REPUBLIC OF AZERBAIJAN

In manuscript right

"INCREASING THE PERFORMANCE OF EQUIPMENT APPLIED IN THE WELL WORKOVER BY REDUCING THERMO-MECHANICAL STRESSES"

Specialty: 3313.02 - "Machines, equipment and processes"

Scientific field: Technical sciences

Applicant: **Amir Mustafayev Gochu**

Dissertation submitted for scientific degree of Doctor of Sciences

ABSTRACT

Baku - 2024

The dissertation was performed at the "Mechanics" department of Azerbaijan State Oil and Industry University.

Scientific advisor: Doctor of technical sciences, professor
Babayev Sabir Habib

Official opponents: Doctor of technical sciences, professor
İbrahimov Nazim Yusif

Doctor of technical sciences, dosent
Çələbi İftixar Qurbanəli

Doctor of technical sciences, professor
Aslanov Zabit Yunus

Doctor of technical sciences, professor
İsmayılov Nizami Şayı

ED2.02 Dissertation Council of the Higher Attestation Commission under the President of the Republic of Azerbaijan operating at the Azerbaijan State Oil and Industry University

Chairman of the Dissertation Board:
Doctor of technical sciences, professor
Ibrahim Habibov Abulfaz

Scientific secretary of the dissertation council:
Ph.D. in technology, docent
Tahir Jabbarov Gaffar

Chairman of the scientific seminar:
Doctor of technical sciences, professor
Ali Aga Rustamov Zakir

AZƏRBAYCAN RESPUBLİKASI ELM VƏ TƏHSİL NAZİRLİYİ
AZƏRBAYCAN DÖVLƏT NEFT VƏ SƏNAYE UNİVERSİTETİ
İMZANI TƏSDİQ EDİRƏM
ADNSU-nun Elmi katibi
dosent N.Əliyeva

GENERAL CHARACTERISTICS OF THE WORK

The relevance of the work and degree of development : The relevance of the topic is to reduce the level of corrosion caused by friction on the contact surfaces of the well repair equipment, to determine the factors affecting the formation of stresses in the cutting-destructive zone, to minimize the temperatures and to extend the life of the equipment.

One of the main factors that ensure the safe operation of repair equipment inside the well is to maintain the required level of thermal-physical regimes in their moving parts.

The main reason for the premature failure of the equipment used in the overhaul of wells is the thermomechanical stresses generated on the contact surfaces of the cutting elements that interact with the objects subjected to destruction, the large amount of heat released from the working surfaces, the erosion of the cutting-destructive elements and the decrease in destructive capacity. One of the main reasons that create the tension-deformation situation is sliding friction caused by dynamic loads in the working areas of the tools and equipment working inside the well. Difficulties in lubrication and cooling of the contact areas of devices operating under the influence of high pressure and friction lead to an increase in temperatures in these areas and deterioration of working conditions inside the well.

The main goal of the thesis work is to determine with scientific evidence the causes of temperature stress in the overhaul of wells and moving parts of repair equipment, to adjust the mode parameters and to decide on the rational design of the structure.

One of the other issues raised in the work under review is to analyze the physical-mechanical composition of composite matrix materials against high temperatures, to increase the cutting ability and strength of the cutting elements of the tool.

Research object. FZ135 type downhole milling unit was selected as the research object.

The subject of the study. It is to partially reduce or completely eliminate thermal stresses and temperatures in moving parts (tribonodes and touching surfaces) of equipment used in overhaul of wells (milling of metal objects) .

Research goals and objectives: The main goal of the research is to reduce the effect of external forces that create thermal stresses and temperatures in the tribonodes and contact areas of the repair equipment, increase the strength and cutting ability of the cutting elements, carry out the repair according to modern technologies, take into account the real working conditions of the equipment, and both the cutting elements and to analyze the physical and mechanical properties of the objects subjected to disintegration.

The solution of the following issues is considered in the implementation of the research work .

1. Development of methods for determining heat flow distribution and cooling coefficients;
2. To determine the influence of thermomechanical factors on the corrosion occurring in tribonodes of equipment used in major repairs;
3. Analysis of the stress-deformation state in the contact areas of objects subjected to disintegration with the cutting part of the tool;
4. Determination of forces affecting cutting elements based on theoretical and experimental studies;
5. Analysis of physical-mechanical properties and temperature resistance of composite materials and laboratory testing;
6. Simulation of the dependence of temperatures on mode parameters with SOLID WORKS and M-EXCEL software and simulation of the obtained experimental research results with field data;
7. Evaluation of efficiency between the new design of the downhole milling machine and the existing design.

Research methods: The issues raised in the dissertation were solved using modern static-probabilistic methods of theoretical, laboratory and field research:

1. **SOLID WORKS** simulation software;
2. **M-EXCEL-2016** security software;
3. Finite element method;
4. Theory of complex variable functions ;
5. The solution of research by planning method.

Main clauses defended:

1. Analysis of the causes of accidents in wells and their elimination methods, constructions of equipment and tools used

in overhaul of wells, and their operational characteristics.

2. The results of scientific research studies on the reduction of thermal stresses and temperatures on the frictional surfaces of repair and rock-destructing equipment.

3. Development of methods for determining temperature coefficients in reports on temperatures in solid and alloyed compounds.

4. Determination of bending, compression and temperature stresses affecting the strength of composite grains working under the influence of bending and compression deformations in tribonodes of equipment and tools.

5. Determination of mode factors affecting the efficiency of the tool in milling.

6. Structural changes made to the structure of the well cutting milling unit.

7. Confirmation of the reliability of theoretical studies in experiments conducted in laboratory and field conditions.

Scientific novelty of the study:

In order to reduce thermal stresses in the overhaul of wells, in the working areas of repair equipment operating under complex conditions, the dependence of temperatures on regime parameters was determined, methods were developed that determine the coefficients of heat flow distribution and cooling as the main factors in solving thermal-physical problems, heat conduction and heat transfer with temperature drop and temperature gradient, the differential equations determining the dependence between the temperature transfer coefficients were determined, and a complex solution to the problems related to temperatures for mixed materials with composite composition was given. Axial and radial forces that create a stress-deformation state in the milling zone, the sizes of the cutting elements and their positions in the group were analyzed and their effect on the cutting ability and productivity of the tool was determined. In order to reduce temperatures in the cutting zone, structural changes that could cause cavitation were made in the structure of the downhole milling machine, and the model of the new structure was tested. The degree of agreement of the results obtained from the experimental studies with the practical results was determined and the factors aimed at reducing temperatures were taken into account in the design of the cutting part of the tool.

Theoretical and practical importance of the research: In the research studies conducted on heating issues, the methods for determining the distribution and cooling coefficients of the heat flow, which take into account the reduction of temperatures, were developed, to evaluate and predict the stress-deformation state and temperature regulation in hard and alloyed joints by means of linear and non-linear regression analysis. mathematical writings of differential equations (taking into account initial and boundary conditions) have been obtained.

The scientific research conducted in the direction of reducing thermal stresses and temperatures in the formation and design of the geometric dimensions of the cutting part and tribonodes of the equipment and tools used in the overhaul of the wells allows to speed up the repair and restoration works, to use devices that are reliable, long-lasting and economically effective against temperatures and corrosion.

The solution of theoretical and practical issues creates good opportunities for the design of the device, equipment and tools to be used in the drilling, operation and repair of wells, improvement of the cutting and destructing parts, ensuring their reliable operation and their application in practice.

Research approval and application of results:

The results obtained on the basis of scientific and experimental studies are aimed at reducing thermal stresses and temperatures on the contact surfaces and tribonodes of the equipment used in the overhaul of wells. In reports dealing with thermal issues, using heat flow distribution and cooling coefficients, the effect of temperatures on the cutting part of the tool and external forces on the formation of cutting elements was determined, and the obtained positive results were recommended for practical purposes.

The new structural model of the wellbore milling machine capable of creating cavitation, determined by scientific evidence, was compared with the model of the existing construction, tested in laboratory conditions, and the obtained positive results were reflected in milling and well washing.

During the research, the objects corresponding to the physical and mechanical characteristics of the metal or other objects riveted in the wellbore were tested, the optimal mode parameters were determined, and the obtained results were offered to the fields and scientific research institutes engaged in the overhaul of the wells.

Publication rate: 85 articles, 2 textbooks, 1 monograph were published and 1 patent was prepared based on the results of the conducted scientific research.

Publication, approval and application of the work: The main provisions of the dissertation work were discussed at the following conferences and published in the following journals:

1. The advantage of composite materials used in downhole cutting tools, Nafta-gaz 2024, no. 1, pp. 19-29, Doi: 10.18668/ NG.2024.01.03.
2. Austrian Journal of Technical and Natural Sciences Scientific journal No. 3-4 2018 (March-April) ISSN 2310-5607, pp. 24-28.
3. International Journal of Engineering Research and Technology, ISSN 0974-3154, Volume 13 No. 12 (2020), © International Research Publication House, pp. 4832-4834.
4. Methodology of Designing the Cutting Part of Well Milling Devices on the Basis of Composite Alloys Modern science Founders; Scientific Research Center "Institute of strategic studies" (Moscow) ISSN: 2414-9918, pp. 410-417.
5. A study of factors affecting wear and destruction of teeth in gear mechanisms (scope) Nafta-gaz 2023, no. 9, Doi: 10.18668/NG.2023.09.06, pp. 604-610.
6. Reduction of thermal tensions and temperatures formed in the tribonodes and surfaces of the equipment and tools Used in well workover and restoration works (scope) Nafta-gaz 2023, no.10, Doi: 10.18668/NG.2023.09.06, pp. 661-669.
7. Improving the efficiency of the milling tool by reducing the temperature in the milling zone depending on the main mode parameters, Nafta-gaz, Nafta-gaz 2023, no. 12, Doi: 10.18668/ NG. 2023.12.02, pp. 764-775.
8. The differential expression of the equations that ensure the thermal balance of metals and alloy compounds, materials of the

International Scientific Conference entitled H. Aliyev Epoch in the Development of Science and Education in Azerbaijan, July 4-5, 2023, pp. 615-621.

The materials presented in the thesis work are used in the formation of working areas of the repair equipment, taking into account the temperature regimes in the overhaul of the wells.

The name of the organization where the dissertation work was performed: "Mechanics" department of Azerbaijan State Oil and Industry University.

Applicant's personal contribution to the research conducted. In the dissertation, the applicant substantiated the relevance of the research works, identified the issues raised by studying the technical literature data, determined the directions of the researches, carried out their implementation, independently solved the construction of theoretical and mathematical models. He analyzed the results of the experiments, held discussions at scientific conferences, compiled scientific articles based on the obtained results.

The structure and scope of the dissertation: The dissertation consists of an introduction, 5 chapters (Chapter I 73555, Chapter II 37227, Chapter III 123286, Chapter IV 58865, Chapter V 101438 signs), general results, 197 scientific references, including 30 tables, 45 figures and 63 graphs. The total volume of work is 417605 signs.

MAIN CONTENTS OF THE WORK

In the introduction of the dissertation work, the justification of the relevance of the topic, the honest statement of the goals and tasks of the research, scientific novelty, practical importance and the main provisions put forward for defense are given.

In the first chapter, the causes of accidents occurring during drilling, operation and repair of wells, erosion of tools and equipment caused by friction in triboknots, breakdowns and thermal stresses were analyzed. The results of research show that the main reason for the occurrence of accidents is the violation of technological processes, the riveting of the crashed objects and their dependence on their position in the well.

The results of the analysis show that timely detection of accidents, correct selection of equipment to be used in major repairs, and improvement of existing structures are important conditions for increasing the efficiency of repair and restoration works.

During the studies, it was determined that three-pointed drill bits have more productivity than other bits in digging solid rocks (Figure 1).

Conducted researches show that it is possible to restore the wells in need of restoration by using cutting-destructing milling devices in the overhaul of wells. The efficiency of these tools depends on their construction, longevity, cutting ability and milling mode (Figure 2).

In the process of drilling and milling, many factors affecting the surface of tools, including high temperatures, vibrations, torsional and bending deformations, hydraulic forces create dangerous situations during their operation. Regulation of heating processes, obtaining optimal temperature regimes helps to prevent tool corrosion and disintegration.

The productivity and efficiency of modern construction milling equipment allows to reduce accidents in the wellbore and increase oil and gas production.

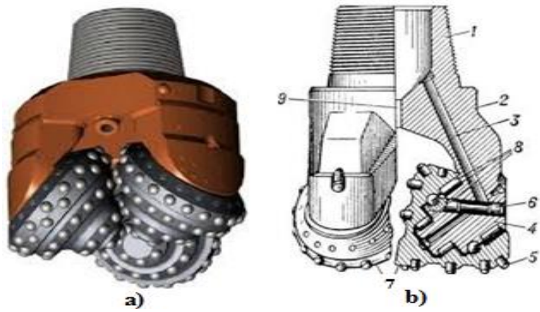
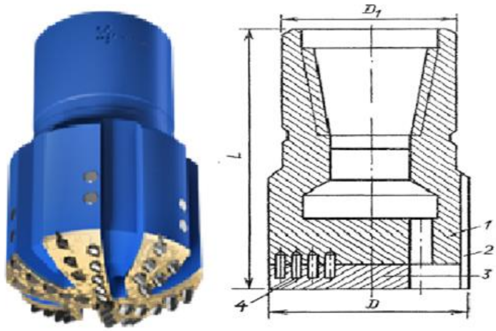


Figure 1. Three-bladed drill bit intended for drilling solid rocks a) structural view; b) schematic view

1-connecting thread with an external cone (nipell) ; 2-sections of the bit; 3-opening channels in the paws and pin for cooling the support (3); 4-pin in paw; 5-hard alloy teeth on semi-spherical working surfaces (5); 6-lock pin; 7-cones; 8-rolling bearings; 9- the central channel intended for cooling the well and cones



a) b)

Figure 2. Well-bottom milling tool a) structural view; b) schematic view

1-body; 2-relite; 3-cutting-polishing area; 4-cutting layers

At the same time, in this chapter, information is given about the constructions, characteristic features and basic requirements of milling devices with different geometric shapes in Azerbaijan and foreign countries. The positive and negative aspects of the cutting elements of milling machines produced in foreign countries and their comparative characteristics with instruments produced in our republic are given.

The second chapter is devoted to the analysis of scientific research studies aimed at the full or partial reduction of temperatures and temperature stresses caused by friction in their working areas, taking into account the mode parameters of downhole equipment .

In this chapter, the main goal of conducting research on temperatures is to analyze the results of previously conducted theoretical and practical research, and to give an analysis of the causes that create temperatures and temperature stresses on the contact surfaces of the equipment and tools used in the overhaul of wells, and the factors affecting their reduction.

Since the tools and equipment used in the drilling and repair of wells are very close to each other according to the working principle, the temperatures generated on their touching surfaces actually differ little from each other.

Therefore, the results of the research conducted on temperatures in both areas were examined.

- the effect of temperatures and temperature stresses on the heating and cooling of the pulleys in the brake systems of lifting winches, the determination of non-stationary temperatures and temperature stresses in the friction pair of the brake and the effect on the work of the winch, the minimization of temperatures on the contact surfaces of the friction pair during the oscillating movements occurring in the brake system;

- solving problems of isoperimetric variation in the determination of the volume that provides heat transfer and the optimal shape of the bit, partial determination of the value of the distribution and cooling coefficients of the heat flow in drilling and milling, the study of the thermal regimes of single-pointed bits taking into account thermal-physical parameters [121][1];

- the changes made in the construction of single-ball bits and downhole milling devices in order to create cavitation and the destructive effect of cavitation on metals and rocks, the factors affecting the reduction of temperatures on the contact surfaces of cutting and rock-destructing tools, the factors affecting the rapid washing of wells and the resistance of the tool to corrosion analysis [74] [2];

theoretical and practical researches in determination of optimal mode parameters in milling of factors affecting the cutting ability of composite materials in milling of metal objects [149] [3];

---

[1] Faradzhev T.G., Aliyev A.M., Mustafaev A.G. Generalized differential equation of thermal conductivity for an arbitrary measure of space and body shape. Изв. Vuzov, "Oil and Gas", 1991, No. 6, pp. 32-42.

[2]Mustafaev A.G., Gafarov F.M., Mustafaeva N.S., Allahverdiev S.G. The influence of cavitation on the resistance of wellbore destruction tools and the efficiency of cleaning in the bottom-hole zone of wells. -Scientific Works ASMA, №2, 2010.

