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Optimization Method for PDC Drill Bits in Hechuan

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Abstract: The Hechuan region is located in the eastern part of the Sichuan Basin, with extremely complex crustal structures, including geological structures such as fault zones and fold zones. In the Hechuan area, the geological conditions are diverse and complex, including volcanic rocks, sedimentary rocks, metamorphic rocks, etc. The physical properties and strength of these formations vary, posing great challenges for drilling operations. In order to improve drilling efficiency, it is necessary to optimize the type of PDC bit. Firstly, the rock breaking principle of PDC drill bits was elaborated. Secondly, we optimize PDC drill bits based on their drillability, rock drillability, and compressive strength. Through the comprehensive analysis of the above three methods, the suitable types of PDC drill bits for the Hechuan area of the Sichuan Basin can be determined. According to the complexity of geological conditions and the different properties of rocks, PDC bits with strong adaptability, high wear resistance and impact resistance, strong cutting ability and guidance can be selected to improve drilling efficiency and reduce drilling costs.

Keywords: Hechuan Region; PDC Bit; Rock Characteristics; Drill Bit Optimization.

1. Introduction

With the development of oil and gas resource extraction, the complex geological conditions in some areas have become apparent. These areas generally have hard and highly abrasive formations, leading to slow drilling speed and limited footage of individual drill bits. Frequent tripping and replacement of drill bits and tool combinations are required, resulting in low drilling efficiency. The geological structure of the Hechuan area is very complex, mainly manifested in the development and activity intensity of fault zones. The existence of fault zones causes drastic changes in the strata. Not only does the thickness of the formation change significantly over a short distance, but it also leads to phenomena such as faults and dislocations in the formation. This complex geological structure brings uncertainty to drilling operations, making drilling engineering design and operation more complex.

The strata in the Hechuan area are mainly composed of volcanic, sedimentary, and metamorphic rocks [1,2]. In the "Shuanglong Mountain" area near Hechuan, the texture of volcanic rock is very hard. Volcanic rocks have high hardness and strength, so it is necessary to use harder drill bits during drilling and pay attention to cooling the drill bits. Sedimentary rock is formed by long-term compaction and consolidation of sediment, including sandstone, shale, mudstone, etc. In the Hechuan region, sedimentary rocks are mainly distributed around water bodies such as rivers and lakes, such as the banks of the Hechuan River. Sedimentary rocks have a layered structure and a relatively soft texture. Sedimentary rocks have strong plasticity and solubility, which can easily lead to problems such as wellbore collapse and kick. Metamorphic rocks are formed by changes in the structure, chemical composition, and mineral composition of the original rocks under geological processes such as high temperature and pressure. In the Hechuan region, metamorphic rocks are mainly distributed in mountainous and highland areas, such as the "Wuling Mountain" area near Hechuan. Metamorphic rocks have block or sheet like structures. The presence of metamorphic rocks poses certain challenges to drilling operations, as their physical properties and strength are often high, requiring the selection of more wear-resistant drill bits and stronger drilling techniques.

Due to the geological conditions and rock characteristics of the Hechuan area, problems such as slow mechanical drilling speed and limited footage of individual drill bits have become prominent [3,4,5]. The development well in Hechuan Block requires at least 5 trips in the second spud section, mainly concentrated in the high grinding section of Xujiahe, requiring 7 trips with an average mechanical drilling speed of 4.09m/h. Frequent tripping, replacing drill bits, and adjusting drilling tool combinations greatly reduce drilling efficiency and increase drilling risks [6].

Therefore, it is necessary to make breakthroughs in drilling technology and carry out the optimization of PDC bits to improve drilling efficiency, and to study their optimization methods. PDC drill bits are anisotropic superhard materials with polycrystalline drill blades, which have excellent wear resistance and efficient drilling speed. By conducting in-depth research on the geological structure, rock characteristics, and drilling techniques in the Hechuan area, suitable PDC bits can be selected and drilling parameters can be optimized to improve drilling efficiency and reduce drilling risks [7].

