



Experimental study of pleated fabric cartridges in a pulse-jet cleaned dust collector[☆]

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ABSTRACT

Six pleated filter cartridges with different base media and geometrical dimensions were tested in a full-size dust collector periodically cleaned by a short burst of pulse-jet. The evaluation was performed under two different cleaning modes called clean-on-demand (to clean the filter once the pressure drop reaches a preset value) and clean-on-time (to clean the filter at a fixed time interval). The filter performance was evaluated by the effective residual pressure drop and downstream particle concentration. The results showed that the pleat ratio, defined as the ratio of pleat height to pleat pitch, had a great influence on the preferred operating mode for cleaning the filter. Clean-on-time mode demonstrated better performance for filters with a high pleat ratio (>4.0), while clean-on-demand mode performed better for filters with a low pleat ratio (<4.0). The test results also showed the tank pressure was critical for cleaning the pleated filter cartridges, whereas the pulse duration only had a small effect on the cleaning efficiency. With the same base media, cartridges with surface treatment such as fine fiber were superior to those without surface treatment. Pulse-jet cleaning could also promote particle penetration through filter media. The downstream particle concentration during cleaning was at least twice of that during filtration process for all pleated filter cartridges tested. Further, the downstream particle concentration was independent of the applied cleaning mode and the cleaning intensity in this study.

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1. Introduction

Dust collection technology has been applied to control particulate emission and to recover valuable particles in many industries such as solid-fuel-fired power generation, plasma-aided manufacturing, and bulk solids processing. As the dust is collected on filter bags or pleated cartridges, the pressure drop across the filters is increased. The filters need to be replaced or cleaned to achieve the desired collection performance. One of the typical technologies that allow filters to be reused is the reverse pulse-jet cleaning. Its fundamental operating principle was extensively studied for fabric filters [1–6] and for solid (ceramic, metallic, etc.) filters in hot gas filtration [7–9]. The basic principle of fabric filtration is to introduce dust-laden air flows into a large box (i.e., baghouse or dust collector) containing suspended flat-sheet filter bags or pleated filter cartridges. When a particle-laden air flow enters the filters at a constant velocity (typically 2–6 cm/sec), particles are captured and form a dust cake on the filter surfaces. During the particle collection process, the pressure drop across the filters (ΔP) is increasing as the dust cake is building up on the filter

surface. Eq. (1) shows ΔP consists of the pressure drops from the filter medium and from the dust cake under the operation of constant face velocity.

$$\Delta P = \Delta P_r + \Delta P_c \quad (1)$$

where ΔP_r is the effective residual pressure drop immediately after pulse-jet cleaning, consisting of the pressure drop of a virgin filter and the pressure drop due to particle seepage, and ΔP_c is the pressure drop of the dust cake depending upon the inlet dust concentration, face velocity, and operating filtration time.

To keep dust collectors working under a reasonable level of pressure drop (tolerated by the capacity of the fan for long-time operation), different cleaning methods (i.e., shaking, reverse-air, and pulse-jet) are adopted for dislodging the dust cake periodically. The pulse-jet technique, where the fabric filters are exposed to short bursts of compressed air from a nozzle in the reverse filtration flow direction for releasing the surface dust cake, is more popular due to its operating dependability and cleaning effectiveness. The operating procedure of a typical dust collector (baghouse) is shown in Fig. 1(a).

Numerous experimental studies on the pulse-jet cleaning of fabric filter bags have been conducted. Previous studies for fabric filter bags [2–6,10] demonstrated that the most critical factor in dislodging the dust cake on pulse-jet filter bags is the overpressure (ΔP_{over}). The overpressure magnitude can be estimated from the difference between

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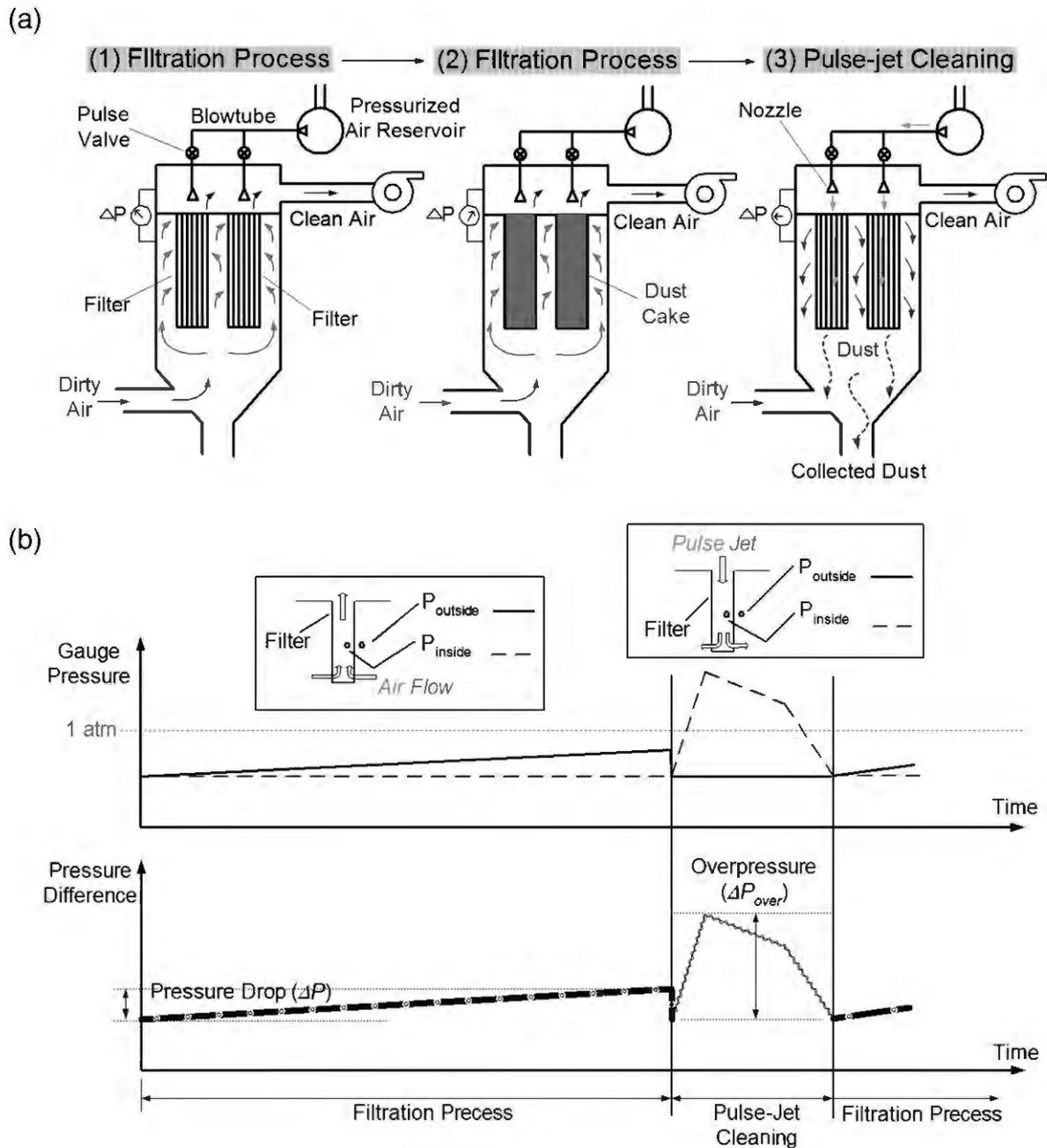


