DOI: 10.18454/PMI.2017.3.346

UDC 622.481.22

SAFETY PROVISION DURING HEATING OF COAL DOWNCAST SHAFTS WITH GAS HEAT GENERATORS USING DEGASSED METHANE

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The article describes new technology of heating downcast shafts in coal mines in Ukraine using heat generators (air heaters) of mixed and indirect action type. It compares this method with traditional heating systems for downcast shafts and describes all their disadvantages. It is shown that application of new heating technology enables not building such elements as boilers and pipelines and not buying metal-consuming heaters. These peculiarities will help to significantly reduce capital and operation costs for construction and operation of heating system with significantly shortened commissioning periods for heating systems.

The article describes an example of heater unit design layout for heating downcast shaft in mine «Scheglovskaya-Glubokaya» at colliery group «Donbass» using mixed type heat generators. It presents a layout of sensors for controlling parameters of ventilation air flow taking into account incoming hazardous combustion products form methane-air mixture combustion in channels of heating unit. The article mentions features of automated control system providing protection of heat generators in emergency situations. It also notes disadvantages of mixed type heat generators limiting their application in Russian Federation.

Together with heat generators of mixed type the article also describes a working principle of heat generator of indirect action type, which to the fullest extent possible meets requirements of Russian Federation legislation and regulation for application of this heat generators in coal mines conditions. The article has a principal working scheme of heat unit layout using this type of generator. It is shown that after development of corresponding normative documents regulating processes of design, construction and operation of heating units using heaters of indirect action, their application in Russian coal mines will be possible without breaking Safety standards and rules.

***Key words*:** safety, mine, shaft, heating, technological process flow chart, temperature, heater, heat generator, methane-air mixture, concentration

***How to cite this article*:** Alabyev V.R., Korshunov G.I. Safety Provision During Heating of Coal Downcast Shafts with Gas Heat Generators Using Degassed Methane. Zapiski Gornogo instituta. 2017. Vol. 225, p. 346-353. DOI: 10.18454/PMI.2017.3.346

Introduction. The issue of provision of cage shaft safe operation has been and still stays to be one of the main pressing issues in coal mining. This issue becomes very acute in winter periods because due to huge water abundance in shafts in case of negative temperature of outside air it freezes and walls become covered with ice. This leads to icing of slopes, offtake rods, reduction of their cross-section area, which results in further jamming of hoisting vehicles, power cables breakage and ice falling in a shaft. The periodical freezing and melting of roof support materials causes temperature deformations, which leads to failure of upper part of shaft support. All of this significantly lowers safety of mining operations and creates real hazards for mine workers' health and safety, and justifies the need for improving existing methods and tools and finding new and more efficient air heating systems technology.

The technological process flow for heating downcast shafts that is being currently used in the majority of coal mines consists of the following key elements: coal or gas boiler for production of heating medium (hot water as a rule), calorific unit for heating the air coming into the mine, and heat network for delivering heating medium from boiler to calorific unit through pipelines. The presence of chain «boiler-heater transportation system-calorific unit» predefines the inadequate reliability of such systems since in case of appearance of emergency situations in at least one of any of these elements it creates a hazard of water freezing in heating network and parts of air heaters and consequently improper heating of air supplied in a shaft for its ventilation. This explains the necessity for presence of strict safety requirements applied for this technological flow process of heating mine shafts.

DOI: 10.18454/PMI.2017.3.346

For example, for provision of stable supply of heating medium to hot air units there must be an indispensable condition of creating in heating networks a backup supply network pipeline and calorific units must have additional tools for protecting heat exchange units providing measures for prevention of water freezing in emergency cases. Besides this, for provision of process reliability there should a possibility to have backup group hot air units with corresponding fittings for quick connection to hydraulic network and heat exchange surface area of hot air units should have extra 10-20 % [8].

