Dynamic and static pressure combined water injection and dust reduction technology in fully mechanized top coal caving face

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Abstract. In order to solve the problem of high dust concentration in fully mechanized top-coal caving face with difficult wetting and high dust production, a combined water injection test of "long period static pressure, alternating dynamic static pressure and static pressure in stress-affected zone" was carried out in Wangjialing Coal Mine with the engineering background of fully mechanized top-coal caving face in 20107 and combined with the previous water injection test and field actual situation. By comparing and studying the wetting and dust-reducing effects of different water injection methods and borehole spacing, the water injection process parameters suitable for this kind of coal seam are obtained. The field practice shows that the wetting radius can be increased to 3 m by the combined water injection process. In the water injection area with 5 m drilling spacing, the total dust removal efficiency can reach 57% and the respirator dust removal efficiency can reach 70%. It can effectively solve the dust hazard problem of the working face, and the effect is remarkable.

1. Introduction
With the popularization of mechanized mining in coal mines, the productivity of coal mines has been greatly improved, and the dust hazards have become increasingly prominent. Especially, the dust production in coal face can reach more than 3000mg/m3, which seriously endangers the health of workers [1-3]. Coal seam water injection is the most effective and direct means of dust control in coal face [4-8]. Coal seam water injection can pre-wet coal body before mining, increase water content of coal body, reduce flying ability of fine particle dust, change coal strength, and reduce coal dust production during mining [9-12]. The water injection effect of coal seam is directly related to the occurrence characteristics of coal seam itself. For coal seam with good porosity and wettability, the water injection effect can reach 60%~80%, but for hydrophobic coal seam with low porosity and poor wettability, the traditional water injection technology has only 10%~20% water injection effect [13-15], which can not meet the requirements of dust control, so it is urgent to solve the problem. Water injection technology in wet coal seam is studied. Through the comparative study of dynamic and static pressure combined water injection technology in non-wetting coal seam of fully mechanized caving face, the author investigates the effect of water injection and obtains the optimum parameters of water injection technology suitable for this kind of coal seam conditions.
2. General situation of Engineering
The average thickness of No. 2 coal seam in main mining face of Wangjialing Mine in 20107 is 5.8 m, the dip angle of coal seam is 2 ~4, the Pu's coefficient f of coal seam is 1.5, the porosity of coal seam is low (2.7%), the permeability is poor (the fracture is not developed basically), the wettability is poor (the hydrophobic coal seam), the dryness is fragile (the original moisture content is 1.2%), the length of working face is 230 m, the mining height is 3.0 m, air supply is 1 600-1 800 m³/min, the position wind speed of the shearer driver is 2.6 m/s, and the high-strength fully mechanized caving mining technology results in large dust production at the working face. The original dust concentration at the driver's position reaches 2 300 mg/m³, up to 3 000 mg/m³, which seriously endangers the health of the workers.

In order to control dust hazards in working face, a stage-by-stage coal seam water injection test was carried out. In the previous stage, a single long-period static pressure water injection test was carried out. The water increment in the range of 2 m borehole is only 0.5%, and the overall dust reduction efficiency is less than 10%. Because of the short injection time, the water increment in the range of 2 m borehole is only 0.8%, and the total dust reduction is only 0.8%. The efficiency is about 25%; neither of the two water injection methods can solve the dust problem in the working face. Therefore, the joint injection of "long-period static pressure and alternating dynamic and static pressure and stress-affected zone static pressure" should be carried out in 20107 working face. Water test is carried out to study the technological parameters suitable for coal seam water injection in this kind of working face.

3. Technical parameters of combined water injection
On the basis of the water injection tests carried out in the working faces of 20104 and 20105, the joint water injection tests were carried out in the working faces of 20107. According to the distance between borehole and working face, the combined water injection technology of "long-period static pressure and alternating dynamic static pressure and static pressure in stress-affected zone" is carried out sequentially. At the same time, the effects of different spacing of water injection boreholes on dust reduction, 12 boreholes (5, 10, 15 m spacing) were designed in three areas to conduct water injection tests.

![Figure 1](image-url)

**Figure 1.** Water injection modes in different stages of combined water injection

3.1. Borehole parameter design
In order to compare with the previous water injection test, the combined water injection test was carried out in the return air lane of the working face in 20107. The drilling arrangement and design parameters are the same as those of single long-period static water injection and single dynamic water injection. The drilling arrangement is shown in Figure 2. In order to investigate the effect of different spacing of water injection boreholes on dust reduction, 12 boreholes (5, 10, 15 m spacing) were designed in three areas to conduct water injection tests.
Specific design parameters of boreholes are: (1) the location of boreholes: distance from bottom plate 1.6 m; (2) borehole diameter: according to site conditions, 100 mm; (3) borehole length: 210 m; (4) borehole inclination: bedding boreholes with 4 degrees elevation; (5) borehole spacing: 5 m between 1-4 boreholes, 10 m between 5-8 holes, 15 m between 9-12 holes, 10 m between 4 holes and 5 holes. The spacing of holes m, 8 and 9 is 20 m.

