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REDUCTION OF GREENHOUSE GAS EMISSION THROUGH PROCESSING OF COAL MINE METHANE USING ENERGY-CONVERSION TECHNOLOGY

High-rate and high-output mining of gas-bearing coal includes currently a set of gas drainage activities. Coal methane is both an industrial hazard and ecological peril as its atmospheric emission aggravates greenhouse gas effect, but at the same time, methane is a valued basic material. The concern in connection with the environmental aspect of coal methane problem has lately grown essentially. This article addresses the problem of improvement of the coal mine methane utilization technology with a view to reducing atmospheric emission of greenhouse gases. The author substantiates the need to develop the smaller scale chemistry approaches to utilization of methane recovered in gas drainage. This trend seems to be promising for the coal sector due to the specific nature of gas release sources. The test data of the energy-conversion technology in processing of methane recovered in pre-mine drainage, with production of colloidal carbon using recuperative heat exchanger are presented. This technology features unique ecological measures. The challenging trends of the technology improvement are planned, including utilization of decontamination gas.

The existing systems of methane utilization are insufficiently effective because of inconstant parameters of methane–air mixtures.

Gas recovered in pre-mine drainage has the most stable composition. However, pre-mine drainage is only used in 2–3 mines in Russia. The main reasons for the slow pace of the pre-mine drainage expansion are the organizational and financial complexities because of necessity of long-term completion of wells after hydraulic impact. Extensive employment of the technology can promote a dramatic reduction in greenhouse gas emission and the enhanced mining safety.

Keywords: *methane, hydrogen, mine, gas drainage, greenhouse effect, longwall, utilization, emission, gas release*
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Introduction

Increasingly much attention is paid lately to the challenging problem of reduction in greenhouse gas emission in underground coal mining [1, 2]. The top priority is methane-related safety of mining. In view of the higher rate of coal production, gas drainage becomes indispensable technology even in mines ranked within category II by methane hazard. Wide application of gas drainage is a framework for the mine methane utilization and, as a consequence, for the integrated use of coal and gas resources.

Methane is mostly removed from underground openings by ventilation facilities (except for the Vorkuta mines) [3, 4], and methane concentration is under 0.75% in this case, which disables commercial use of the gas. This is one of the major causes of atmospheric emission of

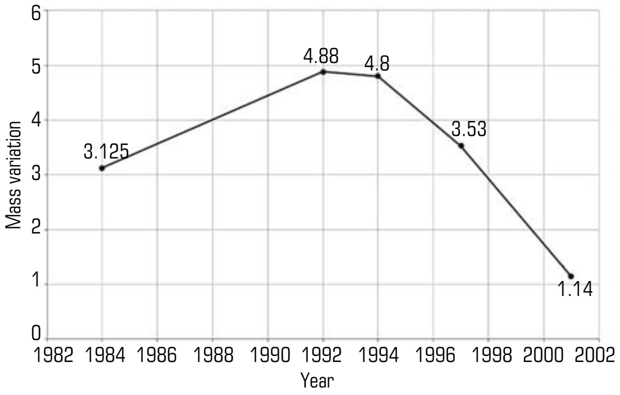

Fig. 1. Time history of mass variation of atmospheric methane in 1984–2001

methane at the level of 70–80% during underground coal mining [5, 6]. High-rate gas releases in coal mines enhance explosion risk of methane in mine air [7, 8].

At the present-day level of coal production, ventilation capacities are exhausted, and if gas content of coal seams is more than 13 m^3/t of ash-free dry weight (hereinafter, AFDW), it is obligatory to undertake coal gas drainage.

Methane in the recent practices of coal mining is not only one of the hazards but also a high-valued resource.

Normalization of mine air usually involves a set of gas drainage techniques to ensure methane emission from different sources. In the meanwhile, only gas drainage of rock mass after stress relaxation features a high efficiency. Moreover, gas drainage efficiency increasingly lowers in deeper level mining and due to a more acute disbalance between the rates of first mining and coal face work. As a result, the criticality of gas emission grows. The gas drainage methods currently in use reduce gas content not more than by 10–15%, while the required gas emission reduction is 40–50%. Such reduction is impossible without increase in coal permeability [9]. Mine methane utilization toward reduction in greenhouse gas emission is the most effective approach but it lacks application in Russia because of uncertainty of location of gas sources, variability of compositions of methane–air mixtures (methane concentration can range from 5 to 90%), and deficient economic stimulation of this technological direction. The only way of ensuring the constant composition of a methane–air mixture (MAM) is pre-mine drainage which produces gas having natural composition [10].

