https://doi.org/10.33271/nvngu/2022-4/084

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ECOLOGICAL ESTIMATION OF INSTALLING GEOTHERMAL SYSTEMS ON TERRITORIES OF CLOSED COAL MINES

Purpose. To conduct an ecological estimation of calorific value for two alternative energy sources: traditional coal combustion and heat recovery from geothermal modules.

Methodology. The methods of comparative analysis for environmental impact of energy production due to coal use in comparison with the alternative of using geothermal modules and heat pumps are used. The technique for gross emissions estimation from coal combustion processes for the conditions of Donbas mines and equivalent volumes of potential energy from heat pumps is applied.

Findings. The ecological estimation of geothermal modules as alternative sources of thermal power on a territory of liquidated mines of Donbas is performed. A comparative estimation of the potential for thermal energy production by coal combustion and using geothermal modules is performed based on the analysis of average characteristics of coal in the Donetsk basin, as well as a calorific value of fuel. The parameters necessary for technical and economic estimation of the efficiency of implementing geothermal modules for providing alternative heat supply are calculated.

Originality. For the first time, a comparative estimation of the potential for thermal energy production by coal combustion and using geothermal modules has been performed based on analysis of average coal characteristics in the Donetsk basin, as well as a calorific value of fuel. Equivalent mass of coal, which can be preserved due to the operation of geothermal modules for conditions of liquidated mines of Donbas and mines of Selydove group, is calculated according to the values of additionally obtained thermal power of geothermal modules ΔP_{th}.

Practical value. According to the calculations, the amount of geothermal power U_{th} from mine water in terms of equivalent mass of coal during the heating season is estimated as $7.63 \cdot 10^6$–$1.76 \cdot 10^8$ MJ for open geothermal systems based on mine water discharge in Donbas; $0.49 \cdot 10^6$–$0.57 \cdot 10^6$ MJ for modules of geothermal circulation of Selydove group of mines. It is proven that the implementation of geothermal modules for thermal energy production in operating and closed coal mines is a promising environmentally friendly technology with long-term technological potential, economic and social benefits.

Keywords: *geothermal modules, thermal energy, coal combustion, liquidated mines, alternative heat supply*

Introduction. The current economic and energy crisis, dependence on imports of primary fuel and energy resources raises the issue of their economic and rational use. Global trends in energy development indicate a decrease in coal production and consumption against the increasing share of alternative power sources. In this regard, geothermal energy looks like one of the priority directions for implementing "green" technologies, which meets the global goals of sustainable development of the United Nations (Combating Climate Change, Innovation and Infrastructure, Clean Energy, Clean Water).

Ukraine's state policy on energy conservation makes a focus on significant expansion of the use of non-traditional and renewable energy sources, taking into account the environmental component. In accordance with the provisions of the "Energy Strategy of Ukraine for the period up to 2030", non-traditional and renewable energy sources are given important attention.

In the coming years, the savings of traditional fuel and energy resources at the level of 8–10 % of their total consumption should be ensured. This can save significant amounts of traditional energy and financial expenditures from the state budget for their import [1, 2]. Also, this way will potentially meet the energy needs of Ukraine with minimal costs for the maintenance and operation of the fuel and energy complex, significantly improve the environmental situation and allow predicting the prospects for its long-term development in the energy sector.

Electricity production, cold and heat supply of various purposes, concomitant removal of valuable industrial components from water can be achieved only through the use of geothermal energy and related products.

Trends in geothermal energy development. Nowadays, the energy production in the developed countries is formed under the influence of two main aspects. The issue related to ecology and environmental protection is becoming more important, which makes it necessary to develop waste-free and environmentally friendly technologies in the energy sector. This forwards the search for new renewable and resource-saving sources and technologies of energy production.

The second aspect is the constant growth of energy demands with increasing limited reserves (natural gas, coal, etc.). Therefore, alternative solutions in the form of renewable energy sources, namely geothermal, began the fast development.

