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Technological realization of the energetic module which is based on underground coal combustion

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Grounded technological scheme of energetic module, based on the use of underground energy combustion or gasification of coal deposits. The main elements of the energetic module: 1) waste heat exchanger working levels; 2) channels that combine working levels with the surface; 3) interim moving coolant; 4) technical complex on the surface and underground equipment. The proposed scheme uses ground water as a natural mobile heat-transfer agent, which comes up to the surface under the action of its own natural pressure or by pumping it up through natural or artificial channels. The peculiarity of the proposed energetic module is the concentration in one place of receipt and removal of heat energy and transforming it into electricity, which eliminates transportation costs for long distance carrier.

The main differences between this energetic module and modern thermal electric stations are the relatively low initial parameters of heat-transfer agent, which require using heat-and-power equipment in the area of wet vapor and creating systems of offsetting a large amount of low potential heat out of the turbines` condenser and a system of water-intake and pipelines for moving the heat-transfer agent from wells to the turbines and offsetting water used. In hydrogeological conditions of Dnipro brown coal basin the water from under-coal seam comes to surface via vertical wells perform pumping from the above-coal layer. The extraction of the heat-transfer agent is performed during the entire period of exploitation of the coal deposits both during the period of its burning, and during the cooling.

After the heat transfer agent is brought to the surface, it is conducted to a power installation which is arranged according to the configuration of the territory by local pipelines without transportation on long distance and its losses of energy conditions. After all the heat transfer agent is worked out in the energy installation, it is transferred to be purified and then is pumped back into the water-bearing horizons. Besides the proposed technical scheme is ready to use and spatial layout of the circuit power module suitable for implementation in terms Dnipro brown coal deposit.

Keywords: power module, underground coal, underground coal gasification, intermediate rolling coolant, Dnieper brown coal deposits.

Обґрунтування технологічної реалізації енергетичного модуля підземного спалювання вугілля

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Обґрунтовано технологічну схему енергетичного модуля, що базується на використанні енергії підземного спалювання або газифікації вугільних покладів.

Розглядаються основні елементи енергетичного модуля: 1) породний теплообмінник робочого горизонту; 2) канали, які об'єднують робочий горизонт з поверхнею; 3) проміжний рухомий теплоносій; 4) технічний комплекс на поверхні та підземне обладнання.

Особливість запропонованого енергетичного модуля полягає у концентрації в одному місці систем отримання і вилучення теплової енергії та її трансформації в електричну, що дозволяє виключити витрати на транспортування теплоносія на велику відстань.

Крім того, запропоновано готові технічні рішення та просторові схеми компонування енергетичного модуля, придатні для реалізації в умовах Дніпровського буровугільного родовища.

Ключові слова: енергетичний модуль, підземне спалювання вугілля, підземна газифікація вугілля, проміжний рухомий теплоносій, Дніпровське буровугільне родовище

Introduction. The main elements of the energetic module for underground coal combustion burning (UCC) are 1) the rock heat-exchanger of the working level; 2) uncovering channels, connecting the working level with the surface; 3) the mobile heat-transfer agent; 4) the technical complex on the surface and underground equipment.

The proposed scheme uses a natural mobile heat-transfer agent (ground water), which comes up to the surface under the action of its own natural pressure or by pumping it up through natural or artificial channels (wells, galleries). The circulation of the heat-transfer agent is performed through systems of water-intake, force-pump and exploitation wells.

The special feature of the projected module is that systems of extracting heat and systems of its conversion into electric energy are all concentrated in one place, which saves the expenses of transferring heat across large distances. Therefore the determining factors of its basing are geological-hydrogeological and thermal conditions – the temperature of rocks and their collective capacities at the depths accessible for drilling and water-intake, and also the storage and temperature of heat transfer - ground water.

Presentation of the general material. Figure 1 shows the principal technological scheme of an energetic module based on UCC with natural rock heat-exchange agent (natural pervious collector) (Dikiy, 1989). This module consists of four systems, practically independent one from another: 1) the system of extraction (force-pump and collectors); 2) pipe-lines; 3) conversion systems (turbines, generators, heat-exchange and ancillary equipment); 4) technical water supply (Sadovenko, Zholudiev, 2005).

