

Article

The Synergistic Effect of the Filtration Area Controlled by the Electromagnetic Valve and Injection Pressure on Pulse-Jet Dust Cleaning Performance

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Abstract: In engineering pulse-jet dust collector applications, the filtration area and injection pressure are chosen mostly based on experience. The peak pressure is tested under different injection pressures and filtration areas controlled by an electromagnetic valve, and then comprehensively analyzes the effects of dust intensity, uniformity, and air consumption on dust cleaning to obtain a better filtration area controlled by an electromagnetic valve and injection pressure. The results show that considering the uniformity and intensity of dust cleaning, the filtration area of 33 m² under the injection pressure of 0.4 MPa should be preferentially selected, with a standard deviation of 0.246 and a variance of 0.061. The filtration area of 27 m² under the injection pressure of 0.3 MPa should be preferentially selected considering the unit air consumption, uniformity, and intensity of dust cleaning, the standard deviation of 0.252, and the variance of 0.064. The paper presents a theoretical foundation for selecting the optimal injection pressure and filter area regulated by an electromagnetic valve in pulse-jet dust collector systems.

Keywords: long bag filter; filtration area controlled by an electromagnetic valve; injection pressure; uniformity of ash cleaning; environmental health



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1. Introduction

In the process of industrial production of dust collectors, in order to improve the cleaning effect of the dust collector, the general method is to increase the pulse injection pressure [1–3]. Meinke et al. [4] indicated that by improving the pulse cleaning energy output by 30%, a unique computer-modeled pulse cleaning technology would more easily “pulse off” dust from the surface of the filter, improving filtration efficiency and prolonging filter life. Yan et al. [5] used peak pressure and its arrival time as an index and showed that the pulse filter’s dust removal performance can be significantly improved by increasing the injection pressure. Moreover, the operating resistance of the pulse filter barrel can be reduced, and the dust removal efficiency of the pulse filter barrel can be improved. Ren et al. [6] examined the static pressure distribution along the surface of the filter during the pulse-jet cleaning process, reduced incomplete cleaning, and realized a more stable operation of the dust collector by using high pressure. Chen et al. [7,8] found that if the injection pressure was too low, the force entering the filter bag would be insufficient, the pressure difference between the inner surface and the outer surface of the filter bag would be large, and the ash removal efficiency would be poor. However, if the injection pressure was too high, it could easily cause excessive ash removal from the filter bag, reducing the service life of the filter bag and increasing the input cost of equipment.

There have been many experimental studies on electromagnetic pulse valves, which are an important component of pulse filter cartridge dust collectors and the executive

mechanism for implementing pulse dust cleaning. Lin et al. [9] conducted in-depth comparative experiments on different electromagnetic valves with different diameters and found the injection volume of a large electromagnetic valve was higher than that of a smaller one, and the resistance of pulse valves was lower. Litchwark et al. [10] designed a test system to measure the pressure change characteristics of the pulse valve and obtained the mathematical equation of pressure change during the injection process by mathematical fitting. Many methods [11,12] investigated the effect of injection performance parameters on electromagnetic pulse valves and concluded that the higher the injection pressure, the higher the air consumption of one injection of an electromagnetic valve. Under the same air consumption, the higher injection pressure provided the top-drawer effect for the ash removal of an electromagnetic pulse valve.

Humphries and Madden [13] established that about 60% of the dust on the bag filter can be removed at a peak pressure of about 300 Pa and that when the pulse pressure exceeds the minimum value, the amount of dust falling off increases slightly. Lu et al. [14] showed that for fly ash, the average pressure of cleaning is 500–600 Pa. In order to guarantee ash removal, a pressure peak of 600 Pa meets the minimum requirements for cleaning performance. Wang et al. [15] obtained that once the pressure of the filter reaches 5282 Pa, the bag filter will be damaged. Based on the research and analysis above, our team selected the peak pressures of 600–5000 Pa for the effective cleaning performance of the filter bag in this experiment.

