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INFLUENCE OF COAL ROCK HARDNESS AND CONFINING PRESSURE ON SPECIFIC ENERGY CONSUMPTION OF PDC BIT DURING GAS EXTRACTION BOREHOLE

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ABSTRACT

Specific energy consumption have a great influence on drilling performance of PDC bit in the process of gas drainage in soft coal seam. Study influence of coal rock hardness and confining pressure on specific energy consumption is very important. The mathematical model of specific energy consumption is built according to the coal rock cutting principle. Gas drainage drilling experiment table was built and Gas drainage drilling experiment was carried out under different coal rock hardness and confining pressure. The results indicate that specific energy consumption increase with the increase of coal rock hardness. Specific energy consumption increase with the increase of confining pressure. It provides a good theoretical basis for practical work.

KEYWORDS: Specific energy consumption, Coal rock hardness, Confining pressure.

INTRODUCTION

Specific energy consumption have a great influence on drilling performance of PDC bit in the process of gas drainage in soft coal seam gas drainage borehole. So study specific energy consumption of PDC bit drilling for gas extraction in soft coal seam is very important. When the confining pressure increased gradually, the increase of damage became slow along with the accumulative special energy absorbency, i.e., the higher confining pressure, the more energy needed for amphibolites to reach the same damage level. The formulas were putted forward for the damage, accumulative special energy absorbency and confining pressure [i]. For sandstone and granite with a single fracture, there is obvious hysteresis effect for the restitution of permeability in the process of unloading of confining pressure [ii]. The volume strain sensitivity to the confining pressure of low permeability gas shale decreases after an initial increase with the increase of confining pressure, and the permeability sensitivity to the confining pressure is gradually reduced with the increase of confining pressure[iii]. As the confining pressure increased, the maximum accumulated rock energy increased exponentially, the residual elastic energy density increased linearly, and the maximum dissipated energy density risen exponentially, indicating that the confining pressure enlarged the rock energy transmission and weakened the intensity of energy release[iv].The experimental results within the confining pressure of 100 MPa revealed that the dispersion of the strengths resulted from the fissures or cracks in the specimens decreased as the increasing of the confining pressure[v].With the increasing of unloading speed of confining pressure, the time of coal maintaining at a stress plateau phase reduces, and it tends to 0, and the easier coal is to be fail After the start of unloading confining pressure, the time of coal maintaining in the stage of stress plateau showed a power function relation with unloading speed of confining pressure[vi].The energy dissipation of rock specimen presents nonlinear relationship with time, while the energy dissipation of rock specimen presents linear relationship with lateral deformation. Under the same lateral deformation level, the greater the confining pressure is, the greater the energy dissipation is, and the rock specimen presents more brittle characteristic[vii]. When gas pressure was greater, the effective confining pressure was smaller, and the radial deformation produced by unloading was greater. When the unloading failed confining pressure difference was smaller, coal would be easier to get unstable failure[viii]. The method of using the shearer motor working parameters to reflect the hardness of coal and rock is put forward. Mathematical model between the shearer motor working parameters and the hardness of coal and rock is established by analysis of the stress combined with the mechanical model of the pick cutting coal and rock. It provides mathematical basis about the test [ix]. The specific energy consumption declined with the overall increase in power and particle size [x]. According to the radial vibration signals of two layers wavelet packet decomposition of each frequency band energy feature vector and the hardness of coal mining machine perception relation formula, a fuzzy membership function was built. the coal and rock properties characterization cutting hardness factor q was defined, and its value was equal to the coal and rock characteristics of fuzzy membership degree. The measured data show that the characteristics of coal cutting hardness of the fuzzy set method is more close to actual mining coal and rock conditions[xi]. Since the vertical stress distribution of coal and rock can reflect the risk of rock burst, the influence of hardness and thickness of coal seams with a hard roof and a hard floor on the vertical stress distribution of coal and rock was simulated. The

