

Environmental justification of the distribution of pressure drop in a dead-end low-pressure gas network

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Abstract. The gas supply system is determined by the classes of the elements of the gas transmission network associated with the pressure of the pumped natural gas. Laying gas pipelines in urban areas requires sufficient space around the pipes as a safety zone. The gas pipelines of the first level include gas communications in which the methane pressure is high or medium. To eliminate dead-end sections, gas pipelines are backed up (duplicating individual segments or ringing). The creation of a dead-end network is allowed only in small settlements. Dead-end network is a gas pipeline branching in various directions to gas consumers. Each section of the branched network has a one-way power supply.

1 Introduction

In branched low-pressure gas networks, gas is supplied to the consumption node in one direction; therefore they are dead-end networks [1-3]. Thus, consumers connected to branched networks have a one-way power supply. If an element of a branched network is out of work, then all consumers that are connected behind this element will not receive gas. In a dead-end network, transit costs are unambiguously distributed across sections [4]. A change in the diameter of a section of a branched network does not affect the distribution of costs in other sections and only leads to a change in pressure at the initial point of the network.

Hydraulic losses and the diameter of the sections depend on the length of the network. So, the hydraulic losses of pipelines along the length are reduced as a result of its minimization, the diameters of the sections can be reduced as well and, as a consequence, the metal consumption of the system decreases [5]. Since transit costs in the network are uniquely determined, therefore, the estimated costs for all sections are known. Thus, each section is characterized by two unknowns: the diameter d_i and the pressure loss.

2 Methods

If the number of sections of the dead-end network is P , then the total number of unknowns will be $2P$. For each section, one can write the equation of hydraulic losses:

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$$\Delta p_i = a \frac{Q_i^\alpha}{d_i^\beta} l_i,$$

where Δp_i is pressure loss at the section;

a is a gas property dependent coefficient;

l_i is a section length;

d_i is a section diameter;

α , β are system indicators, which generally depend on the gas flow mode and pipe roughness.

Such equations can be p , therefore, the remaining number of unknowns will be p .

Distribution gas networks rely on a constant design pressure drop [6]. With this principle in mind, additional equations can be written in a following way:

$$\sum_1^k \Delta p_i - \Delta p = 0.$$

These equations establish that in each direction from the feed point to the end point “ k ” the sum of the pressure losses should be equal. The number of such equations is equal to the number of endpoints “ k ”.

The remaining number of unknowns (extra unknowns) is $f = p - k$, since there is only one input in each node of the branched network, therefore, the number of nodes, excluding the first, is equal to the number of sections, that is:

$$p = m - 1.$$

Using the ratio, one can write:

$$f = p - k = m - 1 - k = m - (1 + k).$$

The equation that determines the number of extra unknowns has the following interpretation: the total number of nodes m , the number with a given $(1 + k)$, that is, the first and all end nodes. Thus, the number of extra unknowns is equal to the number of nodes with unsettled pressures.

3 Results

To determine unnecessary unknowns, an additional condition must be specified. This condition is the minimization of the reduced cost functions [7-9]. Taking into account the fact that operating costs with a slight change in diameters practically remain unchanged, it is possible to minimize the cost of gas pipelines or even the metal consumption.

Analyzing the process of minimizing the cost function from the standpoint of the distribution of losses over the sections of gas pipelines, it can be argued that the pressure losses between successively located sections should be distributed so that the total cost of the network is minimal [10]. This suggests that the optimal solution will correspond to the optimal shape of the piezometer, which should be determined while minimizing the cost function.

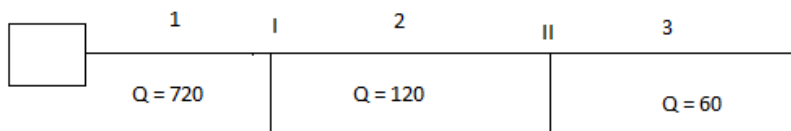


Fig. 1. Building cold supply system classification.

Table 1. Preliminary calculation of the gas pipeline diameter.

