https://doi.org/10.33271/nvngu/2022-4/023

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THE METHODS TO CALCULATE EXPEDIENCY OF COMPOSITE DEGASSING PIPELINES

Purpose. To develop methods for calculating of the expediency to use mine degassing system, made of the current composites, to improve safety in heavily loaded longwalls.

Methodology. Solving the problems involved analysis of the current studies concerning the methane-air mixture removal from stopes while mining gaseous coal seams. Standard schemes of gas transmission systems have been considered as well as peculiarities of the methane-air mixture transportation using underground vacuum pipelines made from steel and composites.

Findings. Expert evaluation concerning economic expediency to replace the traditional steel pipelines by the modern composite gas lines for the available mine degassing systems, has helped develop methods calculating the operational indices of degassing networks made from the recent polymeric materials.

Originality. Methods have been developed to calculate technical and economic parameters of degassing network, made from the modern composites, and upgrade the current degassing systems to reduce expenditures connected with the captured methane-air mixture transportation from wells to vacuum pump stations.

Practical value. Implementation of the findings as for the evaluation of the technical and economic parameters and introduction of the innovative engineering solutions to replace the traditional steel degassing pipelines by the recent gas lines made of long composite chains, involving minimum joints, has been scheduled by Ukrainian gaseous coal mines.

Keywords: *degassing, underground vacuum pipeline, methane-air mixture, composite pipeline, steel pipeline*

Introduction. Load increase and acceleration of stope advance with the use of new facilities and mining methods have resulted in the increased methane emission in the worked out area.

The current technique to degas carbonous formation as well as the worked-out area is based upon the use of underground degassing systems (UDSs) where metal degassing pipelines are their key components. Generally, the degassing pipelines are mounted on small supports located within the floor of underground mine workings; another way is to suspend them to clamping devices. During operation, the degassing pipelines are influenced by aggressive mine environment resulting in corrosion of the pipes [1]. Moreover, the pipelines demonstrate linear deformations depending upon changes in spatial arrangement of mine workings under the effect of rock mass.

Globally, long composite pipes are applied for degassing systems. Research [1] has determined that such composite pipelines, being a part of degassing systems in coal mines, are quite promising from the engineering and economic viewpoints. To compare with traditional steel pipelines, composite ones have much lower hydraulic resistance coefficient and a smaller number of joints. In addition, they never rust, which decreases significantly air pressure of a pipeline and, consequently, power consumption while transporting methane-air mixture. At the same time, coal enterprises have no methodological recommendations as for the expediency to use degassing polymeric pipelines in mine environment.

Topicality. Currently**,** intensive development of gaseous coal seams formulates a problem of timely disposal of methane-air mixture from stopes as well as from the worked-out area of operating longwalls while providing its quality indices for further use as energy feedstock. The problem arises from air pressure of steel pipelines being higher to compare with the composite ones due to abundant mine air inflow as a consequence of the metal corrosion and leakage of pipe joints resulting from rock mass deformations. The tendency of steel pipelines to rust in aggressive underground environment has factored into the design of composite pipelines which may operate for 40–60 years [2]. Such composite pipelines have a number of advantages over the steel ones, namely: decreasing of construction and operational costs; resistance to electrochemical corrosion; lesser roughness of internal surface; and 20 % increase in output.

The analysis of the current underground degassing pipelines [3] has shown that operation of the steel ones is followed by significant economic loss depending upon:

1) considerable air pressure of degassing pipeline resulting in the increased electric power consumption by vacuum pumps;

2) repairs whose frequency is stipulated by operation of the pipelines;

3) deterioration of gas mixture quality due to mine air inflow into a degassing column through the corrosion holes and pipe joints.

Hence, substantiation of the parameters of degassing pipelines, operating in aggressive underground environment, is quite an important problem of coal industry.

Purpose is the development of methods to identify expediency of an underground composite degassing system improving labour safety in high-load longwalls.

Literature review. Construction of pipelines from modern composites is accepted in the world oil-and-gas industry [2]. It is common knowledge that composite pipelines are used to develop reliable pressure systems for transportation of gas and crude oil; for delivery lines of wells; for lift headers; and for different piping systems of engineering infrastructure of the oil-and-gas sector.