Besides this, it should be noted that such shaft heating systems have low efficiency rate (60-65 %) due to multi-staged process of transferring heat from boiler to air. These technological processes have high heat lag and cannot provide timely reaction to wide fluctuations of atmospheric air temperature, as a result there were some cases of heavy icing of shafts causing drastic consequences [12].

The inadequate reliability, high energy and capital output ratio and long periods for building and installation works during implementation of traditional shaft heating process flow technology created a necessity to search for new methods and tools of providing temperature mode in downcast shafts in coal mines. The new trend in development of new shaft heating systems in coal mines is using hot air as heating medium, which significantly reduces the risk of emergency situations. The main tendencies and ways of improving the technology of coal mine downcast shaft heating systems are described in paper [3].

In the beginning of last decade in Ukraine they started to use a new technological system of shaft heating at some mines, its key element is industrial heat generators working on natural gas [6]. The usage of these heat generators as parts of heating system was justified from the point of view of significant reduction of capital and operational costs, because in this case there was no need to construct traditional boilers and heating pipelines. The process of putting this system into operation was also simplified and took less commissioning time but usage of this type of heat generators was limited by Ukraine State Health and Safety Supervision Authority due to presence of open flame. Therefore, they were classified as direct fired air heaters, which are prohibited to use in coal mines because of fire risk and possibility of toxic combustion products coming into air used for shaft ventilation. The obvious advantages of new downcast shaft heating technology raised the issue of adjusting gas industrial heat generators to coal mine conditions.

Object and research methods. Summarizing practices of applying principally new technology of heating downcast shafts based on industrial heat generators using mine degassing methane as fuel. The analysis of prospects and possibilities of using these systems for heating downcast shafts in coal mines of Russian Federation.

Discussion results. In December 2000 at mine «Glubokaya» of OJSC «Shakhtoupravlenie Donbass» as a result of an experiment they accepted into operation the first experimental-industrial calorific unit for heating downcast shaft air with industrial heating units of mixed type VGS-1, which had been working on natural gas till the end of heating season. Though at that moment several technical problems in the field of safety had not been resolved the first experience of its operation turned out to be very efficient. Due to absence of such structural elements as boiler and heating pipelines the annual economic effect form implementation of new air heating equipment was over 200 thousand dollars including capital costs expenses savings above 100 thousand dollars, which is two times less than expenses on construction of traditional downcast shaft heating system. in these conditions the commissioning period for new shaft heating system was 9 months instead of several years. The shaft heating process efficiency has also significantly improved [10].

The positive experience of using heating units VGS-1 for heating downcast shaft in mine «Glubokaya» allowed recommending this technological system of shaft heating for other mines as well. It was decided to construct another calorific unit at mine «Scheglovskaya-Glubokaya» of the same colliery group.

