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Influence of injection pipe characteristics on pulse-jet cleaning uniformity in a pleated cartridge filter

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ABSTRACT

Pleated cartridge filters are widely used to remove dust in industrial processes. However, pulse-jet cleaning is not uniform between filter cartridges. This is due to uneven transient pressure below the injection holes leading to the increase of operating resistance and decline in the cleaning cycle, both of which are detrimental to pleated cartridge filter operation. Therefore, the injection pipe plays an important role in pulse-jet cleaning. In order to provide guidance for injection pipe design, a pulse-jet cleaning experimental system was designed. Experiments involved a constant total filtration area under four working conditions; the effects of the injection hole diameter, the number of injection holes, the jet distance, and the tank pressure on pulse-jet cleaning were studied by testing the static pressure on the inner wall of the cartridge. This also allowed optimization of the jet distance, orifice ratio, injection hole diameter, and internal cartridge volume. The results showed that 1) the transient pressure below the injection holes increased gradually along the airflow direction of the injection pipe, and 2) the peak positive pressures on the corresponding cartridge inner surfaces also increased. Both of these pressure values increased with increasing tank pressure. Peak positive pressure on the inner wall of the cartridges first increased, and then decreased with increasing jet distance. The injection hole diameter and the optimum jet distance can be described by mathematical models developed from this study. The optimum jet distance decreased with increasing injection hole diameter. The optimum orifice ratio range was 0.6–0.8 under the optimum jet distance, adoption of which improved the pulse-jet intensity significantly. Injection hole optimization resulted in gradually decreasing injection hole diameter along the airflow direction of the injection pipe and increased the pulse-jet uniformity by a factor of 5–8. The internal volume of the cartridge influenced pulse jet cleaning under constant filtration area.

1. Introduction

Fine particulate matter presents a hazard to human health and the environment. Pleated cartridge filters have been used widely in the field of dust removal for their high collection efficiency, low resistance, low price, small footprint, and so on [1–5]. During operation, the running resistance of the filter increases with the accumulation of collected dusts and more energy is needed to maintain gas flow through the filter medium [6]. Therefore, it is necessary to clean the filter medium to keep the cartridge filter in good working condition. Pulse-jet cleaning is an effective and widely used method for filter medium regeneration [7–9]. The stable folded structure and rigid cartridges are more difficult to deform and damage during pulse-jet cleaning than are flat-sheet filter bags. However, pleated filter cartridges with a high number of folds are harder to clean than flat-sheet filter bags, resulting in incomplete or patchy filter cleaning [10–12]. This is reflected in inconsistent static pressure along the depth of the cartridge [13, 14]. Meanwhile, uneven transient pressure below the injection holes leads to increasing operating resistance and decline in the cleaning cycle, both of which are detrimental to pleated cartridge filter operation [15, 16].

Previous researchers [14–21] found that design and operating parameters such as nozzle diameter, nozzle type, jet distance, pulse duration, and filter material influence pulse-jet cleaning performance in filters. Yan et al. [14] found that supersonic nozzles can improve static pressure uniformity on the inner wall of the cartridge. Park et al. [17] researched the pleat geometry of the cartridge (the ratio of pleat height to pleat pitch), showing that the pressure drop across the pleated filter medium increased when the pleat geometry value exceeded 1.48. Suh et al. [18] found that the dust cake resistance was minimized at the optimum injection distance. Zhang et al. [19] demonstrated that the optimum jet distance could be calculated using jet theory and an empirical formula. This formula cannot be used to solve the optimum jet distance for the cartridge filter directly due to differences in structure and materials between the filter bag and filter cartridge [14]. Qian

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et al. [20] obtained a formula for the optimum jet distance without a nozzle through a combination of experimentation and theoretical modeling. Owing to the complexity of the pulse-jet airflow, nozzle type has an influence on the optimum jet distance. Fan et al. and Zhang et al. [15, 21] numerically simulated injection hole optimization, showing that injection hole outlet flows were more uniform after optimization.

Most of these studies used numerical simulation during pulse-jet cleaning to measure outlet flow uniformity in injection holes and improve the uniformity of the static pressure on the single cartridge inner wall. In this paper, an experimental system for injection pipe pulse-jet cleaning was designed and a series of experiments were performed to study the uniformity of cartridge cleaning with different injection holes during pulse-jet cleaning. The static pressure was measured at three points along the length of the cartridge with different tank pressures, numbers of injection holes (numbers of cartridges), injection hole diameters, and jet distances. The equation for calculating the optimum jet distance with a nozzle was established and the optimum orifice ratio was obtained. A comparative analysis of cleaning effectiveness was performed before and after injection hole optimization.