In the pulse jet process, as the air consumption of the electromagnetic pulse valve varies greatly under different injection pressures, the range of filtration area controlled by the electromagnetic valve is extremely wide. The manufacturer can only give a wider range based on the application experience, while it does not give a specific basis for selection (combined with the results given by the manufacturer, the filtration area controlled by the electromagnetic valve is about 14–36 m² controlled by a 2" electromagnetic valve). This paper investigates the influence of injection pressure and filtration area controlled by the electromagnetic valve on pulsating dust-cleaning in the jetting process of a long filter bag ($\Phi 160 \times 6000$ mm). The peak pressure variation along the bag filter direction is tested under different injection pressures and different filtration areas, and finally, the effects of dust cleaning intensity, uniformity, and air consumption on dust cleaning are comprehensively analyzed; in this case, the better filtration area controlled by an electromagnetic valve and injection pressure are obtained. These experimental results provide powerful guidance for the application of the long bag filter in industrial uses.

2. Experimental Equipment and Methods

2.1. Experimental Apparatus

Figure 1 shows a schematic of the experimental system (Mianyang Liuneng Powder Equipment Co., Ltd., Mianyang, Sichuan Province, China). The experimental system consisted of an air-source system, injection system, filtration system, and data acquisition system. Air source system containing air compressor (GA 5/13, Atlas Copco, Nacka, Sweden), electrical control cabinet (power is 5 kW, Schneider Electric Co., Ltd. Rueil-Malmaison, France), and pressure reducing valve (DBR-4000, Schneider Electric Co., Ltd.). The injection system included a pulse valve (DMF-Y-50S, Shanghai Bag Filtration Equipment Co., Ltd., Shanghai, China), seamless steel injection pipe (40 mm inner diameter, 50 mm outer diameter, 3.0 m length, 16 mm nozzle diameters, and the distance between each injection hole was 200 mm) and Air tank (Sweden Co., Ltd., Sweden). The filtration system consisted of an induced fan (XFC-7500), Box (400 × 400 × 12,000 mm), bag filter ($\Phi 160 \times 6000$ mm, polyester needle punched felt material, permeability 25 m³·m⁻²·min⁻¹, weight 500 g·m⁻²) and steel frame cage, etc. The data acquisition system included a pressure transducer (QSY8135, Mianyang Qishiyuan Science and Technology Co., Ltd., Mianyang, China), an acquisition instrument (USB-8512E, Mianyang Qishiyuan Science and Technology Co., Ltd.), and a computer.

