Modeling gas energy process of underground coal combustion

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Abstract. Protective coal pillars in underground mining are technological losses in the technology of extracting coal at the Angren deposit. During the mine operation, a significant part of the coal remains in the mine space. Extracting them is not possible with traditional energy-mechanical technologies. The paper considers a new extraction technology - energy-heat technological unmanned extraction of brown coal energy from the underground space of spent mine fields. The research results on the experimental sites of the technology of underground combustion of brown coal are presented. A simulation topological scheme of coal pillar combustion with a special chamber has been implemented. The burning rates of coal and heat fluxes in time are determined. The possibility of extracting the energy of coal in the form of a physical heat flow from the underground space of the mine to the daylight surface has been established.

1 Introduction

In the energy sector, much attention is paid to fuel resources and modern technologies for using and converting energy carriers [1]. As the experience of industrial development of fuel resources shows, annually, about 12% of energy carriers (mainly coal) remain in the bowels [2]. These losses are associated with the abandonment of pillars; the impossibility of conducting work with increased gas mobility, fire hazard, and rock pressure; revaluation and write-off of inventories, and other unforeseen circumstances.

An analysis of the development of thick coal seams in the mines of Uzbekugol OJSC of the Republic of Uzbekistan shows that unexploited reserves make up a significant amount of coal [3].

2 Object and methods of research

This paper presents a completely new technology for extracting the remaining reserves. This technology is based on the complete combustion of coal in the subsoil, in their direct occurrence, followed by the extraction of thermal energy from the products of complete combustion [4].

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The advantage of this technology is:

- unmanned method of extracting coal;
- insignificant need for operational consumables;
- practical absence of ash and ballast part of coal;
- complete absence of harmful nitrogen oxides;
- lack of underground and surface freight traffic flows;
- lack of permanent ventilation facilities;
- lack of complex and expensive electrical cable network and substation;
- sufficient heat output;
- involvement of nearby combustible components in the combustion process;
- use of the coal seam space as an energy-technological underground boiler unit;
- ecological cleanliness;
- high mineral recovery factor.

The disadvantages of this technology include:

- the presence of either operational losses, technological pillars, or out of balance or non-industrial reserves;
- the practical impossibility of controlling the combustion process directly in the coal seam;
- the relatively low energy potential of combustion products;
- uneven rate of coal combustion in the seam;
- significant fluctuations in the daily temperature of atmospheric air;
- uncertainty of the location of the firing front in time and space;
- the impossibility of high-quality management of the underground combustion process;
- mandatory adoption of all security measures and prevention of the penetration of the fire front into the working areas of the mine.

3 Results and discussions

These or other advantages and disadvantages must be experimentally investigated; appropriate measures should be taken to improve the underground combustion process's technical, economic, and environmental performance.

Figure 1 shows a flow chart of the underground combustion process of coal pillars for thick seams of the Angren deposit. According to technological conditions, coal pillars are preliminarily prepared, i.e., technological drifts are laid for air supply and combustion products removal, air supply and gas exhaust wells are drilled, the coal pillar is contoured by mine workings according to the accepted topological scheme, a surface heat engineering complex is installed, which is connected to the gas exhaust well. Moreover, the gas outlet well is calculated to work under a vacuum.

With the technology of underground burning of coal pillars, all safety measures are taken to prevent the penetration of the fire front into the working areas of the mine [5].

The process of underground combustion is similar to the process of underground gasification of coal according to the principle of structural design. It differs only in that the hydraulic air pressure in the coal seam is lower than atmospheric pressure; there are no powerful turbocompressor gas blowers, special electrical substations of small capacity, and no bulky pipeline for combustible gas, etc.

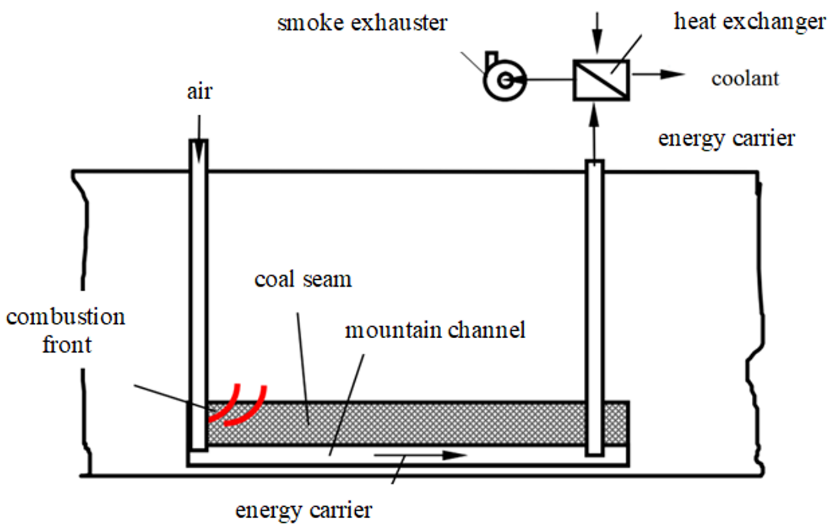

Fig. 1. shows the technological scheme of the process of underground combustion of coal pillars

According to the experimental studies carried out on a model plant [6-16], the possibility of underground coal combustion with subsequent extraction of thermal energy from combustion products is shown.

