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ABSTRACT

of the dissertation for the degree of Doctor of Philosophy

IMPROVEMENT OF TECHNOLOGICAL SOLUTIONS WHEN DRILLING INCLINED WELLS IN LAYERS WITH HIGH DEVIATION ANGLES

Speciality: 2523.01 – “Well drilling technology”

Field of science: Technical sciences

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GENERAL CHARACTERISTICS OF THE WORK

Relevance of the problem. Currently, it is planned to achieve the main part of the current oil and gas reserves, and in the near future, to ensure a high production level of hydrocarbons due to the exploitation of offshore deposits.

In the old oil and gas extraction regions, the decrease in reservoir pressure, lower production, and high dilution of wells are the result of intensive exploitation of oil and gas fields. There is a need to search for new technical means and technologies for drilling wells in complex geological conditions.

Drilling of inclined, horizontal and multi-bottom wells is also being carried out in areas with difficult terrain and already exploited deposits. At this time, the effectiveness and quality of the results of the work are determined by the accuracy of the realization of the well project profile. The practice of drilling inclined and horizontal wells is primarily due to the insufficient study of geological sections, the lack of realization of the project profile and the decrease in the efficiency of geophysical research.

It should be noted that Azerbaijani drillers have achieved improvement of drilling quality and mechanical speed of inclined wells on projects developed for complex conditions in a number of fields of Azerbaijan, minimizing the occurrence of accidents and complications.

However, the continuous increase in the depth and deviation of inclined wells, the future improvement of techniques and technology during the complication of drilling conditions, increasing the accuracy of the management of inclination parameters, and reducing the resources and time for drilling wells, and their costs. The applied drilling technology of directional wells is based on solutions developed in the 70s and 80s of the last century. Therefore, the improvement of the quality of the construction of inclined and horizontal wells, the application of the technology of the multi-bottom wells construction is impossible without the development of new modeling methods and the testing of new technical and technological solutions.

Thus, the problem of developing scientific-methodical, technological and technical solutions that allow ensuring the high quality of inclined wellbores formed in complex geological conditions is urgent.

Purpose of work. Improvement of technological solutions by increasing the accuracy and quality of drilling inclined oriented wells taking into account the characteristics of layers.

Research object. Technologies for drilling inclined multiple wells from a sea base.

Research subject. Analysis, accuracy and quality assessment of inclined well drilling technologies.

The main tasks of the study:

- review and summarization of scientific-technical and patent literature information on drilling efficiency of inclined wells of various authors;
- analysis of the factors affecting the quality of the inclined well drilling process;
- development of the scheme of calculation of the vertical and horizontal projections of the well and the optimal number of inclined multiple wells, taking into account their coordinates, the probability of interception of wellbores;
- analysis of resistance forces and friction coefficients in different layers based on the analysis of complex geological-technological information during the drilling of inclined wells;
- development of practical recommendations for improving the quality of drilling inclined wells and development of practical recommendations for environmental protection, decision making.

Problem solving methods. Probability-statistical methods were used during processing and analysis of primary data. During the drilling of inclined wells with the help of those methods, the factors that play a role in choosing the number of drilled multiple wells based on the inclinometric measurements of the wellbore, and the resistance forces formed against the movement of the drilling tool were analyzed. These methods made it possible to reveal and analyze the cause-and-effect relationships between the factors considered in the dissertation work.

Scientific novelty of the work:

- an algorithm allowing to specify the coordinates of multiple wells was proposed, taking into account the errors during the measurement of the optimized orientation of the wells and the distance between them, the azimuth and zenith angles, and avoiding the interception of wellbores;
- the number of wells with a multiple inclination is justified from the point of view of technical and economic factors, and an algorithm for determining their optimal valve is proposed;
- an improved calculation scheme for determining the friction coefficient is proposed as a result of the analysis of the resistance forces against the movement of the drilling tool.
- as a result of the analysis of the danger of the drilling waste discharged from the well during drilling, a methodology for assessing of environmental risks was proposed.

Defensive clauses:

- the algorithm for determining the coordinates of multiple wells and avoiding the interception of wellbore;
- algorithm for determining the optimal number of wells during multiple drilling;
- analysis of the forces of resistance to the movement of the drilling tool and the factors influencing them.

The practical importance of the work. When drilling multiple wells, a well-reasoned selection of well coordinates, their profile and the optimal number plays a key role. The number and profile of the selected wells should be directed to the intended goal, first of all, to prevent the wellbore interception. As in any process, drilling inclined wells requires a minimal investment of time and resources. In the thesis work, the justification of the selection of the well profile in the construction project of the inclined wells, the calculation of the wellhead coordinates, the errors of measuring the angles are reflected along with other parameters.

Profile of inclined wells should be fast and qualitative, technically feasible, economically viable. In this regard, the studies carried out in the work allow to take into account the errors in the calculation of angular parameters of inclined wells, wellhead coordinates. The calculation scheme proposed in the work made it possible to economically justify the optimal number of wells within the block. In addition to the mentioned, their calculation results, taking into account the factors affecting the resistance forces and the friction coefficient, confirm the practical importance of the dissertation, taking their place in the design of inclined well construction projects in the future.

