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Improving the Efficiency of Rock Destruction Tools when Drilling Wells in difficult Mining and Geological Conditions

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ABSTRACT

Air blast drilling is effective in the most unfavorable conditions for liquid flushing: when drilling in areas with significant circulation losses, when there are difficulties with water supply, in high mountainous or difficult terrain, or in areas with harsh climates.

However, air has a low heat capacity compared to liquid flushing solutions, this affects the operation of rock cutting tools through high contact temperatures with irreversible consequences such as deformation of matrices, destruction of diamonds, grinding, reduction of diamond hardness and tool burns. To prevent these problems, there is a need to develop technical means and technology to effectively ensure the temperature regime of the rock-cutting tool.

This article discusses the possibility of normalizing and regulating the temperature regime of the rock-cutting tool due to forced cooling of the cleaning air at the bottom hole to negative temperatures, and a new design of the drilling projectile for drilling with air purging is developed. The results of experimental studies of the developed design of the drilling projectile are also presented.

Key words : Air purging, drilling, Rank effect, well, vortex tube, compressor, drill string, flushing fluid, bottom hole, temperature mode.

1. INTRODUCTION

Air blast drilling is effective in the most unfavorable conditions for the use of flushing fluids: when drilling in areas of significant circulation losses, with difficulties with water supply, high-altitude or difficult terrain or in areas with a harsh climate [1].

When drilling wells in rock formations, rock destruction is accompanied by significant heat release, as about 1% of the mechanical energy supplied to the bottom hole is spent on rock destruction itself, and the rest of the energy is dissipated in the form of heat [2].

High temperatures of the drilling tools create emergency situations in the form of diamond drill bits burning, which takes 8÷10% of time to eliminate [3,4,5]. It is obvious, that the increase of efficiency is directly connected with providing the optimal temperature regime when drilling wells.

Bits cooling conditions at drilling with blowing are significantly worse than at using gas-liquid systems. Therefore, normalization of the rock destruction tool temperature mode at drilling with blowing is possible, first, due to increase of mass flow rate at moderate speeds of air movement during expansion of through channels and annular gaps and, second, due to forced cooling of blowing air [6,7].

The first direction would require an increase in mass flow rate of the compressor while increasing its power, which is inefficient. The second way is more acceptable, provided an efficient cooler is developed.

2. DEVELOPMENT OF A VORTEX TUBE DESIGN FOR DRILLING WITH AIR BLOWING

In [6] researches on using a vortex tube as an air cooler are given. The results of the experimental studies allowed us to substantiate the possibility of obtaining negative temperatures of blowing air without the need to increase the compressor capacity. This allows us to state that application of vortex tubes in drilling is rather energy efficient.

The vortex effect, or Rank's effect, is that if a tangentially swirling stream of gas is fed into a pipe, then under certain conditions there will be a temperature separation of the gas in the pipe. A cooler flow will form in the center than at the periphery, and a gas with a much lower temperature will exit through the central hole at one end of the pipe than at the inlet. Peripheral layers of gas having higher temperature will exit through the throttle hole at the other end of the pipe [8,9].

Based on the calculations performed, the vortex tube design shown in Fig. 1 has been proposed.

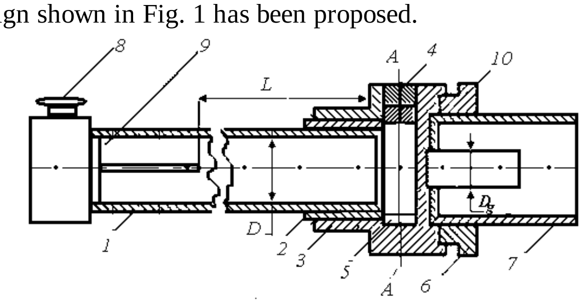

Figure 1: Construction of vortex tube.
1 - tube, 2 - nut, 3 - body, 4 - volute, 5 - diaphragm, 6 - nut, 7 - tube, 8 - throttle, 9 - cross-over, 10 - gasket

