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IMPROVING THE CAPACITY OF MINE DEGASSING PIPELINES

Purpose. To identify features of methane-air mixture flow within the steel degassing pipelines as well as within those ones made of composite materials, to develop engineering solutions improving their reliability for actual use.

Methodology. To solve the problem of increasing the capacity of mine degassing pipelines, an analysis of fundamental studies on the physical and mechanical properties of mine methane and the processes of its recovery in a mine environment is conducted. Schemes of operating gas-transmission systems and peculiarities of functioning of zonal vacuum gas pipelines in the conditions of intensive removal of rocks of the bottom of underground workings and deformations of the massif are considered. Based on the results of expert assessment of production situations, potential reserves for enhancing the efficiency of in-mine gas pipelines have been determined. Reliability indicators of traditionally applied steel pipes and their analogues from composite materials used abroad are established, innovative technological and technical solutions for their construction at Ukrainian mines are recommended.

Findings. According to the expert evaluation of the operation modes of mine degassing lines and analysis of the world practices to apply pipes made of composite materials for mining industry, an engineering solution concerning the improvement of operating degassing systems as well as their capacity has been substantiated.

Originality. Innovative engineering solutions as for the modernization of the underground degassing systems, which allow increasing the capacity of mine pipelines, and provide maintaining of the quality the captured methane-air mixture in the process of its transportation from wells to vacuum pump stations, have been substantiated.

Practical value. Implementation of the research results to decrease hydraulic resistance within the degassing mains as well as introduction of innovative engineering solutions for the construction of main degassing pipelines from long links of composite pipes with a minimum number of butt joints has been scheduled for Ukrainian mines dealing with the development of gassy coal seams.

Keywords: *degassing, hydraulic resistance, condensation, underground vacuum pipeline, methane-air mixture, composite pipeline*

Introduction. The process of gas-bearing coal seam deepening makes the degassing system more important. Against the background of the basic tasks intended to provide labour safety of miners and increase per face output in terms of a gas factor, mining intensification has identified the problems of mine methane drainage through the underground pipelines to the surface for its further utilization with the help of power plants.

Literature review. Studies by A. T. Airuni, L. A. Puchkov, N. O. Kaledina, V. A. Malashkina, A. F. Bulat, B. V. Bokiy, K. K. Sofiyskiy, S. P. Mineiev, V. N. Kocherga [1, 2], and other scientists concern physics of methane recovery in the process of gas-bearing coal seam development as well as their influence on the performance of complex and powered stopes. At the same time, the problem to define rational modes of methane-air mixture transportation through the underground degassing pipeline is understudied from the viewpoint of the hydrodynamic process.

The following can be considered as the key features of methane-air mixture transportation thorough the underground vacuum pipeline:

- significant extent of underground pipeline network;
- gas mixture flow under the vacuum conditions;
- water, liquid, coal dust, and rock dust vapours within the captured mixture;
- air inflow through the leakages of flange connections of joints of vacuum pipeline into the system throughout its length.

Fundamental studies [3] have identified that excess in the established parameters of specific volume of air, drawn-in from the mine working atmosphere, results in the increased specific pressure losses within a pipeline to compare with the design variables. The increase in output of methane-air mixture with simultaneous decrease of methane concentration in it factors into liquid accumulation within low pipeline spots; hence, a hydraulic pipe section decreases as well.

Papers [4] consider theoretical problems of methane-air flow within the mine gas lines. They also mention that the listed negative factors are the key reasons of the increased electric power costs to transport the mixture through the network of degassing pipelines. At the same time, there are no recommendations concerning the improvement of the operating systems of underground gas pipelines as well as the development of new engineering solutions of their enhancement under actual conditions of mine environment.

The experiments have confirmed [5] that methane-air mixture transportation through the curved (both in the plan and in profile) pipeline results in the greatest underpressure of the system and in the methane dilution in the mixture due to local accumulation of liquid, coal and rock dust inside the pipeline as well as in the joint of its sections. Fig. 1 demonstrates typical areas of admixture accumulations, potential zones of changes in air resistance of the pipeline, and the decreased capacity of the mine gas line.