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results indicate that with the decrease of the coal thickness, the stress in coal and rock will increase, while the harder the coal is the greater the vertical stress in coal and rock will be, resulting in an increase of risk of rock burst[xii]. The results show that theoretical model on plane and rotary cutting specific energy consumption offers consistent mathematical description; rotary cutting specific energy consumption shows a synchronous increase due to increased cutting speed when there is no change in cutting thickness; the increase rate is0. 73% for cutting specific energy consumption of unit speed[xiii]. It is found that the amount of specific energy is constant at pressures higher than 16MPa and consequently, micro cracks that appeared on sample surface at low pressure are absent at higher pressures[xiv]. Regarding the process of rock yield deformation and failure as a process of energy release and energy dissipation, a failure criterion of deep rocks subjected to coupling effects of confining pressure and temperature is proposed according to the principle of least energy consumption. With a clear physical meaning, this failure criterion shows that if both the plastic dissipation energy and heat conduction dissipation energy caused by temperature gradient in rocks reach to a critical value, the rock will lose its load carrying ability[xv]. Under the yield platform at triaxial state, along with the increase of circular action times of impact loads, the Young′s modulus and the yield stress of specimens decrease, and the yield strain increases. The failure configurations of sandstone change with the confining pressure from axial tensile failure to compression-shear failure; and the critical confining pressure is 10 MPa. Specific energy absorbency value against lower confining pressure level is more than the value under higher confining pressure with the same energy of incident wave. The formulas among with the specific energy absorbency,the incident energy and confining pressure are put forward[xvi].In order to study specific energy consumption of PDC bit drilling for gas extraction in soft coal seam to improve the drilling performance of PDC bit. Up to now, lots of researches have been done, however, paper about study the influence of coal rock hardness and confining pressure on specific energy consumption is few. So drilling experiment table is built and drilling experiment is carried out under different coal rock hardness and confining pressure. In this paper, influence of coal rock hardness and confining pressure on specific energy consumption is researched and some conclusions are obtained.

TEST BENCH

According to the theory of rock cutting and breaking, the gas drainage drilling test bench (Fig1) is built. The test bench mainly has two parts, the power system and the testing system. The test rig drilling experiments is not only used in drilling coal rock with PDC bit , but also in a variety of types of bits drilling test.

1- fluid cylinder; 2-coal wall support; 3-clamper; 4-advanced gear; 5-gyroscope; 6-control Table; 7-test coal wall; 8-drilling bit; 9-drill pipe; 10-flow sensor; 11-pressure pickup; 12-data acquisition; 13-display interface; 14-flow digital display meter; 15-draught fan

Figure1:Gas drainage drilling experiment table

Power system

The dynamic system of the test bench adopts ZDY1900S full hydraulic drilling machine. The rig is mainly composed of a host machine, pumping station and control station. Pump station is driven by the motor rotation, the hydraulic oil will be transferred to the feed passage and the rotary actuator, the control console on the pole realizes the drill rotation and feed. The drilling machine not only provides power for the drilling tool, but also provides the confining pressure load for the confining pressure loading device on the top of the coal wall support. At the top of the coal wall support, HSG90/63 engineering hydraulic cylinder is provided, the rated working pressure of the hydraulic cylinder is 16MPa, and the stroke is 640mm, so as to meet the requirement of applying the confining pressure to the coal wall. The hydraulic circuit of the hydraulic circuit is additionally provided with two-way hydraulic lock, so as to ensure the stablity of the confining pressure in the operation of the hydraulic cylinder.

Test system

YSV dynamic signal acquisition and analysis software were used in testing system for drilling test data acquisition system; Measurement of feed resistance and pressure difference between hydraulic inlet and outlet of hydraulic

motor was obtained according to FST800-201G222A-16B pressure sensors. The main performance parameters of the sensor: range: 0-31.5 Mpa; sensitivity: 158.73 output voltage: 0-5 V; standard engineering unit: mv/Mpa; measurement accuracy: 0.5%FS; the flow of the hydraulic system using the model for the turbine flow sensor LWGY-15A, the nominal pressure 6.4MPa, maximum pressure loss is 0.0035 MPa, the turbine flow sensor and the hydraulic motor return oil pressure sensor on the pipeline in series. According to the above power system and the test system, provide the maximum torque of 1900Nm and maximum speed of 300r / min, feed stroke of 600mm. According to the working performance of the drilling rig, the displacement of the main oil pump in the pump station is changed to change the rotating speed of the drilling machine. The rotating speed range of the drill bit is 85-300 r/min. Adjust the displacement of the auxiliary oil pump in the pump station to change the feeding speed of the drilling mechanism. The feeding speed range of drilling mechanism is 0-3m/min.

