Calculation of gas supply pressure using plastic pipes for preventing accidental emissions

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Abstract. Technological (production, operational and repair) risks come to the fore, minimizing which requires optimization of the work of structural units responsible for a reasonable assessment of the technical condition, maintenance and repair of facilities, timely renewal of production facilities with minimization of wear and tear of equipment, which is a risk factor in the failure of the gas transmission system. In addition, based on the noted features of gas transportation enterprises, in the risk management block, logistics risks, safety risks, environmental, social and (in a certain aspect) financial risks should play a significant role. Objectively, in order to establish an acceptable range of risks, it is necessary to collect statistical data on the occurrence of risk factors for the foreseeable period in order to leave for constant monitoring those risk factors that appear regularly in the gas transmission system. The construction and operation of gas pipelines play an important role in the reasonable and technical transportation of gaseous substances. Noteworthy, algorithm for calculating the proposed medium pressure gas pipeline was developed, accordingly, in this research, the gas flow area was determined. The results showed that based on the calculations of underground average pressure of polyethylene pipes, the average gas pressure was 5,733 Pa, withstands pressure was up to 8009.7 Pa, withstands stress on the pipe wall was up to 0.024 MPa, and emission loss was 3964.4 m3 when there was an accident.

1 Introduction

The key performance indicator of a gas transmission company is the fulfillment of the plan for gas transportation in the given volumes, terms and quality of gas, and the target indicator of the risk management unit in the gas transmission system is the minimum of failures (losses from realized risks) in gas supplies (maximum reliability) [1-3]. As a result, technological (production, operational and repair) risks come to the fore, minimizing which requires optimization of the work of structural units responsible for a reasonable assessment of the technical condition, maintenance and repair of facilities, timely renewal of production facilities with minimization of wear and tear of equipment, which is a risk factor

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in the failure of the gas transmission system [4]. In addition, based on the noted features of gas transportation enterprises, in the risk management block, logistics risks, safety risks, environmental, social and (in a certain aspect) financial risks should play a significant role [5]. Objectively, in order to establish an acceptable range of risks, it is necessary to collect statistical data on the occurrence of risk factors for the foreseeable period in order to leave for constant monitoring those risk factors that appear regularly in the gas transmission system. Clearly, to choose according to objective probability, although the level of static probability is low, risk factors that can lead to large losses for the enterprise should be left [6-10].

The construction and operation of gas pipelines play an important role in the reasonable and technical transportation of gaseous substances. In addition, from an economic point of view, this transfer can have a significant negative impact on nature due to its serious vulnerability to the process under study. Clearly, polyethylene pipes that are intended for gas supply are first tested for strength. Polyethylene pipes, due to their exceptional plasticity, are resistant to dynamic influences and therefore have proven themselves well in seismic hazardous areas [11-13]. For example, according to the data of the Colombian Environmental Protection Agency on the accident rate of pipelines made of various materials during an earthquake in this country, steel pipes had 0.52 failures per 1 km, followed by gray iron pipes with 0.97 failures, and pipes made of PVC had 0.8 failure. Noteworthy, no damage was recorded on polyethylene gas pipelines [14, 15].

The current state of the gas pipeline gas supply system is characterized by a long service life of existing gas pipelines with a significant increase in gas volumes through them and the construction of new powerful systems operating at elevated pressure. Ensuring the operational reliability of gas pipelines in these conditions is becoming increasingly important [10-11]. Therefore, this research intended to develop an algorithm and a mathematical model of industry regulation for updating the gas pipeline system of gas supply, operation of gas pipelines of polyethylene pipes. The model calculates and selects the optimal reconstruction method, that is, a two-stage gas supply system [5]. Clearly, the purpose of the production system has a great influence on the composition and significance of risks.