The main differences between this energetic module and modern thermal electric stations are the following (Dyadkin, Pariyskiy, 1977; Kochin, Кіbel, Rose, 1948): 1) relatively low initial parameters of heat-transfer agent, which require using heat-and-power equipment in the area of wet vapor and creating systems of offsetting a large amount of low potential heat out of the turbines` condenser; 2) a system of water-intake and pipelines for moving the heat-transfer agent from wells to the turbines and offsetting water used.

Let us consider the constructive scheme of the projected energetic module in more detail. The working level is a coal seam worked by the methods of underground coal combustion or underground coal gasification. We suggest using traditional methods of underground coal burning, for it is not the product of burning that is significant, but the thermal energy produced (Frank-Каmeneckiy, 1987). Thus the technological problem of controlling the process of burning, the selection and transfer of the products is in many ways solved.

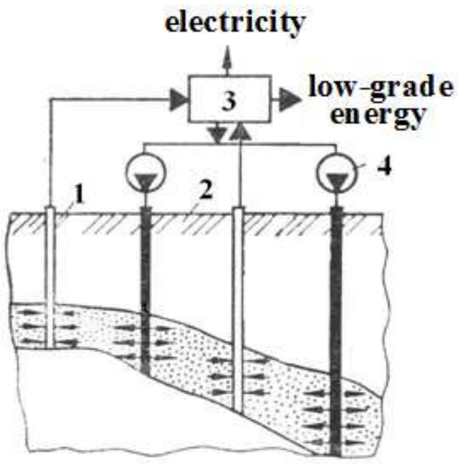

Figure 1. Principal technical scheme of energetic module based on UCC: 1 – water-intake well; 2 – key well; 3 – system of converting thermal energy from heat-transfer agent into electric energy; 4 – force-pump.

Extraction of the ground water-heat transfer agent is made through uncovering channels and in generally looks as follows. During the starting period of operating the generator, when burned out space, which can serve as a hydro-geological window between the under- and above-coal water bearing horizons, has not yet developed in the coal seam, a water intake is made through vertical wells from both seams. The wells are made on the plan in the centre between key wells of the underground generator (Fig. 2 – 4).

Because the radius of a well`s influence in sandy deposits is comparable with the distance between a pair of exploitation wells (which provides drafting and extracts the products of burning), only one water-intake well could be used placed in the centre between the exploitation wells. It is equipped so that the water intake is obtained simultaneously from two horizons, which are divided by the coal seam (Maloyan, Maloyan, 1968). The influence of this well will spread also to nearby generators, which allows it to be used after cooling of the nearest generator, i.e. until the waters throughout the radius of influence are cooled. The distance from the water intake well to the axis of the underground generator, on the one hand, does not exceed the radius of hydrogeological influence of the well and thermal influence of the generator, and on the other hand, is determined by the radius of perturbation from the incoming drafting, to avoid penetration of gas into water intake. As an underground generator burns out, the vertical intake is changed with combinatory water intake, where the functions of the vertical canal are performed by the burned out space of the coal seam, which has the configuration of a horizontal cavity extending along the direction of the incoming draft (Fig. 5). In such hydrogeological conditions, this is place where the water from under-coal seam comes to, and the vertical wells perform pumping from the above-coal layer. Thus, the extraction of the heat-transfer agent is performed during the entire period of exploitation of the ground, both during the period of its burning, and during the cooling.

For extracting the most heated heat-transfer agent it is recommended to perform pumping at the intervals of depths which are maximum near the coal seam, i.e. for above-coal seam – in the near-floor part (depth 90…95 m), for under-coal seam – in the near -roofing part of the seam (depth 105…110 m), and the rest of the well shaft should be isolated by well casings.

