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# RESEARCH OF FACTORS AFFECTING THE EFFICIENCY OF ROCK BREAKING EQUIPMENT

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**Abstract:** *Nowadays 35-40 % of all the drilling works, performed on mining and geological exploration enterprises, are made by air bottom hole cleaning, and the rest 60-65 % are made by flushing liquids on water base. Air drilling and bottom hole cleaning due to low heat conductivity of air generates high temperature at a borehole bottom thus negatively affecting the efficiency of rock destruction tool; while drilling with water based flushing fluids causes efficiency reduction of rock destruction tool due to formation of slurry mode at a borehole bottom. This paper presents the results of the study of the factors negatively affecting the performance of hammers.*

**Keywors:** *drilling, Well, rock breaker, auger temperature, mud regime, mechanical speed of drilling, auger resource.*

**INTRODUCTION.** In the process of drilling wells with compressed air cleaning it is important to study temperature modes of breaker hammers. As a result of increasing the volume of drilling works and deepening of wells, the increase of throughput capacity of the borehole bottom creates the necessity to study the temperature modes of rock destruction tools and create effective methods of their rationing. In the process of drilling hard rock, a large amount of heat is released as a result of rock crushing, where only 1% of the mechanical energy transferred to the crusher is used to break the rock, and the rest is dissipated as heat, which, in turn, causes an increase in the temperature of the breaker [1].

In air-cleaned drilling, temperature factors cause deformation of the rock destruction tool matrix, wear and hardness of the teeth, and tool burning, which leads to a sharp decrease in rock penetration. Tool breakage and increased waiting and lowering work for tool replacement leads to increased cost of work. It has been observed that the micro-hardness of the teeth decreases by 30% when the temperature of the diamond hammer reaches 550-600 and by 60% when the temperature reaches 800 $^{\circ}$C. Time costs for elimination of negative influence of high temperatures on a rock breaker make 10-12 % [2].

The durability of demolition hammers directly depends on the temperature conditions at borehole bottom. High temperatures in the borehole bottom cause temperature deformations in the teeth of diamond toothed demolition hammers, which causes grinding of cutting edges of the teeth, cracking and loss of the matrix.

A study of the temperature conditions of rock hammers during drilling shows that abrasion of teeth occurs when their temperature reaches 600 $^{\circ}$C and cracking occurs when their temperature reaches 800 $^{\circ}$C or more. Cracking is observed on the upper surfaces of the connecting part of the tooth predominantly in large-sized teeth, and abrasion in small-sized diamond teeth [3].

**MATERIAL AND METHODS.**When drilling hard and low-abrasive rocks, smooth surfaces are formed on cutting edges of diamond teeth, in this case the process of rock destruction acquires fatigue nature (friction erosion) and mechanical drilling speed is sharply reduced. Tooth abrasion occurs during drilling with compressed air, as the tooth cooling is worse due to the small heat capacity of air compared to water. Grinding can also occur as a result of mechanical destruction of the tooth. Mechanical tooth deformation occurs as a result of increased read pressure, i.e. [4]:

$$R_{ax} > \psi \rho_N Z_T, \quad (1)$$

-$R_{ax}$ - is the breaker load, N;

- coefficient of normal steady load;

-$r_N$ - allowable normal load per tooth, N/axis;

-$Z_T$ - number of teeth simultaneously acting on borehole bottom.

Grinding teeth of the rock breaker cause increased load on the remaining teeth and lead to premature mechanical deformation of the teeth, i.e., breakage and overgrinding. Mechanical wear of diamond teeth often occurs when drilling in hard formations due to fracture or chipping due to the high resistance of the rock to penetration of the teeth. At the same time, there is a burning of teeth and deformation of cutting edges even at low axial pressure at the borehole bottom [5].

When drilling hard rock, high-temperature separation occurs, which reduces the microhardness and abrasiveness of the teeth of the rock destruction tool and increases the mechanical deformation. In solid rock drilling, the temperature deformations of the rock destruction tool prevail, so there is a need to normalize the temperature factors and take their influence into account.

