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HEATING COAL MASSIF FROM THE CHANNEL OF UNDERGROUND GASIFICATION

Technical developed countries are searching alternative gas resources for decision of emerging energy challenges. Those resources may be syngas generated from coal seams or coal pieces. It may be manufactured by way transformation a coal in a gas fuel. Several countries tried to receive this gas from the coal seams by way underground gasification. But results aren't good now. A reason of these difficulties consists in deficiency of science information about thermal and chemical regularities which allow have control for the coal seams gasification process both a picture of distribution of high temperature into coal massif and its thermal condition during gasification process. This article allows understand changes in thermal process taking place into a and coal seam during the gasification process more deeply and to receive mathematical description of a temperature distribution into the heated coal seam on a modern level.

Key words: *coal seam, gasification process, thermal condition, distribution of temperature, depth of coal seam, losses of temperature*

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Introduction

Electricity generation on coal fuel includes the supply of a coal from coal enterprises to the thermal power plant. In this process the energy of coal fuel is consumed on the entire technological chain and its efficiency is very low. This technology suffers serious shortcomings, including labour-intensive mining and transport by way a rail or water and preparation of a coal for use in the thermal power station and it thermal efficiency of 38–42%. In the same time generation of electricity from a gas fuel has significantly higher thermal efficiency up to 48–52%. It is almost impossible to raise the thermal efficiency of a coal-fired power plant to the level of a gas power plant. This can be done only by turning coal into gas fuel.

In addition, coal power is one of the dirtiest processes and destroys the environment. Around 18,000 people die each day as a result of air pollution [1]. In fact, the number of deaths attributed to air pollution each year — 6.5 million deaths — is, according to the World Health Organization (WHO), much greater than the number from HIV/AIDS, tuberculosis and road injuries combined. Air pollution also brings major costs to the economy and damage to the environment. Energy production and use is the most important source of air pollution coming from human activity and so, for these reasons, the IEA has — for the first time — undertaken a major study on the role of energy in air pollution. Growing attention to air pollution, puts aggregate global emissions of the main pollutants on a slowly declining trend to 2040. Fuel combustion increases steadily to help meet a one-third rise in global energy demand. But global emissions of particulate matter are projected to fall by 7%, sulfur dioxide by 20% and nitrogen oxides by 10% over the period to 2040. These challenges can also be addressed through the transition of coal power to synthetic fuel from coal. For countries where natural gas reserves are absent or limited it is very important to use natural coal seams for production of synthetic gas too.

Named tasks may be decided through development underground or surface coal gasification (UCG or SCG). This is way to significantly increase the thermal and environmental efficiency of using coal fuel for electricity generation and reduce harmful energy emissions into the atmosphere.

So, a task of modern mining science and practice to do research different mechanisms underground gasification processes into a coal massif. The major problem of these complicated physical and chemical and thermodynamic mechanisms is the problem of temperature distribution in the coal massif being of high-temperature gasification channel. Decision of the task will open a way to create project of production of high calorific syngas and more wide development of effective coal energy technologies. This problem considers in our article.

Analysis of the problem of obtaining high-quality clean synthetic gas

In the last two decades started serious work on reducing gas emissions into the atmosphere of products from coal combustion in coal-fired power plants. So, in the early nineties of the last century in the framework of the National energy strategy, the United States have worked the project of Clean Coal Technologies (CCT) [2].

The basis of the CCT is the system of integration SCG with combined cycle of power generation on united enterprise (Integrated Gasification Combined Cycle — IGCC), which differ by the presence of gas and steam turbine in the same aggregate. This system combines the transformation the coal from solid phase to synthetic gas (coal gasification) with a combined cycle to be produce electricity the highest energy efficiency. In the system three kinds of gaseous fuels may be possible to obtain a coal gasification process. There are fuel gas with a low heat of combustion (a mixture of CO, H_2, CH_4, and N_2) and the syngas with medium calorific value (a mixture of CO with H_2) and artificial gas with high CH_4 content and high calorific value (a substitute for natural gas (SNG). Each type of a gas can be implemented using special technological conditions only.

