GRAPH-ANALYTICAL METHOD FOR ESTIMATION OF FLOWS DISTRIBUTION IN LOW-PRESSURE GAS TRANSPORT SYSTEMS

Zhivko KOLEV[+]*, Pencho ZLATEV*[+]*, Valentin BOBILOV*[+]*, Ilia ILIEV*[+]*,*
Georgi GENCHEV[+]*, Plamen MUSHAKOV*[+]

[+]UNIVERSITY OF RUSE "ANGEL KANCHEV", Bulgaria.

Abstract. The purpose of the work is to create a simplified physical model of a closed local gas system at low pressure (up to 500 mbar) for supply of consecutively connected single consumers or group consumers. Graph-analytical method for estimation the distribution of flows in ring and linear system for transport of technical fluids has been developed.
Keywords: graph-analytical method, closed local gas system, signle gas consumers, group of gas consumers, distribution of flows.

1. INTRODUCTION

In the transport process of isothermal incompressible fluids (water, liquefied petroleum gases, lubricants, diesel, oil, etc.) correction in the density of the fluid does not have to be done. In gaseous products (gas, acetylene, oxygen, compressed air, etc.) where are substantial pressure drops there should be introduced a correction for both the density and the compressibility factor.

The use of ring (closed) gas transport systems is determined by a variety of reasons - to ensure uniform and with a lower risk gas supply process, ensure quantity of fluid in duplicate gas distribution points with low let in ability, providing gas supply to customers in conditions of future infrastructure reconstructions, and so etc. [2, 3, 4].

The tasks that need to solve the developed graph-analytical method are:

► evaluation of the permeability capacity of the main contour and the deviations for the individual consumers in nominal work conditions;

► evaluation of the permeability capacity of the main contour and the deviations for the individual consumers in work conditions different than nominal (failures, introducing of new consumers, etc.);

► evaluation of the pressure drop in any contour section in nominal and different than nominal work conditions.

2. METHODOLOGY

In Figure 1 is shown a principal scheme of a gas supply ring system with one or more external gas sources (the second source is indicated by a dotted line) [1].

The input factors which are necessary for carrying out the specific calculations are:

- estimated consummated quantity of natural gas at nominal (or non-nominal) operation conditions for each of contour consumers Q_n, Nm^3/h;

- geometric and hydrodynamic characteristics of the gas pipe sections (lengths l_i, m ; specify diameters d_i, m ; type of local resistances ξ_i ; specify coefficients of friction λ_i ; average density of the natural gas $\rho, kg/m^3$);

- nominal working pressure of the circular gas transport system p, mbar;

- minimum working pressure at the point of supply to each consumer $p_{n,min}$, mbar.

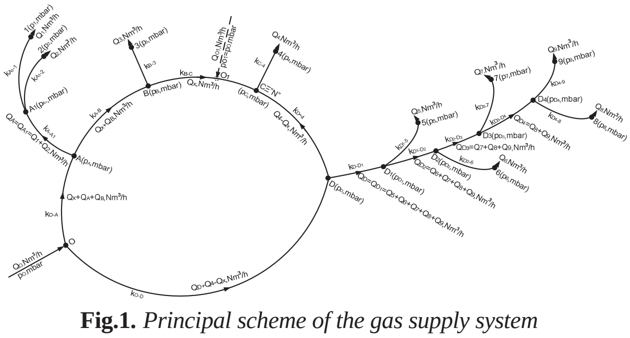

Fig.1. *Principal scheme of the gas supply system*

2.1. Analitycal method for identification of the « neutral » point in the circular contour

Evaluation of the permeability capacity of the main contour in nominal or non-nominal operation conditions has been done by specifying the location of the "neutral" point "N" and the balance sheet of the material flows. The "neutral" point in the main circular contour is the point where the gas enters from the two branches of the contour (left and right). Therefore, the sum of pressure drops in the left branch is equal to the sum of pressure drops in the right branch [1].

The points of the circular contour, leading to individual consumers or groups of consumers have been identified by letters, respectively, A, B, C, D and the point of the incoming gas flow in the circuit (the natural gas source) - with the "O". The gas consumers have been marked with numbers (from 1 to 9).