Geothermal energy in some countries (Hungary, Iceland, Italy, Mexico, New Zealand, Russia, USA, Japan) is widely used for heat supply, electricity generation and others. Thus, in Iceland, the Earth's heat provides 26.5 % of electricity generation. In the United States, 19 geothermal power plants with a total capacity of 1,300 MW are located in the Valley of Geysers. The world's most powerful Heber geothermal plant with the capacity of 50 MW was also built in the United States. According to various forecasts, the capacity of geothermal stations by 2030 will increase to 40–70 million kW. Nowadays, 58 countries use the heat of their geothermal resources not only for electricity production, but also directly in the form of heat: for heating baths and swimming pools – 4 %; for heating – 23 %; for heat pumps – 12 %; for heating greenhouses – 9 %; for water heating in fisheries – 6 %; in industry – 5 %; for drying of agricultural products, melting of snow and conditioning – 1 %; for other purposes – 2 % [3].

The main advantages of geothermal technology are inexhaustibility of power, independence of electricity output from the season and environmental conditions, lower emissions of carbon dioxide (CO_2) and carcinogenic products into the atmosphere, independence from world energy prices. An important feature of geo-electric stations (GeoES) is practically constant electrical and thermal load throughout the life cycle (capacity factor), which reaches 92 % (for comparison: in nuclear energy – 90 %, coal – 85 %, terrestrial wind – 38 %, solar – 20 %) [4].

Today, about 90 countries around the world have significant potential for heat and electricity production, and 24 of them are using geothermal technology in practice. The total capacity of existing GeoTPPs (thermal) and GeoPPs (electric) in the world is about 85 GW, about 15 % of which is used for electricity production and the rest – for heat production. In 2014, the global electricity production at power plants exploiting planet heat amounted to 73.6 billion kWh per year, which is equivalent to saving about 25 billion m^3 of natural gas [5] and reducing of 148 million tons of CO_2 emissions.

Today, about 80 GeoES are operated in Europe, for example in Italy, Iceland and Turkey that cover leading positions in electricity generation. Until the beginning of 2015, geothermal power plants with a total capacity of 12.64 GW operated in the world, the largest increase in capacity in recent years was observed in Kenya, the United States, Turkey, New Zealand and Indonesia. The world's largest capacity of GeoES belongs to the United States and amounts 3.45 GW (5.6 GW according to the forecast for 2020), the top three countries also include the Philippines (1.87 GW) and Indonesia (1.23 GW; projected – 3.5 GW in 2020) [2].

By 2030, the global geothermal electricity market is forecasted to grow rapidly, especially in Iceland, East Africa, Central and North America, the United States, Japan, and New Zealand, where conditions are the most favorable for its development. By 2030, the total capacity of such power plants will have reached 25.0 GW, and by 2050 – 75.0 GW [2, 7].

Compared to global trends, Ukraine has significant geothermal energy resources. Deposits of thermal groundwaters suitable for industrial development are located in some regions of Ukraine namely in Zakarpattia, Mykolaiv, Odesa, Kherson regions and in the Autonomous Republic of Crimea. The annual technical potential of this type of energy in Ukraine is estimated as equivalent to 12 million tons of conventional fuel, which opens wide opportunities for the development of geothermal energy in the country [3].

According to expert estimates, the theoretically possible capacities of underground power sources in Ukraine exceeds 40 GW in the capacity, and the economically feasible potential is comparable to 10 GW [5], which is equivalent to 10 units of modern nuclear power plants. In Ukraine, the most promising territories for the development of geothermal industry are Transcarpathia, Sumy, Chernihiv, Kherson, Donetsk, Luhansk and Poltava regions.

There are also good prospects for the application of geothermal electricity. The regions with the minimum acceptable thermal water temperature (from 90 °C) and sufficient flow are Transcarpathia and Prykarpattia (over 550 million m^3 per year), Chernihiv, Sumy and Kherson regions, where development of the network of small capacity GeoES (0.05–5 MW) is reasonable. In this case, it is reasonable to use binary cycle installations with low-boiling working fluid. In Transcarpathia, where the temperature of rocks is 230–275 °C at the depth of 6 km, and 90–100 °C – at the depth of 2 km respectively, as well as in Kharkiv region (Izyum site) the development of GeoES with an electric capacity of 50 MW may be justified [4].

It is also important to find alternative energetic resources in the former and old mining regions, where environmental problems are becoming more acute due to the long-term industrial activity with limited resources, which in fact should be the basis for environmental protection. The range of environmental problems associated with man-made environmental impact due coal mining and further processing technologies varies for different mines and regions.