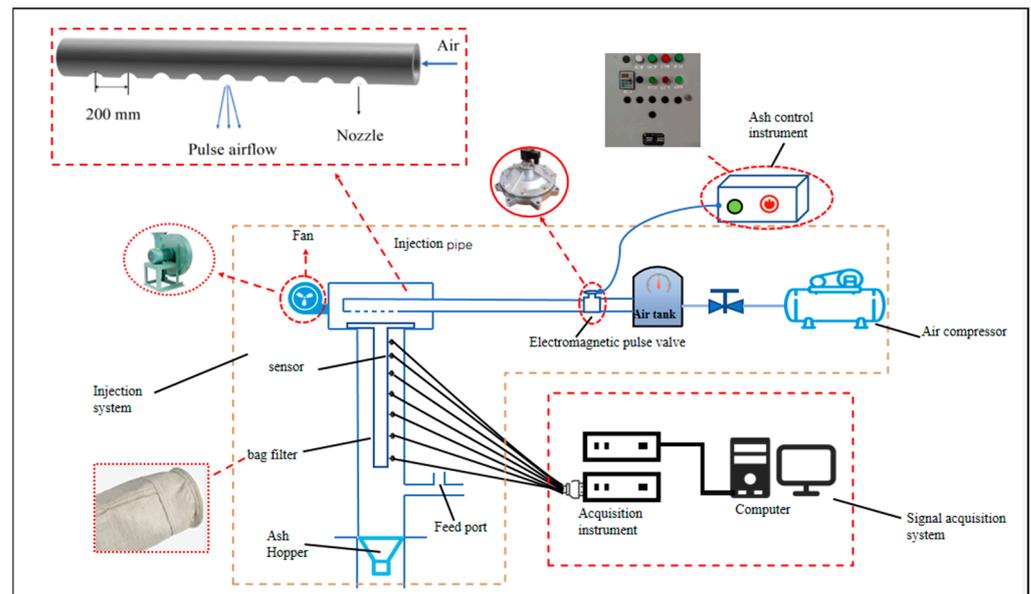


Figure 1. Schematic diagram of the experiment system.

2.2. Experimental Preparation

The air consumption of one injection of an electromagnetic valve can be used to evaluate the energy consumption of the injection [16,17]. In engineering applications, increasing the pressure of compressed air requires increasing the cost. In addition, when the starting times of solenoid valves are the same, the greater the injection pressure, the greater the consumption of air, and the higher the operating cost of equipment [18,19]. The air consumption of one injection of an electromagnetic valve Q_p can be calculated according to the equation below:

$$Q_p = \frac{P_0 V}{P_a} \left[1 - \left(\frac{P_1}{P_0} \right)^{\frac{1}{K}} \right] \quad (1)$$

where P_0 and P_1 denote the absolute pressure before and after the pulse injection in the air tank, MPa. P_a is the normal atmospheric pressure, which is 0.10325 MPa. V is the gas volume, which is $13.2 \times 10^{-3} \text{ m}^3$. K is the adiabatic exponent, which is 1.4.

Absolute pressures before and after the pulse injection in the air tank were recorded, and the data were the simple mean of the 75 times; then, the air consumption of one injection of an electromagnetic valve in each experiment was calculated by Formula (1), and the energy consumption of the injection was estimated, results was provided in Figure 2. Comparing the air consumption at an injection pressure of 0.1–0.4 MPa indicates that the air consumption of an electromagnetic valve under an injection pressure of 0.2 MPa was 1.23 times greater than at 0.1 MPa, 0.3 MPa was 1.48 times higher than at 0.1 MPa, and 0.4 MPa was 1.83 times more than at 0.1 MPa. This trend is generally the same as found in previous studies [20].

The air consumption of a pulse valve increases with the increase of injection pressure, and the energy consumption of the whole injection system is mainly from electric energy for the compressed air. As shown in Figure 2, the inclination of the air consumption curve, which can be concluded that when the injection pressure increases from 0.3 MPa to 0.4 MPa, the increase in air consumption is the largest, i.e., the increase in energy consumption is the largest [3,7,21–23]. The lower the injection pressure, the more energy is saved, but in actual production, it is necessary to employ a certain injection pressure in order to achieve the established ash removal effect. At the same time, the more pressure the filter bag bears, the shorter its use cycle. Therefore, to meet the requirements of ash cleaning strength, a lower injection pressure should be chosen (the injection pressure is less than 0.3 MPa in this study as long as feasible).