Calculation formula of drilling performance

The drilling torque that drives the gas drainage bit to do the rotary motion is output from the variable displacement motor of drilling rig gyroscope. After second gear down, drilling rig principal axis and hydraulic chuck are driven to rotary motion. The drill pipe transfers the torque to the drill bit, so that the bit cuts the coal rock under the action of the torque. The actual output torque of the drilling rig is:

$$T = \frac{\Delta P Q \eta_{\mathrm{m}}}{2\pi \mathrm{m}} \tag{2-1}$$

In the formula; T-- actual output torque of drilling rig; ΔP-- Pressure difference of import and export; Q-- Flow of the hydraulic system; n---Rotating speed of drilling pipe; η_{m} -mechanical efficiency, take 0.95. The feeding resistance of the bit during drilling(W) are as follow;

$$W = P_3 \pi R^2 \tag{2-2}$$

In the formula; P3---Pressure of feed oil-way; R--Inner cylinder radius of feed hydraulic cylinder.

Each PDC bit includes eight cutters and the power is regard as the same, so

$$W_1 = 2 \cdot \pi \cdot \mathrm{n} \cdot 8T \cdot t + 8w \cdot v \cdot t \tag{2-3}$$

W1 is total consume power, n is rotating speed, v is feeding speed, t is drilling time.

$$v = \pi R_1^2 \cdot v \cdot t \tag{2-4}$$

V is volume of drill hole. R1 is radius of drill hole.

$$H_w = 2.7 \times 10^{-4} \cdot \frac{W_1}{V} = 2.7 \times 10^{-4} \cdot \frac{2 \cdot \pi \cdot \mathrm{n} \cdot 8T \cdot t + 8w \cdot v \cdot t}{\pi R_1^2 \cdot v \cdot t}$$

$$= 2.7 \times 10^{-4} \cdot \{ \frac{32 \cdot \pi n R_0 \cdot b_0 \cdot \sqrt{R^2 + \left(R - \frac{v}{3n\cos\alpha}\right)^2} \cdot C\cos\phi \cdot \cos(\theta + \alpha)}{\cos(\psi + \alpha + \theta + \phi)} + 160\mu \sqrt{R^2 + \left(R - \frac{v}{3n\cos\alpha}\right)^2} \cdot R_0 \cdot f \left[\frac{0.6}{\cos\alpha} + \frac{1}{3}\left(\Delta L_f - \frac{0.6}{\cos\alpha}\right)\right]}{\pi R_1^2 \cdot v}$$

$$+ \frac{16 \cdot b_0 \cdot \sqrt{R^2 + \left(R - \frac{v}{3n\cos\alpha}\right)^2} \cdot C\cos\phi \cdot \sin(\theta + \alpha)}{\cos(\psi + \alpha + \theta + \phi)} + 80 \sqrt{R^2 + \left(R - \frac{v}{3n\cos\alpha}\right)^2} \cdot f \left[\frac{0.6}{\cos\alpha} + \frac{1}{3}\left(\Delta L_f - \frac{0.6}{\cos\alpha}\right)\right] \}$$

HW is specific energy consumption.

It's obvious feeding resistance, drilling torque and specific energy consumption not only are correlated with cutter rake angle, cutting condition, but also feeding speed and rotation speed. This paper studies distribution rule based on specific energy consumption with different cutter rake angle of PDC bit during gas extraction borehole.

RESULTS AND DISCUSSION

Influence of coal rock hardness on specific energy consumption

In order to research the influence of coal rock hardness on specific energy consumption, drilling coal rock experiment is carried out under different coal rock hardness. Working condition parameters in the process of drilling coal rock are as follows: coal rock hardness is f=0.65, f=1.03 , f=1.3, f=2.4 and f=3.24 . Confining pressure is 7 MPa, feed speed is 0.5 m/min, rake angle of PDC bit is 10°, R_0 is 94 mm, rotating speeds is 190 r/min. Drilling torque is obtained under different rotating speed in Tab.1. Specific energy consumption under different coal rock hardness are shown in Fig.2

Table1:Drilling torque and feeding resistance under different coal rock hardness

Coal rock hardness （f)	Drilling torque (N·m)			Feeding resistance(KN)		
	Maximum value(N·m)	average value(N·m)	standard deviation	Maximum value(KN)	average value(KN)	standard deviation
0.65	370.7	353.2	18.7	3.9	3.2	0.39
1.03	378.4	364.7	11.6	4.9	4.0	0.65
1.3	417.2	385.5	19.2	4.9	4.8	0.27
2.4	428.6	400.3	21.5	5.3	5.0	0.33
3.24	459.7	420.1	24.8	5.9	5.2	0.53

H_w of f=0.65, f=1.03, f=1.3, f=2.22 and f=3.24 are 33.6 KN/m^2, 34.72 KN/m^2, 36.73 KN/m^2, 38.14 KN/m^2 and 40,12 KN/m^2 respectively.

