

Study on parameters optimization of coalbed gas drilling drainage by high pressure water jet

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Abstract. Coalbed gas is a kind of non-conventional energy with non-pollution and high-quality. High pressure water jet technology has many advantages in coalbed gas drilling drainage, due to no heat effect, high flexibility, and high surface quality. To reduce the energy consumption of this technology, especially for the hard coal rock, the water jet parameters optimization is studied in this paper. Based on an established three-dimensional damage numerical model and the orthogonal design tests, it analyzes the influence characteristic of different water jet parameters on coal bed gas drilling drainage and obtains the optimal water jet parameters combination finally. The results could improve the efficiency of high pressure water jet drilling drainage.

1. Introduction

Coalbed is the associated resource of coal, with no pollution and high energy. The traditional mechanical drilling technologies have many drawbacks, like plugging and sticking and so on. However, these problems can be avoided by high pressure water jet technology. Meanwhile, this technology has extra advantages, such as no dust, no toxic gas, no spark and so on. So, the high-pressure water jet technology will be one of the main methods in coalbed gas mining engineering [1].

In recent years, high pressure water jet has made some progress in coal bed gas drilling drainage, but there are still some disadvantages, for example, the energy consummation is higher, especially for the hard coal rock (6-8 times higher than the mechanical drilling). Many scholars commit to the related researches, such as Ge et al studied the influence radius of the high-pressure water jet drilling [2], Li et al analyzed the stress distribution rule of the high-pressure water jet impacting coal [3]; Wang et al investigated the permeability variations around the coal seam after high pressure water jet drilling [4].

However, the work on parameters optimization of high pressure water jet is not enough, but it is one of the key scientific issues. Therefore, this paper conducts researches on the influence characteristics of different water jet parameters on water jet drilling efficiency and the optimal parameters combination of water jet drilling. It is significant that the results can provide technical supports to high pressure water jet application in coal bed gas drilling drainage.



The damage is the essential factor to high pressure water jet drilling drainage efficiency, for damage evolution will affect the permeability and stability of coal rock. Therefore, in this paper, it studies the drilling efficiency by the damage in coal rock under high pressure water jet. However, the damage in coal rock is hard to be measured, as it's a quite complex physical mechanics process that high pressure water jet drilling coal rock. So, in this paper it establishes a numerical model of high pressure water jet impacting coal rock to study the damage evolution in coal rock under high pressure water jet, based on the fluid mechanics, damage mechanics and the fluid-solid coupling penalty function algorithm.

2. Numerical simulation

2.1. Numerical model

Governing Equations:

$$\frac{\delta \rho}{\delta t} = -\rho \frac{\delta v_i}{\delta x_i} - w_i \frac{\delta \rho}{\delta x_i} \quad (i, j = 1, 2, 3) \quad (1)$$

$$v \frac{\delta v_i}{\delta t} = \sigma_{ij,j} + \rho b_i - \rho w_i \frac{\delta x_j}{\delta x_i} \quad (2)$$

$$\rho \frac{\delta E}{\delta t} = \sigma_{ij} v_{i,j} + \rho b_i v_i - \rho w_i \frac{\delta E}{\delta x_j} \quad (3)$$

Where ρ is the material density, v_i is the material velocity, w_i is the relative velocity between material speed and mesh, σ_{ij} is Cauchy stress, b_i is the body force, E is the energy [5].

The constitute equations for coal rock, water jet, air are written as follows:

$$\sigma^* = [A(1-D) + BP^{*N}] \left(1 + C \ln \dot{\varepsilon}^* \right) \quad (4)$$

$$P = a_1 \mu + a_2 \mu^2 + a_3 \mu^3 + (b_0 \mu + b_1 \mu + b_2 \mu^2) E \quad (5)$$

$$P = c_0 + c_1 \mu + c_2 \mu + c_3 \mu + (c_4 + c_5 + c_6 \mu) E \quad (6)$$

Where σ^* is the normalized equivalent stress, A is the cohesion parameter, B is the pressure hardening coefficient, C is the strain-rate sensitivity coefficient, N is pressure hardening exponent, P^* is the normalized pressure, $\dot{\varepsilon}^*$ is the normalized strain rate, $\mu = V^{-1} - 1$, V is relative volume. Damage (D) is accumulated from both the equivalent plastic strain increment and the equivalent plastic volumetric strain increment, which is expressed as,

$$D = \sum \frac{\Delta \varepsilon_p + \Delta \mu_p}{\varepsilon_p^f + \mu_p^f} \quad (7)$$