[3] Amir G. Mustafayev, Mahmud A. Ismayilov, Mirkamran M. Salimli, Chingiz R. Nasirov. Improving the efficiency of the milling tool by reducing the temperature in the milling zone depending on the main mode parameters, Nafta-gaz, Nafta-gaz 2023, no. 12, Doi: 10.18668/ Ng.2023.12.02, pp.764-775

- justified evaluation of thermal-physical parameters in the heat exchange between the cutting and rock-destroying tools and objects subject to disintegration within the well [91] [4];

- development of the basic scheme of the device used in milling and drilling processes and provision of control measuring devices;

-experimental study of the stresses that occur at the lower limits of the endurance of metals and during damage caused by fatigue, the damage accumulated in machine parts during step loading, methods of reporting on the strength and longevity of lifting and lowering equipment;

-complications in the drilling of the second pipe in the overhaul and their elimination, determination of the load on the reamer's bits when cutting the service pipeline, partial release of rivets by applying force when cutting riveted pipes, determination of leakage locations in the space behind the pipe, temperature measurements in sea conditions the results of research studies, the results of theoretical and experimental studies, such as the development of methods of combating sand jam elimination, were examined.

These sources, which cover a wide spectrum, provide good opportunities for conducting theoretical and practical researches in the reduction of temperature stresses and temperatures generated in the friction areas of equipment used in major repairs [96] [5].

It should be noted that in the course of researches, heat conduction, heat distribution, heat transfer, temperature transfer, and cooling coefficients were either partially taken into account or not taken into account at all in the determination of temperatures and temperature stresses in drilling and milling

Examining the results of the research conducted in order to achieve the goal set in the dissertation creates a solid foundation for the

---

[4] Mustafaev A.G., Nasirov Ch.R. Development of a mathematical model of hydrodynamic pressures when operating wells by the gas lift method. Materials of the All-Russian scientific and technical conference (with international participation) "Problems of geology, development and exploitation of deposits, transport and processing of heavily extracted oil", 8-10 December 2021, pp. 75-78.

[5]A.G. Mustafaev, Research of thermal processes on contact surfaces of well-destroying instruments, Modern technology in oil and gas business-2017, "Collection of works inter. Scientific Technical Conference», USOTU, 2017, pp. 136-138

development of methodologies that take into account the distribution and cooling coefficients of the heat flow as the main factors affecting the strengthening of the working areas of the tools used in major repairs and the reduction of thermal stresses, and allows to determine the dependence of these factors on the temperature gradient and temperature stresses. [87] [6]

In the third chapter, the dependences of the temperature drop and temperature gradient on the thermal energy distribution (heat flow distribution, heat transfer, heat transfer and temperature transfer coefficients) caused by the interaction of electromagnetic waves in thin long layers and contact areas of cylinders are defined.

In this chapter, the obtaining of isothermal surface, the heat flow through the isothermal surface according to Fourier's hypothesis, the mathematical equation of heat transfer, the linear dependence of heat transfer coefficients on temperatures, the comparison of heat transfer coefficients between pure metals and alloyed compounds, the direct relationship between temperatures and heat transfer coefficients in non-metals, in alloyed compounds of different composition dependence of heat transfer coefficients on the structure, porosity and moisture content of metals, comparisons of heat transfer coefficients between wet, wet and dry materials, changes in the logarithmic curve of temperatures generated in the inner and outer layers of the cylinder in a moving environment, numerical values of heat flow distribution and cooling coefficients, the number of factors characterizing heat transfer and the mathematical writing and boundary conditions of the differential equations required to establish the relationship between these factors have been determined [14] [7].

At the same time, in this chapter, a detailed analysis of graphical dependences is provided, which determines the dependence of the heat flow distribution and cooling coefficients on the temperature gradient

---

[6] Mustafaev A.G. , Pashaeva V. B , Determination of the FVI cooling criterion in the process of drilling and milling, Actual problems of humanities and natural sciences No. 7, 2017, Russia, pp. 44-46

[7]Mustafayev A.G., Kheyrabadi G., Differential expression of the equations that ensure the heat balance of metals and alloy compounds, materials of the Internationa Scientific Conference entitled H. Aliyev epoch in the development of Science and Education in Azerbaijan, July 4-5, 2023, 615-621

and temperature drop in the cooling of reinforced areas along the volume of metal and rock-destroying cylindrical tools.

Since the temperatures in metals or alloy compounds with different temperatures and heat exchanges are unevenly distributed throughout the cross-sectional area and volume of the body, in order to more accurately determine the dependence of the heat transfer coefficient on temperatures, first, the linear dependence of temperatures was used:

$$\lambda = \lambda_0[1 + b(T - T_0)] \quad (1)$$

where λ_0 is the value of the heat transfer coefficient at initial temperatures (T_0), *b* is a constant quantity, determined empirically.

It requires the reduction of the number of factors characterizing heat conduction to the minimum limit and the mathematical writing of the differential equation required to establish the relationship between them.

The differential equation in heat conduction is based on the law of conservation of energy.

The amount of heat (dQ) is equal to the sum of the change in internal energy released from the elementary volume due to internal sources and (dQ_2)*the* amount of heat supplied to the entire volume dQ_1)in the elementary time interval (*dt)* :

$$dQ_1 + dQ_2 = dQ \quad (2)$$

where dQ_1 is the amount of heat given to the elementary volume (*dV)* in the elementary time interval (dt*)* , dQ_2 - the amount of heat released from the elementary volume (dV) in the elementary time interval *(dt)* due to internal sources, *dQ* - the elementary volume of the body in the elementary time interval (*dt),* (*dV*) - the change of internal energy (figure 3,a).

Then the amount of heat dQ_1 is expressed as follows:

$$dQ_1 = -\left(\frac{\partial q_x}{\partial x} + \frac{\partial q_y}{\partial y} + \frac{\partial q_z}{\partial z}\right) dxdydzdt \quad (3)$$

dQ_2 in equation (2) :

$$dQ_2 = q_\text{v} dV dt \tag{4}$$

q_v is the specific productivity of internal heat sources; (dV) - the amount of heat density divided by the unit volume of the body in a unit time section (*dt)*.

The third component of equation (2) characterizing the change of internal energy (dQ):

$$dQ = c\rho \frac{\partial T}{\partial t} dV dt \tag{5}$$

Considering statements (3), (4) and (5) in (2):

$$\frac{\partial T}{\partial t} = -\frac{1}{c\rho}\left(\frac{\partial q_x}{\partial x} + \frac{\partial q_y}{\partial y} + \frac{\partial q_z}{\partial z}\right) + \frac{q_V}{c\rho} \tag{6}$$

of the amount of heat onto *the axis ox*, *oy* and *oz* are as follows (figure 3, b):

$$q_x = -\lambda \frac{\partial T}{\partial x};\ \ q_y = -\lambda \frac{\partial T}{\partial y};\ \ q_z = -\lambda \frac{\partial T}{\partial z} \tag{7}$$

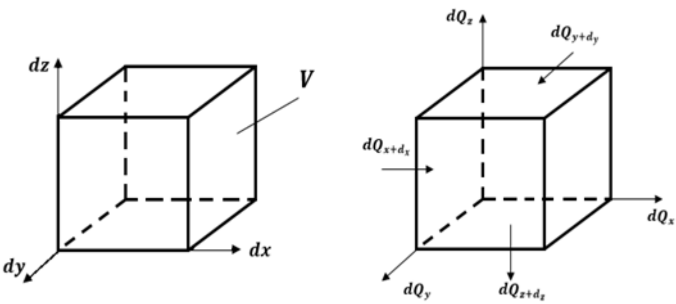


Figure 3. Schemes that determine the heat transfer equation

a) scheme of placing the volume element in space. b) Heat transfer distribution scheme on the sides of elementary parallelepiped with volume dx dy dz

$$\frac{dT}{dt} = \frac{\lambda}{c\rho}\left(\frac{\partial^2 T}{\partial x^2} + \frac{\partial^2 T}{\partial y^2} + \frac{\partial^2 T}{\partial z^2}\right) + \frac{q_v}{c\rho} \qquad (8)$$

In equation (8) if to substitute $\frac{\lambda}{cp}$ by a :

$$\frac{\lambda}{c\rho} = a \qquad (9)$$

and $\left(\frac{\partial^2 T}{\partial x^2} + \frac{\partial^2 T}{\partial y^2} + \frac{\partial^2 T}{\partial z^2}\right)$:

$$\frac{\partial^2 T}{\partial x^2} + \frac{\partial^2 T}{\partial y^2} + \frac{\partial^2 T}{\partial z^2} = \nabla^2 T\ , \qquad (10)$$

If to substitute (9) and (10) in (8), then we express the heat transfer equation as follows:

$$\frac{\partial T}{\partial t} = a\nabla^2 T + \frac{q_{\mathrm{v}}}{c\rho} \qquad (11)$$

where a is the temperature transfer coefficient, $\nabla^2 T$ - the Laplace operator in the Cartesian coordinate system.

Laplace operator in Cartesian coordinate system $(\nabla^2 T)$ we define as follows:

$$\nabla^2 T = \frac{\partial^2 T}{\partial r^2} + \frac{1}{r}\frac{\partial T}{\partial r} + \frac{1}{r^2}\frac{\partial^2 T}{\partial \varphi^2} + \frac{\partial^2 T}{\partial z^2} \qquad (12)$$

where r and φ are radial and angular coordinates, respectively.

In spherical coordinates, the Laplace operator $(\nabla^2 T)$ is expressed as follows:

$$\nabla^2 T = \frac{\partial^2 T}{\partial r^2} + \frac{2}{r}\frac{\partial T}{\partial r} + \frac{1}{r^2}\frac{\partial^2 T}{\partial \mu^2}\left[(1-\mu)\frac{\partial T}{\partial \mu}\right] + \frac{1}{r^2(1-\mu^2)}\frac{\partial^2 T}{\partial \psi^2} \quad (13)$$

$$\mu = \cos\theta \quad (14)$$

where μ– is coefficient of equaiton charectiristic, θ and ψ are angular coordinates.

If we consider (14) in (13), then the Laplace operator is found as follows:

$$\nabla^2 T = \frac{\partial^2 T}{\partial r^2} + \frac{2}{r}\frac{\partial T}{\partial r} + \frac{1}{r^2}\frac{\partial^2 T}{\partial \mu^2}\left[(1-\cos\theta)\frac{\partial T}{\partial \cos\theta}\right] + \frac{1}{r^2(1-\cos\theta)\frac{\partial T}{\partial \psi}} \quad (15)$$

Equation (11) is the differential equation of heat conduction.

This equation characterizes the temperature change in the process of heat conduction at any point of the body.

The temperature transfer coefficient (a) is a physical parameter used in the solution of non-stationary thermal processes of metals and alloy compounds, and characterizes the speed of temperature change. The heat transfer coefficient (α) characterizes the thermal conductivity of the objects, and the temperature transfer coefficient characterizes the thermal inertia properties of the objects.

It can be concluded from equation (8) that the change of temperatures in a certain period of time is directly proportional to the value of the temperature transfer coefficient (a) for any point of the object in space . In other words, the greater the rate of temperature change at any point of the body, the greater the temperature transfer coefficient.

Since the differential equation of heat conduction is determined according to the general laws of physics, this equation creates a general idea of the transfer of heat energy and includes all stages of the heat transfer process [7] [8].

Initial and boundary conditions are added to the differential equation in order to distinguish only those involved in the process from the infinite number of factors involved in heat conduction and to give a complete description of the mathematical notation of the process.

In physical conditions, the distribution law of internal heat sources can be given together with the physical parameters of the body (λ , c , ρ etc.).

In non -stationary processes, it is necessary to provide the initial conditions in order to determine the distribution law of temperatures inside the body during the initial time period.

Initial conditions for determining the temperature distribution law by analytical method:

$$t = 0, \qquad T = f(x, y, z) \tag{16}$$

inside the body are evenly distributed, then the initial conditions are simplified:

$$t = 0, \qquad T = T_0 = const \tag{17}$$

Boundary conditions can be defined in several ways.

The distribution of temperatures on the surface of the body at any time interval can be given by the boundary conditions of the first type:

$$T_s = f(x, y, z, t) \tag{18}$$

[8]Mustafayev A.G., Karimova I.M, Bayramova F.I, Methods of regulating temperature stresses on the touching surfaces of a milling ax, ISSN 2220-1025 Scientific Works of Azerbaijan State Marine Academy Proceedings of Azerbaijan State Marine Academy #1 Baku-2018

T_s are temperatures on the surface of the body; *x*, *y*, *z* are the coordinate axes of the object the temperature of which is determined: *t* is time.

The value of the heat flow at any point of the object's surface at any time interval can be given by the second type of boundary conditions, and the equation can be written analytically as follows:

$$q = f(x, y, z, t) \qquad (19)$$

where q is the heat flow density on the surface of the body.

In the simplest cases, the density of the heat flow on the surface of the body remains constant depending on time:

$$q = q_0 = const \qquad (20)$$

This type of heat change occurs in the heating of high-energy devices and metals.

Ambient temperature (*T.m.*) and heat exchange between the surface of the body and the environment are given by the third type of boundary conditions . The Newton-Richman law is used in heat exchange between the body's touching surfaces and the environment .

Heat exchange between the surface of the body and the environment is a complex process that depends on a large number of factors.

According to the Newton-Richman law, the amount of heat falling on a unit surface of an object in an elementary time interval is equal to the difference in temperature between the surface of the object (T_s) and the surrounding environment ($T_s > T_e$) :

$$q = \alpha(T_s - T_e) \qquad (21)$$

where α is the heat transfer coefficient .

The heat transfer coefficient characterizes the intensity of heat transfer between the surface of the object and the environment.

According to the law of conservation of energy, the amount of heat released from the unit surface of the body in a unit time period during heat transfer should be equal to the amount of heat supplied to the volume of the body in that time period:

$$\alpha(T_s - T_e) = -\lambda \left(\frac{\partial T}{\partial n}\right)_s \quad (22)$$

where n is the normal to the surface, the index " s " (when n =0) indicates that temperatures and temperature gradients are related to the surface of the object.

We can write the boundary conditions of the third type finitely as follows:

$$\left(\frac{\partial T}{\partial n}\right)_s = -\frac{\alpha}{\lambda}(T_s - T_e) \quad (23)$$

Equation (23) is a heat transfer equation, essentially a special expression of the law of conservation of energy by keeping temperatures constant on the surface of the body.

The heat transfer coefficient depends on many factors. Since the heat transfer coefficient (a) does not change when solving many problems, a constant value of this coefficient is found when solving problems related to heat conduction.

The fourth type of boundary conditions characterizes the heat exchange conditions of metals and alloy compounds with the environment according to the law of heat conduction. At this time, it is assumed that the contact between the objects is more perfect and the temperatures are evenly distributed on the contact surfaces.

Under the considered conditions, the heat flow passing through the touching areas of the bodies in contact is evenly distributed, i.e .:

$$\lambda_1 \left(\frac{\partial T_1}{\partial n}\right)_s = \lambda_2 1 \left(\frac{\partial T_2}{\partial n}\right)_s \quad (24)$$

In solving problems related to the fourth type of boundary condition, the temperature curves obtained from the ratio of the tangents of the inclination angles at the points of contact of metals and alloy compounds with the environment remain constant (Fig. 4):

$$\frac{\text{tg}\varphi_1}{\text{tg}\varphi_2} = \frac{\lambda_2}{\lambda_1} = const \tag{25}$$

During heat exchange between metals and the medium, the ratio of the tangents of the inclination angles at the contact points of the metals with the medium remains constant, being equal to the ratios of the heat transfer coefficients.

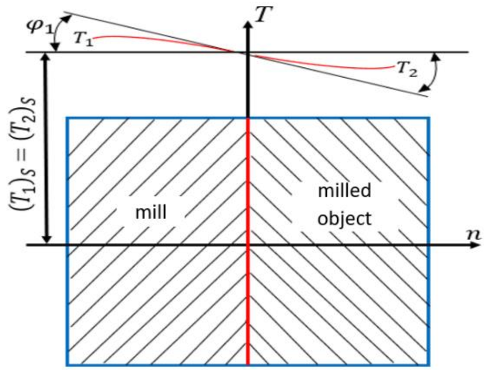


Figure 4. The scheme of determining the boundary conditions of the fourth type

If the temperatures are equalized in the contact areas of two objects in mutual contact (a cutting object and an object subjected to disintegration by a rock-crushing tool), then tangents passing through the contact areas pass through the points separating those areas.

