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ABSTRACT

of the dissertation for the degree of Doctor of Philosophy

DEVELOPMENT OF THERMODYNAMIC METHODS TO PREVENT COMPLICATIONS IN DRILLING WELLS ON GEOTHERMAL SOURCES

Speciality	2523.01 – Well drilling technology
Field of science:	Technical science
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Baku - 2024

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AZƏRBAYCAN RESPUBLİKASI TƏHSİL NAZİRLİYİ "AZƏRBAYCAN DÖVLƏT NEFT VƏ SƏNAYE UNİVERSİTETİ" PUBLİK HÜQUQİ ŞƏXS ELMİ KATİB

GENERAL DESCRIPTION OF WORK

Relevance and development of the topic. To ensure significant investment in the fuel and energy balance, as well as geothermal energy, the state needs to put together solutions for geomechanical, hydromechanical, hydrogeological, thermophysical, technological and other tasks related to the creation and operation of efficient and geothermal energy costs. systems.

Over time, systems and complexes associated with geothermal energy should play an increasingly important role in the formation and development of the national economy, as well as an important factor in achieving sustainable economic growth.

Geothermal energy is a potential source of renewable energy, but it will require continued price reductions and greater use to be viable. The development of more efficient methods for extracting geothermal energy is also needed to make it more cost-effective. It is necessary to develop a productive technology for extracting geothermal energy from the bowels and find optimal plans for its use.

The foundation of reliable, hydrodynamic, thermohydrodynamic and revealing the best calculations of geothermal systems is an important link in the chain of interrelated issues of heat and power engineering.

On the territory of the Republic of Azerbaijan, thermal waters are almost ubiquitous. Thermal waters are confined mainly to the deposits of the Absheron stage of the productive stratum, the Maikop suite, as well as to the deposits of the Cretaceous age. So far, the studies carried out have generally been exploratory in nature.

In 2005-2015, a national program for the development of alternative energy was approved in Azerbaijan, and a special agency for alternative energy was created under the Ministry of Industry and Fuel. Therefore, it is optimal and necessary to develop a scientific and innovative methodological basis for the criteria for assessing the state of thermophysical, thermohydrodynamic and rheological properties of drilling and cement slurries.

In 2021, the Ministry of Energy of Azerbaijan intends to soon start studying the potential of geothermal energy sources in the liberated territories of the republic.

Thus, the reserves of thermal waters in the Kalbajar region are estimated at 3,093 thousand m^3, and in Shusha - 412 m^3 per day.

Objectives and tasks of the research. Development of thermohydrodynamic methods to prevent complications when drilling wells on geothermal sources in order to obtain alternative energy.

The main objectives of the study. Study of thermohydrodynamic features of geothermal sources on the territory of the Republic of Azerbaijan;

Study of the influence of the Joule-Thomson effect on the balance of thermohydrodynamic pressure when drilling geothermal wells;

Study of the possibility of developing a method for preventing loss of drilling fluid;

Study of the possibility of developing a method for preventing sticking of a drilling tool;

Development of the influence of the temperature factor, which has a significant impact on the magnitude of hydrostatic pressure when drilling geothermal wells;

Study of the influence of the electromagnetic field strength on the coefficient of thermal conductivity of the drilling fluid;

Determination of thermal conductivity coefficients of drilling and cement mixtures when drilling geothermal wells.

Methods for solving the tasks set. The tasks set were solved by applying theoretical, laboratory and field research.

The main provisions for defense. Method for preventing sticking of the drilling tool;

Method for preventing absorption of drilling fluid in the process of drilling geothermal wells;

Method and models for determining the influence of the temperature factor in the well-reservoir system on complications during well drilling;

Method for assessing the thermophysical properties of drilling and cement slurries and the influence of the electromagnetic field strength on the thermal conductivity of the drilling fluid.

Scientific novelty of the research.

A method is proposed to prevent sticking of the drilling tool;

A method has been developed to prevent absorption of drilling fluid in the process of drilling geothermal wells;

A method and models are proposed for determining the influence of the temperature factor in the well-reservoir system on complications during well drilling;

A method has been developed for assessing the thermophysical properties of drilling and cement slurries and the influence of the electromagnetic field strength on the coefficient of thermal conductivity of the drilling slurry.

Practical significance of the results of the work. The developed method for determining the influence of the temperature factor on the change in the density of the drilling fluid was applied to the well No. 1862 of the Sadan area and the well No. 1703 of Lokbatan-Puta-Gushkhan of the Azneft Production Association. Both wells were successfully drilled to the design depth without any complications.

The main provisions of the dissertation work were reported and discussed:

1. Eighth International Conference on Soft Computing, Computing with Words and Perceptions in System Analysis, Decision and Control ICSCCW–2015.

2. 12th International Conference on Application of Fuzzy Systems and Soft Computing, ICAFS – 2016.

3. V International Scientific and Practical Conference of Young Scientists "Youth Energy for the Oil and Gas Industry" - 2020.

4. Dedicated to the 98th anniversary of the national leader Heydar Aliyev the 2nd international student research and science conference on "Petroleum Geoscience and Engineering" - 2021.

5. The XXII International Scientific Symposium "Turkic World Between East and West" Türk Dünyası ("Şərqlə Qərb arasında Türk dünyası") Andijan/Uzbekistan – 2022.

6. Dedicated to the 99th anniversary of the national leader Heydar Aliyev the 3rd international student research and science conference on "Petroleum Geoscience and Engineering" - 2022.

Publications. The main materials of the dissertation were published in the form of 14 printed works, including 7 theses, 4 of which were presented at International scientific and technical conferences (Vienna, Austria, Turkey, Tatarstan).

Structure and scope of work.

The dissertation consists of an introduction, 4 chapters, conclusions and proposals, 27 figures, 13 tables, a list of references, including 206 titles and 2 appendices. The total number of characters is 164342.