The pressure of drafting conducted to the generator should exceed the hydro-static and dynamic pressure of water flow to prevent flooding of the combustion source by incoming water. In a first approximation its magnitude can be compared with pressure of hydraulic fracturing. On the other hand, the studies (Zholudiev, 2004) show that the area of dispersion of pressure in the seam, with no relation to its magnitude, is in the interval of 5…7 m from the seam edges. Thus heated water will be pumped to the area of pumping, and the incoming cold water will not be affected by it while it is beyond the limit of the area of the perturbed zone (Fig. 6 and 7).

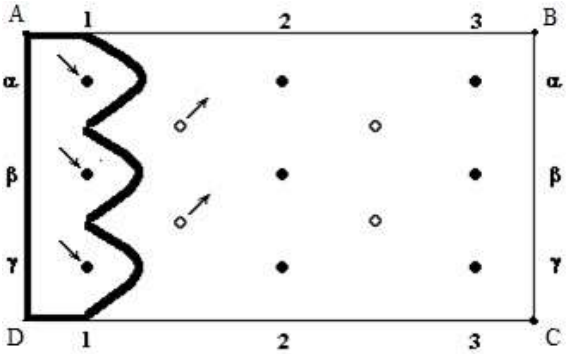

Figure 2. The scheme of arranging the exploitation wells and water-intake wells on the UCC ground during the starting period: ABCD – the area of working seal; 1, 2 and 3 rows of exploitation wells; α, β and γ - wells in a row; ↘● - key well; ↗○ - water intake well; ▬ - burned out space of working level (used-out channel).

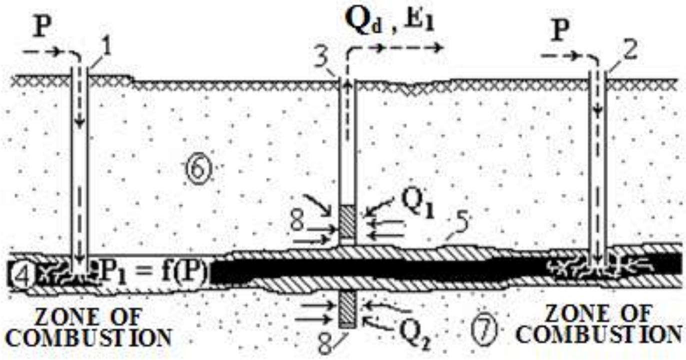

Figure 3. Longitudinal schematic section of underground part of UCC module in the starting period: 1 – key drafting well of *n* row; 2 - key drafting well of *(n + 1)* row; 3 – water intake well; 4 – working coal seam; 5 – clay; 6 and 7 – above and under coal horizons, respectively; 8 – intaking part of the water intake; *P* – pressure of drafting; P_1 – pressure of gas in a seam; Q_1 and Q_2 – water from above- and under coal horizons, respectively; Q_d – debit of vertical water-intake; E_1 – extracted thermal energy of the mobile heat-transfer agent; E_2 – the loss of energy of heat-transfer agent.

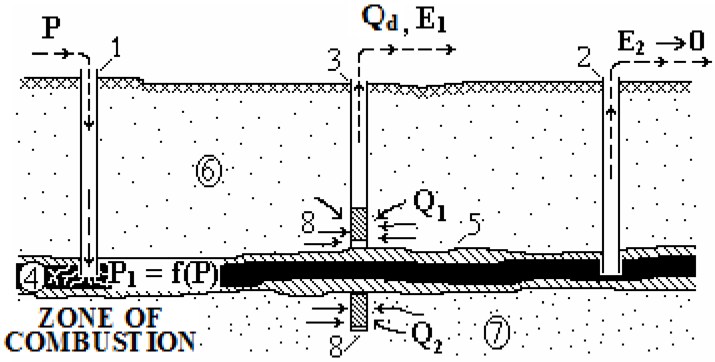

Figure 4. Transversal schematic section of underground part of UCC module in starting period: 1 – *α* – key well of n row; 2 – *β* – key well of n row; 3 – water intake well; 4 – working coal seam; 5 – clay; 6 and 7 – above and under coal horizons, respectively; 8 – water intaking part of water intake; *P* – pressure of drafting; P_1 – pressure of gas in a seam; Q_1 и Q_2 – water from above- and undercoal horizons, respectively; Q_d – debit of vertical water-intake; E_1 – the extracted thermal energy of the mobile heat-transfer agent.