Fig. 1. (a) Operation of a baghouse or a dust collector; (b) Typical pressure variation with time during operation of a dust collector.

the pressure developed inside the bag due to the high speed pulse-jet (P_s) and the operating pressure drop of the bag at the time the pulse is released (ΔP). That is

$$\Delta P_{over} = P_s - \Delta P \quad (2)$$

As shown in Fig. 1(b), this peak pressure generated by the high speed pulse-jet can release the surface dust cake when the pressure is sufficient to overcome the adhesive force between the cake and the filter or the cohesive force inside the dust cake. Leith et al. [11–13] investigated particle penetration and re-deposition of pulse-jet fabric filter bags at high filtration velocity. They found that the penetration was nearly constant for all particle sizes ranging from 0.3 to 4.0 μm in diameter but increased with increasing filtration velocity. The highest particle penetration can be found during pulse-jet cleaning but it decreased after cleaning. Using dust tracer techniques to measure the amount of redeposition, they demonstrated that redeposition

increases with increasing filtration velocity and that the pulsed bag itself was the most important site for dust redeposition. Lu and Tsai [14–16] conducted a series of experiments to study the operation parameters on a pilot-scale pulse-jet baghouse. In these studies they found that the filtration performance varies with the tank pressure, nozzle diameter, distance between nozzle and bag top, and pulse duration of the baghouse system. The experimental results also showed that a specific critical tank pressure existed in their baghouse system. The bag can not be cleaned effectively using a tank pressure lower than the critical value, but the cleaning performance can be improved only slightly by using a tank pressure higher than the critical value. This important conclusion was also drawn by Humphries and Madden [10]. They observed that the dust cake was not dislodged uniformly from the fabric filter at low pulse pressures. Humphries [17] tested nine different fabric filters to demonstrate the influence of the fabric structure on the pulse-jet cleaning efficiency. Hindy [18] conducted an investigation to determine the pressure

drop, filtration cycle time, and outlet particle concentration of the polyester needlefelt fabric filter bag using three different operational modes. The three modes included clean-on-demand with a maximum pressure drop fixed at 1500 Pa and 2500 Pa, and clean-on-time at a 1-min cleaning frequency. For this study, clean-on-demand mode is defined as filter cleaning by reverse pulse-jet once the pressure drop across the filter media reaches the preset maximum allowable value. The filter is cleaned at a fixed interval in the clean-on-time mode. His experimental results showed that the residual pressure drop from clean-on-time at a 1-min cleaning frequency was increasing linearly and nearly two times higher than those from clean-on-demand at 2500 Pa and 1500 Pa after 70 hours of operation time. Moreover, his particle penetration data showed that the highest concentration was observed in clean-on-demand at 1500 Pa during the filtration process, and the particle concentrations were high at the beginning and decreased with operating time for each experiment.

As expected, most studies of fabric filtration were concentrated on the filters with a flat surface geometry. Recently the application of pleated filter cartridges in dust collectors has attracted a lot of attention because pleated filters offer a larger filtration surface compared with flat-sheet filter bags if both of them are in the housing of the same dimension. The objective of this study is to investigate the filtration and cleaning performance of pleated filter cartridges, having different base media and surface treatments, under different pulse-jet cleaning modes.

2. Experiments

2.1. Test procedure

VDI guideline 3926, Testing of Filter Media for Cleanable Filters, was developed in Germany in December 1994. The guideline was updated in December 2001 by specifying the filter face velocities required to test the filter sample, the type of test dust, the pulse valve opening time, and new testing procedures [19]. The main differences in testing parameters between the original and updated VDI guideline 3926 are summarized in Table 1. Basically it proposes the test procedures and laboratory setup for round, flat filter samples in a cross-flow filtration. A bench-scale test device was designed so that the experimental conditions and the experimental parameters could easily be controlled and changed. Some characteristic data such as effective residual pressure drop, duration of filtration cycles, concentration of particle penetration, and residual dust mass inside and on the filter are suggested to be recorded for comparing and evaluating different filter samples. The experiments conducted in this study

Table 1
VDI guideline 3926.