The differential equation (5) together with the boundary conditions represents the complete mathematical notation of specific heat transfer problems. Such issues are solved either analytically or individually.

In the solution of heat transfer processes, methods of modeling physical processes with computer programs or thermal analogues are also used.

The in-depth study of heat transfer in metals and alloys requires both theoretical and experimental scientific research to solve temperature problems. In heat transfer experiments, temperatures are measured by stationary and non-stationary methods

Since stationary methods are simpler and more perfect methods, temperature fields are considered constant during research. Since the temperature fields change during the studies conducted with non-stationary methods, the determination of temperatures in heat conduction is based on certain regularities. Full fulfillment of all conditions included in the theoretical part during experiments is one of the main difficulties of this method. The advantage of the non-stationary method is that it allows to obtain other information about thermal conductivity, heat transfer and heat capacity of materials.

If the temperatures generated inside the body change only in the direction of the thickness of the body, then the equation expressing heat transfer is written as follows [142][9]:

$$\frac{\alpha \partial^2 T}{\partial x^2} = \frac{\partial T}{\partial t} \qquad (26)$$

Initial conditions of (26):

$$T_t = T_0 \quad = const \qquad (27)$$

is obtained due to the balance of two heat flows: heat transfer $\left(q_{x=\delta} = -\lambda \left(\frac{\partial T}{\partial x}\right)_{x=\delta}\right)$from the deep layers of the cooled body to its surface and heat transferred from the surface to the heat carrier $q = \alpha(T_s - T_e)$:

$$-\lambda \left(\frac{\partial T}{\partial x}\right)_{x=\delta} = \alpha(T_s - T_e) \qquad (28)$$

x=0 according to the symmetry condition of temperature fields , then:

$$\left(\frac{\partial T}{\partial x}\right)_{x=0} = 0. \qquad (29)$$

[9] Hasanov VG, Mustafayev AQ, Aliyeva IK, Hasanova LA, Aliyev HM, Abdullayeva AR, Methodic of Determination of Coefficient Value of Heat Flow Distribution at the Processes of Drilling and Milling (Part 1), International Journal of Engineering Research and Technology, ISSN 0974 -3154, Volume 13 No.12 (2020), © International Research Publication House, 4832-4834

Equations (26)-(29) are solved analytically, usually by reducing to a dimensionless quantity:

$$\bar{T} = \sum_{n=1}^{\infty} \frac{2 \sin \mu_n}{\mu_n + \sin \mu_n \cos \mu_n} \cos(\mu_n X) \exp(-\mu_n^2 Fo) \qquad (30)$$

where $\bar{T} = \frac{T_s - T_e}{T_{s_0} - T_e}$ are dimensionless temperatures; μ_n is the root of the characteristic equations, $\frac{\text{ctg}\, \mu_n = \mu_n}{Bi}$; F_0 is the Fourier number (dimensionless time), $F_0 = \frac{at}{\delta^2}$; *Bi* is a Bio number, $Bi = \frac{\alpha\delta}{\lambda}$.

Bio number is characterized as the ratio of heat transfer resistance $(R_\lambda = \frac{\delta}{\lambda A})$ to the thermal resistance of heat transfer $\llbracket(R\rrbracket_\lambda = \frac{1}{\alpha A})$ from the center of the solid body to its surface. According to the condition (30) for thermally treated thin long objects, the number *Bi* approaches zero ($Bi \to 0$). The value of *Bi* is taken as $Bi < 0.1$

Based on the results of the conducted research, the following graphical dependencies were built:

The relationship between temperature drop and cylinder radius (in the direction of increasing radius) is shown in grahp 1. As it can be seen from the graph, as the radius of the cylinder increases, the temperature drop also decreases.

Graph 2 shows the dependence of the temperature gradient on the radius of the cylinder. It can be seen from the graph that the radius increase in the non-stationary regime causes the temperature gradient to change according to the parabolic law.

The dependence of the temperature drop on the cooling coefficient (*Bi* criterion) is described in graph 3.

As it can be seen from the graph, when the cooling coefficient increases, the probability of temperature drop decreases and gradually decreases. In the intervals of *Bi* 0.1 ÷0.2, the process goes to the steady state.

Graph 4 shows the dependence of the temperature gradient on the cooling coefficient.

We can see from the graph when the value of the cooling coefficient increases (after the value of *Bi* =0.1), the temperature gradient moves to the stationary mode.

Graphs 5 and 6 present the dependences of fluid consumption (Q_m) on the radius of coverage (r) and *Bi* criterion during cylinder heating and cooling . It can be seen from the graphs that as the radius and cooling coefficient (*Bi*) increases, the fluid consumption also increases.

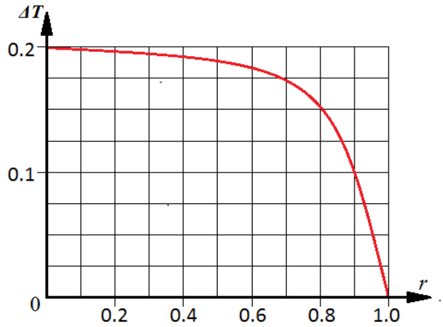
Graphs 7 and 8 show the dependence of temperature drop and fluid consumption on the heat transfer coefficient.

It can be seen from the graphs that as the heat transfer coefficient increases, the temperature drop decreases (Graph 7), and the liquid consumption increases to a certain extent and then goes to a steady state (Graph 8).

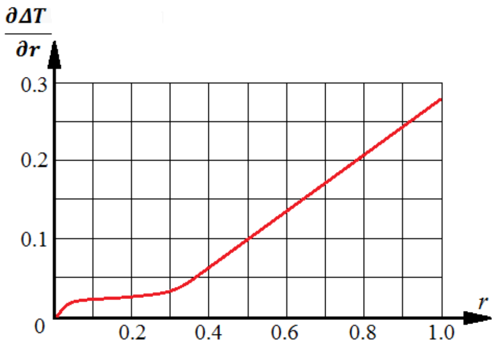
Graphs 9 and 10 show the dependences of the inertia functions from the I and I I design on the heat transfer coefficient. It can be seen from the graphs that as the heat transfer coefficient increases, the inertia function decreases, and then it goes to a steady state.

The obtained theoretical results provide good opportunities to find the values of the heat transfer coefficients in the differential equations that provide heat processes in the cooling and heating of the contact areas of the cylindrical tool with a plane of symmetry, and to clean the cooled surface from abrasive, rock and other metal particles. Tools and equipment are exposed to very large dynamic loads, high contact stresses, and sliding speeds while working inside the well. A significant part of the energy supplied to the tool is spent on eliminating internal and external friction, which prevents heating of the contact surfaces. The continued generation of heat on the contacting surfaces causes the tool to overheat.

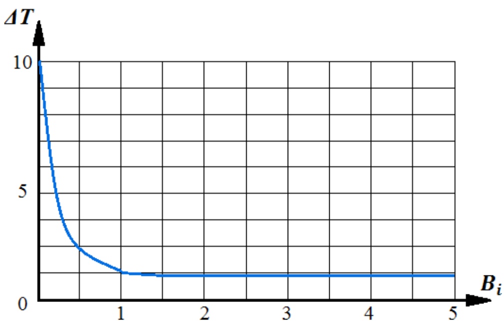
The results of the conducted scientific and experimental studies show that in the mechanical destruction of objects with different mechanical-physical properties accompanied by friction, the load falling on the tools and equipment is unevenly distributed, since the heat separated from their contact areas cannot fully cover the contact areas, and in these areas and in the environment, - evenly distributed.



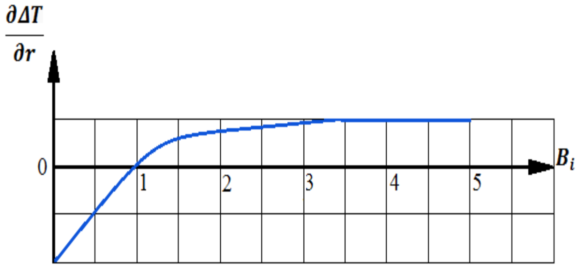
Graph 1. Dependence of the temperature drop (ΔT) on the cylinder radius (r).



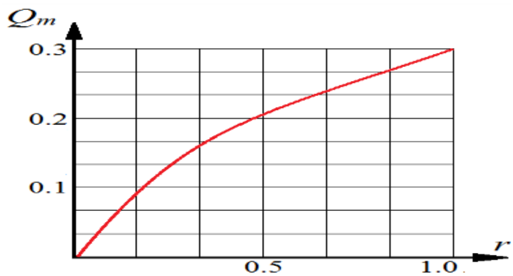
Graph 2. Dependence of the temperature gradient $(\partial\Delta T)/\partial r$ on the radius of the cylinder



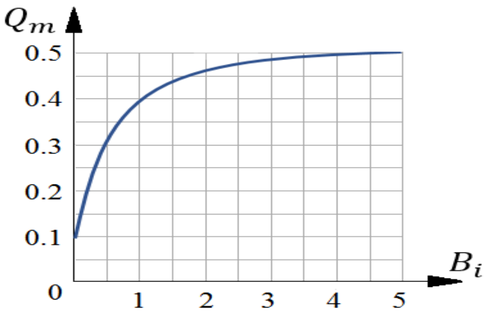
Graph 3. Dependence of the temperature drop (ΔT) on the cooling coefficient (B_i criterion)



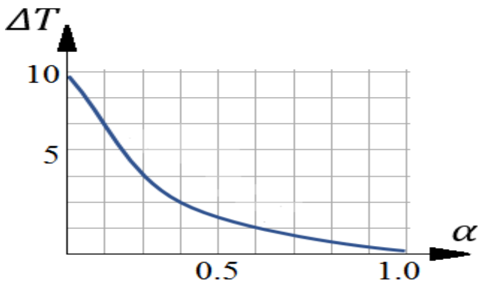
Graph 4. Dependence of the temperature gradient (∂ΔT)/∂r)on the cooling coefficient (Bi criterion)



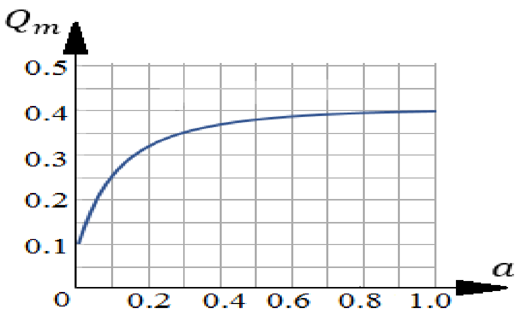
Graph 5. Dependence of fluid consumption (Q_m) on the radius (r) of the area subjected to destruction



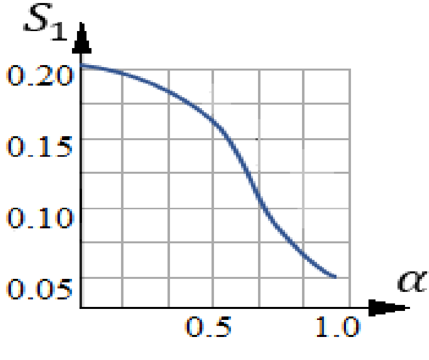
Graph 6. Dependence of liquid consumption (Q_m) on the cooling coefficient (FB_i criterion).



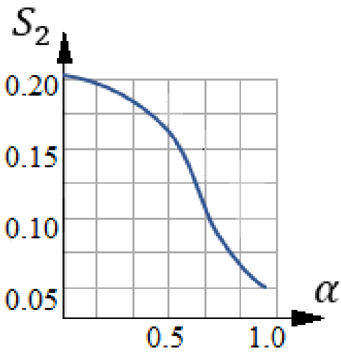
Graph 7. Dependence of the temperature drop (ΔT) on the heat transfer coefficient (α).



Graph 8. Dependence of fluid consumption (Q_m) on the heat transfer coefficient (α).



Graph 9. Dependence of the inertia function (S_1) from the I design on the heat transfer coefficient (α)



Graph 10. Dependence of the inertia function (S_2) from the II design on the heat transfer coefficient (α)

Since the number of factors affecting the heat exchange generated on the contact surfaces of the tool working inside the well differs sharply from the number of factors in other fields of mechanical engineering, the method of heat flow distribution coefficient determined for these fields cannot be used in drilling and milling. The previously determined methodology for the heat flow distribution coefficient can only be used to determine the heat generated in one-dimensional areas in drilling [148] [10].

The results of theoretical studies show that temperature stresses arise on the contacting surfaces of the tool in both normal and tangential directions, and the difference of these stresses is determined as follows within dimensionless quantities:

$$\begin{cases} \bar{\sigma}_{rr} = \dfrac{\sigma_{rr}}{2G\left(\frac{1+\mu}{1-\mu}\right)\beta T_{or}} = \dfrac{\Delta T}{x} \\ \sigma_{\theta\theta} = \bar{\sigma}_{\varphi\varphi} = \dfrac{\sigma_{\theta\theta}}{2G\left(\frac{1+\mu}{1-\mu}\right)\beta T_{or}} = \dfrac{d\Delta T}{dx} \\ \bar{\sigma}_{rr} - \bar{\sigma}_{\theta\theta} = \dfrac{\Delta T}{x} - \dfrac{d\Delta T}{dx} \end{cases} \qquad (31)$$

---

[10]Mustafayev A.G., Chingiz Nasirov, Reduction of thermal tensions and temperatures formed in the tribonodes and surfaces of the equipment and tools used in well workover and restoration works, Nafta-gaz 2023, no. 10, Doi: 10.18668/Ng.2023.10. pp. 670-678

where $\bar{\sigma}_{rr}$ is the temperature in the radial direction $\bar{\sigma}_{\varphi\varphi}$ - temperature in the normal direction; β - the coefficient of linear expansion from temperature. G is the modulus of elasticity of the second type.

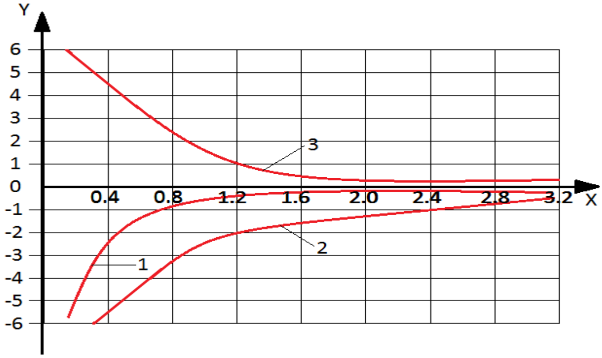
Based on formulas (31), graphs showing the dependence of temperature stresses caused by friction "x" dimensionless quantity ($\frac{x_1}{x_0}$ for different values of the ratio) were constructed (Graph 11, 12). From graph 11, it can be seen that there is an intense reduction of the stress generated in the radial direction; In the area of x≤1 (at all values of $\frac{x_1}{x_0}$ ratios), the process stabilizes after a certain period of time. Analysis of graph 12 shows that when the ratio $\frac{x_1}{x_0}$ changes, the value of the voltage difference also changes. $\frac{x_1}{x_0}$at small values of the ratio, the voltage difference is positive (Graph 12, curves 1 and 2), and at values $\frac{x_1}{x_0}$>0.8, the voltage difference is negative.

Due to the theoretical studies, reports were made in the **M-EXCEL-16** [149] [11] security program based on the given dimensions of the tool, and according to the results, 3D and two-dimensional graphs showing the change of temperatures depending on the internal and external radii of the tool and time were constructed (Graph 13, 14, 15, 16).

It can be seen from the graphs that depending on the radius, the temperatures vary according to the law of parabola, depending on the time, the temperatures increase for a certain period of time, stabilize after about 55-60 seconds, and the process goes to the stationary mode [93] [12].

