

On the formation of a mine-based energy resource complex

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Abstract. The paper represents the analysis, which has helped to determine tendencies of the formation of energy resource complex based on the available mining facilities. The approach helps prolong operating life of the mine with the depleted balance reserves or the one being under abandonment. The proposed technologies of generator gas production by anaerobic digestion of organic raw material in the methane-tanks as well as other approaches to the combined formation of new energy systems make it possible to reorient the mine operation. The approach is extremely important for rather depressed mining regions as it helps solve the problem of social strain. Formation of the joint power and chemical production allows both improving economic expediency and preventing negative ecologic impact on surface and underground mine environment. The proposed tendencies make it possible to outline further issues to be highlighted in the following authors' studies.

1 Introduction

Current needs of the humanity in resources and energy are growing rapidly. That situation required creating new energy sources and technologies for their production. Innovative tendencies in the development of modern technologies in geoenergetics are necessary to get renewable energy sources and to develop secondary resources [1 – 4]. Energy-saving potential in Ukraine accounts for about 40% of the total energy market. Taking into consideration both current technological development and growing economic potential, volume of the renewable energy sources in Ukraine is 1.5 – 2.0 bln tons of reference fuel being by 5 times higher than the total national energy supply [5 – 8]. In this context, development and implementation of the renewable energy sources is at its initial stage while energy generation from those sources is only about 1.6% of the total world one [4, 9 – 10].

Considerable potential of the energy and secondary resources is accumulated within the technogenic underground and surface mine areas [11 – 15]. Transportation of the resources must be considered too [16 – 18]. Use of that potential is first of all connected with the mining sites and mines being either in stagnation or closed [19, 20]. Those technogenic territories are meant to be used for the development of mine energy resource complex (MERC) to produce energy and get secondary resources for the efficient and safe utilization of technogenic space of the mining enterprises [21 – 24].

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Formed within the technogenic mine area, the enterprises for generating electric and thermal energy and getting industrial products from the secondary resources and renewable energy sources consist of such modular and mobile segments of the complex low-waste production as [25, 26]:

1. Utilization of kinetic energy of wind flows of underground space, surface facilities, and waste dumps to generate electric energy;
2. Generation of electric energy by using kinetic flows of the underground space water;
3. Generation of electric energy by using renewable energy sources in terms of solar-wind energy complexes;
4. Recuperation of the heat of rock mass, ground and waste water, and waste dumps;
5. Getting valuable elements from the secondary resources by implementing the technologies of heap, well, and block leaching;
6. Utilization and processing of organic waste with the help of gas generator plants within the underground space and purification and processing of the gasification products in terms of surface complex of the industrial mine site.

2 Development of technologies during the formation of energy resource complex

Previous studies paid considerable attention to the cogeneration technologies of the energy material production in terms of the operation of mining enterprises [9, 15, 21, 22, 27 – 29]. Possibility to apply heat pump generation, wind and solar energy generation, thermal energy use, use of differences in air flow temperature and pressure in the development mine workings, shafts, and on the surface as well as other technological improvements are analyzed in detail [30, 31].

Special attention is paid to the economic, environmental aspects of mining and geological activities, waste processing and development of technogenic deposits in terms of mining areas [32 – 36].

The use of software in establishing the geomechanical characteristics of the rock mas with examples of practical realization is described in the following works [27, 37 – 40]. In works [41 – 43] special attention was given to combine different methods of geomechanical problems solving. This paper considers the possibilities of innovative technological improvements while forming the mine-based energy resource complex.

2.1 Wind generation plants

Cone-shaped waste dumps, covering the area of 50 – 1242 ha and being 20 – 100 m high with average height value of 49.5 m, are formed from the barren rock on the surface of the mine allotted territory [44 – 46]. In terms of those dumps, average natural air flow velocities reach 5.5 – 10.4 m/s; maximum velocities reach 15.6 – 22.7 m/s.

Special-purpose areas are formed on the prepared terricone surface to mount wind generation plants which are connected in a wind generation system (WGS) taking into account the conditions of wind energy capacity and mine dump unsuitability for the development [31]. Fig. 1 represents the technological scheme of such an energy system based on the mine dumps.

To utilize the energy of technogenic flows and wind and to mount the wind energy plants, facilities of the industrial mine site are used: roofs, mechanical floors, and areas of technogenic landscape of mining enterprises where air flows create the injection effect.