BRIEF SUMMARY OF THE WORK

The introduction substantiates the relevance of the problem, the purpose of the work, defines the main objectives of the study, ways to solve them, scientific novelty, the main protected provisions, the practical value of the work, the structure and scope of the work. The dissertation consists of 4 chapters.

The first chapter examines the analysis of the current state of the problems of drilling geothermal wells at the technical and technological level of theoretical and field data, stock works of the SIPI "Neftegaz", scientific and technical literature, patents and documents published in 2011-2020. in the USA, Germany and other leading countries. All of them basically correspond to the research topic of the dissertation on thermohydrodynamic methods for preventing complications when drilling geothermal wells.

The main focus of modern energy policy is on trying to find measures that will improve energy efficiency and reduce the environmental impact of energy consumption. This is a general strategy for using non-standard renewable energy sources. One type of renewable energy with great potential is geothermal energy, which is widely used in practice. Despite the extensive experience of geothermal energy, the share of geothermal energy in the fuel and energy balance of Azerbaijan is not very large. The limited scale of modern use of geothermal energy clearly demonstrates the potential of a rich resource base.

The temperature of geothermal water can vary greatly depending on its location. Since temperature is a criterion used to subdivide groundwater in terms of their quality in many domestic and foreign classifications. Due to the variety of approaches to assessment and the high conditionality in choosing the temperature range, there is no unified classification of geothermal waters yet. Depending on the thermal potential, geothermal waters can be divided into the following groups: low-temperature (up to 40°C), thermal (40-60°C), high-temperature (60-100°C), overheated (above 100°C).

The intervals of temperature changes in the Cretaceous deposits are: for the Muradkhanly deposit - 71-150^{0}C, for the Sorsor areas - 73-105^{0}C, Dzharly - 64-111^{0}C, Duzdag - 98-136^{0}C, Garajalli - 80-105^{0}C, Mil - 86 -110^{0}C.

In addition to those mentioned above, there are temperature measurements by area: Dalimamedli (101^{0}C), Terter (123^{0}C), Amirarkh (130^{0}C), Zardab (109^{0}C), Sovetlyar (127-138^{0}C), Shiringum (118^{0}C), Ajidere (98^{0}C), Agjabedi (110^{0}C), Borsunly (148^{0}C), Beylagan (61^{0}C).

In the Saatly area, temperature measurements were made only in well 1SG, where at a depth of 2890 m it is 57^{0}C, increasing to 144^{0}C at a depth of 8229 m.

Based on the averaged temperature values over the areas, a geothermal map was constructed for the Upper Cretaceous aquifer complex, from which it can be seen that, over the territories of the trough, from the zone of sediment outcrop to the day surface, passing along the southwestern side of the trough to the central, most submerged, temperature increases from 80^{0}C to 140^{0}C. The central zone outlined by the 140^{0}C geoisotherm generally coincides with that.

The Eocene aquifer complex was illuminated by 66 measurements carried out in 27 wells in 9 areas of the Yevlakh-Agjabadi trough.

For the areas of Dalimamedli, Duzdag, Agjabadi and Sovetlyar, the measurement interval is 98-119^{0}C. It is somewhat higher in the areas of Borsunly - 130-132^{0}C and Shiringum - 120-138^{0}C. Insignificant data are available on the areas: Gazanbulag (97^{0}C), Gedakboz (106^{0}C), Amirarkh (130^{0}C). In the Dzharly area, thermal waters were discovered by a well in the Upper Cretaceous deposits with a flow rate of 20,000 m^3/day and a temperature of 100^{0}C, the amount of heat carried out by water per year is 1.4×10^9 Gcal (63 MW), for the entire flowing time (15 years) of the taken-out heat amounted to $21 \bullet 10^{10}$ Gcal.

In the Kurdamir region, thermal waters with a flow rate of 10,000 m^3/day with a temperature at the mouth of 82^{0}C were discovered by one well. The amount of heat carried out by water is 7.5×10^5 Gcal (27 MW).

On the Dzharly area of the Yevlakh-Agjabedi trough, the Upper Cretaceous complex of thermal waters is promising. The water temperature is more than 90^0C, the flow rate is about 8000 m^3/day, the thermal power is 350 MW. On the Shirvanly area, thermal waters with a flow rate of 3000 m^3/day with a temperature of 60^0C were discovered by one well. The amount of heat carried out by water is $1.1 \cdot 10^6$ Gcal (4.37 MW). Based on the exploration work carried out, the southwestern side of the Kura depression has sufficient reserves of thermal waters that can be used cost-effectively and comprehensively for the purpose of heating residential and industrial facilities, greenhouse and greenhouse facilities, obtaining chemically rare elements, as well as for balneological purposes.

Complications in the construction of geothermal wells and methods of prevention and elimination

Due to the high demand for energy and the growing environmental concerns associated with the oil industry, geothermal fields are considered an excellent renewable source of energy. Because of this, the number of geothermal exploration and drilling projects to access geothermal reservoirs has increased significantly over the past decades. Geothermal energy can be obtained by drilling wells in geothermal fields and transferring the earth's heat using reservoir fluid extracted from geothermal wells. Advances in drilling technology in the oil industry are the key to the development of geothermal drilling.

Geothermal wells are classified into three categories based on their temperature: low-temperature (less than 150°C), medium-temperature (from 150 to 200°C) and high-temperature (more than 200°C). However, in geothermal wells, the temperature can exceed the critical water temperature, at which the drilling and completion process becomes increasingly difficult.

The reservoir conditions have caused many problems in drilling geothermal wells, including those related to the control of well integrity and losses. In addition to high temperatures, hard formations impose additional technical restrictions on the choice of drill bits, casing strength, drilling fluid and cement formulations. These conditions create a need for a large number of technological advances to cope with the challenges in the well drilling process.

