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MINING OF COAL DEPOSIT ON THE BASE OF "LOCAL COAL GAS ELECTRIC COMPLEXES"

The article analyzes the problems of modern energy efficiency of mining of coal deposits. Traditional technology of mining of coal seams differ technical and environmental shortcomings that have taken place over the last century the use of the fossil coal for energy needs. The modern requirements of the use of energy saving technologies require a coal transition to gas fuel and more extensive using of a clean technology with higher energy efficiency. A comprehensive approach both the coal and power generating technologies needs to increase of energy efficiency use as well as for creation in the energy sector of our country these complexes.

The schemes and connections of the individual blocks of such technological complexes are discussed. Data about the relationship of capital costs for construction of the complexes, depending on their capacity, and estimation their technical and environmental performance are cited.

***Key words:** coal deposit, shortcomings of coal industry, power station, energy effectiveness, environment, local coal and energy complex, coal gasification, gas flue from coal*
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Introduction

The natural coal has extracted more 40-ty countries with a volume of more 8 bln t. Development of the coal industry connects to improving of capacity and performance of basic and auxiliary processes in mines and quarries. An important element of progress in the coal industry is technology of a control and automation and robotics of technological processes. Reducing of a scale of the devastating impact of mining on the environment will have important meaning for progress in coal mining too. According to the Energy strategy of Russia until 2030 year the goal of an energy policy of the Russian state is the maximum efficient use of natural energy resources and potential of the energy sector for sustainable economic growth. Natural coal will play the important role in an economy of our country [1–3].

The subject of this work is to develop ways to increase of energy efficiency of using existing resources of the coal deposits and decrease of negative influence of these processes on the environment. Any technology and, in particular, complex and energy-intensive such as coal — energy cycle should be improved that will greatly affect for the economy of the state. For further growth of energy efficiency we will evaluate shortcomings which take place in a process use of hydrocarbon resources both for traditional coal extraction and conventional technology of coal energy together. These shortcomings have, as a rule, international character what increase importance decision of this problem. Disadvantages of coal and energy complex will show on the example of Russia.

Technological disadvantages of coal-power generation technology

Energy efficiency assessment in conventional coal and energy complex (CCEC) includes the energy costs for: the construction of the surface structure of coal mines, the system of mine workings, mechanization of the breaking of rock mass and a coal seam, mine or open pit and the far transporting it by rail and/or waterway, preparation of delivered coal to the power station, production of electricity by thermal power stations, as well as operating costs and depreciation costs of equipment employed in the process of coal mining. Accounting for one ton of the conditional fuel the calculations show that total specific using of useful energy of the coal is around 10–12% of the total quantity of potential thermal energy of the coal. So academician V. V. Rzhevsky has assessed beneficial using of the potential energy of the coal in modern coal and energy industry.

Operating losses in the development of standard coal seams are calculated as extraction factor which equals in average about 25% depending on the thickness and angle of bedding of a coal seam. Also, there are so-called off-balance sheet reserves that includes very thin coal seams and heavily disturbed areas developed reservoirs. Therefore, the total losses of coal in the deposits can reach 40–55%. Reducing of these losses and it engaging in the economy of off — balance-sheet stocks is quite possible if to use of borehole mining methods, in particular their underground gasification.

In the last period, labor productivity in coal miners of Russia was lower than in coal mines of the USA in 8–10 times. It was equal of 1,48–1,53 kt/year of one worker for open pit and for underground coal enterprises consisted of about 1 kt/year.

The ash of fossil coal varies from 6 to 50%. The average ash content of the extracted coal estimated at 24–26% in Russia. Reduction of ash content and moisture of the coal at 5–6% reduces the cost of electricity production by 8–10%. However, the proportion of washed coal in energy production is 12–15%. Recent attempted tests allowed to increase part of washed coal and enhance of range of these coals. Nonetheless, from the point of view of increasing of the mining efficiency and energy complex, the mineral part of the coal seams must be leave in the coal deposits during a process of underground coal gasification for example what can reduce the energy and economic losses of the coal companies.

The volumes of mine workings in the mines largely determine the overall efficiency in coal energy industry. So, 3320 m of the mine workings on every one million tons of the extracted coal were developed average in Russia in 2015. Reducing dramatically the extracted rocks volume may be used through borehole technologies development of coal deposits. Due to the low performance of borehole hydraulic technology and it inability to meet the extensive needs of the market in the coal raw material, the focus should be on the processes both underground and surface gasification of the coal seams which eliminates expenditures on construction of the expensive mine workings .

