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TECHNICAL NOTE

Investigation of Thermal Operational Regimes for Diamond Bit Drilling Operations

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ABSTRACT

This paper reviews existing studies and investigates thermal operational regimes of diamond bit during drilling operations. The operating temperature of the diamond core drill is studied under bench condition and an optimal thermal range are presented. Based on this study, it was noted that glazing of diamond tools is observed at temperatures less than 327°C, and normal wear of diamond tools is observed at temperatures within the range of 327-660°C. Burning-in of diamond cores is accompanied by heating the matrix to temperatures above 800°C.

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1. INTRODUCTION

The efficiency of drilling with diamond core drills is primarily determined by the properties of the rocks, the rational design of the diamond core drills, number of diamonds and the choice of optimal drilling technology [1-6]. Rock properties that affect the drilling process are very diverse. However, properties such as hardness, strength, and abrasiveness have a great impact on the drilling process. According to the drillability grade, all solid rocks can be divided into hard fractured, compact hard rocks and highly compact hard rocks [3, 7]. According to the degree of fracturing, the following rock groups are distinguished: weakly fractured rocks; medium fractured rocks; highly fractured rocks; very highly fractured rocks [5].

The hardness and fracturing of rocks have a significant impact on the bit wear [1-3, 8, 9]. With an increase in the degree of fracturing of rocks, the efficiency of rock-cutting tools is significantly reduced. The effect of rock fracturing on the wearing of diamond bit's matrix in very hard rocks is much more pronounced than in less hard ones. This is due to the special fracture mechanism conditions of fractured rocks during diamond drilling. As a result of the interaction of a diamond bit with a fissured rock, a large number of large drilling cuttings are formed. The size and amount of drill cuttings formed depend on the critical drilling parameters, the internal diameter of the core pipe and the diameter of the core column [8]. Due to the large amount of rock cuttings formed during drilling of fractured rocks the diamond core drill often gets burned.

During drilling of solid compact rocks the amount of rock cuttings significantly decreases, leading to the polishing diamond core drill. Attempts by drillers to eliminate glazing often resulted in a burning in diamond core drill. A number of researches have been conducted to fully understand the mechanism of glazing and burning [10-13]. The main cause of glazing is insufficient load on the rock-destroying tool. Burning-in is associated with the sludging-up of the bottom hole and the termination of circulation the cleaning agent caused by rock cuttings clogging the washing course (Figure 1).

As reported in literature [14], the glazing mechanism is associated with high temperatures in the zone of contact of diamonds with rock.

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Figure 1. Diamond core drill with traces of rock cuttings in the washing course

Authors proposed a formula for calculating the temperature in the zone of contact of the core drill with the bottom of a well.

$$t_{\alpha} = \frac{10NK}{K_0} \quad (1)$$

where N - power at bottomhole in Watts (W); K – coefficient of heating-up of core drill (K = 0.9); K_o - heat transfer intensity indicator in Watt per °C.

In the calculations using the above formula, the temperature during polishing can reach 400 °C and more. However, during running-in of the diamond core drill, when the temperature in the core drill-to-borehole contact zone does not exceed 60-70 °C glazing can occur [9, 15].

According to literature [7, 16], the effect of rotary speed and axial load on the temperature in the matrix and wear rate of the core drill was investigated. It was established that during normal wear of the crown, the temperature in the matrix is in the range of 100 – 200 °C, and during burning-in, the temperature increases to 800 °C or more. The occurrence of burning-in is associated with the following condition.

$$V_t \geq \frac{l_1 V}{l_1 + l_2} \quad (2)$$

where V_t - current value of the mechanical drilling speed in m/s; V - filtration rate of the washing liquid into the bottomhole surface in m/s; l_1, l_2 - length of washing channel and sector of the drill core's matrix in m.

Base on literature [17], the bench temperature was measured when drilling with diamond core drills. Thermocouples were installed within certain interval along the breadth rock slab to measure the temperature. As the rock slap was drilled, the diamond core drill was exposed to thermocouples and the temperature values in the core drill-to-borehole contact zone were recorded. It was established that during normal drilling process, the temperature in the contact zone was in the range of 100-200 °C.

2. METHODS AND MATERIALS

In the course of the research on the mechanism of these forms of abnormal wear of diamond bit, the authors carried out theoretical and bench studies of the operating temperature of diamond core drills in the contact zone of diamond cores with the rock.

To measure the temperature in core drill-to-borehole contact zone, melting indicators were used (fuse links). This method is widely used in tribotechnics to measure temperature in hard-to-reach places and gives satisfactory results [16]. Fusible inserts, which are short length pipes (length of 3-5 mm), are placed at special holes on a testing surface. Alloy melting temperature is different for each pipe. The fusible inserts are installed on the testing surface within the temperature range, which covers the predicted values. The measurement accuracy is 1- 6 %. Higher accuracy thus, indicates a minimum difference between the melting temperatures of adjacent insert indicators [18-20].

The temperature in the contact zone of the bit's matrix with the bottom hole was investigated. To measure the temperature of the rock-cutting tool in the contact zone, a core drill with a special design was used. The washing course in the bit's matrix was blocked with brass alloy. Recesses into which fusible inserts (tin (melting point 232°C), lead (327 ° C), aluminum (660 °C), brass (800 °C)) were installed when drilled through the brass alloy from the face of the matrix. The circulation of the cleaning agent was carried out through the watercourse made in the body of the diamond core drill [21]. The glazing of the diamond core drill was created by reducing the axial load; in order to create the pre-burning of the diamond core drill, the axial load was increased above the permissible load. The burning-in of the diamond crown was created by forcibly ceasing the circulation of the cleaning agent. The drilling parameters are shown in Table 1.