2 Materials and Methods

In this research, branch, “Khududgaz Fergana”, of “Hududgaztaminot” was selected as a study site, where all research experiments conducted, especially on gas supply polyethylene pipe for medium pressure pipeline (PE 159). Clearly, the specific pressure loss was carried out according to the methodology “Calculation of a gas pipeline in accordance with SP 42-101-2003” [15]. Besides, algorithm for calculating the proposed medium pressure gas pipeline was developed, accordingly, in this research, the gas flow area was determined, followed by a section with a medium-pressure polyethylene pipe, determination of the coefficient of friction of gas in the gas pipeline, calculation of hydraulic gas requirement, and calculation of the gas pressure on the gas pipeline (Fig. 1).

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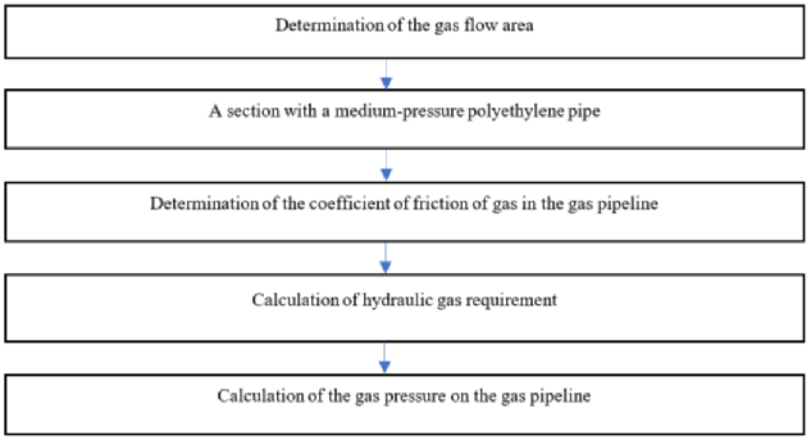

Fig. 1. Algorithm for calculating the proposed medium pressure gas pipeline.

Furthermore, the pressure drop of the gas pipeline section was determined as following [3-5]:

$$\mathrm{P}_n - \mathrm{P}_k = 626{,}1\lambda \frac{Q_0^2}{d^2} \rho_0 l \quad (1)$$

Where:

R_n - gas pressure in the design area, Pa;
R_{to} is the final gas pressure in the design area, Pa;
λ is the coefficient of hydraulic friction;
l - estimated length of a gas pipeline of constant diameter, m;
d - internal diameter of the gas pipeline, cm;
p - gas density under normal conditions, kg/m ^{3}
Q_0 - gas consumption, m ^{3} / h, under nominal conditions.

Moreover, the final gas pressure in the gas pipeline section was calculated using the below given formula:

$$P_k = P_n - R \cdot l_p \quad (2)$$

Where:

P_n- initial gas pressure in the gas pipeline, Pa;
R is the actual specific pressure drop in this section, Pa/m;
lp - length of the gas pipeline, m.

The strength of the gas pipeline calculation was carried out according to the following formulas:

$$MRS = \frac{PE}{10} = \frac{80}{10} = 8\ MPa \quad (3)$$

Besides, the strength of the gas pipeline was also calculated using the algorithm developed in this research (Fig. 2).

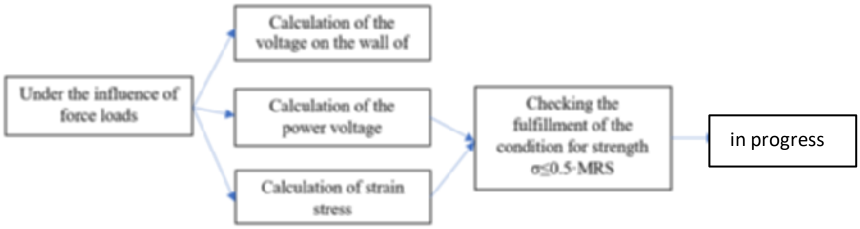

Fig. 2. Algorithm for calculating the strength of the proposed medium-pressure gas pipeline.

