Application Research on Pulse Continuous Discharge-type Interference Bed Separator

Xin Liu1,2,*
1Tiandi (Tangshan) Mining Technology Co. Ltd., Tangshan, 063012, China;
2Hebei Coal Washing Engineering Technology Research Center, Tangshan, 063012, China
*liuxin@cctegts.cn
*Corresponding author’s e-mail: 598640408@qq.com

Abstract: In view of the problems of the traditional interference bed separator, such as hole plugging, wall material accumulation and discontinuity of tailings discharge, the mechanical structure of the separator is improved and optimized, and a forced discharge jammer is added, rotating at a constant speed in a flow field at a low speed. According to the laboratory model, the flow field distribution in the main tank of the separator is numerically analyzed to determine the rotational speed and range of the forced discharge jammer, the experiments of slime screening, disturbing bed separation and coal slime floating and sinking are carried out on the 1/3 coking coarse coal slime. The analysis and experimental results show that the possible deviation of Pulse Continuous Discharge-type Interference Bed Separator on 1 ~ 0.25mm narrow-grained coarse slime is 0.146, indicating that the separation effect is better.

1. Introduction
The separation of coarse coal slime is an important link in coal preparation production, and its separation effect directly affects the overall technical index of coal preparation plant, and is an important link in coal preparation production. As the main equipment for the separation of coarse coal slime, the traditional Interference Bed Separator has been widely used in recent years. However, due to its own structural characteristics, problems such as hole plugging, wall sidewall accumulation and discontinuity of tailings discharge often occur, which not only affects the yield and quality of slime products, but also delays the normal production of coal preparation plant.

In view of the above problems, considering various factors, the existing Interference Bed Separator mechanical structure is improved and optimized, and a forced discharge mechanism is added in the tank near the top of the Water Distribution Board, the servo motor drives the forced discharge mechanism through the coupling to rotate at a low uniform speed, and the pressure vessel and discharge port under the water distribution board form a circulation system. The squeeze valve and solenoid valve jointly control the discharge volume and discharge frequency of the sorting machine to achieve an even discharge effect. It can not only prevent the accumulation of materials near the underflow opening and the wall of the vessel, and realize a smooth discharge to ensure the sorting effect, but also reduce the number of discharge openings, greatly reduce the cost of large sorting machines, and improve the market competitiveness.
2. Operating principle of Pulse Continuous Discharge-type Interference Bed Separator

The density and size of coal slime particles are different, so the settling velocity is different in the same rising flow\cite{1}. The settling velocity of high density and coarse particles is high, and that of low density and fine particles is low. Under a certain velocity of rising water flow, the particles will sink when the settling velocity is larger than the rising velocity of water flow, and float when the settling velocity is smaller than the rising velocity of water flow. Thus, the separation of multi-component Particle Group by density and granularity is realized. When the settling velocity of the particles is equal to the rising velocity of the current, they will be suspended and remain in the fluid. The particles in the fluid will accumulate and gradually form a dense layer of suspended particles with a certain density, the suspended particles in the dense layer are in dynamic equilibrium due to the disturbance of water flow. If the particle size of the particle group is equal or within a narrow range of particle size, the sedimentation speed of the particles depends on the density of the particles, and particles of different densities will be sorted according to density under the action of a certain rising water flow \cite{2}.

With the popularization of Interference Bed Separator, the requirements for the stability of particle movement and flow field distribution in the main tank are becoming higher and higher. At the same time, as the stability of the flow field is closely related to the discharge of the rising water and the discharge system of the tailings, with the increase of the processing area of the separator, there will be accumulation of tailings farther away from the tailings valve and located at the wall and other places in some cases, which may cause clogging of the water distribution plate. The structure diagram of Pulse Continuous Discharge-type Interference Bed Separator is shown in Figure 1. The working principle is as follows: The feed material is fed tangentially into the main tank body of the sorting machine through the feeder, and the top water is pumped into the pressure chamber at the bottom of the sorting machine by the clean water pump through the water distribution pipe, and then the upward water flow is generated in the main tank body of the sorting machine through the water distribution plate distributor. The particles in the feed that have a settling velocity equal to the rising water flow rate are suspended in the main tank to form a dense layer of suspended particles with a certain density. The density of the dense layer can be controlled by adjusting the flow rate of rising water. When it reaches a steady state, the particles whose settling velocity is lower than the rising flow velocity will enter the overflow and become the concentrate, while the particles whose settling velocity is higher than the rising flow velocity will enter the bottom flow through the bed and become the tailings, so as to achieve separation\cite{3-4}.