A distinctive feature of the degassing system operation under the Western Donbas conditions is the following: the degassing pipelines are laid in mine workings experiencing intensive heaving of ground floor and heavy inflows. Moreover, the region mines operates predominantly near the boundaries of mine fields. Hence, the pipeline extension up to 3–5 kilometers results in the increased underpressure developed by vacuum pumps. Traditionally, steel pipes to erect mine pipelines are delivered in the form of 4.0 m long measuring sections. Thus, in actual practice, up to 250 joints fall on a kilometer of a degassing pipeline. Increase in the mine pipeline extension factors into increasing amount of the air getting into the degassing system through the joint leakages. The abovementioned decreases drastically the methane concentration within the captured mixture while increasing hydraulic resistance of the system [6].

The latter depends upon the fact that within typical areas of the curved gas line, a methane-air mixture flow within the curved gas line factors into intensive sedimentation of mechanical components as well as into ingress of mine air transported by the ventilation facilities (Fig. 1). In total, that results in the decreased capacity of the operating gas transmission network.

Hence, the intensive development of gas-bearing coal seams generates the necessity to adapt the gas transmission system to the actual conditions of mine environment and vary the available approaches as for its capacity determination. The abovementioned is required to achieve proper degasification efficiency and improve capacity of the pipeline system.

In practice, the improvement of degasification system capacity involves installation of parallel gas pipeline sections in the process of its modernization. Nevertheless, that gives rise to the actual extension of an underground gas line as well as to the increased number of joints of steel pipes.

According to the requirements listed in [7], steel pipes with no less than 2.5 mm wall thickness or those ones made of other materials applicable for mine conditions, are recommended to erect degassing gas lines.

It should be mentioned that it is extremely important for the degassing system design to pay specific attention to substantiation of its capacity whose indices are defined with the help of the prognosticated volume of methane-air mixture getting to the system, pressure within the gas line in its nodes, specific pressure losses during transportation, and rational diameters of the pipeline in terms of the corresponding sections.

Mine degassing system is the branched network of specific pipelines: well lines with ∅100–150 mm diameter; sectional lines with ∅150–250 mm diameter; and the main ones with ∅250–530 mm diameter (Fig. 2). Borehole pipelines and sectional ones are equipped with stop valves as well as with short pipe sections having external thread (i.e. nozzles) for gas sampling, control of pressure, temperature, and gas mixture consumption.

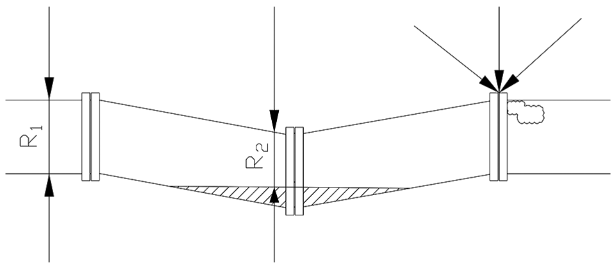

Fig. 1. Typical areas of the accumulations of mechanical sedimentation and mine air ingress into a pipeline:

– areas of mechanical sedimentation accumulations;

– mine air ingress into the pipeline

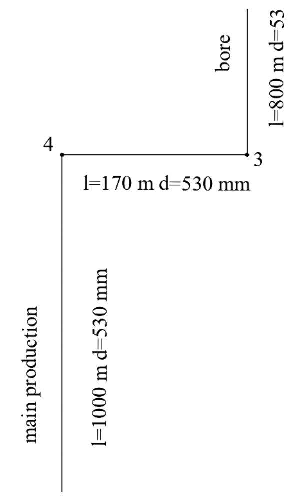

Fig. 2. Standard schemes of a mine degassing pipeline

Fig. 2 shows actual schemes to connect sections of degassing pipelines, being of proper diameters, from a place of methane-air flow to the surface vacuum-pump station.

According to [6], the volume of methane-air mixture, supplied to a pipeline per a time unit, is determined by means of the expression

$$Q_{sm.r} = Q_{sm.v} \cdot k_3, \qquad (1)$$

where $Q_{sm.v}$ is rated consumption of the methane-air mixture, m^3/min; k_3 is a reserve coefficient taking into consideration forecasting error of methane release (assumed as $k_3 = 1.1$).