Drawing equation for pressure drops equality in the contours "left" and "right" to the “neutral” point "N", it has been reported that the only unknown parameter is the gas flow "Q_x", entering the point "N", for example from the left.

The pressure drops in the pipeline contour have been determined by the classical equation [2, 3, 4]:

$$\Delta p_{ij} = k_{ij}.Q_{ij}^{\ 2}, \text{ Pa} \qquad (1)$$

where: k_{ij} is the characteristic of the pipe section i-j, $Pa/(Nm^3/h)^2$;

Q_{ij} – transported quantity of natural gas in the pipe section i-j, Nm^3/h.

The characteristic of the pipe section i-j has been determined by the equation:

$$k_{ij} = \left(\frac{\lambda_{ij}.l_{ij}}{d_{ij}} + \sum \xi_{ij} \right) . \frac{8.\rho}{\pi^2.d_{ij}^{\ 4}}, \frac{\text{Pa}}{(\text{Nm}^3/\text{h})^2} \qquad (2)$$

For specify the "neutral" point location in the circular contour the balance equation (3) has been used [1]:

$$\sum_{i,j}^{L} k_{ij} \left[\left(\sum_{I}^{n} Q_I + Q_x \right)^2 \right] = \sum_{i,j}^{R} k_{ij} \left[\left(\sum_{I}^{n} Q_I + Q_N - Q_x \right)^2 \right] \qquad (3)$$

where: Q_I is the current quantity of gas flowing from left (L) or right (R) in the direction of the "neutral" point "N", Nm^3/h;

Q_N - nominal quantity of natural gas in the "neutral" point "N", Nm^3/h.

The identification process is iterative, so it is logical the "neutral" point to be searched in the center of mass load as the first approach. If there is improper selection (incorrect identification), the roots of the algebraic equation describing the pressure drops on opposite points will be imaginary.

The analytical solution of equation (3) may lead to the following results:

► Receive at least one real root - it is assumed to be reliable and based on it the final distribution of natural gas within the contour is assumed as follows:

- from the left contour brunch: $Q_{N_L} = Q_x$, Nm^3/h;
- from the right contour brunch: $Q_{N_R} = Q_N - Q_x$, Nm^3/h.

► Lack of real root - the procedure requires re-identification of the "neutral" point "N". It is advisable to make the choice of the next point along the contour (left L or right R) with less gas flow.

The next step is re-solving the equation (3), etc. to find a real root for Q_x.

After determination the exact distribution of the fluid to the consumers connected to the circular contour the next step is procedure of more precise determination of the fuel pressure drops. It can be assumed that the characteristics of the pipe sections k_{ij} are parameters, constant at a value and slightly dependent on pressure drops and the nature of the flow.

Comparing the received pressure p_n in the gas supply point of the specified consumer with the minimum operating pressure $p_{n,min}$ may result in an adjustment in the adopted diameter d.

In the example of a circular scheme shown in Figure 1 there is one source of natural gas (shown by a solid line), and it has been determined that the "neutral" point is point C. If there is a change of the operation conditions (include of new sources of natural gas, changes in the quantity of gas from the sources, include of new consumers, changing the quantity of gas consumed by any of the consumers, exclude of consumers, failures, etc.) there could be a change of the "neutral" point location.

2.2. Graph-analytical method for determination of pressure drops in group of consumers from contour section and the pressure of specifed consumer

When there is a group of consumers connected to ring gas supply contour it is essential to determine the distribution of pressure drops in the contour section. This is necessary for determination of the supply pressure p_n for each consumer, as it was described above (it is necessary $p_n \geq p_{n,min}$). For this purpose graph-analytical method has been developed. The method has been applied for the group of consumers supplied from point D (5, 6, 7, 8 and 9) and in particular, for determination of the supply pressure of consumer 7 (Figure 1).

Figure 2 shows the graphical model of the method applied to determination the pressure in point 7.