Approval of work. The main provisions of the dissertation were presented at the following scientific conferences:

1. A collection of scientific articles on the conclusion of priority directions of innovation activity in industry. VII International scientific conference (Kazan, 2021).
2. "World and Russian science: Development and innovation" (Moscow, 2022).
3. Bulatov readings. VI International scientific-practical conference (Krasnodar, 2022).
4. International scientific and technical conference dedicated to the 75th anniversary of the Ufa State Oil Technical University (March 24, 2023).
5. Technical and technological systems. Proceedings of the XIV International scientific conference Krasnodar 2023.
6. Oil and Gas Institute of the Ministry of Science and Education. Republican scientific-practical conference of young scientists and specialists 2023.

Structure and scope of work. The dissertation consists of an introduction, 5 chapters, conclusions and proposals, used sources and appendices. Dissertation generic symbol 215127.

THE MAIN CONTENT OF THE DISSERTATION WORK

In the introduction, the main provisions of the dissertation are given, the relevance of the research conducted on the topic of the dissertation is justified, its scientific innovations and the methods of solving the issues are explained.

The first chapter is devoted to the analysis of the current state of scientific researches devoted to the complications related to the properties of rocks during the drilling of inclined and multiple wells. Here, the experience and development dynamics of inclined oriented wells are analyzed, and a general scheme covering the period of inclined drilling is given.

The research materials collected up to now show that the conducted research works and their application have had high results, and despite this, there is still a need for further improvement of the technique and technology aimed at the full verticality of the upper intervals of the wells and more correct orientation of the wellbore. Also, it is necessary to do serious work in the field of creating a technique that allows controlling the curvature parameters of inclined wells from the wellhead. In the first chapter, an overview of the studies devoted to the analysis and provision of the stability of the well walls was briefly given and analyzed. It has been shown that the well drilling process is characterized by complex mountain-geological conditions. Here, during drilling, one can find rocks with different physical and mechanical properties, which are exposed to different values of pressure, temperature, and different fluids. Due to their influence, the drilling conditions become complicated and the successful implementation of the process becomes much more difficult. As mentioned in many works, the failure of well wall stability occurs mainly in clayey rocks.

Thus, the review of scientific research works dedicated to the drilling of inclined wells in different conditions showed the conduct of deep, fundamental scientific research in the direction of development and improvement of new technologies. Among them, it is possible to mention the works related to the study of the influence of the characteristics of rocks on the quality of drilling wells based on geophysical, geotechnological studies, and geomechanical modeling. It should be noted that, up to now, many works have been carried out on the improvement and development of the technology of drilling inclined wells, the study of the influence of various factors on it, and important results have been obtained. In many fields, the need to pay attention to the accuracy of the process, the justification of the location points of the wells, in addition, to the drilling of multiple inclined wells in many fields, requires the introduction of new issues of drilling management, including both from the point of view of direction (zenith and azimuth angles) as well as to determine the exact location of objects (in the spatial coordinate system).

The review shows that the experience of drilling wells and the analysis of their results is one of the important issues. This allows to formulate the goal of the scientific research at the initial stage, around which a literature review and critical analysis should be conducted, to define and form the main tasks, methods, and methodology of the goal-oriented research.

In this regard, based on the analysis and discussion of the experience and results of drilling wells in various fields, we identified the problem that should be focused on, and which defines the purpose of this work, that is, the improvement of technological solutions by increasing the accuracy and quality of drilling inclined oriented wells taking into account the characteristics of the layers.

Methodologically, these researches can be considered as part of a single system, the elements of which are located at different levels, the approximate scheme of which is shown in Figure 1. As it can be seen from the scheme, different methods, tools, techniques and principles are applied at each level.

This system includes the following elements as a component: object; subject and tasks of the research, methods and means of their solution. The analysis of the studies on the problem considered in the previous section allows to formulate the main research questions.

