https://doi.org/10.33271/nvngu/2024-4/035

S. P. Minieiev[1],
orcid.org/0000-0002-4594-0915,
L. A. Novikov[*1],
orcid.org/0000-0002-1855-5536,
O. S. Yanzhula[2],
orcid.org/0009-0000-8906-0656,
O. Y. Belousov[3],
orcid.org/0009-0002-8201-8783,
R. V. Makarenko[4],
orcid.org/0009-0003-5639-570X

1 – Institute of Geotechnical Mechanics named by N. Poliakov of National Academy of Sciences of Ukraine, Dnipro, Ukraine
2 – "Metinvest Holding" LLC, Pokrovsk, Ukraine
3 – "Pershotravenske Mine Department" of "DTEK Pavlohradvuhillia" PJSC, Pershotravensk, Ukraine
4 – "Mine Management named after the "Heroiv Kosmosu" of "DTEK Pavlohradvuhillia" PJSC, Pavlohrad, Ukraine
[*] Corresponding author e-mail: lnov710@gmail.com

ASSESSMENT OF THE CONTAMINATION DEGREE OF GAS PIPELINE BRANCHES DURING MINED-OUT SPACE DEGASIFICATION

Purpose. To determine the patterns of changes in the gas mixture parameters in the final gas-drainage pipeline section during draining-out of gases from the mined-out space through the gas pipeline branches with impaired throughput capacity.

Methodology. Theoretical studies of gas mixture flows in mine gas-drainage pipelines, as well as the laws of gas dynamics and hydromechanics are used to solve the task set.

Findings. It has been revealed that the methane concentration remains constant in the section of the gas-drainage pipeline, which is located in an uncontrolled ventilation working area. In this case, methane concentration decreases in the gas-drainage pipeline behind the insulating jumper in the zone influenced by the outlet ventilation jet. It has been found that the reduced hydraulic diameter of the gas pipeline contaminated branch leads to an increase in the absolute gas mixture pressure, a decrease in its flow rate and methane yield in the final gas-drainage pipeline section. By solving quadratic regression equations, the ratios linking the hydraulic diameter of the gas pipeline contaminated branch with the gas mixture parameters in the final gas-drainage pipeline section have been obtained.

Originality. A relationship between the hydraulic diameter of the gas pipeline contaminated branch, draining-out the gas mixture from the mined-out space, and the gas mixture parameters in the final gas-drainage pipeline section has been revealed.

Practical value. The obtained ratios for the hydraulic diameter of the gas pipeline contaminated branch make it possible to estimate its throughput capacity and, by the time new branches are set, if necessary, increase the discharge in the gas-drainage pipeline to maintain the necessary degasification efficiency.

Keywords: *coal mine, gas-drainage pipeline, gas mixture, gas pipeline branches, contamination*

Introduction. Currently, the number of coal mines on the territory of Ukraine is decreasing. At the same time, at abandoned mines there is a problem of extracting methane from the coal-rock mass. Part of the methane migrates to the earth's surface, resulting in environmental pollution. In this regard, to improve the ecology of coal-mining regions, an urgent issue is to determine the mining-geological conditions for methane redistribution within the coal-rock mass [1], as well to develop and implement new effective gas-drainage methods [2].

A decrease in the throughput capacity of the suction degasification network and the efficiency of the mine gas-drainage system is associated with contamination of site and main gas-drainage pipelines, as well as with a leak tightness failure. Over time, accumulations of rock particles and water form on the inner surface of gas-drainage pipelines. They penetrate into the gas pipeline from gas-drainage wells and are localized in places with abrupt changes in the direction and velocity of the gas mixture. Corrosion products are also formed along the length of the degasification network sections. Their formation is caused by oxidative processes when the gas pipeline walls interact with a wet gas mixture and water that can penetrate from gas-drainage wells. This results in an increase in the roughness of the inner surface of the gas-drainage pipeline and an increase in pressure losses due to friction.

Gas-drainage pipeline leak tightness failure is characterized by formation of through cracks and holes, as well as gaps between the flanges of the gas pipeline links. These damages are caused by the following factors: technological influences and rock displacements; corrosion processes; loosening the tightening of the flange joint bolts.

In the latter case, air inflows into the degasification network occur. As a result, the methane concentration in the gas mixture is reduced.

To restore the required methane concentration, various vacuum control devices are used at the mouths of gas-drainage wells [3]. In this case, the gas mixture is purified from solid and liquid components. The discharge value in the gas-drainage pipeline is also increased by connecting additional vacuum pumps or by switching the existing vacuum pumps to a new mode [4]. However, the tightness failure of flange joints results in an additional increase in air inflows and energy consumption at the vacuum-pump station. Therefore, to restore the throughput capacity of degasification network sections, vacuum pumps are stopped, and measures are taken to replace and clean gas-drainage pipelines.

Literature review. Analysis of the state of mine degasification networks [5] shows that some of the gas pipelines of degasification networks are in an unsatisfactory technical condition. This leads to increased aerodynamic resistance and air inflows. It is noted in [5] that replacing damaged gas pipelines can reduce vacuum losses and air inflows during gas mixture transportation. As a result, the yield of produced methane increases. In addition, gas hydrate crystals can be formed on the inner surface of gas pipelines under certain conditions [5, 6]. These formations significantly reduce the throughput capacity of gas-drainage pipelines.

Failure to drain gases from the mined-out space increases the risk of accidents associated with gas mixture ignition [7, 8].