The method has been presented in „[(-p, Δp) - Q]" diagram. Originally from point D (the point from which the contour section has been supplied) the graphically dependence "$k_{D\text{-}D1} = f(Q, \Delta p)$" has been built. When detecting $k_{D\text{-}D1}$ with the maximum flow of natural gas in the contour section ($Q_D = Q_{D1} = Q_5 + Q_6 + Q_7 + Q_8 + Q_9$) the pressure drop $\Delta p_{D\text{-}D1}$ has been determined graphically. The next step is to build graphically the dependence "$k_{D1\text{-}D2} = f(Q, \Delta p)$" in the same „Δp - Q" diagram from starting point D_1. To better visualize the summation of pressure drops, each next diagram "k = f(Q, Δp)" has been built over the previous one, considering the change of gas flow (in the case considering the deflected flow Q_5 to consumer 5).

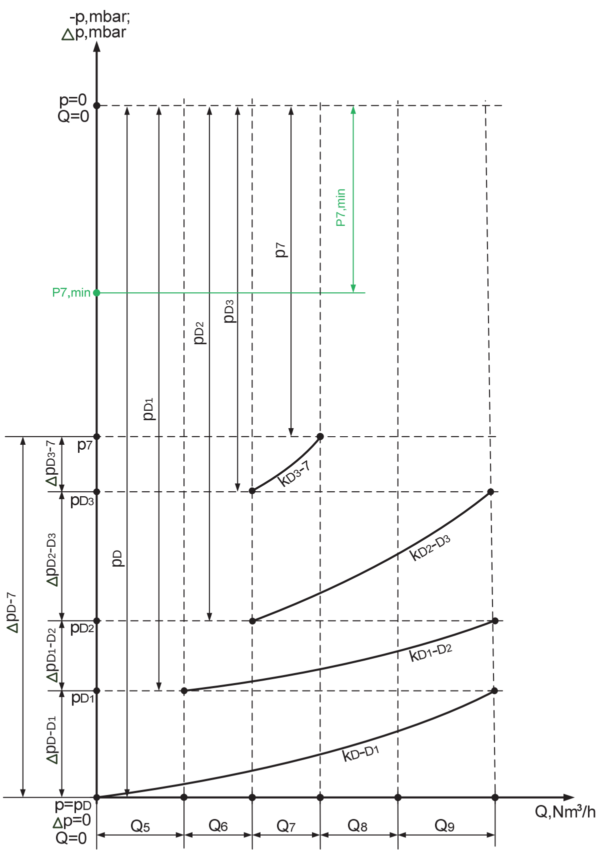

Fig.2. *Graph-analytical method - determination of the supply pressure of consumer 7*

When detecting $k_{D1\text{-}D2}$ with the flow $Q_{D2} = Q_6 + Q_7 + Q_8 + Q_9$ the pressure drop $\Delta p_{D1\text{-}D2}$ has been determined. Similarly the pressure drop $\Delta p_{D2\text{-}D3}$ has been determined graphically. The next step is determination of the pressure drop in the line "D_3 – 7". For this purpose the graphically dependence "$k_{D3\text{-}7} = f(Q, \Delta p)$" has been built from the starting point lying above the starting point for the diagram "$k_{D2\text{-}D3} = f(Q, \Delta p)$". When detecting $k_{D3\text{-}7}$ with the flow Q_7 the pressure drop $\Delta p_{D3\text{-}7}$ has been determined. The sum of the obtained pressure drops gives the total pressure drop $\Delta p_{D\text{-}7}$ in the line „D – D_1 – D_2 – D_3 – 7". On ordinate „(-p)" of „[(-p, Δp) - Q]" diagram the predefined minimum working pressure $p_{7,min}$ has been noted according to the requirements of consumer 7. The next step is determination of pressures in: point D (p_D), point D_1 (p_{D1}), point D_2 (p_{D2}), point D_3 (p_{D3}) and the working pressure in point 7 ($p_7 = p_D - \Delta p_{D\text{-}7}$). It is seen that in the case shown in Figure 2 consumer 7 can work because $p_7 > p_{7,min}$.