The following negative factor of conventional technologies of coal mining is the availability of injuries of miners. The risk of underground worker activity is quite high. Way of increase of safety in the coal and energy complex must contain technological solutions to minimization of underground labor. Wide using both the open pits and the borehole technologies for a development of coal deposits may successfully solve this social problem.

In Russia, the production of 1 mln t of coal is accompanied by the discharge into open waters of 3.22 mln m^3 of polluted waste waters, issuing and placing on the surface of 1.48 mln m^3 of overburden, a violation of 10.2 ha of land, emissions of 2.93 thousand t of harmful substances. These negative effects can largely neutralize by the use of alternative environmentally friendly borehole technology including the process of the gas fuel manufacture from the coal seams.

The average length of the transport arm for extracted coal sales in Russia now is 2.5–3 thousand km. Rail transport in some regions is adding 60–80% to the cost of the extracted coal what results in more expensive products and production of electricity in the coal-fired power plants. To reduce the cost of railway transportation of coal is possible generate electricity directly to the mine field or not further of 3–5 km away. To do this, coal must be converted to a gaseous fuel and electricity which is distributed through the regional grid.

With accounting all mentioned shortcomings, in 1995 in Moscow State Mining University (MSMU) the idea was formulated to combine the coal mining and the power generation process into a single technological complex and to develop of the coal deposits on the base of the use of borehole technology [4]. In the development of the idea to the University was formulated scientific concept — development of coal deposits on the basis of Local coal-gas-electricity complexes (LCGEC). The proposal of the Institute of problems of comprehensive exploitation of mineral resources of Russian Academy of Sciences about use of the energy of rock pressure as a renewable energy source [5] is included in our concept.

An idea of LCGEC include decisions about both an intensification of combustion of the coal and increase of the efficiency of the transformation of coal into gas fuel. In recent times there are also proposals for the creation coal and energy clusters in a coal region of Russia [6, 7] affirming above mentioned the concept of MSMU.

In advanced Russian generating company "Mosenergo" 1 MW of power generation manufactures 0, 45 workers. But average index for developed countries is 0.28 people per 1 MW. Based on these data, the energy efficiency of electricity generation from a coal should grow very quickly in Russia. This growth of labor productivity in the coal energy technologically closely links with the transformation of the coal in the gas. And this requirement may be provided through the MSMU concept.

In finally, the sharp increase in power generation with current energy efficiency 32–38% can achieve by using in LCGEC modern gas-steam combined cycle power plants running on the gas from gasification of a coal with efficiency more than of 50% .

Status of innovative preparing and development of coal-power complex

The technological schema of LCGEC may vary depending on the geological conditions, purpose, conditions of delivery of electric energy and its production capacity.

The block — scheme of flows of the gas fuel during operation of Local coal-gas-electricity complex (cluster) to gas turbine or combined cycle unit is cited in **Fig. 1**. Therefore,

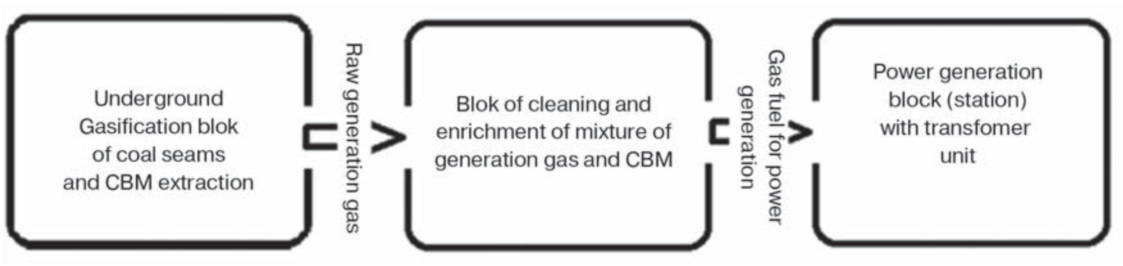

Fig. 1. Block — scheme of Local coal-gas-electricity complex on the base of underground gasification process: the arrows show direction of moving of a gas fuel