Accurate knowledge of drilling fluid properties in downhole conditions and during drilling operations is critical. Changes in these properties must be minimized to ensure efficient and cost-effective drilling. Elevated temperatures encountered in geothermal wells significantly affect the rheology of the drilling fluid. In addition, high temperature destroys the polymeric additives present in the drilling fluid and reduces the viscosity of the drilling fluid, thereby degrading its performance and creating serious problems for drilling operations.

The transfer of technologies and achievements in the field of oil and gas drilling to the geothermal industry and the transition to automated operations will ensure cost-effective drilling and make geothermal projects more feasible.

Since the drilling fluid is of particular importance in the construction of wells, the correct selection of the type and its parameters of the drilling fluid, depending on the lithological section and geological conditions of the well, is of particular importance. Currently, a large number of types of drilling fluids have been developed and used around the world, suitable for the specific characteristics of various fields. It should be noted that most of the complications that arise during the construction of wells are associated with the drilling fluid. Therefore, an important condition is the correct choice of the type, rheological parameters and density of the drilling fluid according to the lithological section of the well.

Since the drilling of geothermal, oil and gas wells is carried out according to the same technology and with the same drilling fluid, then when drilling geothermal wells, it is necessary to choose the right drilling fluid prescription indicators. The dissertation work explores the complications that may arise when drilling geothermal wells, depending on the temperature factor and ways to prevent them.

As stated above, the drilling of geothermal wells does not differ in principle from the technology of drilling oil and gas wells. The difference is that when drilling geothermal wells, it is necessary to take into account the temperature factor, which significantly affects the hydrodynamic pressure. To do this, when choosing a well design, chemicals for drilling fluids, grouting material for fixing casing strings, it is necessary to choose a heat-resistant material. For example; Iceland, which has extensive experience in drilling high-thermal wells, takes a safety factor of 2 when calculating the strength of casing strings.

Geothermal well design should take into account the expected productivity and operation of the well.

The main factors that determine the complexity of drilling high-thermal wells are the high temperature of the rocks, the coolant itself, the presence of absorption zones, rock falls.

The geological complexity of drilling geothermal wells is as follows:

- absorption of washing liquid;
- landslides and collapse of rocks;
- clamping of the drilling tool;

When drilling geothermal wells, the following must be considered:

- in a reasonable design of the well, taking into account the geological and technical conditions, flow rate, pressure and temperature of the reservoir fluid;
- to achieve high mechanical and travel speed it is necessary to use advanced drilling technologies;
- to prevent accidents and complications in the well during drilling, it is necessary to constantly monitor the drilling fluid and adjust its parameters and temperature;
- introduction of wellhead blowout prevention equipment, a check valve and a set of equipment for a four-stage drilling mud cleaning system;
- cementing of the casing string must be provided up to the wellhead;
- for reliable fastening of geothermal wells, cement material resistant to high temperatures of the ShPTSS and USChTs brands should be used;

It should be noted that, depending on the temperature, a change in the structural viscosity and ultimate shear stress of the drilling fluid has a strong effect on the pressure in the well when the drilling tool is lowered. In this regard, this factor should be taken into account in order to avoid complications when drilling geothermal wells.

The main type of complications in the construction of geothermal and oil wells are mud losses. An analysis of the complications that arose in the wells drilled by the Complex Drilling Works and GULF drillinq trusts on the Apsheron Peninsula in 2010-2019 shows that the complications were mainly associated with the loss of drilling fluid, which was 9-11 % of total calendar time. It should be noted that the time to liquidate absorption to a significant extent, adversely affects the technical and economic performance of drilling organizations.

Works to eliminate losses of the drilling fluid are associated not only with material costs, at this time there is also a deterioration in the reservoir properties of the productive formation, which causes additional oil losses.

It is very difficult to establish any regularities in the occurrence of absorptions and to choose effective measures and technology for the prevention and elimination of absorptions due to the large number of factors that cause the phenomenon of absorption.

Modern lost circulation methods are as follows:

1. preventive measures to prevent absorption of drilling mud during the construction of a well;

2. special methods of elimination of zones of loss of drilling fluid (for example, pumping tampons into the zone, isolation work, installation of a blocker, etc.).

During the construction of a well, lost circulation takes a lot of material and time to eliminate, so the prevention of lost circulation as a preventive measure is of particular economic importance.

In this regard, the application of measures to prevent loss of drilling fluid and the improvement of technological methods for eliminating losses, the use of new technologies and materials that give the maximum economic result, are of exceptional importance.

When applying preventive measures, inert fillers of various sizes and purposes are mainly used. The effectiveness of fillers depends on the correct selection of the size of the filler in accordance with the size of the open channel. Data from Rogers V.F. show that with a permeability even up to 200 mD, with insignificant pressure drops (up to 0.7 MPa), clay particles can penetrate to a depth of 2–3 cm.

In America, in 90% of cases, a filler is added to the drilling fluid to prevent losses when drilling fractured rocks. Various materials are used as fillers: cord fiber, rubber crumb, cellophane shavings, crushed stone, sand, chopped straw, sawdust, wood shavings, sunflower husks, walnut shells, granulated plastics, mica, lumps of quarry clay and other materials.

Various inert fillers have been developed and used in Russia. When adding fillers to drilling and cement slurries, their clogging ability increases, which helps to reduce the consumption of slurries and materials for their preparation, as well as reduce the time spent on insulation work.

Foreign firms produce more than 500 types of various types and sizes of fillers and use them for the purpose of early warning and elimination of absorption. For example, QUIKSIL. Filler compositions more effectively clog the absorption zone.

Fillers must meet the following requirements:

- The size and shape of the fillers must be such that they can fill the open channel;
- Filler material should not be subjected to various chemical treatment, pressure and temperature;

The permeability of the filler material should vary between 400-1200 kg/m^3 for use in drilling fluids of various densities.