Where $\Delta\varepsilon_p$ and $\Delta\mu_p$ are the equivalent plastic strain and the equivalent plastic volumetric strain, respectively, $f(P) = \varepsilon_p^f + \mu_p^f = D_1(P^* + T^*)^{D_2}$ is the material fracture plastic strain under actual pressure, D_1 and D_2 are the material constant. T^* is the normalized hydrostatic tension [6-7].

The main mechanical parameters of coal rock are shown in Table 1.

Table 1. The main mechanical parameters of coal rock.

$\rho / g \cdot cm^{-3}$	G/GPa	f_c'/GPa	T^*/MPa	P_{crush}/GPa	μ_{crush}
1.4	5.0	0.02	0.2	4	0.001

2.2. Geometrical model and boundary condition

The whole computational area is a cube, which is 50mm×50mm×50mm, and the coal rock is 50mm×50mm×30mm, water jet is 1.8mm(diameter)×20mm(height), 50mm×50mm×20mm for air shown in Figure 1. The down boundary of coal rock is at the support of gemels. Up and down surfaces and side surfaces are in non-reflecting boundary condition, and $Y=0$ in XOZ coordinate plane, $X=0$ in YOZ coordinate plane [7].

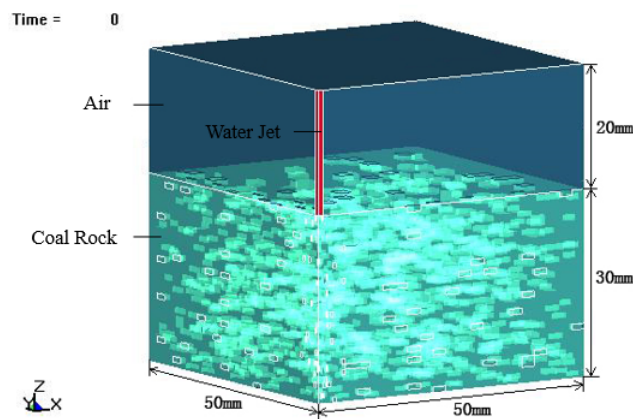


Figure 1. The overall geometrical model.

3. Orthogonal design tests

3.1. Principle of orthogonal design

All $A, B, C, \dots$ represent factors; R is the level of each factor; A_i is the level i ($i = 1, 2, 3, \dots$) of the factor A with number; X_{ij} is the value of the factor J with level i ($i = 1, 2, 3, \dots; j = A, B, C, \dots$).

Y_{ij} is the experimental result of the factor J with level i , following the normal distribution, K_{ij} is the summation of the experimental results from 1 to n , and K_{ij} is defined as:

$$K_{ij} = \sum Y_{ij} (k=1,2,3,\dots,n) \quad (8)$$

It studies the factors sensitivity by the range analysis method. When one factor is changed, it can calculate the influence of changing factors on the experimental results by keeping other factors unchanged. And then, the similar comparison of another factor is carried out. The range R_i of factor i is:

$$R_1 = \max\{K_{1j}, K_{2j}, K_{3j}, \dots, K_{ij}\} - \min\{K_{1j}, K_{2j}, K_{3j}, \dots, K_{ij}\} \quad (9)$$

3.2. Orthogonal design tests

According to the high-pressure water jet parameters feature, the water jet diameter, the water jet velocity and the abrasive concentration, are selected as the factors, as shown in Table 2. A $L_9 (3^4)$ orthogonal design is selected in the paper, and Table 3 is one of the typical $L_9 (3^4)$ orthogonal tables. Because the three parameters do not affect each other directly, it is unnecessary to consider their interaction. From the experimental results, as shown in Table 4, it can be seen that the damage in test 7 is 0.64 as the largest one, so the optimal parameters combination is A3B1C3 from the orthogonal design test.

Table 2. The factors and levels of the orthogonal tests.