![Figure 1. Structure diagram of Pulse Continuous Discharge-type Interference Bed Separator](image)
3. Flow field distribution law in the main tank

3.1. Model and parameters

In this paper, a small-scale pulsed continuous discharge type interference bed separator is taken as the simulated object. The main parameters are shown in Table 1, and the cross-section of the experimental model is shown in Figure 2. According to its working principle, the Eulerian Model in FLUENT is chosen to simulate the flow field distribution of the separator. Firstly, the boundary conditions of the computational domain are determined, including the entrance conditions, the exit conditions and the wall treatment, etc.[5]. The bottom outlet is treated as wall, the wall is set as standard wall, the top water inlet is set as velocity inlet, the overflow outlet is set as pressure outlet, and the bottom outlet is set as velocity outlet.

| Name                                 | Structural parameters | Parameter value |
|--------------------------------------|-----------------------|-----------------|
| Pulse Continuous Discharge-type Interference Bed Separator | Diameter/mm          | 600             |
|                                      | Height/mm             | 2450            |
|                                      | Thickness/mm          | 8               |
| Water distribution board distributor  | Number of holes       | 96              |
|                                      | Pore Diameter/mm      | 5               |
|                                      | Open Ratio/%          | 0.61            |
|                                      | Scraper size/mm       | 180x172x3       |
| Forced discharge jammer              | Number of scrapers/piece | 4 ~ 6         |
|                                      | Rotational Speed/(r/min) | 0.1 ~ 1     |

Figure 2. Sectional view of the experimental model
3.2. Numerical simulation

The axial velocities of the Cross sections of the experimental model, that is, X=0 and Y=0, are shown in Figure 3. On the right side of the scale shown in Figure 2, the bottom plate of the pressure chamber is 0 mm. At the 0mm position shown in the scale on the right side of Figure 2 is the bottom plate of the pressure chamber. The rising water enters the pressure chamber from the protruding position on the bottom side of X=0. The flow rate is set to 20m³/h. During the simulation, the bottom flow port is set to Normally open, evenly discharged at a flow rate of 2 m³/h. The upward flow from the self-pressure chamber into the main tank through the distributor can not be kept completely uniform, resulting in uneven flow field in the main tank. As can be seen from Figure 3, the area where the nozzles of the water distribution plate are dense is bright blue, that is, the velocity of the flow field is vertically upward. When the scraper speed is 1r/min, the flow field near the tank wall basically moves upward at a speed of 1.43m/s, and most of the middle area sinks at a speed of 1.88m/s, indicating that there is a large sinking speed near the wall of the feed pipe, and the overflow can not reach the top of the tank at the inner layer, and then move to the outer circle and flow out of the tank. When the rotating speed of the scraper is 0.2 r / min, the local sinking velocity appears near the wall of the 1000-1600 mm section in the tank, which has little influence on the overall flow field distribution. Figure 4 is a graph of the radial variation of axial velocity of different heights in the sorter under the condition of 0.2r/min.

![Figure 3. Axial velocity cloud at different blade speeds](image-url)
According to the simulation results of the flow field distribution in the separator, when the rotating speed of the scraper of the forced discharge Jammer is above 0.5 r/min, the axial speed difference between the area near the wall and the middle area of the tank increases with the increase of the speed. Therefore, it is unreasonable to set the interference layer from the water distribution plate to the overflow according to the point of view that the area with the highest floating and sinking speed is the interference layer. Therefore, in the practical application, when the speed of the scraper is 0.2 r/min as the initial setting value, then fine-tune according to the actual observation.

4. Introduction of the test system

4.1. Control objects
The control object of the test system is the experimental device of pulse continuous discharge type sorting. The flow chart of the device is shown in Figure 5. The system includes the automatic control system of rising water flow and the automatic control system of bed density. The rising water flow automatic control system is to install the flowmeter and pressure gauge on the rising water main pipeline to detect the flow value and pressure value, and to form a closed-loop control loop with the flowmeter and the Electric Butterfly Valve, according to the deviation between the set value of flow rate and the measured value of flow rate, the valve opening of the top water pipe can be adjusted automatically by PLC operation, so that the measured value of flow rate can follow the set value of flow rate, thus the aim of controlling the rising water flow stability of the equipment can be achieved. The automatic control system of bed density measures bed density by means of a densitometer installed at a certain depth of bed. It forms a closed-loop control loop of the density meter and the tailings pulse discharge system, and then automatically controls the servo motor speed and pinch valve opening through the PID closed-loop loop according to the deviation between the set value of the...
density and the measured value, so that the density detection value can track the flow setting value in real time, so as to achieve the purpose of controlling the bed density and tailings discharge.