- fillers should not be abrasive.
- the properties of the filler should not change during storage.

Liquidation of absorption zones can be divided into three main groups:

- alluvium of fillers;
- pumping cement mixtures;
- installation of overlapping pipes (profile overlapping pipes and “tails”).

To prevent lost circulation in high-temperature wells, the following measures should be taken:

- decrease in the flow rate (speed of the upward flow) of the solution;
- SPO speed limits;
- pacing of the drilling tool during drilling mud displacement before starting the pumps and smooth restoration of circulation;

- selection of the appropriate bottom hole assembly (BHA);
- prevent the formation of seals.
- reducing the density of the solution, including the use of aerated solutions and foams;

Loss prevention is ensured by the minimum excess pressure on the absorbing formation and the prevention of sharp pressure fluctuations in the well.

This is achieved through:

- reducing the density of the solution, including the use of aerated solutions and foams;
- decrease in the flow rate (speed of the upward flow) of the solution;
- SPO speed limits;
- pacing the tool before starting the pumps and smoothly restoring circulation;
- application of RSS (rotary-controlled system);
- selection of the appropriate bottom hole assembly (BHA);
- prevent the formation of seals.

Installation of overlapping pipes (profile overlappers and "tails")

The most effective way to eliminate absorption zones abroad is to block the channels with the help of fillers.

When liquidating absorption zones abroad, they also use: solutions with high water loss, cement-bentonite mixtures, gilsonite cement, solar bentonite solutions, fast-setting mixtures, casing running.

In recent years, wells in the United States have been mainly drilled at a balanced pressure in the well-reservoir system using the required composition of fillers.

According to the authors of the collection, the problem of liquidation of absorption zones in the United States is considered practically solved. On the one hand, it is necessary to recognize the high level of technology for passing absorption zones in the USA, on the other hand, the stratigraphic section of the deposits is characterized by the absence of huge carbonate cavernous-fractured strata.

Thus, the above brief analysis shows that when drilling geothermal wells, in order to prevent complications and to improve technical and economic indicators, it is necessary to develop the following complex methods and technological tasks:

- high temperature destroys the present polymer additives present in the drilling fluid and reduces the viscosity of the drilling fluid, thereby deteriorating its characteristics and creating serious problems for drilling operations;
- influence of temperature difference in the "well-formation" system on complications in the drilling of geothermal wells;
- based on the analysis of field data, water sources, the concept of alternative energy development in the Republic of Azerbaijan were studied;
- development of innovative scientific methods and models for determining the influence of the temperature factor on complications in the drilling of geothermal wells;
- study of the influence of time on complications during drilling of unstable borehole walls in the process of drilling - to implement the results of the study in production and determine their impact on technical and economic indicators.

The second chapter discusses the development of thermohydrodynamic methods for drilling wells on geothermal sources, in order to obtain alternative energy.

In connection with the continuous growth of world energy consumption and the gradual depletion of the traditional source of its oil and gas, coal in the earth's crust, the attention of scientists and specialists is focused on the search for new sources of energy. At the same time, very promising geothermal energy is of particular importance, since its reserves are not limited, and its use does not cause environmental degradation.

The carrier of the deep heat of the Earth is thermal water and porohydrotheria. Their use in the electric power industry competes with oil, gas, coal, peat, both in economic and sanitary and hygienic terms.

In addition, the energy crisis, irresistibly approaching the world economy, puts forward the use of thermal waters, one of the renewable sources of geothermal energy, among the most important problems of our time.

An analysis of geological materials shows that in the Talysh-Lenkoran zone, thermal waters with a temperature of about 100^0C can be discovered by deep wells.

The Lesser Caucasus is of particular interest in terms of the geothermal regime. In its central and southern parts, thermal waters are confined mainly to areas of development of igneous rocks, mainly Quaternary volcanism. A feature of the geology of the thermoanomalous sections of this region is the superposition of the anti-Caucasian (transverse-Caucasian) folding on the more ancient folding of the northwestern direction.

The well-known resort area Istisu (Kelbajar district) for more than 40 km along the valley of the river. Istisu is characterized by an anomalous thermal regime. The geothermal step on the southern slopes (the resort of Istisu and the Bagyrsakh site) decreases to 2-5 m or less, and for the entire resort area it is close to 18 m/^{0}C, i.e. is also much less than the average for the Earth's crust.

In tectonically broken areas, an increase in temperature is sometimes traced up to the surface, and the release of carbon dioxide gas jets is observed. As drilling operations have shown, the temperature of thermal waters in the Bagyrsakh site increases rapidly with depth and reaches 80^0C at a depth of about 100 m.

In the Caspian-Cuban zone (SE slope of the Greater Caucasus), 8 specially drilled wells discovered thermal waters with a temperature of 50-84^0C and a total flow rate of 12,360 m^3/day.

The amount of heat carried out by water is 4.2x106 Kcal (12MW).

The world experience of recent years in the construction of geothermal power and heat stations shows the following technical parameters for economically viable facilities: the minimum temperatures at the mouth of geothermal wells should be:

- to generate electricity 120^0C
- to obtain heat 80^0C.

At the stage of creating a technological scheme for the development of geothermal fields, the requirements for the production of drilling operations should include the development of conventional vertical, inclined and horizontal wells into branching multilateral wells. At the same time, to develop typical designs of wells and types of the design profile of the trunk for the construction of branching multilateral wells. For drilling branching multilateral wells, a complex of technical means, currently used in the construction of sidetracks, can be used.