Level	Factors		
	Diameter /mm(A)	Velocity /m/s ² (B)	Abrasive concentration/%(C)
1	1.0	250	0
2	1.5	400	5
3	2.0	500	10

A is the water jet diameter, B is the speed of water jet and C is the abrasive concentration. 1, 2, 3 represent each level of factors.

Table 3. $L_9 (3^4)$ orthogonal table.

Test number	A	B	C	D
1	1	1	1	1
2	1	2	2	2
3	1	3	3	3
4	2	1	2	3
5	2	2	3	1
6	2	3	1	2
7	3	1	3	2
8	3	2	1	3
9	3	3	2	1

Table 4. The Orthogonal test results.

Numbler	Factors			Damage (D)
	A	B	C	
1	1	1	1	0.34
2	1	2	2	0.54
3	1	3	3	0.53
4	2	1	2	0.57
5	2	2	3	0.61
6	2	3	1	0.49
7	3	1	3	0.64
8	3	2	1	0.51
9	3	3	2	0.61

3.3. Range analysis

The range R represents the quantitative influence of factors on experimental results. From the range analysis in Table 5, it can be seen that the influence of parameters on damage (D) is: $K_1 > K_2 > K_3$. Therefore, factor C (the abrasive concentration) is the most important factor that affects the efficiency of water jet drilling drainage, factor A (the water jet diameter) is second, and factor B (the water jet velocity) is third.

Table 5. Range analysis.

Numble	Factors		
	A	B	C
K_1	0.470	0.517	0.447
K_2	0.557	0.553	0.573
K_3	0.587	0.543	0.593
Range R	0.117	0.036	0.146
The sensitivity	$C > A > B$		

3.4. Effect curves

For further study on the influence of parameters on coal rock damage, the effect curves of damage and factors are established. The horizontal ordinate is factor level and the vertical coordinate is investigation target, as shown in Figure 2. It can be seen that there is the greatest damage in the level 3 with the water jet diameter 2.0mm, the water jet velocity 400m/s and the abrasive concentration 10%. Since there is no the above combination in the orthogonal test, it is simulated with the parameters combination. After numerical calculation, it shows that damage $D=0.67 > 0.64$, and it accords with the effect curves. Therefore, the optimal parameters of high pressure water jet drilling drainage are: the water jet diameter is 2.0mm, the water jet velocity is 400m/s and the abrasive concentration is 10%. From Figure 2, the influence rules of the parameters on the damage can be obtained. It can be seen that the damage grows with the water jet diameter and abrasive concentration increasing. And, with the water jet velocity increasing, the damage grows firstly and then decreases.

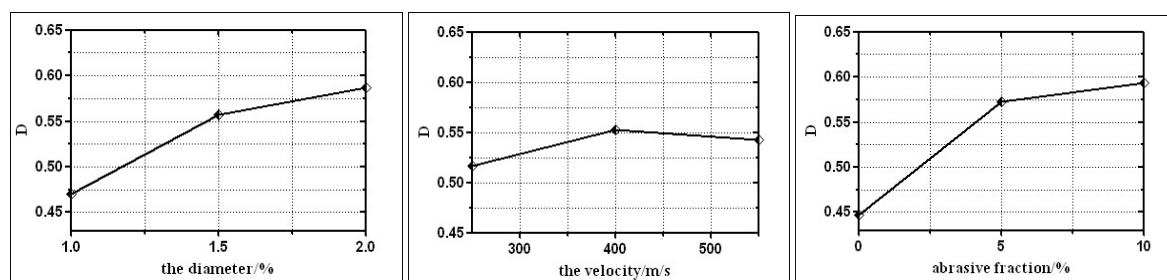


Figure 2. Effect curves of water jet parameters.

4. Conclusion

Based on an established three-dimensional damage numerical model and the orthogonal design tests, in this paper it studies the parameters optimization of coalbed gas drainage by high pressure water jet. The results show that the influences of water jet parameters on damage (D) is: the abrasive concentration > the water jet diameter > the water jet velocity. And by the orthogonal design test results and range analysis, the optimal parameters combination of high pressure water jet drilling drainage is obtained: the water jet diameter is 2.0mm, the water jet velocity is 400m/s and the abrasive concentration is 10%.

Acknowledgments

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