The work [9] develops a mathematical model of transition from the calculated gas-drainage pipeline diameters to standard values, which allows optimisation of gas pipeline diameters. Conditions for replacing the gas-drainage pipeline with a parallel connection consisting of several branches are determined.

Calculation of gas transportation system parameters is the subject of the paper [10]. It has been revealed that with intensive water inflow from gas-drainage wells, flooding of gas pipelines can occur.

It is stated in [11] that in order to reduce air inflows into the gas-drainage pipeline and reduce the probability of formation of water accumulations, it is necessary to ensure high-quality tightness of the flange joints of the gas pipeline links and reduce the number of the route slopes.

When calculating mine gas-drainage systems, a problematic issue is to determine rational modes for gas mixture flow [12]. This problem can be associated with the degasification network topological peculiarities and the presence of local hydraulic resistance (places for setting control-measuring and regulating equipment, turns, branching, and gas pipeline deflections).

In [13], a mathematical model for the isothermal natural gas flow in a pipeline with a variable section is proposed to identify solid component clusters. The position of clusters is determined by the intensity of the reflected pressure waves.

The technical principles and characteristics of methods for detecting contamination in gas pipelines are described in [14]. Commonly used methods for removing contamination are presented. To obtain information regarding the localization of gas pipeline contamination, the internal surface of the pipeline is visualized. In this case, radiation sources of gamma rays, x-rays, ultrasound and electromagnetic waves are used.

In [15], a method for determining the location of contaminants in a gas pipeline based on implicit nonlinear finite-difference modeling is proposed. It is noted that this method provides excellent results even when working with additive measurement noise.

Research results in [11, 16] show that the impact of rock displacements can lead to deflections and deformations of the gas-drainage pipeline with a corresponding reduction in its throughput capacity. In particular, deflections of gas-drainage pipelines under the influence of rock mass deformations mainly occur in the places of flange joints of gas pipeline links. This also contributes to the formation of water accumulations, the deposition of coal and rock dust, and the tightness failure of flange joints. It is therefore necessary to develop new technical solutions for modernizing gas pipelines [17].

Analysis of the rock pressure influence on underground gas pipelines shows [18] that in most cases, the occurrence of cracks in the gas pipeline walls is caused by tensile stresses, as well as horizontal compression of rocks. Crack formation also occurs as a result of corrosion processes [19, 20]. In this case, the natural gas concentration decreases in places where air penetrates through cracks.

In [21], a mathematical model of displacement impact on an underground pipeline is presented. It has been found that under the action of compressive horizontal stresses the pipeline links are pressed against each other. This causes damage to flange joints. It is therefore recommended to use pipelines made of thermoplastic materials in the area of mining operations.

In [22], a multi-sensor network is proposed for assessing and monitoring the performance of underground metal pipelines. Using discrete sensors, the pressure and flow rate of gas or liquid, as well as the distribution of equivalent stresses, are determined.

Damage to gas pipelines is mainly caused by impact forces, pipe material defects, corrosion and internal erosion processes, ground movements and improper technical maintenance [23].

Unsolved aspects of the problem. The influence of contaminants on gas mixture parameters and its movement modes [12] in site and main gas-drainage pipelines is an insufficiently studied issue. For example, in places where water accumulates, there are marked fluctuations in the flow rate and absolute pressure of the gas mixture [24]. In addition, it is necessary to take into account the complex degasification network structure, where the gas mixture parameters depend on the route configuration, gas pipeline leak tightness, output of gas-drainage wells, local hydraulic resistances and other factors.

During draining-out of gases from the mined-out space through gas pipeline branches, there is a problem of their contamination with rock. Contamination of the branches causes the amount of gas mixture to change below the required values. As a result, the degasification efficiency decreases.

Research purpose is to determine the patterns of changes in the gas mixture parameters in the final gas-drainage pipeline section during draining-out of gases from the mined-out space through the gas pipeline branches with impaired throughput capacity.

Problem statement. It is necessary to determine the influence of the gas pipeline branch hydraulic diameter in the place of its contamination with solid components on the concentration and yield of methane, absolute pressure and gas mixture flow rate in the final section of the site gas-drainage pipeline.

Methods. According to [25], draining-out of gases from the mined-out space through gas pipeline branches is used in the pillar system of mining the extraction site and a backflow ventilation scheme, when the ventilation working behind the stoping face is maintained, but is not controlled. In this case, gas pipeline branches are set as the stoping face advances.

Fig. 1 shows a case of rock debris contamination of a site gas-drainage pipeline branch in uncontrolled ventilation working area.

Fig. 1 shows that rock debris fell into the gas pipeline second branch due to local roof rock sloughing. Representing the dimensions of the gas-dynamic parameters in the SI system, the ratio is presented for determining the required vacuum pump supply, the absolute gas mixture pressure in the vacuum pump suction nozzle and the nominal bore diameter of the gas-drainage pipeline [25, 26]

$$Q_v = Q_r + \Delta Q = Q_r + 1.67 \cdot 10^{-5} L_t; \qquad (1)$$

$$p_v = 133.3\left(k_1 + 60k_2\frac{Q_v}{n_v}\right);$$

$$D = 0.46786\left(\frac{Q_v^2}{\Delta P_{res}}\right)^{0.188} = 0.47632\left[\frac{Q_v^2 L_t}{P_b - P_v}\right]^{0.188},$$

where ΔQ is normative total air inflows into the gas-drainage pipeline, m^3/s; $L_t = l \cdot n$ – gas-drainage pipeline length, m; l – length of gas pipeline links, m; n – the number of links; D – nominal bore diameter of the gas-drainage pipeline, m; $\Delta P_{res} = (P_b - P_v)/1.1L_t$ – specific pressure loss, Pa/m; p_v – absolute gas mixture pressure in the vacuum pump suction nozzle, Pa; k_1, k_2 – vacuum pump characteristic coefficients; $n_v = (k_1 + 60k_2Q_v)/350$ – vacuum pump quantity; Q_r – required gas mixture flow rate drained by degasification equipment, m^3/s.