Figure 5. Flow chart of the device

4.2. System hardware composition
The control system hardware of Pulse Continuous Discharge-type Interference Bed Separator consists of touch screen, PLC, servo motor, electric pinch valve, solenoid valve, densitometer, pressure transmitter, electromagnetic flowmeter and Electric Butterfly Valve. Among them, the servo motor is connected with the forced discharging mechanism through a coupling, the electric pinch valve and the electromagnetic valve are connected with the bottom discharge port, and the electromagnetic flowmeter is installed on the vertical rising water pipeline, and the Electric Butterfly Valve and the pressure transmitter are installed on the ascending horizontal pipeline.

Through the analysis of the requirements and principles of the control system, the systems are all controlled by analog quantities. From the point of view of satisfying the requirements of the system and considering the economic cost, the Siemens SMART series PLC is selected as the controller and an external analog input/output module is connected. The touch screen selects MCGS configuration software as the system monitoring equipment, and the control interface is shown in figure 6, which is convenient for real-time monitoring and timely adjusting the system running state.

Figure 6. Touch screen control interface
4.3. System software design
In the Pulse Continuous Discharge-type Interference Bed Separator control system, PLC is both a communication interface and a controller, and the control tasks of the system are completed by the PLC\(^6\). The control system program is written in STEP 7. The main program includes data acquisition, logic operation, data storage, PID algorithm operation and so on. It adopts linear programming, all instructions are in one instruction block, the program structure is intuitionistic and clear\(^7\)\(^-\)\(^9\).

In order to realize the accurate control to the rising water flow and the separation density, the PLC is used to carry on the PID adjustment to the analog quantity, the PID control has the strong flexibility and the adaptability, various varieties of PID control and improved control methods can be used to realize the parameter self-tuning of the controller\(^10\)\(^-\)\(^11\). This control system realizes the self-tuning of rising water flow and bed density by adjusting the loop gain P and integration time T. The parameters can be set in real time on the control interface, which is intuitive and convenient.

As a control system monitoring device, the touch screen needs to be configured under the WinCC configuration software, and complete the production of the Pulse Continuous Discharge-type Interference Bed Separator's outline structure, the establishment of variables, the setting of attributes, and the connection of variables with the PLC on the WinCC configuration interface.

5. Experimental research

5.1. Raw coal screening experiment
In this experiment, Liyazhuang 2 # 1 / 3 coking coarse coal slime of Shanxi Province was used as the experimental object, and the screening experiment was carried out according to GB/T477-2008 Coal Screening Test Method, the results are as Table 2. The raw coal ash content of the coal slime is low, only 14.91%, and with the decrease of the slime size, the washability is better. The main particle size distribution of coal slime is 0 ~ 2mm, of which the coarse coal slime with a diameter of 1 ~ 0.25mm accounts for nearly 30% of the original coal sample, and the ash content is close to the ash of the full-grained slime. Therefore, this part of coarse slime is taken as the feeding object of this washing.

| Granularity /mm | Yield /% | Ash content /% | Positive cumulative yield /% | Positive cumulative ash % | Negative cumulative yield /% | Negative cumulative ash % |
|-----------------|----------|----------------|-----------------------------|--------------------------|-----------------------------|--------------------------|
| +3              | 12.23    | 21.66          | 12.23                      | 21.66                    | 100.00                      | 14.91                    |
| 3 ~ 2           | 7.54     | 18.71          | 19.77                      | 20.53                    | 87.77                       | 13.97                    |
| 2 ~ 1           | 21.68    | 15.56          | 41.45                      | 17.93                    | 80.23                       | 13.53                    |
| 1 ~ 0.25        | 27.96    | 14.89          | 69.41                      | 16.71                    | 58.55                       | 12.77                    |
| -0.25           | 30.59    | 10.84          | 100.00                     | 14.91                    | 30.59                       | 10.84                    |
| Total           | 100.00   | 14.91          |                            |                          |                             |                          |