A gas line diameter, in terms of which vacuum pumps will provide the required mixture consumption, is identified as follows

$$d = 0.04\left(\frac{Q_{sm.v}^2}{\Delta P_s}\right)^{0.188}. \qquad (2)$$

Generally, if series connection of pipes, being of different diameters, takes place (Fig. 2), then their equivalent diameter is calculated

$$d_{equiv} = \left(\frac{\left(d_n \cdot d_{n+1}\right)^{5.33}\left(l_{n+1} + l_n\right)}{l_{n+1} \cdot d_i^{5.33} + l_n \cdot d_{n+1}^{5.33}}\right)^{0.188}, \qquad (3)$$

where d_n is a pipeline section diameter, m; d_{n+1} is a diameter of the following section, m; l_n is length of the pipeline section, m; l_{n+1} is length of the following section, m.

To provide the required capacity, the nearest-neighbour standard pipeline diameter is assumed traditionally for all sections of the degassing network. Operational parameters of the gas transmission network are determined for each of the sections.

At the same time, despite tough requirements [8], design of the operational parameters of gas transmission systems does not involve dynamic changes in a pipeline profile taking place under the influence of geomechanical processes occurring within the rock formation. The mine analysis helped understand that the underground workings, equipped with a gas line system, experience linear deformations of the pipeline within its joints resulting from the wall rock convergence and floor rock heaving.

Diagnostics of technical condition of mine pipelines using the developed facilities [9] made it possible to define that the deposits of mechanical impurities, leakages of their joints, and intensive air intake are available within the areas of active deflection of a pipe joint profile. According to the studies [8], roughness of the internal walls of steel pipeline originates and its capacity drops within the areas of intensive deposition of mechanical impurities.

To reduce roughness of linear pipelines and improve their capacity, recommendations have been developed internationally as for the use of flexible composite pipes to erect in-mine pipeline systems.

Paper [10] lists the design features as well as the engineering data of composite pipes (i. e. those ones made of glass reinforced plastic). However, there are no recommended practices concerning the erection of mine gas transmission systems, their operation, control, and integrity diagnostics.

Development of the basic requirements to design new-generation gas transmission system has resulted in the requirement to carry out comparative analysis of operational efficiency of traditional steel gas lines and gas lines made of composite materials. The following is considered as the performance indices of the gas transmission line use in the mine environment being constantly time-and-space-dependent: material strength, durability, roughness, and adaptive capacity to changes in the pipeline-route profile resulting from the intensive coal mining.

Composite pipes, manufactured abroad, are of a multilayer structure. Moreover, each of the layers has definite functions. To reduce roughness, an internal layer of the composite pipes is made of high-density polyethylene. Its reinforcement involves right-about winding up of a four-layer metal tape or that one made of a steel cord (Fig. 3).

The configuration is based upon the idea to decrease the admixture deposition inside the pipeline and improve its adaptive capacity in terms of the curved route formation. As a rule, external pipe layer is low-pressure polyethylene to protect the piping against environmental impact and mechanical damage.

The largest manufacturers of composite pipes [11] list specification of their product (Table 1) providing recommendations concerning its use in such environment-control systems of mine enterprises as degassing, drainage, stowing systems and so on. At the same time, no examples of its operation under the actual mine conditions are available.

The nominal diameters of plastic pipelines within mine degassing systems are almost unapplied. The fact depends upon numerous technical, technological, and organizational reasons as well as upon the lack of regulatory documents covering their industrial application in the actual mine environment, and specific studies.

To provide the rated capacity of degassing systems, mine gas transmission lines are shaped using the pipes with corresponding diameters depending upon the volume of methane-air mixture supplied to the system (Fig. 2). In the context of [12], the captured methane volume is identified with the help of its content in coal formation, degassing methods applied by the mine, and integrity of the facilities to recover it. Industrially, two main gas pipelines are required to support the necessary efficiency of a gas transmission system.