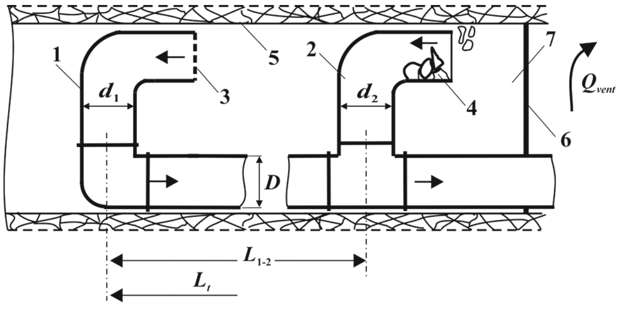

Fig. 1. Rock contamination of a gas pipeline branch:

1, 2 – gas pipeline branches; 3 – a protection grid; 4 – rock debris accumulation; 5 – mined-out space; 6 – an insulating jumper; 7 – uncontrolled ventilation working area; Q_{vent} – the amount of air supplied to the extraction site; D – the nominal bore diameter of the site gas pipeline, m; d_1, d_2 – the nominal bore diameter of the gas pipeline branches, m; L_t – the length of the site gas pipeline, m; $L_{1\text{-}2}$ – the distance between branches, m

In formula (1), the value of total inflows does not take into account the lack of flange joint tightness. In particular, for a 4 m long link, the normative value of inflows is small and amounts to $6.68 \cdot 10^{-5}$ m^3/s.

In real conditions, air inflows depend on the size of the gap between the flanges and the discharge in the gas-drainage pipeline. The value of inflows through flange joints can be determined using the empirical formula given in [4].

The absolute gas mixture pressure at the place of setting the first branch (Fig. 1) is determined by the formula [25, 26]

$$P_1 = 133.3\sqrt{(133.3^{-1}P_v)^2 + 4.8 \cdot 10^{-5} L_t D^{-5.33} (60Q_v)^2}. \quad (2)$$

Formula (2) does not take into account the change in the gas mixture density in places where air flows through the flange joints and, accordingly, the change in pressure loss along the length of the gas-drainage pipeline links.

Determine the flow rate of the gas mixture entering through the first branch of the gas pipeline. According to [27], the ratio for the pressure difference at the beginning and end of the branch has the form

$$P_b - P_1 = 0.8106 \cdot q_1^2 \cdot d_1^{-5} \cdot \lambda_1 \cdot \rho_0 \cdot L_d \cdot T_1 \cdot T_0^{-1}, \quad (3)$$

where P_b is barometric pressure in the ventilation working, Pa; q_1 – a flow rate of gas mixture entering through the first branch, m^3/s; d_1 – the first branch nominal bore diameter, m; L_d – the branch length, m; ρ_0 – gas mixture density under normal conditions, kg/m^3; $T_1 \approx T_w$ – an average gas mixture temperature in the first branch, K; T_0 – gas temperature under normal conditions, K; T_w – gas mixture temperature in the ventilation working, K; λ_1 – Darcy coefficient for the first branch.

Taking into account local hydraulic resistances, from expression (3) determine the flow rate of gas mixture entering to the gas-drainage pipeline through the first branch

$$q_1 = \sqrt{(P_b - P_1)\left[0.8106 \cdot \rho_0 \cdot L_d \cdot d_1^{-5}(\lambda_1 + \zeta_r)\right]^{-1}}, \quad (4)$$

where L_d is the branch length, m; $\zeta_r = 0.5$–0.6 – the local hydraulic resistance coefficient at the point of branch rotation.

Darcy coefficient value is determined by the formula [28]

$$\lambda = 0.11(d^{-1}\Delta + 64\mathrm{Re}^{-1})^{0.25}, \quad (5)$$

where Δ is the absolute equivalent roughness of the inner branch surface, m; Re – the Reynolds number; d – the nominal pipe bore diameter, m.

In gas-drainage pipelines with inflows (except for welded pipe joints), a change in gas dynamic parameters occurs at the places of pipe flange joints. In this case, it is possible to consider a gas-drainage pipeline with gas supply sources uniformly distributed along its length. In particular, formula (2) does not take into account the change in the gas mixture density and methane concentration in places of air inflows.

The gas mixture flow in the gas-drainage pipeline obeys the quadratic law. The correlation between the absolute pressures of the gas mixture at the beginning and at the end of the gas pipeline link is as follows [4]

$$p_{j-1}^2 - p_j^2 = p_{j-1} \cdot \rho_{j-1} \cdot Q_{j-1}^2 \cdot S^2 \cdot \lambda_j l \cdot D^{-1}, \quad (6)$$

where p_j is the absolute gas mixture pressure at the end of the link, Pa; p_{j-1} – the absolute gas mixture pressure at the beginning of the link, Pa; ρ_{j-1} – the gas mixture density at the beginning of the link, kg/m^3; Q_{j-1} – gas mixture flow rate at the beginning of the link, m^3/s; S – the flow passage section area of the gas pipeline link, m^2; λ_j – the Darcy coefficient for the link.