Several demonstration projects combined cycle IGCC [3] have been implemented in several countries (USA, Canada, Australia, etc.). Among them are: environmentally friendly system operating on product of coal gasification and ultrapure system working on hydrogen fuel. As a rule, in the projects the syngas was obtained. The demonstration projects consisted of several stages mainly:

- fuel and producer gas is formed by reaction of the coal with the oxidant, i.e. air or steam or oxygen;
- cleaning the generating mixture of harmful solid and gaseous impurities (sulphur and nitrogen oxides, carbon dioxide);
- clean gas is burned in a gas turbine to generate electricity;
- outgoing heat from the gas turbine is used to generate steam, which is fed into the steam turbine.

The installation of IGCC is consided the most effective among the other innovative technologies in the coal — power engineering. Sulfurous, nitrogenous substances and pulverized solid particles (products of direct coal combustion) are removed from the gas mixture prior to its combustion in a gas turbine. Containing in coal and associated with a sorbent a sulfur is removing from the coal after cooling. Thus, reducing of sulphur and nitrogen dioxides there are more than of 99 %. For example, the nitrogen is removed through transfer in an ammonia what can be almost completely removed.

The integrated technology of coal mining based on the processes of ground and underground gasification of coal control with the technological schemes and parameters of the process. However, process itself of underground gasification of coal (UCG) and production of gas fuel as well as its quality characterize by low stability and handling.

In recent years, it were proposed methods of reducing these disadvantages [4, 5], for example, use floating point for supplying an oxidant into the channel of fire during burning the coal seam, which allows more reliable to control both the configuration of channel in a massif of the coal seam and non-contact cooling of the gas mixture in the well. This method extends flow rate of outgoing gas fuel from wells and increases energy efficiency of the all process. The company "Lawrence Livermore National Laboratory (LLL)" of USA used the term "CRIP" for the controlled movement the feed point of fresh air in a coal seam [6].

In the specific geological conditions is possible to obtain stable raw producer gas of low calorific value, but conditions of exploitation of power generation units requires of enrichment by a coal methane of gas mixture for the achievement of the required heat of combustion of it. Such mixing of gas and methane flows is recommended in the technology Local coal and gas and electricity complexes (LCGEC).

The technology proposed in 1995 [7] into the Moscow State Mining University (MSMU) and developed in a scientific concept in 1996 [8]. Further projects have been developed for its use in the coal basins of Russia [9]. The technology solves a very important problem of sharp increase of efficiency of coal-fired power plant [10] and a significant reduction of the ecological load on the environment in the part of greenhouse gases, sulphur and nitrogen oxides [11]. Today, there is the clean and energy effective technology for a coal deposits mining on the base of underground coal gasification and methane extraction from the coal seam and power generation into one energy complex.

However, the wide using of the innovative technologies of UCG in a coal — energy industry meets serious difficulties. Reasons are both deficiency of understanding a temperature distribution in the burning coal massif and a level of heating of the coal seam for producing of combustible gas mixture with high quality. For innovative technologies LCGEC the knowledge is especially important as the generated gas is sent in a highly efficient turbine of a combined cycle to generate electricity and where high quality of gas fuel very need. Thus, the unknown question consists in researching a thermal mechanism of burning channel into the gasified coal seam and temperature distribution from a wall of the coal seam in deep of its. The article bases on the mathematical modeling and gives numerical interpretation for temperature of UCG process.

The study of phenomenon of burning into a coal seam during underground gasification process was carry out by scientists of the Soviet Union Chukhanov Z.F., Kreinin E.V., Shirokov M.F., Goldenberg S.A. etc in the 40–50s of the last century and later Ianchenko G.A. (Moscow State Mining Univercity). An attention of scientists were focused to calculations for the length of the firing channel and the heat balance of the gasification process and influence a height of coal seam on efficiency of its [12].

Under the influence of heat on rocks depending on their mineralogical and chemical composition and structure and porosity and the its natural state the various physical and chemical processes were studied the transition of a substance from one phase state to another, polymorphic transformation, thermal expansion, the phenomenon of hydration and dehydration reactions of compound, decomposition, recovery, oxidation as well as the thermal decomposition and coking of a coal with the maximum exit of gaseous products in the temperature range of 700–1100 °C. Chigik Yu.I., Walsh, S.D.C., Lomov, I. and Beloved Syria made the study of temperature changes in the coal mass in the processes of ventilation of mines or fires in the mine [13–15]. The studies carried out both under normal conditions and in case of endogenous fires by method of mathematical modeling and numerical experiment. The mathematical model of heat transfer in the rock mass, based on the finite element method allowed to research the prediction of the distribution and parameters of a heat flow in the rock mass and mining workings.