In general, the construction of the vortex tube (Fig. 1) consists of the body 3, in the annular cavity of which a tangential rectangular channel of width b and height h is made. On the outer side of the rectangular channel to the housing, a fitting for supplying compressed air is attached. In the annular cavity of the housing a flared tube 1 of strictly cylindrical shape with polished inner surface with diameter D is installed, and then a volute 4, so that it's opening (the dimensions of which correspond to the rectangular channel of the housing) coincides with the channel, forming a nozzle entrance. A diaphragm 5 with a hole Dg and a sealing gasket 10 with a nut 6 are inserted into the same body cavity. In the opposite end of the tube 1 at distance L from the snail a four-bladed cross 9 and choke 8 are tightly mounted.

The vortex tube is characterized by small dimensions and has no moving parts, which allows using it as a bottom-hole cold generator when drilling wells.

Modern mining-geological conditions require improvement of drilling technology and increase of drilling performance by creating new high-efficiency drilling tools for well penetration in various mining-geological conditions. Introduction of new drilling tools with high durability and increased mechanical drilling speed increases operational efficiency of drilling rigs. The best results are obtained by using a vortex tube directly at the bottomhole.

In order to improve efficiency of rock destruction tool operation, on the basis of normalization of temperature regimes when drilling wells with bottom hole cleaning by air, a new design of drilling tool including a vortex tube was developed (Fig.2).

Drilling tool with a vortex tube works as follows. When drilling a well, compressed air through the outer tube 3 through the inlets 7 is supplied to the generator of the cold fraction 6 of the vortex tube 5 and is swirled in it. The flow of compressed air when passing through the vortex tube is divided into two streams, a cold air stream and a hot air stream. The flow of cold air flows out of the nut opening 4 and through the adapter 2 and the drill bit 1 goes to the borehole bottom for carrying the fracture products into the annular space with the simultaneous cooling of the drill bit. The generator of cold fraction in this device is made removable, which can be replaced with another type of generator that allows changing the cooling mode if necessary when changing the drilling conditions.

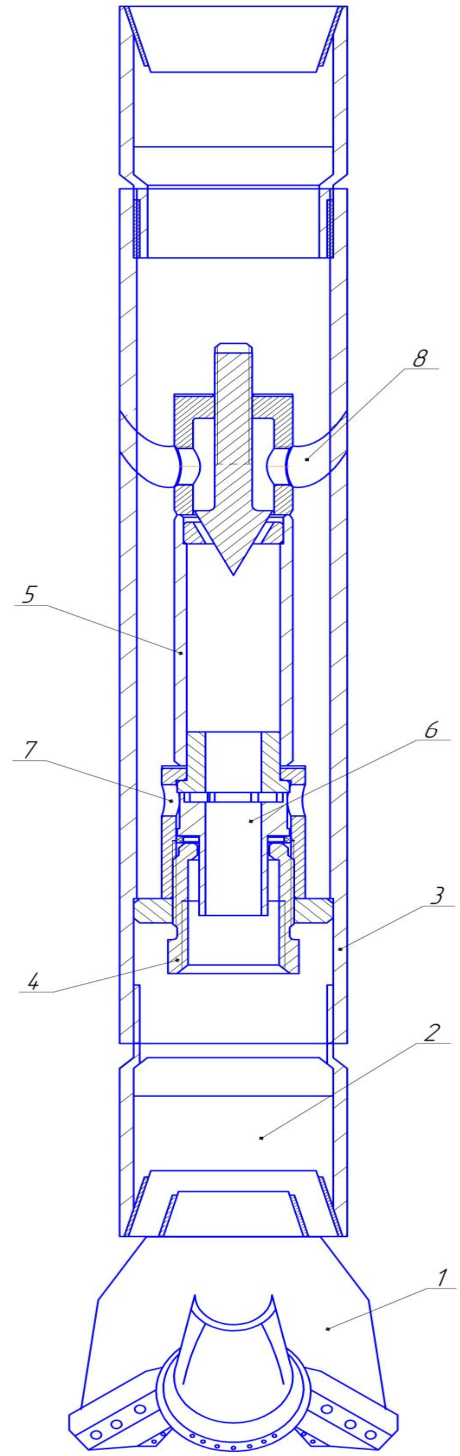

Figure 2: Drilling tool incorporating a vortex tube for drilling with bottom hole cleaning by air.