Given the scale of the simulation of the combustion process, some assumptions are made that can be neglected.

Based on the generalization of experimental studies, the main technological features of underground burning of coal pillars have been established.

Firstly, it has been established that the ignition process should ensure guaranteed coal combustion at the initial stage.

Secondly, the influence of the topological scheme of the coal pillar on the uniform and stable combustion is determined.

Third. The average daily temperature fluctuation affects the burning rate of coal.

Fourth. The fundamental possibility of extracting coal energy up to 20% in the form of useful thermal energy has been established.

Thus, the proposed technology of underground combustion allows the remaining coal reserves in the subsoil to be involved in the fuel and energy balance to increase the coal utilization rate.

An experimental semi-industrial installation (Fig. 2) was developed and created, which implements the recovery processes for balance energy resources. Experimental studies were carried out according to a special program, providing a systematic approach to the study of the process.

The following tasks were set before the research:

I. Develop topological schemes for carrying out the process of burning a coal seam;

II. Organization of underground ignition of a coal seam;

III. Control and management of the coal seam combustion process.

The developed experimental setup allows the study to be carried out simultaneously on four variants of topological schemes of mine workings. Each experiment at the facility reduces time and money, given that the duration of the experiment is one and a half to two months.

Fig. 2. Experimental pilot semi-industrial plant

This is because it is necessary to lay fuel on a previously prepared layer of kaolin, then lay a mixture of kaolin that imitates the earth's crust following the similarity of a scale transition. Then the ignition and combustion of the fuel. After the attenuation of the combustion process, the temperature of the formation at the installation reaches 200 ^{0}C to 1000 ^{0}C, which requires some time for them to cool down. When all the installation components have cooled down, dismantling, excavation of the surface layer of the formation, fixing and analysis of the state of ash and slag, and cleaning of ash are carried out.

The first experiments on the setup made it possible to determine the best topological scheme (Fig. 3). All further studies focused on this one. They mainly focused on the uniformity and completeness of combustion, the high temperature level of flue gases, the temperature gradient of the coal seam, etc.

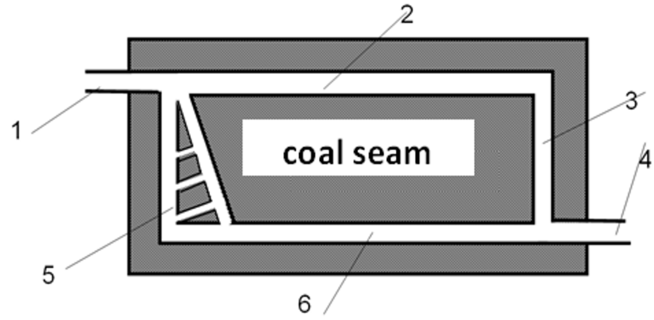

Fig. 3. A variant of the topological scheme for the ignition of a coal pillar on a model plant. 1 is air supply well; 2, 3, 6 are underground mine workings; 4 is gas outlet well; 5 is zone of intensive coal combustion

As can be seen from Figure 3, the topological scheme includes an air inlet and gas outlet wells, underground mine workings, and a zone of intensive coal combustion. Mine workings imitate industrial mine workings taking place on a semi-industrial coal pillar. The zone of intensive combustion is designed to rapidly heat the coal seam. As you know, the coal seam under the earth's crust has a temperature equal to the temperature of the earth's crust (surface). Therefore, burning a relatively small amount of coal in an intensive mode, contributed to the rapid heating of the coal seam. After the combustion of this zone, the usual design mode of coal combustion is included in the scheme, and the steady-state combustion of coal occurs during the established operating time of the experimental installation.

The heat balance of the underground coal combustion process consists of the following components:

$$Q_{yg} = Q_{gor} + Q_{to} + Q_{pod} + Q_{gr} + Q_{end} + Q_p$$

where Q_{yg} is calorific value of coal; Q_{gor} is the heat of combustion products carried out of the formation; Q_{to} is heat carried out from the reservoir by the coolant; Q_{pod} is heat required to maintain the combustion process; Q_{gr} is heat expended for heating the soil; Q_{end} is heat absorbed by endothermic reactions. Q_p is the heat carried by water vapor.

The heat of the combustion products removed from the formation is equal to:

$$Q_{gor} = Q^{N_2} + Q^{O_2} + Q^{CO} + Q^{CO_2} + Q^{H_2} + Q^{CH_4}$$

where the heat content of gases, respectively Q^{N_2} is nitrogen, Q^{O_2} is oxygen, Q^{CO} is carbon monoxide, Q^{CO_2} is anhydride carbonate, Q^{H_2} is hydrogen, Q^{CH_4} is methane.