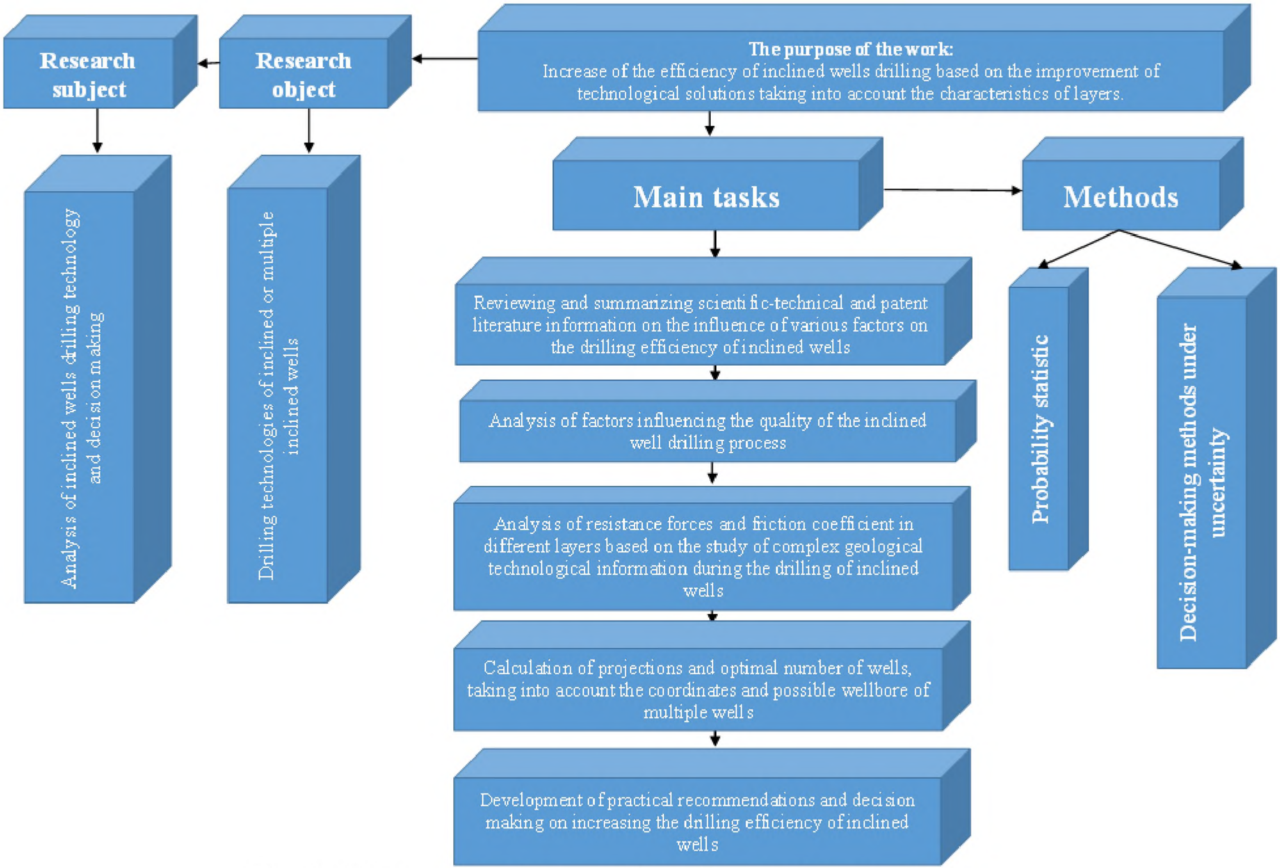

Fig. 1. Structural scheme of the dissertation work.

Thus, in the review given in the first chapter, the modern state of the problems of predicting the stability of well walls and geomechanical modeling were considered. From the review of the literature, it can be concluded that the reduction of time and material costs for the prediction, prevention and elimination of complications during well drilling is one of the most important directions of increasing the efficiency and quality of well construction.

A brief overview of the researches, as well as the role and importance of geomechanical modeling during the assessment and prediction of possible complexation intervals, showed that in connection with this, it is necessary to conduct complex geophysical, hydrodynamic and geological-technological studies during the drilling of wells.

As it can be seen from the above overview, the methods and tools used in the management of the well in foreign practice, mainly the control node, the obtaining of information, the regulation of the wellbore, as well as various tools and equipment that ensure the drilling of layers with a small thickness, have been developed and applied. The system of measurements made during drilling allows the process to be carried out in automatic mode.

Thus, the literature research and review conducted in the first chapter allow to put forward the following ideas.

1. Predicting, preventing, and reducing the time and materials spent on preventing problems that may arise during well drilling is one of the important directions for improving the efficiency of well construction.
2. The mentioned studies, which can be useful in the construction of inclined and horizontal wells, allow to add the experimental data necessary for the operational study of the properties of the geological section, to evaluate the real capabilities of the software of the corresponding methods in practice.
3. It allows to effectively plan future work on relevant information and methodology, to choose better research methods and to reduce decision-making time for the analysis of the results of drilling inclined and horizontal wells related to the study of azimuth and zenith angles of the well.

The second chapter is devoted to the assessment of the drilling quality of inclined multiple directed wells in oil and gas fields where inclined multiple wells are applied.

One of the main problems during the drilling of inclined wells is the presence of factors such as high friction in the complex inclined well profile, unsatisfactory elasticity of the drill string and insufficient displacement of the curvature to the opening point of the productive layer, the complexity of the profile due to the high risks of formation of complications - the presence of factors such as finding the coordinates of the final wellbores. In order to increase the efficiency of drilling multiple wells at different times, calculation schemes providing for the stepwise optimization of the profiles and projections of the wells based on the coordinates of the wellhead were proposed and implemented, as a result of which effective and economically justified technical-technological solutions were developed. It should be noted that in the process of drilling multiple wells, the relevant technology and strategy may change. In the reviewed chapter, the well placement coordinate system was specified during multiple inclined drilling.