For high gas mixture velocities, the second term in formula (5) can be neglected. Then expression (6) is as follows

$$p_{j-1}^2 - p_j^2 = 0.11 \cdot p_{j-1} \cdot \rho_{j-1} \cdot Q_{j-1}^2 \cdot S^{-2} \cdot \Delta^{0.25} \cdot l \cdot D^{-1.25}. \quad (7)$$

The methane concentration in the gas mixture and its density at the end of the gas pipeline link are determined by formulas [4, 28]

$$C_j = 100\frac{I_j}{Q_j};$$

$$\rho_j \approx (\rho_m)_0 \frac{T_0}{T_j}\frac{p_j}{P_0} C_j + (\rho_a)_0 \frac{T_0}{T_j}\frac{p_j}{P_0}\left[1 - (\rho_m)_0 \frac{T_0}{T_j}\frac{p_j}{P_0} C_j\right],$$

where Q_j is gas mixture flow rate, m^3/s; I_j – methane yield, m^3/s; $(\rho_m)_0$ – methane density under normal conditions, kg/m^3; $(\rho_a)_0$ – air density under normal conditions, kg/m^3; P_0 – gas pressure under normal conditions, Pa; T_j – gas mixture temperature, K.

By performing a sequential calculation of flange joints in the direction of gas mixture flow using formula (7), determine the absolute pressure value P_2 at the places of setting the second gas pipeline branch (Fig. 1).

By analogy with (4), the gas mixture flow rate entering through the second branch is determined by the formula

$$q_2 = \sqrt{\frac{P_b - P_2}{0.8106 \cdot \rho_0 \cdot L_d \cdot d_2^{-5}(\lambda_2 + \zeta_c + \zeta_r)}},$$

where ζ_c is the local hydraulic resistance coefficient in the place of rock debris accumulation; λ_2 – the Darcy coefficient.

The coefficient ζ_c value is determined by the formula

$$\zeta_c = \frac{1}{2}\left[\left(1 - \frac{(d_2)_G^2}{d_2^2}\right)^2 + \left(\frac{d_2^2}{(d_2)_G^2} - 1\right)^2\right],$$

where $(d_2)_G$ is gas pipeline branch hydraulic diameter in the place where rock debris accumulates.

For the total gas mixture flow rate drained through the gas pipeline branches, the following condition should be met

$$q_\Sigma = q_1 + q_2 \geq Q_r. \quad (8)$$

Research results and their analysis. When calculating the gas mixture parameters in the site gas-drainage pipeline with branches, the following initial data are used:

- the total gas mixture and air inflows into the gas-drainage pipeline correspond to their normative values (no gas pipeline leak tightness failures are observed);
- the uncontrolled ventilation working depth – 800 m;
- the gas-drainage pipeline length – 1,100 m;
- the gas pipeline link length – 4 m;
- the gas mixture temperature in uncontrolled ventilation working area – 298 K;
- the average gas mixture temperature in the gas-drainage pipeline – 293 K;
- the average methane concentration in uncontrolled ventilation working area – 3 %;
- the methane concentration in the outlet jet of the extraction site – 0.48 %;
- the quantity of gas pipeline branches – 2;
- the distance between gas pipeline branches – 30 m;
- the amount of gas mixture that must be drained from the mined-out space – 0.5 m^3/s;
- hydraulic diameter of the second branch in the place of its contamination with rock debris varies from $0.5d_2$ to d_2.

As a result of the calculations, it is accepted: $D = 0.183$ m; $d_1 = d_2 = 0.183$ m.

Gas mixture amount drained through the gas pipeline uncontaminated branches is $q_1 = 0.2044$ and $q_2 = 0.2956$ m^3/s.

The calculated values of the gas mixture flow rate drained through the gas pipeline branches, taking into account the contamination of the second branch, are given in the Table.

The analysis of the obtained calculated values of the gas mixture flow rates shows that if the hydraulic diameter in the second branch of the gas pipeline in the place of its contamination is $(d_2)_G \leq 0.9d_2$, then the total gas mixture flow rate

Table

Flow rate of the gas mixture drained through the gas pipeline branches

$(d_1)_G$, m	q_1, m^3/s	$(d_2)_G$, m	q_2, m^3/s	q_Σ, m^3/s
$d_1 = 0.183$	0.23772	$d_2 = 0.1830$	0.26754	0.50526
		$0.9d_2 = 0.1647$	0.25463	0.49235
		$0.8d_2 = 0.1464$	0.21542	0.45314
		$0.7d_2 = 0.1248$	0.16202	0.39974
		$0.6d_2 = 0.1098$	0.11120	0.34892
		$0.5d_2 = 0.0915$	0.07098	0.30870

drained through the branches becomes lower than necessary. Therefore, the inequality (8) is not satisfied.

Fig. 2 shows the nature of the change in methane concentration along the length of the site gas-drainage pipeline when its second branch is contaminated.

Fig. 2 analysis shows that the methane concentration remains constant in the 40-m-long gas-drainage pipeline section, which is located in the uncontrolled ventilation working area. In this case, the reduction in methane concentration in the gas-drainage pipeline begins behind the insulating jumper.