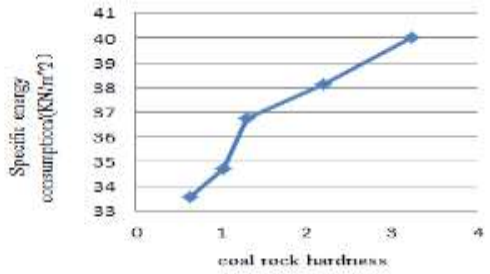

Figure2: Influence of coal rock hardness on specific energy consumption

Fig.2 shows specific energy consumption decrease with the increase of coal rock hardness because of these things; Cutter cuts coal rock become more difficult with the increase of coal rock hardness. So under the same condition, the larger coal rock hardness is, the more energy consumes

Influence of confining pressure on specific energy consumption

In order to research the influence of confining pressure on specific energy, drilling coal rock experiment is carried out under condition of different confining pressure. Working condition parameters in the process of drilling coal rock are as follows: coal rock hardness of coal is f_0:f_0 = 1.03, confining pressure is 3 MPa, 5 MPa, 7 MPa and 9 MPa, rotating speed is 190 r/min, rake angle of PDC bit is 10°, R is 13 mm, R_0 is 80 mm,feed speed is 0.7 m/min. Drilling torque and feeding resistance are obtained under different confining pressure are shown in Tab.2. Specific energy consumption under different confining pressure is shown in Fig.3

Table2: Drilling torque and feeding resistance under different confining pressure

confining pressure （MPa)	**Drilling torque (N·m)**			**Feeding resistance(KN)**		
	Maximum value(N·m)	**average value(N·m)**	**standard deviation**	**Maximum value(KN)**	**average value(KN)**	**standard deviation**
3	335.8	317.2	13.5	3.16	2.50	0.48
5	398.9	351.8	15.9	4.04	3.45	0.42
7	400.1	366.1	12.8	4.61	3.93	0.39
9	422.1	375.3	21.1	5.56	4.74	0.48

Hw of 3 MPa, 5 MPa, 7MPa and 9 MPa are 30.2 KN/m^2 , 33.53 KN/m^2, 34.92 KN/m^2 and35.83KN/m^{2}respectively

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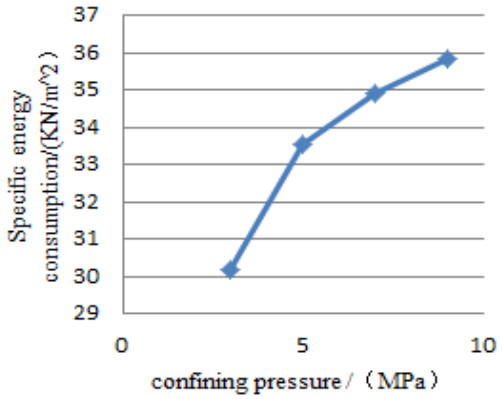

Figure3: Influence of confining pressure on specific energy consumption

Fig.3 shows specific energy consumption increase with the increase of feeding speed because of these things; Confining pressure can change the nature of the rock, the larger the confining pressure is, the larger the compressive strength and shear strength of rock is, which makes it difficult to cut coal and rock, so that make the specific energy consumption become larger

CONCLUSIONS

Specific energy consumption have a great influence on drilling performance of PDC bit in the process of gas drainage. The mathematical model of specific energy consumption is built according to the coal rock cutting principle. Gas drainage drilling experiment table is built and drilling experiment is carried out under different coal rock hardness and confining pressure. Specific energy consumption decrease with the increase of coal rock hardness because of these things; Cutter cuts coal rock become more difficult with the increase of coal rock hardness. So under the same condition, the larger coal rock hardness is, the more energy consumes. Specific energy consumption increase with the increase of confining pressure because of these things; Confining pressure can change the nature of the rock, the larger the confining pressure is, the larger the compressive strength and shear strength of rock is, which makes it difficult to cut coal and rock, so that make the specific energy consumption become larger. According to the paper, the relationship between coal rock hardness, confining pressure and specific energy consumption was analyzed. It provides a good basis for applying different confining pressure in actual work and energy consumption when drills different coal seam. In the paper, we know the relationship between coal rock hardness, confining pressure and specific energy consumption in soft coal seam, but we do not know it in medium-hard coal rock and hard coal rock, study the relationship is next important task.

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