Experience shows that multiple drilling allows to significantly reduce the volume of work related to construction and installation operations, i.e. the volume of construction of roads, electric and communication lines, to reduce the volume of transportation, etc.

Drilling wells by the multiple method has a number of significant advantages. First of all, it is economically profitable, because the costs of funds and time for the organization of areas for wells, access roads and other communications are significantly reduced, the time for constructing wells, adjusting areas, operation and maintenance is significantly reduced.

In addition, multiple drilling is also beneficial from an environmental point of view, as it can significantly reduce the area of contaminated soil that is drilled. However, since offshore inclined wells are multiply drilled, new drilling technologies require the development of technical means and equipment.

One of the main characteristics of the drilling of multiple inclined wells is the possibility of interception of wellbore during drilling. The prevention of the interception of the wellbore during the drilling of inclined multiple wells is related to it.

Before drilling a specific inclined well, geological data obtaining and analysis are usually carried out, and geomechanical models are built taking into account all preliminary data as much as possible. At this time, taking into account the coordinates of their well heads, the methods of selecting the coordinates of well bottoms are applied on the basis of calculations. In order to optimize the profiles of inclined wells, it is possible to consider both the displacement of the coordinates at the bottom of the wells, at the point of access to the formation and the change of the azimuth of the wellbore, as well as the option of drilling neighboring multiple wells.

In this regard, in the current section of the work, a calculation scheme allowing to estimate the curvature parameters of multiple wells is given based on the information about the wellhead coordinates. As a rule, during the development and design of measures to prevent the interception and collision of inclined multiple inclined - wellbores, problems arise due to the incompatibility of the software in designing the conditions for calculating the drilled track and the curvature parameters of multiple wells.

The structures of multiple wells drilled from a sea bed differ in the system of coordinates selected during the construction of the sea bed, the method of directing the inclined well bores to different azimuth directions of the trajectory, and the vertical depths of the wells. In this case, it is necessary to clarify the data on the wells with the help of the data on the previously drilled wells. The optimization technology for avoiding the interception of a series of inclined wells has been studied by a number of researchers. Thus, in order to evaluate and specify the coordinates of the wells, the mutual position of different well heads, the distance between them, and the interception of the wellbore were considered, and as mentioned in the works of recent years, all this was justified during the design of multiple drilling of wells.

As we know from drilling experience, in the past solving such problems was always done with conventional wellbore anti-collision technology. In many cases, it may happen that a collision does not occur when the forecast indicates a collision, or, on the contrary, the forecast indicates that a collision will not occur, and, as a result, we witness a collision. In order to solve the problem, the causes of the observed event should be analyzed. A review of the collected studies shows that three types of technical solutions are proposed in the literature to prevent wellbore collisions.

As it can be seen from the above discussion, the successful application of the method against the wellbore interception is based on four main conditions:

- the measured trajectory parameters can be in agreement with the actual drilling trajectory in terms of accuracy;
- adjustment of the designed trajectory of the well to the actual drilled trajectory;
- if the adjacent well data is accurate, the actual calculated inclined wellbore trajectory should also be in high agreement with the actual drilled trajectory;
- one of the accurate methods during the development of measures against the interception of inclined wellbores is the scanning method, which allows to accurately determine the relative location of two points in the trajectories.

Errors that may occur will directly affect the results of the anti-collision scan and will also affect the results of the measures to be developed.

Various problems arise during the measures taken against the collision of wellbores. Their occurrence is mainly related to the accuracy of measurement of trajectory curvature parameters of inclined wellbore.

Factors affecting the accuracy of trajectory measurements, accuracy of the inclinometer instrument; whether the measuring equipment is subjected to interference; accuracy of measurement point location; alignment of the tool axis with the well axis, etc.

The accuracy of the inclinometer device, the calculation of the total error of the output as elements of the accuracy index are proposed in the existing literature. Table 1 shows the accuracy of our measurement tools (devices) used in different companies as an example.

Table 1.

Accuracy of inclinometric measuring tools

Device model	Errors		
	Zenith angle $\Delta\alpha$	Azimuth $\Delta\,\varphi$	General $\Delta\beta$
YST-48R	±0.1°	±1.0°	±0.11°
YST-35S	±0.1°	±1.0°	±0.11°
YSS-32	±0.2°	±1.5°	±0.24°
YSS-25	±0.2°	±1.5°	±0.24°
YSS-48F	±0.2°	±1.5°	±0.24°
FES-1	±0.1°	±1.0°	±0.11°
EMS	±0.1°	±1.0°	±0.11°

As it can be seen from Table 1, all instruments have errors of one degree or another during inclinometry.

In order to calculate that error, it is suggested to use the following formula in the available literature:

$$\Delta\beta = 2arcsin\sqrt{sin^2\left(\frac{\Delta\alpha}{2}\right) + sin^2\left(\frac{\Delta\varphi}{2}\right)\cdot sin^2\left(\frac{\Delta\alpha}{2}\right)} \qquad (1)$$

Using the formula (1), the accuracy of measuring tools (devices) applied in different companies has been calculated depending on the accuracy of azimuth and zenith angles and reflected in table 1. In the reviewed chapter, as a result of the analysis and summarization of the works carried out in the Department of Well Drilling of ASOUI until now, the construction and calculation of the plan of multiple wells are given.

