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Application of groundwater for underground coal gasification and incineration

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The energy issue is one of the most significant issues for Ukraine due to its lack of energy supplies. Coal remains are the main fuel and power resource, which will fulfill the need for chemical raw material for the next few centuries. The problem of coal excavation is priority for Ukraine. One of the main aspects is rationalization of mining and protection the environment. Underground coal gasification (UCG) and underground coal incineration (UCI), which unites mining and their underground processing in one technical process which can solve all difficulties, but the implementation is problematic due to fundamental disadvantages. One of ways of improving the underground mining and optimizing of these processes is using groundwater as an intermediate heat-transfer carrier.

Key words: coal, underground coal gasification, underground coal incineration, ground water.

Підземні газифікація та спалювання бурого вугілля з використанням підземних вод

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Для України енергетичне питання є одним з головних у зв'язку з браком вітчизняних енергоносіїв. Вугілля залишається основним енергоносієм, який також здатний забезпечувати потреби у хімічній сировині на кілька століть. Тому проблеми вуглевидобувної галузі є для України одними з пріоритетних. Проблема раціонального видобутку вугілля з одночасним захистом навколишнього середовища є одною з пріоритетних для України. Підземні газифікація (ПГВ) і підземне спалювання вугілля (ПСВ), які поєднують розробку корисних копалин з їх одночасною підземною переробкою в єдиному технологічному процесі, здатні вирішити ці проблеми. Одним із способів вдосконалення розробки може бути використання як проміжного теплоносія підземних вод.

Ключові слова: вугілля, підземна газифікація, підземне спалювання, підземні води.

Introduction. It is difficult to study the processes of UCG and UCI and to carry out the main stages of the technical work of underground generators. Increase in efficiency of the process can be achieved by decreasing losses of heating energy and increase in activity and durability of coal burning.

Connection between coal burning and environmental fossils and groundwater allows one to state that they have a mutual effect and form a heating and physical complex, the components of which actively interact and form a general thermal field. (fig. 1) (Silin-Bekchurin, Bogorodickiy, Kononov, 1960).

Interest is shown in underground waters of the area of thermal influence of underground generators of heat which have high thermal parameters and mobility, thus can be used as an intermediate heat-transfer source.

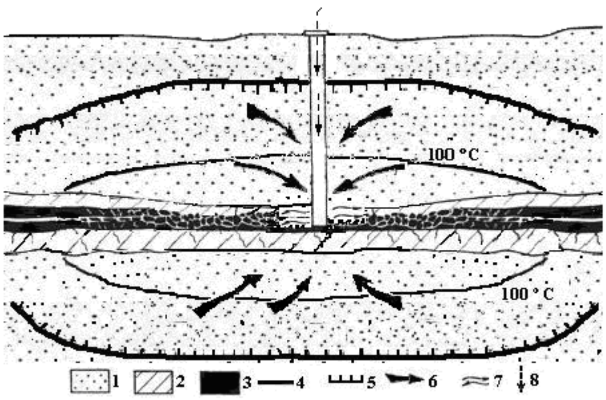

Fig. 1. Thermodynamic scheme of underground generator:
1 – sand; 2 – clay; 3 – coal; 4 – 100 °C isotherm;
5 – area of generator`s thermal influence;
6 – groundwater movement; 7 – gas flow in layer;
8 – blowing.

Collecting the heat requires methods of heat concentration and methods of driving it to the surface. The transfer of the heat by groundwater eliminates the need for collecting the products of gasification and allows movement to a simpler scheme – underground burning.

By mathematical modeling an analysis was made of thermal and hydro-gas-dynamical performances of underground coal burning.

Presentation of the general material. Thermal energy from an underground generator is transferred by convection-diffusion gas flow and groundwater. For assessing the influence of burning and cooling the underground generator we used thermo-physical common factors, which are based on the Fourier law and are presented in the equation (Belyaev & Ryadno, 1992)

$$\frac{\partial T}{\partial \tau} = a\,(\frac{\partial^2 T}{\partial x^2} + \frac{\partial^2 T}{\partial y^2} + \frac{\partial^2 T}{\partial z^2}) = a\nabla^2 T, \quad (1)$$

where a – coefficient of heat conduction; T - temperature; ∇^2 - Laplace operator.