Test Conditions	1994 Version	2001 Updated Version
Filter face velocity	5 cm/sec	3–5 cm/sec
Inlet particle concentration	5 g/m ³	No change
Pressure drop limit before cleaning	1000 Pa (or 4 in-H ₂ O)	No change
Tank pressure	0.5 MPa (or 72.56 psi)	No change
Test dusts	Aluminum oxide, limestone, and titanium oxide	Aluminum oxide only
Pulse valve opening time	not specified	60 msec
Number of cycles	100	Phase 1: Conditioning for new filter (30 × clean-on-demand & sampling) Phase 2: seasoning (10000 × clean-on-time@5 sec) Phase 3: Stabilizing (10 × clean-on-demand) Phase 4: Seasoned (30 × clean-on-demand & sampling)

followed most of the recommendations in VDI guideline 3926, but some test conditions (including filter face velocity, tank pressure, pulse valve opening time, and test time) were changed due to the nature of this parametric study and the capability of apparatuses used for the experiment. The details will be discussed in the following sections.

2.2. Experimental apparatus

Fig. 2 shows the pilot-scale dust collector used for testing the pleated filter cartridges in this study. The operation of our dust collector is closer to real conditions in industry than that of the experimental setup specified in VDI guideline 3926. The dimensions of the compartment of the dust collector are 0.76 m (width) × 0.76 m (depth) × 1.22 m (height). For testing purpose, one or two filters can be installed in parallel in the dust collector.

The filter test system was designed to provide stable and uniform dust concentration inside the dust collector for evaluating the performance of filter cartridges in a long-term operation. A hopper was connected to the dust collector for collecting the dust released from the filter surface by the pulse-jet during cleaning periods. The collected dust fell down to the screw-type dust feeder whose feeding speed can be set according to the experimental conditions. With an axial fan and a blower, the test dust from the feeder was transported to the dust collector at a constant rate. This particle generation system can continuously provide constant inlet dust concentrations for testing different filter cartridges by adjusting the dust feeding rate corresponding to the filtration area of test filter under the fixed filter face velocity. A baffle was installed in the hopper to function as an impactor to remove agglomerates of the test dust from the particle-laden supply air. The baffle also acted as a flow distributor to cause a more spatially uniform distribution of dusty air in the dust collector. For every test in this study, the dust concentration inside the dust collector was monitored by taking filter samplings over a 5-minute period with a 4-liters/min sampling flow rate. The pulse-jet from the air compressor was controlled by the pressure regulator when adjusting the level of the tank pressure and by the pulse valve and the sequential timer/relay when changing the pulse opening time and interval.

In this study, the diameter of the nozzle was 3 cm and the distance from the exit of the nozzle to the opening of the test filter cartridge was 22 cm. The downstream dust concentration was monitored by an Aerodynamic Particle Sizer Spectrometer (APS, TSI model 3321) with the sampling probe located in the outlet of the dust collector. Particle penetration data were taken by the APS in 15-sec sampling times during both filtration and pulse-jet cleaning periods. More than 10 samples for both periods were taken to obtain average readings. Two high precision differential pressure transmitters were used to monitor the pressure drop across the filter and the volumetric air flow rate for controlling the filter face velocity via a fan speed controller. We used a computer with a LabView program to connect all devices including transmitters, the sequential timer/relay, and the fan speed controller for controlling experimental conditions and collecting the data.

2.3. Test dust

According to VDI guideline 3926, the particle size distribution for Aluminum Oxide is 99% < 100 μm, 90% < 25 μm, and 50% < 4 μm. The test dust used in this study was hydrated alumina (Al(OH)₃) consisting of 70–82% aluminum oxide (Al₂O₃). To measure the size distribution of the test dust, we used a test system similar to the one reported by Kim et al [20]. A fluidized bed was used to generate and deliver the test particles to a test chamber. The particle size distribution was measured by APS which determined the number mean aerodynamic diameter (D_{ap}) and standard deviation of test particles to be 1.336 μm, and 1.108 μm, respectively. The size

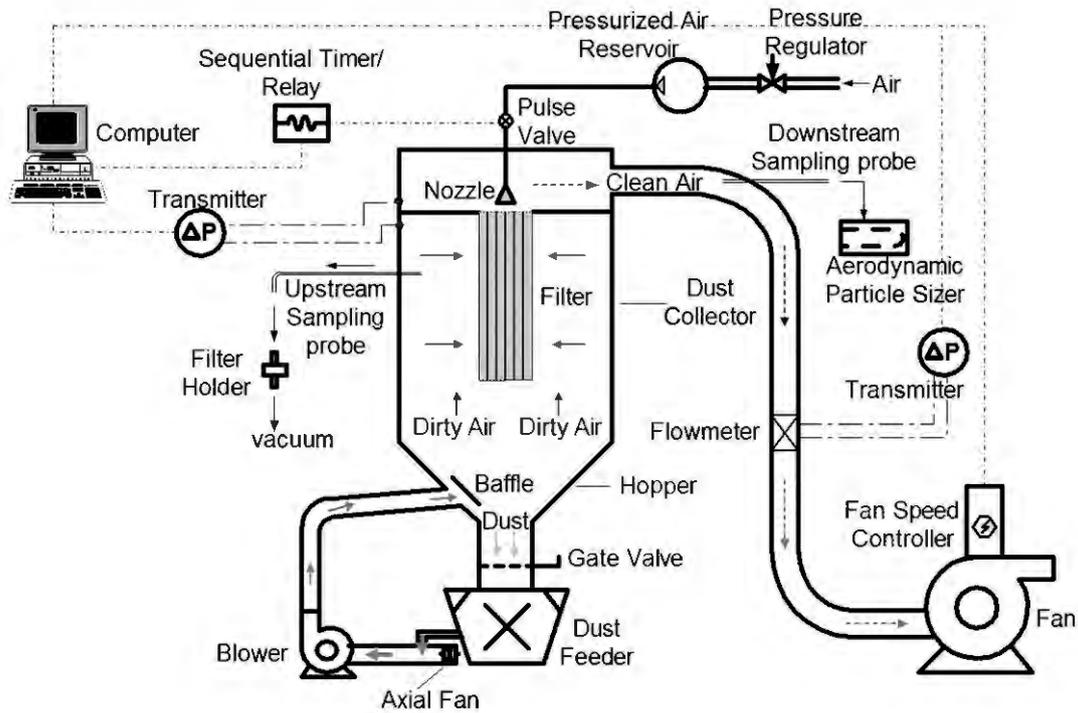


Fig. 2. Experiment setup.

distribution of the test dust is shown in Fig. 3. Smaller particle sizes were used in this study to challenge the filter cartridges.