This nature of methane concentration change is explained by the fact that in the uncontrolled ventilation working area before the insulating jumper (Fig. 1), the average methane concentration in the gas mixture entering from the mined-out space remains constant. As a result, the gas mixture inflows entering to the gas-drainage pipeline do not result in a noticeable change in methane concentration. Behind the insulating jumper in the zone influenced by the outlet ventilation jet, the gas mixture entering from the mined-out space is diluted. Therefore, air inflows entering the gas-drainage pipeline already lead to a decrease in methane concentration.

Fig. 2 shows that as the throughput capacity of the gas pipeline second branch decreases, a more noticeable decrease in methane concentration occurs behind the insulating jumper.

Examine the functional dependences linking the absolute gas mixture pressure, gas mixture flow rate and methane yield in the final section of the site gas-drainage pipeline with the hydraulic diameter of the contaminated branch

$$p_f = f[(d_2)_G];$$

$$Q_f = f[(d_2)_G];$$

$$I_f = f[(d_2)_G].$$

Fig. 3 shows the dependence of the absolute gas mixture pressure in the final section of the site gas-drainage pipeline on

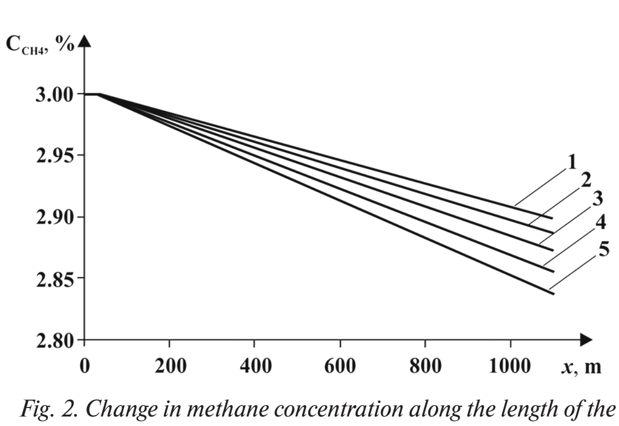

Fig. 2. Change in methane concentration along the length of the site gas-drainage pipeline when the hydraulic diameter of its second branch changes in the place of rock debris accumulation:

1 – $(d_2)_G = d_2$; *2* – $(d_2)_G = 0.8d_2$; *3* – $(d_2)_G = 0.7d_2$; *4* – $(d_2)_G = 0.6d_2$; *5* – $(d_2)_G = 0.5d_2$

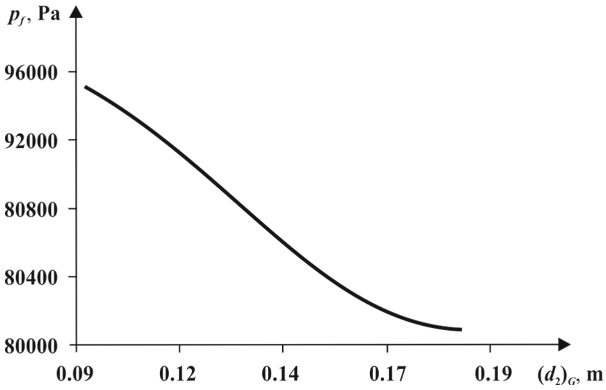

Fig. 3. Dependence of the absolute gas mixture pressure in the final section of the site gas-drainage pipeline on the hydraulic diameter of its branch in the place of rock debris accumulation

the hydraulic diameter of its branch in the place of rock debris accumulation.

Fig. 3 shows that the absolute gas mixture pressure in the final section of the site gas-drainage pipeline decreases with the increasing hydraulic diameter of the contaminated part of the branch. An increase in the flow passage section of the branch in the place of its contamination leads to an increase in the amount of gas mixture entering through the branch. As a result, pressure loss increases along the length of the gas-drainage pipeline. When the hydraulic diameter decreases, the reverse process is observed. That is, there is a decrease in the flow rate of the entering gas mixture, and consequently, in the absolute pressure loss along the length of the gas-drainage pipeline. Fig. 3 analysis shows that with a twofold decrease in the hydraulic diameter of the contaminated part of the branch, the absolute gas mixture pressure in the final section of the site gas-drainage pipeline increases by 1.2 times.

The regression equation for the functional dependence in Fig. 3 is as follows

$$p_f = 729{,}399(d_2)_G^2 - 373{,}097(d_2)_G + 124{,}032. \qquad (9)$$

The coefficient of determination for the resulting regression equation is $R^2 = 0.991$.

Solution to the equation (9) is

$$(d_2)_G = 0.25576 - \sqrt{1.37099\frac{p_f}{10^6} - 0.10464}.$$

Fig. 4 shows the dependence of the actual gas mixture flow rate in the final section of the site gas-drainage pipeline on the hydraulic diameter of its branch in the place of rock debris accumulation.

Fig. 4 shows that when the hydraulic diameter of the contaminated part of the branch increases, the gas mixture flow

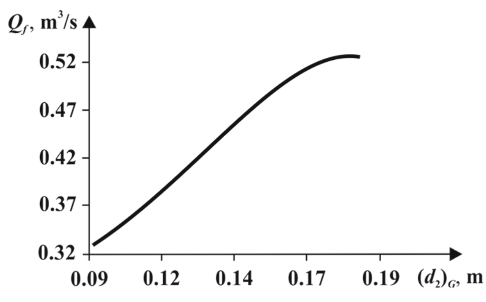

Fig. 4. Dependence of the actual gas mixture flow rate in the final section of the site gas-drainage pipeline on the hydraulic diameter of its branch in the place of rock debris accumulation

rate in the final section of the site gas-drainage pipeline increases. This is explained by a corresponding increase in the gas mixture flow rate entering through the branch. With a decrease in hydraulic diameter, the opposite pattern is observed.