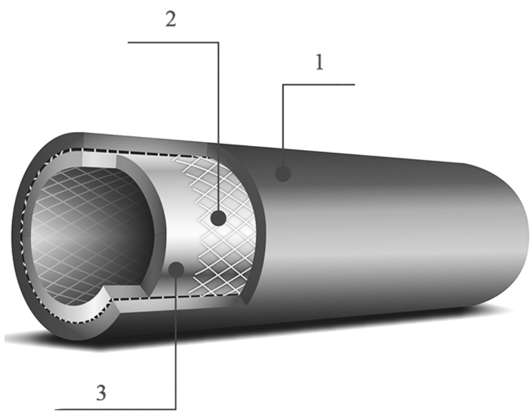

Fig. 3. Design features of flexible composite pipes:

1 – high-density polyethylene; 2 – low-pressure polyethylene; 3 – metal tape

Table 1

Specifications provided by the largest manufacturers of flexible composite pipes

Manufacturer	Country	Product	Nominal diameter, mm	Maximum operating pressure, MPa
FlexSteel	The USA	FlexSteel	50, 75, 100, 150	20.68
Shawcor Ltd	Canada	FlexPipe	50, 75, 100	10.34
Shawcor Ltd	Canada	FlexCord	75, 100	15.51
Fiberspar	The USA	Fiberspar	60, 90, 110, 150, 170	17.24
Thermoflex	The USA	Thermoflex	50, 75, 100, 110, 125, 150	13.8

It is known that small-diameter composite pipelines can transport such mixture volume being comparable with steel pipes with quite a larger diameter. The research confirmed that the index of internal wall surface of a composite pipeline is by dozens times less to compare with steel pipes. The abovementioned is also true for their hydraulic resistance (Table 2).

Hydraulic pipeline resistance is assessed through the amount of energy lost to overcome friction forces [11]. Friction along a pipeline length, curved sections, bends, narrowing of a pipeline diameter due to its clogging and others are considered as the actual hydraulic losses of mine gas transmission line.

The results of assessment of the disassembled mine pipeline sections, modeling of pipe roughness, and operational calculations of degassing gas transmission lines show that conditions of their internal surfaces influence the amount of the energy consumed to transport one and the same volume of a methane-air mixture. The indices, resulting from the complex research, support the importance of variables shown in Table 1. Moreover, they provide the basis to state that to compare with steel pipes, composite ones differ in significantly less degree of internal surface roughness and hydraulic resistance. Hence, their capacity is higher.

In actual practice of mine degassing system operation, numerous joints are the negative factor of hydraulic resistance increase in terms of steel gas transmission lines. Thus, use of the elongated flexible plastic pipes will make it possible to minimize quantity of joints and improve reliability of a degassing pipeline.

Results of expert evaluation concerning the possibility to apply composite pipes as a part of a degassing system have helped understand that sections within the mother entries are

Table 2

Typical roughness (i.e. finish) values of surface for the basic pipe materials in terms of degassing systems [10]

Material/condition	Roughness, mm
Seamless new steel	0.02–0.1
Electric-welding new steel	0.05–0.1
Zink-plated new steel	0.15
Used cleaned steel	0.15–0.2
Lightly rusty steel	0.1–0.4
Rusty steel	0.4–3
Heavily rusty steel	1–2
Steel with deposition	1–4
Fiberglass	0.0001–0.0015

the most adequate parts of a gas transmission line to replace effectively a steel degassing pipeline for the composite one. The matter is that the sections do not need any changes in their length (i.e. neither increase in joint amount nor disassembly). The latter depends upon the fact that in terms of assembly and disassembly schedules of section gas transmission lines are stipulated by specifics of the applied methods to extract coal and support the mining workings.

At the same time, erection of the elongated composite underground degassing pipelines needs the development of specific facilities as well as the integrated techniques to deliver pipe bundles from a manufacturer to their assembly sites.

Traditionally, long components are delivered to a mine with the help of specific flat wagons while forming the unit load devices being hung under cages with their following lowering down to a haulage level and transportation to erection sites [11].

In terms of transportation of oversize loads, maximum allowable, 8 m length steel pipes, delivered by the manufacturers of metallurgical goods to a mine, can be considered as a disadvantage of the method.