It is hard to determine the temperature of ring bit during the operation, which takes into account the average bit temperature resulting from distribution of separate temperature fields over the bit body, formed by tungsten carbide cutting. The temperature of the carbide tooth ring can be determined by the following expression [6]:

$$t_T = \frac{2K_pN}{\pi\sqrt{\lambda_1(\alpha_1 D_1 + \alpha_2 D_2)(D_2^2 - D_1^2)}} + \frac{K_pN}{2Gc_p} + t_1, \quad ℃, \quad (2)$$

-$t_1$ is the thermal conductivity coefficient of the crown material, W/ch (m·℃);

-$a_1$ and $a_2$ – heat transfer coefficients between the crown and the core, between the crown and the Well, W/(m2·℃);

$D_1$ and $D_2$ are internal and external diameters of the crown ring, m;

$t_1$ – initial temperature of compressed air (on the crown), ℃;

N – power consumption of the bit at the bottom of the well, W;

G - consumption of washing liquid, kg/s;

$c_p$–relative heat capacity of air, J/kg·℃;

$K_p$ is the dimensionless coefficient of heat flux distribution:

$$K_p = \frac{1}{1+\lambda_2/\lambda_1\sqrt{a_1/a_2}}, \quad (3)$$

here, a is thermal conductivity coefficient, m2/s (indices 1 and 2 refer to vault material and rock).

Average value of temperature in the body of the crown can be determined by the above expression (2). This expression allows controlling the influence of such factors as power at the bottom hole, flushing fluid temperature, bit cross-sectional design dimensions, bit material and rock character, temperature transfer coefficients, operating mode and flushing fluid flow rate from bit body temperature.

Analysis of the expression shows that there are some effective ways of diamond drill bits cooling when drilling with air cleaning. Hot temperature, formed on the bottom of the hole, spreads to the bit body and drill string. The high thermal conductivity of the core material causes low temperature, moreover, if the height of the ring part of the core is high and the grooves of connection with the string pipe are tight, also the air flow rate is high and the low speed makes the core well cooled.

Expression (2) correctly reflects the basic temperature patterns of the drill bit. However, it is considered necessary to continue scientific research on rationing temperature regimes of rock destruction tools, [6] the following expression is proposed for determining the temperature of cutting parts of crown teeth:

$$t_{tooth} = \frac{K_p N}{K_o} + t_1, \qquad ℃, \tag{4}$$

-Ko¬¬¬¬- heat transfer coefficient of the tooth with the environment;
-(W/℃). ¬¬¬¬¬¬

When the stone crusher has diamond teeth 650 ℃, and in the case of hard alloy, it should not exceed 350-400 ℃, otherwise the hardness of the teeth will decrease and undergo thermal deformation. Based on the analysis of expression (2) above, we can conclude that the temperature condition of the drill bit can be standardized, the design of the drill bit improved, the drilling conditions rationally selected and the air temperature artificially cooled when drilling well with air-cleaning.

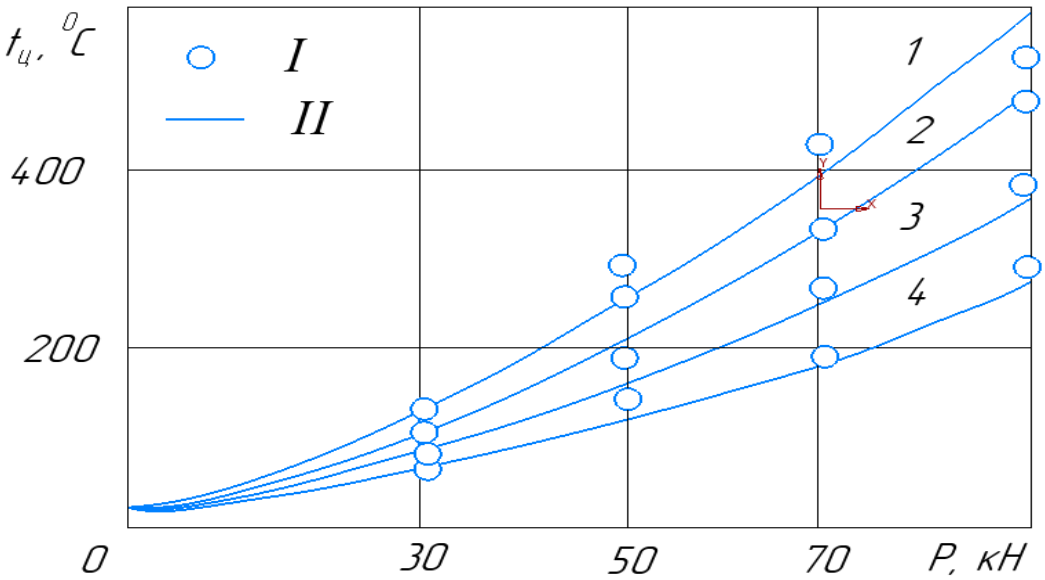
Presence of such complicated elements as teeth, ball and roller bearings, shell of rock destruction bodies makes analytical research of its temperature regimes difficult. In this case, it is necessary to choose one detail that accurately describes the temperature regime of the rock-crushing tool with the rock-crushing tool during the study, [5] the cross-section of the rock-crushing tool shaft with the rock-crushing tool as this part in the work was chosen:

$$t_s = \left[\left(\frac{h}{\lambda_1 f_ц} + \frac{1}{\alpha f_л}\right)\frac{k_1 k_2}{m} + \frac{1}{2G_г c_p}\right] N - \frac{\Psi` \Delta W}{2c_p} + t_1, ℃, \tag{5}$$

h – is the average thickness of the blade of the tool destroying the rock, m;
$f_s$,$f_l$ - cross-sectional area of the trunnion base and the outer surface of the blade, m2;
$\lambda_1$ - heat conductivity factor of the rock destruction tool material, W/h (m·℃);
α – heat transfer coefficient, m2/sec;
$c_p$–- relative heat capacity of the cleaning air, J/kg·℃;
$G_g$ - purifying air flow rate, kg/sec;
$k_1$, $k_2$ - dimensionless coefficient of power loss on friction in the bearings and heat flux distribution in the bearings;
N - power of storage unit, W
m - number of squares;
Ψ` - relative heat of vaporization, J/kg;
ΔW - percentage of humidity.

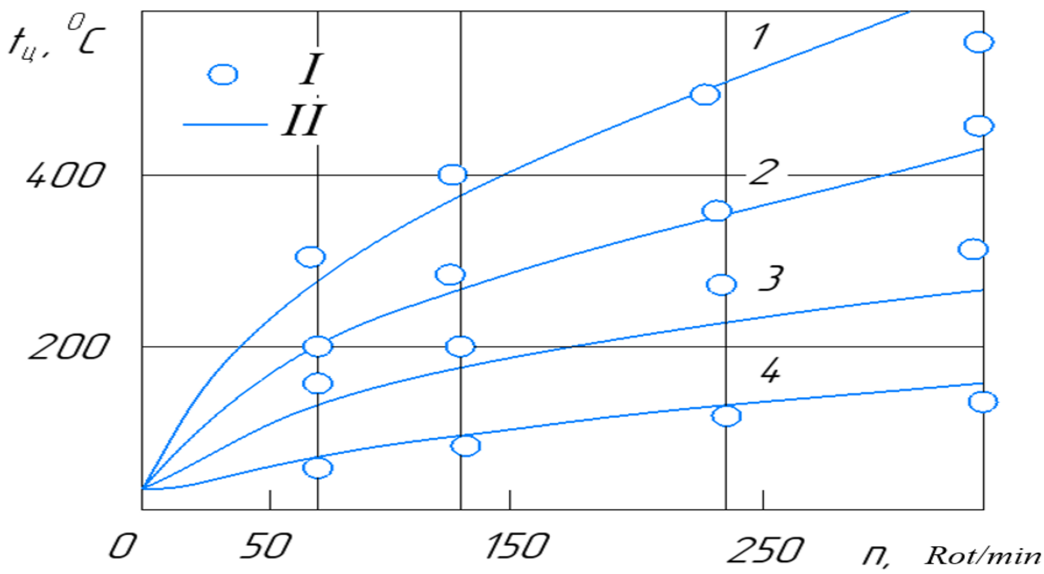
In dry formations, ΔW=0 is taken as ΔW=0 when drilling wells with air cleaning, as well as when drilling with gas-liquid mixtures, in this case the expression is simplified. In some calculations, it is possible to get k_(1)=0.1, k_2=0.5. Using the above expression (5), calculation work for determining the temperature of the rock breaker with a cone was carried out in accordance with the conditions of the experimental studies. In this case the drilling was carried out in dry granite cleaned by compressed air. Figures 1 and 2 show the graph of temperature dependence of the top of three-point drill bit on the drilling modes at different number of revolutions and values of the reference pressure [5].

