Powder Technology 266 (2014) 191–195

Contents lists available at ScienceDirect

Powder Technology

journal homepage: www.elsevier.com/locate/powtec

The optimized relationship between jet distance and nozzle diameter of a pulse-jet cartridge filter

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ARTICLE INFO

Article history:
Received 29 January 2014
Received in revised form 16 May 2014
Accepted 5 June 2014
Available online 22 June 2014

Keywords:
Pulse-jet
Jet distance
Nozzle diameter
Fluid dynamics
Jet angle
Optimum design

ABSTRACT

In order to provide a theoretical guidance for pulse-jet cartridge filters design, the optimized relationship between jet distance (the distance between nozzle and cartridge opening) and nozzle diameter was investigated in a semi industrial pulse-jet cartridge filter, using peak pulse pressure as an index to evaluate the cleaning effect. It is found that, with the increase of jet distance, the peak pulse pressure first increases and then decreases. Obviously, there is an optimum jet distance for each nozzle diameter. And their relationship was analyzed according to fluid dynamics, showing that the optimum jet distance increases gradually with decreasing nozzle diameter and a mathematical model for optimizing jet distance S and nozzle diameter is put forward: $S = (D-d)/2\tan\frac{22.43-0.87d+0.11d^2}{2}$. Finally, this model was verified both by experiments and literature, demonstrating that it can be used to optimize the jet distance when cartridge diameter and nozzle diameter were given.

1. Introduction

As the pollutant standards in China become more and more strict, the research and development of filter, as an important equipment to control the discharge of inhalable particles, are becoming vital and essential, especially after the promulgation of air quality standards for $PM_{2.5}$. Pulse-jet cartridge filter is a new type of filtering dust collecting equipment. Compared with bag filter, it shows a lower resistance and has a smaller volume. Therefore, it is widely applied to control particulate emission and recover valuable particles in many industries such as plasma-aided manufacturing and bulk solids processing [1].

Previous researchers [2–10] pointed out that many design and operating parameters influence the cleaning performance of pulse-jet bag, such as nozzle diameter, jet distance and initial tank pressure. H.C. Lu and C.J. Tsai et al. [2–6] found that filtration curves vary with the initial tank pressure, nozzle diameter, jet distance, jet pump flow rate, filtration velocity and pulse duration of the pulse-jet bag system. The experimental results also showed that a commercial venturi with a small nozzle is a preferred configuration for an effective bag cleaning, and the optimized nozzle diameter is 30 mm, pulse duration is around 300–600 ms, jet distance is 600 mm, and tank volume is 0.3–0.5 m^3. H. Amano et al. [11] discussed the relationship between the ventilation resistance coefficient and the ratio of D/S (D: the upper opening of the pleated-type cartridge filter, and S: the distance between the upper surface of the pleated-type filter and the jet port of the manifold of the jet device) by testing the ventilation resistance coefficient after a pulse, and the optimum ratio (D/S) was in the range of 0.4–0.5. D.Y. Zhang et al. [12] demonstrated that the jet distance S can be calculated through jet theory ($S = \frac{\text{bag diameter}\Phi \times \cot\alpha}{2}$, jet angle α) and experience formula ($S = (\text{bag diameter } \Phi - 48) / 0.353$). These studies provide massive valuable information to the study of pulse-jet cartridge filter cleaning. However, both the structure and material of filter bag and filter cartridge are different [13]. Moreover, almost all studies were focused on the effect of a single operating parameter on a pulse-jet cartridge filter, such as jet distance, nozzle diameter, initial tank pressure and so on, lacking further analysis and discussion on the interaction of parameters, for example, the relationship between jet distance and nozzle diameter.

In this study, a series of experiments was carried out on a semi industrial pulse-jet cartridge filter to discuss the relationship between jet distance and nozzle diameter, using peak pulse pressure as an index to evaluate the cleaning effect. Specifically, a mathematical model for jet distance S and nozzle diameter d was established, and this mathematical model was verified by both experiments and literature.

2. Experiment

2.1. Test facilities and methods

A schematic diagram of the semi industrial pulse-jet cartridge filter is shown in Fig. 1. The experimental setup consists of a compressed air

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http://dx.doi.org/10.1016/j.powtec.2014.06.004
0032-5910/

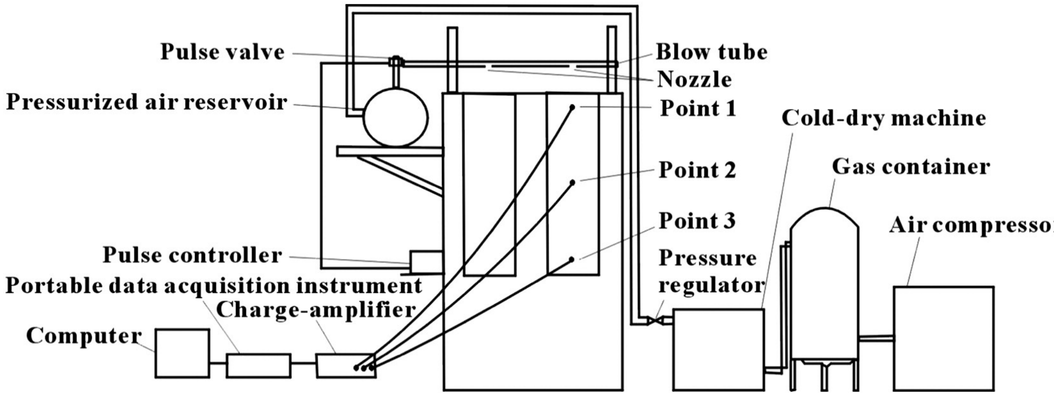

Fig. 1. Schematic diagram of the pulse-jet experimental equipment.