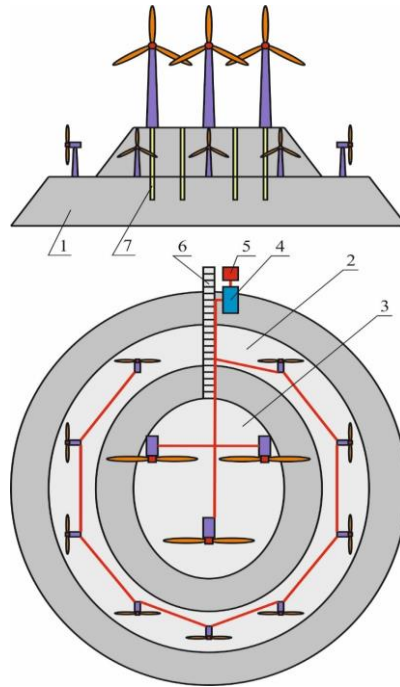


Fig. 1. Technological scheme of the energy system arrangement on the mine dumps basis: 1 – cone-shaped dump of barren rock; 2 – area to mount wind generators with the wind wheel diameter of $D_{w.g} = 2.5 - 3.2$ m and capacity of $N_w = 1.1 - 3.9$ kW; 3 – area to mount main wind generators with the wind wheel diameter of $D_{w.g} = 10 - 18$ m and capacity of $N_w = 9.6 - 50.4$ kW, covered with solar collectors; 4 – unit to control power contactors and chains; 5 – unit to sent the generated power to the electric network; 6 – monorail road; 7 – tubular thermal accumulator.

2.2 Use of water space

Ground water of the technogenic mine space is the potential renewable energy source. Accumulation of the considerable water volumes within the upper levels of the underground space favours accumulation of the potential energy of this energy carrier. Water pass throughout the wells, which lower mouths are equipped with hydroturbines with generators, transforms the kinetic energy of water flows into the electric one. Such a mine micro-HES consists structurally of the pass well reinforced with pipes; hydroturbine; generator; automatic systems to stabilize the output pressure and the flow start and stop; and a series of stop and ballast valves and other elements [21, 25]. Increase in the energy capacity of the flow will depend on the water level heads. Under those conditions, the output of hydroturbines is determined as follows:

$$P_t = \gamma \frac{QH}{\Omega} \eta_t ,$$

where γ is weight of the water volume unit, kg/m^3 ; Q is water consumption, m^3/s ; H is operating head, m; Ω is angular rotation frequency, rad/s ; η_t is overall turbine efficiency, %.

The produced electric energy will be used for the MERC needs. Operating mode of the underground hydroelectric stations will depend on the peaks of electric energy consumption. In terms of maximum energy consumption, the system generates electric power while unloading the mine working from the accumulated water volumes.

Collectors in the mine working of the upper level are filled by means of gravitational component; additional water volumes come from the lower levels. Water supply from the lower-level water collectors to the storage basins takes place within the period of the lowest energy consumption (Fig. 2). Table 1 represents calculation for one energy hydrounits of the underground hydroelectric station.

Table 1. Basic parameters of energy hydrounits of the underground hydroelectric station.

Parameter	Basin volume, thous. m ³	Diameter of a drainage well, mm	Incline angle of a well, degree	Capacity, m ³ /s
Value	6.4 – 17.2	280	80 – 85	1.5
Water head, m	Hydrounit power, kW	Hydrounit operation per year, hour	Working capacity per year, mW	Efficiency of a hydrounit, %
58	776.7	2500	1942	0.91

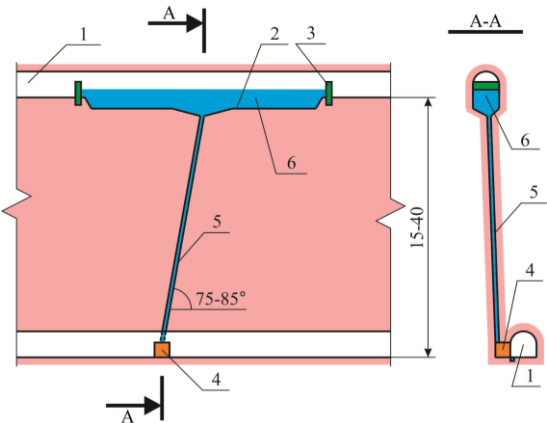


Fig. 2. Scheme of the underground HES to store the energy potential of the mine water: 1 – mine roadway; 2 – water collector; 3 – water-resistant stopping; 4 – hydroturbine chamber; 5 – well; 6 – mine water.

2.3 Systems for mineral raw material leaching

Leaching methods improves considerably the economic, social, and ecological conditions of deposit mining as there is no need to construct mines [47 – 52] or open pits [53 – 58] as well as concentration plants and stockpiling of ore waste after its mining and processing. In this context, preservation of the major share of water resources within the deposit area plays an important role as well [59 – 61]. Essential social advantage of leaching methods is the overall change in the conditions, nature, and productivity of the operations, possibility of total mechanization and automation of a mining process, rational use of surface and underground resources [62 – 64]. Underground leaching technology excludes the staff presence in the mine workings in terms of artificial ventilation and lighting. Moreover, it does not require hard manual work; it increases one-worker productivity by 1.6 – 1.7times, comparing to the open-pit mining, and by 2 times in terms of underground ore mining [65, 66].