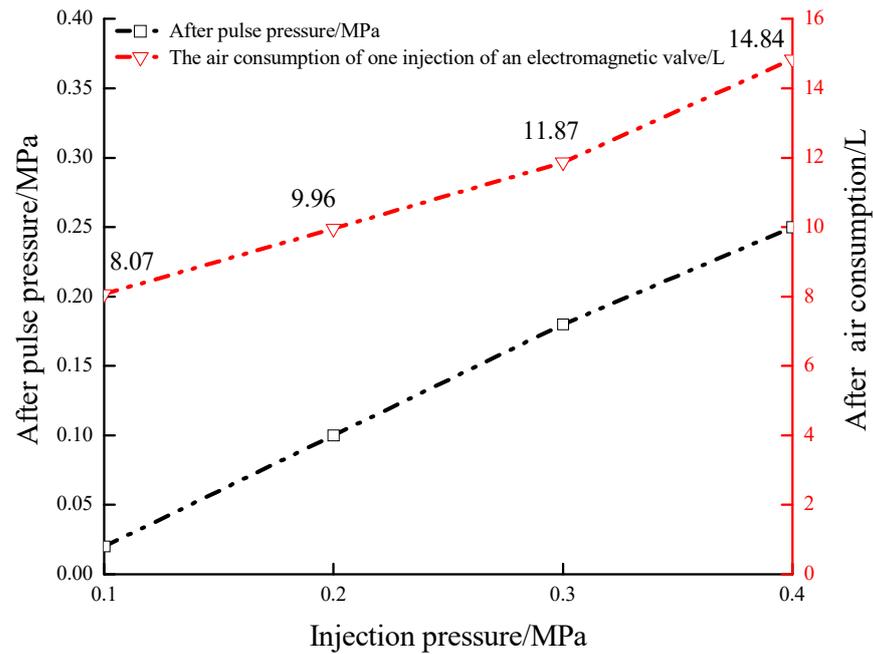


Figure 2. Air consumption of one injection of electromagnetic valve with different injection pressures.

2.3. Experimental Designs

In order to measure the peak pressures of the sidewalls of the bag filter, seven high-precision pressure sensors were used to monitor the peak pressures inside the bag filter, located 400, 1000, 2100, 3500, 4300, 5100, and 5900 mm away from the top of the bag filter, named as points P1–P7, respectively. The detail is in Figure 3. Export signals from the pressure transducer were connected to the import signal from the charge amplifier, and the outlet of the charge amplifier was then linked to the inlet of the data acquisition instrument. Finally, the export signal from the data acquisition instrument was linked to the computer. The sampling rate of data acquisition is 1 kHz. All the tests were repeated six times, and the average was calculated as the final peak pressure of the bag filter.

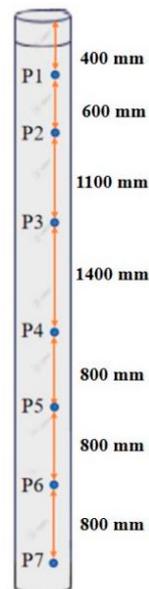


Figure 3. Sensor location in a bag filter.

According to our previous study [14], the jet distance, nozzle diameter, time of the pulse, the electromagnetic valve, filtration area, and injection pressures were 200 mm, 16 mm, 100 ms, 2'', 12–39 m², and 0.1–0.4 MPa, respectively.

3. Results and Discussion

3.1. Research on the Peak Pressure Law

The peak pressures were obtained at a jet distance of 200 mm, nozzle diameter of 16 mm, with different injection pressures (0.1–0.4 MPa) and different filtration areas (12–39 m²) shown in Figure 4.