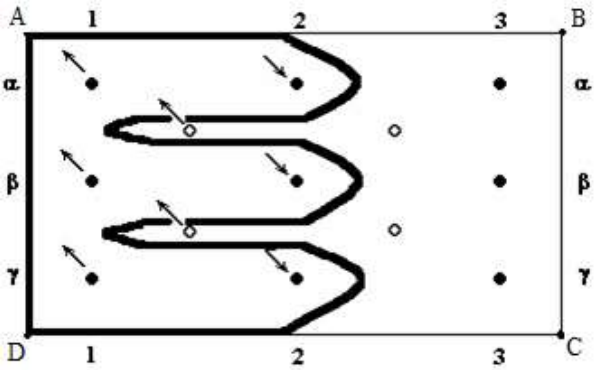

Figure 5. Scheme of arranging exploitation and water-intake wells on the UCC ground and transferring worked out space as the seam burns out: ABCD – the area of working seam; 1, 2 and 3 rows of exploitation wells; α, β and γ - wells in a row; ● - key well; ○ - water-intake well; ● - exploitation well, converted for water-intake from horizontal water-intake channel; ▬ - burned out space of working horizon (worked out cavity in the form of a horizontal gallery).

After the heat transfer agent is brought to the surface, it is conducted to a power installation. The installation is arranged according to the configuration of the area of the exploited coal horizon, with the calculation that the extension of the pipelines does not exceed the distance when heat losses lower the condition of heat transfer agent. After the heat transfer agent is worked out in the energy installation, it is transferred to be purified and then is pumped back into the water-bearing horizons through key wells, arranged at a distance of no less than twice the radius of the influence of the outermost water intake.

The technological scheme of underground coal gasification and underground coal burning uses wells of different purposes and constructions: exploitation, water-intake and water-injection wells, draught key wells and technical wells. The proposed construction of wells for water reflects the general requirements for such excavations which should guarantee: 1) the possibility of obtaining the calculated used water rate; 2) secure isolation of exploited water-bearing horizon; 3) setting of a filter string within the water-bearing horizon; 4) long operational term and possibility of repair and renewal of the well (Belickiy, Dubrovskiy, 1974).

Despite the relatively insignificant depths (about 100 m), a multi-string well is suggested. To prevent the wellhead washing out, collapsing, and to retain its vertical construction, it is recommended to use a conductor-string. It will also prevent contaminated surface water from getting into the well. The distance between the conductor and the wall of the well is cemented or isolated with clay. Intermediate strings overlap intermediate water-bearing horizons, uncovered during the drilling, and also strengthen well shaft bracings (telescopic exits of casing pipes). In the considered geological conditions, sinking is impossible without additional bracings; between the conductor and the exploitation string, an intermediate (technical) string is lowered.

The final diameter of the water-intake well is set depending upon the chosen diameter of the filter, overall dimensions of the pump, and the well`s debit. The inner diameter of the exploitation string, which contains a submersible pump, is larger than the diameter of pump by 15-40 mm. The final diameter of the drilling (water-intaking part of the well) is suggested to fall within a range of about 250-400 mm, because such wells are considered highly-efficient (more than 50 m3/hour). The diameter of well casings can range between 114 mm and 508 mm, but such conditions require the diameters of the exploitation string to fall between 114 mm and 219 mm (Tugay, Ternovcev, 1980*)*. To prevent casing pipes and clutches from being damaged during their descent, the lower part of the string should be fitted with a casing shoe of 300 – 500 mm.