Analysis of the uranium production development opens possibilities for the application of advanced technologies and mining techniques by means of heap, block, and well leaching for other types of ores and resources, which are concentrated in the dumps of barren or low-grade ore and technogenic deposits [67, 68] with the determination of directive values as for each mining method according to the characteristics of the specified raw material (Fig.3) [69, 70].

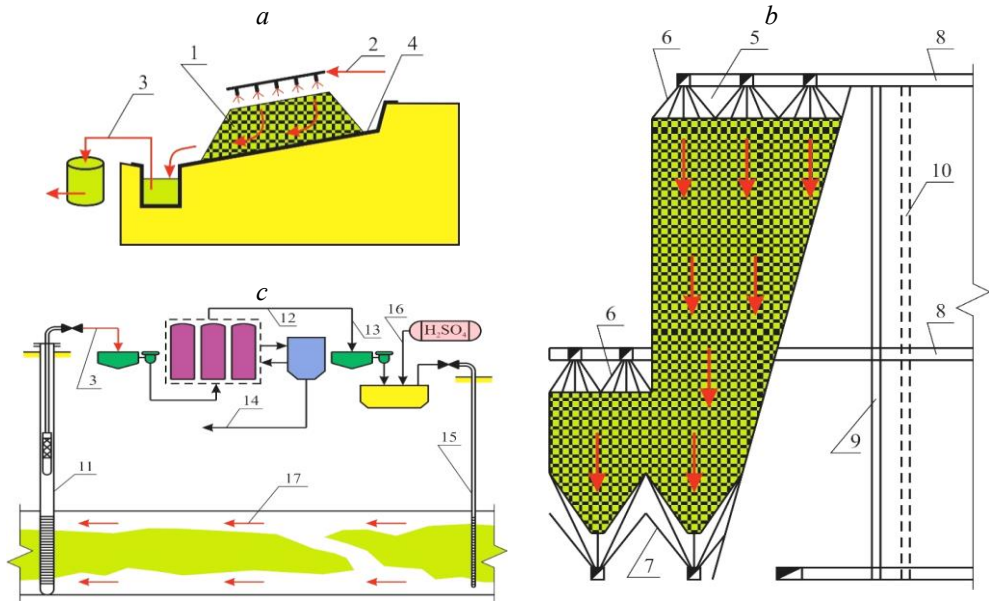


Fig. 3. Technological schemes of heap (a), block (b), and well (c) leaching of metals and elements: 1 – ore; 2 – leaching solution; 3 – product solution; 4 – impermeable layer; 5 – entry pillar; 6 – irrigation well; 7 – collecting wells; 8 – crossdrift; 9 – ore chute; 10 – hoisting; 11 – pump well; 12 – metal extraction from the solution; 13 – solution; 14 – metal concentrate; 15 – injection well; 16 – increasing concentration of H_2SO_4 ; 17 – ore leaching in the deposit.

Basing on the data by the Ministry of Energy of the USA, uranium ore resources with the production cost of 33 USD/kg (oxide content is $U_3O_8 = 0.05\%$) will increase by 9 mln t (uranium content in ores suitable for open-pit and underground development should be 0.12 and 0.22% respectively); in case of production cost being 66 USD/kg, the increase will be by 56.3 mln t (in terms of the same uranium content in the ore); as for traditional mining methods, uranium content in the ore of that cost category should be not lower that 0.08%. The initial capital costs for the underground mining complex (operational unit and plant to process solutions) with the capacity of 225 t of U_3O_8 per year may be from USD 8 mln up to USD 16 mln, including a share of research and production plants. The staff number is 60 – 100 people while the traditional mining and metallurgical complex involves 300 – 500 people. That is one more proof of the considerable potential while forming a mine-based energy complex to product that energy commodities.

3 Development of the technological segments of a mine-based energy resource complex

Technological segments of the MERC located within the industrial mine site provide the processing and utilization of secondary resources (solid and liquid organics, wastes of combustible and lubrication materials, sewage runoff, and organic waste). The segment is the combination of the technology for utilization and production of the gasification products and biogas [8, 71] making it possible to provide quality and mobility of the segment products (Fig. 4).

Gas generators for thermochemical processing and utilization of organic waste have become rather popular in the power generation sector, i.e. the process of gasification-burning at the temperatures of 800 – 1500 °C.