Next stage consisted in study of a temperature into the rock mass around geothermal wells [16]. A mathematical model of a coolant flow from a geothermal borehole was created taking into account different regimes for two-phase flows. Heat losses in the surrounding rocks were determined through the magnitudes of the two-dimensional heat flow. The two-dimensional task of heat conduction in cylindrical coordinates solved taking into account the geometry of the well. Good agreement of calculated data with the field experiment allows use the developed model to calculate and forecast the operating parameters of the geothermal wells.

The article [17] made analyzed the distribution and changes of temperatures between the rock mass around boreholes and fluid of tubular heat exchanger which is used as an energy source as the heat pump. It is shown changes of temperatures in the rock mass and heat extraction as well as comparison the temperatures in the active and referential borehole.

The study of the process of heat transfer from the ventilation channel to high temperature rock mass on a laboratory pilot installation has executed by scientists of China University of Mining and Technology [18]. The results contain an analysis of a transient heat transfer in the model of surrounding rock mass. The results show that the wall of fire channel temperature decreases dramatically at the early stage of ventilation flow, and the temperature of the surrounding rock mass is decreasing constantly with time passing. The relationship between dimensionless temperature and dimensionless radius demonstrates an exponential function approximately. Meanwhile, the temperature disturbance range in the simulated surrounding rock mass extends gradually from the wall to deep area in the surrounding rock mass. Besides, as the air velocity increases, heat loss in the surrounding rock mass rises and the temperature reduction becomes larger.

Thus, the global experience of study of the distribution of temperatures in the wells and rock mass showed that the studied issues are usually function of the thermal connection of the wells drilled in its. The question of assessing the distribution of temperature in the coal seam during underground gasification by high-temperature heating is investigated not enough in a science. Therefore, quality growth of the process fuel gas producing from the coal seam cannot be carried out without the knowledge of physical laws. Mathematical modeling of temperature distribution in the coal masssif near the burning gasified channel of the coal seam may be very effective.

Simulation of a temperature in a coal seam near the burning channel of underground gasification

The temperature distribution in deep of a coal massif determines the temperature character of its heating from the hot channel wall to a coal seam as well as the intensification of chemical reactions to be generated effective gasification of a coal seam. This knowledge is necessary for a more precise definition of combustion parameters of the coal seam and improving the quality of the manufactured gas fuel produced in this process.

Implementation of LCGEC project requires also manufacturing of a synthetic gas of medium or high in calories in the gasification channel and, for this, knowledge of the law of the temperature distribution from the channel walls into a coal massif.

Schema of the gasification zone in a coal's massif and a channel shows in **Fig. 1**. Black color means the coal seam. Red color is fire zone both into a coal seam and in a mine workings. Yellow color and blue color are zones where the air and gases mixture is moving about crushed roof rocks. Yellow arrow shows stream of heat convection from the combustion zone deep into the coal seam. Although the distribution of these zones is approximate and the turbulence of flow takes place this model allows to evaluate distribution of temperature during underground gasification and to obtain more information about a depth and character of heating of the coal seam.

For start point we are taking the temperature in burning channel of 1500 K and are deciding the task of thermal conductivity of the coal seam in stationary conditions. Limited conditions we are taking next: coefficient of thermal conductivity λ = 0,14 Wt/m·K and coefficient of a heat emission α = 0,1 Wt/m^2·K. The meaning of coefficient α we will find as the task for a coal parallelepiped with an area 1m^2 and a perimeter 4m. In these conditions, we take that a heat exchange between borders of the parallelepiped and the coal mass is absent. Thus, in the first approximation we will solve monoaxial task or a linear thermal flow. The task and of its solution will have less accuracy but result of this solution allows to understand mechanism of a heating coal seam near the channel.

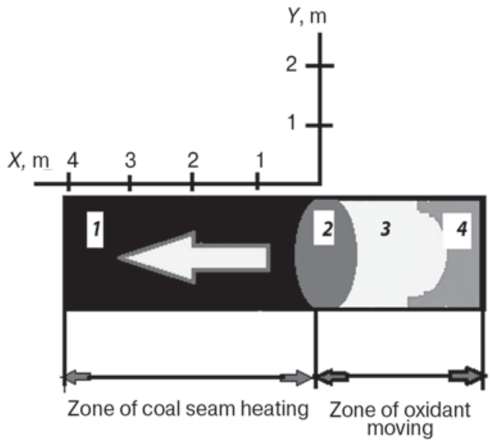

Fig. 1. Scheme of temperature zones in underground conditions during process UCG with zones of:
***1* — vertical section of coal seam along strike line;**
***2* — fire location into coal seam and gasification channel with *t* = 1400÷1600 K; *3* — flow of heat generated gases with lower *t* = 800÷1200 K; *4* — air (oxidant) and gas mixture near crushed roof rocks with *t* ≤ 700 K**