DOI: 10.18454/PMI.2017.3.346

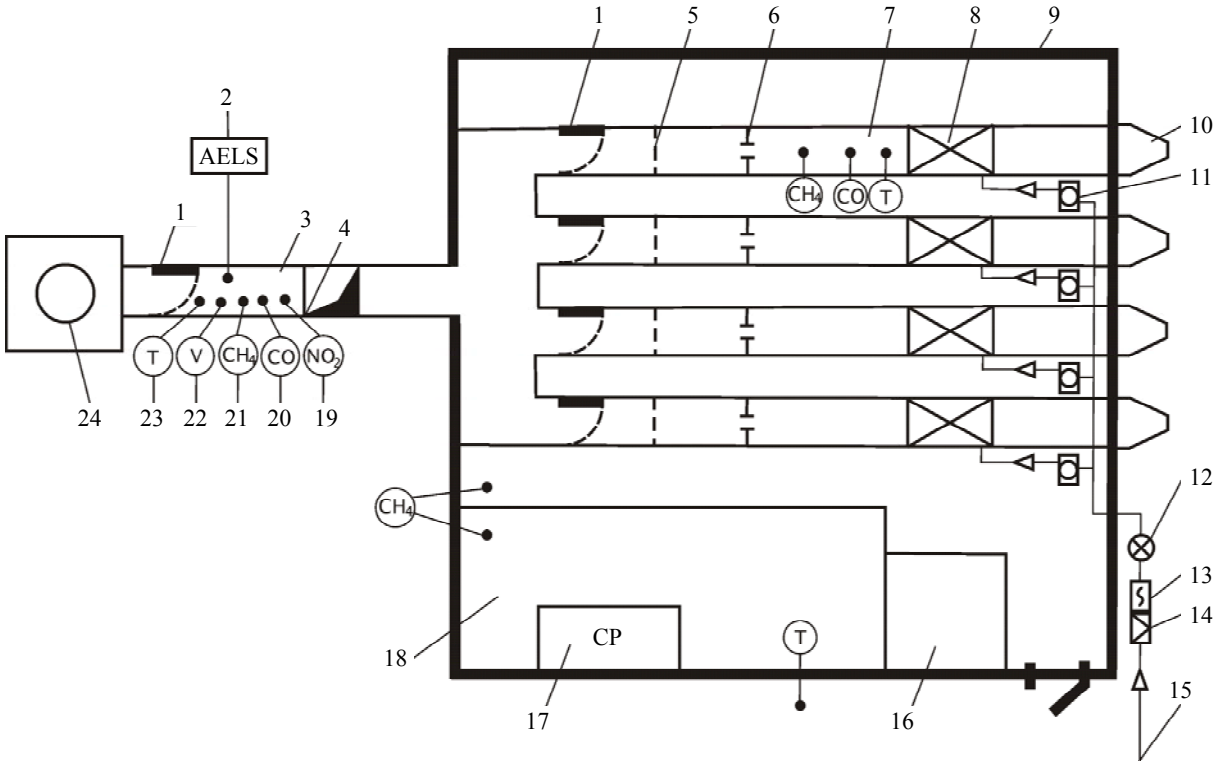


Fig.1. The scheme of calorific unit at mine «Scheglovskaya-Glubokaya»

1 – fire-proof door; 2 – AELS unit; 3 – common hot air supply channel; 4 – mixing chamber; 5 – protection screen; 6 – explosive valve; 7 – hot air channels of heating units; 8 – air heating units VGS-1; 9 – calorific unit building; 10 – air intake traps of heating units; 11 – gas equipment unit; 12 – gas offtake; 13 – flame arrester PGA; 14 – flame arrester OPS-2; 15 – gas pipeline supplying methane-air mixture; 16 – utility unit; 17 – control panel; 18 – operator's position; 19 – nitrogen oxides and dioxides control sensor; 20 – carbon oxide control sensor; 21 – methane sensor; 22 – air speed control sensor; 23 – temperature control sensor; 24 – downcast shaft

In 2006 OJSC «Dongiproshakht» implemented a project of using the mixed type of air heaters VGS-1 for heating cage shaft N 1 of mine «Scheglovskaya-Glubokaya» of OJSC «Shakhtoupravlenie «Donbass». In order to save fuel resources, instead of natural gas it was decided to use methane-air mixture (MAM) produced out of coalmine methane through degassing of a currently mined formation. Since application of such systems for heating downcast shafts is prohibited by safety rules the mine administration received a relevant approval of Ukraine State Health and Safety Supervision Authority for operating the heating unit under supervision of specialists from Makeevsky Research and Development Institution. This being said it should be noted that at that moment Ukraine didn't have current regulatory documents standardizing the processes of design, construction and operation calorific units using open flame heating units working on coalmine degassed methane. As a result, Makeevsky Research and Development Institution conducted relevant research and as a result developed safety regulations for systems for downcast shaft heating processes using flame heating units and degassed methane as fuel [1, 2, 9]. The principal diagram of design of calorific heating unit using air heaters of mixed type is shown at Fig.1.