Practices of composite pipeline operation during crude oil and gas transportation show that relevant composite pipes should be applied for different media and conditions since their incorrect selection while designing results in different emergency situations.

Paper [4] represents recommendations concerning the use of such composite gas lines by coal industry. The author states that composite pipes have minor roughness of internal surface and, hence, low hydraulic resistance of a vacuum pipeline. It is recommended to identify pressure losses within the composite gas lines with absolute equivalent roughness of internal roughness of internal pipe surface, being $K_e = 0.0002$ mm, using the dependence

$$\Delta P = 43.39\frac{V_p^{1.75}}{d^{4.75}}\rho_o v^{0.25} L_p,$$

where ΔP is pressure losses within a pipeline section, Pa; V_p is analytical gas consumption, m^3/h; d is internal gas line diameter, cm; ρ_o is gas density if conditions are standard, kg/m^3; v is coefficient of kinematic gas viscosity, m^2/s; L_p is analytical length of a pipeline section, m.

Some experiments [1] have helped understand that analytical roughness for new steel pipes (involving local blowouts within joints) is 0.02 and 0.10 mm. It excesses significantly the roughness of a composite pipeline.

No available information sources considered calculation methods for operational parameters of the underground composite degassing systems.

Task setting. Research [3] has identified that corrosion of metal pipelines, roughness of internal walls, hydraulic resistance during methane-air mixture transportation, and mine air, coal and rock dust transfer from atmosphere of mine workings to a degassing pipeline influence operational parameters of the underground gas-drainage systems. The abovementioned supports the idea that flange joints are not tight within the pipes. At the same time, due to the lack of experiments concerning operational parameters of underground composite degassing systems, indices of their analytical calculations should be considered as the conditional ones. That depends upon the following. Early theoretical studies did not involve transportation conditions of long composite pipes, their delivery to underground mine workings, and expenditures connected with installation taking into consideration mine environment parameters. Hence, a demand arose for the development of methods to identify expediency of degassing polymeric pipeline use under the conditions of mine environment while shaping degassing systems providing safe operations in high-load longwalls.

Targets of the research are as follows:

- to analyse economic feasibility in order to replace traditional steel pipelines with modern composite gas lines for the available mine degassing networks;
- to develop calculation methods for operational indices of degassing networks made from the current composites.

Results. Extensive operational practices of steel degassing pipelines have shown that its useful life is no longer than 10 years [5].

Up to now, steel pipes of mine degassing lines as well as main pipeline are considered as the components of transport and technological systems which provide balance of its cost, reliability, accessibility, and suitability to be repaired.

Under these conditions, the total expenditures connected with the construction and operation of underground degassing lines should involve cost of steel pipes, their delivery to mine, installation activities, joint tightening, replacement of rusted elements, and their repair.

It has been defined experimentally that aggressive environment provokes significant corrosion damage of steel degassing lines impacting fundamentally their health and degrading operational indices [3]. It should be mentioned that the available method of pipe production, using plain carbon steel delivered to mines for degassing system construction, does not involve any specific cover (i.e. chemical protection) preventing corrosion. Thus, the most efficient way to solve the problem is employment of corrosion-proof pipes being commonly used by the related sectors.

According to the recommendations proposed in [6, 7], composite pipes are the alternative to the traditional steel pipes since they have the following advantages:

- high corrosive resistance to an aggressive environment;
- light weight and simple installation;
- higher output (almost by 20 %) owing to smooth surface since equivalent roughness of a steel pipe wall is $K_e = 0.01$ mm to compare with $K_e = 0.0007$ mm in terms of a composite pipe [8];
- high strength, elasticity, and flexibility;
- low gas permeability.

The analysis of the economic performance of composite pipelines has shown that their relative expensiveness as compared to steel analogues is the basic obstacle to apply them. Nevertheless, light weight of polymeric pipes, ability to transport them in coils, and their simple operation help reduce the costs for delivery and installation of pipe links (Fig. 1) [1].

Transit of steel pipes from the surface down to a mine as well as through mine workings corresponds to the current system *PACOD,* transportation rules for long goods [9].

Delivery of long pipelines in coils to a mine and their installation reduces drastically the number of joints while favouring decrease in the expenditures connected with installation activities.