Mathematical modelling of the burning process into a coal seam

The basic equation for the distribution of heat by J. B. Fourier Q (J) in a solid linear form in a period of some time with the first-kind boundary conditions is

$$Q = -\lambda \frac{dT}{dx} \cdot dS d\tau, \qquad (1)$$

where λ is the coefficient of thermal conductivity of a solid, W / (m · K); S and x — sectional area and body length, m^2 and m, respectively; T — temperature, K; S — temperature of body area, m^2; τ — time, s. Based on (1), the stationary temperature distribution in a rectangular solid (block of a coal array) with a cross-sectional area of p = 4 m^2 and a perimeter of S = 4 m and a certain length l (m) is described by a second-order differential equation with a thermal parameter a

$$T''(x) - a^2 T(x) = 0; \qquad (2)$$

$$a = \sqrt{\frac{\alpha p}{\lambda S}}, \mathrm{m}^{-1}, \qquad (3)$$

where α (W / K · m^2) and λ (W / K · m) are the parameters characterizing the specific geometry and thermal quality of the combustion channel and thermal conductivity of coal, respectively. Equations (2) and (3) are solved using the conformal Laplace transform method, which simplifies the solution of the problem. Using the conformal transformation tables for the original function (2), we find a solution for x through it picture

$$T(x) = \frac{T_2 sh(ax) + T_1 sh(a(l-x))}{sh(al)}, \qquad (4)$$

where T_2 is the temperature in the heating zone of the coal mass from the wall of the firing channel, K; T_1 is the temperature at the end of the selected coal parallelepiped at a distance from the wall of the combustion channel by l (m), K; $sh(ax)$ is the hyperbolic sine of the dimensionless parameter (ax).

Numerical simulation of the process was carried out for the following boundary conditions:

at $x = 0$ (wall of the firing channel in the coal seam) $T_2 =$ = 1500 K;

at $x = l$ (deepening into the coal mass from the wall of the fire channel) $T_l = 300$ K with regard to the numerical value of the thermal parameter a (3)

$$a = \sqrt{\frac{\alpha P}{\lambda S}} = \frac{0{,}1 \cdot 4}{0{,}14 \cdot 1} = 1{,}69,\ 1/\text{m}. \qquad (5)$$

The parameter "a" means taking into account the thermal characteristics of the coal seam and the geometrical dimensions of the heating zone of the adjacent coal seam. Using (4 and 5), we carry out their numerical simulation. In **Fig. 2** shows the relationship between temperature and depth (x) of coal seam heating during underground gasification.

This relationship has next mathematical form

$$t = -3.8x^3 + 75.3x^2 - 534.2x + 1460.4,\ \text{K}, \qquad (6)$$

Thus, during underground gasification, the temperature in the depth of the coal mass decreases very rapidly. This means that only a small area of the coal seam near the canal wall (about 0.05–0.1m) will undergo the process of manufacturing a combustible gas mixture. In addition, the coal seam at a depth of 1–1.6 m will be heated, which should strengthen and enrich the further gasification process.

Using the results of this study and linking knowledge of the Lurgi process [19], it is better to produce higher quality gas fuels from coal. As the channel temperature increases to 1000–1300 K, a narrow zone of the coal seam will be heated and the Lurgi process initiates the production of synthesis gas, which will contain combustible components up to 92% and a calorific value of 17.3 MJ/m^3 [20–23] .

Simulation data show that the coal seam near the combustion channel must be heated to the temperature of coking. If the gasification temperature rises to 1300–1350 K, the process of coking coal seam will occur, which will accompanied by an increase in its plastic properties and porosity. These processes contribute to the reduction reaction of the oxidizing of a carbon and the conversion of coal to carbon monoxide and hydrogen, which significantly improves the quality and calorific value of synthetic fuel formed in the gasification channel.