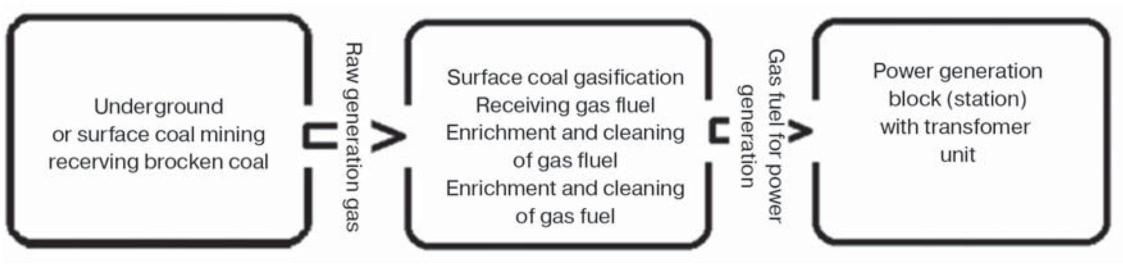

Fig. 2. Scheme of surface coal gasification with power generation: the arrows show direction of moving of a gas fuel

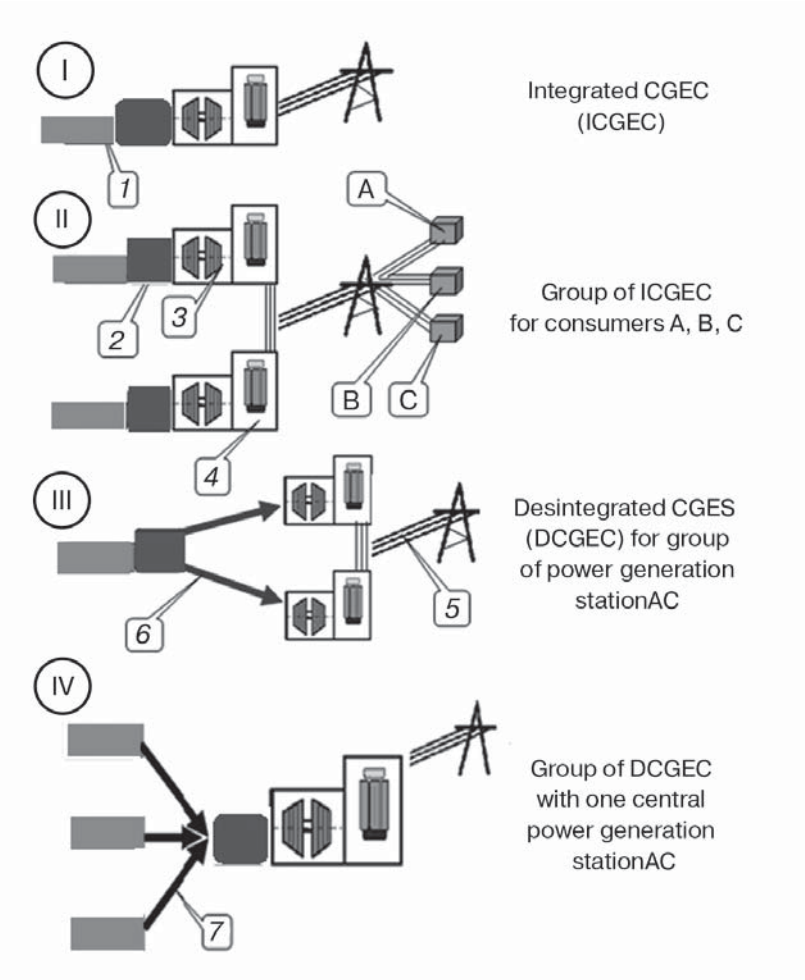

Fig. 3. Principle options of Local CGEC layout:
***1* — underground gasification block; *2* — cleaning and enriching block; *3* — power generation station; *4* — transfomer; *5* — high volt line; *6* — gas pipe line; *7* — railway transport of coal (CGEC — Coal-Gas-Electrical Complex)**

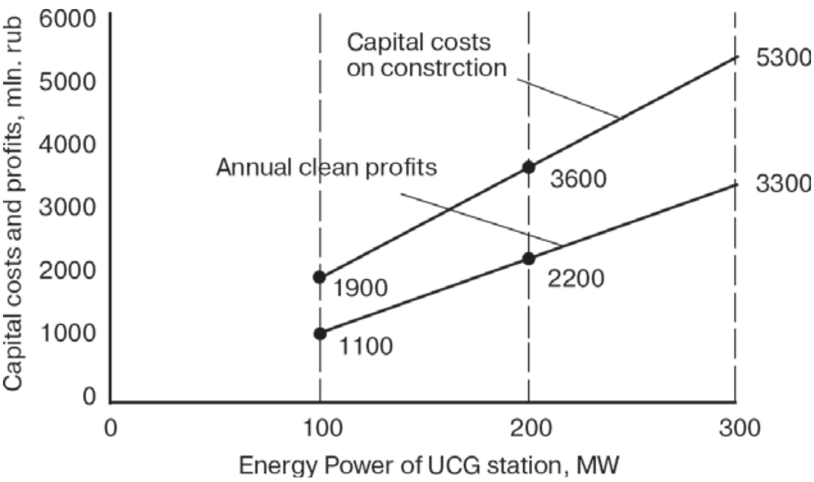

Fig. 4. Capital costs of an electricity production generated on the base of synthesis gas from underground coal gasification (UCG) process