Clearly, the longitudinal axial stress from the force and deformation stress was calculated using the following formula:

$$\sigma_{npNS} = \frac{2\cdot\mu\cdot P}{\left[1-\frac{2}{SDR}\right]^{-2}-1} - \alpha\cdot E(te)\cdot\Delta t; \tag{4}$$

Where:

μ- Poisson's ratio of pipe material according to SP 42-101-2003 is taken equal to 0.43;
P - working pressure, MPa;
SDR - standard dimensional ratio;
a - coefficient of linear thermal expansion of the pipe material, taken according to the method of SP-42-101-2003 is 2.2 10^{-4}.
$E\ (te)$ - creep modulus of pipe material at operating temperature, MPa;
$\Delta\ t$ - temperature difference [4-6, 11].

Fig. 3 shows the calculation of the volume of emergency gas releases, which occur mainly from leaks, from the rupture of obsolete pipes, as well as from emergency situations on gas pipelines.

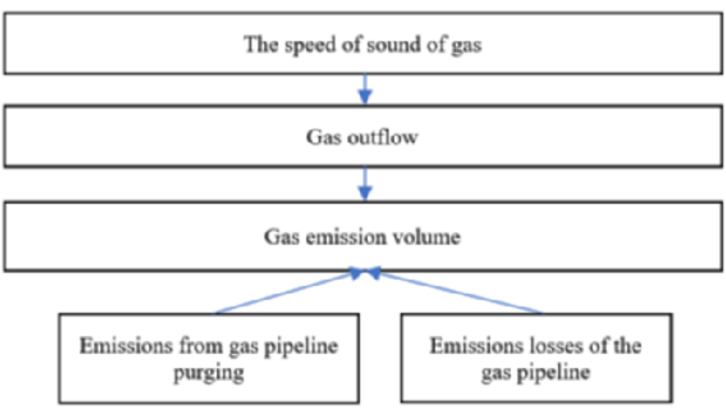

Fig. 3. Calculation of the volume of emergency gas release.

The calculation is carried out according to the methodology of RD 159-39.4-079-01 "Methodology for determining gas consumption for technological needs of consumers".

Next, the speed of sound in natural gas was calculated using the following formula:

$$W_{sound} = 18{,}591\cdot(T_r \ \cdot k\cdot Z/\rho_0)^{0{,}5}; \tag{5}$$

Where;

Tg is the gas temperature, K;

k is the adiabatic index;
Z is the gas compressibility factor;
ρ_0 is the absolute density of the gas, kg/m³.

3 Results and discussions

According to Table 1, the initial pressure was 6000 Pa, followed by the final pressure (2370 Pa), Gas density (0.685 kg/m³), and kinematic viscosity was $14.39 \cdot 10^{-6}$ m²/s. Moreover, the data of estimated hourly gas consumption was obtained from "Hududgaztaminot (Territory gas supply)". Accordingly, the estimated hourly gas consumption was 20 m³/hour.

Table 1. Initial data for hydraulic calculation.

Initial pressure, Pa	Final pressure Pa	Gas density, kg/m³	Kinematic viscosity, m²/s
6000	2370	0.685	$14.3 \cdot 10^{-6}$

It was found that the pressure drop of the gas pipeline section was determined (Table 2). The result was $P_n - P_k = 626{,}1 \cdot 0.043\ \frac{34}{15{,}9^2} 0{,}685\ \cdot 1000 = 0{,}267\ Pa/m.$

Moreover, the coefficient of friction was also determined by the movement of gas in the gas pipeline (Table 2):

$$R_e = \frac{Q_0}{9\pi \cdot d \cdot v} = 0{,}0354\ \frac{Q_0}{dv}$$

$$R_e = 0{,}0354\ \frac{20}{15{,}9 \cdot 14{,}3\ \cdot 10^{-6}} = 3540$$

Where: υ is the coefficient of kinematic viscosity of gas, m²/s, and under nominal conditions for natural gas it is $14.3 \cdot 10^{-6}$. Hydraulic friction of the proposed gas pipeline (λ) was identified:

$$\lambda = \frac{1}{(1{,}82\ \cdot lgRe - 1{,}64)^2} = \frac{1}{(1{,}82\ \cdot lg3540 - 1{,}64)^2} = 0{,}043$$

According to the results, the final gas pressure in the gas pipeline section, P_k was equal to (Table 2): $P_k = 6000 - 0{,}267\ \cdot 1000 = 5733$

Table 2. The results of research experiments on pressure in the gas pipelines.