Fig. 4 analysis shows that with a twofold decrease in the hydraulic diameter of the contaminated part of the branch, the gas mixture flow rate in the final section of the site gas-drainage pipeline decreases by 1.6 times.

The regression equation for the functional dependence in Fig. 4 is as follows

$$Q_f = -9.666(d_2)_G^2 + 5.0086(d_2)_G - 0.0574. \quad (10)$$

The coefficient of determination for the resulting regression equation is $R^2 = 0.991$.

Solution to the equation (10) is

$$(d_2)_G = 0.2591 - 0.0517\sqrt{22.8668 - 38.664 Q_f}.$$

Fig. 5 shows the dependence of methane yield in the final section of the site gas-drainage pipeline on the hydraulic diameter of its branch in the place of rock debris accumulation.

Fig. 5 shows that with an increase in the hydraulic diameter of the contaminated part of the branch, the methane yield in the final section of the site gas-drainage pipeline increases. This nature of the yield change is associated with an increase in the gas mixture flow rate entering through the branch. By analogy with Fig. 4, a decrease in the hydraulic diameter leads to a decrease in the flow rate of the entering gas mixture, as well as the methane yield. In turn, the gas mixture in the gas-drainage pipeline behind the insulating jumper will be diluted by air inflows, and the methane concentration will decrease.

Fig. 5 analysis shows that with a twofold decrease in the hydraulic diameter of the contaminated part of the branch, the methane yield in the final section of the site gas-drainage pipeline decreases by 1.63 times.

The regression equation for the functional dependence in Fig. 5 is as follows

$$I_f = -0.2896(d_2)_G^2 + 0.1501(d_2)_G - 0.0022. \quad (11)$$

The coefficient of determination for the resulting regression equation is $R^2 = 0.991$.

Solution to the equation (11)

$$(d_2)_G = 0.2591 - 1.7265\sqrt{0.02 - 1.1584 I_f}.$$

In case of contamination of the gas pipeline branches, in order to increase the flow rate of the gas mixture drained from the mined-out space, it is necessary to increase the discharge in the gas-drainage pipeline. This is achieved by switching the vacuum pump(s) to a new mode, or by connecting additional vacuum pumps. Adjustment valves are also used to increase discharge. It is advisable, if necessary, to implement these measures when degasification efficiency decreases during the time interval between the installations of new branches.

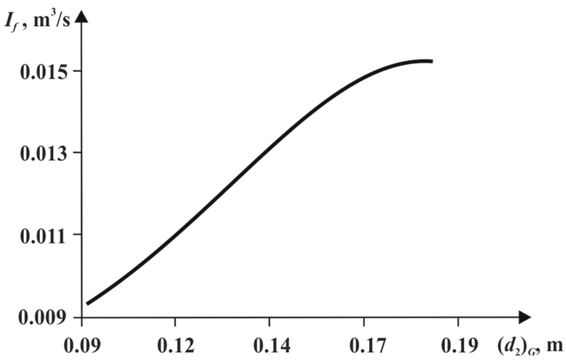

Fig. 5. Dependence of methane yield in the final section of the site gas-drainage pipeline on the hydraulic diameter of its branch in the place of rock debris accumulation

The authors plan to study the influence of leak tightness of gas-drainage pipeline section, which is located in the uncontrolled ventilation working area, on the gas mixture parameters in the gas pipeline.

Conclusions.

1. In the section of the gas-drainage pipeline with branches, which is located in the uncontrolled ventilation working area, the methane concentration remains practically unchanged. At the same time, behind the insulating jumper in the area affected by ventilation, the methane concentration in the gas pipeline decreases. This is due to dilution of the gas mixture entering from the mined-out space by the outlet ventilation jet with a corresponding decrease in methane concentration in the inflows entering to the gas pipeline.

2. The absolute gas mixture pressure in the final section of the site gas-drainage pipeline increases with a decrease in the hydraulic diameter of the gas pipeline contaminated branch. This is due to a decrease in the amount of gas mixture entering through the branch, and a corresponding decrease in pressure loss along the gas-drainage pipeline length.

3. When the hydraulic diameter of the gas pipeline contaminated branch decreases, the gas mixture flow rate and the methane yield in the final section of the site gas-drainage pipeline increase. This is due to a decrease in the amount of gas mixture and methane yield entering through the branch.

4. With a twofold decrease in the hydraulic diameter of the gas pipeline contaminated branch, the absolute gas mixture pressure in the final section of the site gas-drainage pipeline increases by 1.2 times, the gas mixture flow rate decreases by 1.6 times, and the methane yield decreases by 1.63 times.

5. A relationship between the hydraulic diameter of the gas pipeline contaminated branch with the absolute gas mixture pressure, its flow rate and the methane yield in the final gas-drainage pipeline section has been determined.

References.