1-cone bit; 2-transition tube; 3-outer tube; 4-nut; 5-vortex tube; 6-generator of cold fraction at the cold outlet; 7-inlet opening; 8-tangential opening for hot air outlet.

Hot air from the vortex tube 5 enters the annular space through the tangential hole for the outlet of the hot air flow 8. Since the hole 8 is made tangentially, vortex motion is created in the annulus annulus, which allows to eject the cold flow with fracture products. This improves bottom hole cleaning and has a favorable effect on bit cooling, since energy expenditure for re-crushing rock particles is reduced.

This design of a drilling tool with air blowing makes it possible to supply cooled air directly to the bottom hole, normalize the temperature regime and increase the durability of the rock destruction tool.

The use of cooled blowout air significantly reduces the temperature in the borehole, which creates favorable temperature conditions for rock destruction tool operation, preventing the negative effects of high temperatures at the bottomhole.

3. EXPERIMENTAL STUDIES OF A DRILL WITH A VORTEX TUBE.

In order to estimate the efficiency of the developed drilling tool design and influence of low initial temperatures of the cleaning air on the tool efficiency, the pilot tests were carried out at the Central exploration party of Geological Exploration Expedition of Navoi Mining and Metallurgical Combine.

The scheme of experimental set-up for testing the drilling tool with the vortex cooler is shown on fig. 3.

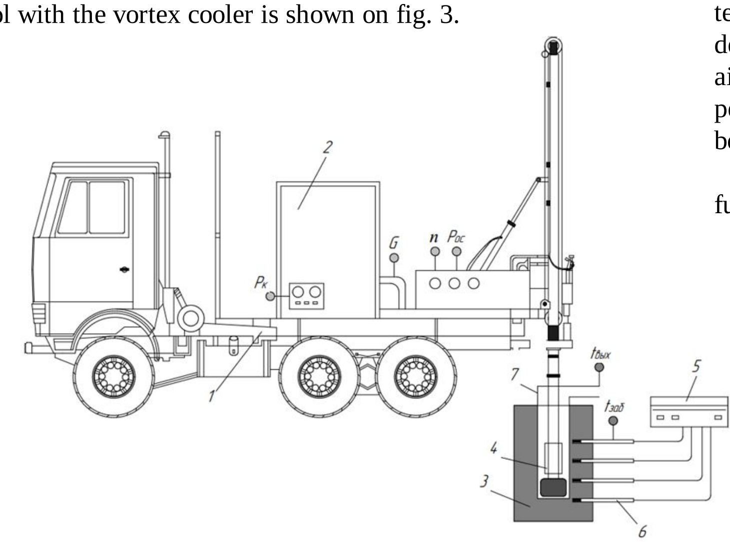

Figure 3: Schematic of the experimental setup for testing a drilling tool with a vortex cooler.

1-Drilling rig, 2-compressor, 3-drilled artificial block, 4-drilling tool containing vortex tube, 5-multichannel temperature meter, 6-thermocouples of K-type, 7-pipe for the removal of cleaning air with cuttings; n- point of drill string rotational speed measurement (rpm), P_{oc}- point of axial load measurement (kN), $P_к$- point of air pressure measurement at compressor outlet (mPa), G- point of air consumption measurement at compressor outlet (kg/s), t_{bb}-point of temperature measurement at bottomhole bottom (°C), $t_{еых}$-point of temperature measurement of the treated air at borehole exit (°C).)