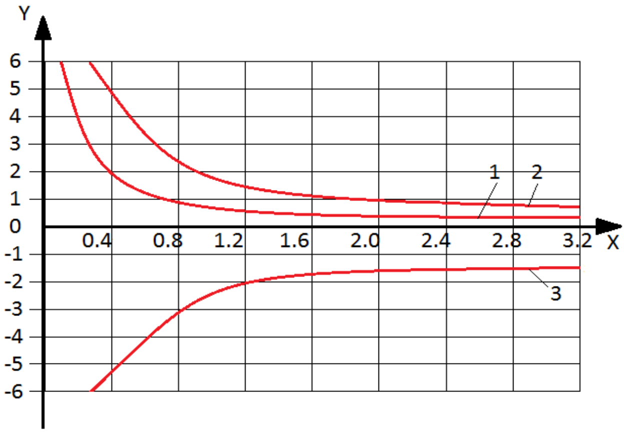
[11]Mustafayev A.G., Ismayilov M.A., Salimli M.M., Nasirov Ch.R., Improving the efficiency of the milling tool by reducing the temperature in the milling zone depending on the main mode parameters, Nafta-gaz 2023, No. 12, Doi: 10.18668/ Ng.2023.12.02, pp. 764-775

[12] Mustafaev A.G. Determination of the coefficient of distribution of heat flows in the process of cutting operational columns, Actual problems of humanitarian and natural sciences, Journal of scientific publications No. 03 (March) - 2018, pp. 29-32



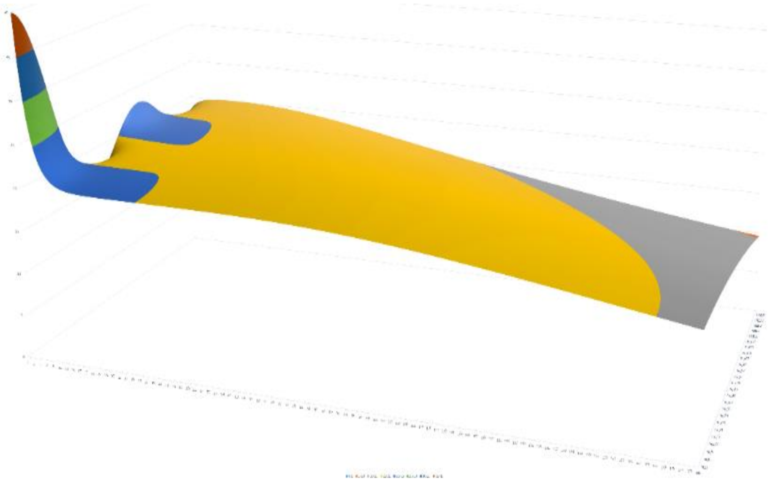
Graph 11. Change of cylinder radial stresses ($y = \sigma_{rr}$) depending on the "x" parameter (at different values of $\frac{x_1}{x_0}$ ratio)

(1-curve $\frac{x_1}{x_0}$=0.2; 2-curve $\frac{x_1}{x_0}$=0.5; 3-curve $\frac{x_1}{x_0}$= 1)

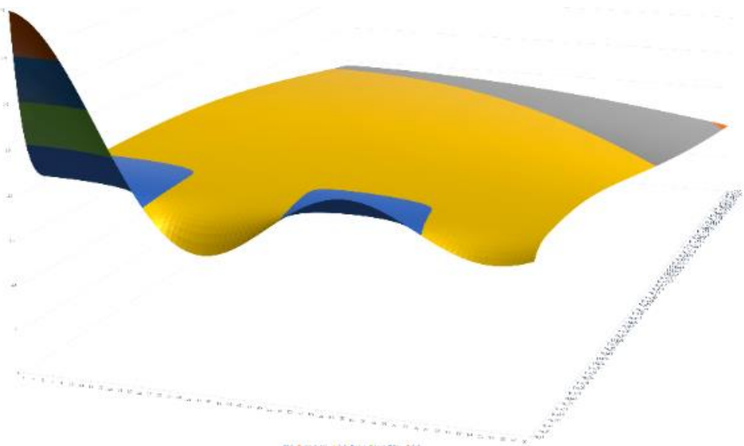


Graph 12. Change of $y = \sigma_{rr} - \sigma_{\theta\theta}$ variation of the voltage difference depending on the " x" parameter (at different values of $\frac{x_1}{x_0}$ ratio)

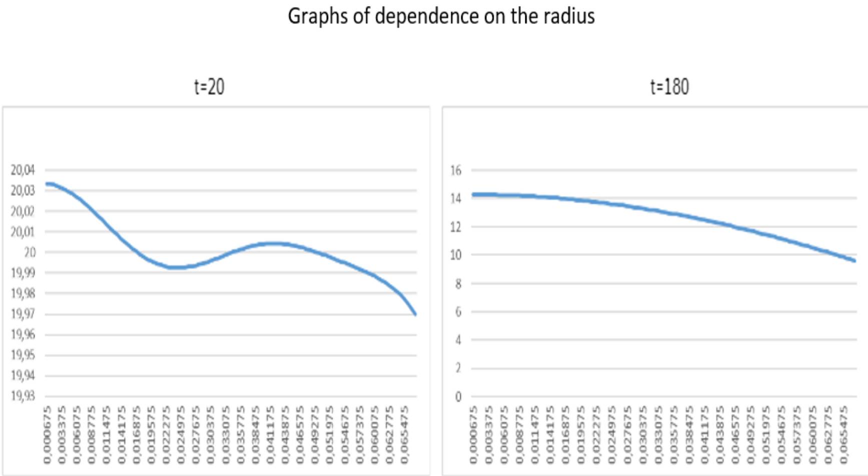
(Curve 1 $\frac{x_1}{x_0}$= 0.2; Curve 2 $\frac{x_1}{x_0}$= 0.5; Curve 3 $\frac{x_1}{x_0}$= 1)



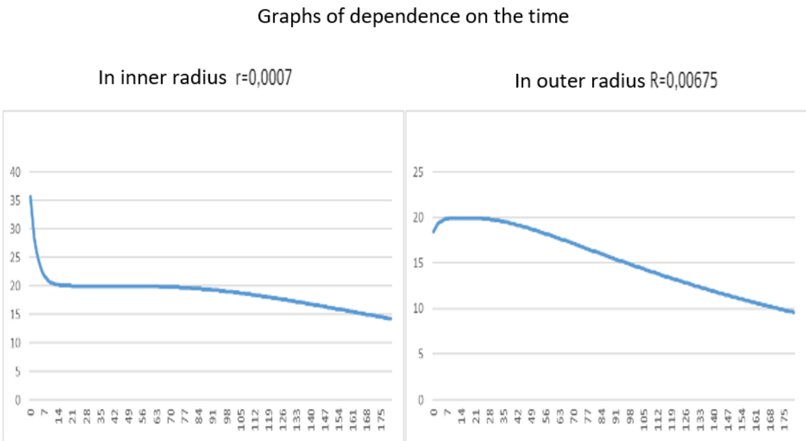
Graph 13. 3D graph of dependence of temperatures on radii and time (frontal view)



Graph 14. 3D graph of the dependence of temperatures on radii and time (top view)



Graph 15. Dependence of temperatures on radii



Graph 16. Dependence of temperatures on time

The obtained results allow to completely or partially eliminate temperature stresses in the design of the construction of the working areas of the tool.

At the same time, these results make it possible to form the construction of the working (cutting and rock-destructing) areas of the tool, taking into account specific technological conditions, thermal resistance and criteria affecting cooling, and the dissipative part of the energy consumption in the cutting part that is lost in the heat source.

As a result of the research conducted in this chapter of the thesis, according to the second law of thermodynamics, the distribution of thermostresses and temperatures in thin long plates and cylindrical areas dependence of the temperature drop and temperature gradient that occur spontaneously under the influence of thermostresses in metals and alloy compounds, on the geometric dimensions of the working area of the tool, the coefficients included in the heating processes and the mode parameters and directing of the obtained results towards decreasing temperatures have been determined.

In the 4th chapter of the thesis, the factors that increase the cutting ability of the cutting elements, resistance to corrosion and longevity of the cutting surface of the tool reinforced with composite elements in the milling process were investigated.

In this chapter, the main focus is on the rules for the use of quality composite materials that meet modern technical requirements, general norms and international standards in the working areas of repair equipment.

The results of the conducted theoretical and experimental studies show that the temperatures vary between the points starting from the axis of symmetry and ending with the outer radius of milling cutters with a cylindrical surface. Since the tool is more affected by the axial force in the direction of the axis of symmetry, it is necessary to select the size and location of the washing channels to be opened in this area in order to ensure the equal distribution of the forces falling on the cutting surface.

For optimal management of the milling cutter, it is necessary to determine the amount of heat generated in the contact zone, the nature of its distribution and effect on tool wear and breakdown.

In this chapter of the dissertation, during the interaction of composite elements with metals, the need to use new types of composite materials that meet modern requirements to increase the cutting ability of the cutting part of the tool, the rise of temperatures on the contacting surfaces, the disintegration of cutting elements and the occurrence of riveting were determined [88] [13].

The main issues related to increasing the working capacity of metal-destructive tools and regulating temperatures are reflected. Based on mathematical models, the criterion of similarity was used in the selection of cooling solutions and materials, and criterion dependencies were used to find the optimal mode parameters in milling and drilling processes, and the regularities of temperature distribution in the contact areas of solid bodies were studied.

On the basis of the results of the conducted theoretical studies, repair equipment from composite materials in the overhaul of wells the effect of temperatures on the prepared cutting chopper parts was studied [147] [14].

At the same time, in order to ensure the efficient operation of the cutting part of the milling machine in the milling process, the physical and mechanical properties of the cutting elements are selected in accordance with the physical and mechanical properties of the objects subject to disintegration, and practical results have been achieved that can help control the temperatures in the contact areas of the tool, adjusting the thermal regime parameters in the working area of the tool. for this purpose, it is proposed to use liquid, air, liquid-air mixture and other cooling solutions.

A detailed analysis of the temperature tolerance of matrix materials that ensure the functionality of tools and equipment was given, and by reducing the friction forces on the surfaces under the influence of the axial load, it was possible to increase the reliability of the cutting surface and extend the life of the tool.

In the case of sliding friction, the moment of frictional forces in the elemental area located at a distance ρ from the rotational play of the planar tool, is expressed as the sum of the elemental force moments:

---

[13] Mustafaev A.G., Pashaeva V.B., Determination of the value of the heat flow distribution coefficient in drilling and milling processes, Actual problems of humanitarian and natural sciences No. 7, 2017, Russia, pp. 47-50 1.

[14]Mustafayev AQ, Chingiz Nasirov, A study of factors affecting wear and destruction of teeth in gear mechanisms, Nafta-gaz 2023, no. 9, Doi: 10.18668/Ng.2023.09.06, 604-610

$$M_{fr} = \sum dM_{fr} = \int_r^R fq\rho^2 d\varphi d\rho = fq2\pi \int_r^R \rho^2 d\rho = \frac{2}{3} fQR\left(\frac{R}{R+r} + \frac{r}{R}\right) (32)$$

where F is the axial force evenly distributed over the area of the tool $\pi(R^2 - r^2)$(Fig. 5).

q - the specific special pressure per unit area:

$$q = \frac{F}{\pi(R^2 - r^2)} \quad (33)$$

or:

$$M_{fr} = \frac{2}{3} fQ\left(\frac{R^3 - r^3}{R^2 - r^2}\right) = \frac{2}{3} fQR\left(\frac{R}{R+r} + \frac{r}{R}\right) \quad (34)$$

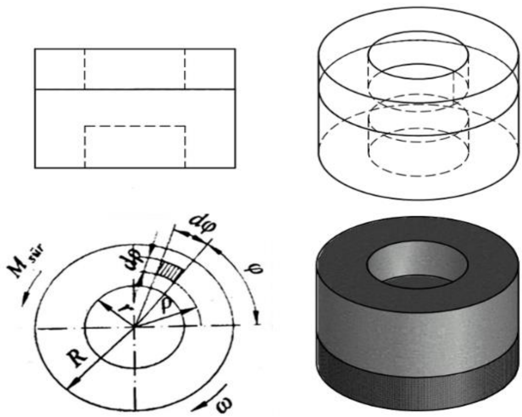


Figure 5. The scheme determining the friction moment in the contact areas of a planar tool

If to consider that the cylindrical cutter and the rock breaker $r = 0$ on the surface of the tool, then the frictional moment on the whole surface is found as follows:

$$M_{fr} = \frac{2}{3} fQR \quad (35)$$

Frictional forces between solid bodies depend not only on the coefficient of friction, but also on the type of deformation and the shape of the surfaces causing the sliding. When the torque is transmitted, a normal pressure (P) is created between the cutting elements of different configurations that enter the working area of the tool . Under the influence of normal pressure (P) and frictional forces, (F_{fr}) cutting elements are in complex stress state.

The effect of bending and twisting stresses, which affect the loss of cutting ability of the cutting elements with composite content reinforced in the working area of the downhole milling tool used in the overhaul of wells and the reduction of efficiency in milling, and the nature of the distribution of heat generated in the contact zone, were considered in this chapter of the thesis.

In general, increasing the cutting ability of cutting elements reduces the resistance forces in the contact areas with the metals they are in contact with, equal distribution of the load on the contact surfaces of the tool in the state of tension deformation, and due to the periodic shocks of the cutting surface, the cutting elements are damaged by friction and worn due to the influence of bending and torsional stresses in order to prevent microcracks and discharges, it requires the correct selection of the composition of the filler connecting the composite elements, strengthening the composition of the matrix materials, reducing the relative sliding speed, using high-quality surface-activated cooling solutions, ensuring the gradual occurrence of corrosion and rapid lowering of temperatures.

The results of a large number of scientific research studies show that tool overloading and torque reduction, as well as an increase in thermal stresses on the contacting surfaces, cause plastic deformations in the connection between the cutting elements and, as a result, the cutting elements collapse. In order to avoid this problem and to ensure the strength of the composite grains in the communication, reporting methods for hardness and strength of the cutting elements, the composition of the material reinforcement is required.

During the conducted theoretical and experimental studies, taking into account the stress-deformation situation in the milling zone, which affects the efficiency of the milling tool (the cutting ability of the cutting elements, wear resistance and longevity) of composite matrix materials and the physical-mechanical properties of the objects subjected to the collapse and the effect of impact forces were determined. Based on the obtained results, constructive changes were made in the structure of the milling machine in order to increase the milling productivity.

By using composite materials in the reinforced areas of the downhole milling tool, positive results have been obtained in increasing its efficiency and preventing corrosion problems.

During the conducted research, it was determined that and as the sizes of the metal destroyed during milling of the grains in close contact with each other increase, the stresses between the grains gradually increase. If the grain breaks off sawdust up to 2 mm thick from the metal, then the grain is in communication the tension in the strengthened zone will gradually increase, if the grain breaks off the metal with a thickness of 3 mm or more, then the compressive stress in the connection will increase and exceed the allowable limit. The yield of large-sized (3-5 mm) mixed grains with a composite composition is very low. Although the thickness of the sawdusts that these grains tear from the metal is large, the forces spent on sawing exceed the required forces, which reduces the strength of the grains in the matrix. As a result, the large grains in the bond begin to break and the specific productivity in milling decreases [141] [15].

Due to the small distance between the small grains in the contact and the large participation in milling, the volume of sawdust they remove from the metal is greater.

In order to achieve high productivity in milling, it is considered more appropriate to reinforce the working surface of the tool with composite grains of different sizes (from 0.5 mm to 5 mm) (Graph 17. and 18.).

Reinforcement of the cutting surface of the milling cutter by this method has been confirmed in the conducted experiments [139][16].

---

[15]Mustafayev A.G., Staty of heat Processes of rock cuffing (rocks cuffers) tool, Austria Journal Technical and Natural Sciences, No. 3 Vienna – 2018, pp. 23-29

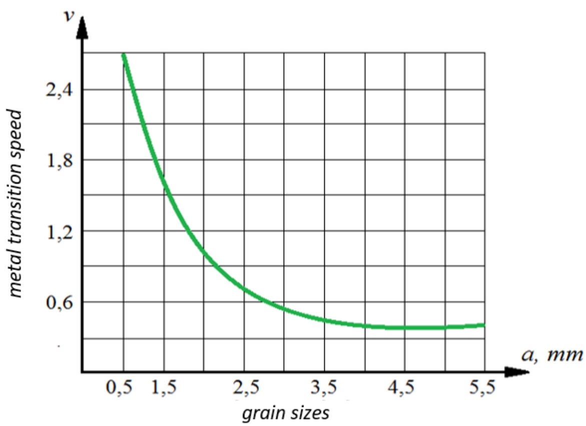
[16]Mustafayev A.G., Amirova A.M., Determination of the rational arrangement of grains I the cutting edge of milling tool and their impact on milling process productivity, Austrian journal of technical and natural sciences is an international, German/English/Russian language, peer-reviewed journal. ISSN 2310-5607. Scientific journal. No. 9-10 2017 (September-October), pp. 23-26

Physico-mechanical indicators of metals in milling are one of the main factors affecting the wear and productivity of the reinforcing part of the milling machine.