Donetsk coal basin is considered as the perspective territory for the use of low-potential geothermal resources. The minimum technologically acceptable temperature of rocks for the purposes of electricity production with existing technical capabilities is 150 °C. This temperature of rocks within Ukraine is recorded at depths of 3–10 km (in Donbas area – 4–6 km). According to the estimates, the resources of geothermal energy in the most promising areas in Ukraine vary in the depth range of 3–10 km and are evaluated as 15 trillion tons of conventional fuel (TCF), and up to 7 km – around 3 trillion TCF respectively. In the Dnipro-Donetsk basin and Donbas, the forecast resources of petro-geothermal energy in the range of depths of 4–10 km are 9 trillion TCF, including up to 7 km – 1.9 trillion TCF. The density of resources at technologically accessible depths of 4–5 km is about 7 million TCF [8].

Modern technological schemes and equipment for power extracting differ depending on the site conditions. The paper [9] presents particular advantages, technological and ecological aspects of planet natural heat application from coalfield deposits of the Central-Eastern part of the Dnipro-Donetsk depression (Ukraine). The developed and economically justified potential of oil and gas wells in the experimental zone gives a pattern of utilization of underground heat simultaneously with main technological scheme.

Technological parameters and geometric topology of geothermal heat exchangers are also modified. For example, in [10] the authors proposed approaches to improving the designs and network structures for heat-transfer media circulation in the bottom-hole space of oil-and-gas reservoirs. It is emphasized that the most efficient use of thermal waters is achieved via an integrated approach, which provides the most complete cycle for application of water thermal potential in a number of technological processes, including residual and associated extraction of valuable industrial components from mine water.

Upon completion of underground operations and consequent closure, majority of coal mines are flooded and the temperature of mine water can be utilized in geothermal recovery applications with heat pump installations. So, in winter the low-capacity heat of mine water is used for heating purposes, and in summer the process can be reversed and the heat transferred back to the underground storage to provide effective cooling [11].

Such mine water heat storage capacity reveals an effective geothermal potential for alternative power engineering [12] that was analyzed for the conditions of coal mines in the Austrian Central Coal Basin (ACCB) in comparison with the reduction of carbon dioxide emissions due to the use of fossil fuels. The research results show a potential capacity of 50 MWt and possible power generation of 112,000 MWh/year with an electric production of 14,000 MWh/year. As a result, the reduction of CO_2 emissions can achieve up to 80 % in comparison with conventional fuel sources.

Geothermal energy helps to reduce a mine's environmental impact and Greenhouse Gas (GHG) emissions and improves its reputation within local communities, while "greening" its portfolio and contributing to sustainable development and the process of acquiring and retaining a social license to operate [13].

In 2050, the potential growth of the Earth's natural heat exploiting in Europe will achieve electricity production level of around 100–210 TWh/yr and geothermal heat usage of 880–1,050 TWh/yr. This sector will contribute 4–7 % to overall power generation. European geothermal capital market could increase to 160–210 billion US$/yr [14].

As a renewable source that is independent from seasonal and climatic conditions, planet heat is expected to have a significant role in the decarbonization of the power generation sector and thus in the transition to a low-carbon economy. The contribution of these renewable technologies to worldwide electricity production is comparatively low, although it has growing trends. In 2019, the industry generated 92 TWh of electricity, approximately 0.3 % of global electricity generation from all sources [15].

Economic feasibility analysis shows that geothermal systems, when compared with conventional energy systems, are characterized by a higher cost of electricity generation (average-weighted levelized costs of electricity 110–170 EUR/MWh in comparison with 60 EUR/MWh for conventional systems), mainly due of the higher (1.5 times) total installation costs [16].

To assess the prospects for the construction of power plants using a particular type of energy, a parameter known as the LEC-factor (*Levelized Energy Cost*) is widely used. This is the ratio of all costs of electricity production by the station during its life cycle (initial investment, maintenance cost, fuel price, loans, interest, etc.) to the amount of electricity produced during the same period ($/1.0 MW·h). This economic indicator determines the average cost of electricity (C) during the life cycle of a generating facility and allows comparing power plants running on different energy sources. According to the estimates of the Open Energy Information international organization, we have the following global values of this indicator (Fig. 1) designed for 2019 [17].