5.2. Interference bed experiment and sorting effect
A sorting experiment was carried out on coarse coal slime with a particle size of 1-0.25mm in the raw coal. According to the numerical simulation results, the initial top water flow was set to 20m\(^3\)/h, and the forced discharge jammer speed was set to 0.2r/min. In order to investigate the separation effect of the experimental system, the input material, clean coal and tail coal were collected to conduct the floatation experiment to evaluate the separation effect of Pulse Continuous Discharge-type Interference Bed Separator. The experimental results are shown in Table 3.
Table 3. Results of 1-0.25mm particle size floatation experiment

| Density level (g/cm³) | Feed Yield (%) | Clean coal Ash content (%) | Rate in this level (%) | Rate in full sample (%) | Tail coal Ash content (%) | Rate in this level (%) | Calculated Raw coal Ash content (%) | Distribution rate (%) | Deviation |
|----------------------|----------------|---------------------------|------------------------|------------------------|--------------------------|------------------------|------------------------------------|----------------------|-----------|
| -1.3                 | 17.97          | 4.03                      | 30.61                  | 24.71                  | 4.09                     | 0.27                   | 0.05                               | 4.09                 | 0.21      |
| 1.3-1.4              | 25.08          | 8.54                      | 35.75                  | 28.86                  | 7.83                     | 1.24                   | 0.24                               | 7.83                 | 0.82      |
| 1.4-1.5              | 18.44          | 15.00                     | 22.62                  | 18.26                  | 15.03                    | 2.02                   | 0.39                               | 15.03                | 2.09      |
| 1.5-1.6              | 12.21          | 20.54                     | 6.48                   | 20.24                  | 20.63                    | 9.65                   | 1.86                               | 20.63                | 7.09      |
| 1.6-1.7              | 10.41          | 31.96                     | 2.79                   | 22.35                  | 21.89                    | 4.22                   | 32.11                              | 6.47                 | 32.11     |
| 1.7-1.8              | 8.60           | 45.00                     | 1.04                   | 0.84                   | 45.61                    | 25.15                  | 4.85                               | 45.37                | 5.69      |
| +1.8                 | 7.28           | 73.82                     | 0.71                   | 0.57                   | 73.26                    | 39.78                  | 7.67                               | 73.78                | 8.24      |
| Total                | 100.0          | 0                         | 20.71                  | 100.00                 | 80.72                    | 10.59                  | 19.28                              | 50.19                | 100.00    |

According to the experimental results, the narrow-grained coarse coal slime with a diameter of 1 to 0.25mm is better, because the input part is less than 1.6g/cm³, the density level accounts for more than 70% of the whole sample, the fine coal ash is divided into 10.59%, the clean coal yield is 80.72%, the tailings ash is divided into 50.19%, the actual sorting density is about 1.61 g/cm³, and the possible deviation Ep value is 0.146, indicating that the sorting effect is better and can fully meet the sorting requirements of coarse coal slime, especially coking coal.

6. Conclusion

Through numerical simulation and laboratory tests on the Pulse Continuous Discharge-type Interference Bed Separator experimental model, the following conclusions are drawn:

(1) Compared with the traditional structure Interference Bed Separator, the improved forced discharge jammer has less disturbance to the flow field distribution in the main tank during rotation at a low uniform speed (less than 0.5r/min), which has less disturbance to the flow field distribution in the main tank, hardly affects the dynamic balance of suspended particles in the dense layer, and can assist the gangue near the bottom outflow and the wall to discharge as soon as possible, to prevent clogging the aperture of the water distribution plate.

(2) The test model of Pulse Continuous Discharge-type Interference Bed Separator has good separation effect and high separation precision for Liyazhuang 2 # 1 / 3 coking coal because of its high separation precision. When it is used to separate narrow-size coarse coal slime with diameter of 1-0.25 mm, the ash content of clean coal is 10.59%, the yield of clean coal is 80.72%, the possible deviation Ep value can reach 0.146, the index is ideal.

(3) According to the experimental application in laboratory, it is shown that Pulse Continuous Discharge-type Interference Bed Separator has a good separation effect on the coal slime, providing a good theoretical basis and practical guidance for the next step of large-scale equipment, which is of great significance.

Acknowledgments

This work was supported by a grant from Special Project of Technology Innovation and Entrepreneurship Fund, Tiandi Technology Co., Ltd(2019-TD-QN015). Furthermore, I would like to thank Zhengyi Qi, Aijun Qian and Wei Jiang for excellent technical support.

Fund Project: Special Project of Technology Innovation and Entrepreneurship Fund, Tiandi Technology Co., Ltd(2019-TD-QN015); Leading scientific and technological innovation talents of...
Tangshan City in 2019(No.:19130201F); Advanced Mineral Processing Equipment Innovation Team of China Coal Technology Engineering Group Tangshan Research Institute (No.:205A4101D)

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