As it is known, the number of inclined multiple wells is justified by various indicators, the main of which are the conditions taking into account the following:

- fire safety;

- technical possibilities of well drilling;
- economic feasibility.

1. It is confirmed in the relevant regulations that the productivity of the wells, which are multiple wells drilled from one base, should not exceed 4000 tons, and the gas factor should not exceed $200m^3/m^3$ in order to comply with fire safety.
2. From a technical point of view, the maximum number of wells within the block n_{max} is determined by the following expression:

$$n_{max} = \frac{\pi \cdot a_{inc}^2}{t} \quad (2)$$

$$t = b \cdot h$$

where a_{inc} - the maximum inclination (deflection) of the well from the vertical direction, approved by the norm; t-field processing geometric network density; b-the distance between the horizontal rows of the network; h - the distance between wells in a row in the horizontal direction.
3. Justification of the number of wells from an economic point of view. The followings are taken into account when calculating the number of wells in the economic point of view:
• installation of drilling rig framework, assembly-disassembly works, construction of roads, laying of electric lines, installation of oil transportation lines, etc. Reduction of funds spent on work
• increase in costs due to the necessity of artificial inclination of wells;
• increase in the length of wells along the wellbore.

Methodology for calculating the optimal number of multiple inclined wells drilled on the basis of one sea.

In accordance with current practice and relevant guidelines, the cost of the base of one of the inclined wells for specific conditions is determined by the following formula:

$$C = \frac{1}{m+1} C_0 \left(1 + \frac{m}{n}\right) \quad (3)$$

For example, as mentioned in one of the articles, for the wells drilled by the Nefteyugansk Drilling Department, the statement would be as follows:

$$C = 0{,}2C_0(1 + \frac{4}{n}) \quad (4)$$

Similarly, as a result of the statistical analysis carried out, the following formula was obtained for the multiple wells drilled in the "Neft Dashlari" field:

$$C = \frac{1}{36}C_0(1 + \frac{35}{n}) \quad (5)$$

Here: C – the cost of individual base;

Co - funds that can be spent on the construction of the base during the drilling of one (single) well; n - the number of wells in one multiple.

As a result of the analysis and research, the following statement was obtained for determining the optimal number of wells:

$$n = \sqrt{\frac{0.972C_0}{aa_1\delta_0(1+bk)}} \quad (6)$$

Optimum number drilled from one sea base for the above mentioned "Neft Dashlari" conditions:

$$n_{opt} = \sqrt{\frac{0{,}972C_0}{6\delta_0(1+1{,}5k)}} \quad (7)$$

At the value of the above-mentioned constants, as well as at the value of productivity of inclined and vertical wells $k=1.5$, the optimal number of wells can be determined by the following simple formula:

$$n_{opt} = 0{,}223\sqrt{\frac{C_0}{\delta_0}} \quad (8)$$

The graph of the dependence of (8) is shown in figure 2.

Based on the research conducted in the second chapter, the following can be noted.

An improved calculation scheme is proposed, according to which, the decision on the collection and analysis of data at the initial stage the coordinates of the wells, verification, calculation of the length of the interval necessary to obtain the required values of the aiming azimuth of the probe, the drilling angle, the zenith angle, the required values of the zenith angle and azimuth, the actual received depending on the coordinates of the well bottom, the determination of the value of the pointing angle of the lateral transmitter and the adoption of technological solutions, the correction of the trajectory of the wellbore, changing the assembly based on the results of the comparison of the actual and project profile of the well is performed.

All mentioned stages can form the mathematical basis of problem setting and development of software for control of well trajectories from multiple areas to be drilled from foundations in the considered future field.

An algorithm is proposed that takes into account the relative position and the distance between the wellheads, the evaluation and specifying of the well coordinates, and the goals of avoiding the interception of wellbores.

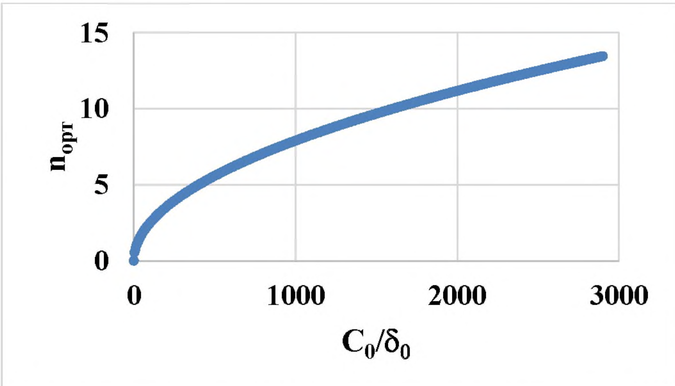

Fig. 2. The dependence of the optimal number of wells on the ratio of the funds that can be spent on the construction of the base during the drilling of one (single) well to the cost of one meter of the vertical well

As production experience shows, well coordinates should be selected correctly, errors should be calculated and taken into account in order to prevent the interception of wellbores. Two wellbore collisions can occur in a dense well spacing in an oilfield or high-density multiple wells in misguided projects. In this regard, it was proposed to calculate the errors that occur when different devices are used during inclinometry measurements.