Also, the cost of energy when utilizing the geothermal component depends on the following factors: the characteristics of the coal deposit, its depth, hydrogeological conditions, temperature gradient, the development of the overall infrastructure of the area, distance to consumers, reserves, and others. The main parameters of underground thermal waters are temperature, mineral composition, aggressiveness and hardness.

Nowadays, the main factor holding back the mass use of underground thermal resources in our country is a fairly large initial investment, which is about 50 percent (the cost of resource exploration, design and construction). At the same time, in developed countries, which have long used this technology in a wide range of different industries, it is economically feasible, especially in comparison with traditional types of energy production. For example, the unit cost of building geothermal power plants in the United States is on average 38 % lower than the construction of nuclear power plants, and 50 % lower than the construction of coal-fired power plants. The cost of electricity is 25–30 % lower than at traditional power plants [5].

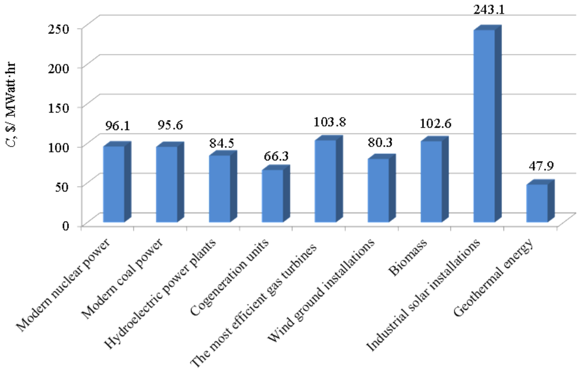

Fig. 1. The cost of electricity from various power generation facilities

This problem could be in some measure solved by the fact that the development of geothermal resources of our country offers partial use of existing wells, as well as redevelopment of existing facilities of decommissioned oil and gas fields in already explored thermal groundwater fields.

In recent decades, the technical equipment of most thermal power plants has become obsolete, almost all power units have exhausted their estimated resource, and more than half are beyond the limit resource and physical wear. At the same time, the use of equipment for cleaning gas emissions of power plants from sulfur oxides increases the cost of electricity generation in fact twice, reduces the technical and economic indicators and increases the inefficiency of energy use.

A powerful negative impact of thermal power plants and boilers is the gross emissions of gases and harmful substances into the atmosphere, which can be reduced by operating geothermal modules for heating buildings using heat pumps instead of conventional energy sources (coal, oil and natural gas). The reduction of these emissions can be estimated by branch normative documents used for calculation and assessment of gaseous emissions from specific technologies for obtaining energy, i.e. coal burning processes.

From the point of view of loading on environment at operation of hydrothermal underground resources, it is much less than when using classical power systems. New technologies used in this field can minimize the environmental impact, but despite all the advantages of exploiting geothermal resources in energy, it is advisable to pay attention to environmental aspects of their operation.

Environmental aspects. In accordance with the provisions of the UN International Convention on Climate Change (Paris Charter, 2015), renewable energy sources, including natural heat of our planet, have been recognized as one of the priorities and an effective tool in combating global climate change. However, the use of the Earth's energy has both advantages and certain disadvantages in environmental sense. Therefore, in economic assessment of the potential of geothermal modules in a specific area, a comparative analysis of the efficiency of traditional and alternative energy should be used, taking into consideration environmental component.

The main contamination in the use of geothermal energy occurs during the stages of construction, drilling and operation – chemical pollution of water and soil, as well as the atmosphere by gases. The primary source of chemical pollution is thermal water, which can have a wide range of characteristics such as mineralization, hardness and aggressiveness.

The process of extracting groundwater from aquifers can intensify subsidence and deformation of the Earth's surface, soil movement, even earthquakes at the micro level. Such cases have been reported in Germany; however, they are local in nature and not widespread.

Rationale for the installation and operation of geothermal energy facilities should include a comparative analysis of the environmental impact of both new and old, partially replaceable energy sources, i. e. both geothermal modules using heat pumps and thermal power plants and boilers. Such a comparative analysis should include consideration and assessment of the energy and environmental feasibility of using coal as a traditional fuel for the Donbas region and alternative resources in the form of geothermal modules that can be installed in closed and flooded mines (Fig. 2).