the project construction and operation of the complex shall be performed into all three blocks simultaneously with the process of underground or/and surface gasification of a coal and extraction of coalbed methane (CBM). These gas flows are connected in total generated mixture in it complex. Calorific value of this mixture achieves to 32 MJ/m^3.

This scheme is used in conditions when a quality of manufactured production answers of requirements providing of normal quality of gas fuel for gas turbines. Also, in these conditions may be use extracting a coalbed methane from the coal deposits as an instrument of enrichment of the gas fuel.

There is other variant of the technology using extracted a coal from the coal seam for generation of syntes gas too (**Fig. 2**).

This scheme is named Integrated gasification combine cycle (IGCC) because it includes blocks of both the surface installation for gasification of the coal seam and power generation steam and gas with power generation of combined cycle into the single cluster [8]. If individual units separated in space at a far distance then the scheme is called disintegrated (DGCC). The choice between the schemes in the project is decided on the basis of the feasibility analysis and by way a comparison.

The fuel for generating stations can represent the following technological schemes: the mixture gases from the gasification of a coal on the surface or/and synthetic mixture gas of underground gasification from coal seams with added the coal-bed methane which is extracted in the same coal deposit. The degree of purification of fuel gas is characterized removal of carbon dioxide, sulfur oxides, nitrogen oxides and mineral particles.

The project should be selected both the optimal structure of the complex and to optimize transport and commercial links between generating units and consumers of energy.

According to the method of disposal of carbon dioxide the schemes are divided as with the procedure of sequestration, without it and with of the procedure of injection of carbon dioxide into the mined-out space of coal mines or in natural cavities of the Earth.

As the type of power generation the power plants may have a gas turbine, steam turbine and the installation of combined cycle where steam and gas turbines work in the single unit on the one axis.

Technological complex according to the degree it integration may be both single complect of coal mining and power generation and several blocks with coal gasification and delivery of the gas fuel and purification and processing of it on the remote power generation stations.

The type of transport links between the producer of power generation and the consumer may differ both a single connection in which one or several producers work on the one consumer or extensive communications (network), which delivers electricity from one or a group of producers to a group of consumers for example factories, mining enterprises, residential sector etc.

Thus, the technological scheme of the coal and energy complex may be complex and variable and multi-stage.

Options of layout of the technological blocks in the Local coal and gas and electricity complex are shown in **Fig. 3**.

Given the rapid growth of natural gas prices, the cost of synthesis gas will be quite competitive in the market for gaseous fuels. In **Fig. 4** shows the comparative capital costs for electricity generation using UCG technology in the function of electric power affiliated stations [9].

The data show a linear relationship capital costs and annual profits of the enterprise from the growth of its electric power in a sufficiently broad range of 100 to 300 MW.

After receiving in a gasifier the syngas is cleaned to remove contaminants (pollutant) and acid gases. As the result, the dry gas has average calorie. If the air is used as oxidant the heat of combustion of this gas amounts to 3–5 MJ/m^3. The use of oxygen and increased pressure raises of combustion heat of gas fuel to 13 MJ/m^3. According to USA data the composition of this gas with the average calorific value is equal 38% H_2, 16% CO, 12% CH_4, 34% CO_2 what gives 5.6–11.2 MJ/m^3.

The extraction of carbon dioxide allows increase the heat of combustion of a mixture of the combustible gases up to 18–20 MJ/m^3. That is a gas of middle calorie. This gas mixture may use as the gas fuel for power generation in a gas turbine.

The technology LCGEC use the unit of combined cycle what differs favorably from technology of coal power stations due to the greater stability of the gasification process and less content of carbon dioxide in a gas mixture. This factor allows achieve higher degree of purification of a mixture of CO_2 and reduce the cost of CO_2 removal technology. In **Table 1** there is comparison of the emissions of contaminants taking place during operation of coal-fired thermal power plants and technology of LCGEC [10].