Despite the long and rich experience of pre-mine drainage in Russia (hydraulic pre-splitting of coal), the technology has found no wide application, for the first turn, because of high capital cost of equipment and special design drilling, and due to the required completion of wells after the implementation of hydraulic impact, which takes a long time. Moreover, the economic stimulation and regulatory framework are inadequate [11].

In deeper level mining with the increase in face output and work pace, the issue of gas safety in mines becomes more critical [4, 12] and calls for the wide application of gas drainage methods.

Gas zonality

For the development of process solutions on the enhancement of gas drainage efficiency, optimization of its cost and reduction of ecological impact, we undertook a detailed analysis of statistical data and scientific information on stimulation of gas drainage efficiency in coal mines [13–16] and on utilization of mine methane as the reduction of its emission should be provided by the Paris Agreement and by the Russian Coal Industry Development Program 2035.

Figure 1 depicts the mass variation of atmospheric methane over the period of 20 years irrespectively of seasonal fluctuations [17]. It is seen that the introduced limitations enable reduction in atmospheric methane but its anthropogenic emission calls for new technologies and process solutions for industrial processing of methane released.

Contained in the natural sorbent, coal methane features high chemical purity, which condition its processability without expensive chemical purification.

Based on the chemistry and ratio of the main gas components in coal, from direct sampling and from the chemical analysis of the samples, there are four gas zones: carbon dioxide–nitrogen, methane–nitrogen, nitrogen–methane and methane (**Table**) [18, 19].

Methane release from associate seams is predicted with regard to geological location of coal seams, their methane content and daily average coal production output. The methane content of coal seams being mined is assumed from the data of geological exploration, or is calculated with regard to natural outgassing from the seams when relieved from rock pressure in the sites of longwall operations [20–22].

Chemical analysis of geological coal samples

Zones (top downward)		Gas components, %			Methane content, m^3/t AFDW	Spreading depth, m
		CH_4	N_2	CO_2		
Gas weathering	Carbon dioxide–nitrogen	0.0–5.0	53.5– 65.5	34.5– 41.5	0.02– 0.10	0– 50
	Methane–nitrogen	31.8	68.1	0.1	0.3–1.1	от 26
	Nitrogen–methane	46.7	45.0	3.4	1.58– 2.1	от 55
Methane		80.0– 99.6	0.1–19.8	0.2– 3.3	from 5.0	from 55

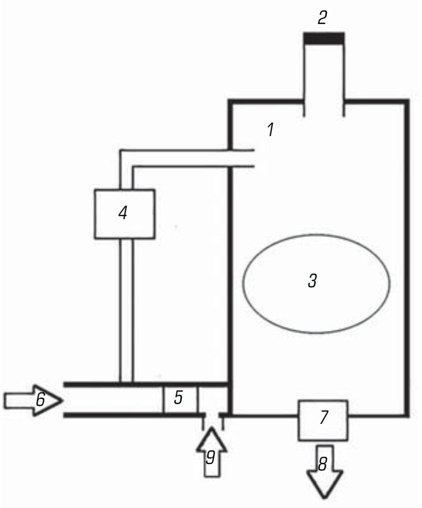

Fig. 2. Thermal method of colloidal carbon production with release of hydrogen:
1 – furnace; *2* – lid; *3* – setting to be heated; *4*, *5* – cocks; *6* – gas; *7* – valve; *8* – gas and colloidal carbon mixture; *9* – air

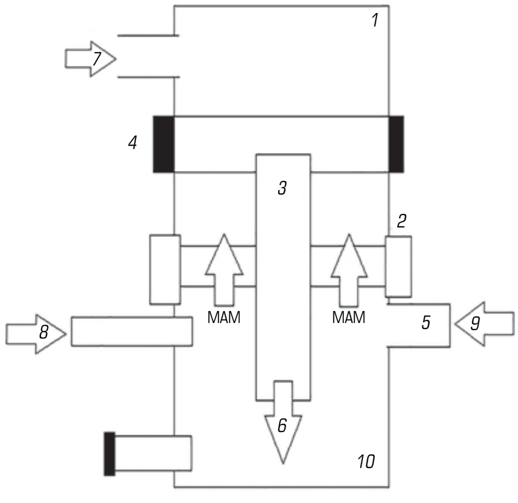

Fig. 3. Experimental plant for methane treatment:
1 – lid; *2* – combustion cell; *3* – methane decomposition surface; *4* – methane flow swirler; *5* – methane and air mixing cell; *6* – colloidal carbon; *7*, *8* – methane; *9* – air; *10* – colloidal carbon cell

Methane utilization and energy-conversion technologies for methane processing

For more than 50 years, theoreticians and practitioners have been developing technologies for coal methane trapping and utilization. To date, for the analysis of gas drainage efficiency, there are approximated analytical solutions which are both demonstrative and sufficiently accurate. Since gas flow velocity is high in the face zone while the gas pressure decreases below its value in the coal body, specifics of operation of gas wells involves, among other things, violation of the linear flow law [23, 24].