2. Rock Breaking Mechanism of PDC Bit

PDC drill bits are tools that use cutting teeth to cut the formation and break rocks. Due to the high-speed rotation of the drill bit underground and its operation in high-temperature environments, the rock in the formation has a certain degree of elasticity and plasticity. During the cutting process, the cutting teeth continuously enter the formation, cutting and breaking the rock, thus the rock cutting process is similar to the cutting process in metal processing.

The rock cutting process is essentially an extrusion process. In the extrusion process, the rock becomes a chip by slip deformation. When the rock just touches the cutting edge of the cutting teeth, the stress at the contact point leads to elastic stress and strain inside the rock. As the cutting edge approaches the rock, the elastic stress inside the rock gradually increases. At a certain point, the shear stress reaches the yield strength of the rock, and the rock begins to slide along an "initial slip surface" of equal shear force (e.g., surface OA in Figure 1). The left side of this slip surface

represents the region of elastic deformation and the right side represents the region of plastic deformation.

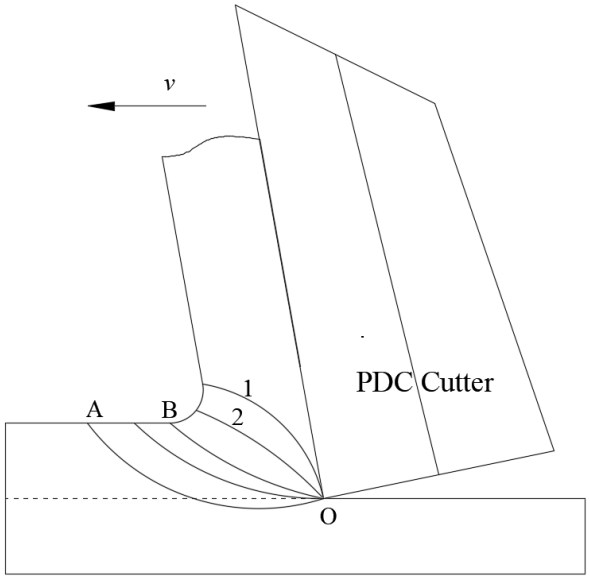


Fig 1. PDC Drill Bit Rock Breaking Mechanism Diagram

Rock through the OA surface when the cutting edge to move, slip deformation is getting bigger and bigger, when the rock moved to OB, the figure between the rock layer 1 and 2 will no longer along the slip, but together with the cutting teeth along the pre-dip surface outflow, so called the initial slip curve, but called the termination of the slip curve.

When the rock flows out along the forward inclined surface, due to the pressure and friction of the forward inclined surface of the cutting teeth, the bottom layer of the cutting (a layer close to the forward inclined surface) produces a large extrusion and shear deformation, and as a result, the lower layer expands, and the cutting flows out in the opposite direction to the forward inclined surface, leaving the forward inclined surface and becoming a chip.

The above is the typical process of chip formation, the cutting layer first produces elastic deformation, through the cutting layer slip and cutting layer away from the cutting teeth and other stages to complete the cutting. Since the bottom of the drill bit is concave cone, its space volume is small, when the drilling fluid is sprayed out at a certain jet speed and impacted on the bottom of the well, the concave cone space forms a very high pressure, and the rock chips can flow out of the bottom of the well into the annulus in time under the action of this high pressure. Therefore, there is no obstacle to the removal of rock chips caused by differential pressure when the drill bit is cutting and breaking rock.