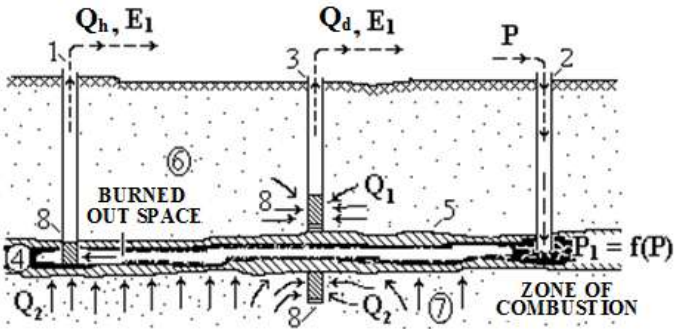

Figure 6. Longitudinal schematic section of underground part of UCC module after the formation of horizontal channel: 1 – key drafting well of n row; 2 – key drafting well (n + 1) row; 3 – water intake well; 4 – exploited part of coal seam (horizontal water intake channel); 5 – clay; 6 and 7 – above- and under-coal horizons, respectively; 8 – intaking part of water intake; *P* – drafting pressure; P_1 – pressure of gas in the seam; Q_1 and Q_2 – water from above- and under-coal horizons, respectively; Q_d – debit of vertical water intake; Q_h – debit of horizontal water intake channel; E_1 – thermal energy of mobile heat transfer agent.

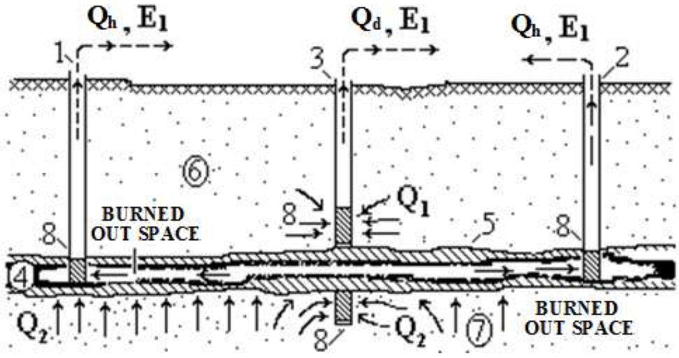

Figure 7. Transversal schematic section of underground part of UCB module after the formation of horizontal channel: 1 - α – key well of n row; 2 – β – key well of n – row; 3 – water intake well; 4 – exploited part of coal seam (horizontal channel); 5 – clay; 6 and 7 – above- and under-coal horizons, respectively; 8 – intaking part of the water intake; Q_1 and Q_2 – water from above- and under-coal horizons, respectively; Q_d – debit of vertical water intake; Q_h – debit of horizontal water intake channel; E_1 – thermal energy of mobile heat transfer agent.

The arrangement of the face zone around the well is chosen with consideration of the geological characteristics of the productive seams and water-bearing horizons in the roof and floor part. It is advised to drill below the floor of a productive coal seam, lowering the exploitation string by 4-5 m in the under-coal horizon, and to perforate the wall of the pipe after it has been cemented and the cement ring. The arrangement of the face zone around the well is done with a shank or with a filter, lowered directly on the exploitation string.

The arrangement of the face zone with the face unfixed by a casing pipe provides the best conditions for the heat-transfer agent to flow in the well, for it has maximum surface of connection with the water-bearing horizon. Such construction is recommended for use in wells drilled in homogenous seams, which have no clayey interlayers. It can contain filters of different construction: metal shank-filters, metal-ceramic, sandy-plastic and gravel filters. The later are preferable as they can be easily replaced.

For other cases, we suggest arranging the face zone with total cementing of the well`s floor and perforation of the casing string, although such construction worsens conditions of the flow. For maintaining the strength of the casing pipe, the number of perforation holes should not exceed 40-50 per 1 m of its length.

Perforation is a necessary element which allows hydrodynamic connection of the productive horizon with the well, but its significant disadvantage is damaging the cement stone, which causes premature flooding of wells. The choice of perforation type should be made taking the particular conditions into consideration, for each type is characterized by a particular penetration depth and configuration of holes. Uncovering with no perforator, which is done using a filter with acid-soluble plugs is not recommended due to the great thickness of the water-bearing horizons.