Thus, control and management of wellbore collision prevention in shelf areas and generally complex geological conditions are clarified. This growing trend requires special attention to prevent wellbore collisions with neighboring wellbores in developed fields. As it is known, production wellbore collisions can cause many accidents. It should be noted that studies conducted by well-known companies, especially Baker Hughes and BP, have demonstrated modern drilling technology in fields being developed to minimize risks. Accordingly, in the present work, an algorithm is proposed to minimize the risk of inclined wellbore encounters while simultaneously reducing the non-producing time, special attention has been paid to the placement of technology and technical tools to the reduction of uncertainty of the direction due to the use of the results if measurement in the drilling process with the help of MWD systems, taking into account the characteristics of the geological section. As a result of the analysis, a calculation scheme was proposed for computing the optimal number of wells in multiple drilling.

The third chapter provides an analysis of the processes and related parameters during the drilling of inclined wells. Taking into account the works carried out in order to increase the quality of drilling inclined wells, the analysis of the resistance forces against the movement of the drilling tool was carried out, the ways of collecting primary data to use the existing mathematical expressions during the calculation were determined, taking into account the coefficient of friction, the drilling string in the intervals of the increase and decrease of the zenith angle was determined. a calculation scheme for calculating the resistance forces in four cases, consisting of lifting and lowering cases, was drawn up.

The purpose of this section was to examine the possibilities and limitations of the models used, as well as to determine to what extent this model can help in the study and identification of well drilling problems in the conditions of Azerbaijan. During the study of the model, relevant studies were conducted to use the information reflected in the existing works. As it is known, torque and frictional forces are generated as a result of friction between the drill string and the wellbore. Calculations of torque and resistance are of great importance. The success of well drilling can be affected by torque and resistance forces, especially in complex drilling conditions of deep wells. Usually, a model based on the analysis of the friction process is used to study the effect of friction on the torque and resistance values. The coefficient of friction is perhaps the most complicated and uncertain factor to calculate. The coefficient of friction is a property of the surface. It is determined empirically and shows how rough the surface is. The higher the coefficient, the rougher the surface. Usually, the coefficient of friction for water-based drilling fluid systems is assumed to be in the range of 0.25-0.40. The resistance of the drill string appears as an additional load to move the drilling string up and down the well; the torque in the model describing them is the torque required for the rotational motion of the model pipe. In order to have an accurate model, it is important to determine the appropriate friction coefficients for different drilling conditions. In the analyzed works, it is proposed to determine it indirectly, by measuring resistance forces. In this regard, the considered section presents the results of the analysis of the friction models developed in recent years, applying them to different well conditions. The main purpose of the mentioned analysis is to model the friction coefficient for different well conditions in order to justify the capabilities and limitations of the developed models, as well as to clarify whether the model can be used for well prediction conditions. In this regard, the modeling of resistance forces and engine torque in accordance with well drilling has been considered in recent years. It should be noted that the regularities reflected in recent studies have been used in well drilling and have led to good results. So, in 1993, British Petroleum (BP) drilled a well in the Witch field in England. The well profile has a deviation of 10.1 km from the onshore platform. Since then, the drilling of large wells has increased worldwide. Some of these wells were drilled in the Al-Shaheen field in Sakhalin, Qatar.

Thus, the operator of the "Sakhalin-1" Exxon "Neftegas" project informed about the completion of the drilling of the well with the longest wellbore in the world. OP-11, located in the "Odoptu" field, has a record length of 11,475 m. All work was completed within 60 days. Since 2003, 6 of the 10 deepest wells on the planet have been drilled with the help of the "Yastreb" device of "Sakhalin-1". A 12,300 m well was drilled by the Maersk company in the "Al-Shaheen" oil field in Qatar. A better understanding of the bottomhole forces from these types of wells has improved torque and resistance models as they constrain remote drilling objects and determine well success. In 2001, Aadnoy and Anderson proposed new analytical expressions for expressing wellbore friction. Those statements were systematized, the parameters included in them were determined from the literature and partially from the drilling experience, and information was prepared for calculating the resistance forces.

As a general rule, it is known that friction is considered higher when the amount of side bends along the entire trajectory of the wellbore is large. Various forces act on the drill string, including axial, inclination, frictional and hydraulic loads.

The general block diagram of the procedure for calculating and specifying the friction coefficient is shown in the dissertation work. The calculation for finding the compensating force on the surface is carried out according to the "bottom-up" principle, where the well curvature accumulation area is first divided into sections depending on the size and specific gravity of the drill string, as well as the geometry of the well pipe, shown in the work. This is incorporated into the model along with the structure of the drill string, the properties of the drilling fluid and the coefficient of friction. This method is called the "bottom-up" calculation method, but first the calculation is made for the lower force of the pipe, that is, the lower part of each section, knowing this value, then the upper force of the pipe element (F2) is calculated.