Conclusion

The study of the thermal mechanism of underground gasification of a coal seam showed that in a narrow region

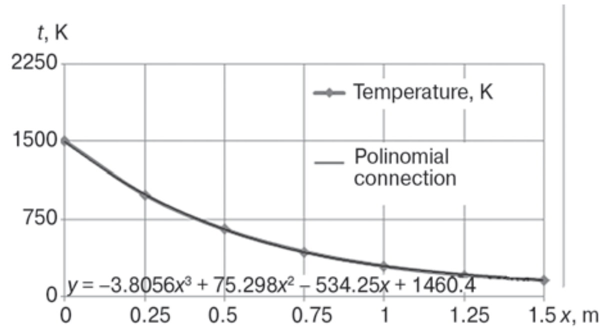

Fig. 2. Temperature distribution (*t*) inside the coal massif depending on the distance *x* (m) from the wall of the fire channel *t* = *f* (*x*)

from the walls of the combustion channel to the depth of the coal seam there is a coal burning zone and an overheated thermal preparation zone for its burning, where synthetic gas production occurs.

The results of numerical simulation confirm that the maximum temperature loss occurs at a distance of 0.5–1 m from the coal seam wall over the depth of the formation. The function $T = f(x)$ has the character of a decreasing polynom. It is important that the polynomial line for $x > 1.5$ m decreases very slowly, and the temperature at the depth of the coal seam is more than 540–500 °C. This means deep and uniform heating of the coal seam and its effective preparation for the subsequent gasification process.

The UGC process should occur in a layer of coal seam with steam and/or oxygen treatment. This fact is important for the future use of LUGEC technology. Managing the UCG process, it is necessary to observe the established high-temperature parameters of the thermodynamic state of the coal massif and the synchronization rate of the firing of the coal bed gasification channel with the maximum specific output of the generating gas (syngas) from the coal. This reaction is widely used to produce high-calorie high-calorie synthetic gas from a coal seam.

The findings obtained from the results of these studies can be used to calculate the parameters of underground gasification of any coal seams.

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INTEGRATED MULTI-LEVEL GEOFLUID MECHANICS MONITORING SYSTEM FOR MINE WATERWORKS*

The article sets out a methodical framework of an integrated multi-level geofluid mechanics monitoring system for the mining and processing industry and illustrates the system implementation in the Kola Peninsula. The system is based on the multi-disciplinary observations, including ground-based and GPS (satellite) survey, geological engineering, hydrogeological and geotechnical measurements, aerial photography, geomechanical assessment, as well as subsurface, ground-based and spaceborn radar sensing. The structure of the system provides five monitoring levels, out of which the first four levels (subsurface, ground-based, airborn and spaceborn) are related with the daylight surface, while the fifth level (computer) means geofluid mechanics modeling and multi-version prediction in the analysis of various combinations of nature and technology impacts. The actual observations and subsatellite sites at waterworks of tailings ponds are illustrated in terms of processing plants of Kovdor GOK, Kola MMC, Oleniy Ruchey GOK and OLKON companies. Within the last 4 years, the integrated research into the state of these structures has been carried out jointly with the multi-level and different-scale scheduled measurements using check and control bench marks. From the obtained evidence, characteristics of the mechanical strength as well as permeability and deformation behavior of waterworks dams are revealed. The implemented research proves that the multi-level geofluid mechanics monitoring of waterworks within the systematic multi-disciplinary investigations enables early-stage detection of hazardous seepage, deformations and damages, as well as well-timed response and command decision-making to prevent emergencies and accidents. The experience gained in the integration of space, subsurface and ground-based radar sensing into surveying and hydrogeological observations makes it possible to state that the created system can efficiently be used in the geofluid mechanics monitoring of waterworks in the mining and processing industry.

Key words: *multi-level monitoring, multi-disciplinary integrated research, waterworks, mines*
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Introduction

In high-rate mineral mining and processing regions, there are many various-purpose waterworks which are potential hazard objects usually categorized as critical. Mineral mining considerably affects local natural systems, which results in violation of relative natural equilibrium of hydrological regime, activation of tectonic faults and crust movement. The latter can initiate hazardous events (subsidence, displacement, dislocation, landslide, rock bursts, earthquakes, gas outbursts, heavy water flooding, etc.). These events can become triggers of waterworks damage and failure, which brings considerable social and economic losses: toxic contamination of lands, rivers and lakes; destruction of closely spaced towns and industrial infrastructure, calamities, shutdown of mines and processing plants and, as a consequence, economic disbenefit in amount of hundreds millions of dollars [1–14].

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