To increase the flow rate of geothermal wells, it is proposed to drill multilateral wells (Fig. 2.4). At the same time, based on the selected hydrodynamic parameters and using the Mascat-Bochever hydrodynamic method, we determine:

$$\sum_{i=1}^{n} Q = \frac{2\pi \sum_{i=1}^{n} k_{mi} S_i}{\frac{2\sum_{i=1}^{n} a_i t_i}{r_{ki}^2} + ln\frac{r_{ki}}{r_i} - 0,75}$$

where Q – well productivity, m^3/day

k_m - water permeability of complexes, m^2/day

S - allowable level reduction, m

a – thermal conductivity, m^2/day

t - estimated service life (10^4day)

r - well radius, m

$r_к$ – radius of conditional power circuit, m, π =3,14

n – number of wells

$$r = \sqrt{\frac{F}{\pi}}$$

where, F - area of thermal water intakes

The filtration coefficient is determined by the value of the permeability of water-bearing rocks

$к_ф$ = У/μ - $к_{пр}$

where У – specific gravity of thermal water, taken 1,0-1,01 g/sm^3

μ – dynamic viscosity of water adoption 0,01 N

$к_{пр}$ - rock permeability coefficient, MD.

According to this formula, the coefficient of filtration of rocks of productive deposits of the Caspian-Guba oil and gas region is calculated. The admissible decrease in the level was determined by the effective power of the thermal water-bearing complex according to the value s=0.5.

In the third chapter, the influence of the temperature factor of the drilling fluid on the occurrence of complications in the process of drilling geothermal wells is studied.

It seems of particular interest to study the efficiency of geothermal well drilling, which can be provided as a control parameter - to apply the temperature of the drilling fluid entering the drilling well. Studies show that in some cases, with significant values of the temperature difference between the bottomhole formation zone and the drilling fluid, in accordance with the Joule-Thomson effect, the values of pressure drops in geothermal wells can be significant. The above becomes relevant especially in those cases where traditional hydrodynamic methods do not give an effect.

When calculating the balance of hydrodynamic pressure on the walls of geothermal wells, it is necessary to take into account the Joule-Thomson effect. Having a temperature differential to balance the pressure allows you to maintain a normal drilling process by controlling the temperature of the drilling fluid.

The task is formed as follows: what should be the temperature of the drilling fluid at the inlet to the drilling geothermal well, so that from a hydrodynamic point of view, the drilling process proceeds without complications.

It is known that the pressure in the well is defined as the sum of the hydrostatic pressure of the drilling fluid column and the hydrodynamic pressure due to the movement of the drilling fluid in the well Pg.d., i.e.

$$P_{скв} = \gamma l + P_{г.д.}$$

where l – well depth;

γ – specific gravity of the drilling fluid.

The pressure in the bottomhole formation zone is usually, as noted above, calculated without taking into account the Joule-Thomson effect.

Taking into account the Joule-Thomson effect, the pressure in the bottomhole zone is determined by the formula:

$$P'_{пл} = P_{пл} + \frac{1}{\alpha}(T_{пл} - T_{скв})$$

From the hydrodynamic and thermophysical points of view, the normal process of drilling geothermal wells will be provided if the following conditions are met:

$$\gamma l + P_{\text{г.д.}} = P_{\text{пл}} + \frac{1}{\alpha}(T_{\text{пл}} - T_{\text{скв}}).$$

According to the well-known Darcy-Weisbach formula and taking into account the Joule-Thomson effect, after some mathematical transformations, the corresponding formulas were obtained to determine the thermohydrodynamic pressure in the annulus.

Thus, based on the Joule-Thomson effect, the presence of a temperature difference that ensures the balance of pressure makes it possible to maintain a normal drilling process by controlling the temperature of the drilling fluid and is one of the effective parameters for controlling drilling technological processes that prevent wall deformation wells.

The same chapter also proposes a method for preventing lost circulation during drilling of geothermal wells. Based on theoretical studies and processing of field data, it was found that the Joule-Thomson effect occurs in the well-bottomhole formation zone, which can be used to prevent certain types of complications and accidents encountered during well drilling. The essence of the application of the Joule-Thomson effect when drilling wells to control some processes is to compensate for the pressure drop (ΔP) by backpressure (ΔP_0) due to the temperature difference between the bottomhole formation zone and the well. At the same time, accidents caused by pressure drops are also prevented. The process of compensating for pressure drop by backpressure can be carried out in various ways. However, the most realistic way, in our opinion, is the method based on the regulation of the wellhead temperature of the drilling fluid. Thus, the problem is formulated as follows: what should be the temperature of the drilling fluid at the wellhead so that the backpressure arising due to the Joule-Thomson effect compensates for the pressure drop between the well and the bottomhole formation zone.

Thus, at a known temperature (T_{20}), the temperature of the outgoing drilling fluid (T_{10}), which provides normal conditions for the circulation of the drilling fluid, allows us to draw conclusions about the change in temperature at the wellhead, as well as at the entrance and exit from wells to regulate the pressure drop in the "well-formation" system.

This chapter proposes a method for eliminating stuck drilling tools when drilling geothermal wells. Sticking of the drilling tool when drilling geothermal wells belongs to the category of the most severe types of complications and, as a rule, leads to large material losses. A number of technological factors have a significant influence on the process of occurrence of sticking.

So, in practice, sticking often occurs due to jamming of the bits. Of course, many objective and subjective reasons contribute to this, in particular, the discrepancy between the type of rock cutting tool and the rock being drilled, the wrong choice of drilling mode parameters, poor-quality cleaning of the bottom hole from cuttings, the presence of a washed pipe in the drill string, etc. However, already estimated calculations can show that during long-term (continuous) operation of the rock cutting tool at the bottom and its unsatisfactory cooling, thermal expansion of the bit by 2-4 mm can occur. And with good compatibility of the type of rock cutting tool with the rock being drilled, this interval, drilled without taking the bit off the bottom, may have an irregular cylindrical shape, which in this case is the root cause of jamming. It follows that when drilling out intervals that are dangerous from the point of view of bit jamming, it is necessary to reduce the duration of continuous drilling.