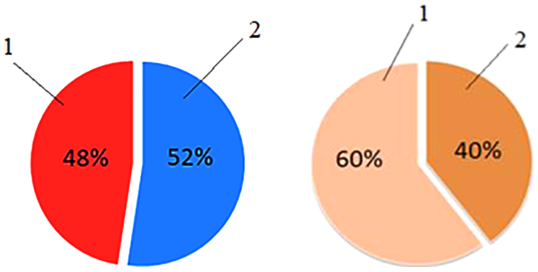
As a result, cost of the installed long meter of a composite pipe drops significantly and becomes cheaper than the installed long meter of a steel pipe.

Low indices of roughness and hydraulic resistance are among the most important advantages of composite pipes influencing greatly the operational parameters of a gas transmission system. Equivalent roughness of polymeric pipes is $K_r =$ $= 0.0007$ and $K_r = 0.01$ mm in terms of steel ones.

Taking into consideration the factors for mine environment, technical-and-economic expediency is assessed to construct composite pipelines and traditional steel pipelines.

Research [10] has determined that implementation of composite pipeline in the system of a mine degasification system implies a number of positive technical-and-economic indices owing to the increase in productivity of the pipeline system; low hydraulic resistance; and no necessity to construct cathodic protection structures.

It should be mentioned that design of degassing systems focuses on substantiation of their output whose indices are de-



a *b*

Fig. 1. Comparative costs to construct steel and composite pipelines:

a – pipe cost: 1 – steel pipe; 2 – polymeric pipe; b – cost of pipeline installation: 1 – steel line; 2 – composite line termined with the help of the predicted amount of methane-air mixture, supplied to the system, pressure in the pipeline within its nodes, specific pressure losses while transporting, and rational diameters of the pipeline for relevant sections.

The technical-and-economic assessment is based upon the industry methods of Naftogaz of Ukraine [8] which ignore engineering factors as well as design features of pipes, expenditures connected with their delivery to a mine, and assembling and dismantling operations while constructing underground gas lines.

Economy of traditional steel degassing pipeline replacement for a modern composite gas line is assessed in terms of a degasification system in *Krasnolymanska* mine using the methods of investment project efficiency [11].

Fig. 2 demonstrates actual interconnection scheme of sections of the degassing pipelines in *Krasnolymanska* mine with proper diameters from MAM location up to the surface vacuum pipe station.

The calculation is performed in terms of current prices of the based period ignoring VAT. Operating mine gas line DN 320 is taken as an example (Fig. 3).

A decade is assumed as the calculation period. Expenditure is accepted in terms of specific indices based on 5 km of a pipeline.

Replacement of steel pipes with the composite ones decreases the number of joints and decelerates formation process of the areas where mechanical impurities are deposited as well as sections where the pipeline diameter is narrowed. The abovementioned makes it possible to improve the total operational efficiency of a gas transmission system of a mine.

Table 1 shows the source data to calculate indices for the replacement of steel degassing pipeline in *Krasnolymanska* mine with composite one.

The efficiency (P_p) of a composite pipeline at different assessment stages has been defined using the expression [11]

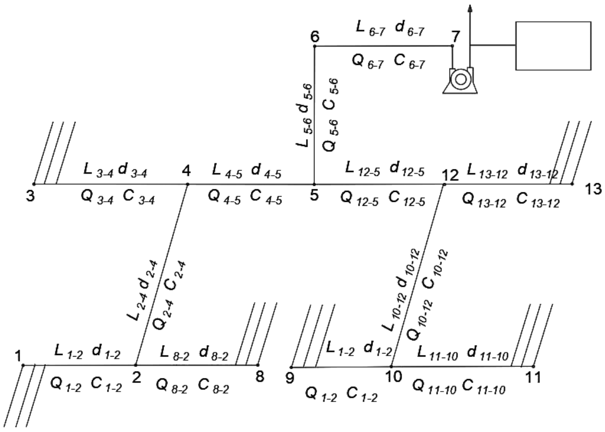


Fig. 2. Model framework of underground degassing pipeline:

l_i – section length, m; Q_{mm} – consumption of methane-air mixture, m^3/m; C_i – methane concentration, %; 1–9 – joints of the pipeline