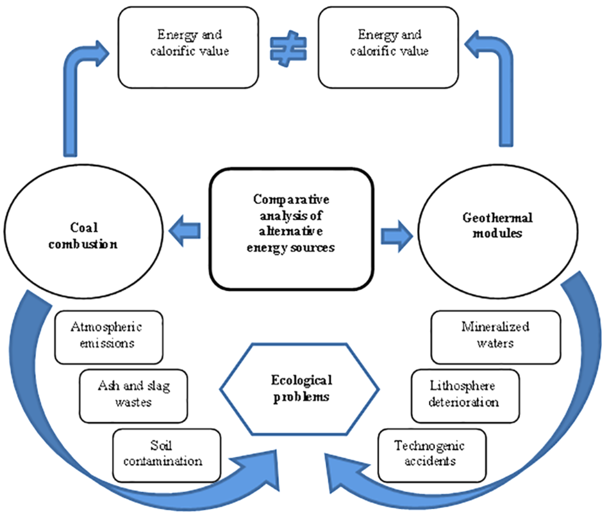

Fig. 2. Methods of comparative analysis of using the coal and geothermal modules

Table 1 shows the average properties of coal in the Donetsk basin, as well as the calculated calorific value of fuels, which allows assessing their potential for power generation. However, harmful effects on the environment from traditional heat and energy generating systems (thermal power plants, boilers) are associated with emissions of harmful gases and dust, as well as the accumulation of ash and slag waste.

If we also take into consideration air pollution associated with mining, waste heaps, mine boilers, drying plants of coal processing plants, degassing and ventilation systems, etc., it becomes clear what the scale of man-made load in the region is. Dumps of the coal industry (both operating and non-operating), especially the flammable ones, are sources of constant pollution of the atmosphere with dust, oxides of carbon and sulfur. And, according to forecasts, in the near future reduction of harmful emissions from dumps into the atmosphere is not expected, despite changes in storage technologies.

According to current estimates, the coal industry releases about 1.1 million tons/year of harmful substances, into the atmosphere, in particular: solids (dust) – about 38 thousand tons; sulfur oxides – about 122 thousand tons; carbon monoxide – 150 thousand tons; nitrogen oxides – about 9 thousand tons; hydrocarbons – 465 thousand tons; other gaseous substances – 256 thousand tons [2].

Atmospheric emissions, solid and liquid wastes from mining, which are formed from the combustion of fossil fuels, require implementing the latest waste-free and environmentally friendly technologies in industry and energy sector.

Each thousand kW/h of electricity generated from renewable sources, on average, avoids emissions of 4.2 kg of particulate matter, 5.65 kg of sulfur oxides, 1.76 kg of nitrogen oxides, and each GCal of heat produced – 0.2 kg of solid particles, more than 3 kg of sulfur oxides and about 1 kg of nitrogen oxides [2].

For a detailed environmental assessment of the combustion process of different coal types, the normalized emissions of pollutants, kg/ton are available (Table 2).

According to average indicators, the Ukrainian coal mines produce about 3 billion m^3 of methane per year, most of which is released into the atmosphere when the mines are ventilated. The main reason is the inefficiency of methane utilization, because only a small number of mine degassing systems are used (mainly as fuel in mine boilers), but most of methane enters into the atmosphere. Due to the low concentration of methane in the degassing pipelines, inconsistent flow and content of gas

Table 1

Main properties of coal in the Donetsk basin [16]

Coal type	Humidity W^r, %	Ash content A^r, %	Sulphur content S^r, %	Caloricity Q_i^r, MJ/kg	Caloricity Q_i^r, CCal/kg
Jet-coal (raw)	13.0	28.0	3.5	18.50	4419
Jet-coal (concentrate)	14.0	10.0	3.0	23.74	5670
Gas coal (raw)	10.0	28.0	3.5	20.47	4889
Gas coal (concentrate)	10.0	11.0	3.0	25.95	6198
Fat coal (raw)	6.0	25.0	3.0	23.36	5579
Fat coal (concentrate)	10.0	16.0	3.5	25.12	6000