Composite pipes are more advantageous since they can be transported in coils (Fig. 4) where their total length is up to 1000 m depending upon a diameter [11]. Plastic characteristics of composite pipes as well as their stress-strain behaviour make it possible to erect pipelines with a minimum number of joints, i. e. while unreeling them right from a coil.

World practices to shape the extended pipelines with the help of integral long-length sections of plastic pipes were applied by the related industries for the analysis of the possibility to erect underground main gas line using composite pipes where minimum quantity of joints is involved. To implement the idea, a schedule to deliver long-length sections to a mine has been developed [13]. The technique is to design special-purpose transportation devices providing delivery of one-piece pipe sections from a mine surface down to a haulage level through a shaft. Then, underground mine workings are used to deliver the sections to a site where the main gas line is assembled.

The developed schedule for delivery of the composite pipes (with up to 1000 m length) to a mine (Fig. 5) helps solve the engineering problem of forming the main sections of a degassing pipeline involving minimum quantity of joints, i. e. a problem of avoiding separation of the pipes into the specified sections.

The schedule to deliver composite pipes involves operations of unreeling, their lowering through a shaft down to haulage level, and laying them into the runners of transport carriages equipped with horizontal and vertical rollers to hold a pipe in its transportation position (Fig. 6).

The designed system of transport equipment prevents from pipe sagging, making it possible to deliver long-length joints of plastic pipes through the curved mine workings right to assembly site.

The innovative engineering techniques help solve a problem to improve reliability of a mine degassing pipeline as well as its capacity. Replacement of steel pipes for composite ones decreases the number of joints; it prevents from the formation of zones, where impurities are deposited, and areas, where the

Fig. 4. Transportation of composite pipes in coils

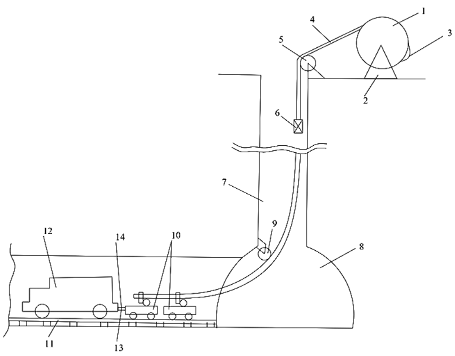

Fig. 5. Schedule to deliver plastic pipelines to a mine:

1 – reel; 2 – pedestal base; 3 – brake; 4 – pipe; 5 and 9 – guide pulleys; 6 – load block; 7 – shaft; 8 – shaft station; 10 – guide devices; 11 – hauling track; 12 – electric locomotive; 13 and 14 – couplers

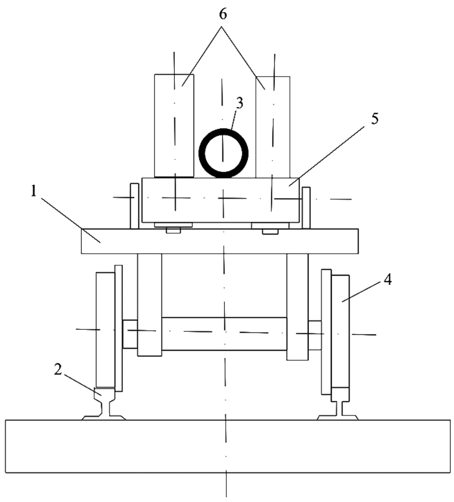

Fig. 6. Guide device:

1 – frame; 2 – hauling track; 3 – plastic pipe; 4 – wheelset; 5 – horizontal roller; 6 – vertical rollers

gas line diameter is narrowed. Finally, the abovementioned makes it possible to increase the whole efficiency of a mine gas transportation system.

The following dependence is applied to assess the performance of an underground vacuum degassing pipeline in operating mines

$$E = \frac{Q_f}{Q_r}, \qquad (4)$$

whre Q_f, Q_r are eactual consumption of methane-air mixture and the rated one respectively, m^3/min.

According to recommendations by [12], the efficiency of composite vacuum pipeline is identified using the dependence

$$E_p = E_g + E_c, \qquad (5)$$

where E_g, E_c are indices of the gas transmission line efficiency and capacity.