According to the mentioned simple block diagram, a calculation scheme for computing the values of relevant forces was proposed and calculations were made taking into account the preliminary information collected from the mentioned sources through the proposed and used formulas in the relevant cases.

Analysis of the research results collected up to now allowed to systematize the obtained mathematical expressions, as well as to improve the corresponding calculation scheme for computing the resistance forces taking into account the friction coefficient. Thus, during the drilling of inclined wells, especially wells with high deviation, relevant problems related to the load on the drilling tool, resistance forces, and torque appear. In addition to theoretical researches, studies of the effects of negative factors and their reduction can play a role in making the right decisions by conducting research studies in the field conditions and by complementing each other.

In this regard, calculations were made using the preliminary information collected in the next, **fourth chapter**, as a result of which the resistance forces were determined for the above-mentioned cases, as a result, the value distribution reflected in figure 3.

If the zenith angles from the picture and the results of the calculations are as shown, when the third straight interval is drilled in the three-interval inclined well profile, the load on the hook during the lifting of the drilling string depends significantly on the zenith angle. The same load in the ranges of the zenith angles α_1= 15-30° and α_2= 8-20°, respectively gets the maximum value.

These surfaces constructed as a result of calculations using the mentioned formulas allow to observe the change of the resistance force, the change during lifting and lowering in the case of falling and increasing curvature depending on the zenith angles and the measured load acting on the upper part of the pipe, according to the increase and decrease of the zenith angles. Calculation results using those formulas are given in the appendices of the thesis.

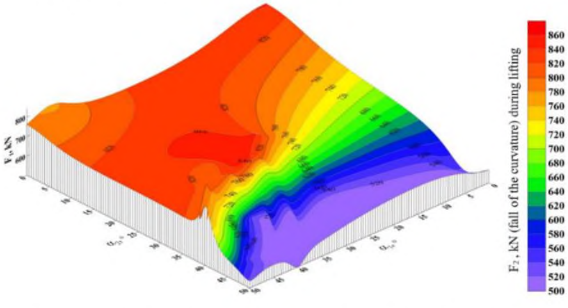

Fig. 3. A surface representing the distribution of the resistance force corresponding to the case of lifting the drilling string during the fall of the curvature

As it can be seen from the figures, an increase in the resistance force is observed when the angle decreases. Depending on the measured load acting on the upper part of the drilling string, when the value of that load increases, the resistance force increases in all cases. This is clearly seen from equations (3.13-3.16) reflected in table 4.1.

Thus, the dependences derived from the researches [51,53,54] were analyzed, calculations were made through them, and appropriate three-dimensional models (surfaces) were constructed that reflected the change of the output parameter-resistance force in different cases.

As it was mentioned, in the process of drilling of inclined wells, since the drilling tool rests on the bottom wall of the wellbore due to its own weight, during movement, part of it is exposed to frictional forces with the clay crust formed on the well wall, and on the other hand, with the drilling fluid. As a continuation of the researched calculations, the analysis of the effect of those factors on the resistance forces is interesting and attracts attention. In this regard, this issue is considered in the next sub-chapter.

In the process of drilling inclined oriented wells, since the drilling tool rests on the bottom wall of the wellbore due to its own weight, during movement, part of it is exposed to friction forces with the clay crust formed on the well wall, and on the other hand, with the drilling fluid.

The distribution scheme of the forces while the drilling tool rests on the inclined well wall is investigated, and simple formulas for express calculations are proposed.

It should be noted that the increase in the structure of the drilling fluid in a stationary state depending on time means that more force is spent than the actual weight of the tool at the moment of removal (in motion) of the drilling tool from a static state. The change in the weight of the tool at the moment of movement in the lifting hook occurs due to the molecular attraction or adhesion forces in the contact areas of the pipe with the drilling fluid on the one hand, and with the clay crust on the other.

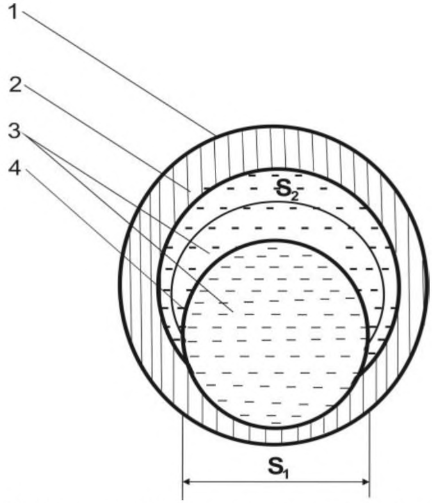

Fig. 4. Scheme of the cross-sectional area of the well 1- well wall, 2- clay casing, 3 – drill pipe, 4 – drilling fluid, S_2 – contact area of the drill pipe with the clay solution, S_1 – the contact area of the drill pipe with the clay crust

Molecular attraction or adhesion forces depend on the size of the contact areas of the objects, the dynamic and static shear stresses of the clay crust and the clay solution.