# of study site	Length of the study site	Gas consumption, m³/h	Diamete g/n *dy*, mm	Number R_e	ʎ, coefficient of friction	Pressure drop R, Pa/m	Node pressure , Pa
1	1000	34.0	159	3540	0.043	0.267	5.733

According to Eable 3, the pressure in pipeline was 6000 P_p, followed by pipeline diameter (0.159 m), material (PE 80, SDR11-9.1), operating temperature (10 °C), Δt (20) and Elastic bending radius of the pipeline was 10 m.

Table 3. Initial data for the calculation of the gas pipeline.

Pressure in pipeline, P	Diameter of the gas pipeline Dc, m	Material	Operating temperature °C	Temperature difference Δt	Elastic bending radius of the pipeline, m
6000	0.159	PE 80, SDR11-9.1	10	20	10

Noteworthy, the strength of the gas pipeline calculation was carried out. It was found that the strength of the gas pipeline was:

$$MRS = \frac{PE}{10} = \frac{80}{10} = 8\ MPa$$

Moreover, the stresses on the pipe wall of the proposed gas pipeline are determined by the following formula:

$$\sigma_{npNS} = \frac{P\ \cdot (SDR-1)}{2} = \frac{0{,}006\ \cdot (9{,}1-1)}{2} = 0{,}024\ MPa$$

Afterwards, the longitudinal axial stress from the force and deformation stress was calculated, and the result was 8009.7 Pa (Table 4):

$$\sigma_{npNS} = \frac{2 \cdot 0{,}43 \cdot 6000}{\left[1-\frac{2}{9{,}1}\right]^{-2} - 1} - 2{,}2 \cdot 10^{-4} \cdot 12000 \cdot 20 = 8009{,}7\ Pa$$

Furthermore, gas release time was 1200 s, gas density was 0.685 kg/m^3, and molar component of nitrogen was 0.21 (Table 4).

Table 4. Initial data for calculating the loss in the gas pipeline.

Atmospheric pressure Pa, Pa	Gas temperature, °C	Gas release time, s	Gas density, kg/m^3	Molar component of nitrogen
7080	4.5	1200	0.685	0.21

Noteworthy, the speed of sound in natural gas was calculated, and the result was:

$$W_{sound} = 18{,}591 \cdot (4{,}5\ \cdot 1{,}428 \cdot 0{,}104/0{,}685)^{0{,}5} = 18.350\ \text{m/s}$$

Afterwards, the adiabatic index was calculated by the formula:

$$K = 1{,}556\ \cdot (1 + 0{,}074 \cdot x_n) - 3{,}9 \cdot 10^{-4} \cdot Tr \cdot (1 - 0{,}68 \cdot x_n) - 0{,}2 \cdot \rho_0 + \left(\frac{P_a}{T_r}\right)^{1{,}43} \cdot \left[384 \cdot (1 - x_n) \cdot \left(\frac{P_a}{T_r}\right)^{0{,}38} + 26{,}4 \cdot x_n\right]; \quad (6)$$

Where:

x_n is the molar component of nitrogen;

Pa is the absolute gas pressure, MPa.

