THE PETRO- AND HYDROTHERMAL POTENTIAL OF THE KARAGAN-CHOKRAKIAN DEPOSITS FOR THE CENTRAL PART OF THE TEREK-CASPIAN FOREDEEP

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Abstract

The article discusses the assessment of the thermal potential of the Karagan-Chokrak deposits of the Middle Miocene of the Terek-Caspian trough. The choice of research object is due to the fact that these deposits are the most studied in terms of lithological, stratigraphic, and thermophysical properties. These deposits are characterized by high temperatures, low mineralization, relatively shallow depths, accessibility of known groundwater deposits to potential consumers, and the presence of a significant number of drilled wells. To assess the resource potential of thermal energy, a large amount of available geological and geophysical data on known geothermal fields and oil field wells was summarized and analyzed. Using this data, digital models were created: the depth of the bottom of the deposits; the thickness of the formations; the distribution of average temperatures in the formation across the area, the material composition of the rocks, etc. For the formation conditions, calculations were made of the specific heat capacity of the rock skeleton and formation water, as well as an assessment of the radiogenic component of the heat flow. An area analysis of the distribution of thermal field parameters created by factors of various nature shows that the peculiarities of temperature distribution across the area and section may be due to: in the first case, by the elevated or depressed position of the deposits; in the second case, by the degree of infiltrative "cooling," i.e., the presence of "heat-resistant" rocks (e.g., clay deposits in Maykop); in the third case, the warming effect of rocks within disturbed folds, which we see in areas of modern geodynamic activity, and lastly, the material composition of rocks differing in the presence of long-lived isotopes of uranium, thorium, and potassium. The assessment of the thermal resource potential of the studied object shows that this type of renewable energy source has enormous reserves. The task of their comprehensive development lies solely in the development of modern geotechnological technical solutions and environmentally sound methods of their use.

Keywords: geothermal field, heat capacity, sedimentary deposits, porosity, formation water, radiogenic heat generation.

I. Introduction

According to materials from the International Geothermal Congress in Reykjavik, geothermal energy is used in 88 countries around the world, and its use increased by 52% by 2020 compared to 2015. Installed capacity reached 10.7 GW, with an average annual growth rate of 8.73%. Heat energy consumption is 283.58 TWh/year, which is 72.3% more than in 2015, and is increasing at an average annual growth rate of 11.5% [8].

The use of this amount of geothermal energy leads to savings of up to 81.0 million tons of oil equivalent per year, which prevents the emission of 78.1 million tons of carbon and 252.6 million tons of CO_2 into the atmosphere. By 2025, the installed capacity of geothermal energy is projected to reach 19.3 GW with consumption of up to 480 TWh/year [12].

In Russia, the use of geothermal resources is most developed in the Kuril-Kamchatka region, Dagestan, Krasnodar Krai, the Chechen Republic, and to a much lesser extent in other regions. Thermal water is used for industrial purposes, centralized heat supply, individual space heating, greenhouse heating, bathing and balneological purposes, drying agricultural crops, and fish farming. Currently, about 1,000 geothermal heat pumps are in operation in the regions of Russia. According to V.D. Svalova's estimates, by 2020, the use of geothermal energy in Russia amounted to 433 MW of installed capacity and energy production of 8.475 TJ/year [11].

The plans for the development of geothermal energy until 2030, as part of the implementation *of the Strategy for Scientific and Technological Development of Russia* (approved by Decree of the President of the Russian Federation No. 145 of February 28, 2024), envisage capital investments of 15 billion rubles.

There are 15 known thermal water deposits in the study area, of which only 9 are currently in use. One deposit is in conservation and 4 deposits are in the state reserve. Thermal waters are used industrially only at the Khankalsky thermal deposit, where a geocirculation system (GCS) is used to maintain reservoir pressure, and in 2014, a 1 MW geothermal power plant was commissioned, also operating in GCS mode [15].

This study aimed to investigate and evaluate the petrothermal and hydrothermal resources of the Karagan-Chokrakian sandy-clay deposits of the Middle Miocene in the central part of the Terek-Caspian foredeep, with a view to assessing the prospects for further development of thermal energy use.