![Diagram of boreholes].

**Figure 2.** Arrangement of water injection boreholes in coal seam

### 3.2. Water injection process parameters

Previously, 12 boreholes in three areas designed for long-period hydrostatic water injection in 20104 face had hydrostatic water injection pressure of 2.0 MPa, 24 hours a day, and continuous water injection for more than 60 days, thus realizing long-term immersion of coal body and increasing water content of coal body through natural infiltration; at the same time, the single hydrodynamic water injection pressure in 20105 face was 8-15 MPa, with distance between them. At the 140 m position of the working face, dynamic pressure water injection is carried out for 6 hours in the morning, and no water injection is carried out for the rest of the time, which lasts for 15 days. The purpose of high pressure permeability enhancement and hydraulic increase of macro-cracks is achieved [15-16].

Summarize the experience of two kinds of water injection methods in the early stage, and carry out joint water injection test in 20107 working face by using the same water injection equipment and water injection process parameters. After drilling, the hole is sealed immediately for hydrostatic water injection. According to the site conditions, the hydrostatic water injection pressure is 2.0 MPa, which maintains the hydraulic immersion in the hole and infiltrates the coal body naturally. When the working face is pushed to 140 m away from the borehole, the dynamic and static pressure combined water injection is carried out. The dynamic pressure water injection adopts BZW400-16 pulse pump. The injection pressure is 8-15 MPa, and the early dynamic pressure water injection is 6 hours every day. The remaining time is changed to static pressure water injection, which lasts for 15 days. The coal fracture is expanded by pulse pressure and the hydraulic infiltration passage is increased. When the working face advances to 60 m away from the borehole, it stops dynamic and static water injection and switches to full-day static water injection. At the same time, the pump station and pipeline are moved forward to carry out the next group of borehole dynamic and static water injection. When the working face advances to 30 m away from the borehole, hydrostatic water injection is carried out in the stress-affected area of the stope, and flow injection is controlled in the newly generated fracture area of the mine pressure, so as to further increase the scope of hydraulic immersion and enhance the effect of water injection [17]. When the working face advances to 5-10 m from the borehole, stop water injection and withdraw the hydrostatic water injection pipeline.
3.3. Sealing method
Drawing lessons from previous experience of coal seam water injection in working face, expandable sealing device is used to seal holes, which requires the depth of sealing device into the borehole to be 8-10 m. (1) The outer diameter of the sealing device is 90 m, matching the drilling requirement of 94 mm drill bit, and the free expansion outer diameter is not less than 110 mm; (2) the effective sealing length is 1.5-2.5 m; (3) the rated working pressure is 16 MPa; and (4) the lowest sealing expansion pressure is less than 2.0 MPa.

4. Analysis of combined water injection effect
During the water injection cycle in the past two months, the sealing device has good sealing and no water running phenomenon. After water injection statistics, the water injection volume of each injection hole is 300-400 m$^3$, the average water injection volume of single hole is 361.8 m$^3$, and the daily water injection volume is 8-12 m$^3$, which achieves good results. When the theoretical water injection volume of single hole is calculated by 4% of total water content and 1% increase of water content, when the distance between boreholes is 5, 10 and 15 m, the theoretical water injection volume of single hole is shown in table 1.

| Borehole spacing /m | Theoretical water injection rate of single hole /m$^3$ | Water content increased by 1% | Total moisture reached 4% |
|---------------------|------------------------------------------------------|-----------------------------|--------------------------|
| 5                   | 109.6                                                |                             | 255.8                    |
| 10                  | 219.2                                                |                             | 511.6                    |
| 15                  | 438.4                                                |                             | 1023.2                   |

By calculating the theoretical single hole water injection volume, the theoretical water increment can reach more than 1% when the borehole spacing is 5 m and 10 m, but when the borehole spacing is 15 m, the current water injection test can not meet the requirements. At the same time, the theoretical calculation results also reflect that the actual water injection volume of single hole is larger than the theoretical water injection volume under the condition that the distance between boreholes is 5 m and 10 m, and the expected effect of water injection is better.

4.1. Analysis of Water Increment in Coal
In order to investigate the effect of hydrodynamic and hydrostatic water injection in return air roadway in 20107 working face, the wetting radius of hydrodynamic and hydrostatic water injection was determined by taking drilling cuttings to test the water increment of coal body.

![Figure 3. Sampling drilling arrangement](image)
Drilling cuttings are sampled around the No. 6 water injection hole in the return air lane and at the working face. The layout of sampling boreholes is shown in Figure 3.

After sampling and testing, the nearer the water content of coal is to the water injection hole, the higher the water content is. The total water content is above 2.0% in the 3 M range of the water injection hole, the increment of water content is 1.03%~1.37%, and the average is 1.20%. The water injection effect is better. When the distance from the borehole is more than 3 m, the average increment is about 0.5%, and the water content increases relatively less. The variation curve of water content is shown in Figure 4.