Experimental work was carried out as follows: thermocouples 6 were installed on the drilled rock block 3 with hardness coefficient f=7 and connected to the multi-channel temperature meter 5. In the upper part of the drilled-out block there was installed a branch pipe 7 for drainage of clean air with cuttings. The drilling tool with the vortex tube 4 was connected to the rotator of the drilling rig 1, then the compressor 2 was started, then the drilling rig 1, the compressed air pressure ($P_к$) on the compressor, the rotation frequency (n) and the axial load (P_{oc}) were set.

After the operation mode was stabilized, air flow rate (G) at the compressor outlet, bottomhole temperature ($t_{заб}$) and cleaning air temperature ($t_{вых}$) at the borehole outlet were measured. The duration of experimental drilling (T) for the given parameters in each case was 10 minutes, after which the penetration length (L) was measured.

Experimental work was performed in several stages with different rotational speed (n), axial load (P_{oc}), pressure ($P_к$) and flow rate (G) of compressed air.

4. RESULTS OF EXPERIMENTAL TESTS OF A DRILLING TOOL WITH A VORTEX COOLER

The results of experimental studies of drilling tool design with vortex tube allowed to establish the dependence of temperature change at the borehole bottom ($t_{заб}$) on the temperature of purging air supplied to the borehole ($t_{охл}$), the dependence of temperature change of purging air flow (t_x) on air pressure (P), as well as the dependence of rate of penetration on the temperature of purging air supplied to the borehole ($t_{охл}$).

The change in the temperature of the purge air flow as a function of air pressure is shown in Fig. 4.

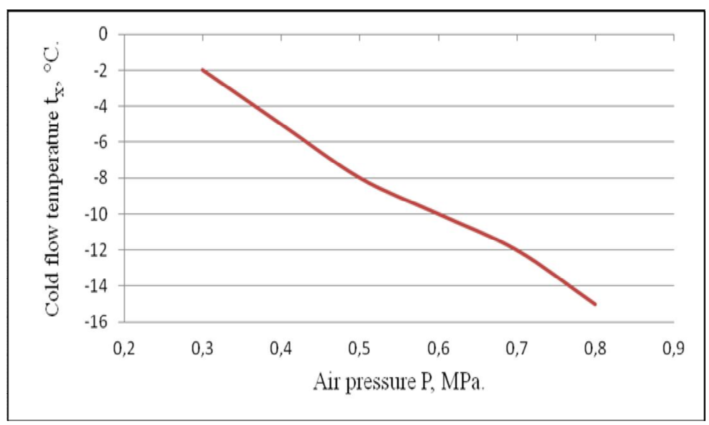

Figure 4: The graph of the dependence of the temperature of the cooled air flow (t_x) on the pressure (P) generated by the compressor.

At a compressed air pressure of 0.3 MPa the temperature of the cooled air flow was -2 □, and at a pressure of 0.8 MPa -15 □. As the compressed air pressure increased by every 0.1 MPa the temperature of the cooled air decreased by 2-3 □.

The change in the temperature at the bottomhole from the axial load at different temperatures of the cleaning air has a dependence close to linear and is shown in Fig. 5.

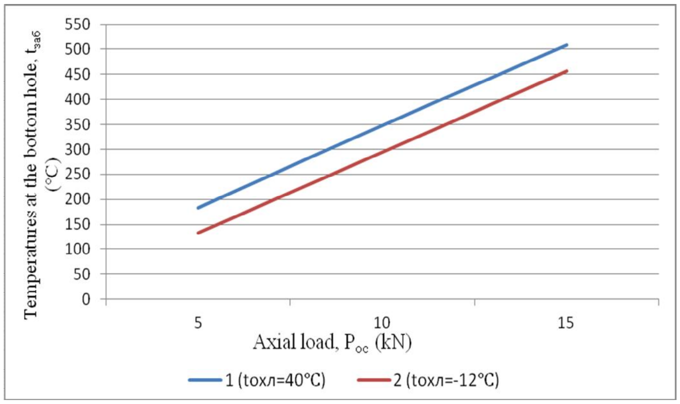

Figure 5: Dependence of temperature change at the bottomhole ($t_{заб}$) at rotational speed of the drill string n=200 rpm on the axial load (P_{oc}) with different temperatures of purging air ($t_{охл}$).