The choice of deposits is due to the fact that they are the most studied in terms of thermophysical parameters and known lithological and stratigraphic structure. The formation waters of these deposits are characterized by high temperatures, low mineralization, and relatively shallow depths. In general, both in terms of lithology and physical properties, the Karagan and Chokrak deposits in this area differ little.

II. Methods

To assess the resource potential of thermal energy, a large amount of available geological and geophysical data on known geothermal fields and oil field wells was summarized and analyzed. Using this data, digital models were created: the depth of the base of the deposits; the thickness of the formations; distribution of average temperatures in the formation across the area, material composition of rocks, etc. For formation conditions, calculations were performed for: water density, specific heat capacity of rock matrix and formation water, radiogenic component of heat flow, and overall area distribution of the petrothermal and hydrothermal potential of the studied deposits.

All calculations and subsequent constructions were performed in the Quantum GIS system, which has open code, allowing for the management of geodata and the maintenance of a unified database.

III. Data

The Karagan-Chokrakian deposits of the Terek-Caspian foredeep are represented by interlayers of sandy-aleuritic, clayey, and clayey-carbonate rocks. At the same time, clayey carbonate rocks "... play an extremely subordinate role and constitute on average 2-3% of the entire section and in rare cases reach values of 11-13% in limited, local areas ..." [6].

Karagan deposits are thin, up to 50-100 m thick, and usually lie on top of Chokrak deposits, often with erosion. They are divided into two suites: the lower - Sunzha suite and the upper -Manas suite. Both suites are composed of sandy-aleuritic and clayey rocks with interlayers of clayey-carbonate formations.

Chokrakian deposits are divided into two parts: the lower - Makhachkala suite, predominantly clayey with interlayers of marl; and the upper - Sernovodsky suite, sandy-clayey. In some cases, the thickness of the chokrak reaches 700 m.

Rock density. The sedimentary rock matrix consists mainly of three basic components: sandy-aleuritic, carbonate, and clayey, which have different mineralogical densities. The sandy-silty component is represented by quartz (65...85%) with an admixture of feldspars, glauconite, and siliceous rocks. The mineralogical density of quartz is $2.65 \cdot 10^3$ kg/m^3, glauconite – $3.05 \cdot 10^3$ kg/m^3, and feldspars and siliceous rocks $(2.3 \div 2.6) \cdot 10^3$ kg/m^3. Overall, the average mineralogical density of the sandy-silty component is $2.67 \cdot 10^3$ kg/m^3.

Carbonate deposits are represented mainly by calcite with a mineralogical density of $2.71 \cdot 10^3$ kg/m^3 and much less frequently by dolomite with a density of $2.87 \cdot 10^3$ kg/m^3. As a rule, Chokrak rocks are characterized by low carbonate content, and only a few compacted interlayers have a carbonate content of more than 2-3%. The average density is 2.72×10^3 kg/m^3.

Clay deposits are represented by hydromicas, sometimes mixed with montmorillonite and glauconite. The mineralogical density of these minerals varies from $2.85 \cdot 10^3$ to $3.05 \cdot 10^3$ kg/m^3 and averages $2.87 \cdot 10^3$ kg/m^3, which significantly exceeds the density of quartz and calcite.

According to petrophysical and geophysical studies, the porosity of the deposits varies on average within a narrow range, mainly from 16 to 22%, with more than 75% of samples characterized by a porosity of 18-22%. The work [3] presents data on the correlation of core data with well logging data (density gamma-gamma, neutron and acoustic logging) for the Khankala deposit, where the average porosity value was 19.6%. The weighted average value for the core was slightly lower at 19.4%. According to the author, the slightly lower porosity value for the core was due to incomplete (82%) rock removal during sampling.

The mineralogical density of the rock matrix of these deposits, based on core and well logging samples, shows that it is not very dependent on the degree of lithification and varies within a narrow range, mainly from 2.65 to $2.70 \cdot 10^3$ kg/m^3, with 50% of samples at $2.66 \cdot 10^3$ kg/m^3.