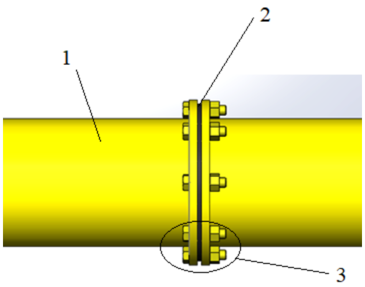


Fig. 3. Structural peculiarities of the underground degassing pipeline:

1 – gas line section ($L = 4.0$ m); 2 – paronite pad; 3 – flange joint

Table 1

Comparative characteristic of the operational and economic indicators of composite and steel pipelines

Indicator	Measurement units	Value of the indicator	
		Composite pipeline	Steel pipeline
Life	years	60	10
Pipeline cost	thousand dollars	197.34	179.4
Installation expenditures	thousand dollars	212.7	333.13
Capital investment	thousand dollars	410	518.5
Cost of the major repairs	thousand dollars	23.92	29.9
Output	m^3 per minute	120	100
Economic effect	thousand dollars per annum	80.5	72.68

$$P_p = \sum_t^P \frac{V_t}{(1+P)^{t-t_b}},$$

where V_t is investment by an enterprise from a project implementation in the t^{th} year of the calculation period; P is a discount rate (relative units, r.u.) taking into consideration reduction in value of later costs; t_b is cost at the basic time made at t moment.

An index of the project efficiency is determined with the help of the expression [11]

$$IP_p = \frac{P_p}{\sum_t^P \frac{K_t}{(1+P)^{t-t_b}}} + 1,$$

where K_t is capital investment connected with the project implementation.

Fig. 4 demonstrates a comparative analysis of the efficiency indices of composite and steel pipeline installation.

The defined (P_p) and (IP_p) indicators support the idea that composite pipes are by 1.5 times more efficient from economic viewpoint; moreover, their efficiency index is 40 % higher to compare with the steel systems.

Current methods to define basic degassing parameters for coal mines in Ukraine have been developed for the specific mining and geological conditions. The methods are of advisory nature.

However, the available variety of the proposed methods to calculate degassing parameters is not efficient relative to the composite gas lines. Moreover, rather often, actual operational parameters of the network cannot correspond to the analytical ones.

Diagnostics of technical conditions of the mine gas transmission lines and examination of their dismantled components have helped understand that deflections, mainly resulting in water accumulation zones, intensive corrosion of internal pipe walls, and mechanical depositions of coal and rock dust take place right within the flange connection areas. Formation of such zones is argued by health of the degassing pipeline as well as mine air inflow. Availability of internal corrosion, water accumulations, and mine air inflow decreases substantially capacity of the underground gas transmission line inclusive of qualitative characteristics of the captured methane-air mixture and efficiency of MDS on the whole [3].

The abovementioned material creates the necessity to develop recommendations improving the current calculation methods of MDS parameters [12] since it is a topical scientific and practical task.

The recommended methods include determination of optimum values of methane-air mixture transit through the sections of composite pipes, diameter of the pipe section, and drag coefficient of 1 long meter of the section. The criteria to

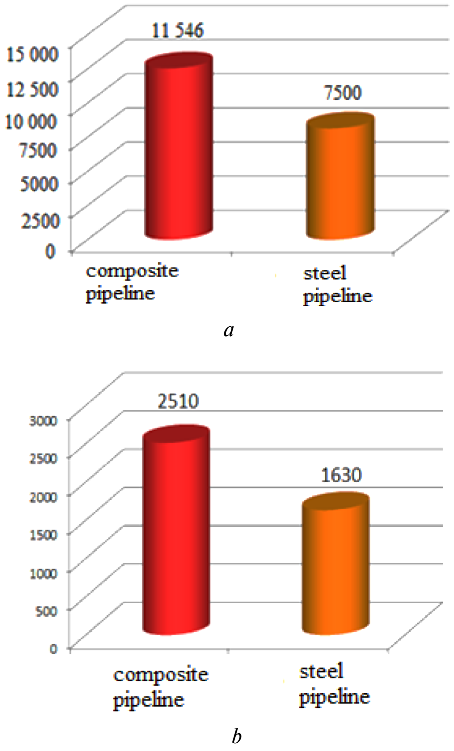


Fig. 4. Efficiency indices of the implementation of pipelines:

a – pipeline efficiency Em, thousand dollars; b – efficiency index IEp, m.u.