According to a project in order to maintain the air temperature in cage shaft not less than 5 °C with air flow rate of 900000 m^3/h there were installed four air heaters VGS-1 (item 8 at Fig.1) with heating power of 1 MW each. Every air heating unit warms the air up to 100 °C with air flow rate of 50000 m^3/h. The controlling and monitoring of air heaters operations was planned to be done through control switchboard panel (17), located at operator's unit (18). The protection of air heaters form working in emergency cases was provided with the help of automated system, which performed protective trip of heating unit by stopping gas supply to burner unit in the following situations:

a) when temperature of hot air rises above 100 °C;
b) when controlled flame of burner device is out;
c) when methane concentration reaches the maximum admissible concentration;

DOI: 10.18454/PMI.2017.3.346

d) when electric voltage of automatic circuit is lost (loss of electric power supply);

e) when air flow speed or direction is changed.

The gas consumption and hot air flow in every heating unit, as well as air temperature and its flow rate at five meters from the connection point of heating unit channel and downcast shaft are under constant supervision. In case of emergency situation, the electric magnetic valves at the entrance of gas equipment unit are closed (11), before burners unit and at the ignition place, and the electric magnetic gas offtake valve (12) is opened (except for the cases when there is no electric power supply). When reaching the maximum possible values (controlled by automatic safety system) the sound and light alarm is switched on.

The building of heating unit and channels of air heaters are equipped with fire extinguishing systems. The air outlet channels of air heaters are provided with the possibility to install fire-proof doors with mechanic drive 1, which are designed for cutting off the channels off in case of fire due to air flow tripping in the shaft or if methane concentration in channels has been above 0.5 % for more than ten minutes. In place of connection of common air supply channel with a shaft there has been installed the fire-proof folding door. There are four fire-proof folding doors designed for regulation of the cold air supply process in mixing chamber, which simultaneously serve as fire-protection devices by cutting off the air heaters from a downcast shaft.

At levels 534, 784 and 915 meters of the mine they have installed the equipment for continuous automatic control of air flow consumption and direction DRPV-1, which provided protective trip off gas supply to burners in case of air flow tripping in a downcast shaft or abrupt reduction of air flow rate (for more than 15 %).

To discover and suppress the unauthorized burning there has been installed some equipment for localizing explosions through AELS (automated explosion localization system) unit. In order to do this, in common air supply channel for heated air they have installed two flame sensors and explosion suppressor VPU-30P (item 2). They also installed power source unit and coupling device USD in the operator's unit. The AELS unit works in a waiting mode. When there is a flash in calorific channel the flame sensor registers it and sends a control signal to ignitor of explosion suppressor VPU-30P, which switches on and injects to a place of flash a charge of inert dust and thus localizes further distribution of combustion and explosion.

When the air heaters are working there is a possibility to control the concentration of carbon dioxide concentration (CO) in the air within 5 meters from the point of connection of calorific unit and a shaft and in air intake channels of air heaters, as well as concentration of nitrogen dioxide (NO_2) and nitrogen oxides (calculated as NO_2) within 5 meters from the point of connection of calorific unit and a shaft. There is a set inspection period for these gases.

The gas supply for air heaters has been done through external degassing networks with a pressure of 15-20 kPa and concentrations of methane-air mixture from 30 to 50 %. The diameter of supplying pipeline is 325 mm (item 15). At the place of building entrance, they installed the fire arrester OPS-2 (item 14) and flame arrester PGA (item 13). The degassing gas consumption flow rate per one heater was 300 m^3/h. There has been introduced a gas offtake (item 12) for releasing the methane-air mixture excess, its diameter is 219 mm and the height is 2 meters above the highest point of the building roof. The gas offtake has manually operated valves.

The analysis of mine readiness for implementation of new technology solutions has shown that the project documentation was done in accordance with corresponding requirements of normative regulations [9], and operating personnel have been trained a course of «Peculiarities of operating gas heaters VGS-1 using methane-air mixture as fuel. Additional requirements to safety rules when operating VGS-1 working on methane-air mixture». The specialists have concluded that colliery group «Donbass» can provide the following of requirements of regulatory legal acts in the field of Occupational Health and Industrial Safety during implementation of a project on operation of gas air heaters VGS-1 working on coalmine degassed methane, and State Ministry of Industrial Safety, Occupational Safety and Mines Inspectorate of Ukraine has issued a relevant permission to perform highly hazardous operations.