Water saturation. The bulk density d_p of water-saturated rocks based on well logging data, using the results of core analysis, sampling, and testing of productive formations, is determined by the formula:

$$d_p = d_{sk} \cdot (1-K_p) + d_v \cdot K_p. \quad (1)$$

from which the total porosity of rocks is:

$$K_p = (d_{sk} - d_p) / (d_{sk} - d_v). \quad (2)$$

where d_{sk} - the matrix density, kg/m^3;
d_v – formation water density, kg/m^3.

The formation water of the Karagan-Chokrakian deposits has low mineralization, h.e., the mineralization of water for known thermal deposits in the territory is $(1.65 \div 3.7) \cdot 10^{-3}$ kg/m^3 [5]. Taking into account reservoir temperatures of 80÷110°C and reservoir pressures of 2.0÷3.0 MPa, the estimated density of reservoir water is determined by the average value of $0.98 \cdot 10^{-3}$ kg/m^3.

Specific heat capacity and thermal conductivity. The thermophysical parameters of sedimentary rocks, including those of Karagan-Chokrak, have been studied repeatedly and are given in numerous works of Dagestan region scientists. These works provide typical values of the thermophysical parameters of rocks, including the specific heat capacity for the studied Karagan-Chokrak and other sedimentary deposits. [1, 4, 7, et all].

To analyze and evaluate thermal potential, the geothermal field must first be divided into stationary and non-stationary components: radiogenic and "tectonothermal," associated with the processes of heat transfer from the subsurface during limited periods of tectonic and magmatic activity [2]. Accordingly, the thermal conductivity of the medium is the sum of conductive heat exchange and the radiation component.

For lithological and stratigraphic conditions similar to those under study, Mammaev O.A. et al. performed thermal conductivity calculations to account for both components. Based on his research, it was concluded that "... with a quasi-stationary geothermal field, the most satisfactory results in calculations created by mantle heat sources are obtained by solving a one-dimensional stationary heat conductivity equation" [9, 10].

At the studied geothermal fields of the Dagestan, it was found that the share of the radiogenic component of the sedimentary thickness up to 5 km in the heat flux observed at the surface reaches an average of 10% or 6-7 mW/m^2 [9].

For a homogeneous lithological-stratigraphic layer, the potential petrothermal energy of the rock keleton is determined by the formula:

$$Q_{c.n.} = C \cdot t \cdot V(1-K) \cdot p. \tag{3}$$

where $Q_{c.п.}$ - the potential thermal petrothermal energy of dry rock in J;
C - the specific heat capacity of the rock, J/kg·°C;
t - the average temperature in the formation, °C;
V = a·b·h – volume of rock together with pores, m^3;
p =2.66 ·10^3 kg/m^3 – specific density of rock;
K = 0.19 – porosity coefficient, units.

The potential thermal energy of formation waters in sedimentary strata, taking into account mineralization, temperature, and pressure, is determined by the following formula [13]:

$$Q_{пв} = C_в \cdot t \cdot V \cdot K \cdot \varrho. \tag{4}$$

where $C_в$ = 4.1868 ·10^3 J/(kg· ^{0}C - specific volumetric heat capacity of formation water at the surface.

Under reservoir conditions, the specific heat capacity of bound water changes smoothly with increasing pressure and temperature [7]. With increasing pressure, the heat capacity also decreases and, with increasing temperature, taking into account mineralization, temperature, and pressure [2], is:

$$C_{пв.} = C_в \cdot 3.1 \cdot 10^{(-3)}\, G = 4.09 \cdot 10^{(-3)}\ J/(кг \cdot {}^0C. \tag{5}$$

where G - the mineralization of water in reservoir conditions, kg/m^3

Radiogenic component. To calculate the amount of radiothermal generation in rocks due to the decay of isotopes of naturally occurring radioactive elements ($_{238}U$, $_{232}Th$, and $_{40}K$), the following formula from [2], is used:

$$A = 0.132\,(a \cdot U + b \cdot Th + c \cdot K) \cdot p. \tag{6}$$

where A - heat generation, mW/m^3;
p - the specific density of rocks, kg/m^3;
$_{238}U$, $_{232}Th$, $_{40}K$ – content of radioactive elements uranium, thorium, and potassium in rock in % by weight;
a, b, c – conversion factors.