Thus, we receive a picture of temperature change over time. In an environment which is close to uniform, the coal burning reaches 30 meters, the cooling process (≈ 3 years) is several times longer than the operating period (≈ 6 months), and the warming-up of the generator is practically unaffected by decrease in the temperature of the other generator which was stopped at the same time.

When modeling a two component system (water-saturated rocks), we used the equation of convective-diffusion heat transfer,

$$c_r \frac{\partial T}{\partial t} + c_w v \frac{\partial T}{\partial x} = \lambda \frac{\partial^2 T}{\partial x^2}, \quad (2)$$

where c_r and c_w are the coefficients of volumetric heat capacity of rock and water; v – speed of water filtration; λ - coefficient of heat conduction.

In this case, radius of action of a single generator decreases to ~ 10 m, the cooling speed becomes much higher, and the initial thermal regime practically refreshes in six months. The heat area of surrounding rocks in general does not exceed the first few meters (5…7 m on average) (fig. 2). Also we evaluated the influence of water filtration in the range from 0 to 15 m/day. On the one hand, the increase in filtration speed decreases the efficiency of the generator, and on the other hand, it increases its cooling (Zholudiev, 2003).

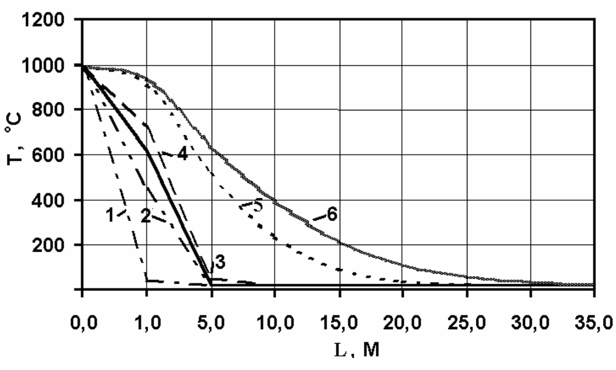

Fig. 2. The temperature change (T) according to the distance from the burning (L) including and not including the influence of groundwater filtration: 1 and 2 – the burning period is one month, with and without water correspondingly; 3 and 4 – period of burning is two months, with and without water correspondingly; 5 and 6 - period of burning is six months, with and without water correspondingly.

The presence of gas and liquid substances and their binary composition in the generator`s influence area requires the inclusion of common factors of each phase in the dynamics description (the so-called Stefan problem). Depending on the distance from the burning, there are 3 zones: the gaseous zone, the two-phase zone of concentration (transitional zone) and the zone of the liquid stage.

The limits of the transitional zone are defined by the temperature at the beginning (T_b) and at the end (T_e) of condensation. The heat of phase transformation (E) is exuded in the capacity of the two-phase zone and can be calculated with introduction of the function of the heat source q(T) in the ratio of heat transmission to the interval of temperatures $T_b \ldots T_e$ (Belyaev & Ryadno, 1992)

$$\rho\,(T)\; c_{eff}\,(T) \frac{\partial T}{\partial \tau} = div\;(\lambda\;(T)\; grad\; T) + q(T)\;, \qquad (3)$$

where ρ – density; c_{eff} – efficient heat conductivity which equals $c_{eff}(T) = c_0\,(T) - E\frac{\partial \psi}{\partial \tau}$,

$$\psi = \frac{V_l}{V_o} = \frac{c_g - c_0}{c_g - c_l} = \psi\,(T)\;,$$

where V_l i V_o – capacities of the liquid and two-phase zones; c_g, c_0, c_l – volumetric heat capacity of the gaseous, transitional and liquid phases.