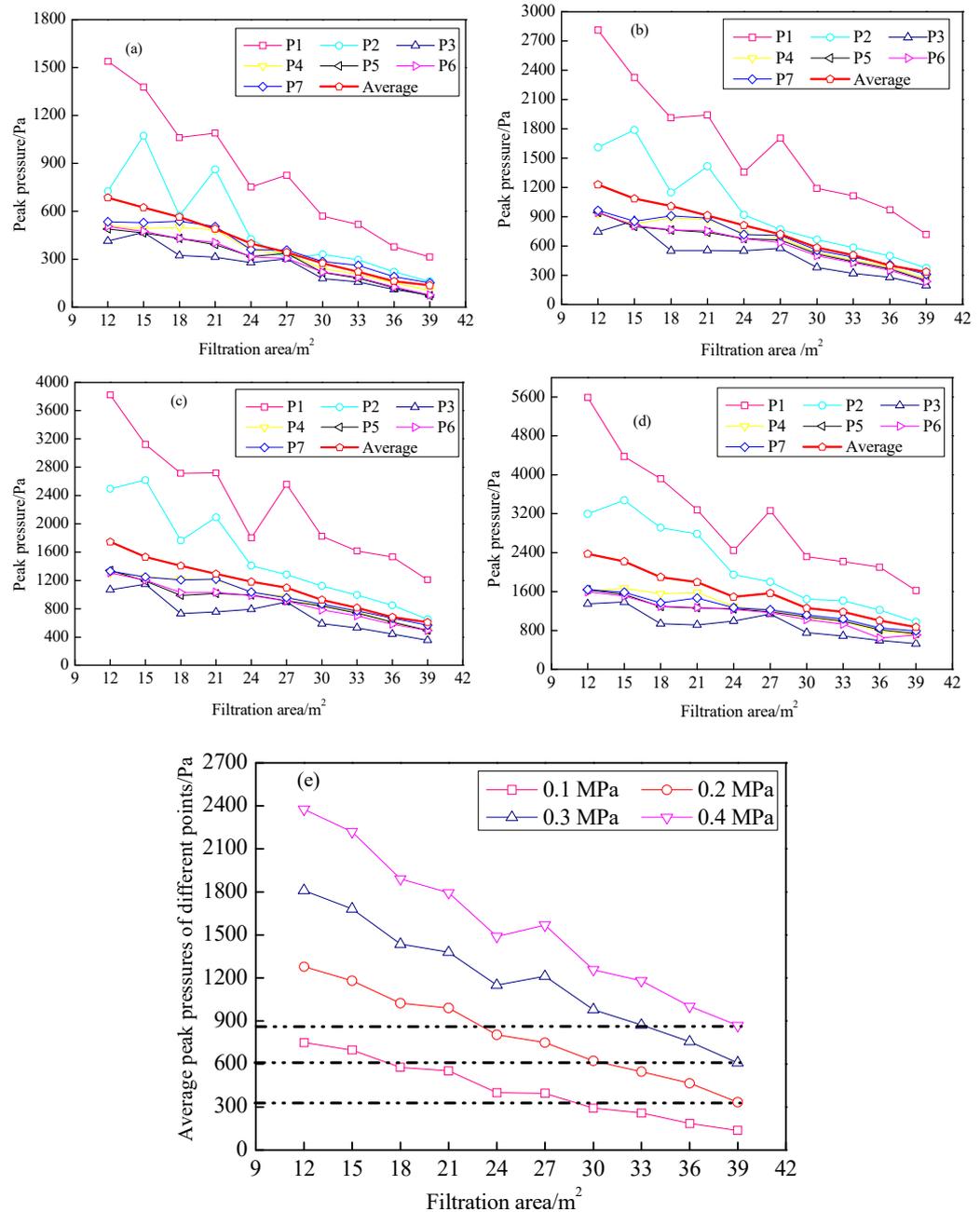


Figure 4. The relationship between the peak pressure and the different filtration area, (a) 0.1 MPa, (b) 0.2 MPa, (c) 0.3 MPa, (d) 0.4 MPa of injection pressure. (e) the average values of the pressure peaks of different points under different injection pressures and different filtration areas were extracted separately and reflected the influence of the filtration area controlled by an electromagnetic valve on the peak pressure of the sidewall.

According to Figure 4a–d, for all the pulse pressures, the filtration areas from 12 to 24 m², the peak pressures in the bag filter outside walls decreased with filtration area (all points), the filtration areas from 24 to 27 m², the peak pressures of different points increased briefly and then decreased with the increase of filtration areas to 39 m².