supplying system, a test rig for pulse-jet cleaning performance experiment and a data acquisition system. Compressed air is provided by screw compressors (UD18A-7, Chengdu, China). The cleaning pulse of the compressed air (0.6 MPa) is kept at constant by pressurized air reservoir (volume, 26.8 L) and controlled by a pulse valve (CA25T010-305T type with diameter 1″, Goyen Co., Ltd., Australia.); the pulse duration is triggered by pulse controller (SXC-8A1, Chengdu, China) and last for 80 ms. Three high precision pressure transducers (MYD-1540A) were used to monitor the pulse pressure inside the cartridge. Two cartridges ($\Phi 325 \times 660$ mm) in Fig. 1, made by polyester and coated with PTFE membrane, were included in the experimental system. The opening diameter of the two filter cartridges was 215 mm and the filter area was 9.7 m^2.

2.2. Characterization

There are lots of parameters that can be used as the index of bag cleaning, such as peak pulse pressure, initial pressure rise rate, fabric acceleration and average pulse overpressure [1–5,13–20]. The initial pressure rise rate can be indirectly calculated by peak pulse pressure. Fabric acceleration is mainly used for evaluating the vibration strength of flexible filter material [19], which may not be suitable for cartridge filter since it doesn't like flexible bag filter [13]. L.M. Lo and C. Yan et al. [1, 13] pointed out that the average peak pulse pressure on the filter cartridge surface is more closely correlated to cleaning than to overpressure. Considering these factors, peak pulse pressure was chosen to evaluate dust cleaning effect in this study, and it can be detected directly according to the volatility change [3–5,17].

2.3. Experimental design

In order to understand the relationship between the nozzle diameter and jet distance, the peak pulse pressure at various nozzle diameters and jet distance along the filter cartridge were measured, and the experimental arrangement is given in Table 1. Three high precision pressure transducers were used to monitor the pulse pressure inside the cartridge, located 60, 330 and 600 mm away from the top of the cartridge, named as points (1)–(3), respectively. The cleaning pulse pressure varied with time was recorded simultaneously by computer, as shown in Fig. 2. The sampling rate of data acquisition is 1 kHz and the inherent frequency of sensor is 40 kHz.

3. Results and discussion

3.1. Influence of nozzle diameter on the optimum jet distance

The peak pulse pressures obtained at different jet distance and nozzle diameters are shown in Table 2. For a set jet distance and nozzle diameter, the peak pulse pressure increased from point (1) to point (3). For instance, for 8 mm nozzle diameter and 420 mm jet distance, the peak pulse pressure at points (1)–(3) are 378, 592 and 2110 Pa, respectively. This trend agrees with the result of L.M. Lo et al. [1]. At a set nozzle diameter, the peak pulse pressure increases first with increasing jet distance and then decreases. This fact reveals a critical jet distance, the optimum jet distance for a set nozzle diameter. H.C. Lu and C.J. Tsai et al. [5] also demonstrated that there is an optimum distance depending on nozzle and bag diameter. And the optimum jet distances, for a nozzle diameter of 8, 11, 13, 16, 19 and 22 mm are 510, 480, 360, 300, 240 and 180 mm (the bold data in Table 2), respectively. Also, for a given nozzle diameter, at the optimum jet distance, peak pulse pressure at point (1) and the average pressure of points (1)–(3) is the highest. For instance, for an 8 mm nozzle diameter, the optimum jet distance is 510 mm. Under this condition, peak pulse pressure of measuring point 1 and average peak pulse pressure of the three measuring points were the highest, which are 499 Pa and 1099 Pa, respectively. It is also found that in Table 2, with the reduction of nozzle diameter, the optimum jet distance increases gradually. The reason for this is that, with the reduction of nozzle diameter, the area of nozzle decreases, then increasing the nozzle exit airflow velocity. Therefore, the smaller the nozzle diameter, the longer the optimum jet distance.

3.2. A mathematical model for optimum jet distance and nozzle diameter

Based on the previous analysis, in order to obtain a general rule between the optimum jet distance S and nozzle diameter d, according to the jet-flow theory, a mathematical model for optimum jet distance and nozzle diameter was provided. As shown in Fig. 3, converting the jet distance into jet angle, and the geometric relationship between jet

Table 1
Experimental arrangement.

	Nozzle diameter/mm					
	8	11	13	16	19	22
The testing range of jet distance/mm	150 ~ 565	150 ~ 565	150 ~ 510	150 ~ 420	150 ~ 360	150 ~ 270