DOI: 10.18454/PMI.2017.3.346

The observation of operation of new downcast shift heating system using heaters VGS-1 has been performed within the framework of a program and method of conducting research tests with two air heaters VGS-1. The results of thermophysical measurements of working downcast shaft heating system are given in Table 1.

Table 1

Results of thermophysical measurements

Sampling time	Outside air temperature, °C	MAM temperature in gas pipeline, °C		MAM pressure, Pa	MAM concentration, %	Air temperature after heaters, °C		Air temperature at the beginning of a shaft, °C
		Beginning	End			№ 2	№ 3	
19:00	–8.3	32.6	1.7	12940	45.5	96.0	105.9	12.1
20:00	–8.3	32.6	1.1	13040	45.6	104.1	110.5	12.1
21:00	–7.0	32.7	1.4	13040	45.6	106.3	112.3	12.2
22:00	–6.9	32.8	1.6	13140	45.6	106.5	112.7	12.0
23:00	–7.0	32.9	1.7	13040	45.6	107.2	114.5	12.4
24:00	–6.9	32.9	1.8	12940	45.6	108.0	117.1	12.6
01:00	–5.9	32.9	1.7	12940	45.8	111.8	122.3	13.2
02:00	–6.0	33.1	1.6	12850	45.9	118.2	119.6	13.1
03:00	–5.5	33.2	1.4	11670	46.1	111.9	119.3	13.1
04:00	–6.5	33.1	1.2	11180	46.1	113.3	120.1	14.0
05:00	–7.0	33.1	1.1	11770	46.2	116.1	121.5	14.0
06:00	–6.3	33.1	1.1	12450	46.1	114.0	118.0	13.7
07:00	–6.5	33.2	1.5	12360	46.1	112.6	117.0	13.6

The analysis of the observation results has shown that the downcast shaft heating system had stable operation. The air flow consumption rate in air heaters VGS-1 at time of observation was 42000 m^3/h, and the fresh air consumption rate in a shaft was 780000 m^3/h. The air temperature after heaters was ranging from 96 to 121 °C, and in addition air temperature at the entrance to air supply shaft was from 12.1 to 14.0 °C. Methane-air mixture pressure and concentration in gas pipeline was supported within the set range of values. The unified telecomminucation system (UTAS) installed at the mine provided control of all key parameters of air heating system operation and was controlled by the mine dispatcher and calorific unit operator.

From data in table 1 it follows that in case of insignificant reduction of atmospheric air temperature (up to –8 °C) the methane-air mixture temperature at the end of suppling gas pipeline has almost reached the possible limit and was 1.0-1.7 °C. In case of further reduction of outside temperature, the temperature of methane-air mixture at the end of supplying gas pipeline will reach negative values. To avoid frosting of mine gas pipelines it was suggested to improve insulation of gas pipeline and dry the methane air mixture. In this case, the possible heat calculations of permissible length of overland pipeline (item 15 at Fig.1) from overland wells to heating unit building (9), which provides absence of icing at its internal surface, were suggested to perform using the method [4], based on analytic research [13].

During tests, they also analyzed samples of mine methane from degassing system of mine «Scheglovskaya-Glubokaya» of OJSC «Shakhtupravlenie «Donbass» for quantitative composition. The results are the following, %:

O_2 ..... 8.46
N_2 ..... 51.91
CH_4 ..... 38.84
C_2H_6 ..... 0.0615
C_3H_8 ..... 0.0106
i-C_4H_{10} 0.0023
h-C_4H_{10} 0.0019
CO_2 ..... 0.763
He ..... –
H_2 ..... –

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The tests were carried out on chromatograph LHM-8MD and «Gasokhrom 3101» using checking gas mixtures. As it is seen from the data there are no traces of sulfur-containing compounds in coalmine methane.