After lowering the exploitation string and cementing the upper end of the casing pipes, the wellhead should be fixed with a surface wellhead for encapsulation of the voids between the pipes, and for suspension and fixating of casing strings. Flange conjunctions are unified and could be installed on every type of string heads. We suggest installation of slip hanger suspension of pipes, which is easy to set. The exploitation string is fastened with wedges and goes through a packer with wrapper rings.

The construction features of connections make it possible to hang the intermediate and exploitation strings on slips and control the pressure in the inner pipe (Belickiy, Dubrovskiy, 1974).

Water-heating wells are drilled for pumping water used in the installation and purified water back into the water-bearing horizon for circulation of the mobile heat-transfer agent. The construction of the key well in most cases does not differ from the construction of water-intake wells. Moreover, as the drilling front moves some water-intake wells will become key wells. When inner-contour water flooding and pattern water flooding occurs, arranging water-intake wells for water pumping is normal. Existing constructions of the key well suggest pumping water through tubing strings, lowered with a packer and an anchor. The space which is above the packer should be filled with a liquid that is neutral to metal. The face should have a filter thick enough for pumping the planned amount of water, a sump, to a depth of less than 20 m for accumulation of mechanical suspended solid particles (Vdovin, 1980). It is reasonable to use inserted (replaceable) filters which can be periodically lifted from the wells and be cleaned. Wellhead assembly of the key well is set for water supply and regulating the amount of water which flows into the well, for different technical procedures of flushing, tapping, processing, etc.

Another group of wells include gas-injection wells, gas collecting wells and ventilation wells. Unlike water wells, they are able to work in the conditions of heightened pressure. On the one hand, the constructional arrangement is similar to the abovementioned wells, but on the other hand, they adjust the construction for technology of gas output and oil production. It should be also considered that the energy consumption of gas injection will be significantly higher due to its density which is smaller than water (by 7-15 times) (Charniy, 1948), so for maintaining the necessary pressure in the combustion face, the wellhead should be equipped with a sort of production tree. Moreover , an acceptable level of 10% of pressure lost can be achieved only by accurate control of hermiticity of the ground-surface pipeline and uniformity of gas movement in the seam. Breakthrough of gas into the well along the areas with high penetrability is the most common complication in this system.

The element of control can be a production tree, and perform the following functions: hermetization of the annular space between the casing string and lifting pipes; 2) directing the gas liquid mixture`s movement; 3) suspension of equipment installed at depth; 4) creating back-pressure in the wellhead; 5) conducting research, tapping and other technological operations (Belickiy, Dubrovskiy, 1974). For maintaining the set operation regime, crane devices or sliding locking devices should be used.

The necessary equipment for arranging gas wells should include packers for separating certain parts of a well, for example the area around the face zone and the other parts. In this case, they perform different functions: protecting the casing string from being affected by the seam pressure, contact with aggressive seam solutions, direction of drafting pressure into the combustion region, increasing the coefficient of efficiency and the possibility of operating the above- and under-coal horizons separately. To ensure the fixation of a packer at a certain interval, an anchor is required.

Inner-seam combustion heat source can be achieved using burners of different construction, electric and voltaic arc, detonation or direct ignition (Kolokolov at all, 2000). Taking to consideration the significant water penetration into rocks, the combustion face should be hermetically isolated before combustion, and for easier combustion, it should be dried by heated air. The most efficient way is electric lighting or detonation, which use the same equipment as perforation. Burners require more complicated equipment, and the direct ignition is of low efficiency due to instability of its source and complicity of its transfer to the face.

After ignition, oxidant-air or oxygenic solution is provided under pressure to the same well for maintaining the combustion. Its construction is similar to the construction of an exploitation water-intake well, and the main difference is in the quantitative parameters; the diameter of the well`s shaft and of the casing pipes, productivity of the pumping equipment, etc.

Gas injection into the seam is performed by high-pressure compressors. In the conditions of forward combustion`s influence upon the seam, the face should have a key well of combustion source and the face should later be moved towards the exploitation well. The low-pressure compressors provide the air to the high-pressure compressors, which pump it into the seam. Initiation (ignition) of combustion is performed by electric heaters, lowered into the well on a wireline. The setting pack includes a block of measuring and regulation of 8 wells. The final decision in choosing the pumping equipment depends upon particular conditions and at this stage of study the following division can made: for gas products – compressors, for liquid products – pumps.