The heat of water carried out by vapors was determined from the equation:

$$Q_p = (W_{abs} + W_{gr} + W_{vv}) \cdot i_p$$

where Q_p is heat content of water vapor, W_{abs} is moisture in coal, W_{gr} is moisture transferred from the soil, W_{vv} is air moisture, i_p is enthalpy of water vapor.

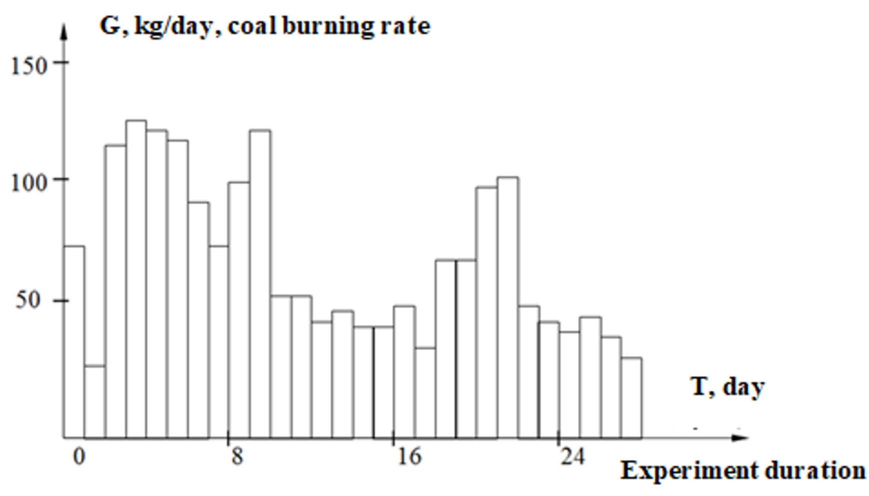

Fig. 4. Histogram of the average daily amount of fuel burned

According to the balance equations, the fuel combustion rate was determined, and histograms of the average daily fuel consumption were compiled (Fig. 4.). We determined the temperature of the flue gases from the model plant and also calculated the average daily heat output to the day surface (Fig. 5).

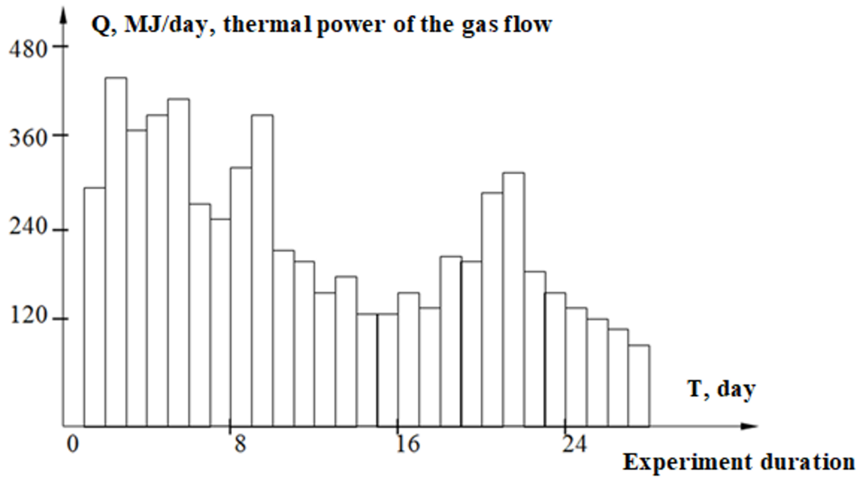

Fig. 5. Histogram of the average daily amount of heat with exhaust gases.

As the histograms of the average daily fuel consumption show, on the first day, the rate of coal combustion was 100-120 kilograms per day, and then it was 40-60 kilograms per day.

The histogram of the average daily heat output to the day surface approximately repeats the characteristic features of the average daily fuel consumption histogram. So at the beginning, the thermal power of gas flows averaged 360 MJ per day and subsequently decreased to the calculated value, that is, an average of 120-130 MJ per day.

4 Conclusion

In conclusion, we note that the simulation of the heat-technological approach to extracting brown coal from the remaining guard pillars has been successfully implemented on an imitation experimental field model installation.

- The implemented experimental studies have shown:
- the fundamental possibility of choosing a topological scheme for burning coal in underground way;
- the possibility of obtaining a thermal impulse at the beginning of coal ignition according to the developed topological scheme;
- the ability to manage the processes of underground combustion of coal pillars;
- receive a sufficient amount of heat and a satisfactory temperature of the combustion products on the day surface of the installation.

Experimentally determined the average daily rate of coal combustion in the amount of 100-120 kilograms per day at the stage of heating the air supply channels and mine workings and subsequently amounted to 40-60 kilograms per day. The histogram of the average daily heat output to the day surface approximately repeats the characteristic features of the average daily fuel consumption histogram.

A part of the initial thermal power of gas flows of 360 MJ per day is used to heat the ignition zone. Subsequently, steady flows of 120-130 MJ per day are useful heat flows for extracting operational thermal energy on the day's surface.

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