Section No.	Section length, m	Estimate consumption, m ³ /h	$d \times S$, mm	Specific pressure drop $\frac{\Delta P}{l}$, Pa/m	Differential pressure across the section Δp , Pa
1	120	720	219×6	1.6	192
2	120	120	108×4	1.8	216
3	120	60	89×3	1.8	216
	Σ 360				Σ 624

The pressure loss on the local resistances is assumed equal to 10% of the linear losses [12]. Preliminary selection of diameters is carried out according to a constant specific pressure drop, which is equal to

$$\frac{\Delta P}{l} = \frac{624}{1.1 \cdot 360} = 1.515 \text{ Pa/m}$$

We calculate the nodal correction pressures δp and the optimal pressure drops in the sections at the first correction.

$$\delta p'_I = \frac{\sum A_i \Delta p_i^{-1.21}}{1.21 \sum \frac{A_i \Delta p_i^{-1.21}}{p_i}} = \frac{-3.5}{1.21 \cdot 0.043} = 67.3;$$

$$\delta p''_{II} = \frac{\sum A_i \Delta p_i^{-1.21}}{1.21 \sum \frac{A_i \Delta p_i^{-1.21}}{p_i}} = \frac{-0.6}{1.21 \cdot 0.024} = -20.7;$$

$$\delta p''_I = \frac{\sum \delta p_{a.n} \left(\frac{A_i \Delta p_i^{-1.21}}{p_i} \right)_{s.a.n.}}{\sum \frac{A_i \Delta p_i^{-1.21}}{p_i}} = \frac{-20.7 \cdot 0.013}{0.043} = -6.3;$$

$$\delta p''_{II} = \frac{\sum \delta p_{a.n} \left(\frac{A_i \Delta p_i^{-1.21}}{p_i} \right)_{s.a.n.}}{\sum \frac{A_i \Delta p_i^{-1.21}}{p_i}} = \frac{-67.3 \cdot 0.013}{0.024} = -36.5;$$

$$\delta p_I = \delta p'_I - \delta p''_I = -67.3 - 6.3 = 73.6;$$

$$\delta p_{II} = \delta p''_{II} - \delta p''_{II} = -20.7 - 36.5 = -57.5.$$

Let's calculate the nodal correction pressures and pressure drops in the sections at the second correction:

$$\delta p'_I = \frac{\sum A_i \Delta p_i^{-1.21}}{1.21 \sum \frac{A_i \Delta p_i^{-1.21}}{p_i}} = \frac{-1.18}{1.21 \cdot 0.032} = -30.5;$$

$$\delta p_{II}'' = \frac{0.15}{1.21 \cdot 0.036} = 3.44;$$

$$\delta p_I'' = \frac{\sum \delta p_{a,n} \left(\frac{A_i \Delta p_i^{-1.21}}{p_i} \right)_{s.a.n}}{\sum \frac{A_i \Delta p_i^{-1.21}}{p_i}} = \frac{-3.4 \cdot 0.016}{0.032} = 0.5;$$

$$\delta p_{II}'' = \frac{-30.5 \cdot 0.016}{0.036} = -13.5;$$

$$\delta p_I = \delta p_I' + \delta p_I'' = -30.5 + 0.5 = -30;$$

$$\delta p_{II} = 3.4 - 13.6 = -10.2.$$

The additional pressure to the drop in the section δp_s in the absence of an adjacent node is equal to δp , and in the presence of an adjacent node it is equal to the sum of δp and δp of an adjacent node with the opposite sign.

Thus:

$$\Delta p_{s1} = -30;$$

$$\Delta p_{s2} = -30 + 10.2 = -19.8.$$

Table 2. Determination of gas pressure drops in sections.

Node	Section	Adjacent nodes	Δp	$Q^{0.368}$	$\rho^{1.21}$	$\Delta p^{-1.21}$	A	$A \Delta p^{-1.21}$	$\frac{A \Delta p^{1.21}}{\Delta p}$
I	1		-192	11.4	312	$0.18 \cdot 10^{-2}$	3556.8	-6.4	0.03
	2	II	216	5.88	312	$0.16 \cdot 10^{-2}$	1834.6	2.9	0.013
						Error $\frac{3.5 \cdot 100}{0.5 \cdot 9.3} = 75.3\%$			
II	2	I	-216	5.88	312	$0.16 \cdot 10^{-2}$	1834.6	-2.9	0.013
	3		216	4.55	312	$0.16 \cdot 10^{-2}$	1420	2.3	0.011
						Error $\frac{0.6 \cdot 100}{0.5 \cdot 5.2} = 23.1\%$			

Table 3. Iteration 1.