A significant element of technical equipment is ground-surface or underground group pumping stations (GPS). The first are pump stations in the usual sense. Their parameters are defined by the following factors: 1) total water-intake (or acceleration capacity of key wells), arranging the total efficiency of GPS; 2) the pressure of pumping/gas injection (pressure when wells accept the provided amount of water/gas, plus the loss for friction, local resistance, overcoming the difference in geometrical heights); 3) number of activated wells, which is defined by dimensions of GPS. Every two operating pumps should have one pump in reserve.

Conclusions. Underground group pumping stations are electrical centrifugal pumps of high efficiency ECIMSP (electrical centrifugal installations for maintaining seam pressure). They can be lowered into subartesian wells and pump the water or inject the water into the seam at the same time. Because ECIMSPs are larger than the usual diameter of exploitation wells, their usage requires construction of special wells (depth to 30 m, diameter 700 mm), which is also possible for the described energy-module. Serial ECIMSPs could be set in a pit or a simple well with a cement bridge at a depth of 30-40 m. The water is conducted to the annular space between the walls of the well and the string or is withdrawn from the water-bearing horizon. For the purposes of cyclic flooding of the area being mined, the usage of ECIMSP is the best choice, because it allows pumping the heat-transfer agent and injection of the water for heating using the working of the same water-intake.

References

Charniy I. A., 1948. Podzemnaya gidromehanika [Underground hydromechanics]. Gostichizdat, Moscow, 196 p. (in Russian).

Dikiy N. A., 1989. Energoustanovki geothermalnih elektrostanciy [Power generating systems of geothermal power plants].High school, Moscow, 198 p. (in Russian).

Frank-Кameneckiy D. A., 1987. Diffuziya I teploperedacha v himicheskoy kinetike [Diffusion and heat transfer in chemical kinetics]. Nauka, Moscow, 502 p. (in Russian).

Kolokolov O. V. (Eds), 2000. Theoriya I praktika termokhimicheskoy tekhnologiyi dobichi I pererabotki uglya [Theory and practice of thermo-chemical technology of booty and processing of coal]. Typography of National mining University, Dnepropetrovsk. 281 p. (in Russian).

Maloyan A. V., Maloyan E. A., 1968. Prakticheskie rascheti po bureniyu skvazhin na vodu [Practical calculations for drilling wells for water]. Nedra, Moscow, 203 p. (in Russian).Zholudiev S. V., 2004.

Materials of the international investment scientific and practical conference "Production of synthetic motor fuel from the coal of the Donetsk basin, as a component Energy security of Europe ", Luhansk, p. 24 - 25. (in Russian).

Raschet gazodinamicheskogo rezhima podzemnogo generator [The calculation of the gas-dynamic mode of underground generator]. Ukrainian coal, 11. 33 – 34. (in Russian).

Sadovenko I.A., Zholudiev S.V., 2005. Geotechnologicheskie I ekologicheskie aspekti regulirovaniya processa gazifikaciyi I szhiganiya uglya na meste ego zaleganiya [Geotechnological and ecological aspects of regulation of the process of gasification and coal combustion at the site of its occurrence].

Tugay A. M., Тernovcev V. E., 1980. Vodosnabzhenie. Кursovoe proektirovanieие. Uchebnoe posobie dlya VUZiv [Water supply. Course design. Textbook for high schools]. Visha shkola, Kyiv, 208 p. (in Russian).

Vdovin Y. I., 1980. Vodosnabzhenie naselennih punktiv na severe [Water supply of settlements in the north]. Stroyizdat, Leningrad, 134 p. (in Russian).

Zholudiev S. V., 2004. Raschet gazodinamicheskogo rezhima podzemnogo generator [The calculation of the gas-dynamic mode of underground generator]. Ukrainian coal, 11. 33 – 34. (in Russian).

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