1. Korovyaka, Ye., Astakhov, V., & Manukyan, E. (2014). Perspectives of mine methane extraction in conditions of Donets'k gas-coal basin. *Progressive Technologies of Coal, Coalbed Methane, and Ores Mining*, 311-316. https://doi.org/10.1201/b17547-54.

2. Koroviaka, Ye., Pinka, J., Tymchenko, S., Rastsvietaiev, V., Astakhov, V., & Dmytruk, O. (2020). Elaborating a scheme for mine methane capturing while developing coal gas seams. *Mining of Mineral Deposits*, *14*(3), 21-27. https://doi.org/10.33271/mining14.03.021.

3. Denysenko, V., & Abakumova, O. (2013). Solutions quality management methane mixture while extracting the degassing mining system. *Heoloh Ukrainy*, (3), 124-130. https://doi.org/10.53087/ug.2013.3(43).245587.

4. Minieiev, S. P., Novikov, L. A., Liutyi, M. O., & Makarenko, R. V. (2022). Impact of degasification pipeline tightness on air inflows and methane concentration. *Naukovyi Visnyk Donetskoho Natsionalnoho Tekhnichnoho Universytetu*, *1*(8)-*2*(9), 86-93.

5. Kostenko, V. K., Bokij, A. B., Brigida, V. S., & Zinchenko, N. N. (2010). Analysis of the actual state of degasification systems of coal mines in Ukraine. *Problemy ekolohii*, (1/2), 7-14.

6. Sahith, S., Pedapati, S. R., & Lal, B. (2020). Investigation on Gas Hydrates Formation and Dissociation in Multiphase Gas Dominant Transmission Pipelines. *Applied Sciences*, *10*(15), 5052. https://doi.org/10.3390/app10155052.

7. Bulat, A. F., Minieiev, S. P., Smolanov, S. N., & Belikov, I. B. (2021). *Fires in mine workings. Isolation of emergency sections*: *monograph*. Kharkiv. ISBN 978-617-7305-74-2.

8. Kocherga, V. N., Sytnik, I. V., & Levchinskij, G. S. (2014). Efficiency of integrated degassing of mining areas at Krasnolimanskaya mine. *Coal of Ukraine*, (11), 26-30.

9. Besschasnyy, O. V., Mukha, O. A., & Puhach, I. I. (2015). The method of transition from computed value of diameter of gas pipeline to standard value. *Naukovyi Visnyk Natsionalnoho Hirnychoho Universytetu,* (4), 85-90.

10. Prytula, D. A., Dudlya, Ye. Ye., & Bokiy, B. V. (2016). Methodology for calculating parameters of the ground degassing gas-transport

system for conditions of the a.f. zasyadko mine. *Geotechnical Mechanics*, *130*, 78-91.
11. Shirin, L. N., & Yegorchenko, R. R. (2022). Simulation of the conditions of interaction of the elements of the transport and technological system "mine as pipeline – mining production". *Oil and Gas Power Engineering*, (1), 88-96. https://doi.org/10.31471/1993-9868-2022-1(37)-88-96.
12. Shirin, L. N., Bartashevsky, S. E., Denyshchenko, O. V., & Yegorchenko, R. R. (2021). Improving the capacity of mine degassing pipelines. *Naukovyi Visnyk Natsionalnoho Hirnychoho Universytetu*, (6), 72-76. https://doi.org/10.33271/nvngu/2021-6/072.
13. Adeleke, N., Ityokumbul, M. T., & Adewumi, M. (2012). Blockage Detection and Characterization in Natural Gas Pipelines by Transient Pressure-Wave Reflection Analysis. *SPE Journal*, *18*(02), 355-365. https://doi.org/10.2118/160926-PA.
14. Li, H., Zhang, Y., Jia, W., Hu, X., Song, S., & Yang, F. (2024). Reduced capacity of gas pipelines in case of blockages. *Gas Science and Engineering*, *122*, 205187. https://doi.org/10.1016/j.jgsce.2023.205187.
15. Scola, I. R., Besançon, G., & Georges, D. (2018). Blockage location in pipelines using an implicit nonlinear finite-difference model optimization. *IFAC-PapersOnLine*, *51*(24), 935-940. https://doi.org/10.1016/j.ifacol.2018.09.687.
16. Bazaluk, O., Kuchyn, O., Saik, P., Soltabayeva, S., Brui, H., Lozynskyi, V., & Cherniaiev, O. (2023). Impact of ground surface subsidence caused by underground coal mining on natural gas pipeline. *Scientific Reports*, *13*, 19327. https://doi.org/10.1038/s41598-023-46814-5.
17. Shyrin, L., Yehorchenko, R., & Sergienko, M. (2021). Specifics of diagnostics of technical condition of transport and technological system "mining gas pipeline – mine working". *Geoengineering*, *6*, 28-37. https://doi.org/10.20535/2707-2096.6.2021.241823.
18. Kalisz, P. (2019). Impact of Mining Subsidence on Natural Gas Pipeline Failures. *IOP Conference Series: Materials Science and Engineering*, *471*(4), 1-10. https://doi.org/10.1088/1757-899X/471/4/042024.
19. Mysiuk, R., Mysiuk, I., Yuzevych, V., & Pawlowski, G. (2022). Determining the Place of Depressurization of Underground Pipelines (Gas Pipelines): New Solutions in Industry based on Thermal Image Analysis Using Computer Vision. *Path of Science: International Electronic Scientific Journal*, *8*(10), 1001-1010. https://doi.org/10.22178/pos.86-9.
20. Sopilnyk, L., Skrynkovskyy, R., Lozovan, V., Yuzevych, V., & Pawlowski, G. (2019). Determination of Economic Losses of Gas Transportation Companies from Accidents on Gas Transmission Pipelines. *Path of Science*, *5*(1), 1008-1017. https://doi.org/10.22178/pos.42-4.
21. Kliszczewicz, B. (2021). Analysis of the Pipelines Functional Safety on the Mining Areas. *Periodica Polytechnica Civil Engineering*, *65*(4), 1126-1133. https://doi.org/10.3311/PPci.18639.
22. Li, M., & Feng, X. (2022). Multisensor data fusion-based structural health monitoring for buried metallic pipelines under complicated stress states. *Journal of Civil Structural Health Monitoring*, *12*, 1509-1521. https://doi.org/10.1007/s13349-022-00609-w.
23. Yan, S., Li, Y., Zhang, S., Song, G., & Zhao, P. (2018). Pipeline Damage Detection Using Piezoceramic Transducers: Numerical Analyses with Experimental Validation. *Sensors*, *18*(7), 2106. https://doi.org/10.3390/s18072106.
24. Bratakh, M. I., Dobrunov, D. Ie., & Shkeir, A. (2017). Influence of the hydraulic condition of the industrial gas pipeline system on the regime of operation of gas production complex facilities. *Rozvidka ta rozrobka naftovykh i hazovykh rodovyshch*, *4*(65), 59-64.
25. On approval of the normative document "Design of coal mine degasification and operation of degasification systems. Rules" No. 304 (2022). *Ministry of Energy of Ukraine*. Retrieved from https://mev.gov.ua/sites/default/files/field/file/Наказ%20304_0.pdf.
26. Markin, V. A., Jurchenko, B. P., Timofeeva, N. L., & Kocherga, V. N. (2014). Calculation methodology of vacuum pumps operation mode in the presence of resistance at suction and discharge. *Sposoby i sredstva sozdanija bezopasnyh i zdorovyh uslovij truda v ugolnyh shahtah*, *1*(33), 29-37.
27. Ksenych, A. I., Serediuk, M. D., & Vysochanskyi, I. I. (2015). Methodology of hydraulic calculation of low-pressure ring gas networks with concentrated gas withdrawal. *Rozvidka ta rozrobka naftovykh i hazovykh rodovyshch*, (1), 97-104.
28. Bulat, A. F., Bun'ko, T. V., Jashhenko, I. A., Shishov, M. V., Miroshnichenko, V. V., Alab'ev, V. R., ..., & Kokoulin, I. E. (2018). *Improving the functioning of coal mines: ventilation, conditioning, degassing, ecology: monograph*. Dnipro: Zhurfond. ISBN 978-966-934-163-1.

