Research on the Treatment of Coal Washing Wastewater by Pressureless Filtration Technology in Yidong Preparation Plant

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Abstract. This article takes the coal washing wastewater of the Yidong Coal Preparation Plant as the research object. With the change of the raw materials to be washed, the effect of its existing treatment process is not ideal. The multi-factor response surface analysis of the four factors of PAC dosage, PAM dosage, stirring speed and stirring time was carried out, and the optimal dosage and operating parameters were obtained as PAC dosage 30.52 mg/L, PAM dosage The dose is 20.75 mg/L, the stirring speed is 407 r/min, and the stirring time is 82.5 s. Through the field industrial test, the application effect and rationality of the pressureless filtration technology are verified.

1 Introduction

Coal washing is an indispensable link in the coal production, and it is the basis and premise for achieving clean coal utilization, energy saving, emission reduction and sustainable development. The main coal preparation method adopted internationally is wet coal preparation. According to the relevant provisions of the current national standard [1-4], the coal preparation plant should realize the recovery of the coal washing wastewater, and the closed circuit of the washing water should not be discharged. At the same time, the production wastewater in the plant should be collected and incorporated into the coal washing wastewater treatment system Recycling after unified purification is an effective measure for environmental protection and green production. The existing thickener of Shaanxi Yidong Mining Co., Ltd.’s coal preparation plant as a slime water treatment process has an effluent suspended solids concentration of 300 mg/L ~ 500 mg/L. Meet the actual production requirements. To this end, this paper proposes the use of pressureless filtration technology as an improved process of slime water treatment in the coal preparation plant. The four main factors of the PAC dosage, PAM dosage, stirring speed and stirring time that affect the concentration of suspended solids in the effluent are Theoretical analysis, and based on the actual test results, the feasibility of pressureless filtration technology is demonstrated.
2 Determination of characteristics and indicators of coal washing wastewater

2.1 Features of coal washing wastewater and raw water quality

Wet coal preparation requires a large amount of water [5]. Generally, the circulating water used for the production of tons of coal in the heavy medium separation process is $3 \text{ m}^3$ ~ $5 \text{ m}^3$, of which the new water per ton of coal does not exceed $0.1 \text{ m}^3$. After the washing process, these waters contain a lot of fine particles and become coal washing wastewater. The main pollutants in coal washing wastewater are: suspended solids, oils, organic chemicals, etc., which are measured by sampling the water source of Yidong Coal Preparation Plant. Table 1 shows the raw water quality.

| category          | pH       | temperature/°C | Suspended matter concentration/\text{mg·L}^{-1} | Cod/\text{mg·L}^{-1} | ζ Electric potential/m V |
|-------------------|----------|----------------|--------------------------------------------|----------------------|---------------------------|
| Value             | 6.5~8.5  | 10~30          | 60 000~100 000                              | 20 000~40 000        | -10~20                    |

2.2 Technology status

The goal of coal washing wastewater treatment is mud water separation. Currently, the most commonly used coal washing wastewater treatment technology is coagulation and sedimentation technology, which usually uses two or more agents in combination to coagulate and then flocculate. Commonly used coal washing wastewater treatment devices include concentrators, sedimentation towers, sedimentation tanks, etc. The most commonly used is the concentrator. Its main treatment process is "coal washing wastewater $\rightarrow$ concentrator $\rightarrow$ recycle water reuse (sludge pressure filtration)", Yidong Coal Preparation Plant adopted the above conventional treatment process. In addition, there are electric treatment technology, microwave treatment technology and microbial treatment technology [6].

The pressureless filtration technology was developed on the basis of a five-year research and development program conducted by the University of South Australia in cooperation with industrial partners from food, beverage and manufacturing [7]. Its working principle is: It is filtered by the hole filter screen, the suspended matter in the raw water is trapped on the filter screen, and the clean water flows into the clean water tank below through the filter screen; at the same time, it consists of two sets of "double-acting" spray guns with high water pressure and low flow rate that use the equipment's own water production. The cleaning mechanism reciprocates along the plane of the filter screen. The lower group of spray guns removes the substances trapped by the filter from the mesh holes, and the upper group of spray guns sweeps the removed materials from the surface of the filter and collects them in the recovery box.