In turn, indices of efficiency and capacity are determined by means of the dependences

$$E_g = \frac{Q_d - Q_s}{Q_d}; \qquad (6)$$

$$E_c = \frac{Q_r - Q_d}{Q_d}, \qquad (7)$$

where Q_s is volume flow rate of a methane-air mixture at a well output, m^3/s; Q_d, Q_r are actual and rated volume flow rates of the methane-air mixture, m^3/s.

Objective assessment of the degassing pipeline performance should involve straightness coefficient of a gas transmission line (k_{pt}).

Analytical volume flow of methane-air mixture within vacuum pipeline is determined as follows

$$Q_r = Q_d(1 - k_{pt}), \quad (8)$$

where k_{pt} is straightness coefficient of a pipeline.

The effective performance coefficient of a vacuum pipeline E_g, calculated using the dependences, is compared with its maximum possible value E_{g1} being determined for admissible indices of indices of tightness, pipeline straightness, and non-availability of mechanical accumulations.

Taking into consideration changes in the efficiency coefficient Eg per certain operational period, the capacity of underground degassing pipeline is evaluated as well as its tightness.

The assessment results, concerning the performance of the current degassing systems, have helped identify that calculation of operational pipeline parameters within the mine workings with intensive floor rocks should involve a correction coefficient of the gas transmission line straightness *kpt* considering changes in the pipeline profile resulting from the geomechanical processes of the rock mass.

Conclusions. Use of plastic pipelines for degassing systems of coal mines is promising both technically and commercially. Compared with steel pipes, the hydraulic resistance coefficient of plastic ones is by an order less, which factors into the substantial reduce in power consumption connected with the methane-air mixture transportation. Moreover, cost of plastic pipes is half than that of steel ones. The proposed engineering solutions make it possible to widen opportunities of using plastic gas transmission lines as a part of coal mine degassing system and to improve traditional steel pipelines.

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Підвищення пропускної спроможності шахтних дегазаційних трубопроводів

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Мета. Встановити особливості руху метаноповітряної суміші у сталевих дегазаційних трубопроводах і трубопроводах із композитних матеріалів, розробити технічні рішення із підвищення їх надійності в реальних умовах експлуатації.

Методика. Для вирішення завдань щодо підвищення пропускної спроможності шахтних дегазаційних трубопроводів проведено аналіз фундаментальних досліджень фізико-механічних властивостей шахтного метану та процесів його вилучення в реальних умовах шахтного середовища. Розглянуті схеми діючих газотранспортних систем і особливості функціонування дільничних вакуумних газопроводів в умовах інтенсивного здимання порід підошви підземних виробок і деформацій гірського масиву. За результатами експертної оцінки виробничих ситуацій виявлені потенційні резерви підвищення ефективності роботи внутрішньошахтних газопроводів. Установлені показники надійності традиційно експлуатованих сталевих труб та їх аналогів із композитних матеріалів, що використовують за кордоном, рекомендовані інноваційні технологічні й технічні рішення для їх спорудження на шахтах України.

Результати. За результатами експертної оцінки режимів роботи шахтних дегазаційних газопроводів і аналізу закордонного досвіду застосування в гірничій промисловості труб із композитних матеріалів обґрунтовано технічне рішення щодо вдосконалення діючих дегазаційних систем і підвищення їх пропускної спроможності.

Наукова новизна. Аргументовані інноваційні транспортно-технічні рішення щодо вдосконалення підземних дегазаційних систем, що дозволяють підвищити пропускну здатність дегазаційних трубопроводів і забезпечити підтримку якості метаноповітряної суміші при транспортуванні її від місця виділення до місця утилізації.

Практична значимість. Практичне застосування результатів дослідження зі зниження гідравлічного опору в магістральних дегазаційних трубопроводах і впровадження інноваційних технічних рішень зі спорудження магістральних дегазаційних газопроводів із довгомірних ланок композитних труб з мінімальною кількістю стикових з›єднань заплановано на шахтах України, що розробляють газоносні вугільні пласти.

Ключові слова: *дегазація, гідравлічний опір, конденсація, підземний вакуумний газопровід, метаноповітряна суміш, композитний трубопровід*

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