The calculations were made for the temperature range of T_b – 374,15 °C (critical temperature), T_e – 100 °C within enthalpy of change phase 1930 kilojoules/kilogram (according to the temperature of 200 °C), for the operating period of 6 months (Zholudiev, 2005). The results of the calculations present the change in time of the activity of the thermal field around the generator and allow it to be compared with experimental data (fig. 3). The areas of increase in curvature of the curves correspond to the transitional zone of condensation. Comparing the temperature regime separately from the water evaporation, binary liquid and water, with the resulting curve, which includes the transition between these phases, contributes elaborations to the results obtained by traditional methods (Zholudiev, 2003, Kolokolov, 2000).

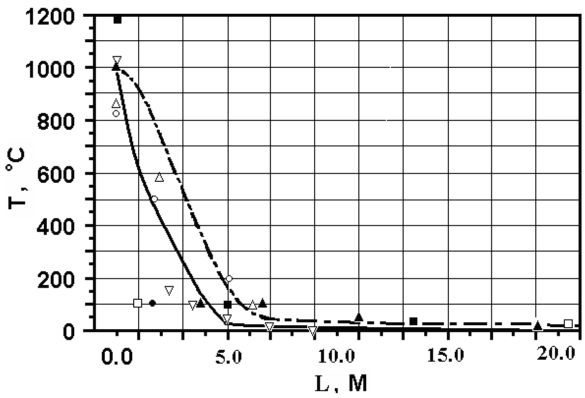

Fig. 3. Comparison of the obtained dependencies with the experimental data according to ▲ and □ – O. I. Sylin – Bekchurin for water-bearing bed and rocks; ● – Institute of the Earth`s Physics; ○ – E. O. Pohrebez`kyj; ■ – N. V. Yefremochkin; ▽ - I. D. Derhunov; △ - O. O. Men`aylov; estimation curves according to the time of burning ▬ - 3 months, ▬ ▬ - 6 months.

When studying the gas phase, we studied the dynamics of blowing, which is transferred to the heat generator, and also the selection of energetic or technological gas and water evaporations. The one-way movement of gas in coal layer is described using the equation (Koshlyakov, Gliner, Smirnov, 1970)

$$\frac{\partial^2 P}{\partial^2 x} = \frac{m}{nkP_0\sigma(t)} \frac{\partial P}{\partial t} , \qquad (4)$$

where P – pressure of the gas at the moment of time t; P_0 – initial pressure; m – porosity; n – the polytroping indicator; k – penetrability of the environment,

$$\sigma(t) = \frac{P}{P_0} + \left(1 - \frac{P}{P_0}\right) e^{-\frac{\mu n}{n+1}t} , \qquad (4)$$

where μ – viscidity of the gas; ς – constant, which characterizes the gas movement in the layer.

Gas-dynamic regime of underground generator and the blowing influence area were calculated within different pressure (0.2…2.4 MPa) and different meanings of penetrability of the environment (porosity of 0.2…0.5; filtration coefficient of 1.0…15.0 m/day) for operating period of 6 months (fig. 4).

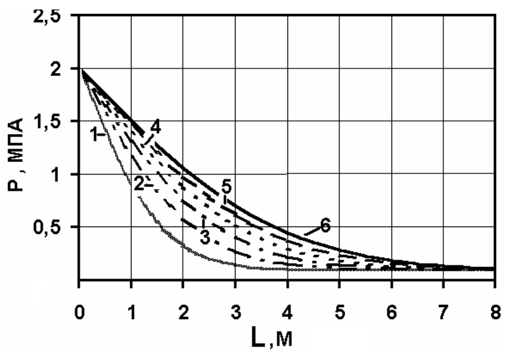

Fig. 4. The change in gas pressure (P) in the layer on different distances (L) from the blowing area in the time: 1...6 for the burning terms of 1, 2, 3, 4, 5, 6 months correspondingly.

Six months after operating with losses of pressure and gas in the layer, which do not exceed 10 %, the blowing influence zone enlarged by no less than 7 m (on the middle of the term to 5…6 m). The zone range practically corresponds to the gas generator`s thermal influence range. Thus, we can state that groundwater is affected by the blowing pressure, which is being supercharged, and the character of their condition is defined by the generator`s gas-dynamic regime, and by changing the blowing pressure and selecting gas, to some extent, the water regime of the underground generator can be regulated (Zholudiev, 2004).