Table 2

Specific emissions of pollutants from coal combustion

Type of burning	Coal type	Normalized emissions of pollutants, kg/ton				
		NO_x	CO	SO_2	Fly ash	Ash slag
Furnaces with hand throwing on a fixed horizontal fire-bars	Jet-coal (raw)	2.165	52.170	70.2	51.6	5.7
	13–50 mm*	2.451	57.725	57.6	46.0	6.3
	Gas coal (raw)	2.902	65.875	50.4	47.6	7.2
Furnaces with mechanical throwing and a fixed grate	Fat coal (raw)	2.381	17.298	70.2	33.5	20.4
	Jet-coal (raw)	2.708	19.139	57.6	29.9	22.6
	13–50 mm*	3.174	21.842	50.4	30.9	25.7
Furnaces with mechanical throwing and a direct-course chain grate	Gas coal (raw)	2.364	17.390	70.2	43.9	19.8
	Fat coal (raw)	2.690	19.242	57.6	39.1	21.9
	Jet-coal (raw)	3.154	21.958	50.4	40.5	25.0

Note. * The average size of coal pieces13–50 mm* mixtures, uncertainties with their further use, it is not expected to significantly increase the capturing and utilization of the methane in the near future [2].

Taking into account the volume of coal production and consumption, there is an increase in greenhouse gas emissions, which has more than doubled over the past 15 years and equivalent to 350 million tons of CO_2. This is primarily due to the increase in volumes and changes in the brand of coal as a fuel in power plants.

According to the performed calculations of greenhouse gases, the emission of CO_2 estimated in tons per day for each type of fuel is obtained by the formula

$$E = K_1 K_2 K_3 \Delta P_{th} \Delta t_{op}, \qquad (1)$$

where K_1 is the coefficient of carbon oxidation in the fuel ($K_1 = 0.98$ for coal, $K_1 = 0.99$ for oil products, $K_1 = 0.995$ for gas); K_2 is the coefficient of carbon emissions ($K_2 = 25.58$ t/TJ for coal, $K_2 = 20.84$ t/TJ for oil products, $K_2 = 15.04$ t/TJ for gas); K_3 is the coefficient of carbon into CO_2 recalculation ($K_3 = 44/12 \approx 3.67$); ΔP_{th} is additionally obtained heat power of geothermal module; Δt_h is the duration of heating season.

The value ΔP_{th} presents an equivalent mass of coal that can be saved by operating geothermal modules. Calculations of emission reductions were performed taking into account the calorific value and other properties of coal in Donetsk basin (Table 1), as well as the values of specific emissions of solid and gaseous pollutants into the atmosphere during coal combustion in various boiler devices (Table 2). It was assumed, that the coal mine boiler houses usually burn the coal type "D-concentrate" with calorific value of 23.74 MJ/kg.

Results. It should be noted that the method [13] takes into account the coal properties and characteristics of combustion process emissions. Therefore, further using this technique, the potential reduction of harmful gaseous emissions is estimated on the basis of forecast indicators for additional heat output ΔP_{th} from open geothermal systems in Donbas (Table 3), which varies in the range of 0.53–12.23 MW.

Calculations of the energy amount U_{th} and the equivalent mass of coal M_c are conducted under conditions of geothermal system operation for 4000 hours of the heating season (167 days from late October to early April). Potential energy production for open geothermal systems in Donbas will be $7.63 \cdot 10^6$–$1.76 \cdot 10^8$ MJ, respectively.

The heat capacity of geothermal modules in some periods of winter with very low temperatures may be insufficient for heating purposes, which requires the joint use of heat pumps that convert thermal energy of mine water and conventional heating systems exploiting gas or coal. At the same time, under the conditions of potential implementation of open geothermal systems in Donbas coal mines with drainage and discharge to surface watercourses, it is possible to obtain the amount of energy equivalent to several hundred or several thousand tons of coal of certain type, as well as reduce the relevant gross emissions of atmospheric pollutants.

The mass of potentially saved coal and the volume of reduced atmospheric emissions for already flooded mines of Selydove group with discontinued drainage are significantly lower due to lower thermal capacity. Also, these geothermal modules would work in open circulation systems that have significantly less thermal capacity (Table 4). The expected energy output from mine water is estimated in the range of $0.493 \cdot 10^6$–$0.563 \cdot 10^6$ MJ.