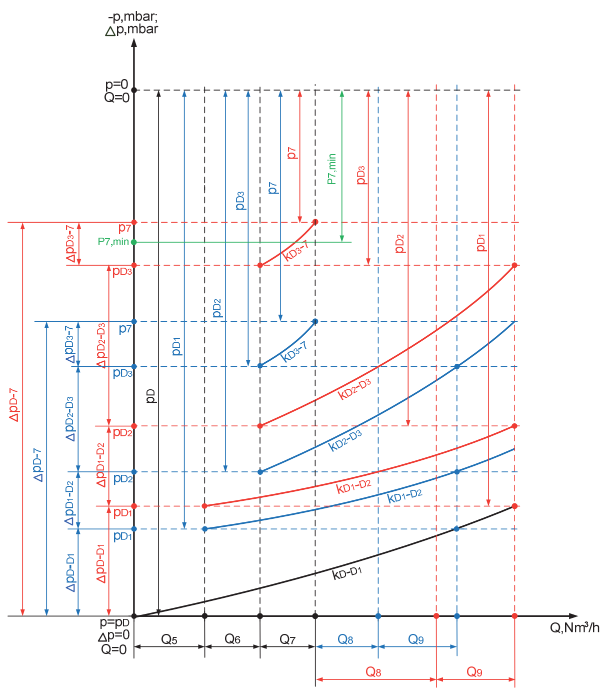

Fig.3. *Graph-analytical method – varying of the working pressure of consumer 7 when there is a change of the gas flow to consumer 8*

If there is a change of the working parameters of the system it is possible to change the supply pressure of any of the gas consumers.

In figure 3 is shown how by using of the developed graph-analytical model it can be visualized the reduction of working pressure of consumer 7 as a result of only the increased consumption of gas by consumer 8. The blue color shows the parameters in the initial moment (refer to Figure 2) and the red - the parameters after increased gas consumption Q_8. It is seen that the increasing of Q_8 leads to increasing of the whole gas flow which supply point D ($Q_D = Q_{D1} = Q_5 + Q_6 + Q_7 + Q_8 + Q_9$). As a result bigger pressure drop Δp_{D-D1} has been reported. The starting point of diagram "$k_{D1-D2} = f(Q, \Delta p)$" moves upwards. Since the gas flow Q_{D2} is bigger as a result of the increasing of Q_8 bigger pressure drop Δp_{D1-D2} has been reported. Similarly the pressure drop Δp_{D2-D3} has been increased. Because the consumed quantity of gas from consumer 7 does not change, it remains constant and the pressure drop Δp_{D3-7} in the line „$D_3 – 7$". As a result of increasing of Δp_{D-D1}, Δp_{D1-D2} and Δp_{D2-D3} the total pressure drop Δp_{D-7} have been increased. The latter leads to a reduction of the working pressure p_7, and as is shown in the example illustrated in Figure 3, the pressure becomes less than the minimum working pressure for consumer 7 and the consumer can not work.

3. CONCLUSION

The developed analytical method for identification of the "neutral" point in the ring circular contour enables the dynamic redistribution of the gas flows. If in the system there are more than one sources of natural gas (the sources must supply gas with the same pressure) to determine the locations of the "neutral" points the scheme needs to be broken the required number of contours. The determination of the exact value of the static pressure p_I in any point of the circular contour allows display modes of unacceptably high pressure drops.

The developed graph-analytical method for group of consumers allows through appropriate software continuously monitoring of operating parameters and their influence on the final supply pressure for each consumer of natural gas. It is also possible that the method can be used in the design of the gas supply systems. The convenience of the proposed model consists of evaluating the visibility and simplified structure of utilities (software, graphics) and the ability to "clarify" the nature of the curves of hydraulic pressure drops as a function of flow rate.

REFERENCES

[1] Bobilov, V., D. Radev, Z. Kolev, P. Zlatev, G. Genchev, P. Mushakov. *Specifications for consumers' gas supply at ring circuit contour*. Scientific Conference of University of Ruse, volume 50, series 1.2, Ruse, Bulgaria, p.78-82, in Bulgarian (2012).

[2] Zhila, V., S. Kalchevski. *Gas supply and effective use of natural gas*. Sofia, Bulgaria, ISBN 978-619-160-122-6, in Bulgarian (2013).

[3] Komina, G., P., A. O. Proshutskii. *Hydraulic calculation and design of gas pipelines: a manual of discipline "Gas supply" for students from the speciality 270109 – Gas supply and Ventilation*. ISBN 978-5-9227-0179-2, in Russian (2010).

[4] Nikolov, G. *Distribution and use of natural gas*. Sofia, Bulgaria, ISBN 978-954-92023-1-1, in Bulgarian (2007).