As shown in Figure 4e, the average values of the pressure peaks of different points under different injection pressures and filtration areas were extracted separately and reflected the influence of the filtration area controlled by an electromagnetic valve on the peak pressure of the sidewall. First, the peak pressures increased with injection pressures; this trend agrees with the results obtained by Lin et al. [9] and Döring et al. [20]. Second, in filtration areas from 12 to 39 m², the peak pressure declined gradually. From the inclination of the line in Figure 4e, in the filtration areas from 27 to 30 m², the change was larger than other changes, and for the filtration areas from 24 to 27 m², the peak pressure was increased. Finally, the pressure peaks obtained by increasing injection pressures can also be achieved by reducing the filtration area controlled by the electromagnetic valve. When the injection pressure was 0.4 MPa and the filtration area was 39 m², the average peak pressure along the bag filter was about 900 Pa. Therefore, for an average peak pressure of 900 Pa, we can choose an injection pressure of 0.3 Mpa and a filtration area controlled by an electromagnetic valve of 33 m² or an injection pressure of 0.2 Mpa and a filtration area controlled by an electromagnetic valve of 21 m². When the injection pressure was 0.3 Mpa and the filtration area was 39 m², the average peak pressure along the bag filter was about 600 Pa. Thus, for an average peak pressure of 600 Pa, we can choose an injection pressure of 0.2 MPa and a filtration area controlled by an electromagnetic valve of 30 m² or an injection pressure of 0.1 MPa and a filtration area of 15 m². When the injection pressure was 0.2 MPa and the filtration area was 39 m², the average peak pressure along the bag filter was about 375 Pa. Hence, for an average peak pressure of 375 Pa, we can choose an injection pressure of 0.1 MPa and a filtration area of 27 m².

These results show that in order to reduce energy consumption, the filtration area controlled by an electromagnetic valve can be reduced while maintaining adequate dust cleaning performance.

3.2. Dust-Cleaning Intensity

As shown in Figure 5, two straight lines parallel to the abscissa axis indicate that the peak pressures were 600 Pa and 5000 Pa. The peak pressure in this range can not only achieve adequate cleaning performance but also ensure the bag filter will not be damaged. The other two broken lines represent the maximum and minimum values of the peak pressure of the side wall under different filtration areas. The area between the two lines is the range of the peak pressure of the side wall and represents a filtration area controlled by an electromagnetic valve that can meet the requirements of effective cleaning performance under different injection pressures, while the other area indicates the filtration area controlled by an electromagnetic valve which cannot meet the ash removal requirements.

As can be seen from Figure 5a, when the injection pressure was 0.1 MPa, the filtration areas controlled by a 2'' electromagnetic valve were 12–39 m², and the minimum peak pressures were all below 600 Pa. Even when the filtration area was larger than 30 m², the maximum peak pressures could not reach 600 Pa, i.e., under the condition of injection pressure of 0.1 MPa, the filtration areas between 12–39 m², the system could not meet the cleaning performance requirements. Therefore, the filtration area controlled by a 2'' electromagnetic valve cannot be used with a 0.1 MPa injection pressure for the dust cleaning experiment.

In Figure 5b, when the injection pressure was 0.2 MPa, the filtration area controlled by a 2'' electromagnetic valve was 12–15 m², all the minimum peak pressures were over 600 Pa, and the maximum peak pressure was less than 5000 Pa, which can meet the cleaning requirements. When the filtration area controlled by an electromagnetic valve exceeds

15 m², although the maximum peak pressure was less than 5000 Pa, the minimum peak pressure was less than 600 Pa, which cannot achieve the required effect of cleaning.

