a ring gas supply scheme is more rational in terms of operation and economic efficiency.

Literature

1. Pipeline transportation of oil and gas. / Under general ed. by V.A.Yufin. - M.: Nedra, 1988. -368 c.
2. Korotayev Y.P., Shirkovsky A.I. Gas production, transportation and underground storage. - Moscow: Nedra, 1997. - 487 c.
3. Novoselov V.F., Golyanov A.I., Muftakhov E.M. Typical calculations at designing and operation of gas pipelines.- M.:Nedra,1982 г .-136 p.
4. Sadullaev R., Yuldashev B.E. Computer modeling of processes of functioning of pipeline systems/ Reports of Scientific-theoretical and methodical-practical conference of faculty of Tashkent regional pedagogical institute - Angren, May 22-23, 2003. - C. 200-202.
5. Sadullaev R., Yuldashev B.E. Construction of tracing algorithm and information support of pipeline systems/Systems and methods of information processing and analysis: Collection of scientific articles. -M: Hot Line Telecom, 2005. - c.107-115.
6. Sadullaev R., Yuldashev B.E. Creation of information support of pipeline networks// Collection of Scientific and Practical Conference of TOPPI, Fan and Technology, 2004. - C.208-211.
7. Khujaev I.K., Yuldashev B.E., Kukanova M.A. Mathematical model of a circular gas pipeline with uniform path gas withdrawal// Journal "Reports of the Academy of Sciences of the Republic of Uzbekistan". No. 6, Tashkent-2011. - C.10-12.
8. Khujaev I.K., Yuldashev B.E., Kukanova M.A. Efficiency of the ring structure of the gas pipeline and the algorithm for calculating its hydrodynamic indicators // Voprosy Computatel'noy i Applied Math. Analytical methods and computational algorithms for solving problems of mathematical physics. - Tashkent, 2011. - Vyp. 126. - C.132-143.
9. Yuldashev B.E. Creation of a computer model for hydraulic calculation of the ring network of gas pipelines with one feeder node// Scientific and Practical Journal "Branch Aspects of Technical Sciences" № 3(15), 2012. - C.37-40.
10. Yuldashev B.E. Creation of computer model for calculation of hydraulic linkage of gas networks// Journal "Problems of Informatics and Energy" № 6, Fan,2008 г . - C.88-92.
11. Yuldashev B.E. Creation of computer models of pipeline networks// Joint issue on materials of republican scientific-practical conference "Modern control and information systems". - T.: October 2-3, 2003. - C. 128-131
12. Yuldashev B.E. Management and creation of a computer model for calculating the hydraulic linkage of gas networks// Journal "Intellectual Property Management" № 1, 2011. - C.20-23.
13. Yuldashev B.E., Sadullaev R. Computer modeling of processes of functioning of pipeline systems// Collection of Scientific and Practical Conference of TOPPI, Fan and Technology, 2003. - C.200-202.
14. Yuldashev B.E., Khujaev I.K., Kukanova M.A. Hydraulic calculation of "crush" in a circular gas pipeline with two feeds and one withdrawal// Sochi, "European Researcher". № 1(16), 2012. - C.30-36