From the graphs shown in Figures 1 and 2 above, we can conclude that the results of calculations and experimental tests are very close to each other. The analysis of expression (5), which allows determining the temperature regime of the rock fracturing tool with a cone bit, shows that the large heat exchange surface of the cone bit, high thermal conductivity of its material and a large volume of air flow at low speed reduce its temperature regime. It is also possible to lower the temperature regimes by reducing the initial air temperature. Investigation of influence of mud regime formation at borehole bottomhole on the work of rock destruction tool




Number of rotations:1 – 350; 2 – 242; 3 – 131; 4 – 68;
I – test points; II – (5) lines resulting from calculations by expression

**Fig1**. The graph of the pressure reading of the temperature of the nozzle of the three-point valve at different revolutions




bullet pressure: 1 – 90; 2 – 70; 3 – 50; 4 – 30;
I – test points; II – (5) lines resulting from calculations by expression

**Fig2.** The graph of the dependence of the temperature of the tip of the three-pointed bit on the drilling rotation at different reading pressures

While drilling it is necessary to consider preservation of crushed rock in the form of cuttings under the rock destruction tool, their particle size distribution, shape and size, their movement under the rock destruction tool after separation from the formation and their interaction with the body. The formation of the cuttings regime adversely affects the durability of the rock destruction tool and the mechanical drilling speed.

**RESULTS AND DISCUSSION.** The maintenance of slurry mode under the rock destruction tool body accelerates erosion of its matrix and causes tooth loss. In addition, the teeth of the rock destruction tool leave pits and scratches, causing erosion. In addition, the formation of slurry as a result of repeated crushing of rock detached from the massif reduces the mechanical speed of drilling and leads to an increase in energy consumption for rock crushing. The number of drilling mud particles generated during drilling is the same as per one revolution of the rock destruction tool during deepening:

$$\text{Б}_{sh} = \frac{V_p}{V_{sh}}, \quad (6)$$

Here, $V_p$ – the volume of crushed rock under the rock crushing tool;
$V_{sh}$ – volume of one slurry particle.

$$V_p = S_з \cdot h_{rot} \cdot К_p \cdot К_т, \quad m^3, \quad (7)$$

here, $S_з$– the surface of the ground, m$^2$;
$h_{rot}$– indentation in rotation, м;
$К_p$ – rock crushing coefficient;
$К_т$ – the coefficient of reduction of the volume occupied by the slurry as a result of the protrusion of the teeth in the body of the rock-breaking tool.

$$h_{rot} = \frac{v_м}{n}, м, \quad (8)$$

here, n – number of rotations;$v_м$ – mechanical speed, if

$$\text{Б}_{sh} = \frac{S_з \cdot v_м \cdot К_p \cdot К_т}{\overline{V}_{sh} n Z}, \quad (9)$$

Z – number of sectors.

Figures 3 and 4 below show the movement of slurry particles under the ball body of a diamond-toothed crown and a diamond-shaped bit.