The particle size of pollutants that can be treated by this process is between mechanical filtration and microfiltration. The coal industry currently uses this technology for clean coal recovery [8]. This article is a theory and experiment of using this technology for coal washing wastewater treatment. To explore, we must first determine the judgment index of the experiment.
2.3 Main judgment indicators of the test

According to the relevant provisions of the current National Standards of the People's Republic of China, the water quality standards for coal preparation water include suspended solids concentration, suspended solids particle size, pH value, and total hardness. Because the pressureless filtration technology mainly treats the raw water by physical and chemical methods, the pH value and total hardness of the raw water are less affected and the same agent is added to the concentration process used by the coal preparation plant, and the difference in pH value and total hardness of the effluent is small. And because the filter pore size is not more than 300 μm, and the particle size of the effluent suspended solids meets the requirements of the specifications, combining the above-mentioned characteristics of raw water quality, the determination of suspended solids concentration is the main judgment index of this test.

3 Experimental research

3.1 Small-scale pilot test research

3.1.1 Direct filtration test

In this test, the water pH was 7.82, the water temperature was 25.7 °C, and the suspended matter was 8.8 × 10^4 mg/L. Through the minimum dosage test, the minimum dosage of PAC was determined to be 30 mg/L, and the minimum dosage of PAM was 7.5 mg/L. Through a single factor test, the optimal PAC dosage range was determined to be 5 mg/L ~ 30 mg/L, and the optimal PAM dosage range was 10 mg/L ~ 35 mg/L.

According to the test results of the best dosage, choose the best PAC dosage of 20 mg/L and the best PAM dosage of 15 mg/L. The test determines that the optimal stirring speed range is 400 r/min ~ 800 r/min; During the test of the optimal mixing time, it was found that the floc was broken when the mixing time exceeded 300 s. According to the actual production needs, the optimal mixing time ranged from 10 s to 150 s. The single factor analysis test results are shown in Table 2 ~ Table 5.

3.1.2 Response surface analysis of coagulation filtration test

response surface analysis method was used to analyze 4 factors (PAC dosage-x₁, PAM dosage-x₂, stirring speed-x₃, stirring time-x₄) to 3 response values (75 μm filter Influence of effluent suspended matter concentration-y₁, 150 μm filter effluent suspended matter concentration-y₂, 300 μm filter effluent suspended matter concentration-y₃).

| Filter aperture/μm | PAC /mg/L |
|-------------------|-----------|
|                   | 5         | 10        | 20        | 30        | 40        | 50        |
| 300               | 114.1     | 95.6      | 65.1      | 108.3     | 160.2     | 271.9     |
| 150               | 111.8     | 93.7      | 64.8      | 107.8     | 159.7     | 269.7     |
| 75                | 101.9     | 90.8      | 62.3      | 105.3     | 157.2     | 247.8     |
Table 3. Test results of the optimum dosage range of PAM.

| Filter aperture/μm | 5  | 7.5 | 10 | 15 | 20 | 30 | 40 |
|-------------------|----|-----|----|----|----|----|----|
| 300               | >1000 | 416.6 | 219.9 | 147.8 | 121.2 | 129.3 | 351.8 |
| 150               | >1000 | 409.4 | 219.4 | 147.3 | 118.5 | 114.8 | 345.5 |
| 75                | >1000 | 397.7 | 208.3 | 103.1 | 95.1 | 95.4 | 302.5 |

Table 4. Test results of the optimum mixing speed range.

| Filter aperture/μm | 100 | 200 | 300 | 400 | 500 | 700 | 900 |
|-------------------|-----|-----|-----|-----|-----|-----|-----|
| 300               | 470.4 | 284.1 | 209.9 | 139.1 | 127.8 | 123.8 | 170.8 |
| 150               | 463.6 | 257.0 | 192.7 | 138.8 | 123.4 | 122.9 | 167.6 |
| 75                | 392.5 | 169.6 | 158.0 | 125.9 | 122.9 | 120.8 | 160.1 |

Table 5. Test results of the optimum mixing time range.

| Filter aperture/μm | 10 | 30 | 90 | 150 | 210 | 300 | 600 |
|-------------------|----|----|----|-----|-----|-----|-----|
| 300               | 231.1 | 139.5 | 110.1 | 92.4 | 63.4 | 51.1 | 51.8 |
| 150               | 230.0 | 137.4 | 109.7 | 96.6 | 63.3 | 50.4 | 49.3 |
| 75                | 184.4 | 126.6 | 105.0 | 97.1 | 61.4 | 50.2 | 46.4 |

Based on the aforementioned single-factor test results, determine the level of quadratic regression design factors, see Table 6 for details.

