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Nomogram Method as Means for Resource Potential Efficiency Predicative Aid of Petrothermal Energy

K F Gabdrakhmanova, G R Izmailova, P A Larin, E R Vasilyeva, M A Madjidov and S R Marupov

Ufa State Petroleum Technological University, Branch of the University in the City of Oktyabrsky, Russian Federation, 54a, Devonskaya St., Oktyabrsky, 452607, Russia

E-mail: klara47@mail.ru

Abstract. The article describes the innovative approach when predicting the resource potential efficiency of petrothermal energy. Various geothermal gradients representative of Bashkortostan and Tatarstan republics regions were considered. With the help of nomograms, the authors analysed fluid temperature dependency graphs at the outlet and the thermal power versus fluid velocity along the wellbore. From the family of graphs plotted by us, velocities corresponding to specific temperature were found. Then, according to thermal power versus velocity curve, power levels corresponding to these velocities relative to the selected fluid temperature were found. On the basis of two dependencies obtained, nomograms were plotted. The result of determining the petrothermal energy production efficiency is a family of isocline lines that enables one to select the optimum temperature and injection rate to obtain the required amount of heat for a particular depth and geothermal gradient.

1. Introduction

In recent years, the idea of geothermal energy use has become widespread in many countries, mainly due to the price increase of the known types of fuel (oil, gas). In addition, according to judgmental forecasts, the production-decline rate of organic fuel production is expected worldwide. Intense extraction of non-renewable energy resources from the bowels of the Earth, in independent European energy agencies analysis [1], can lead in a few decades to a sharp drop in the power potential of hydrocarbons. The Earth's energy, stored in the subsurface, is huge, for this reason; that is why the necessity arises to develop methods for predicting geothermal energy.

In modern conditions, there is a real opportunity to use the heat of the Earth's interior everywhere for solving the problems of remote consumers power supply regardless of consumption volume and territorial location. As to Russia, taking into account its vast territory, this circumstance is of great importance [2].

One of the main methods for petrothermal energy prediction is geophysical methods [3,4], the most significant of which are the value of recoverable thermal energy reserves, the initial production rate, stratum depth and thermal gradient.
Unfortunately, the specific character of oil and gas facilities is such that even additional and advanced studies do not allow increasing the reliability and accuracy in determining the possibility of petrothermal energy extraction. This yields the necessity for generalization that allow one, even at relatively low confidence of a number of object characteristics, to reveal the most significant dependencies reflecting their effectiveness. The most effective and correct approach in this situation can be the nomogram method.

2. Materials and methods
As study materials, the results of geological and field researches of more than 30 wells in Tatarstan and Bashkortostan were considered. Based on observations, the main characteristics are determined - the temperature gradient, the rate of injection, the power of thermal energy, the depth and temperature of the liquid at the outlet.

Thus, when plotting nomograms, it is necessary to reflect possible variations of just two geological-field description of the reservoir - thermal gradient, the depth of the wells.

There are many methods for plotting nomograms [4,5,6,7,8], and their essence reduces to the possibility of defining the most significant measures influencing the technology efficiency. When using nomograms, the results of field-geological study are used taking into account the most substantial data [9,10,11]. It is obvious that it is impossible or problematic to reflect simultaneously the dependence of the indicators from several (more than two) factors from the point of view of their perception (it is known that multidimensional dependencies are difficult to visualize, therefore minimization of space features is required) [8].

3. Method of nomograms plotting.
Let us propose the most universal form of nomograms plotting, which is not related to each geological and trade indicator, but to a complex parameter that reflects their combined effect. The utilization efficiency of these nomograms has been proved in laboratory experiments [12,13].

The main point of such nomograms plotting is reduced to obtaining a series of efficiency assessment of depth energy usage, depending on the thermal gradient, stratum depth and withdrawal rate. Further, using the obtained cloud of points in the coordinate system (temperature, velocity, depth), the dependence of considered assessment of efficiency (in the capacity of which the received heat assessment can be used) on the complex of the kte parameter (the coefficient of technological efficiency, kte = thermal power) is plotted [14,15].

The amount of heat obtained depends on the geothermal gradient, the well depth and injection rate of coolant (thermal fluid).

1. First, it is a fairly simple variation; it can be improved by introducing various algorithmic variations.
2. Second, all three parameters are regulated: 1) the greater the depth, the higher the thermal gradient; the higher the injection rate, the lower the outlet temperature.

In principle, for achieving this goal, it is enough to plot the temperature dependence at the output and the thermal power on the speed.

The use of such nomograms is a very efficient and universal instrument that allows excluding the necessity for large-scale real calculations and at the same time to characterize the application prospect of the field correctly.

Let us consider some results of such nomograms plotting for Tatarstan fields.

Figures 1 and 2 show nomograms with different geothermal gradients $G_1 = 0.02 ^\circ C / m$ and $G_2 = 0.03 ^\circ C / m$. 
Figure 1. Nomogram for determining the amount of heat depending on the depth with thermal gradient $G = 0.03 \, ^\circ C / m$.

- - - - - fluid temperature at the outlet,
- - - - - heat power,
____ - isoclines corresponding to a certain temperature. 1 - 1000 m, 2 - 1500 m, 3 - 2000 m, 4 - 2500 m.

For example, Figure 1 shows that $25 \, ^\circ C$ aligns with 4 points of different speeds corresponding to different depths of 1000, 1500, 2000, 2500 m. For example, at depth 1500 m, the optimum speed is $0.05 \, m/s$, output power is 4 kW. $35 \, ^\circ C$ at the outlet can be achieved at the wells with a depth of 1500, 2000, 2500 m. At depth of 1000 m, achieving this temperature is ineffective and impossible, since the bottomhole temperature is $30 \, ^\circ C$. 
Figure 2. Nomogram for determining the amount of heat depending on the depth with thermal gradient $G = 0.02 \, ^\circ C / m$.

...... - fluid temperature at the outlet,
- - - - - - heat power,
_____ - isoclines corresponding to a certain temperature. 1 - 1000 m, 2 - 1500 m, 3 - 2000 m, 4 - 2500 m.

The technology of such monograms is reduced to the following (see Figures 1 and 2). From nomograms at a certain injection rate and well depth, it is possible to select technologies for using deep heat for various purposes.

The nomogram is plotted for various thermal gradients and injection rates. For use, let us select the nomogram with a known geothermal gradient and determine the required injection rate by the present technology. Also, this nomogram allows selecting wells by their investment appeal.

4. Conclusion.
The developed technique of nomograms plotting allows determining the selection criteria at different injection rates and geothermal gradients. The research data will allow developing a technique of well selection with the most attractive terms.

A technique for plotting nomograms was developed, which differs from the known ones that makes it possible to select wells by minimum geological and field researchers.

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