Node	Section	Adjacent nodes	δp	Δp_{s2}	Δp	$\Delta p^{-1.21}$	$A \Delta p^{-1.21}$	$\frac{A \Delta p^{1.21}}{\Delta p}$	
I	1		-73.6	-73.6	-265.6	$0.12 \cdot 10^{-2}$	-4.3	0.016	
	2	II		-16.4	199.6	$0.17 \cdot 10^{-2}$	3.12	0.016	
						Error $\frac{1.18 \cdot 100}{0.5 \cdot 7.42} = 31.8\%$			
II	2	I	-57.2	16.4	199.6	$0.17 \cdot 10^{-2}$	-3.12	0.016	
	3			57.1	158.8	$0.23 \cdot 10^{-2}$	3.27	0.02	
						Error $\frac{0.15 \cdot 100}{0.5 \cdot 6.39} = 4.7\%$			

According to Tables 2, 3, 4, the difference in section 1 must be increased, while the diameter of the section will decrease, and the difference in section 3 must be reduced, which will lead to an increase in diameters.

Table 4. Iteration 2.

Node	Section	Adjacent nodes	δp	Δp_{s2}	Δp	$\Delta p^{-1.21}$	$A \Delta p^{-1.21}$	$\frac{A \Delta p^{1.21}}{\Delta p}$
I	1	II	-30	-30	-295.6	$0.11 \cdot 10^{-2}$	-3.9	0.013
	2			-19.8	179.8	$0.2 \cdot 10^{-2}$	3.7	0.02
				Error $\frac{0.2 \cdot 100}{0.5 \cdot 7.6} = 5.2\%$				
II	2	I	-10.2	19.8	179.8	$0.2 \cdot 10^{-2}$	-3.7	0.02
	3			-10.2	148.6	$0.2 \cdot 10^{-2}$	3.6	0.02
				Error $\frac{0.1 \cdot 100}{0.5 \cdot 7.3} = 2.7\%$				

Table 5. Final calculation of diameters.

Section No.	d , MM	Specific pressure drop $\frac{\Delta P}{l}$, Pa/m	Differential pressure across the section Δp , Pa
1	194×6	2.1	252
2	108×4	1.9	228
3	90×4	1.2	144
			Σ 624

Let's calculate the comparison of costs by $\frac{\Delta P}{l} = \text{const}$:

$$k = b \sum dl = b (21.9 \cdot 120 + 10.8 \cdot 120 + 8.9 \cdot 120) = b \cdot 4992.$$

Economics:

$$k = b (1.94 \cdot 120 + 10.8 \cdot 120 + 9 \cdot 120) = b \cdot 4704.$$

The cost reduction is about 5.77%.

Let's calculate comparisons of metal inputs by $\frac{\Delta P}{l} = \text{const}$:

$$M = \sum d \delta l = (21.9 \cdot 0.6 \cdot 120 + 10.8 \cdot 0.4 \cdot 120 + 8.9 \cdot 0.3 \cdot 120) \cdot c = 2415.6.$$

Economics:

$$M = (19.4 \cdot 0.6 \cdot 120 + 10.8 \cdot 0.4 \cdot 120 + 9 \cdot 0.4 \cdot 120) \cdot c = 2347.2$$

Metal savings are about 2.8%.

4 Conclusions

As a result of the calculations, the pressure losses are distributed between successive sections and the cost of the gas distribution system reduces by 2.8%. In this case, the gas pressure drop in section 1 increased, which means that the diameter value decreased from 219×6 to 194×6 . In section 3, the gas pressure drop decreased and this led to an increase in diameter from 89×4 to 90×4 .

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