The essence of the proposed method for preventing accidents and complications when drilling geothermal wells, based on the Joule-Thomson effect, is as follows:

- the temperature factor should be taken into account when drilling geothermal wells;
- when the density decreases due to temperature changes, there is no need to thicken the drilling fluid, but it is necessary to regulate its density by passing the drilling fluid through a degasser. In this case, the weighting of the drilling fluid can lead to additional complications in the wellbore (sticking of the drilling tool, loss of drilling fluid, etc.).
- as an optimal option, it was proposed that the value of the temperature change during technological operations in the well

(flushing, drilling) be equal to the hydrodynamic resistance created in the annulus. That is;

$$P_{г.д.с} = \frac{1}{\alpha}\left(T_{пл} - T_{ck}\right)$$

- depending on the temperature, the change in the structural viscosity and ultimate shear stress of the drilling fluid has a strong influence on the pressure in the well when the drilling tool is lowered. In this regard, this factor should be taken into account in order to avoid complications when drilling geothermal wells.

In this chapter, based on theoretical and field data, an attempt is made to determine the static and dynamic deformations of rocks during the reciprocation of a stuck drilling tool, taking into account such basic factors as contact temperature, friction force, contact pressure, mechanical properties and geometric dimensions of the contacting bodies . It is assumed that the surface of one of them is an elastic layer (permeable rocks), and the second is a rigid body (drill pipes), which is pressed against the elastic one with some force.

The chapter outlines the determination of the permeability of water-saturated rocks when drilling geothermal wells.

The most common and powerful source of thermal energy on Earth is the heat of water-saturated and dry rocks. In many areas at a depth of 3-5 km is 150-250%. A typical temperature rise depends on the depth of the earth and is approximately 2.5-3°C for every 100 meters of depth. At a depth of 5 km, the temperature is approximately 125°C, and at 10 km, about 250°C. The rate of temperature increase with depth varies significantly throughout the

Earth by a factor of 25!

Based on the collection of analysis of hydrogeological and geothermal data from deep exploration wells for oil, gas and geothermal waters, as well as our own lithological and hydrogeological studies, a thermal energy resource model was developed for the formation and distribution of geothermal waters in the Cretaceous and Paleogene deposits of the Yevlakh-Agjabedi thermal artesian basin.

Despite the relevance of the topic, at present, thermo-hydrodynamic studies of geothermal wells have been little studied. Therefore, this paper proposes to determine the permeability of water-saturated rocks based on information about the change in flow rate and pressure of the drilling fluid over time, obtained from the wellhead. The method is based on the exact solution of the inverse problem of quasi-dimensional unsteady motion of a viscoelastic medium in pipes and annular space using the Laplace transform.

The solution of the inverse problem is to determine the constant coefficients included in the differential equations and in the boundary conditions.

In the fourth chapter of the dissertation work, studies are given on the influence of thermophysical and rheological characteristics on the properties of drilling and cement slurries when drilling geothermal wells.

Movement of drilling and cement slurries with constant thermal properties in the pipe-annulus system. It is important to take into account the average velocity V_i. It is assumed that the change in temperature in the axial direction is greater than the change in temperature in the radial direction.

The change in the temperature of the flow of drilling and cement slurries along the depth of geothermal wells can be determined by solving the differential equation:

$$\frac{\partial T_i}{\partial t} + V_i \frac{\partial T_i}{\partial z} = \alpha_i^2 \frac{\partial^2 T_i}{\partial z^2} \qquad (1)$$

initial and boundary conditions are given in the following form:

$$T_i(z,0) = T_{i0} + A_i z;\ T_1(0,t) = f(t)$$
$$T_i(l,t) = T_{i0} = const;\ \frac{\lambda_1}{\lambda_2}\frac{\partial T_1}{\partial z}(l,t) = \frac{\partial T_2}{\partial z}(l,t) \qquad (2)$$

where T_i – drilling or cement slurry temperature;;

A_i – temperature gradient;

z – coordinate;

a_i – temperature-conductivity coefficient;

l – depth of the well;

λ_1, λ_2 – thermal conductivity coefficients of the pipe and the annular space, respectively.

The essence of the proposed method is to determine the thermal characteristics of the flow of drilling and cement slurries using the solution of equation (1) under conditions (2) and with an additionally given boundary condition:

$$T_2(0,t) = \varphi(t) \tag{3}$$

To solve the formulated problem, the Laplace transform is used.

The coefficient of thermal conductivity of drilling and cement slurries varies over time depending on the temperature at the wellhead, so it can be determined by measuring the change in temperature over time. Can be used to measure temperature over time at a specific location in a well. This change in temperature can be constant or change over time.

Now consider the case when the bottom hole temperature changes with time.

We will consider the movement of drilling fluid with constant thermal properties in the pipe-annulus system with an average speed .

It is assumed that the change in temperature in the axial direction is greater than the change in the radial direction. The change in the temperature of the drilling fluid flow along the depth of the well is determined by solving the differential equation:

$$\frac{\partial T_i}{\partial t} + V_i \frac{\partial T_i}{\partial z} = \alpha_i^2 \frac{\partial^2 T_i}{\partial z^2} \quad (i = 1,2) \tag{4}$$

The initial and boundary conditions are set as follows:

$$T_i(z,0) = T_{i0} + A_i z; \quad T_1(0,t) = f(t) \tag{5}$$

$$T_2(\ell,t) = \psi(t)$$

$$\frac{\lambda_1}{\lambda_2}\frac{\partial T_1}{\partial z}(\ell,t) = \frac{\partial T_2}{\partial z}(\ell,t) \tag{6}$$

The essence of the proposed method is to determine the coefficient of thermal conductivity of the drilling fluid flow using the solution of equation (6) under conditions (7) and with an additionally given boundary condition:

$$T_2(0,t) = \varphi(t) \tag{7}$$

Applying the Laplace transform, we get:

$$\alpha_i^2 \frac{d^2 T_i^*}{dz^2} = ST_i^* - (T_{io} - A_i z) + V_i \frac{dT_i^*}{dz} \tag{8}$$

Hence, given that the process of temperature recovery is relatively slow, we can assume that s<<1 and, therefore

$$k_{i1} = 0;\ k_{i2} = \frac{V_i}{\alpha_i^2}.$$

The value of hydrostatic pressure is determined by multiplying the specific gravity of the drilling fluid (measured in natural conditions) by the depth of the well.