The calculations use the coefficient values proposed by M.D. Khutorsky [14]: a=0.718·10^{-4} μW/m^3; b=0.193·10^{-4} μW/m^3; c= 0.262 μW/m^3. The results of the calculation are shown in Table 1 below.

Table 1: Value of radiothermal generation per unit volume in the Karagan-Chokrakian deposits for the central part of the Terek-Caspian foredeep

Age of deposits	Lithological composition	Rock density, kg/m³	Average values			Average value relative to volume, %	A, μW/m³
			^{238}U, n·10^{-4}%	^{232}Th, n·10^{-4}%	^{40}K, %		
N_2 kg + N_2 ch	Sand fraction	2050	3.0	5.1	2.1	53.0	0.998
	Silt fraction	2250	5.1	11.2	2.3	23.5	4.36
	Clay fraction	2540	2.0	5.8	2.5	3.5	3.07
Total radiogenic heat generation per unit volume							1.585

Note: *1) rock volume values are taken into account with a porosity coefficient K_{por}=19.6%;*
2) other inclusions constitute an insignificant volume of ~ 0.4%.

The distribution of the radiogenic component of the heat flux was calculated for the area of the corresponding elementary cell, as used in previous calculations. The results of the calculations of the values of the radiogenic component of the heat flux are shown in Figure 3.

IV. Results

The general pattern of the observed field is an increase in thermal potential in the northern and northwestern directions from the minimum values in the south of the territory, in the strip where the sediments emerge on the surface, and further, as the thickness of the sedimentary layer increases, to maximum values in the axial part of the deflection and further north to the zone separating the foredeep from the Skifian Plate. There is a dependence of the increase in temperature and, accordingly, thermal potential as the Karagan-Chokrak sediments sink and the crystalline basement rises. This may be due to an increase in rock density (and a corresponding decrease in thermal resistance) and low absorption of conductive flow. The lowest potential is observed in areas of sedimentary deposition (the Chechen and Ossetian depressions).

In general, a consistently high potential is observed in known fault zones with inherited and modern geodynamic activity. These are the Krayevoy, Tersky, and Sunzhensky faults (seam zones) of sublatitudinal extension and the Benoy-Eldarovsky and Kazbeksky faults of meridional and submeridional extension, which complicate the overall temperature distribution pattern.

The nature of the change in hydrothermal potential generally follows the pattern of petrothermal energy distribution. At lower potential, it shows a more differentiated character, which is probably primarily related to the distribution of temperatures and the thickness of the deposits.

These are the Kraevoy, Tersky, and Sunzhensky faults (seam zones) of sublatitudinal extension. Complications in the overall temperature distribution pattern are associated with intersections between sublatitudinal faults and transverse submeridional faults, namely the Kazbek and Benoy-Eldarov faults. According to deep seismic sounding data, all these faults are characterized by mantle underthrusting.