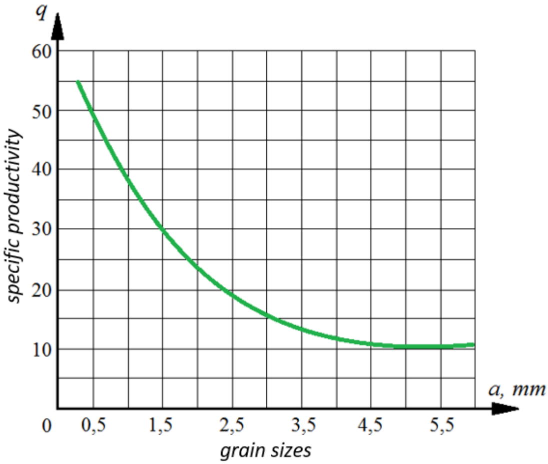
In addition to using composite materials resistant to corrosion and high cutting ability in the milling of solid and hard materials, there is also a need to consider the parameters of the milling mode.

The cutting force in the wellbore of the milling machine cannot be considered as a limiting factor. It is possible to obtain the axial force used for the destruction (sawing) of metals in milling with equipment that has the ability to apply greater force.

The work spent on bending depends on the physical and mechanical composition of the milled metal. The forces of resistance of hard metals against disintegration create a stress-deformation condition in the cutting zone and increase the force and energy indicators to be applied to milling. The stress-deformation state that occurs in the shear zone depends on the resistance of the metal subjected to destruction to plastic deformation.



Graph 17 . Graph showing the dependence of milling speed (*v*) on grain size *(a)*.



Graph 18 . A graph showing the dependence of the specific productivity of the mill (q) on the grain size (*a*).

The higher the shear strength of the metal, the higher its viscosity and malleability.

An increase in the deformation-stress state and temperatures in the cutting zone affects the malleability of the material, as the cutting zone hardens, the cutting forces increase, and as a result, the cutting elements break from connection during cutting, the tool becomes dull, loses its ability to work, and fails prematurely.

The chemical composition and structural structure of metal also affect the processing of crashed metal objects. Chromium (Cr) contained in such metals, on the one hand, increases the viscosity and strength of the metal, but on the other hand, it worsens its processing.

One of the factors affecting the wear of the milling cutter is the effect of the physico-chemical parameters of the materials processed (disintegrated) on the cutting part (Graph 19.).

An increase in the yield point of the processed material causes the cutting elements of the milling cutter to be worn and broken. This is explained by the fact that, depending on the physico-chemical and mechanical properties of the material being milled, the stress-deformation condition in the sawing zone becomes worse, and the cutting teeth in the joint are limited.

As a result, the friction force and temperatures on the contact surfaces increase, and the surface reinforced with composite elements is corroded and fails prematurely.

In general, as the cutting conditions become more complicated in the milling of solid metals, the metal cutting (dispersion) ability of the milling cutter decreases significantly (Graph 20).

One of the main factors affecting milling, disintegration and productivity reduction of the milling work in the wellbore is the high temperatures generated on the touching surfaces.

Despite the detailed research on the determination of the composition of composite materials, their tolerance to temperature stresses and other properties, the number of scientific research works on heat conduction issues caused by temperatures in these materials with electrical conductivity properties is small [140] [17].

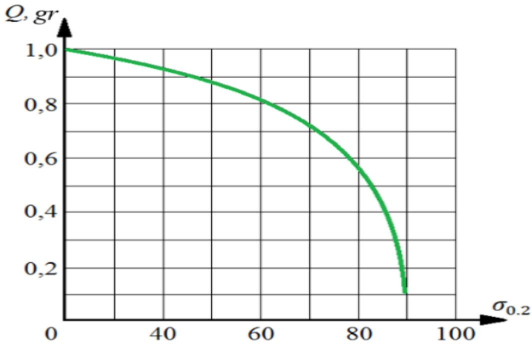


Chart 19. Dependence of productivity on strength limit of milled metals in wearing of cutting elements

When the components of composite materials with electrical conductivity interact with metals, the electric charge formed by friction on the contact surfaces of the tool causes an increase in temperatures on the contact surfaces and overheating of the composite

---

[17]Mustafayev A.G., Aliyeva I.K., Agarzayev B.K., Abdullayev A.R., Heat processes on the contact area of the two-hole milling tools, Austrian Journal of Technical and Natural Sciences Scientific journal, No. 3-4 2018 (March-April), ISSN 2310-5607, pp. 24-28

elements, and the cutting surface of the tool is worn away and fails in a short time.

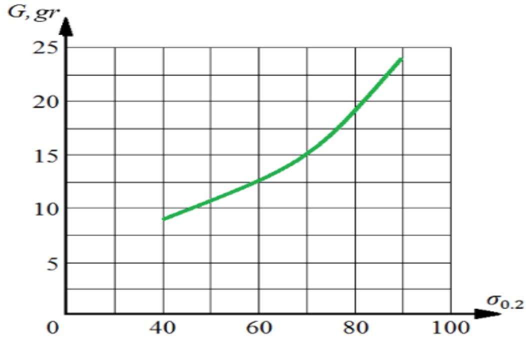


Chart 20. Dependence of the weight of milled metal on the strength limit of milled metals

Therefore, it is necessary to create new types of composite materials that meet modern requirements on the basis of available basic materials in order to increase the cutting ability of the cutting part of the cutting-shredding and destructive tools.

Studies conducted with cutting tools show that the main reason for the formation of high temperatures in the contact areas of the cutting elements with the destroyed metal is the late delivery of the cooling solution to the cutting zone or its intermittent injection. For this reason, sometimes the temperature on the touching surfaces of the tool increases up to 900 ^{0} - 1200 ^{0} C [92] [18].

In the process of milling, the distribution of thermal stresses between the contact surfaces of the milling tool and the crashed metal object is characterized by heat balance and heat transfer (Fig. 6).

The heat balance in milling is determined as follows:

$$Q = Q_d + Q_{c.s} + Q_{r.s} + Q_c + Q_w = Q_{m.m.} + Q_m + Q_s + Q_e \quad (36)$$

[18]Mustafaev A.G., Nasirov Ch.R., Development of a method of improving the performance of well-destroying tools, Materials of the Russian scientific and technical (with international participation) "Problems of geology, development and exploitation of deposits, transportation and processing of difficult-to-extract heavy oil", 8 - December 10, 2021, pp. 208-209

where Q is the sum of the temperatures generated in the milling process; Q_d-temperatures corresponding to the equivalent work during the deformation of the sawdust layer; $Q_{c.s.}$- temperatures caused by friction on the contacting surface of the tool; $Q_{r.s.}$- the temperatures that occur during the smooth removal of sawdust; Q_c- temperatures that occur when metal is cut; Q_w - the temperature of the well; $Q_{m.m.}$– is the sum of the temperatures transferred to the surface of the milling machine; Q_m- temperatures caused by milling metal; Q_s- are sawdust temperatures; Q_e - ambient temperatures.

The heat released from the active area of the milling machine is determined as equivalent to the work spent on milling:

$$Q = \frac{\delta \cdot F_z \cdot \omega}{427S}, \tag{37}$$

where F_z is the substitute for tangential forces in milling; ω– the rotation frequency of the milling machine; δ- a coefficient that takes into account the uneven distribution of the force falling on the contact area; *S* the sum of the areas covered by the grains of the cutting element in contact with the milling object.

Figure 6. Temperature distribution scheme between contact surfaces

A rational cooling system was chosen in order to regulate the temperatures and temperature stresses on the contact surfaces of the milling machine, opening the cylindrical channels in the direction of the central axis on the reinforced surface and allowing only a part of the liquid flow to enter the cooling system channels to be removed from the contact area of the heat flow was determined.

It is possible to improve the cooling system by correctly choosing the parameters of the rational mode in order to prevent the negative situations occurring in the milling process.

During the conducted studies, it was determined that increasing the height of the reinforced area of the tool does not have much effect on the even distribution of heat in this area. As the height of the reinforced area increases, the temperatures at the contact surfaces increase, creating pores and voids in the cutting element assembly, which eventually causes the cutting elements to collapse.

The research results show that the temperatures in milling cutters with a cylindrical surface vary at all points starting from the axis of symmetry to the outer radius of the tool. Therefore, it was proposed to make changes in the diametrical dimensions of the washing channels to be opened in this direction due to the high pressure at the points where the force is more effective around the axis of symmetry.

The number of washing channels to be opened along the Archimedean spiral on the cutting surface of the milling machine in order to remove metal shavings from the working area of the liquid entering the milling zone is determined as follows:

$$K_w \leq \frac{D}{2d} \tag{38}$$

where K_w is the number of washing channels; D - the outer diameter of the milling cutter; d – the diameter of the last washing channel located on the Archimedean spiral:

$$d = \pi l n D, \tag{39}$$

(d_n) of n number of washing channels located along the Archimedean spiral on the surface of the milling machine is determined as follows:

$$d_n = \pi lnD + [K - n], \quad (40)$$

where n is the serial number of channel diameters calculated from the center of the milling cutter.

The reason for the increase in the diameter of the washing channels opened by the Archimedean spiral towards the center of the milling machine is to prevent the tool from being affected by greater forces and to eliminate the stress deformation condition.

Archimedean spiral channels allow even distribution of liquid along the cutting surface and intensive removal of heat from the cutting surface in high modes (Fig. 7, a, b).

During the studies, the amount of heat generated in the contact area, the nature of its distribution, and its effect on tool wear and disintegration were determined for the optimal control of the milling tool working inside the well.

Currently, the properties of matrix materials containing tungsten-carbide (VK8) with a composite content in forming, strengthening and increasing the cutting capacity of the moving parts of downhole cutters used in the overhaul of wells allow them to be widely used in metal cutting, and the scientific research conducted in this field is of great importance. By adding various fillers to the content of composite materials, its tribotechnical properties can be further improved. VK8 composite matrix materials are widely used by companies of foreign countries and CIS countries in the preparation of cutting elements of downhole tools.

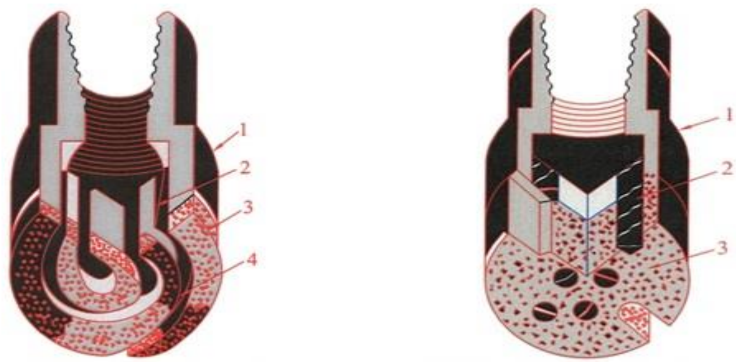


Figure 7. Well-cutting milling cutter

a) Archimedean spiral: 1-body; 2-washing channel; 3-the area of the reinforced surface; 4-Archimedes spiral channel;
b) Milling along the entire surface: 1-body; 2-spiral washing channel; 3-reinforced surface

The advantage of VK8 brand composite materials is that they have high cutting ability, resistance to temperatures (950°-1200°C) and high productivity in metal milling.

The efficiency of the downhole milling tool depends more on the stress-deformation state of the composite elements, the physical-mechanical properties of the composite-containing alloy compounds and objects subjected to disintegration, the value of the impact force and the mode parameters in milling. During the researches, the characteristic features of impact forces affecting the reinforced area depending on the construction of the tool were determined for two extreme situations. In the first case, the effect of the impact forces on the cutting elements on the cutting surface (contact area), and in the second case, the effect on the composite elements in the whole assembly was determined. The stress-deformation state created on the contact surfaces of the tool was treated as a plane stress state, and the forces acting on this area were determined using the finite element method (two-dimensional simplex elements) [95] [19].

In the finite element method, searches were conducted using discrete models to solve physical-mathematical problems, a set of cross-sectional functions was drawn up in the interval of given subfields, a set of subfields covering the entire field and each of them was considered as a finite element. Discrete fields have made it possible to use a simpler system of mathematical equations in solving a system of differential equations. This method was used to define the values of the function in the predetermined subfield interval of each of the discrete models.

The finite element method was performed in the following order:

---

[19] Mustafaev A.G. Investigation of the influence of interrelated factors on the thermal regime of a rock-destructive instrument, Modern technology in the oil and gas business-2017, "Collection of works of the international scientific and technical conference", Ufa State. Oil. Tech. University, 2017, 128-132

1. The considered area is divided into a finite number of elementary subareas, elementary areas have nodal points, and in general approximate the shape of the area.
2. The continuous function at the nodal points is not known in advance, it is only determined later;
3. The unknown quantities in each element were approximated by the collection of certain functions, the functions were used depending on the type of element and the number of nodes included in the element. The polycoms were chosen in such a way that the functions along the boundary of the element maintain their continuity;
4. The solution of differential equations was performed by minimizing a certain functional associated with these equations. In this case, the functional is discretized using the approximation function and its derivative of the given set of finite elements.
5. A system of mathematical equations was obtained as a result of discretization and minimization of the transformed functional.

The solution of these equations determines the value of the function at the given nodes.

Force vector for the element $[\bar{F}]$:

$$[\bar{F}] = [\overline{F_R}]^e + [\overline{F_P}]^e \qquad (41)$$

the calculated area is divided into *n* number of elements, the solution equations of the finite element method:

$$[K][f] = [F] \qquad (42)$$

$$[K] = \sum_{e=1}^{n}[K]^e \text{ matrix of the stiffness} \qquad (43)$$

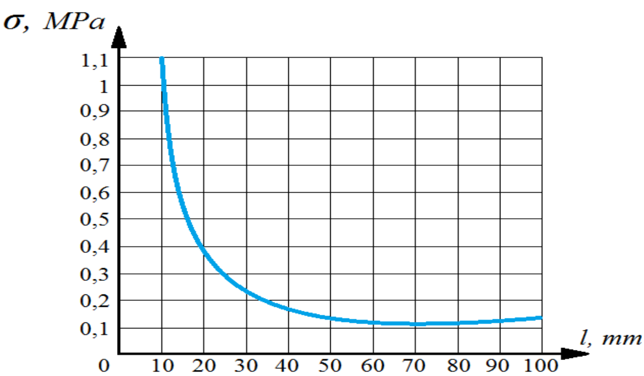
$$[F] = \sum_{e=1}^{n}[F_R]^e + \sum_{e=1}^{n}[F_P]^e \text{ vector of forces} \ (44)$$

where [f] – the displacement vector of the nodes and is determined from the solution of the system of mathematical equations (41).

After determining the displacement of the nodes, the values of stress and deformation at any point of the element were obtained. In the solution of the system of mathematical equations, the fact that the stiffness matrix is positive was taken into account, the solution of the equations was carried out by the summation of square roots method, as a result, the calculation time was reduced [10] [20].

The tangential stresses for the layers of the reinforced area were determined using the finite element method. Under the influence of a single force, the intensity of the distribution of stresses decreases to a minimum level (σ_{max} =1.71-1.84*10^1 MPa) in the contact area of the cutter body with the composite alloys, and the stresses created in the contact areas of cutting elements and metals are maximum (σ_{max} =425-475 MPa) has been determined to reach the limit [150] [21].

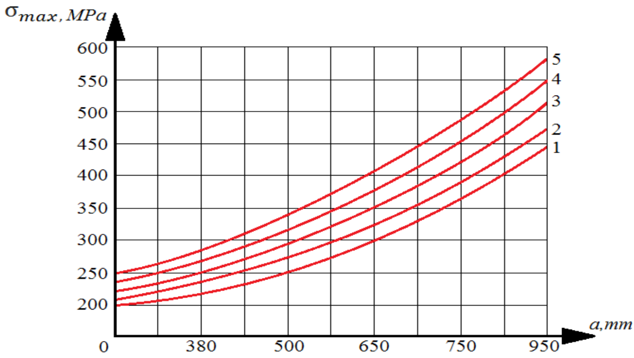
Research results show that the efficiency of composite elements depends more on the mechanical properties of the material of the cutting elements, the impact force and the stress state of the elements.