However, this does not take into account the fact that the drilling fluid in the well, due to the combined influence of pressures and temperatures, changes its volume and density, which affects how much it is able to push through the soil. As a result of pressure, it shrinks. However, since it is also affected by temperature, it expands.

Statistically, under the condition of a linear increase in pressure and temperature with depth, the formula for calculating the hydrostatic pressure in the well can be represented as follows:

$$P = \gamma \cdot H \cdot \varepsilon$$

where, $\varepsilon = \frac{2 - \mathrm{a} \cdot \Gamma \cdot \mathrm{H}}{2 - b\gamma H}$ - correction factor:

γ - specific gravity of the drilling fluid at the wellhead, N/m^3;

H – depth of the well, m;

Г – geothermal gradient, ^{0}C/m;

a – coefficient of isobaric thermal expansion, 1/^{0}C;

b – coefficient of isothermal compressibility versus pressure, 1/Па.

On fig. Fig.1 shows the regularity of the change in hydrostatic pressure with depth, built on the basis of formula (8) for real drilling conditions (γ=1400 N/m^3; a=4•10^{-4} 1/^{0}C; b=4•10^{-10} 1/Pa).

As can be seen from Fig. 1, the value of the isothermal gradient has a significant impact on the value of the hydrostatic pressure on the bottom of the well. This is because a and b are zero when the isothermal gradient is constant. At the same time, as the well depth increases, the discrepancy in the results of hydrostatic pressure calculations increases, sometimes reaching 10 MPa or more.

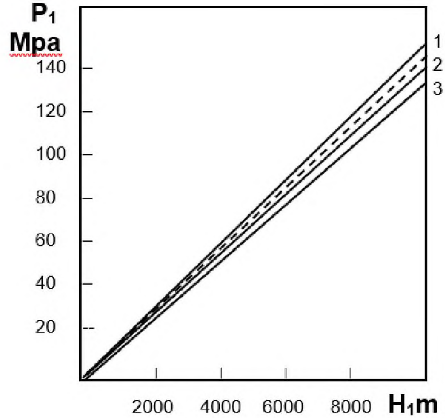

Fig. 1 Hydrostatic pressure in the well compared with the depth of the well:

1;2;3 – Г = 0; 0,02; 0,04⁰c/м respectively

One of the most common problems in deep well drilling is the release of gas or liquid from the formation after drilling is stopped. At the same time, due to periods of tripping, geophysical measurements, repair work, etc., the period of actual downtime can reach several days.

Example. During intermediate flushing of hydrostatic pressure in well No. 8 of the Zardob area at a depth of about 4158 meters, after raising and lowering the drilling tool, a decrease in pressure occurred. At a temperature of 115°C, the drilling fluid density decreased from 1.97 to 1.45 g/cm^3. The next flushing phase occurs after the initial density is restored and the drilling tool enters directly into the near-wellbore zone. Density changes began to occur in the downhole mud flow. A number of similar phenomena are observed during the drilling of most deep and high-temperature wells drilled in the exploration areas of Azerbaijan.

As mentioned earlier, the regulation of hydrostatic pressure by increasing the density of the drilling fluid at high temperatures is impractical. Therefore, it is necessary to take measures to improve the sedimentation stability of drilling fluids. One of the most realistic ways in this case is the widespread use in the process of drilling deep wells of chemical reagents based on water-soluble polymers that ensure the stability of drilling fluids at high temperatures, as well as powdered weighting agents, which do not contain large-sized particles and do not form massive floccules when introduced into the drilling fluid.

Further in this chapter, a method is proposed for determining the allowable rate of descent into the well of drill and casing strings when drilling geothermal wells.

The simultaneous increase in pressure and temperature in the annular space of the well during the descent of the pipe string leads to the need to determine the rate of descent, which excludes the possibility of both hydraulic and thermal fracturing.

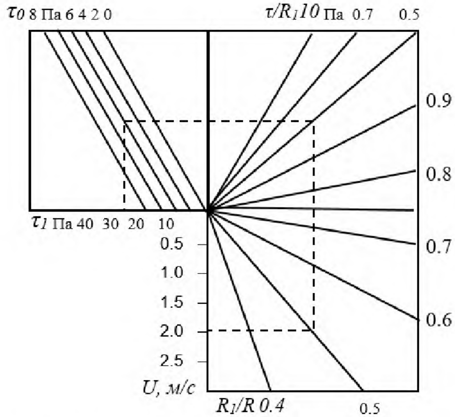

Fig. 2. Nomogram for determining the shear stress that occurs during the structural mode of movement of the drilling fluid in the annulus of the well during the descent of the pipe string

To facilitate calculations under production conditions, based on these studies, nomograms (Fig. 2) were constructed to determine the shear stress in the annular space under structural and turbulent modes of movement of the upward flow of drilling fluid during the descent of drilling and casing strings.

The nomogram for the structural mode of motion is built according to the formula obtained as a result of some simplification:

$$\tau=[u\eta/\ln R_2/R_1]\cdot[1/(R_2-R_1)+3(R_2+R_1)/2(R_2-R_1)]+2\tau_0$$

When constructing a nomogram for a turbulent motion regime, the following formula was used:

$$\tau = \varphi\rho u^2/32\ln^2 R_2/R_1$$

In addition, in the turbulent mode of movement of the upward flow of drilling fluid in the annulus, which occurs during the descent of drilling and casing strings into the well, the value of the generalized Reynolds parameter usually does not exceed 4000. In accordance with this, the hydraulic resistance coefficient in the annulus changes ranging from 0.03 to 0.035.