assess operational efficiency of a degassing system are as follows: depreciated value; pipe repair cost per year; and cost of electric energy consumed by vacuum pump (VP) to transport methane through the section. The depreciated value and pipeline repair are assumed as a proportion from the pipe cost. The value of 1 long meter of a pipe is determined using the expression [13]

$$K_m = b_0 + b_1 D + b_2 D^2,$$

where D is pipe diameter within a section, m; b_0, b_1, and b_2 are empiric formula coefficients.

The cost of electric energy, consumed by methane transportation through a composite pipeline section, is identified by means of the dependence [13, 14]

$$E_e = \frac{Q \cdot h_d}{1000\eta_v} T \cdot c,$$

where Q is air consumption within the section, m^3/s; h_d is section depression, Pa; η_v is efficiency of vacuum pump station, fr.un.; T is operating VPS hours during a year, hours; c is cost of 1 kWh of the consumed energy, UAH.

Calculation of the section parameters should involve determination of admissible methane velocity through composite pipeline, the required pipeline diameter, and tolerable pressure losses per 1.0 long meter of the pipeline.

It should be mentioned that the permissible length of degassing pipes, delivered by manufacturers, is 4.0 m since it depends upon the demands of oversized goods supply in a mine [5].

Current industrial limitations are the noticeable disadvantages of the available procedures of underground steel gas line construction. The matter is that up to 250 joints fall on 1.0 km of its length. In view of intensive rock deformations, numerous faults in air-tightness are observed provoking pressure losses within a system, decreased methane concentration in MAM due to mine air inflow, and increased coefficient of hydraulic resistance.

High plasticity is the advantage of composites providing their transportation in coils with up to 1,000 m total length depending upon the diameter [1]. Plastic properties of composite pipes as well as their physical and mechanical characteristics make it possible to use long-chain gas line construction in the curvilinear mine workings; in addition, the minimal joint number will be involved. Expression [12] helps identify the electric energy, consumed by vacuum station for MAM transportation through the composite pipelines and the total of depreciation expense in addition to repairs per year

$$W = \frac{Q}{1000\eta_v}\left[\frac{4\alpha L}{D} V^2 TC\right] + 0.01rL\left(b_o + b_1 D + b_2 D^2\right), \quad (1)$$

where α is the drag coefficient of a pipeline, H · s^2/m^4; L is degassing pipeline length, m; r is the percentage of a pipe section value, deduced for depreciation and repair, %; V is MAM velocity within a degassing pipeline, m/s.

Since MAM transportation through the degassing pipelines obeys the law of the continued flow, dependence [12] determines the pipeline diameter

$$D = 1.13\frac{Q^{0.5}}{V^{0.5}}. \quad (2)$$

After (2) insertion in (1), the expression of energy consumption value will look like

$$W = \frac{Q}{1000\eta_v}\left[\frac{2.12\beta L V^{0.5}}{Q^{0.5}} V^2 TC\right] + \frac{rL}{100} \times$$

$$\times \left[b_o + 1.13 b_1 \frac{Q^{0.5}}{V^{0.5}} + 1.28 b_2 \left(\frac{Q^{0.5}}{V^{0.5}}\right)^2\right],$$

where β is dimensionless friction coefficient.

Differential equation will be as follows

$$\frac{dW}{dV} = 2.5 \cdot 0.0021\beta L Q^{0.5} TC V^{1.5} - 0.0127 L b_2 \frac{Q}{V^2} -$$

$$-0.5 \cdot 0.0113 L b_1 \frac{Q^{0.5}}{V^{0.5}} = 0.$$

Apply dependence [13] to define velocity of MAM transportation through a composite pipeline

$$V = \frac{4Q}{\pi D^2} = \frac{1.27 \cdot Q}{D^2}.$$

It should be mentioned that pipe joints demonstrate local resistance whose depression is identified with the help of expression [12]

$$h_{m.e} = \frac{\xi \rho V^2}{2},$$

where ξ is the coefficient of local resistance.