Оцінка ступеня забруднення відростків газопроводу при дегазації виробленого простору

С. П. Мінєєв[1], *Л. А. Новіков**[1], *О. С. Янжула*[2], *О. Ю. Белоусов*[3], *Р. В. Макаренко*[4]

1 – Інститут геотехнічної механіки імені М. С. Полякова НАН України, м. Дніпро, Україна
2 – ТОВ «Метінвест Холдинг», м. Покровськ, Україна
3 – Шахтоуправління «Першотравенське» ПрАТ «ДТЕК Павлоградвугілля», м. Першотравенськ, Україна
4 – Шахтоуправління «Імені Героїв космосу» ПрАТ «ДТЕК Павлоградвугілля», м. Павлоград, Україна
* Автор-кореспондент e-mail: lnov710@gmail.com

Мета. Встановити закономірності зміни параметрів газової суміші в кінцевому перетині дегазаційного газопроводу при дегазації виробленого простору вугільної шахти відростками газопроводу з порушеною пропускною спроможністю.

Методика. Для вирішення поставленого завдання використовувалися теоретичні дослідження течій газової суміші у шахтних дегазаційних газопроводах, а також закони газової динаміки й гідромеханіки.

Результати. Встановлено, що на ділянці дегазаційного газопроводу, яка розташована в неконтрольованій частині вентиляційної виробки, концентрація метану залишається постійною. При цьому за ізолюючою перемичкою в зоні впливу вихідного вентиляційного струменя відбувається зниження концентрації метану в дегазаційному газопроводі. Встановлено, що зменшення гідравлічного діаметра забрудненого відростка газопроводу призводить до збільшення абсолютного тиску газової суміші, зниження її витрати й дебіту метану в кінцевому перетині дегазаційного газопроводу. У результаті розв'язання квадратичних рівнянь регресії отримані співвідношення, що зв'язують гідравлічний діаметр забрудненого відростка газопроводу з параметрами газової суміші в кінцевому перетині дегазаційного газопроводу.

Наукова новизна. Встановлено зв'язок між гідравлічним діаметром забрудненого відростка газопроводу, що відводить газову суміш із виробленого простору вугільної шахти, та параметрами газової суміші в кінцевому перетині дегазаційного газопроводу.

Практична значимість. Отримані співвідношення для гідравлічного діаметра забрудненого відростка газопроводу дозволяють оцінити його пропускну здатність і до моменту встановлення нових відростків за необхідністю підвищити розрядження в дегазаційному газопроводі для збереження необхідної ефективності дегазації.

Ключові слова: *вугільна шахта, дегазаційний газопровід, газова суміш, відростки газопроводу, забруднення*

The manuscript was submitted 04.03.24.