2.4. Test filters

Six different filter cartridges were tested in this study (See Table 2 for detailed information on each cartridge.) All filters A, B, and C are made of polyester, but their pleat ratios are different. Additional material (PTFE membrane) covers the surfaces of filters A, B, and C. As shown in Fig. 4, the pleat ratio (β) is defined by the pleat height (H) over the pleat pitch (W).

$$\beta = \frac{H}{W} \quad (3)$$

The higher the pleat ratio, the larger the filter surface area or the smaller the pleat pitches if filter cartridges have the same dimensions. Flat-sheet filter bags can be regarded as a special case of pleated filter cartridges with a pleat ratio near zero. Filters D and E are made of synthetic material. While the surface of Filter D is covered by fine fibers, Filter E has no surface treatment. We can expect that the experimental results from filters D and E will reveal the influence of surface treatment on filtration/cleaning performance because they had the same filtration area. Filter C has the smallest filtration area (3.53 m^2), while Filter F made from cellulose has the largest filtration area (9.57 m^2) among all the tested filter cartridges. The surface of Filter F is also treated with fine fibers. The wide range of pleat ratios for the test filters (2.83 to 11.39) will demonstrate how the pleat ratio influenced the filtration/cleaning performance.

Filter face velocity (or air-to-cloth ratio) is a very important design criterion for operating dust collectors, because other operating parameters (i.e., filtration area of filters, operational pressure drop, and capacity of dust collector) are based on the designed filter face velocity. According to the updated VDI guideline 3926 [19], the test conditions of filter face velocity for flat filter samples should be 3–5 cm/sec. In this study, a filter face velocity of 4 cm/sec was adopted to test all filters except for Filter F. Filter F was tested at 2 cm/sec because of the limited fan capacity of the dust collector.

2.5. Cleaning modes

Two cleaning modes, clean-on-demand and clean-on-time, are usually used for operating cleanable or regenerable filters. Both modes are specified in the updated VDI guideline 3926 for filter testing.

In the clean-on-demand mode (see Fig. 5), a maximum allowable pressure drop, is preset for the dust collector system. During every filtration process, the pressure drop increases as dust is captured and builds up on the filter surface. The pulse-jet is released from the pressure reservoir and passes through the blow tube and nozzle to dislodge the built-up dust cake on the filter once the system pressure drop reaches the maximum allowable pressure drop. After completing the pulse-jet cleaning and before starting the next filtration cycle, the system pressure drop is decreased to a point called effective residual pressure drop. The trace of the effective residual pressure drops from filtration cycles, called the filtration curve, represents important characteristics of the filter under operating conditions. Usually, a cleanable filter experiences three different phases during the filtration process: seasoning, stable operation, and blinding. A highly increasing rate of residual pressure drop is shown in the seasoning period until the filter reaches the stable operation period. The slope of the filtration curve increases again when the filter is in the blinding period, because the inline pulse-jet cleaning is not an effective method to release the dust cake from the filter. The duration of filtration cycle time strongly depends on the cleaning effectiveness and the operating status of filters. As shown in Fig. 5, the duration of filtration cycle time is the longest in the seasoning phase, getting shorter but nearly constant during stable operation, and very short in the blinding phase. When a filter is blinding, offline cleaning should be implemented to recover the filter.

Clean-on-time mode (see Fig. 6) adopts a fixed filtration cycle time to operate the cleanable filters. Similar to clean-on-demand filters, clean-on-time filters experience three phases from seasoning, stable operation, to blinding. An abrupt slope of the filtration curve is common when the filter is in the blinding phase under the clean-on-time mode. The effective residual pressure drops in the stable operation phase are nearly constant or show minor variation for

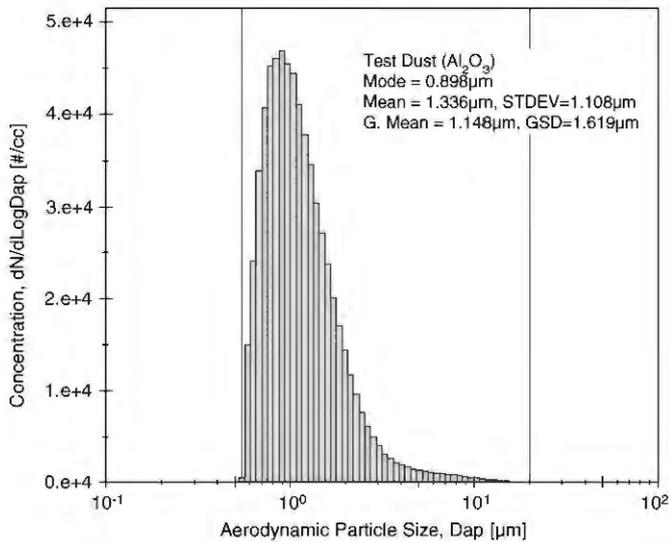


Fig. 3. Size distribution of test dust.

both cleaning modes. Therefore, we used the average residual pressure drop during stable operation to compare the filter performance under specific operating conditions.