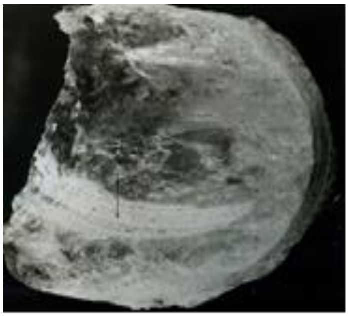
TABLE 1. Drilling parameters

Experiment №	Rate of rotation, rpm	Coring weight, dN	Cleaning agent flow rate, l/min	Type of bit wear
1	600	1000	15	Glazing
2	600	1500	15	Normal wear
3	600	2000	15	Pre-burning
4	600	1000	–	Burning-in

3. RESULTS AND DISCUSSION

During the glazing of the diamond core drill, the tin insert melted, indicating a temperature less than 327 °C, since melting of the lead insert was not observed. There was a gradual reduction in power. The average mechanical speed for glazing was 1.5 m/h. Under normal wear, lead inserts melted. The aluminum and brass inserts were intact. In view of this, the temperature of the diamond core drill in the contact zone with the bottom hole corresponds to the range of 327-660 °C. The average mechanical speed at the same time amounted to 2.3 m/h. During pre-burning-in of the diamond bit, the aluminum insert melted and the brass insert darkened, traces of sintering the rock cuttings with a diamond crown were visible at the end of the matrix. In this case, the face of the matrix of the diamond bit was heated to a temperature of 660 to 800 °C. An increase in the mechanical drilling speed to 3.0 m/h was observed. An increase in temperature above 800 °C corresponds to the burning-in of diamond bits. The rock surface in the contact zone with the diamond bit was smooth during pre-burning-in, while the well's bottomhole was rough (Figures 2(a) and 2(b)).

Figure 3 shows a diamond core drill with traces of pre-burning-in. The fusible aluminum inserts (1), lead (3) and tin (4) melted. Traces of the interaction of diamonds with rock in the form of grooves and micro-breaks were detected.


(a)

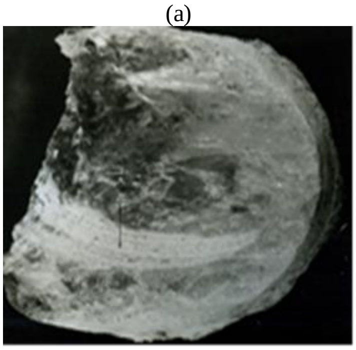

(b)

Figure 2. Bottom hole surface (a) during glazing and (b) during pre-burning

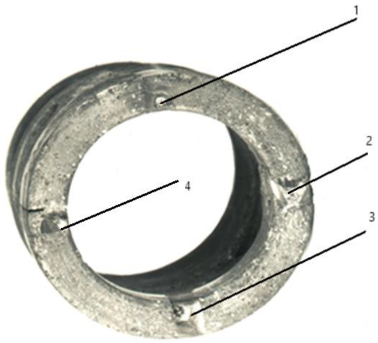


Figure 3. Diamond core drill with traces of the pre-burning-in: 1 - Aluminum fusible insert; 2 - brass fusible insert; 3 - lead fusible insert; 4 - tin fusible insert

4. CONCLUSIONS

Based on this study, the temperature operational regime range of diamond bit for drilling operations was determined. Specifically, the following conclusions have been reached:

1. During glazing of diamond core drills, the tin insert begins to melt, which indicates the matrix end temperature of 232 °C to 327 °C.
2. During glzing of rock surfaces in the contact zone with the diamond core drills no evidence of rock desturction is observed.
3. During normal wear of diamond core drills, lead inserts were melted. No evidence of melting in brass and aluminium inserts were observe.
4. The presence of washing courses in the body of the core drill allows the cleaning agent to freely circulate and sufficiently cool the matrix of the drill.
5. During glazing, the temperature at the face of the matrix is less than 327 °C, during normal wear - from 327 °C to 660 °C, pre-burning from 660 °C to 800 °C. An increase in temperature above 800 °C leads to burning-in of diamond core drill.

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چکیده

این مقاله به بررسی مطالعات و یافته های علمی موجود می پردازد و همچنین رژیم های گرمایی در عملیات حفاری با استفاده از مته های الماسی را مورد بررسی قرار می دهد. دمای عملیاتی مته های حفاری در شرایط واقعی مورد بررسی قرار گرفتند و در نتیجه ی این بررسی بازه ی دماهای بهینه ارائه شده اند. نتایج نشان میدهند که صیقلی شدن الماس ها در ابزارهای مورد استفاده در دمای کمتر از C ° ۳۲۷ اتفاق می افتد، و همچنین حالت معمولی الماس ها در بازه ی دمایی C ° ۳۲۷–C ° ٦٦٠ مشاهده شده است. همچنین داده ها نشان می دهند که سوختن کامل هسته ی الماس زمانی رخ میدهد که دمای ماتریکس به بالای C ° ۸۰۰ برسد.

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