In total, about 90 % of emissions are CO_2, which gives a major input in climate change phenomenon, both globally and regionally. But emissions of sulfur and nitrogen oxides, carbon monoxide and fly ash have a wider range of environmental impacts and adverse effects in natural ecosystems, causing acid rain, classical and photochemical smog, heavy metal leaching and soil acidification. Therefore, the environmental effect of the operation of the geothermal module with the partial replacement of traditional heat and energy generating systems (like thermal power plants, boiler houses) is associated not only with emissions of CO_2, but also other harmful gases and dust particles.

Table 3

Energy and ecological indicators of the efficiency of possible use of open geothermal systems on the basis of mine water discharge in Donetsk coal basin

Coal mines	ΔP_{th}, MW	Energy output $U_{th} \cdot 10^6$, MJ	Equivalent mass of coal M_c, ton	Equivalent emissions of pollutants generated by coal combustion, ton				
				CO_2	NO_x	CO	SO_2	Fly ash
"Novohrodivska 1-3"	8.66	124.704	5253	8600	12,5	90.9	368.8	176.0
"Artema"	2.87	41.328	1741	2800	4.1	30.1	122.2	58.3
"Holubivska"	2.81	40.464	1704	2800	4.1	29.5	119.7	57.1
"Kirova"	0.87	12.528	528	900	1.3	9.1	37.0	17.7
"Lenina"	1.96	28.224	1189	1900	2.8	20.6	83.5	39.8
"Vuhlehirska"	7.52	108.288	4561	7500	10.9	78.9	320.2	152.8
"Poltavska"	0.53	7.632	321	500	0.8	5.6	22.6	10.8
"Chervonyi Profintern"	12.23	176.112	7418	12100	17.7	128.3	520.8	248.5

Table 4

Energy and environmental performance indicators of possible use of geothermal circulation modules compared to the coal consumption at Selydove coal mines

Coal mines	ΔP_{th}, kW	Energy output $U_{th} \cdot 10^6$, MJ	Equivalent mass of coal M_c, ton	Equivalent emissions of pollutants generated by coal combustion, ton				
				CO_2	NO_x	CO	SO_2	Fly ash
"Selydivska"	35.20	0.507	21.4	84.4	0.05	0.37	1.50	0.72
"Novohrodivska-2"	39.10	0.563	23.7	110.9	0.06	0.41	1.66	0.79
"Named after Korotchenko"	34.30	0.493	20.8	77.0	0.05	0.36	1.46	0.70

Taking into account the fact that the potential contribution of NO_x to global warming is estimated to be 298 times higher than CO_2, we can estimate the reduction of the risk of greenhouse gas emissions in the regional context through the use of geothermal energy (Fig. 3). These dependences represent equivalent NO_x and CO_2 emissions from coal combustion according to the potential capacity of geothermal systems.

The combustion of coal, fuel oil and natural gas has specific negative impact on environment due to accumulation of ash and slag wastes, which concentrate heavy metals and radioactive elements. Under conditions of storage in the open environment and insignificant volumes of utilization, ash dumps become the objects of severe pollution of surface and ground waters, atmospheric air, the Earth's surface and underground geological environment as a result of steady processes of heavy metals and salts leaching.

Thus, the choice and substantiation of the direction for the use of geothermal energy should be made on the basis of careful technical and economic assessment of efficiency, taking into account the environmental aspects.

It is necessary to take into consideration:

1. Specific emissions of solid particles and gaseous substances (dust, CO_2, CO, NO_x, SO_2) during combustion of coal in boiler houses (kg/ton) and their value in accordance with the environmental taxes for emissions of atmospheric pollutants.

2. Estimation of the heat energy potential (MJ) for 2 alternative options: obtaining heat energy from coal combustion or geothermal modules.

As the Earth's core heat resources are considered renewable and can be used to generate baseload electricity while producing very low levels of greenhouse gas emissions, they can play a key role in future energy needs [18].

Conclusions. The paper deals with an environmental impact assessment of the installation of geothermal modules as alternative sources of thermal energy on the territory of abandoned coal mines in Donbas area.

Based on the analysis of the averaged coal properties typical for the Donetsk basin, as well as the calorific value of fuel, a comparative assessment of the potential for thermal energy production via coal combustion or the application of geothermal modules is carried out.