2.6. Experimental design

The experimental design for testing the pleated filters is based on the updated VDI guideline 3926 [19] and is summarized in Table 3. Some experimental conditions, such as inlet particle concentration and tank pressure, need to be adjusted in order to take into account the difference in filtration area of test filters. The inlet particle concentration was kept at 5 g/m^3 by changing the feed rate of the screw feeder. Because a great amount of dust deposits on the pipe, baffle, and wall during dust transport, the particle concentration inside the dust collector was only 1.5 g/m^3 (monitored by filter sampling). The tank pressure needed to clean filters also has a strong relationship to the filtration area. Three different levels of tank pressure (0.41, 0.48, and 0.55 MPa) were chosen to test a pleated filter for its effectiveness.

According to updated VDI guideline 3926, a pulse valve opening time of 60 msec is recommended to test the flat-sheet filter samples. A sequential timer was used in this study to control the pulse duration from 30 to 350 msec. Considering the dimensions of the pleated filter cartridges, we adopted a short pulse duration of 100 msec and a long opening time of 350 msec to study the effect of pulse duration on cleaning effectiveness.

As shown in Table 1, 100 filtration cycles in the Clean-On-Demand mode was recommended by the original VDI guideline 3926 in 1994, whereas the updated guideline published in 2001, specifies a more complicated test procedure combining both cleaning modes in a single test. In fact, the main purpose of the test procedure is to obtain

stable data (effective residual pressure drop and filtration cycle time) from a well-seasoned filter. According to our prior filter test, we found that the pleated filter cartridges reach the steady state very quickly, and their filtration capability can be recovered from the blinding state if they are cleaned completely. Therefore, a 1000 minute operating time was used to test the pleated filter cartridges whose performance is stable. On the other hand, we tested one cleaning mode under each operating conditions to study the effect of cleaning modes on the performance of pulse-jet cleaned filters.

3. Results and discussion

The experimental results, including residual pressure drop, filtration cycle time, and downstream particle concentration for the six test filter cartridges, are discussed in this section. The data of effective residual pressure drops and filtration cycle time are reported in the form of average values, and are summarized in Fig. 7 (Filters A, B, and C) and Fig. 8 (Filters D, E, and F) for comparison.

To systematically summarize the complicated results, special notations are used to explain the testing conditions for each data point in Figs. 7 and 8. Geometric shapes are used to represent the cleaning modes used in the test. A square (\boxtimes) represents clean-on-demand mode, and a circle (\otimes) represents clean-on-time mode. Each square or circle is divided into four quadrants. The filter type (i.e., filters A, B, C, D, E, and F) is shown in the upper quadrant to represent which filter was tested. Tank pressure for cleaning (0.41, 0.48, and 0.55 MPa) is indexed as L (low), M (medium), and H (high), respectively, and shown in the left quadrant. Pulse duration (100 or 350 msec) is indexed as S (standard) or E (extended), respectively, and is shown in the right quadrant. The total operation time (min) for the specific test condition is shown in the lower quadrant. Therefore, a



symbol \boxtimes means that filter A was tested under 0.41 MPa tank pressure and 100 msec pulse duration, and it can only keep at stable operation for 316 min if the filtration velocity and dust feed rate were maintained as specified in Table 3.

Two parameters, i.e., residual pressure drop and filtration cycle time, demonstrate the cleaning effectiveness of a pulse-jet-cleaned filter under specific operating conditions. Basically, lower effective residual pressure drop and longer filtration cycle time represent better cleaning effectiveness. In clean-on-demand mode the filtration cycle time is dependent on the effective residual pressure drop; in clean-on-time mode the converse is true—effective residual pressure drop is dependent on filtration cycle time.

The downstream particle concentration is an index to show the performance and the efficiency of pulse-jet-cleaned filter cartridges in reducing contaminant emissions in the surrounding air space. The particle data during the filtration processes and the pulse-jet cleaning periods collected by APS during periods of stable operation are summarized in Table 4. They are reported in the form of averages and standard deviations of total number concentration ($\#/cm^3$) ranging

Table 2
Test filters.

Test Filter	A	B	C	D	E	F
Base media	Polyester	Polyester	Polyester	Synthetic	Synthetic	Cellulose
Surface treatment	PTFE membrane	PTFE membrane	PTFE membrane	Fine fiber	None	Fine fiber
Dimensions (Diameter \times length) [cm \times cm]	32.4 \times 62.9	32.4 \times 62.9	20.7 \times 56.6	23.4 \times 56.6	23.4 \times 56.6	23.4 \times 56.6
Pleat height (H) [cm]	4.8	3	2.4	3.5	3.5	3.8
Pleat pitch (W) [cm]	1.696	0.777	0.556	0.606	0.597	0.334
Total pleat number	60	131	117	121	123	220
Pleat ratio (β)	2.83	3.86	4.32	5.78	5.86	11.39
Filtration area [m^2]	3.99	5.57	3.53	5.11	5.11	9.57

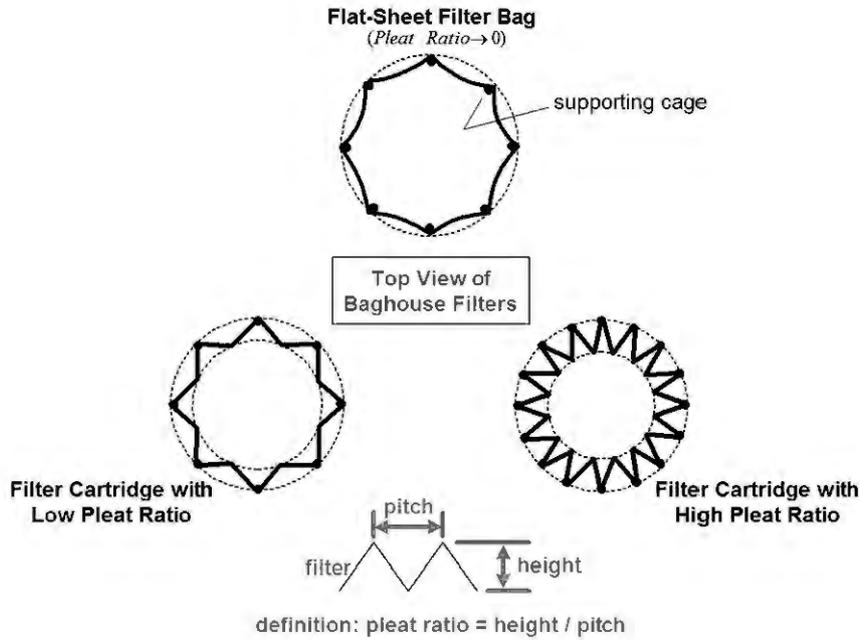


Fig. 4. Pleat ratios of baghouse filters.

from 0.5 to 20 μm . Note that the particle measurement for Filter E was done in the filter blinding phase, because all test conditions blinded the filter.