They also analyzed the composition of gas mixtures produced after MAM burning for presence of toxic combustion products. To reduce inaccuracy of measurements of combustion products samples they were taken directly after burners of air heaters in the channel of hot air (7) (Fig.1). The analysis results and MAC of toxic gases are shown in table 2. As it follows from Table 2, the concentration of toxic gases in channels of hot air do not exceed maximum allowable concentration and there were no sulfur oxides in flue gases.

According to results of testing the experimental-industrial unit for heating caged shaft N 1 of mine «Schglovskaya-Glubokaya» with air heaters of mixed type VGS-1 working on mine degassed methane as fuel was accepted to operation.

Table 2

Results of coalmine methane combustion products analysis, mg/m^3

Component	Concentration	MAC
NO_2	0.0529	2.0
NO (calculated as NO_2)	0.0201	5.0
CO	0.0001	20.0

Among disadvantages of new downcast shaft heating technology using gas air heaters of mixed type there are coming of hazardous methane-air mixture combustion products (CO_2, NO_2 and nitrogen dioxides calculated as NO_2) into mine atmosphere, which is directly and strictly prohibited by currently valid Safety Regulations of Russian Federation [11]. We should not eliminate a hazard of reaching maximum allowable concentration value limit for these gases in the air coming for shaft ventilation, in case of violation of burning mode or troubles with operation of burning devices or failure of automatic control and protection devices. Besides this, there are also no legal and regulatory framework standardizing process of construction, design and operation of downcast shaft heating systems using gas air heaters.

The above mentioned disadvantages of this method of heating downcast shafts of coal mines with air heaters of mixed type predetermined the necessity to improve it keeping its key advantages: the production of thermal energy should be done (whenever it is possible) through combustion of natural gas or MAM; usage of air as heating medium instead of hot water. To do this, the mixed air heaters should be replaced with safer type of heat generators that do not emit toxic combustion products into mine atmosphere.

The solution of this task became possible after changing design of air heaters (Fig.2) [5]. The body of air heater has a sealed wall 4, dividing it in two parts: an outside air heating chamber 7 and heat exchange chamber 13. The sealed wall has thermal siphon pipes 6 with intermediate heating medium. Due to boiling and condensation of intermediate heating medium there is a process of transferring heat from combustion products to shaft ventilation air. The air heater is located outside the overmine building and heated outside air comes in a shaft 9 through hot air channel 8, which reduces the possibility of gases from chimney coming into the mine. The outside air supplying fan 3 produces overpressure in outside air heating chamber and the fan for removing combustion products 14 creates exhausting in heat exchange chamber. Due to this the combustion products do not come into shaft ventilation air, in case of sealed wall 4 or thermal siphon pipes 6 wear out.

The abovementioned engineering changes make the suggested unit design different from mixed type air heaters VGS-1 because hazardous methane-air mixture combustion products do not come into shaft air, which to the full extent meets the requirements [11]. The novelty of suggested downcast shaft heating method was confirmed by declarative patent of Ukraine of invention [7]. For the purpose of this suggested method of heating downcast shafts (Fig.2) there has been developed a principal scheme of heating unit layout, which was described in paper [5].