Root-mean-square pressure drop A_{ave} within a degassing composite network is determined using the dependence

$$A_{ave} = \frac{P_b^2 - P_{end}^2}{(1+K)\sum L},$$

where P_b, and P_{end} are values of absolute gas pressure at the beginning of the network and at its end, MPa; $\sum L$ is total length of a degassing section, km; K is coefficient, taking into consideration pressure losses within the local supports in fractions of the linear ones.

It should be mentioned that the amount of mine air, inflowed within pipe joints, can be described as $q_1, q_2, \ldots, q_n$, and Q_0, where Q_0 is air amounts in the initial (final) section of the pipeline, m^3.

In such a way, amount of MAM, passing through each section is as follows: section one – Q_0; section two – $(Q_0 + q_1)$; section three – $(Q_0 + q_1 + q_2)$; and section n – $\left(Q_0 + \sum_{i=1}^{n-1} q_i\right)$.

Lengths of the pipe sections are specified as L_1, L_2, and L_n.

The total network resistance is equal to the resistance sum of all sections

$$H_0 = H_1 + H_2 + H_3 + \ldots + H_n = \sum_{i=1}^{n-1} H_i.$$

The annual costs for a degassing plant are calculated as follows

$$W_{el} = \left(Q_0 + \sum_{i=1}^{n-1} q_i\right) H_i \frac{TC}{1000\eta} + 0.01 r L_m n_s (b_o + b_1 D + b_2 D^2),$$

where $Q_0 + \sum_{i=1}^{n-1} q_i$ is efficiency of the degassing plant, m^3/s; $\sum_{i=1}^{n-1} H_i$ is pressure loss within the network, Pa; n_s is the number of the pipeline sections, pieces.

Consequently, the proposed methods, defining the expenditures connected with the methane-air mixture transportation through a polymeric pipeline, take into consideration the features of composite networks while helping identify the potential reserves of operational parameters of a gas-transmission system owing to the decreased resistance of MAM transportation as well as quality parameters of the captured gas by means of considerable reduction of the joint number.

Conclusions. Composite pipelines, operating within the degassing systems of coal mines, are promising from the technical and economic viewpoints. Compared to steel pipes, the composite ones have a much lower hydraulic resistance coefficient making it possible to drop significantly energy consumptions for the methane-air mixture transportation. Moreover, composite pipelines are by 1.5 times more efficient from the economic viewpoint; in addition, their efficiency index is by 40% higher to compare with the steel systems. The proposed calculation methods help expand the use of composite pipelines in the degassing systems of coal mines and improve quality of methane-air mixture.

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Методика розрахунку доцільності використання шахтних дегазаційних газопроводів із композитних матеріалів

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Мета. Розробка методики розрахунку доцільності використання шахтної дегазаційної системи із сучасних композитних матеріалів для підвищення безпечної роботи у високонавантажених лавах.

Методика. Для вирішення поставлених завдань виконано аналіз сучасних досліджень процесів відведення метаноповітряної суміші з очисних вибоїв при розробці газоносних вугільних пластів. Розглянуті типові схеми газотранспортних систем і особливості транспортування метаноповітряної суміші шахтними вакуумними трубопроводами зі сталевого й композитного матеріалів.

Результати. За результатами експертної оцінки економічної доцільності заміни традиційних сталевих трубопроводів на сучасні композитні газопроводи для існуючих шахтних дегазаційних систем розроблена методика розрахунку експлуатаційних показників дегазаційних мереж із сучасних полімерних матеріалів.

Наукова новизна. Розроблена методика розрахунку техніко-економічних показників дегазаційної мережі з сучасних композитних матеріалів і модернізації діючих шахтних дегазаційних систем для зниження затрат на транспортування каптованої метаноповітряної суміші від свердловин до вакуум-насосних станцій.

Практична значимість. Практичне застосування результатів дослідження щодо оцінки техніко-економічних показників і впровадження інноваційних технічних рішень із заміни традиційних сталевих дегазаційних газопроводів на сучасні газопроводи з довгомірних композитних ланок і мінімальною кількістю стикових з’єднань заплановано на газо-вугільних шахтах України.

Ключові слова: *дегазація, підземний вакуумний газопровід, метаноповітряна суміш, композитний трубопровід, сталевий трубопровід*

The manuscript was submitted 20.11.21.