Conclusions. Modeling of gas-, hydro- and thermo-dynamical regimes allows one to define the relation between their parameters and defines the opportunity for their parallel regulation. The conducted analysis for balance of water that takes place in the process of underground coal burning has shown the relation between the amount of groundwater and humidity of the blowing, which, it allows flexible process management.

Usually, within UCB the heat from coal burning is selected. The energy for heating the rocks and surrounding\environmental aquifers is not used (Zholudiev, 2004). The heated groundwater around the generator is the heat transfer agent and it should be driven to the surface. Also a conversion should be made in any suitable time for transfer and distribution.

As the burned channel is formed its hydro-dynamic role becomes determinant. It is required to provide the selection of heated water at the time and the flow of cold water to the generator with its further heating. The blowing wrings the heated water out to the pump area. As the water is pumped, it is replaced with cold water, which is relatively rapidly being heated.

The underground generator is cooled naturally after a thickness stratum is burned out. At that time a graduated cooling is observed. According to the results of modeling the intensity of thermal zone narrowing is smaller than the extension during heating. When cooling the burning the role of the heater gradually is given to the rocks and water. When the generator is fully cooled the groundwater is still acting as the heat source. As the thermal zone is achieved, the limit between warm and cold water causes the temperature to drop, which fits in the end of operating the area of the underground generator.

The main task of modeling the flow of the heat-transfer agent for controlling the process was finding optimum pattern of wells, yields and lowering which would contribute to the work of power module at least possible expense. The estimation was made for defining the amount of water which would fit a water collector of a certain size. The factors which manifest themselves – the change of water balance due to vertical leakage, decrease in the pressure, and interference of vertical and horizontal parts of water withdrawal – are defined by calculating the combined water withdrawal, which is on the scheme (fig. 5).

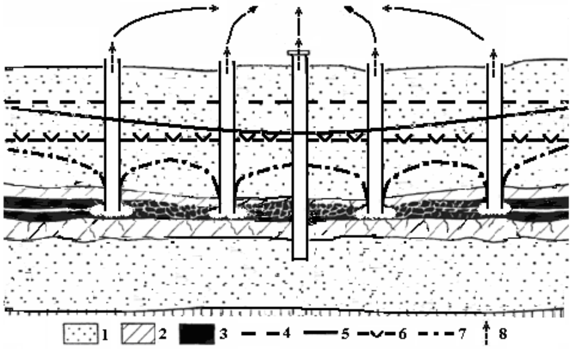

Fig. 5. The scheme of combined selection of a heat transfer agent by vertical wells and horizontal water collectors: 1 – sand; 2 – clay; 3 – coal; 4 – initial level of groundwater of above the coal layer horizon; 5 – also, when selecting a heat-transfer agent; 6 – initial piezometric level of under the coal layer horizon; 7 – also, when selecting a heat-transfer agent; 8 – heat-transfer agent`s flow to the surface.

The calculations were made for different distances between the grounds (20, 30 and 40 m) and the length of water receiving part (50 and 60 m) in different hydrogeological conditions (filtration coefficient of 3, 6 and 9 m/day). The results showed, that the productivity of water withdrawal fluctuates within a wide range (93,3...3544 m^3/day) and depends more upon the filtrating capacities of the rocks and less upon the dimensional scheme of water withdrawal.

It was established that within low coefficients of filtration, the productivity of water collectors will dominate and that vertical in-going flow will be intercepted. Within high parameters of filtration, the channel is not capable of selecting rising pressure of water and there could be a premature breach of cold flow to the thermal zone. In this case the vertical wells will intercept the excessive water flow.

Thus, it is possible to solve the problems of mining the coal deposits in complex hydrogeological conditions and move to developing compact and ecological energy installations for districts under heightened anthropogenic influence.

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