3. Analysis of the Preferred Method of PDC Drill Bits

3.1. Comparison of Drillability of Toothed Wheel Drill Bits and Drill Bit Drillability

As shown in Fig. 2, it is the relationship between the drillability K_{dc} of therock bit and the drillability K_{pdc} of the PDC bit, and Table 1 shows the corresponding grades of the drillability of therock bit and the drillability of the PDC bit. There is indeed a difference in the rock drillability relative to the tusked bit and PDC bit, and the drillability grade value of the miniature PDC bit increases with the increase of the drillability grade value of the tusked bit, and the relationship between the two is nonlinear; below grade 6.5, the drillability grade value of the PDC bit is lower than that of the tusked bit; and above grade 6.5, the grade value of the PDC bit is higher than that of the tusked bit. The reason is related to the rock-breaking mechanism of the two types of drill bits, the tooth wheel drill bit to impact rock-breaking, mainly considering the compressive strength and hardness of the rock, while the PDC drill bit to pressure scraping rock-breaking, mainly considering the hardness and shear strength of the rock, so even if it is the same size of different types of drills, the effect of the role of the rock will also be different, i.e., for the different ways to break the rock drill, the stratigraphy of the different drillability.

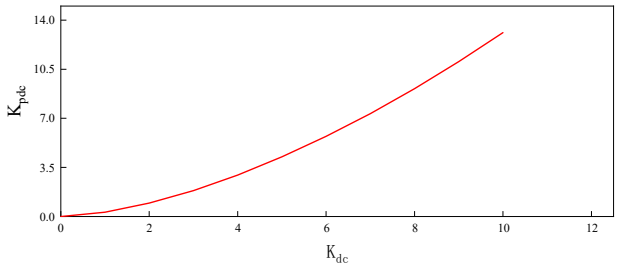


Fig 2. Relationship between drillability (Kdc) of rock bit and drillability (Kpdc) of a PDC bit

Table 1. Drillability level value of PDC bit corresponding to rock bit

K_{dc}	1	2	3	4	5	6	6.5	7	8	9	10.0
K_{pdc}	0.3	1	1.9	3.0	4.2	5.7	6.5	7.3	9.1	11.0	13.1

3.2. Using Rock Drillability for Bit Selection

Usually, the difficulty of resisting fragmentation in a formation is reflected by the drillability level of the rock. The classification of strata based on the drillability level index, drilling speed index, and hardness index of rock micro drilling is shown in Table 2. According to the three major categories of rock: soft, medium, and hard, rock drillability is classified into 10 levels The determined rock drillability corresponds to a certain type of drill bit, and the higher the grade value, the more difficult the formation is to drill. Drillability has led the properties of rocks from general concepts such as strength and hardness to concepts related to practical work such as drilling. Drill bit manufacturers also use the "soft" and "hard" strata as the basis for designing and manufacturing drill bits. There is a corresponding relationship between rock drillability and drill bit type. The drillability measurement values of formation rocks in the eight major oil fields in China have a certain range and distribution pattern. CNPC compared and analyzed them with different drill bit statistical data, and listed the corresponding drill bit models (BitTypes) for different drillability levels (Kd). In practical applications, the variation pattern of continuous rock drillability can be obtained by analyzing logging data, and combined with the corresponding relationship in Table 2, the corresponding drill bit type for the formation can be selected.

Based on the above research, combined with the corresponding relationship between the rock drillability

classification data range and drill bit type provided according to industry standards, and the calculated Kd value, we provide the following recommended drill bit selection table 2.

Sometimes, logging data can be used to quickly and accurately calculate rock compressive strength, shear strength, and hardness, and then hardness parameters can be directly used to determine rock drillability. The specific steps are as follows:

(1) Utilizing uniaxial compressive strength C_0 and shear strength τ_0 Empirical formula calculation for 0 τ_0:

$$\tau_0 = \frac{C_0}{3.464} \quad (1)$$

2) Calculation formula for indentation hardness:

$$Hd = 84.109 \times \tau_0 + 132.59 \quad (2)$$

3) The calculation for drillability value Kd and abradability GD:

$$Kd = 1.9467Ln\left(\frac{Hd}{10}\right) - 2.67 \quad (3)$$

$$GD = \left(\frac{Kd}{3.61}\right)^{\frac{1}{0.3173}} \quad (4)$$

After calculating the Kd value, a suitable drill bit type can be selected based on Table 2.