3.1. Residual pressure drop and filtration cycle time of the pulse-jet cleaned dust collector

3.1.1. Effect of tank pressure and pulse duration

From previous studies for flat sheet filter bags, it was shown that tank pressure is a critical factor in dislodging the dust cake from the filter [2,3,14]. It is also true for pleated filter cartridges, according to the experimental results from this study. As shown in Fig. 7, for example, Filter A failed to work at 316-min operation time under clean-on-demand with 0.41 MPa tank pressure, but it could maintain a stable operation over 1000-min test if 0.48 MPa tank pressure was adopted. The data on the filtration cycle times also showed the same results.

Another important factor influencing the intensity of the pulse-jet is the pulse duration. The test results from this study showed that the length of the pulse duration needs to be determined carefully, because longer pulse durations might result in less cleaning effectiveness in some cases. According to the experimental data, a negative effect of

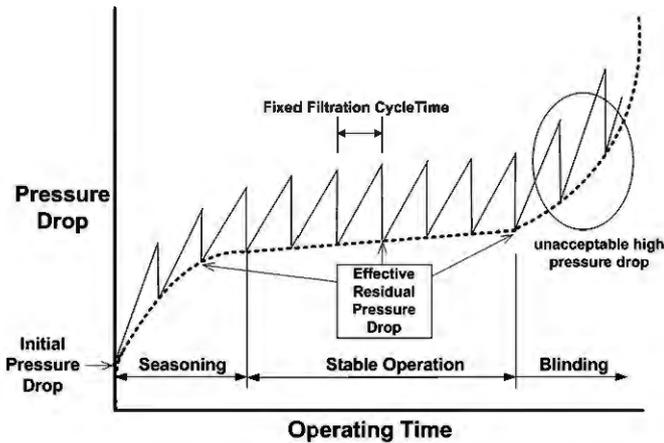


Fig. 5. Clean-on-demand mode.

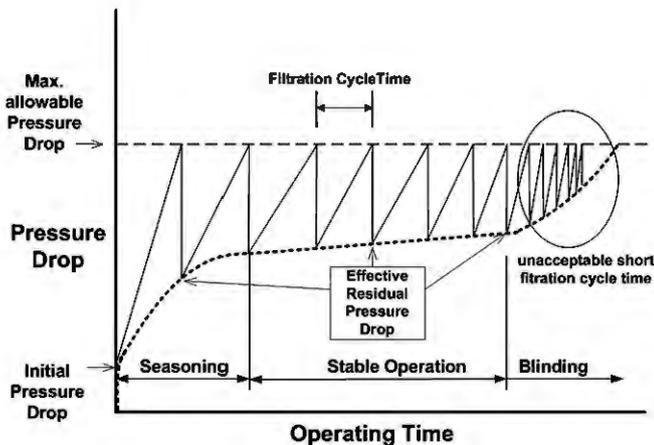


Fig. 6. Clean-on-time mode.

Table 3
Experimental deign.

Test conditions	Settings
Filter face velocity	4 cm/sec for Filters A, B, C, D, and E 2 cm/sec for Filter F
Inlet particle concentration	5 g/m ³ (1.5 g/m ³ inside dust collector according to filter sampling test)
Cleaning modes	Clean-on-demand (pressure drop limit before cleaning = 1000 Pa) Clean-on-time (fixed cleaning frequency depends the average filtration cycle time from clean-on-demand mode for filters)
Tank pressure	0.41, 0.48, or 0.55 MPa (The filter will be cleaned by using the lowest effective tank pressure)
Pulse vane opening time	100 and 350 msec
Test dust	Aluminum oxide (mean particle size = 1 μm)
Test time	1000 min
Measurement of downstream particle concentration	APS

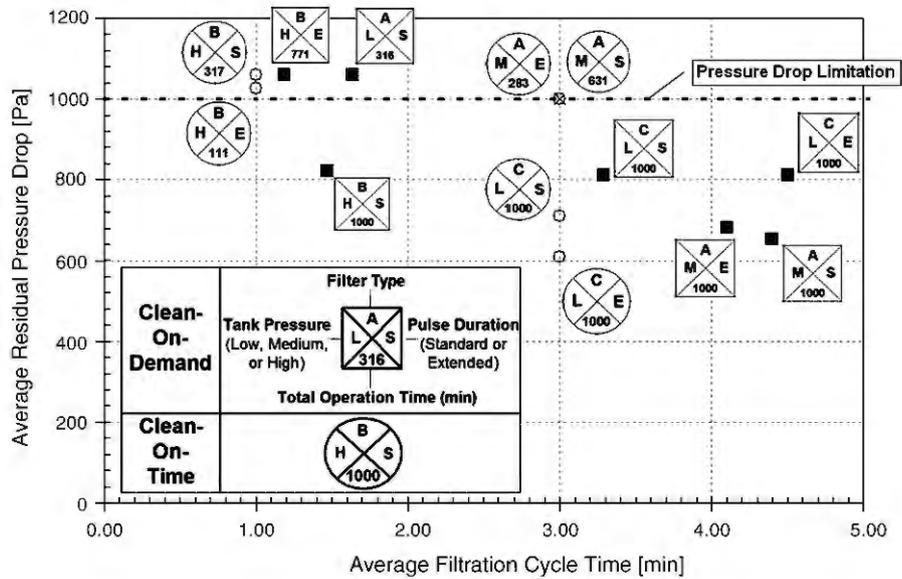


Fig. 7. Summary of average residual pressure drop and filtration cycle time of test filters A, B, and C.