Appropriate devices were used in laboratory conditions to determine dynamic and static shear stress. Static shear stress is the frictional force between fluid layers. Depending on the flow regime in drilled wells, the flow rate is small in the areas near the well wall and the drill pipe in the downstream space, and the maximum in the middle. In such conditions, during movement, a frictional force arises between the layers of the liquid, which characterizes the static shear stress.

On the basis of the scientific research conducted in the department of ASOA (now ASOIU) under the leadership of academician M.P. Guluzade, an expression was proposed for determining the resistance forces against the movement of the tool in wells. As a result of our recent research and analysis, in order to determine the forces acting on the drilling tool during its downward or upward movement, we can find the value of the resistance or adhesion forces by subtracting the weight of the pipes in the liquid environment from the value of the force generated at the moment of upward movement:

$$G_{r.f.} = G_{ind} - \beta G_{ra} \tag{9}$$

Here, $G_{r.f.}$ - value of resistance forces at the moment of upward movement of the drilling tool;

G_{ind} - the weight of the tensile load indicated by the weight indicator when the drilling tool movement is determined,

G_{ra} - the weight of the drilling rig in the air;

$\beta = \left(1 - \frac{\rho_f}{\rho_{st}}\right)$ is the so-called buoyancy coefficient, which takes into account the lightening of the drilling tool in the drilling fluid,

ρ_f - drilling fluid density, N/m^3;

$\rho_{st}-$ the density of the steel drill pipe material, N/m^3.

To determine the forces of resistance to movement during the lowering of the drilling tool into the well, it is necessary to subtract the weight of the drill pipe in the drilling fluid from the weight indicated by the weight indicator, i.e.

In order to calculate the resistance forces against the movements of the pipes in inclined wellbores, the following formulas have been derived. Expressions for the static and dynamic conditions of the resistance forces against the movement of the general tool have been obtained.

After making appropriate transformations in the received formulas, a suitable formula is proposed for calculating the values of resistance forces against the movement of drilling, protective and operational pipes during the drilling of inclined wells for both static and dynamic cases.

Thus, specially relevant formulas were derived to calculate the forces of resistance against the movements of the pipes in inclined wellbores.

The fifth chapter is dedicated to measures taken to protect the environment during drilling. The chapter considers the composition and physical-chemical properties of drilling waste. The results of drilling mud analysis and their statistical analysis are reflected within the framework of those studies. Conducting statistical analysis allowed to develop the ecological risk assessment method. The results obtained here are based on the determination of the concentration of heavy metals in the drilling waste under laboratory conditions and the comparison of the results with the concentrations that can be released. Laboratory researches were carried out on the drilling wastes collected from the fields of Azerbaijan and Kazakhstan at the analytical center of the Institute of Geology and Geophysics of the Ministry of Science and Education of Azerbaijan. As mentioned, the risk assessment dependencies for two hazard classes were obtained.

CONCLUSIONS AND SUGGESTIONS

1. Predicting, preventing, and reducing the time and materials spent on eliminating the difficulties that may arise during drilling of wells, the important areas of focus for increasing the efficiency and quality of well construction have been investigated from the position of a systematic approach.
2. Experience has shown that two wellbore collisions can occur in an oil field or in high-density multiple wells in projects where errors have been made. In order to prevent the collision of the wellbores, it is shown the expediency of making calculations for the purpose of correctly choosing the well coordinates, calculating the errors of the measuring devices.
3. As a result of the analysis of the influence of the errors occurring during the measurement of azimuth and zenith angles in the drilling of inclined wells on the quality of drilling, the accuracy of the measuring tools (devices) applied in different companies was calculated.
4. A calculation scheme and a corresponding formula for computing the optimal number of wells in one block, taking into account the main factors, including fire safety, technical possibilities of drilling wells and economic feasibility, are proposed.
5. The analysis of the research results collected up to the present time allowed to systematize the received mathematical expressions, as

well as to improve the corresponding calculation scheme for computing the resistance forces taking into account the friction coefficient.

6. As a result of the analysis of the resistance forces affecting different parts of the drilling pipeline, especially in the curved areas, as well as the resistance forces arising in the drilling fluid environment, appropriate mathematical expressions were obtained for their calculation.
7. An appropriate formula was proposed for determining the forces of resistance to the movement during the lowering of the drilling tool into the well.
8. Calculation formulas for static and dynamic cases of the resistance forces formed against the movements of the pipe in the inclined well pipe were obtained.
9. An improved classification of environmental pollution sources during well drilling was given. As a result of the analysis of the drilling waste discharged from the well, a mathematical expression was proposed for the assessment of environmental risk.

The main provisions of the dissertation are reflected in the publications published by the author himself and co-authors:

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Candidate's personal contribution

[7], [8], [9],[10],[11],[12] – performed freely.
[1],[2],[3],[4],[5],[6],[13],[14][15] – problem setting, conducting experiments and field research, analysis of results, data collection.

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