Table 2. Rock Drillability Grading Standards and Bit Type Matching Patterns (Recommended Table for Bit Selection)

`	Soft				moderate				hard	
Value of Rock Drillability	1	2	3	4	5	6	7	8	9	10
Drillability (m/h)	≥2.0	2.0-1.0	1.0-0.5	0.5-0.3	0.3-0.1	0.1-0.05	0.05-0.03	0.03-0.01	0.01-0.008	0.008-0.004
Hardness (MPa)	≤100	100-200	200-500	500-700	700-1500	1500-2100	2100-2500	2500-3400	3400-3500	3500-3700
Stratigraphic Level	I-III		III-IV		IV-VI		VI-VIII		VIII-X	
Drillability Value Classification	Kd<3		3≤Kd<4		4≤Kd<6		6≤Kd<8		8≤Kd<10	
Stratigraphic Classification	SS		S		S~M		M~H		H	
Applicable Drill Types	1 (JR)		2 (R)		3 (ZR)		4 (Z)	5 (ZY)	6 (Y)	7 (JY)

3.3. Utilizing Rock Compressive Strength

The type of drill bit is influenced by the type of rock in the formation, and the compressive strength of different rock types also varies. Therefore, it can be said that the compressive strength of rocks is an important factor affecting the type of drill bit, and the corresponding relationship between the two is shown in Table 3. In practical applications, the compressive strength of the formation is obtained from logging data, and then the appropriate drill bit model is selected based on the corresponding relationship between the compressive strength and the type of drill bit shown in Table 3. Establishing a corresponding relationship between compressive strength and drill bit type helps to optimize drill bit types through quantitative formation properties. In practical applications, three methods for optimizing drill bit types can be considered simultaneously, and based on them, modifications can be made to ultimately determine the appropriate drill bit model.

Table 3. Recommendation for Formation Compressive Strength and Bit Selection

Type Of Drill (LADC)	Stratigraphic Hardness	Stratigraphy	Type Of Rock	Compressive Strengths (MPa)
11/12	Extremely soft	Cohesive soft ground with low compressive strength	King Clay, siltstone, sandstone	<25
11/13 43	Soft	Soft formations with low compressive strength and good drillability	Claystone, marl, lignite, sandstone, tuff	25-50
12/13 51/52	Moderate soft	Soft to medium strata with low compressive strength and interbedded hard layers	Claystone, marl, lignite, sandstone, siltstone, hard gypsum, tuff	50-75
21/21 51/53	Moderate	Medium to hard strata with high compressive strength and abrasive interbedded thin layers	Mudstone, chert, hard gypsum, sandstone (calcareous)	75-100
``21/23 53/61	Moderate hard	Very high compressive strength, non-abrasive hard and dense formations	Limestone, hard gypsum, dolomite	100-200
31/34 62/63	Hard	Hard and dense strata with high compressive strength and some abrasive inclusions	Shale (calcareous), sandstone (calcareous), siltstone	100-200
63/73/83	Extremely hard	Extremely hard and abrasive formations	Quartzite, igneous rocks	>200

Usually, rocks such as shale and argillaceous sandstone in deep well sections become very dense and difficult to break under the pressure of the overlying strata. The crushing volume of the teeth of existing cone drills pressed into such rocks is very small, and some do not produce volume crushing at all, leaving only a shallow tooth mark. The pressure holding effect of rock cuttings crushed from these formations under high-density drilling fluid conditions is very obvious, and the

mechanical drilling speed is very slow. Relatively speaking, the pressure holding effect of PDC bits is relatively small, and the mechanical drilling speed and bit life are relatively high. It is recommended to promote the use of PDC drill bits in well sections with a burial depth greater than 2500 meters.

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