According to the results, the absolute gas pressure in the Fergana region was 0.001 MPa.

$$K = 1{,}556 \cdot (1 + 0{,}074 \cdot 0{,}21) - 3{,}9 \cdot 10^{-4} \cdot 4{,}5 \cdot (1 - 0{,}68 \cdot 0{,}21) - 0{,}2 \cdot 0{,}685 + \left(\frac{0{,}001}{273{,}15}\right)^{1{,}43} \cdot \left[384 \cdot (1 - 0{,}21) \cdot \left(\frac{0{,}001}{273{,}15}\right)^{0{,}38} + 26{,}4 \cdot 0{,}21\right] = 1{,}428$$

Calculate the gas compressibility factor:

$$Z = 1 - \left((10{,}2 \cdot P_a - 6) \cdot (0{,}00345 \cdot \Delta - 0{,}000446) + 0{,}015\right) \cdot \left(1{,}3 - 0{,}01444 \cdot \left(T_g - 283{,}2\right)\right);$$

Where: Δ is the relative density of the gas.

$$\Delta = \frac{\rho_0}{1{,}2044};$$

$$\Delta = \frac{0{,}685}{1{,}2044} = 0{,}568$$

$$Z = 1 - \left((10{,}2 \cdot 0{,}001 - 6) \cdot (0{,}00345 \cdot 0{,}568 - 0{,}000446) + 0{,}015\right) \cdot \left(1{,}3 - 0{,}01444 \cdot (277{,}65 - 283{,}2)\right) = 0{,}104$$

Natural gas emission volume:

$$V_e = 110 \cdot S \cdot P_a \cdot \tau; \tag{7}$$

Where:
S is the cross-sectional area of the gas outlet, m^2;
τ is the gas ejection time.

$$V_e = 110 \cdot 0{,}0003 \cdot 100 \cdot 1200 = 3960 \text{ m}^3$$

Besides, the gas cross-sectional area is calculated by the formula:

$$S = \frac{\pi \cdot d^2}{4} = \frac{3{,}14 \cdot 20^2}{4} = 314 \text{ mm} = 0.0003 \text{ m} \tag{8}$$

The volume of natural gas to purge the filled gas pipeline:

$$V_p = 0{,}0029 \cdot k \cdot V_{п} \cdot \frac{(P_a + P_{атм})}{T_r}; \tag{9}$$

Where:
V_p- the volume of the cavity of the gas pipeline, m^3;
k - 1.25 correction factor.
Gas pipeline cavity volume was calculated using the below formula:

$$V_p = L \cdot \pi \cdot r^2; \tag{10}$$

Where:

L is the distance between the disconnecting devices, m.

In this case, the gas pipeline is taken at medium pressure:

$$V_p = 500 \cdot 3{,}14 \cdot 0{,}002 = 3{,}14 \text{ m}^3$$

It was found that the gas purge in the gas pipeline was calculated and the results was:

$$V_p = 0{,}0029 \cdot 1{,}25 \cdot 3{,}14 \cdot \frac{(100190+7080)}{277{,}65} = 4.40 \text{ m}^3$$

In the final stage of the research experiment, the volume of loss of natural gas was determined, which was 3964.4 m^3:

$$V_p = 3960 + 4{,}40 = 3964.4 \text{ m}^3$$

It was reported that based on the calculations of underground average pressure of polyethylene pipes, the average gas pressure was 5, 733 Pa, withstands pressure was up to 8009.7 Pa, withstands stress on the pipe wall was up to 0.024 MPa, and emission loss was 3964.4 m^3 when there was an accident.

4 Conclusions

As a result of the current study, risk management algorithms were calculated and created along with identification based on medium pressure gas pipelines, calculation of the strength of the gas pipeline, calculation of the volume of emergency gas release, geographical information systems and the spatial situation are more possible using the created risk maps.

It was found that the pressure drop of the gas pipeline section was 0,267 Pa/m. Moreover, the coefficient of friction was also determined by the movement of gas in the gas pipeline, which was 3540. It was reported that the longitudinal axial stress from the force and deformation stress was calculated, and the result was 8009.7 Pa. Besides, the speed of sound in natural gas was calculated, accounted for 18.350 m/s.

Based on the calculations of underground average pressure of polyethylene pipes, the average gas pressure was 5, 733 Pa, and emission loss was 3964.4 m^3 when there was an accident.

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