Graph 21. Distribution scheme of tangential stresses in the contact area of the cutting elements on the lower layer of the milling cutter

[20]Mustafayev A.G., Mamishov R., Calculation of the contact stresses between the inner surface of the pipe and the outer surface of the screw tool during the capture of damaged pipes inside the well, Ecology and water management No. 3, 2023, Scientific-technical and production magazine, pp. 89-93

[21]Amir G. Mustafayev, Chingiz R. Nasirov, The advantage of composite materials used in downhole cutting tools, Nafta-gaz 2024, no. 1. Doi: 10.18668/ Ng.2024.01.03, pp. 19-29



Graph 22. Distribution scheme of tangential stresses generated on contact surfaces under the influence of axial load
1-1700 N, 2- 2800 N, 3- 3700 N, 4- 4900 N, 5- 6400 N

In the 5th chapter of the dissertation, the well milling cutter used in the overhaul of wells (Figure 8) and the main factors that ensure the functionality of rock-destructing equipment and tools, the temperatures are determined from the physical-mechanical properties of the destroyed objects, the mode parameters controlled in milling and drilling, and other factors that affect the thermal regimes. Mathematical dependencies determining its dependence on factors (Figure 9) were set, graphical dependencies were determined based on the obtained values (Graph 23-28) and parameters ensuring the adequacy of the milling process were set.

In order to maintain the well fund at the required level and to increase operational efficiency, to reduce the number of unusable wells and to improve repair work, while maintaining the natural processes occurring in drilling and milling, a laboratory stand for the accurate study of the dependence of the temperatures generated in the moving parts of the tool on the regime parameters (Fig. 15) was developed and research works were carried out using different cooling solutions [68] [22]. The dimensions of the arrangements used during the

---

[22]Mustafaev A.G., Zeynalov O.S. Experimental installation for the study of the temperature regime of well cutting tools - "Uchenie zapiski" ASOA, No. 1, 1998, pp. 103-107

experiments (figures 10-11) were changed according to the possibilities of the laboratory conditions, the cutting part of the tool (figure 12) and objects subject to disintegration (figure 13) were provided with thermocouples (figure 14), mathematical models were built, the mode according to the dimensions of the model parameters were selected, experiments were planned and carried out in stages, the results of the experiment were analyzed with SOLIDWORKS and M-EXCEL 2016 software, based on the obtained results, the levels of factors influencing the regulation of temperatures in milling and drilling were determined (figure 8-19).

The experiments were carried out in 5 stages, in all stages the mode parameters were changed according to the values provided in the plan (an orthogonal cube was built), the temperature indicators were registered, and at the end of each stage, the tool and the object to be milled were removed from the device and weighed. According to the difference between the weights before and after the experiment, the degree of wear of cutting-destructive elements, productivity in milling and drilling was determined [35].[23]

During the researches, as the main factors, the effect of axial static load falling on the tool, the rotation frequency of the tool, the consumption of cooling solutions, the geometric dimensions of the cutting elements in the working area of the destructive tool, the mechanical content of composite materials and objects (metal, rock) subjected to destruction (in the average values of the factors) on temperatures was studied. In stages 1-4 of the experiments, the interaction of the factors affecting the productivity of the milling machine was considered. Based on the analysis of regression equations, the results obtained from the experiment were processed, the mathematical model of the effect of mode parameters on temperatures and temperature stresses was obtained, graphs defining the dependence of temperatures on mode parameters were constructed.

[23] Gasanov A.P., Mamedov A.A. Questions about the creation of a well milling tool to increase the operating modes. //M.: Tsintikhim Neftemash, 1985.

23

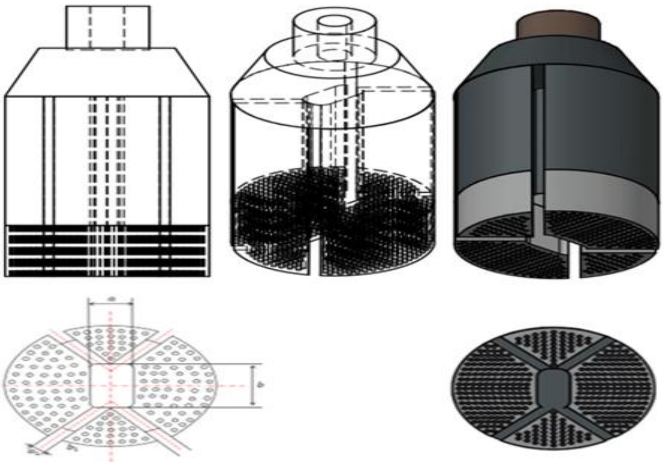


Figure 8. Downhole milling

In order to reduce temperatures and temperature stresses in the drilling-milling zone by using cooling solutions, graphs were created that determine the dependence of the temperature generated in the contact areas of the cutting and rock-destroying tools on the mode parameters (ω, F, σ_{mm}, Q_l, Q_a), T-ω, TF , T-σ_{mm}, TQ_l and TQ_a graphical dependences were analyzed and among these dependences the equations ensuring the adequacy of the milling process were selected [80] [24]. When switching to non-linear regression equations, the smallest values of mean square deviation were found for each factor (from the interaction of factors), graphs corresponding to the equations determining the dependence of temperatures on mode factors (ω, F, σ_{mm}, Q_l, Q_a) were constructed, and the graphs that ensure the adequacy of the process were selected from these graphs (Graphs 23-27) [198][25]

[24] Mustafaev A.G., Gafarov F.M., Mamedov R.V. Increasing the efficiency of the milling tool with reinforced composite material. – Scientific Works, ASMA, №1, 2014, pp. 36-40

[25] Amir G. Mustafayev, Mahmud A. İsmayılov, Mirkamran M. Səlimli, Chingiz R. Nəsriov.Enhancing tht efficiencyof well millinq devices andcleaning wellsfrom milled objects by implementig cavitation in the millingzone Nafta-gaz, Nafta-gaz 2024, no. 11, pp. 696-704, Doı: 10.18668/ NG.2024.11.05.

For the dependence of temperatures on angular velocity (Graph 23):

$$T_\omega = C\left(\frac{1}{\omega}\right)^2 - B\frac{1}{\omega} = 318995\left(\frac{1}{\omega}\right)^2 - 30097\frac{1}{\omega} \qquad (45)$$

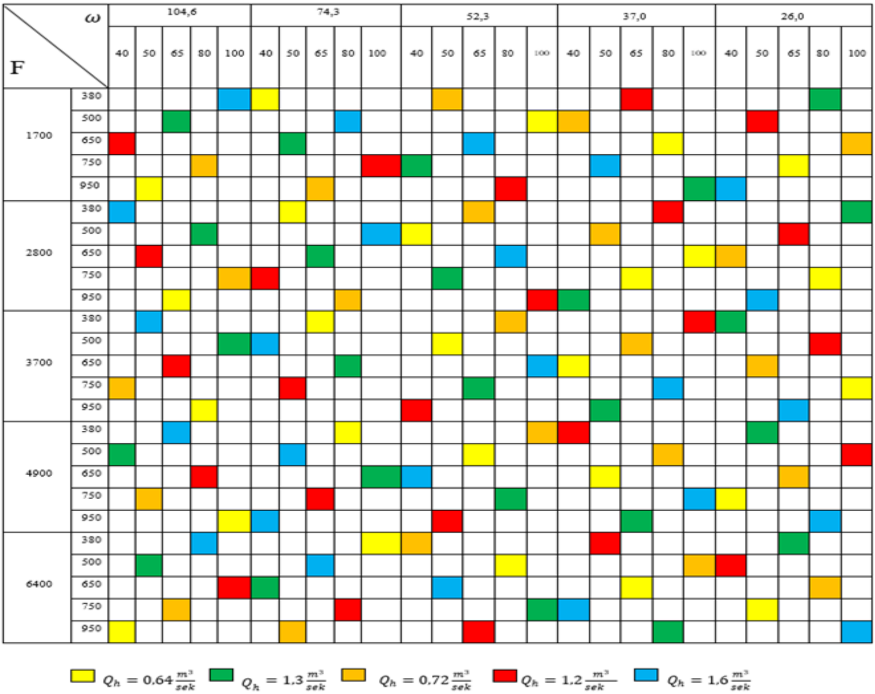


Figure 9. Orthogonal cube

For the dependence of temperatures on axial load (Graph 24):

$$T_F = B \ln F = 135{,}79 \ln F \qquad (46)$$

For the dependence of temperatures on the strength limit of the material (Graph 25):

$$T_\sigma = B \ln \sigma = 81{,}902 \ln \sigma \qquad (47)$$

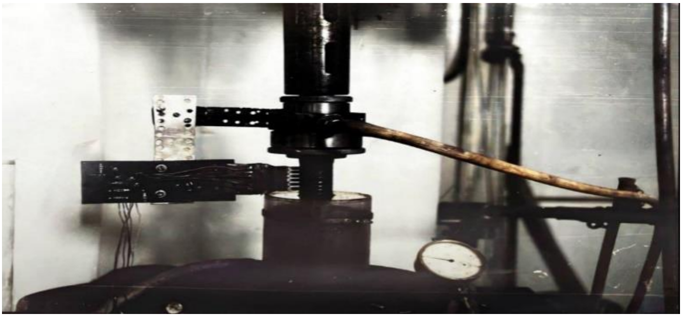


Figure 10. Cooling and measuring temperatures

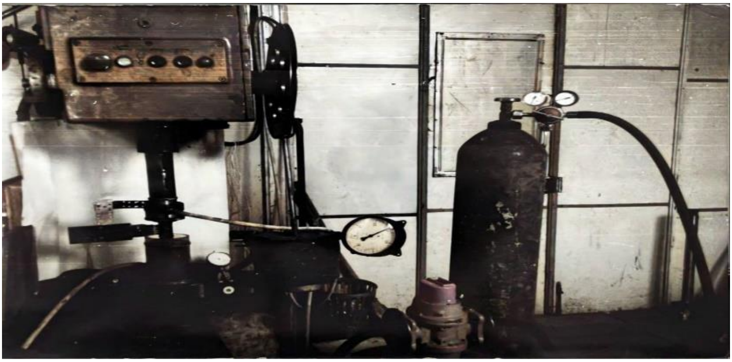


Figure 11. Adjustment of load and air flow to the cutting zone along the axis

Figure 12. Models of QF

Figure 13. Milled metal objects

Figure 14. Equipping the milling model with thermocouples

For the dependence of temperatures on liquid consumption (Graph 26):

$$T_{\mathrm{Ql}} = B \ln \mathrm{Q_l} = -147{,}92 \ln \mathrm{Q_l} \tag{48}$$

For the dependence of temperatures on air consumption (Graph 27):

$$T_{\mathrm{Qa}} = B \ln \mathrm{Q_a} = -124{,}44 \ln \mathrm{Q_a} \tag{49}$$

The LINEST function in **EXEL** was used to find the coefficients for the regression equations $k_{\omega}, k_F, k_{\sigma}, k_{\mathrm{Ql}}, k_{\mathrm{Qa}}, k_{\mathrm{T}}$.

$$k_{\omega} \approx 1.0111, k_F \approx 0{,}9927, k_{\sigma} \approx 0{,}9695, k_{\mathrm{Ql}} \approx 1{,}0662, k_{\mathrm{Qa}} 1{,}0315,\ k_{\mathrm{T}} \approx 0$$

Using these coefficients, a nonlinear regression equation was obtained from a linear regression equation:

$$T = 1{,}0111T_{\omega} + 0{,}9927T_{F} + 0{,}9695T_{\sigma} + 1{,}0662T_{\text{Ql}} + 1{,}0315T_{\text{Qa}}$$

MS EXCEL 2016 software security program was used in the processing of the data obtained from the experiment.
A nonlinear regression equation showing the dependence of temperatures on the values of individual factors $(T_{\omega}, T_{F}, T_{\sigma}, T_{\text{Ql}}, T_{\text{Qa}}, T_{0})$ was determined:

$$T = \frac{a}{\omega^2} - \frac{b}{\omega} + \ln\frac{P^{c} \cdot \sigma^{d}}{\text{Ql}^{e} \cdot \text{Qa}^{f}} \qquad (50)$$

$R^2 \approx 0{,}9757$ non - linear regression equation was determined from the equation.
T=f(F), T=f(ω), T= (σ $_{mm}$), T=f(Q $_{l}$) and T=f(Q $_{a}$) graphs, non-linear regression equation that determines the dependence of temperatures on mode parameters linear regression equation was obtained (Graph 28):

$$T = a/\omega - в/\omega + \ln(F\sigma_{mm})/Q_{l}Q_{a} \qquad (51)$$

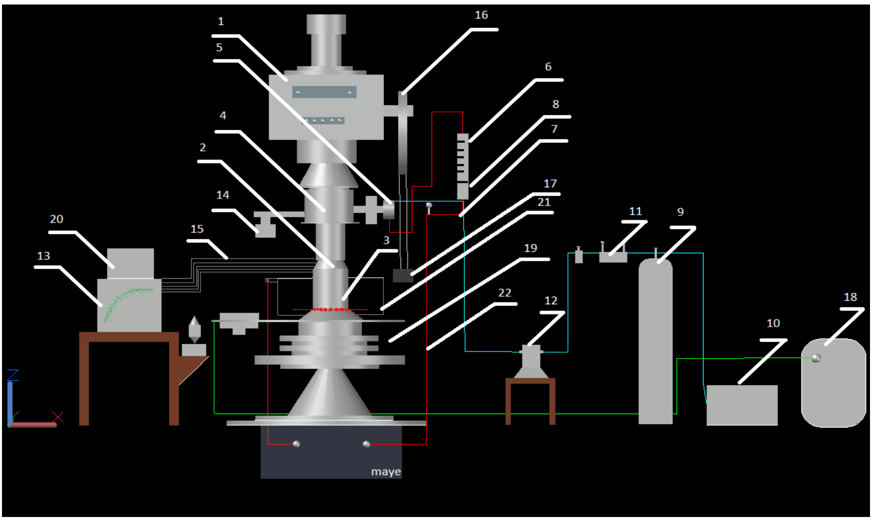


Figure 15. 3D view of the experiment stand

In the 4th stage of the experiment, the application of cavitation was considered in the evaluation of the efficiency of the cutting elements of the wellbore milling tool and in the cleaning of the wellbore with fast technologies. A large number of studies have been carried out using controlled mode parameters and cooling agents (liquid, air and "liquid-air" mixtures) in milling.

The design of the well-bottom milling unit has been changed and it has been designed in a new way. In order to create cavitation inside the device, the channel opened in the direction of the central axis of the milling machine was expanded in the transverse direction, a liquid-gas mixing chamber was created in this area, and a screw plug and a roller valve were placed in the chamber. A screw plug and a roller valve provide continuous injection of air into the liquid-gas mixing chamber and efficient use of the liquid-gas mixture.

One of the advantages of the proposed construction is that the destroyed objects (metal, rock, petrified cement, etc.) are affected by cavitation. By creating cavitation, these objects are struck from a certain distance, the structural construction between the particles of the object is disturbed, microcracks and erosion occur on the struck surfaces, and the objects begin to fall apart from that place, the cutting process accelerates, and after a certain time, the temperature balance is restored. At the same time, cavitation allows cleaning of the well bottom zone from small-sized rock and metal, abrasive particles and other deposits.

Features that distinguish the new construction of the milling machine from the existing construction:

The liquid capacity of the “gas-liquid” mixing chamber in the new design is larger than the liquid capacity in the existing design(fig. 16).

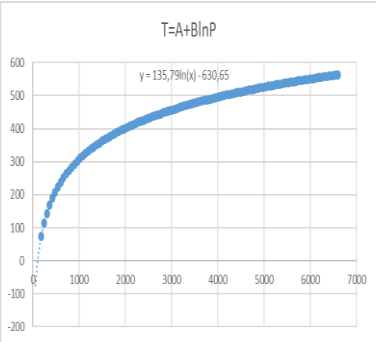
There are no difficulties in installing a screw plug (fig. 17) and a roller valve (fig. 18) in the "gas-liquid" mixing chamber.

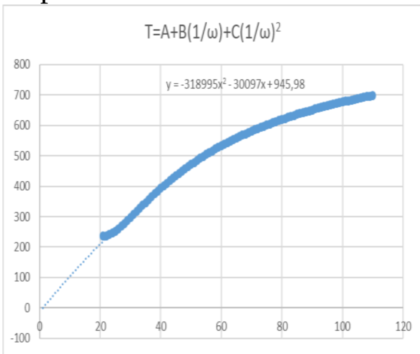
The last burt-shaped screw of the internal thread is fitted with a screw plug by tensioning (fig. 19).