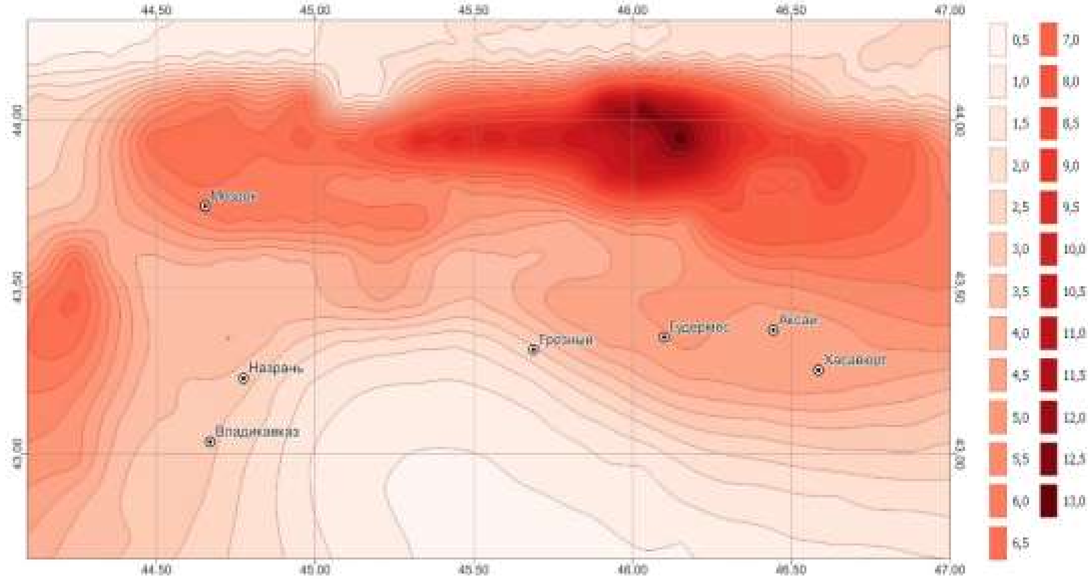

Figure 1: *Map of the areal distribution of the petrothermal potential of the Karagan-Chokrakian deposits for the central part of the Terek-Caspian foredeep, (in* $\boldsymbol{n\cdot 10^{15}\ J}$*)*

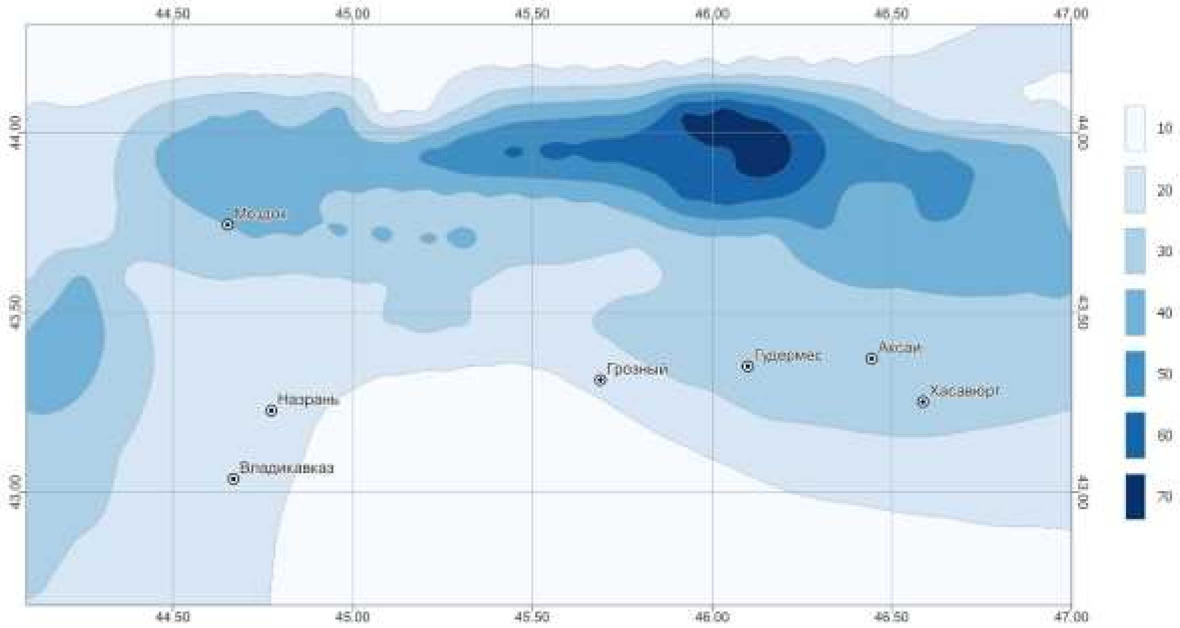

Figure 2: *Map of the areal distribution of hydrothermal potential of the Karagan-Chokrakian deposits for the central part of the Terek-Caspian foredeep, (in* $\boldsymbol{n \cdot 10^{14}\ J}$*)*

The nature of the change in hydrothermal potential generally follows the pattern of petrothermal energy distribution. At lower potential, it shows a more differentiated nature, which is primarily likely related to temperature distribution, stratigraphy, and sediment thickness.