Table 6. Variation range of various factors.

| factor                      | NO. | Level |
|-----------------------------|-----|-------|
| PAC dosage/mg/L             | $x_1$ | -2 | -1 | 0 | 1 | 2 |
| PAM dosage/mg/L             | $x_2$ | 5 | 15 | 25 | 35 | 45 |
| Stirring speed/r·min        | $x_3$ | 100 | 200 | 300 | 400 | 500 | 700 |
| Stirring time /s            | $x_4$ | 10 | 35 | 60 | 85 | 110 | 140 |

The design extracted a total of 22 valid tests, of which the central point test was repeated 7 times, $r = 2.0$. The detailed test results are shown in Table 7.

Table 7. Design and results of RSM.

| NO. | $x_1$ | $x_2$ | $x_3$ | $x_4$ | $y_1$ | $y_2$ | $y_3$ |
|-----|------|------|------|------|------|------|------|
| 1   | -1   | -1   | -1   | 1    | 77.3 | 81.9 | 83.0 |
| 2   | 1    | 1    | -1   | 1    | 78.2 | 91.3 | 92.3 |
| 3   | -1   | 1    | -1   | -1   | 161.7 | 208.1 | 238.9 |
| 4   | 0    | 0    | 0    | 0    | 73.1 | 77.1 | 85.4 |
| 5   | 0    | -2   | 0    | 0    | 465.1 | 489.5 | 492.8 |
| 6   | 0    | 0    | 0    | 0    | 0    | 170.3 | 171.3 | 71.8 |
| 8   | 1    | 1    | 1    | -1   | 178.9 | 195.6 | 201.0 |
| 9   | 1    | -1   | 1    | -1   | 262.6 | 284.1 | 292.0 |
| 10  | 0    | 0    | 2    | 0    | 118.3 | 121.3 | 157.9 |
| 11  | 1    | -1   | -1   | -1   | 153.9 | 155.2 | 156.4 |
| 12  | 2    | 0    | 0    | 0    | 60.4 | 65.8 | 67.7 |
| 13  | 1    | -1   | 1    | 1    | 365.1 | 383.1 | 383.8 |
| 14  | -1   | -1   | 1    | 1    | 78.6 | 79.1 | 79.9 |
Use quadratic polynomials for fitting to establish regression equations, see equation (1) ~ equation (3).

\[
y_1 = 73.21 + 20.51x_1 - 39.12x_2 + 16.20x_3 - 17.59x_4 - 33.31x_1x_2 \\
+ 28.22x_1x_3 - 0.3312x_1x_4 - 17.29x_2x_3 - 14.22x_2x_4 \\
+ 15.13x_3x_4 - 2.11x_1^2 + 54.93x_2^2 + 7.19x_3^2 + 11.46x_4^2
\]  

\[
y_2 = 77.44 + 22.42x_1 - 36.99x_2 + 12.95x_3 - 23.59x_4 - 38.18x_1x_2 \\
+ 30.03x_1x_3 - 2.36x_1x_4 - 21.10x_2x_3 - 18.34x_2x_4 \\
+ 16.79x_3x_4 - 2.71x_1^2 + 58.502x_2^2 + 8.26x_3^2 + 17.94x_4^2
\]  

\[
y_3 = 81.21 + 22.07x_1 - 35.60x_2 + 14.19x_3 - 26.83x_4 - 39.36x_1x_2 \\
+ 32.26x_1x_3 - 3.26x_1x_4 - 23.19x_2x_3 - 20.17x_2x_4 \\
+ 18.87x_3x_4 - 3.92x_1^2 + 57.53x_2^2 + 12.22x_3^2 + 18.27x_4^2
\]

The response surface analysis chart drawn by the regression equation can directly reflect the influence of various factors on the response value, as shown in Figures 1 to 3.

| NO. | x₁ | x₂ | x₃ | x₄ | y₁ | y₂ | y₃ |
|-----|----|----|----|----|----|----|----|
| 15  | 0  | 0  | 0  | 0  | 74.6| 77.9| 81.9|
| 16  | 0  | 0  | 0  | -2 | 172.0| 234.4| 248.8|
| 17  | 0  | 0  | 0  | 0  | 72.4| 79.4| 81.2|
| 18  | 0  | 0  | 0  | 0  | 71.6| 73.3| 77.1|
| 19  | 0  | 2  | 0  | 0  | 125.0| 140.7| 141.9|
| 20  | -1 | 1  | 1  | 1  | 135.3| 148.7| 150.8|
| 21  | 1  | 1  | -1 | -1 | 155.7| 185.0| 195.6|
| 22  | 1  | 1  | 1  | 1  | 84.4| 97.2| 101.1|

Fig. 1. Response surface graph to 75 μ m. Fig. 2. Response surface graph to 150 μ m. Fig. 3. Response surface graph to 300 μ m.