The construction of the milling machine proposed in the new design is not expensive, and there are no difficulties in the manufacturing technology. The obtained results provide good opportunities for solving the problems posed in milling.

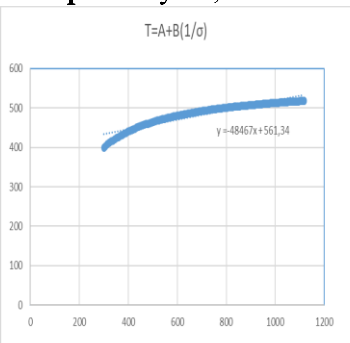
The reliable operation of the downhole tool allows to improve its resistance to corrosion and temperatures, productivity and other indicators, to reduce the costs of the tool in drilling and performing repair work, and to significantly save the time spent on "lowering and lifting" operations.

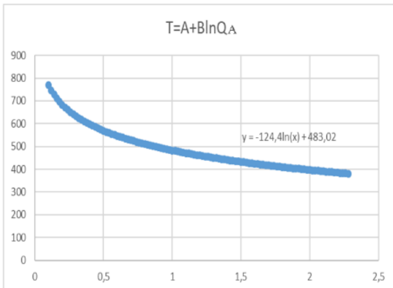
provide good opportunities to effectively use the bottom milling tool used in the overhaul of wells in practice.





Graph 23. y=T; x=1/ω **Graph 24.** y=T; x=P





Graph 25. y=T; x=σ_{mm} **Graph 26.** y=T; x=Q_l;

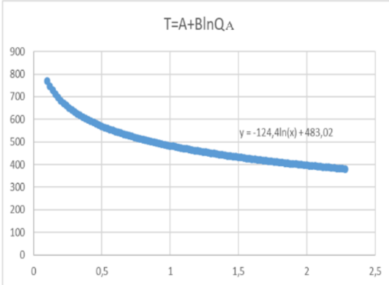


Chart 27. y=T; x= Q_a ;

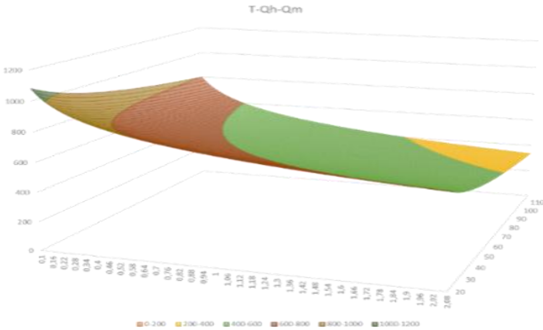


Chart 28. Three-dimensional dependence of temperatures at consumption of "liquid air" mixture at average values of mode parameters (ω, σ_{mm} F)

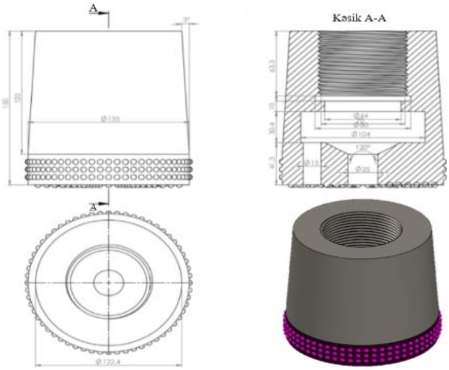


Figure 16. Schematic and 3D model view of the milling tool

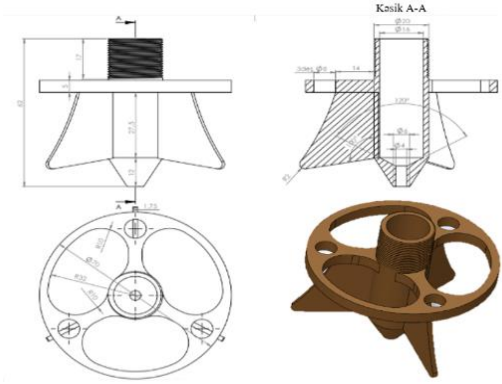


Figure 17. Schematic and structural view of the screw plug

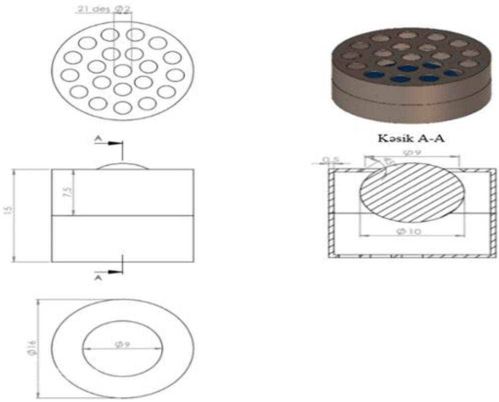


Figure 18. Schematic and 3D model view of a roller valve

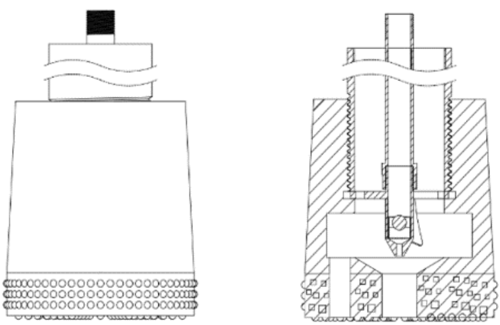


Figure 19. Assembly sketch of the milling machine in the new construction

The research work considered in this chapter of the dissertation work was carried out in the following order.

- on the basis of theoretical and experimental studies, the mathematical model of the downhole milling tool was determined and its mathematical notation was obtained.

- taking into account the factors involved in the solution of heating issues in drilling and milling, using the π theorem, the geometric dimensions of the model simulating the field conditions and the mode parameters ensuring the process were obtained.

- created microcracks throughout the volume of metal and rock samples, formed a cavitation system that ensures their fragmentation into large and small parts and washing the well.

- a laboratory stand providing the model dimensions of the instrument was prepared and laboratory supplies were obtained for conducting experiments.

- the experiments were carried out in planned stages, a cooling device was developed to reduce temperatures and temperature stresses in the cutting and dispersing zone.

-temperatures were measured with thermocouples placed along the volume of the reinforced area of the rotating tool and their transfer to the temperature measuring devices was ensured with compensating wires.

- at all stages of the experiments (using dry friction, liquid, air, "air-liquid" mixture), graphical dependences of temperatures on the controlled mode parameters (at the average values of these factors) were determined separately, and the extent to which these parameters affect the cooling of the moving areas of the tool was compared.

this chapter, the graphical dependences that determine the dependence of the temperatures generated in the working areas of a single-spindle drilling bit on the controlled mode factors have been set.

In the course of research, rocks of different composition were used, and the influence of rational mode parameters and other factors on rock disintegration and temperatures generated in the drill bit cone was determined.

The degrees of influence of each of the results obtained from the experiment on the temperature field were evaluated, and in order to achieve the set goal, equations were used that ensure the transition from a one-dimensional stationary state to a non-stationary state, and the effect of these equations on the effective work of the bit and the quality indicators of the temperatures generated in the interaction zone of the bit and the rock during drilling was evaluated. In all cases, the effect of mode parameters on temperatures was considered in the average values of other parameters.

The prediction of the strength of the bit against temperatures was carried out as follows:

$$P_i = f(x_1, x_2, x_3 \dots x_n) = z[\sum_{i=1}^{n} \varphi_i(x_i)] \qquad (52)$$

φ_i is a one-dimensional monotonically increasing function; x_i- initial variable parameters; z - the output parameters of the function. Based on the research results φ_i, the dependence of φ_i on x_i.

Factors and their levels are listed in table 1.

The factors (x_i variables) included in these functions allow to evaluate the effect of the temperatures generated in the zone of interaction between the bit and the rock during drilling and the quality indicators of the bit.

The influence of regime parameters on temperatures was considered separately in the average values of other parameters.

Using this method, the level of variation of forecasting between z and $\varphi_i(x)$ was carried out in the following order. The investigated factors are determined by $\varphi_i(x_i)$ function, where *i* =1,2,3,.. *n*.

According to $\sum_{i=1}^{n} \varphi_i(x_i)$, the output parameters of z and then the values $z[\sum_{i=1}^{n} \varphi_i(x_i)]$ of temperatures (T) depending on all parameters separately (on average values of other parameters) were determined. During the process, the number of other factors affecting the temperature field was also determined. The obtained information will allow to comprehensively solve the requirements (structural, technical-geological and technological) in the destruction of mountain rocks, to extend the life of the bit, to reduce the number of "lowering-lifting" operations and the costs of drilling a well, and to make optimal decisions in making certain changes in the design of the tool related to temperatures.

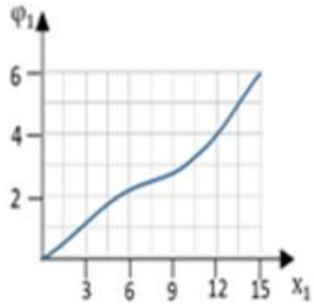
Table 1.

Factors and their levels

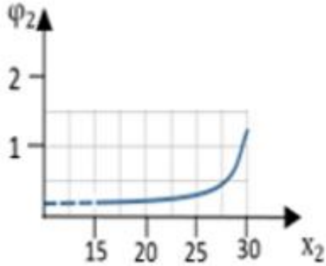
Basic mode factors	Levels of factors				
Bit rotation frequency (x_1), rad/sec	3.3	4.7	6.6	8.4	12
Bit (model) diameter (x_2),mm	26	32	35	50	55
Axial load (x_3),kN	0.98	2.0	3.15	4.68	6.4
The ratio between the hardness of the rock and roller material (x_4)	0.30	0.45	0.60	0.75	0.90
When the rock is in contact with the bit (x_5),sec	60	60	60	60	60
Types and density of coolant (x_6),kg/m^3	air 1000	Liquid 1300	"liquid-air" mixture 1600	"liquid-gas" mixture 1780	excavation solution 1900
Pump efficiency (fluid consumption) (x_7),l/sec	0.0031	0.0047	0.0064	0.0075	0.010
Air consumption (x_8),m^3/sec	0.0004	0.0006	0.0008	0.0010	0.0011

Based on the results of the conducted studies, the criterial dependencies of the rational mode parameters of the rock-destroying tool on temperatures and on each other were determined (Graph 29).

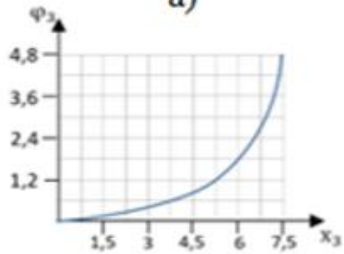
The results obtained from the experiment provide good opportunities to predict the temperature stresses that may arise in the moving parts of the drill bits during the operation of the drill bit, to reduce the temperatures, to control the process, and to establish a work routine that provides rational conditions in the drilling and operation of oil and gas wells.


φ1
6
4
2
3
6
9
12
15
x1

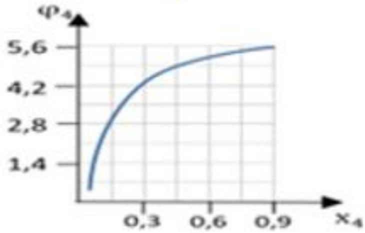
a)


φ2
2
1
15
20
25
30
x2

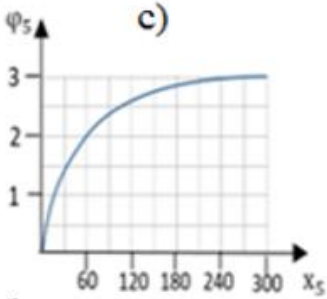
b)


4,8
3,6
2,4
1,2
1,5
3
4,5
6
7,5
x3

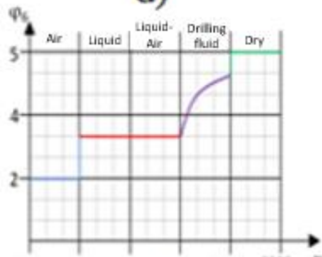
c)


5,6
4,2
2,8
1,4
0,3
0,6
0,9
x4

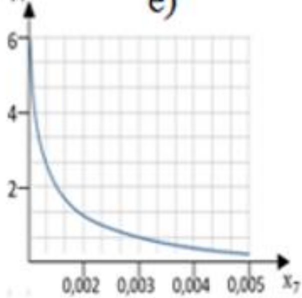
d)


φ5
3
2
1
60
120
180
240
300
x5

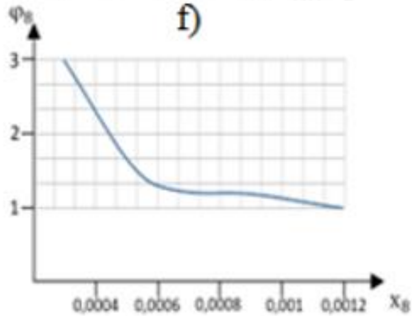
e)


Air
Liquid
Liquid-Air
Drilling fluid
Dry
5
4
2

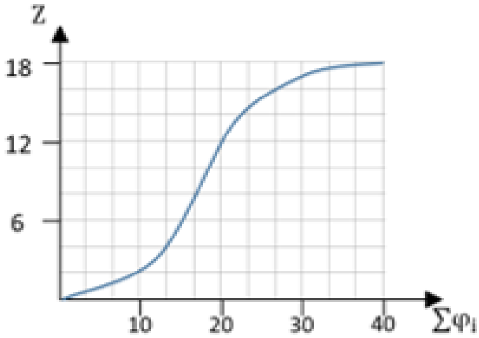
f)


φ7
6
4
2
0,002
0,003
0,004
0,005
x7

g)


φ8
3
2
1
0,0004
0,0006
0,0008
0,001
0,0012
x8

h)



i)

Graph 29. Dependences of temperatures in the working areas of the rock-destroying tool on mode parameters and each other

a) dependence of temperatures on the rotation frequency of the bit; b) dependence of temperatures on diameters of the bit; c) dependence of temperatures on load along the axis; d) dependence of temperatures on the ratio between the rock and the hardness of the material of the rock; e) dependence of temperatures on the density of the cooling liquid; f) dependence of temperatures on the efficiency of the pump; i) dependence of temperatures on the average square deviation of the factors

CONCLUSIONS

1. The causes of accidents occurring in the drilling and repair of wells were investigated, and information on the constructions and operating characteristics of equipment and tools for eliminating defects was obtained. As a result of it model of stress deformation state created in the contact surface of the milling device has been formed.
2. The causes of thermal-mechanical stresses and temperatures on the contact surfaces and tribonodes of downhole milling tools and drill bits (the axial load, rotation freguency and well environment) were investigated. Melhodology for correct determination of the value of

these factors was developed and used in the subseguent stages of the reseach.

3. The model of the heat transfer process resulting from the combined effect of thermomechanical factors in the contact areas of cutting and rock-destroying tools was created and its analytical solution was implemented.

4. Methods for determining the distribution and cooling coefficients of the heat flow affecting the reduction of temperature and temperature stresses on the contact surfaces of composite compounds were developed, and based on these methods, curves showing the graphical dependence of the temperature drop and the temperature gradient on these coefficients were constructed and the value of the heat conduction and cooling coefficients was determined.

5. Mathematical models of cutting and rock-destroying tools were built taking into account the factors involved in heating issues in the drilling and milling processes, and the mode parameters ensuring the milling process were obtained. (The axial load is F=60-70 kN, rotation frequency ω=13.3-18.3 $sec^{-1)}$.

6. In order to evaluate the effectiveness of the technique and technology of reinforcement of the cutting parts of the downhole cutting milling equipment, the deformation stress state caused by friction on the contact surfaces of the cutting elements was investigated, and in order to reduce the forces acting on the cutting elements in the axial and radial direction, the positions of the composite grains of the tool cutting part were analyzed (the optimal position of the front angle of the cutting elements is considered to be the interval $y=27^0$ $+68^0$) and the positive results obtained were taken into account during the reinforcement.

7. The results of cooling with air, liquid and "liquid-air" mixture, which are used to reduce the temperature and thermal stresses generated in the contact area of the tool during interaction with objects subjected to disintegration, were investigated (the percentage of temperature reduction compared to dry friction is 21.6%, with air – 9.3%, 39.2% in cooling with “liquid-air” mixture) and the graphical dependencies of the obtained results were evaluated.