longer pulse durations was found for Filter A under clean-on-time every 3 min at 0.48 MPa, for Filter B under clean-on-demand at 0.55 MPa, and for Filter E under clean-on-demand at 0.55 MPa. We noticed that the average residual pressure drops for all above-mentioned cases were close to or above the pressure drop limitation (1000 Pa). This implies that the used tank pressure is not effective to clean the filters. On the other hand, a positive effect of longer pulse duration was shown for Filter C under clean-on-demand at 0.41 MPa, for Filter D under clean-on-demand at 0.48 MPa, and for Filter F under clean-on-time every 5 min at 0.41 MPa. The average residual pressure drops for these cases were well below the 1000 Pa pressure drop limitation. Therefore, it seems as if longer pulse duration can be used to enhance the cleaning effectiveness of pleated filters only if the dust collector is operated at the effective tank pressure. From the previous discussion it can be seen that the developed overpressure due to an excess of pulse valve opening time might not be high enough to remove the dust cake on the filter surface, if the used tank pressure is lower than the critical value. Further, this lower overpressure caused a negative effect on the residual pressure drop because of the particle redeposition.

3.1.2. Effect of pleat ratio on cleaning mode

According to the experimental study of Hindy [18], clean-on-demand mode was a better method to clean the flat-sheet filter bag than clean-on-time mode based on residual pressure drop. However, our study showed that the pleat ratio of the filter has a great influence on the selection of the cleaning mode. Table 5 summarizes the pleat ratios of test filters and preferable cleaning modes based on the results of average residual pressures and filtration cycle time from Figs. 7 and 8. The filters with lower pleat ratio (less than 4.0 in our study) are better cleaned with clean-on-demand mode, but clean-on-time mode works better on filters with higher pleat ratios (larger than 4.0). The pleat ratio is critical to the selection of the cleaning mode because the static pressure on the filter surface during pulsing could be changed by the pleat geometry (i.e., pleat pitch and height). Detailed information of the surface pressure during pulsing, however, is difficult to obtain from the experiments. Therefore, computational fluid dynamic techniques could be a feasible approach to study how the pleat ratio influences the filter surface pressure during the pulsing and then cleaning mode.

The results also suggested that the cleaning timing is a very important parameter for pleated filter cartridges, particularly for a

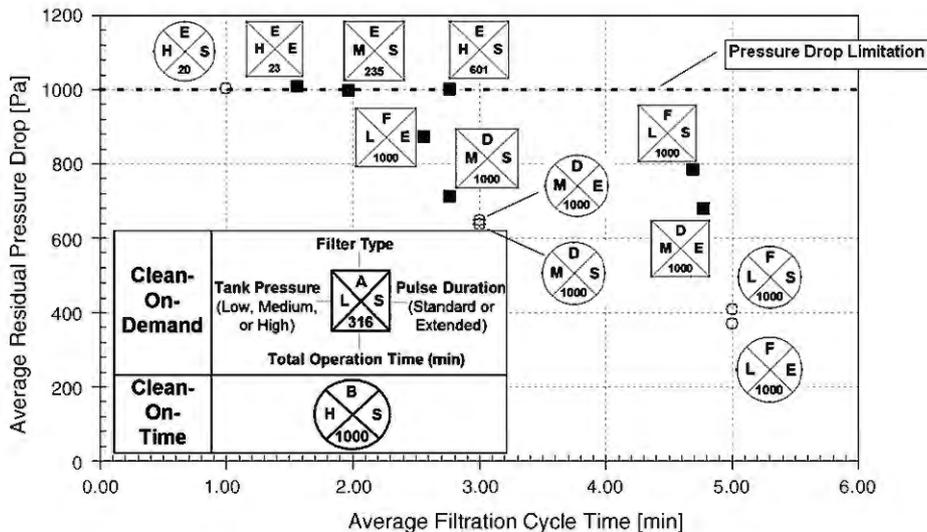


Fig. 8. Summary of average residual pressure drop and filtration cycle time of test filters D, E, and F.

Table 4
Summary of downstream particle concentration at 1 μ m for test filters.

Mode	Tank Pressure [MPa]	Pulse Duration [msec]	Total Number Concentration [#/cm ³] During filtration (During Pulsing)					
			Filter A	Filter B	Filter C	Filter D	Filter E	Filter F
Clean-on-demand	0.41	100			2.2 \pm 0.4 (4.0 \pm 0.6)			4.0 \pm 0.6 (27.6 \pm 4.7)
		350			1.7 \pm 1.0 (3.9 \pm 1.3)			2.9 \pm 0.4 (15.7 \pm 2.3)
	0.48	100	76.5 \pm 20.7 (287.7 \pm 39.2)			2.3 \pm 0.3 (10.4 \pm 1.7)	30.6 \pm 3.9 (73.9 \pm 13.0)	
		350	56.0 \pm 20.0 (148.3 \pm 32.5)			2.0 \pm 0.9 (12.3 \pm 4.0)		
	0.55	100		2.4 \pm 0.4 (5.1 \pm 2.2)			84.4 \pm 14.5 (218.1 \pm 16.3)	
		350		1.4 \pm 0.4 (4.2 \pm 0.6)			66.6 \pm 7.4 (230.5 \pm 24.3)	
Clean-on-time	0.41	100			2.0 \pm 0.3 (4.1 \pm 0.5)			1.9 \pm 0.3 (17.4 \pm 2.6)
		350			3.0 \pm 0.3 (6.3 \pm 1.8)			7.0 \pm 5.1 (30.8 \pm 9.2)
	0.48	100	29.8 \pm 7.8 (80.2 \pm 11.2)			3.7 \pm 0.6 (18.2 \pm 2.8)		
		350	24.6 \pm 5.0 (83.4 \pm 8.7)			4.4 \pm 1.0 (37.7 \pm 6.7)		
	0.55	100		2.5 \pm 0.5 (6.0 \pm 2.7)			83.0 \pm 15.9 (239.1 \pm 4.1)	
		350		2.4 \pm 0.6 (4.7 \pm 0.9)				