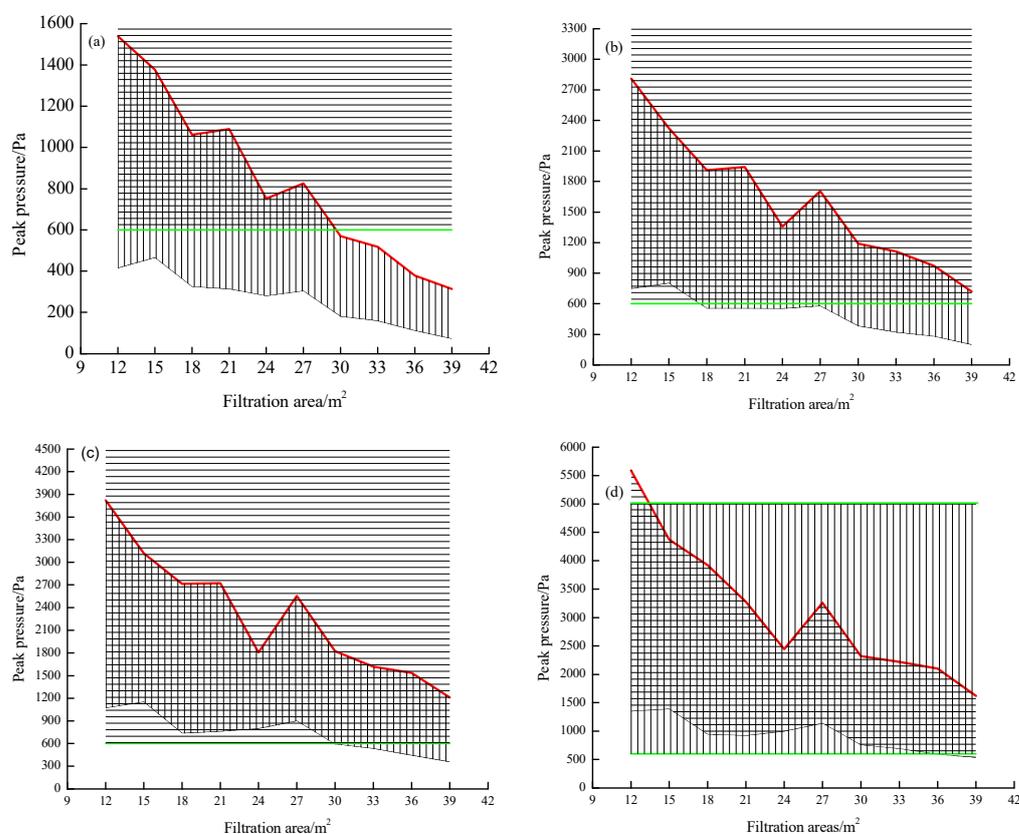


Figure 5. The relationship between the peak pressures and the different filtration areas, (a) 0.1 MPa, (b) 0.2 MPa, (c) 0.3 MPa, and (d) 0.4 MPa of injection pressure.

As seen in Figure 5c, when the injection pressure was 0.3 MPa, the filtration area controlled by a 2'' electromagnetic valve were 12–27 m² and could meet the cleaning requirements. When the filtration area controlled by an electromagnetic valve exceeds 27 m², the minimum peak pressure was less than 600 Pa, which would lead to failure of achieving the cleaning requirements.

As shown in Figure 5d, when the injection pressure was 0.4 MPa, the filtration areas controlled by a 2'' electromagnetic valve were 12–15 m², although the minimum peak pressures were all more than 600 Pa, and the maximum peak pressure exceeded 5000 Pa. Therefore, in practical applications, the bag filter will be severely damaged in this condition. When the filtration areas controlled by a 2'' electromagnetic valve were 15–33 m², the cleaning requirements could be met. When the filtration area controlled by an electromagnetic valve exceeds 33 m², the minimum peak pressure is less than 600 Pa, which would cause ineffective cleaning.

3.3. Ash Removal Uniformity and One Injection of the Electromagnetic Valve

Another factor that determines the effect of cleaning performance is the uniformity of ash removal. Variance and standard deviation are the indexes to be used to measure the deviation of a set of data from the average; they can measure the stability and uniformity of the data. The larger the variance and standard deviation are, the more unstable and the greater the fluctuation of the data will be, which means the worse the uniformity will be. In this paper, variance and standard deviation are used to indicate the uniformity of dust cleaning; there is no standard value, so it can be considered that the smaller the value, the better the uniformity. For injection pressures from 0.1 to 0.4 MPa, the standard deviation

and variance of peak pressures under different filtration areas controlled by electromagnetic valves are shown in Tables 1 and 2.

Table 1. Standard deviation under different filtration areas.