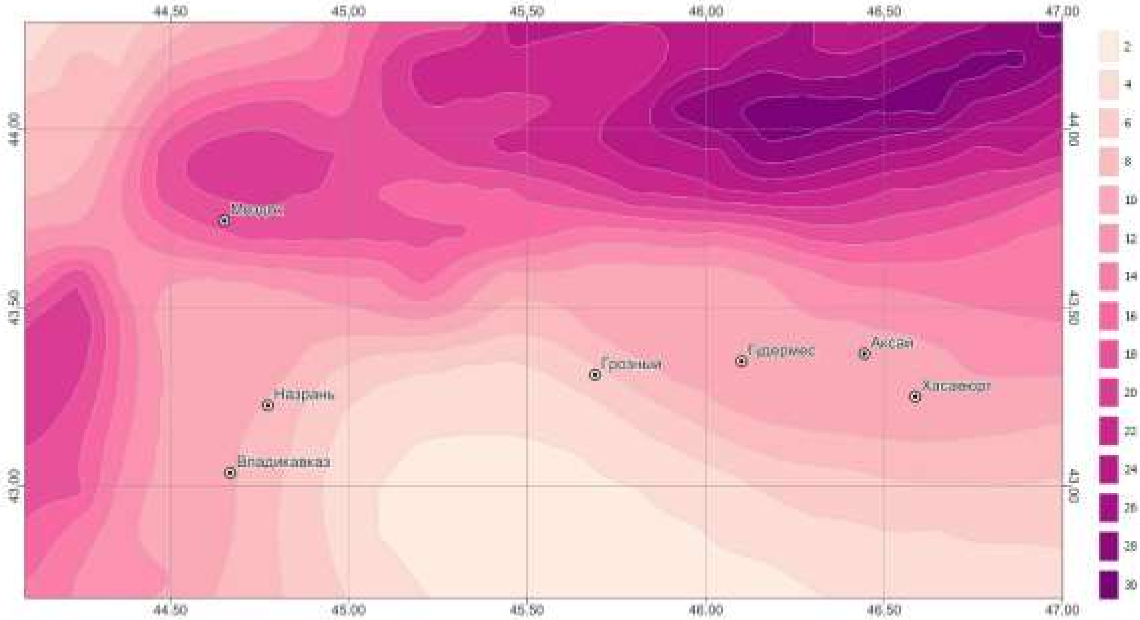

Figure 3: *Map of the areal distribution of radiogenic heat release potential of the Karagan-Chokrakian deposits for the central part of the Terek-Caspian foredeep (in* $\boldsymbol{n \cdot 10^5 W}$*)*

It should be noted that the Middle Miocene complex is distinguished by the overlap of the heat-insulating (low thermal conductivity) strata of the Upper Miocene from above and the Maikop clay deposits from below. Such a differentiated picture of the thermal field distribution shows a significant contribution to the thermal field of the radiogenic component of the decay of long-lived isotopes. This component is significant for terrigenous sedimentary rocks, which are the Karagan-Chokrakian deposits.

V. Conclusion

Thus, the assessment of the thermal resource potential of the Karagan-Chokrak deposits in the central part of the TKP shows that this type of renewable energy source has enormous reserves. The task of their comprehensive development lies solely in the development of modern geotechnology technical solutions and environmentally sound methods for utilizing both hydrothermal and petrothermal potential.

The peculiarities of temperature distribution across the section in the region may be due to: 1) the elevated or depressed position of the sediments; 2) the degree of infiltrative "cooling," h.e., the presence of "heat-resistant" rocks (e.g., clayey sediments of Maikop); 3) the warming effect of rocks within disturbed folds, which we see in areas of modern geodynamic activity; 4) the material composition of rocks differing in the presence of long-lived isotopes of uranium, thorium, and potassium.

One promising area is the use of petro- and hydrothermal energy from oil wells. The study area has a significant number of wells drilled in oil fields that have been decommissioned due to waterlogging of deposits but are technically suitable for operation.