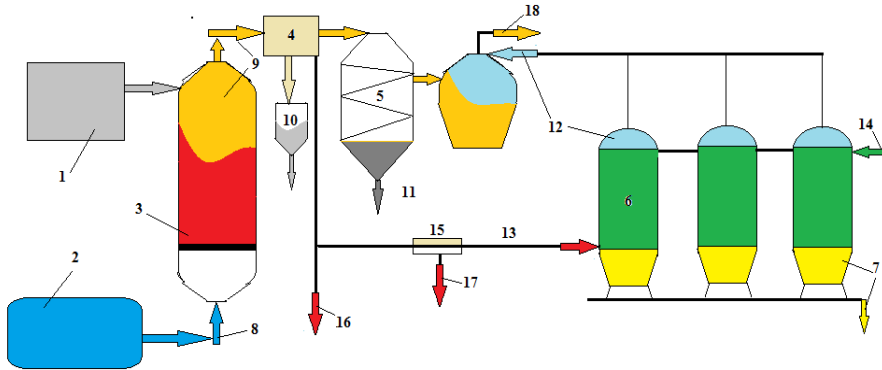


Fig. 4. Scheme of the MERC gas segment to produce generator gas by the gasification of wastes and biogas with the help of anaerobic digestion of organic raw material in methane-tanks: 1 – unit to supply organic raw material; 2 – unit to supply and prepare blowing; 3 – gas generator; 4 – unit for generator gas cooling; 5 – unit to purify generator gas; 6 – biogas plants; 7 – organic fertilizer; 8 – direction of blowing supply; 9 – direction of generator gas output; 10 – condensate; 11 – solid residue; 12 – direction of the generator gas output; 13 – heat supply for biogas plants ($T = 30 - 500\text{ }^{\circ}\text{C}$); 14 – direction of raw material supply; 15 – intermediate coolant; 16 – heat supply for the MERC needs ($240 - 425\text{ }^{\circ}\text{C}$); 17 – heat for the MERC needs ($172 - 368\text{ }^{\circ}\text{C}$); 18 – supply of synthetic combustion gas for the MERC needs.

According to the analytic data, capacity of surface gas generator during the gasification of organic waste will be 2.17 – 3.82 thous. of m^3/hour with the composition of combustible gases (CH_4 , H_2 , CO) of 26.8 – 63.1% and calorific value of 3.4 – 9.2 MJ/m^3 .

A biogas plant consists of six methane-tanks with the capacity of 216.5 – 423.1 m^3/hour with the methane composition of $\text{CH}_4 - 52.4 - 76.9\%$ with calorific value of 15.8 – 21.3 MJ/m^3 , and following fertilizer output: liquid – 2.8 – 5 t/day, solid – 4.8 – 10.2 t/day. Indices of changes in qualitative and quantitative parameters of synthesis gas during gasification in terms of the added methane component of biogas are shown in Fig. 5.

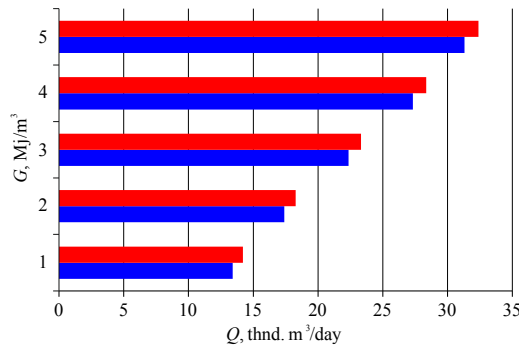


Fig. 5. Changes in the indices of quantitative and qualitative parameters of the combustible syngas components (CH_4 , CO , H_2) in the MERC gas segment in terms of biogas adding to the generator gas depending on the blowing type during gasification: 1 – air; 2 – vapour; 3 – carbon-oxygen; 4 – vapour-oxygen; 5 – oxygen.

Synthesis gas generated in the segment may be used as the energy product, chemical raw material, and the material for electric and thermal energy production. The number of surface gas generators and biogas plants within the gas segment of the MERC complex will depend on the available raw material and needs of the complex in gas and energy product.

4 Conclusions

Formation of the mine-based energy resource complex is one of the method to prolong the operating life of mining enterprises. Moreover, according to the studies, its structure and composition will depend on mining-geological and hydrological conditions; technical and engineering situation; climate of the territories; geographical location of the infrastructure etc. Apart from the considerable industrial importance, such an approach solves the important environmental problem as well. Mining of technogenic deposits, waste utilization, and development of the additional energy sources make it possible to highlight the economic component.

On the other hand, it is also possible to systematize basic tendencies of the functioning of a mine energy resource complex, which involve:

- utilization of kinetic energy of technogenic wind flows of the underground space, surface facilities, and rock dumps to generate electric energy;
- generation of electric energy by using kinetic flow of the underground-space water;
- generation of electric energy from the renewable energy sources by using solar and wind energy generation complexes;
- recuperation of the heat of rock mass, underground and sewage water, and rock dumps;
- getting valuable elements from the secondary sources by implementing the technologies of heap, well, and block leaching;
- utilization and processing of organic waste, involving gas generator plants within the underground space, and purification of the gasification products in terms of surface complex of the industrial mine site.

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