Injection Pressures/(MPa)	Standard Deviation under Different Filtration Areas									
	12 m ²	15 m ²	18 m ²	21 m ²	24 m ²	27 m ²	30 m ²	33 m ²	36 m ²	39 m ²
0.1	-	-	-	-	-	-	-	-	-	-
0.2	0.338	0.311	-	-	-	-	-	-	-	-
0.3	0.358	0.312	0.302	0.274	0.264	0.252	-	-	-	-
0.4	-	0.398	0.372	0.351	0.336	0.325	0.26	0.246	-	-

Table 2. A variance under different filtration areas.

Injection Pressures/(MPa)	A Variance under Different Filtration Areas									
	12 m ²	15 m ²	18 m ²	21 m ²	24 m ²	27 m ²	30 m ²	33 m ²	36 m ²	39 m ²
0.1	-	-	-	-	-	-	-	-	-	-
0.2	0.114	0.096	-	-	-	-	-	-	-	-
0.3	0.128	0.097	0.091	0.075	0.070	0.064	-	-	-	-
0.4	-	0.158	0.138	0.123	0.113	0.106	0.068	0.061	-	-

As described in Tables 1 and 2, when the injection pressure is kept constant, the standard deviation and variance decrease with an increase in the filtration area. At a certain filtration area, the standard deviation and variance increase with an increase in injection pressure. Thus, in this experiment, when the injection pressure is 0.2 MPa, the filtration area controlled by the electromagnetic valve should be selected as 15 m²; when the injection pressure is 0.3 MPa, the filtration area controlled by the electromagnetic valve should be chosen as 27 m², and when the injection pressure is 0.4 MPa, the filtration area controlled by electromagnetic valve should be chosen 33 m².

As observed from Figure 2, when the injection pressures were 0.2, 0.3, and 0.4 MPa, the air consumptions of one injection of an electromagnetic valve were 9.96×10^{-3} , 11.87×10^{-3} , and 14.84×10^{-3} m³. The calculated air consumption per unit filtration area controlled by the electromagnetic valve was as follows: 6.64×10^{-4} , 4.40×10^{-4} , and 4.50×10^{-4} m³·m⁻². Therefore, from the perspective of energy consumption, a filtration area controlled by an electromagnetic valve of 27 m² at an injection pressure of 0.3 MPa should be preferentially selected. The second choice is a filtration area controlled by an electromagnetic valve of 33 m² under an injection pressure of 0.4 MPa, and the last one is a filtration area controlled by the electromagnetic valve of 15 m² under an injection pressure of 0.2 MPa.

The ash removal uniformity of a filtration area controlled by an electromagnetic valve of 33 m² under an injection pressure of 0.4 MPa was compared with a 27 m² filtration area controlled by an electromagnetic valve and injection pressure of 0.3 MPa. It was found that the injection pressure of 0.4 MPa (the filtration area controlled by the electromagnetic valve was 33 m²) produced more uniform ash removal than the injection pressure of 0.3 MPa (the filtration area controlled by the electromagnetic valve was 33 m²). Therefore, when controlling a dust collector with a larger filtration area, the injection pressure should be 0.4 MPa, and when the filtration area is relatively smaller, the injection pressure should be 0.3 MPa.

4. Conclusions

In this study, we investigated the synergistic effect of the filtration area and injection pressure on pulse-jet dust-cleaning performance. The conclusions drawn from this experimental study are summarized as follows:

(1) When the injection pressure was constant, for filtration areas from 12 to 39 m², the peak pressures in the outside walls of the bag filter decreased with the filtration area increasing (all points) and exhibited degradation of ash removal uniformity. When the filtration area is kept constant, the higher the injection pressure, the greater the peak pressure, and the poorer the uniformity in the process of pulse cleaning. In order to reduce energy consumption, the filtration area controlled by an electromagnetic valve can be reduced while maintaining adequate dust cleaning performance.

(2) The injection pressure of 0.1 MPa cannot meet the cleaning performance requirements. Considering the uniformity of ash cleaning, the filtration area of 33 m² under the injection pressure of 0.4 MPa should be preferentially selected. In consideration of the air consumption per unit filter area, the filtration area of 27 m² under the injection pressure of 0.3 MPa should be preferentially selected.

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