The absence of the need to drill wells will significantly reduce the cost of implementing geothermal projects.

CONFLICT OF INTEREST.

Authors declare that they do not have any conflict of interest.

References

[1] Abdulgatova Z.Z. Thermal conductivity of dry and fluid-saturated rocks at high temperatures and pressures. Experiment and modeling: abstract of dissertation... Candidate of Technical Sciences. Makhachkala, 2010, 24 p.

[2] Boganik N.S. Radiogenic heat of the Earth's crust of the Russian Platform and its folded structure: Experience of computational studies of heat flows and temperatures in the Earth's crust and mantle. Moscow: Nauka, 1975. 159 p.

[3] Farkhutdinov, A.M., Ismagilov, R.A. Geothermal resources of the Chechen Republic and prospects for their use // Geoengineering. 2014. No. 2 (22). Pp. 60-63.

[4] Gargatsev I.O., Batyrmurzaev A.S., Mammaev O.A. Assessment of radio heat generation in the sedimentary strata of the Eastern Ciscaucasia (Dagestan) // Dokl. AN RF. 1996. Vol. 346, No. 3. Pp. 396–398.

[5] Gatsaeva, L.S. Geoecological problems of thermal water discharge from well 9-T Kargalinskaya. News of Higher Educational Institutions. North Caucasus Region. Series: Natural Sciences. 2023, No. 4(220), pp. 70-78. DOI 10.18522/1026-2237-2023-4-70-78. EDN WWLUJA

[6] Gmid L.P. On the petrography of clayey carbonate rocks of Karagan and Chokrak in the Grozny-Dagestan region // Oil and Gas Geology. Theory and Practice. 2012. Vol. 7, No. 4. http://www.ngtp.ru/rub/10/48_2012.pdf.

[7] Kurbanov A.A. Patterns of change in the thermophysical properties of fluid-bearing reservoirs under reservoir RT conditions and methods of their application. Makhachkala: Publishing House of the Scientific Center of the Russian Academy of Sciences, 2000. 226 p.

[8] Lund John W., Aniko N. Toth. Direct Utilization of Geothermal Energy 2020 Worldwide Review. // Proc. of the World Geothermal Congress 2020+1. Reykjavik, Iceland, Apr.– Oct. 2021. Pp. 1-39.

[9] Mammaev O.A. Assessment of radio-thermal generation processes in the formation of heat flow using the example of the Prikumskaya zone of Dagestan // Tr. IG DNTs RAN. Issue 58. Regional geology and oil and gas potential of the Caucasus. Makhachkala: ALEF, 2012. Pp. 86–89.

[10] Mammaev O.A., Magomedov R.A., Mammaev B.O. Concentrations of natural radioactive elements in the rocks of the sedimentary strata of the Foothills of Dagestan and their contribution to the observed heat flow // Arid Ecosystems. 2015. Vol. 21, No. 1 (62). Pp. 41–47.

[11] Svalova V.B. Geothermal energy in Russia and worldwide and hydrogeothermal systems in the Caucasus // Monitoring. Science and Technology. 2022, No. 2-01. http://csmos.ru/index.php?page=mnt-issue-2022-2-01

[12] Tomarov G.V., Shipkov A.A. A brief overview of the current state and trends in the development of geothermal energy // Thermal Power Engineering, 2023. No. 2. Pp. 37–46.

[13] Physical properties of rocks and minerals (Petrophysics). Geophysics Handbook. 2nd ed. Ed. by Dortman N.V. Moscow: Nedra, 1984. 455 p.

[14] Khutorskoy M.D. Structure and components of heat flow // Georesources. 2015. No. 4-2 (63). Vol. 2. Pp. 70-82.

[15] Zaurbekov Sh.Sh., Minzaev M.Sh., Cherkasov S.V., Shaipov A.A. et al. Results of the pilot geothermal station project with a heat extraction circulation scheme at the Khankalskoye field in the Chechen Republic // Renewable energy: ways to improve energy and economic efficiency: materials from the Third International Forum. Crimea, Yalta, November 17-19, 2015. Pp. 123–136.