The data show that the emissions of sulfur and nitrogen oxides and mineral particles in the technology of LCGEC significantly lower than from technology of pulverized coal combustion. The decreasing is for sulfur oxides in 13 times and for nitrogen oxides in 5 time and mineral particles in 1.6 times.

The process of coal gasification eliminates the risks associated with the traditional technologies of mining and the emissions pollutants reduced in the range of 25–40% [11]. In the process use of LCGEC, the emissions of SO_x and NO_x are close to zero because their removal take place before the process burning into the gas fuel but not in the smoke gases. The ash of the burned coal remains in the coal deposits and, finally, carbon dioxide emissions are lower than when you work with a unit of a combined cycle on the natural gas. This process allows decrease costs for capture and sequestration of CO_2 by 30–50%.

The economic feasibility of the use of technology is determined through our the objective function with data of USA experience [12, 13]:

Table 1. Comparison emissions of a coal-fired station and technology LCGEC

Parameter	Coal station	LCGEC
Pollutants concentration in the flue gas, mg/cub, m – SO_x – NO_x – Solid particles	 130 150 16	 10 30 10
Elektrical efficiency, %	33–35	42–46

Table 2. General parameters of Local coal-gas-electricity complex in Kuznetck coal basin

№№	Parameter	Unit	Value
1	Block dimensions – at the strike – across the strike	 m m	 200 151
2	Reserves of the block	thousand tons	544
3	Reserves of coalbed methane	mln m^3	348
4	Borehole number in one block – productive 300 mm – supply air 250 mm		 9 6
5	Flow rate: – air – natural generator gas – cleaned generator gas – coalbed methane	 m^3/hour m^3/hour m^3/hour m^3/hour	 55250 82875 66300 1765
6	Power of complex on burned coal	t/day	566
7	Operation time of block	years	2,6

$$(N_e \cdot k_d) \cdot s_{rc} + Q_{an} \cdot S_{var} + (N_e \cdot k_d) \cdot S_c + B_{cd} \cdot S_{sc} \ \min, \ \textit{mln \$/year}, \quad (1)$$

where N_e — electrical power of a complex, kW; k_d — the discount coefficient of the brought investment for one year; s_{rc} — specific capital costs per unit electric power, $/kW; Q_{an} — annual electricity production at thermal power plants, MWh/year; S_{var} —the cost of the variable component per unit of generated electricity, $/MWh; S_c — the cost of the constant component per unit capacity of thermal power plant, $/kW; B_{cd} — mass of the annual emission of greenhouse gases from thermal power plants in terms of carbon dioxide CO_2 equivalent, million ton/year; S_{sc} — specific cost of carbon quota, $/t of CO_2. A expression (1) for Prokopevsko-Kiselevsky region of Kuznetck coal basin has following value

$$F(x) = 10^6 \cdot (0{,}056x_1 + 0{,}487x_2 + 0{,}068x_3 + 0{,}096x_4) \ \min. \quad (2)$$

Thermal power of the LCGEC in the conditions of Kuznetck coal basin was determined as N_t = 130 MW and electric power N_e = 68 MW with energy efficiency of 50%. General indexes of LCGEC project are listed in **Table 2**.

The above mention example reflects a feasibility stage of the project for local geological conditions of Kuznetsk coal basin. This region contains both great reserves of coals and big resources of coalbed methane. Other geological conditions will require other decisions and, for example, the surface gasification process.

Progress in the coal industry lies in the development of deep transformation of coals to produce products with higher added value, as well as in the creation of such clusters as Mencherepsky in the Kuznetsk coal basin, uniting in one company the extraction and processing of the coal into electricity with the electrical capacity of 20 MW [14]. Therefore, the future of coal power is provided in the complex reported in this manuscript.

Data of the articles [15–17] confirm the main provisions of this article.

Conclusion

Analysis of the energy and environmental shortcomings of the coal energy showed the need for further it development on the basis of generation from the coal seams a gas fuel with higher calorific value. Foreign experience says that thermal power plants using gas from coal gasification and power generation in combined cycle power plants can achieve efficiencies of up to 50%. An increase of capital costs has a linear relationship in the range of capacity 100–300 MW. The greatest efficiency of such technology is provided on Local coal-gas-electricity complexes. The options of schematic layout and technological links between the blocks of the complex allow to realize the projects with optimization of the operation costs. Exploitation of such complexes is accompanied by a significant reduction in emissions of sulfur and nitrogen oxides which enables us to reach compliance with their allowable concentrations.

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