Naturally, in practice, especially in wells, in the geological section of which there are thermally unstable rocks, the rate of descent of the drill or casing string should be determined from the condition of ensuring fluctuations in both temperature and hydrodynamic pressure within acceptable limits. At the same time, on the basis of the proposed nomograms, the critical values of the string descent rates are determined, respectively, for hydraulic and thermal fracturing, and the smaller of them, taking into account the safety factor equal to 0.75, is recommended for use.

n this chapter, the influence of the strength of the electromagnetic field on the thermal conductivity of the drilling fluid during the drilling of geothermal wells was considered.

The movement of a conductive drilling fluid with electrical conductivity in a round pipe was considered. Let us assume that the intensity of the uniform magnetic field H (or induction B) is directed perpendicular to the movement of the drilling fluid, and the intensity of the uniform electric field E is perpendicular to B.

The differential equation of heat conduction for non-stationary motion of a conducting fluid in the presence of a transverse electromagnetic field has the form:

$$\frac{\partial T}{\partial t}+V\frac{\partial T}{\partial z}=\alpha\frac{\partial^2 T_i}{\partial z^2}+\sigma(E+VB)^2$$

This dependence is qualitatively similar to the obtained experimental dependences of pure metals.

Note that the parameter B significantly affects the values of $\bar{\lambda}$, and with an increase in E, at the same values of $\bar{T}$, the dimensionless thermal conductivity increases. At low temperatures, the effect of E on thermal conductivity becomes especially noticeable - an increase in B can increase by several orders of magnitude.

Creation of reliable methods and models for optimizing geothermal systems is one of the most important links in the chain of interrelated problems of the development of thermal energy of the bowels.

Formulation of the problem.

This interaction can be regulated in two directions:

- filtration of the drilling fluid and regulation of the rheological properties of the filtered part;
- the permeability of water-saturated sediments is controlled by adding various chemical additives to the drilling fluid.

The stress state of the rocks that make up the walls of the well, which accompanies the drilling process, is influenced by various factors, including the value of the hydrodynamic pressure arising in the well and its change, as well as filtration, structural mechanics, rheological properties and physicochemical parameters of drilling solutions.

It is known that the destruction of rocks that occurs as a result of deformation of the walls of the well leads to landslides and collapses, which in turn leads to a decrease in the technical and economic indicators of drilling, and in some cases to the abandonment of the well. Since clayey sediments form the main part of the geological section in most fields in Azerbaijan, this problem is very relevant for drilling geothermal wells. At present, some proposals have been put forward in Azerbaijan and abroad on this issue and various events have been held. These works, depending on voltage regulation, are divided into three areas: pressure in the wellbore, filtration and regulation of physical and chemical processes. The essence of the activities carried out in the second and third directions is the addition of special inhibitor additives to the drilling fluid. However, since most of these additives are produced for drilling oil and gas wells, this has not been considered for drilling geothermal wells.

In this regard, field data have been collected in areas where deep geothermal wells are being drilled.

CONCLUSIONS AND RECOMMENDATION

1. Based on the analysis of drilled geothermal wells in the territory of the Republic of Azerbaijan, the thermohydrodynamic features of drilling were studied and the map of areas with thermal fields was refined.

2. On the basis of theoretical studies, a method has been developed to prevent sticking of a drilling tool. It is shown that the need to maintain the equality of the value of temperature changes during technological operations in the well (flushing, drilling) to the hydrodynamic resistance created in the annulus.

3. Based on thermohydrodynamic studies, a method was developed to prevent loss of drilling fluid and the effect of temperature difference in the well-formation system during drilling of geothermal wells was assessed.

4. The influence of the temperature factor on the value of hydrostatic pressure has been studied. It has been established that with a change in temperature by 1°C, the pressure changes by 0.4 MPa.

5. On the basis of theoretical studies, the influence of the electromagnetic field strength on the thermal conductivity of the drilling fluid was studied and a method was proposed for determining the thermophysical properties of drilling and cement mortars.

6. Based on the application of the Laplace transform, the coefficients of thermal conductivity of drilling and cement slurries were determined when drilling geothermal wells. It is shown that the temperature gradient (A) significantly affects the values of thermal conductivity $\bar{\lambda}$, and at the same temperatures $(\bar{T})$, with an increase in the electric field strength (E), the dimensionless thermal conductivity increases.

7. The developed method for determining the influence of the temperature factor on the change in the density of the drilling fluid was applied to the well No. 1862 of the Sadan area and the well No. 1703 of Lokbatan-Puta-Gushkhan of the Azneft Production Association. Both wells were successfully drilled to the design depth without any complications.

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Personal contribution of the applicant

Works [5, 8, 11, 13] were carried out independently, in works [1-4, 6–7, 9, 10, 12] participation in setting the problem, conducting research and summarizing the results, in work [14] participation in formulation of the problem and generalization of the results.

The defense of the dissertation will be held at 11 a.m. on June 24, 2024 at the meeting of the ED 2.03 – Dissertation Council operating under the Azerbaijan State Oil and Industry University.

Address: AZ1010, Baku city, D. Aliyeva st., 227.

It is possible to get acquainted with the dissertation in the library of Azerbaijan State Oil and Industry University.

Electronic versions of the dissertation and abstract are posted on the official website of Azerbaijan State Oil and Industry University.

Abstract of 24 May 2024 year sent to the required addresses

Signed for publication 17.05.2024.
Paper Size: A5
Volume: 40593
Number of prints: 20