2. Experimental

2.1. Experimental apparatus

Fig. 1 shows a schematic of the experimental system. The experimental system consisted of air compressor (V-0.25/12.5, Zhengteng Air Compressor Manufacturing Co., Ltd., China), a pressure tank (26.5 L), a pressure regulator (AR2000, Airtac International Group), an electromagnetic pulse valve (DFM-Z-25S, Botou City and Environmental Protection Equipment Manufacturing Co., Ltd., installed between the pressure tank and the injection pipe) with inlet and outlet ports diameters of 31 mm and a pressure range of 0.3–0.8 MPa, a pulse controller (CQ-B-DCYC, Shanghai Trim-Ease Dedustor Engineering&Technology Co., Ltd., with a pulse duration range of 0.02–0.99 s), pleated filter cartridges (wood pulp fiber supported by a rigid wire cage, Foshan Nanhai Lishui Pat Environmental Protection Filter Factory), and seamless steel injection pipes (of 28 mm inner diameter, 31 mm outer diameter, and 1.2 m length; injection holes along the pipe were oriented vertically downwards to avoid inclined jetting, and the nozzles installed in the injection holes all possessed the same diameter).

Fig. 2 shows a sketch of the injection pipes and corresponding cartridges under four working conditions. Four type cartridges (F3, F4, F5, and F6) and a total of 18 cartridges were used to making the total filtration area of the cartridges equal to 18.7 m^2 under four working conditions. Cartridge parameters are shown in Table 1. All of the cartridges used in this experiment are made of same medium. A top view of the cartridge and a scanning electron microscope image of the filter medium at 500-times magnification are shown in Fig. 3. This cartridge is used extensively in the industry due to its small pressure drop and reasonable price. The cartridges were vertically arranged on the tube-sheet; each injection hole corresponds to a cartridge. The central line of the jet flow from the injection hole was centered over the cartridge. There were 26 types of injection pipes were used for the tests, the diameters of injection holes and the number of nozzles are not the same for each type of injection pipes. Among them, 22 types of injection pipes are marked in Fig. 2, and the other 4 types of injection pipes were obtained after optimization in the latter.

A high-frequency pressure acquisition subsystem (manufactured by Mianyang Mingyu Electronic Co., Ltd.) was also used, which possessed three MYD-1540B piezoelectric pressure transducers with a range of 0–100 kPa, one MYD-1540C piezoelectric pressure transducer with a range of 0–1 MPa. All of the pressure transducers are cylindrical shape with the diameter of 7 mm and high of 19 mm, a sensitivity of 8–12 pC/kPa, an inherent frequency of 40 kHz. Besides, this subsystem also included four MCA-02 electric charge amplifiers (a frequency of 0.5–100 kHz) and a MYPCI 4526 data acquisition card (a frequency of 10–200 kHz and four passes).

The pressure of the tank was adjusted by a pressure regulator. The pulse valve opening time and duration were controlled by a pulse controller. The pulse airflow flowed from the pressure tank, through the pulse valve, injection pipe, nozzles, and into the cartridges after the pulse valve was opened. A data collection computer was connected to the charge amplifiers and the data acquisition instrument.

2.2. Experimental design

Parameters including tank pressure, injection hole diameter, jet distance, injection hole number (cartridge number), and so on were varied within the pulse-jet cleaning system to attain different operating conditions. Pulse time of the electromagnetic pulse valve was set as 0.15 s. The MYD-1540C piezoelectric pressure transducer were installed 50 mm below the nozzles (point P0) by a support rod to measure the transient pressure at the nozzle outlet during the pulse-jet process. The high-frequency pressure transducers were removed after this measurement. In order to study the effect of the pulse-jet cleaning on the cartridges, it is necessary to measure the static pressure at various positions along the depth of cartridge. Three MYD-1540B piezoelectric

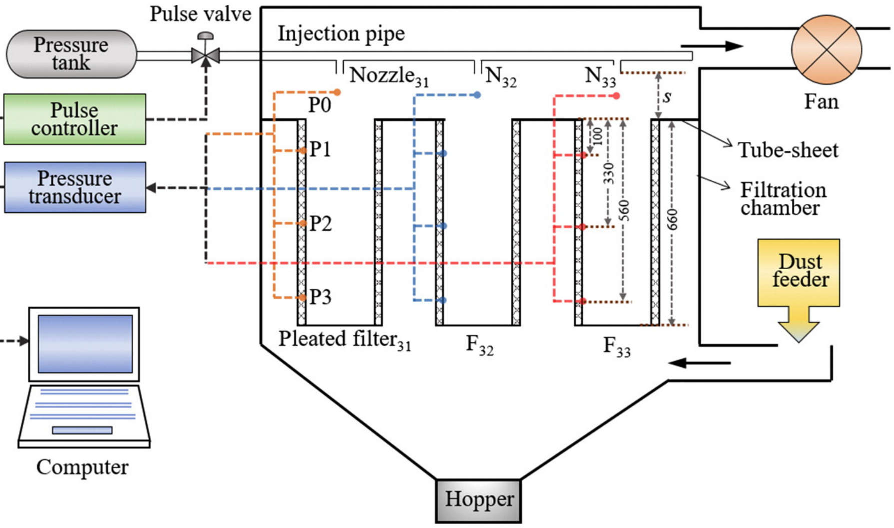

Fig. 1. Schematic of the experimental setup.