Equivalent masses of coal, which can be saved due to the operation of geothermal modules for the conditions of liquidated mines of Donbas and Selydove group mines, are calculated according to the values of additional heat capacity ΔP_{th}. It is determined that the potential energy production from geothermal modules will be $7.63 \cdot 10^6 – 1.76 \cdot 10^8$ MJ – for open geothermal systems of Donbas mines; $0.493 \cdot 10^6 – 0.563 \times \times 10^6$ MJ – for open circulation systems of Selydove group mines, respectively.

However, the feasibility study for the implementation of geothermal modules to provide an alternative heat supply should be carried out with consideration of environmental aspects.

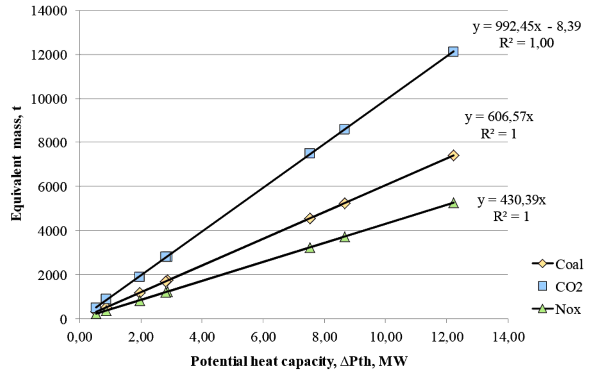

Fig. 3. Equivalent emissions of pollutants from coal combustion according to the potential capacity of geothermal systems

Acknowledgements. *This study is supported by the National Research Foundation of Ukraine (project No. 2020.01/0528) within the program "Science for the Safety of Human and Society".*

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Екологічна оцінка встановлення геотермальних систем на територіях закритих вугільних шахт

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Мета. Проведення екологічної оцінки теплотворної здатності за двома альтернативними варіантами отримання енергії: при традиційному спалюванні вугілля та отриманні тепла від геотермальних модулів.

Методика. Використані методи порівняльного аналізу впливу на довкілля отримання енергії при спалюванні вугілля порівняно з альтернативою використання геотермальних модулів та теплових насосів. Застосована методика розрахунку валових викидів забруднюючих речовин при спалюванні вугілля для умов шахт Донбасу для оцінки обсягів потенційної енергії еквівалентної потужності теплових насосів.

Результати. Виконана екологічна оцінка геотермальних модулів як альтернативних джерел теплової енергії на території ліквідованих шахт Донбасу. На підставі аналізу усереднених характеристик вугілля Донецького басейну, а також теплотворної здатності палива, виконана порівняльна оцінка потенціалу для виробництва теплової енергії при спалюванні вугілля та використанні геотермальних модулів. Розраховані параметри, необхідні для техніко-економічної оцінки ефективності впровадження геотермальних модулів для забезпечення альтернативного теплопостачання.

Наукова новизна. Уперше, на підставі аналізу усереднених характеристик вугілля Донецького басейну, а також теплотворної здатності палива, виконана порівняльна оцінка потенціалу для виробництва теплової енергії при спалюванні вугілля й використанні геотермальних модулів. За значеннями додатково отримуваної теплової потужності геотермальних модулів ΔP_{th} розраховані еквівалентні маси вугілля, що можна заощадити за рахунок експлуатації геотермальних модулів для умов ліквідованих шахт Донбасу та шахт Селидівської групи.

Практична значимість. Відповідно до проведених розрахунків, кількість геотермальної енергії U_{th} із шахтної води в перерахунку на еквівалентну масу вугілля протягом опалювального сезону оцінюється як $7{,}63 \cdot 10^6$–$1{,}76 \times \times 10^8$ МДж для відкритих геотермальних систем на основі скидів шахтної води на Донбасі; $0{,}49 \cdot 10^6$–$0{,}57 \cdot 10^6$ МДж для модулів геотермальної циркуляції Селидівської групи шахт. Доведено, що впровадження геотермальних модулів з метою виробництва теплової енергії на працюючих і закритих вугільних шахтах є перспективною екологічно чистою технологією з довгостроковим технологічним потенціалом, економічним прибутком і соціальними перевагами.

Ключові слова: *геотермальні модулі, теплова енергія, спалювання вугілля, ліквідовані шахти, альтернативне теплопостачання*

The manuscript was submitted 02.09.21.