Drilling with a drill string speed of 200 rpm, with an axial load of 10 kN and an initial cleaning air temperature of 40 °C, the temperature at the bottomhole was 348 °C. Reducing the cleaning air temperature to -12 °C with the same drilling parameters led to a decrease in the temperature at the bottomhole by 54 °C.

The results of experimental tests confirm the possibility of using cooled air to negative temperatures to reduce the temperature at the bottomhole.

When drilling boreholes with bottomhole cleaning with air, low bottomhole temperatures improve the work of rock destruction tools, which leads to faster penetration.

Mechanical penetration rate primarily depends on the drilling parameters, type and volume of the cleaning agent, but when drilling with bottom hole cleaning with air, the cooling conditions of the drilling tool have a significant impact on the value of penetration rate. It is confirmed by the results of experimental studies, shown graphically in Fig. 6.

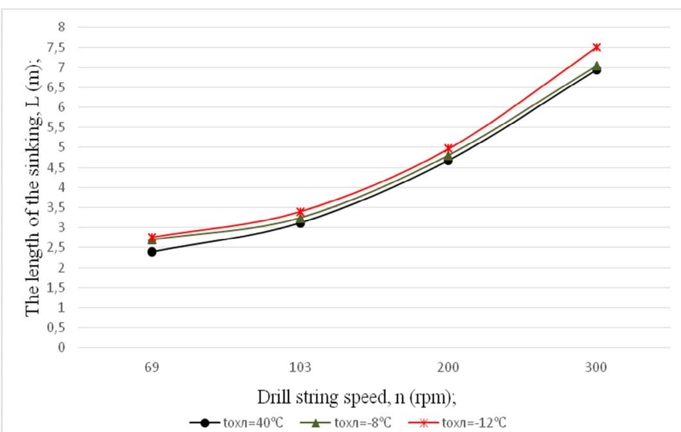

Fig. 6. Dependence plot of mechanical velocity change (v_m) on drill string speed (n) at axial load of 10 kN, with different temperatures of cleaning air ($t_{охл}$).

The dependence of mechanical rate of penetration on drillstring RPM shows that at initial temperature of purging air of 40°C, axial load of 10 kN and drillstring RPM of 69 rpm, the mechanical rate of penetration is 2.6 m/h. As the drillstring RPM increases, the mechanical rate increases. At a rotational speed of 300 rpm, the mechanical drilling speed is 6.8 m/h. The use of cooled air for bottomhole cleaning with the temperature of -12°C under similar drilling conditions leads to an increase in the mechanical rate of penetration. At rotational speed of 69 rpm, mechanical penetration rate amounts to 2,76 m/h, and at rotational speed of 300 rpm it reaches 7,6 m/h.

Thus, depending on drilling modes, penetration rate due to application of purification air cooled to negative temperatures increases by 6-7 % on average. Besides, low temperatures at the borehole bottom contribute to increase of rock destruction tool wear resistance due to prevention of matrix deformation and diamond destruction.

5. CONCLUSION

Production studies proved that the developed new design of the drilling tool with vortex cooler is workable, effective, the use of which allows to reduce the temperature of the rock destruction tool on the face by 50-60 °C on average and increase the mechanical rate of penetration.

The implementation of the proposed design of a drilling tool with a vortex cooler at the Central exploration party of Geological Exploration Expedition of Navoi Mining and Metallurgical Combine ensured low temperatures of blowing air at the borehole bottom, which, in its turn, contributed to increase of drilling efficiency and mechanical rate of penetration.

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