8. Taking into account the physical and mechanical properties of the objects subjected to destruction, changes were made in the construction of the well-bottom milling machine, in order to create

cavitation. Changes in construction help to destroy metals, intensify the process and wash well with fast technologies.

Published works with the topic of the dissertation work:

1. Mustafayev A.G., Gafarov F.M., Allahverdiyev S.G., Hasanov F.N., Determination of temperature stresses generated on the contact surfaces of well instruments - scientific works of ASMA #7, 2008.
2. Mammadov A.A., Mustafayev A.G. etc. Inward-directed device for removing metal objects from the well - patent of the Republic of Azerbaijan I 20090149 State Science and Technology Committee 04.08.2009, pp. 34-40.
3. Gafarov F.M., Mustafayev A.G., Hasanov F.N., Study of regularities of breakdown of oil field equipment in non-stationary loads - scientific works of ASMA, No. 2, 2012.
4. Gafarov FM, Mustafayev A.G., Namazova G.I. Analysis of Fatigue Damage Aggregation Patterns - Scientific Proceedings of ASMA, No. 1, 2015.
5. Mustafayev A.G., Mammadov RV and others. Determining the places of leakage into the back-of-pipe space in operational pipelines and eliminating these defects - scientific works of ASMA, No. 1, 2013.
6. Mustafayev A.G., Karimova I.M, Bayramov F.I. Methods of adjustment of temperature stresses on the touching surfaces of the milling-type ax, ISSN 2220-1025 Proceedings of Azerbaijan State Marine Academy No. 2 Baku-2018, pp. 33-36
7. Mustafayev A.G., Mammadov R.V., Hasanova L.A., Ibrahimov Y.N., Research of effective methods for cleaning oil and gas wells from sand blockage, "Problems of water transport" scientific works of ASMA, Baku-2019. pp. 48-53
8. Amir Mustafayev, Murad Alizade, Characteristics of temperature generation in single crystals of intermetallic alloy with thermoelastic composition with high elasticity subjected to compression deformation. Equipment Technologies Materials ISSN: 2553-8770, EISSN: 2733-2055, DOI: 10.36962/ETM, pp. 163-171
9. Mustafayev A.G., Mamishov R., Calculation of the contact stresses between the inner surface of the pipe and the outer surface of the screw tool during the capture of damaged pipes inside the well,

"Ecology and water management" No. 3 2023, Scientific-technical and production journal, pp. 89-93

10. Mustafayev A.G., Nasirov Ch.R., Agazadeh X., Reduction of thermal stresses and temperatures generated in tribonodes and touching surfaces of equipment and tools used in well repair and restoration works, "Ecology and water management" No. 3 2023, Scientific-technical and industrial journal, pp. 106-110

11. Mustafayev A.G., Nasirov Ch.R., Khalilov M.I., Study of factors affecting the wear and breakdown of teeth in gear mechanisms "Ecology and water management" No. 3 2023, Scientific-technical and production journal, pp. 118-122

12. Mustafayev A.G., Kheyrabadi G. , Differential expression of the equations that ensure the thermal balance of metals and alloy compounds, materials of the International Scientific Conference entitled H. Aliyev epoch in the development of Science and Education in Azerbaijan, July 4-5, 2023, pp. 615-621

13. Mustafayev A.G., Aliyeva D., Calculation of the working resource of the gear wheel in electromechanical motor mechanisms, Issn: 2663-8770, e-issn: 2733-2055, doi:10.36962/etm, Equipment technologies materials, Equipment, technologies, materials). Volume 18(05) issue 06 2023, (vol. 18 (05) issue 02 2023.

14. Hasanov Y.N., Hasanov F.N., Mustafayev A.G., "Determining the uncertainty of final standards", Az. TU. Scientific. Works. No. 1, 2020., pp. 140-146

15. Mustafaev A.G., Ismailov G.E., Methods of combating the complications of oil production facilities in the production of oil and gas in marine conditions, Actual problems of humanitarian and natural sciences No. 02.2019, pp. 40-46.

16. Faradzhev T.G., Aliyev A.M., Mustafaev A.G. Generalized differential equation of thermal conductivity for an arbitrary measure of space and body shape. News of HET, "Oil and Gas", 1991, No. 6, pp. 32-42.

17. Mustafaev A.G., Zeynalov O.S. Experimental installation for the study of the temperature regime of well cutting tools - "Scientific Notes" ASOA, No. 1, 1998, pp. 21-26.

18. Mustafaev A.G., Nadzhafov E.M. Determination of heat release on the contact surface of annular cutters - "Scientific Notes" AzISU , No. 1 1997, pp. 90-92.

19. Mustafaev A.G., Nadzhafov E.M., Determination of the value of the FB criterion in milling processes - Proceedings of the IMM AN of Azerbaijan, Baku, 1997, pp. 231-233.

20. Mustafaev A.G. Investigation of temperature stresses in the cutting part of well milling tools. News of HEI Azerbaijan №5 (45) Baku 2006, pp.31-36.

21. Hasanov R.A., Mustafaev A.G., Zeynalov O.S. Experimental study of the thermal regime of the rock-destroying instrument – "Scientific notes" ASOA, No. 1 1999, pp. 21-26

22. Mustafaev A.G., Huseynov I.B. Investigation of the influence of heat transfer on the contact surface of the milling tool, – Materials of reports of the 2nd international scientific and technical conference: «Problems of mechanical engineering of the 21st century». Baku 2001, pp. 35-39.

23. Mustafaev A.G., Huseynov I.B. Dynamic synthesis of tire-pneumatic couplings (TPC), used for lifting a drilling tool, - Materials of reports of the 2nd international scientific and technical conference: «Problems of mechanical engineering of the 21st century». Baku 2001, pp. 16-21.

24. Gafarov F.M., Mustafaev A.G., Akberova G.R., Mamedov R.V., Calculation of strength and durability of drilling and lifting mechanism parts. Scientific Works ASMA, №7 2008, pp. 31-35

25. Gafarov F.M., Mustafaev A.G., Mustafaeva N.S., Bairamova F.I., Determination by the method of galvanic plating, the influence of voltages below the limit of endurance on the accumulation of damage. – Scientific works of ASMA, No. 8 of 2008. p. 4

26. Mustafaev A.G., Gafarov F.M., Mustafaeva N.S., Allahverdiev S.G. The influence of cavitation on the resistance of wellbore destruction tools and the efficiency of cleaning in the bottom-hole zone of wells. – Scientific Works ASMA, №2 2010. p. 3.

27. Gafarov F.M., Mustafaev A.G., Mamedov R.V. Experimental study of the accumulation of damages by step loading of parts. Scientific Works ASMA, №1 2011.

28. Mustafaev A.G., Gafarov F.M., Mamedov R.V., Gasanov F.I. Installation for the study of temperature stresses on the cutting surface of the milling tool in laboratory conditions. Scientific Works ASMA, №2 2011.

29. Mustafaev A.G., Gafarov F.M., Mamedov R.V., Gasanov F.I. Determination of the optimal deviation of the new face from the old one when tapping and drilling the second barrel. Scientific Works ASMA, №2 2012.

30. Mustafaev A.G. The effect of cavitation of washing - cooling liquid on the milling process. News of HEI Azerbaijan №4 (56) Baku 2008, pp. 38-41.

31. Mustafaev A.G., Osmanov.B.A., Gasanov F.N. Definition of allowable forces when spreading caught pipes. - Tyumen. GOMU Russia, 2011.

32. Mustafaev A.G., Gafarov F.M., Mamedov R.V. Increasing the efficiency of the milling tool with reinforced composite material. – Scientific Works ASMA, №1 2014.

33. Gafarov F.M., Mustafaev A.G., Mustafaeva N.G., Determination of the influence of voltages below the limit of endurance on the accumulation of damage during step loads. - Scientific Works ASMA, №2 2014.

34. Mustafaev A.G., Gafarov F.M., Investigation of heat exchange processes on milling-metal contact surfaces. - Scientific Works ASMA, №2 2015.

35. Mustafaev A.G., Mamedov R.I. et al., Influence of the temperature on offshore wells, ASMA 2016, No. 2, pp. 251-255,

36. Mustafaev A.G., Mamedov R.I., Methods of combating complications in oil and gas extraction on marine construction, ASMA 2016, No. 1, pp. 125-128

37. Mustafaev A.G., Mamedov R.V., Study of thermal regime of rock-destructive tool, XII International scientific-technical conference on "Water transport problems", ASMA, 2017, pp. 168-171.

38. Mustafaev A.G., Pashaeva V.B., Salimova E.N., Determination of the rational arrangement of grains in the cutting edge of the milling tool and their impact on the productivity of the milling process, Actual Problems of Humanities and Natural Sciences No. 7, 2017, pp. 13-17, Russia.

39. Mustafaev A.G., Pashaeva V.B., Determination of the cooling criterion F_B in the process of drilling and milling, Actual problems of humanitarian and natural sciences No. 7, 2017, pp. 44-47, Russia.

40. Mustafaev A.G., Pashaeva V.B., Determining the value of the coefficient of distribution of heat flows in drilling and milling processes, Actual problems of humanitarian and natural sciences No. 7, 2017, pp. 47-50, Russia.

41. Mustafaev A.G., Pashaeva V.B., Research on improving the performance of well drilling tools, Actual problems of humanitarian and natural sciences No. 7, 2017, Russia, pp. 50-53.

42. Mustafaev A.G., Investigation of thermal processes on the contact surfaces of well-destroying instruments, Modern technology in oil and gas business - 2017, "Collection of works Scientific Technical Conference», USOTU, 2017, pp.136-138.

43. Mustafaev A.G., Amirova A.M., Influence of dispersed particles of the composite material welded to the cutting part of the well tool on the specific productivity of the milling process, Modern technology in the oil and gas business-2017, "Proceedings of the international scientific and technical conference", USOTU, 2017, pp. 368-373.

44. Mustafaev A.G. Investigation of the influence of interrelated factors on the thermal regime of a rock-destructive instrument, Modern technology in the oil and gas business-2017, "Collection of works of the international scientific and technical conference", Ufa State. Oil. Tech. University, 2017, pp. 128-132.

45. Photonics: a dictionary of terms / T.E. Kovalevskaya, V.N. Ovsyuk, V.M. Belokonev, E.V. Degtyarev. Novosibirsk: CO PAH, 2004. p. 342.

46. Mustafaev A.G., Alizadeh M., Analysis of the drilling of additional lateral shafts by drilling multi-barrel shafts from the main wellbore Construction Econimics swear Management No. 2, 2024 pp. 152-159.

47. Mustafaev A.G., Nasirov Ch.R., Development of a mathematical model of hydrodynamic pressures when operating wells by the gas lift method. Materials of the All-Russian scientific and technical conference (with international participation) "Problems of geology, development and exploitation of deposits, transport and

processing of trudnoizvlekaemykh heavy oil", 8-10 December 2021, pp. 391-398.

48. Mustafaev A.G., Nasirov Ch.R. Development of a method of increasing the performance of well-destroying tools. Materials of the All-Russian scientific and technical conference (with international participation) "Problems of geology, development and exploitation of deposits, transport and processing of hard-to-extract heavy oils", December 8-10, 2021, pp. 208-209.

49. Mustafaev A. G. Determination of the coefficient of distribution of heat flows in the process of cutting operational columns, Actual problems of humanitarian and natural sciences, journal of scientific publications No. 03 (March) - 2018, pp. 29-32.

50. Mustafaev A.G. Research into improving the performance of downhole destructive (cutting) tools, "Azerbaijan Caspian Sea Shipping" CJSC Azerbaijan State Maritime Academy is dedicated to the 97th anniversary of the birth of national leader Heydar Aliyev "Problems of water transport" XV International scientific and technical conference Report materials XV International scientific-technical conference on "Water transport problems" Baku-2020, pp. 120-122.

51. Mustafayev A.G., Amirova A.M., Pashayeva V.B., Determination of the rational arrangement of grains I the cutting edge of milling tool and their impact on milling process productivity, Austrian journal of technical and natural sciences is an international, German/English/Russian language, peer -reviewed journal. ISSN 2310-5607. Scientific journal. No. 9-10 2017 (September-October), pp. 23-26.

52. Mustafayev A.G., Aliyeva I.K., Agarzayev B.K., Abdullayev A.R., Heat processes on the contact area of the two-hole milling tools, Austrian Journal of Technical and Natural Sciences Scientific journal, No. 3-4 2018 (March-April), ISSN 2310-5607, pp. 24-28.

53. Mustafayev A.G., State of heat processes of rock cutting (destructive) tool, Austria Journal Technical and Natural Sciences, No. 3 Vienna – 2018, pp. 23-29.

54. Hasanov V.G., Mustafayev A.G., Aliyeva I.K., Hasanova L.A., Aliyev H.M., Abdullayeva A.R., Methodic of Determination of Coefficient Value of Heat Flow Distribution at the Processes of

Drilling and Milling (Part 1), International Journal of Engineering Research and Technology, ISSN 0974- 3154, Volume 13 No. 12 (2020), © International Research Publication House, pp. 4832-4834.

55. Mustafayev A.G., Methodic of Determination of Coefficient Value of Heat Flow Distribution at the Processes of Drilling and Milling (Part 2), The XXVI International Scientific Symposium Shusha Triumph of Victory 2022, pp. 208-209.

56. Mustafayev A.G., Khalilov M.I., Agazade H.R., Evolution of the efficiency of the cutting apicity of downhole milling tools with reinforced composite alloys, The XXVI International Scientific Symposium Shusha Triumph of Victory 2022, pp. 306-311.

57. Mustafayev A.G., Nasirov Ch.R., Mathematical equations for temperature control in the contact surfaces of drilling and maintenance equipment, Issn: 2663-8770, e-issn: 2733-2055, doi: 10.36962/etm Equipment technologies materials, pp. 29-37.

58. Mustafayev A.G., Nasirov Ch.R., Mathematical expressions for temperature in the contact zone of teeth of the gear mechanisms, Issn: 2663-8770, e-issn: 2733-2055, Doi: 10.36962/etm Equipment technologies materials.

59. Amir G. Mustafayev, Chingiz R. Nasirov, A study of factors affecting wear and destruction of teeth in gear mechanisms, Nafta-gaz 2023, no. 9, Doi: 10.18668/NG.2023.09.06, pp. 604-610.

60. Amir G. Mustafayev, Chingiz R. Nasırov, Reduction of thermal tensions and temperatures formed in the tribonodes and surfaces of the equipment and tools used in well workover and restoration works, Nafta-gaz 2023, no. 10, Doi: 10.18668/NG.2023.10, pp. 661-669.

61. Amir G. Mustafayev, Mahmud A. Ismayilov, Mirkamran M. Salimli, Chingiz R. Nasirov., Improving the efficiency of the milling tool by reducing the temperature in the milling zone depending on the main mode parameters, Nafta-gaz 2023, no. 12, Doi: 10.18668/ NG.2023.12.02, pp. 764-775.

62. Amir G. Mustafayev, Chingiz R. Nasirov, The advantage of composite materials used in downhole cutting tools, Nafta-gaz, Nafta-gaz 2024, no. 1, Doi: 10.18668/ NG.2024.01.03, pp. 19-29.

63. Mustafaev A.G., Nasirov Ch.R. Methodology of Designing the Cutting Part of Well Milling Devices on the Basis of Composite Alloys Modern science Founders; Scientific Information Center, "Institute of Strategic Studies" (Moscow) ISSN: 2414-9918, pp. 410-417.
64. Amir G. Mustafayev, Mahmud A. İsmayılov, Mirkamran M. Səlimli, Chingiz R. Nəsriov.Enhancing tht efficiencyof well millinq devices andcleaning wellsfrom milled objects by implementig cavitation in the millingzone Nafta-gaz, Nafta-gaz 2024, no. 11, pp. 696-704, Doı: 10.18668/ NG.2024.11.05.

Personal participation of the author in printed works:

Works No. [42,44,52,53,57] were performed independently by the author.

In works No. [1-41,43,45-51,54-56,58-65], setting and solving the problem, conducting experimental researches was performed by the author, and the processing of the results obtained from the researches was performed jointly with the co-authors.

The dissertation defense will be held at the meeting of the ED 2.02 Dissertation Council operating at the Azerbaijan State Oil and Industry University at 10:01 on 2025.

Address: AZ 1010, Baku city, Azadlig avenue 34,

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.

The abstract was sent to the requested addresses on ___________ 2024.

Signed for print: 06.12.2024

Paper format: A5

Volume: 4.5

Circulation: 100