It can be seen from Figures 1 to 3 that the dosage of PAM significantly affects the removal effect of suspended matter, and the dosage of PAC has little effect on the removal effect, indicating that the main effect of the dosage of PAM is greater than the dosage of PAC. In the pressureless filtration process, the size of the flocs directly affected by the dosage of PAM is the main factor of the removal effect. The addition of PAC is mainly to accelerate the reaction speed, and the stirring speed and time are the secondary factors that affect the removal effect.

3.2 Verification of response surface analysis results

Solve the concentration of suspended matter in the effluent of different filters by quadratic regression fitting equation to obtain the optimal dosage and operating parameters: \( x_1 = \)
30.52 mg/L, $x_2 = 20.75$ mg/L, $x_3 = 407$ r/min, $x_4 = 82.5$ s. Under this condition, the concentration of 75 μm, 150 μm, and 300 μm effluent suspended in the quadratic regression fitting equation is respectively 34.46 mg/L, 42.33 mg/L, 42.85 mg/L. According to the above optimal dosage and optimal operating parameters, the verification test was carried out. The concentration of 75 μm, 150 μm, and 300 μm filter effluent suspended solids was 35.58 mg/L, 42.99 mg/L, and 43.13 mg/L, respectively. The concentration of water suspended solids obtained by the regression equation is very close to the experimental value, the error is less than 1%, and the fit is good.

### 4 Industrial test research

According to the signed test results, the optimal PAC dosage was 30.52 mg/L, the optimal PAM dosage was 20.75 mg/L, and the optimal response G value was 700 s⁻¹ ~ 750 s⁻¹. The GT value is 25 000 ~ 62 000. The industrial test comparison of the effluent quality of the pilot plant in different time periods is shown in Table 8. Table 8 Water quality of inlet and outlet of pilot equipment in different periods.

| NO. | original /mg·L⁻¹ | After filtering/mg·L⁻¹ | NO. | original /mg·L⁻¹ | After filtering/mg·L⁻¹ |
|-----|------------------|-----------------------|-----|------------------|-----------------------|
| 1   | 72 493           | 102.92                | 1   | 74 173           | 182.08                |
| 2   | 75 796           | 119.28                | 2   | 69 510           | 188.13                |
| 3   | 95 741           | 128.42                | 3   | 87 227           | 223.34                |
| 4   | 85 629           | 115.37                | 4   | 95 137           | 234.81                |
| 5   | 65 156           | 82.76                 | 5   | 79 582           | 220.87                |

In order to facilitate the comparison of experimental effects and remove the secondary influencing factors, under the condition that only the main influencing factors PAC dosage and PAM dosage are considered, the optimal PAC dosage is 30.52 mg/L and the optimal PAM dosage is 20.75 mg/L dosing, the concentration of suspended matter in the effluent of the pressureless filter is 80 mg/L ~ 130 mg/L; according to the PAC dosage of 10 mg/L and PAM dosage of 25 mg/L in the Yidong Coal Preparation Plant Dosing, the concentration of the suspended solids in the effluent of the pressureless filter is 180 mg/L ~ 240 mg/L; the test results are better than the concentration of 300 mg/L ~ 500 mg/L in the effluent of the existing thickener in the Yidong Coal Preparation Plant Under the best conditions or the existing conditions of the coal preparation plant, the pressureless filtration process is superior to the existing coal washing wastewater treatment process, and can be used as a retrofit implementation plan to meet the actual production of circulating water.

### 5 Conclusion

1) Through single factor test and multi-factor response surface analysis, the optimal dosing amount and optimal operating parameters of the coal washing wastewater crow filtration process of Yidong Coal Preparation Plant are as follows: PAC dosage 30.52 mg/L, PAM dosage 20.75 mg/L, stirring speed 407 r/min, stirring time 82.5 s.

2) Through industrial experiments, according to the best and the PAC and PAM dosages of Yidong Coal Preparation Plant, the concentration of suspended matter in the effluent of
the pressureless filter is 180 mg/L ~ 240 mg/L; the effluent quality is excellent. The concentration of suspended solids in the effluent of the existing concentrator in the YIDONG Coal Preparation Plant can meet the needs of actual production circulating water, verify the rationality of experimental analysis and theoretical research, and determine the superiority of the pressureless filtration process for the treatment of coal washing wastewater.

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