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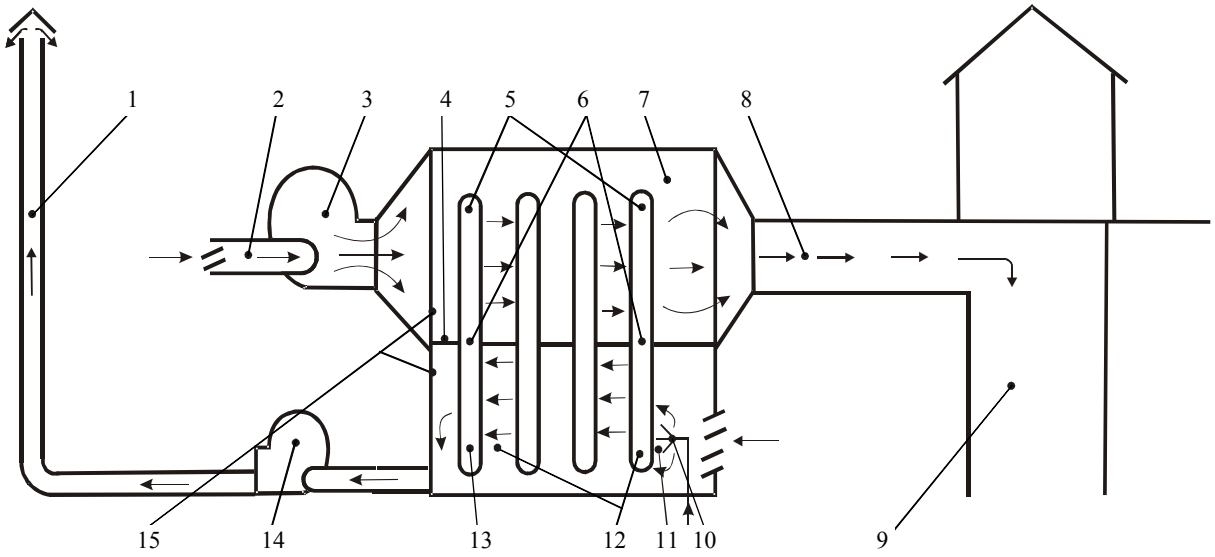


Fig.2. Heating of downcast shaft air

1 – chimney; 2 – outside air supply pipe; 3 – fan for supply of atmospheric air; 4 – sealed wall; 5 – condensing part of thermal siphon pipes; 6 – thermal siphon pipes; 7 – atmospheric air heating chamber; 8 – hot air channel; 9 – shaft; 10 – gas burner; 11 – gas fuel combustion chamber; 12 – evaporation part of thermal siphon pipes; 13 – heat exchange chamber; 14 – combustion products removal fan; 15 – air heater

The downcast shaft heating system using heat generator of indirect action with heating capacity of 750 kW has been successfully introduced at mine «Chaikino-2» of state company «Makeevugol» [2]. During acceptance inspection, the heating unit provided heating of 22000 m^3/h air up to 80 °C and had stable operation under methane-air mixture pressure from 8 to 12 kPa. Furthermore, the consumption of methane-air mixture was 220 m^3/h with methane concentration of 35 ± 2 %. The concentration of hazardous substances in outgoing combustion products didn't exceed the standard values. The safety automatic control of heat generator enabled its safe operation.

Despite positive experience of using mixed type heat generators at coal mines of Ukraine the application of such heating systems in Russian Federation coal producers is impossible taking in consideration the direct prohibition to use them in accordance with safety instructions [11] and absence of normative and technical documentation. That is why at the initial stages it is recommended to pay attention to heat generators of indirect action and develop corresponding normative documentation for their design, construction and operation of such heating systems from the perspective of coal mines of Russian Federation. In future, the variety of industrial gas heat generators can be expanded at the expense of mixed type heat generators since they are simple to use and operate when all necessary changes of current Safety regulations will be made [11].

Conclusion. Current level of telemetric, measuring and control equipment, automated systems enable provision of level required by Safety regulation of safe [11] temperature mode for air supplying shafts in coal mines by using industrial gas heat generators of mixed and indirect action. The implementation of these systems allows significant reduction of capital and operation costs for shaft heating systems with shorter commissioning periods for these systems. Usage of methane-air mixture instead of natural gas as fuel for heat generators promotes economy of fuel resources and improvement of ecological situation in coal mining regions due to reduction of hazardous emissions in outside air when recycling the coalmine degassed methane.

It is necessary to develop corresponding regulatory documents describing the processes of design, construction and operation of heating units using mixed and indirect action types of gas heat generators.

DOI: 10.18454/PMI.2017.3.346

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The paper was accepted for publication on 8 February, 2017.