Data shown are the total number concentration (#/cm³) in the format of average \pm standard deviation. For each test condition, particle penetration data are the overall average of samples obtained by taking 15-sec sampling from APS during filtration and pulse-jet cleaning.

filter with a high pleat ratio. It can be verified by the residual pressure drops during the seasoning phases. Using clean-on-time mode to clean the filters kept the residual pressure drop lower in the seasoning phase than using clean-on-demand mode. This phenomenon was more obvious in filters with a high pleat ratio. However, using clean-on-time mode in filters with a low pleat ratio increased the residual pressure drop constantly. A similar trend can also be found in the experimental results reported by Hindy [18] for a flat-sheet filter bag that can be regarded as a pleated filter with a very small pleat ratio.

3.1.3. Effect of surface treatment for filters

This study also investigated how the surface treatment of filters affects the cleaning effectiveness for the pulse-jet cleaned dust collectors. Filters D and E had the same base media (synthetic fiber) and geometrical dimensions, except that the surface of filter D was covered by fine fibers, whereas the surface of filter E was not. The test results in Fig. 8 showed that filter E could not be kept at stable operation under any test conditions, while Filter D could be operated under stricter test conditions. It seems that surface treatment showed a positive effect for pleated filters in the residual pressure drop and filtration cycle time.

Table 5
Summary of experimental results for Cleaning Mode vs. Pleat Ratio.

Filter	A	B	C	D	E	F
Pleat ratio (β)	2.83	3.86	4.32	5.78	5.86	11.39
Tank pressure used for testing [MPa]	0.48	0.55	0.41	0.48	0.48	0.41
Preferable cleaning mode (clean-on-demand v.s. clean-on-time)	clean-on-demand	clean-on-demand	clean-on-time	clean-on-time	N/A(*)	clean-on-time

N/A(*): No conclusions can be drawn from the test results of Filter E, because Filter E became blinded under all test conditions.

3.2. Particle emission from the pulse-jet cleaned dust collector

The downstream particle concentration was measured to investigate the reduction of dust emissions and filter performance during the periods of filtration process and pulse-jet cleaning. The particle concentrations reported in this study are the average total number concentrations for a 15-sec sampling time. We found that the particle concentration in the filter blinding phase was stable and close to that of stable operation phase. However, the particle concentration in the filter seasoning phase was high at the beginning and then decreased over time until it reached the stable operation phase. The sampling results of average particle number concentration reported here are those taken in the stable operation or filter blinding (Filter E only) phases, and are summarized in Table 4.

As expected, the downstream particle concentration increased sharply during the period of pulse-jet cleaning, and the level of particle concentration during pulse-jet cleaning was at least twice that of the filtration process. However, the downstream concentration was independent of the tank pressure and the pulse duration used to clean the pleated filters, and the pleat ratio only had little effects on the downstream concentration. From this study, the effect of the cleaning mode on the downstream particle concentration is not obvious.

The material used for the surface treatment could influence the downstream concentration. The results of Filters D and E showed that fine fibers could reduce the downstream concentration during pulse-jet cleaning, while the results of Filters A, B, and C could not demonstrate the advantage of using PTFE membrane on the filter surface to lower the downstream particle concentration.

4. Conclusions

Pulse-jet fabric filtration is considered the most efficient method of room-temperature gas cleaning to control particulate emissions in order to conform to strict environmental legislation. Due to their low pressure drop and good filtration efficiency compared with flat-sheet filter bags, pleated fabric filters applied in pulse-jet cleaned baghouses have recently attracted a great deal of attention. The characteristics of pleated filters are expected to be different from common filter bags,

but very little has been published in the literature regarding pleated filter cartridges applied in pulse-jet dust collectors. We investigated the filtration performance of six different pleated filter cartridges for pulse-jet cleaned dust collectors by designing experiments to examine some important operating conditions, such as cleaning modes, cleaning intensity, filter geometry, and filter media. Data were collected on effective residual pressure drop, filtration cycle time, and downstream particle concentration, and reported as the average value for comparing the filtration performance of pleated filters.

The conclusions drawn from this experimental study are summarized as follows.

(1) Pulse-Jet

Test results showed that the dust cake could only be released effectively if a critical compressed tank pressure was used, because the overpressure pulse (the cleaning mechanism of pulse-jet) is strongly related to the tank pressure. If a filter is cleaned by a tank pressure lower than the critical level, simply extending the pulse duration will not enhance the cleaning effectiveness, and it will likely cause earlier blinding of filters. The cleaning intensity has little effect on particle emission from the pulse-jet cleaned dust collector.

(2) Pleat Ratio

The most interesting finding from this study was the relationship between the pleat ratio of filters and the cleaning mode. From the viewpoint of either the residual pressure drop or filtration cycle time, clean-on-demand mode should be adopted for operating low-pleat-ratio filters, but clean-on-time mode should be used for high-pleat-ratio filters. Our study showed that there was a critical pleat ratio near 4.0 that determined the cleaning mode. However, both the variables of pleat ratio and cleaning mode did not show any strong correlation with the downstream particle emission in this study.

(3) Filter Media and Surface Treatment

Particle emission during the pulse-jet cleaning had a strong relationship to the surface treatment of the filters. Filters D and E, in this study, offered an excellent example to demonstrate that sophisticated filter surface treatment can be an effective method to improve the filtration performance. The filter performance as determined by dust emissions can also be enhanced by the surface treatment. However, Filters A, B, and C did not show strong evidence of the advantage of surface treatment with PTFE membrane.

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