![Figure 4. Water content variation curve at different distances from water injection boreholes](image)

Along the direction of the working face, the water content in the return air side of the working face is higher, up to 2.46%. Within the range of 110 m from the return air side, the total water content in the coal body is above 2.0%, and the water injection effect is better; while in the coal body near the intake side, the water increase is less, which may be due to the insufficient depth of the water injection drilling hole, leading to the water injection effect in the coal seam on the intake side. Poor, the water content curve of coal body is shown in Figure 5.

![Figure 5. Water content change curve of coal body along working face direction](image)

Compared with the original water content (1.2%) of the 20107 working face, the average water increment is 1.2% in the 3 M range of the water injection hole, and the wettability of the coal seam is greatly improved in this range, and the water injection effect is better. Therefore, in view of the characteristics of low porosity, poor wettability, low original water content and high dust production of the coal seam, combined with the current water injection effect of coal seam, the effective wetting radius of coal dust water injection is about 3 m, which can provide design basis for joint water injection in the next working face.
4.2. Analysis of Dust Control Effect

Dust concentration tests were carried out in the non-water injection area, the water injection area with 5 m borehole center spacing, the water injection area with 10 m borehole center spacing and the water injection area with 15 m borehole center spacing, respectively, to compare the effect of water injection and dust reduction. The dust concentration test results are shown in Table 2.

| Test location          | Driver position | 10 m downwind side of coal machine | scaffold moving and coal releasing | Remarks                      |
|------------------------|-----------------|-----------------------------------|-----------------------------------|-----------------------------|
|                        | total dust      | respirable dust                   | total dust                        | respirable dust             |
| Unwatered area         | 621.4           | 198.2                             | 467.3                             | 156.6                       | 419.1 134.5                  | Cut coal with adverse wind and spray normal |
| 5 m interval area      | 264.6           | 59.3                              | 165.5                             | 46.5                        | 159.8 42.3                   |                                           |
| 10 m interval area     | 371.5           | 132.5                             | 298.4                             | 98.8                        | 195.2 78.6                   |                                           |
| 15 m interval area     | 503.1           | 175.4                             | 356.8                             | 127.4                       | 317.6 113.2                  |                                           |

According to the test data of dust concentration in the face of upwind coal cutting, the dust concentration is relatively low in the area with 5 m hole spacing, the driver's position is 264.6 mg/m³, the downwind side of the coal machine is 165.5 mg/m³, and the shifting frame is 159.8 mg/m³. The respirable dust can be controlled within 60 mg/m³. Compared with the area without water injection, the areas with combined water injection are lower. The dust effect is remarkable.

Through comparison, it can be seen that the combined injection of "long-period static pressure and alternating static pressure with static pressure in stress-affected zone" has the best effect in the area of 5 m interval between boreholes. The total dust-reducing efficiency is over 57%, the respirator dust-reducing efficiency is about 70%, and the overall average dust-reducing efficiency of the three water-injection areas can reach 45%. The process has achieved good results.

In a word, compared with the effect of single long-period hydrostatic injection and single hydrodynamic injection, the efficiency of combined injection has greatly improved. The water increment has increased from 0.5% of single long-period hydrostatic injection and 0.8% of single hydrodynamic injection to 1.2% respectively, and the overall efficiency of dust reduction has increased from 10% and 25% to 45%, respectively. The effect is remarkable. For coal seams with similar conditions, the water injection method and technology can achieve short-term and high-efficiency water injection and effectively reduce the dust problem in the working face.

Under the present technological parameters, the wetting radius obtained by this test is 3 m, so the optimum drilling spacing is 6 m and the drilling quantity is large. If the drilling quantity needs to be reduced and the water injection can be guaranteed to achieve better results, the high-pressure hydraulic cutting can be used to increase the wetting radius, reduce the drilling cost, and at the same time, the hydraulic cutting has low porosity. Rate coal seam has a good permeability enhancement, which is more helpful for coal dust water injection.

5. Conclusion

According to the previous water injection test and the coal seam condition of the target working face, a combined technology of "long-period static pressure and alternating dynamic static pressure and static pressure in stress-affected zone" was designed to realize high-efficiency water injection in short time.

By comparing the effect of water injection with that of single long-period hydrostatic injection and single hydrodynamic injection, combined water injection can achieve the purpose of soaking coal body for a long time and increasing cracks under high pressure at the same time, and the effect of dust reduction is obviously better than that of single hydrostatic injection and single hydrodynamic injection.

Practice shows that the water increment can reach 1.2% within 3 m of borehole, and the overall dust removal efficiency can reach more than 57% in 5 m of borehole spacing area, and the average dust
removal efficiency can reach 45% in three areas. The water injection technology can greatly improve the water injection effect of this kind of coal seam.

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