The existing systems for methane utilization operate insufficiently effectively, for instance, for the inconsistent parameters of methane–air mixtures. For another thing, the most popular current drainage methods feature shot activity duration, as a rule, which leads to the required regular teardown and re-assembly of vacuum pump stations.

All these necessitate new approaches to methane utilization with regard to methane release sources and characteristics of MAM.

In the author's opinion, the smaller scale chemistry technologies are promising in terms of processing of methane recovered by drainage systems. This is connected with the facts that mine methane sources have comparatively low flow rates (as compared with gas wells) and, sometimes, a short life.

One of such approaches is an energy-conversion technology for methane processing with obtaining colloidal carbon as a useful product. This technology may use various process flows: recuperative heat exchanger, channel, furnace, etc. **Figure 2** shows a facility for the modified method of thermal decomposition of methane in cyclic mode without air access. At the first stage, with the fuel and oxidizer fed from below, a brick or ceramic setting is heated up to 1550 ºC. At the second stage, after redirection of gas flow, gas decomposition takes place with a temperature decreased to 1100 ºC. Then, the cycle is repeated.

Colloidal carbon production from methane

Specialists from the Mining Institute and Spetshakht Montazh Degazatsia Management (Karaganda Coal Basin) tested a technology of colloidal carbon production from methane with regard to the specifics of this promising feedstock. **Figure 3** shows the basic diagram of the process flow.

The experimental plant (see fig. 3) is a so called recuperative heat exchanger where pure methane flows inside it, and methane–air mixture is fed from the outside. The mixture burns down and generates high temperature in the combustion cell. Methane which is inside the heat exchanger gets heated and decomposed, with the release of carbon black and hydrogen.

The experimental plant can operate both in the mode of injection of oxidizer (air) in the mixing cell, and in the mode of natural draught via the breather pipe.

Taking into account the time required for methane decomposition, thermal conversion of methane at a rate of 0.2–0.6 m^3/min needs the following dimensions: diameter—0.5 m, height—1.2 m [25].

Decomposition of methane takes place at a temperature higher than 1100 °C, which governs additional requirements for the technology implementation.

The actual tests of the technology produced the following initial results [25]:

—yield of colloidal carbon—110 kg per 1000 m^3 of methane;
—specific surface—25 m^2/g;
—decomposed methane percent—to 85 %;
—density—400 kg/m^3.

The carbon black properties appeared to be similar to grade T-900 (GOST 7885-86. Carbon Black for Rubber Production. Specifications).

In the tests, the volume ratio of methane spent in decomposition and in combustion was 1:1.

Decomposition follows the pattern below:

$$CH_4 \xrightarrow{t>1100\,^\circ C} C + 2H_2. \quad (1)$$

In addition to colloidal carbon, the technology allows producing hydrogen which enjoys currently great attention as the eco-friendliest fuel. At the cost of the change of the ratio between the flows sent to combustion and to decomposition, this technology features the highest ecological efficiency. The generalized equation of the reaction is given by:

$$CH_4 + (2-a)O_2 = aC + (1-a)CO_2 + 2H_2O, \quad (2)$$

where a is the methane fraction decomposed into carbon and hydrogen according to pattern (1).

Depending on the value of α varying from 0.10 to 0.95, decomposition of methane into carbon and hydrogen needs 9–14% of heat energy liberated during combustion.

Thermal decomposition of methane in the proposed circuit produces waste burn gases (CO_2 and H_2O) heated up to 1300–1400ºC, which enables the heat exchange technology to convert this energy to the steam energy. In this manner, methane converted to carbon black is at the same time a steam generator.

In this technology, emission of carbon dioxide per unit energy derived is reduced by one third, and oxygen consumption is decreased by 20–25% as well.

Such process designs are well-known, as a rule. The peculiarities of the present level of development are new materials, new equipment and control implementation. This enables the high tech solution to the problem, with the on-line control toward improvement of the technology efficiency.

Conclusions

Finally, the test method of colloidal carbon production has high production data (high efficiency, low specific energy input). Furthermore, the technology of mine methane utilization is eco-friendly as it enables reduction in atmospheric emission of carbon dioxide by 40–60% because of using energy of produced hydrogen.

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