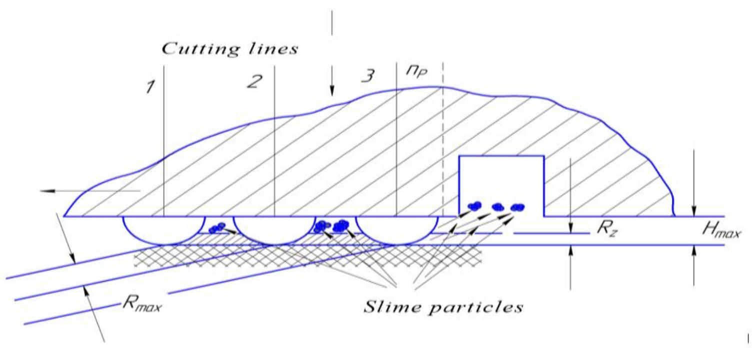



**Fig 3.** The movement of slurry particles under the body and between the teeth of a diamond gear

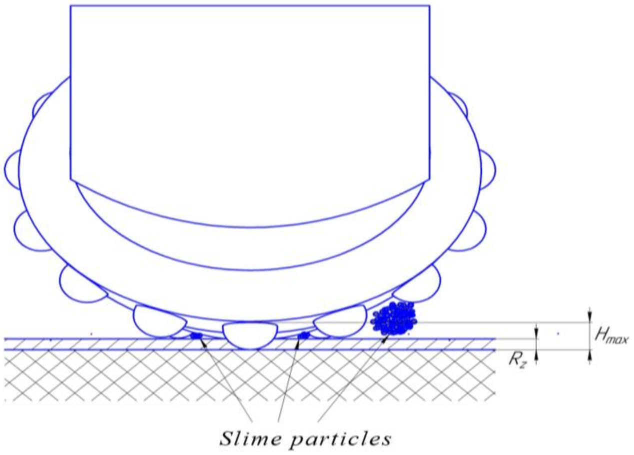



**Fig 4.** The movement of slime particles under the body and between the teeth of a sharp-edged dolot

When the shape of the slurry particles is spherical

$$\overline{V}_{sh} = \frac{3}{4}\pi\frac{D_{cp}^3}{8} = \frac{1}{6}\pi D_{cp}^3, \tag{10}$$

$$Б_{sh} = \frac{6S_з \cdot v_м \cdot K_p \cdot K_т}{\pi D_{cp}^3 Zn}, \tag{11}$$

here,$D_{cp}^3$ – the average diameter of the container, m. In the general case, the amount of drilling mud per unit volume is for the slot being constructed [8]:

$$B_з = \frac{B_{sh}}{V_з - V_т - V_v}, \tag{12}$$

here, $V_т$ – the size of teeth protruding from the body, $m^3$;
$V_v$ – The volume of rock at the bottom of the well, $m^3$.

$$V_з = S_к\left(\overline{H}_{max} - \frac{R_z}{2}\right), \tag{13}$$

$$V_v = \frac{R_z}{2} S_к, \tag{14}$$

$$V_a = n_s V_{as} S_к, \tag{15}$$

here, $S_к$ – the working surface of the dolot body, $m^2$;
$\overline{H}_{max}$ – the average size of the maximum height of the teeth on the cutting line, м;
$R_z$ – This is the indicator of the zabai gadir (GOST 2789-72);
$n_s$ – the number of diamond teeth in the working body of the dolot;
$V_{as}$ – the size of teeth protruding from the matrix, $м^3$.
Thus, the slurry concentration between the bottom of the well and the body of the rock-breaking tool is as follows [8]:

$$K_{sh} = \frac{V_p}{(V_з - V_т - V_v)} = \frac{S_з \cdot h_{rot} \cdot K_p \cdot K_т}{Z\left[S_к\left(\overline{H}_{max} - \frac{R_z}{2}\right) - \frac{R_z}{2} S_к - n_s V_{as} S_к\right]} = \frac{S_з \cdot h_{rot} \cdot K_p \cdot K_т}{Z S_к\left(\overline{H}_{max} - R_z - n_s V_{as}\right)}, \tag{16}$$

$$K_{Sh} = \frac{V_p}{(V_з - V_т - V_в)} = \frac{S_з \cdot h_{rot} \cdot K_p \cdot K_т}{ZS_к(\overline{H}_{max} - R_z - n_s V_{as})}. \quad (17)$$

Slurry particle size is of great importance in eroding the matrix of a rock crusher. The interaction of the minimum size of the slurry particle with the matrix material is as follows [8]:

$$D_{min} = \overline{H}_{max} - R_{max}, \quad (18)$$

here, $R_{max}$ – the maximum protruding height of the rock in the reservoir. During the drilling process, the mud particles directly impact the matrix of the body of the rock-breaking tool without teeth, the surface of which is as follows:

$$S_м = S_к(1 - n_s S_a). \quad (19)$$

Thus, the matrix of the rock-breaking tool is abrasively eroded by drilling mud particles, the abrasive effect of the mud particles depends on the structural and technological parameters of the rock-breaking tool.

**CONCLUSION.** The fact that the heat transfer surface of the chisel bit is large, the thermal conductivity of its material is high, and the high air flow rate at low speeds reduces its temperature regimes. It was also found that the temperature regimes can be reduced by reducing the initial air temperature.

The performance of the drilling process is significantly affected by the condition of the hammer body and its teeth, and the condition of the hammer depends on the movement of drilling fluid particles under its body. In order to avoid abrasive wear of rock breaker due to cuttings and multiple crushing of separated cuttings the volume of cuttings formed at borehole bottom should be equal to the volume between the screw body and the reservoir and it should be able to lift separated cuttings into the screw flushing channel.

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