Influence of Different Cleaning Conditions on Cleaning Performance of Pilot-Scale Pulse-Jet Baghouse

Hsin-Chung Lu[1] and Chuen-Jinn Tsai[2]

Abstract: In this study, a pilot-scale pulse-jet baghouse is utilized to control the particulate emission of an oil-fired boiler. The operating and design parameters, such as filtration velocity, initial tank pressure, and nozzle diameter, were varied to evaluate the cleaning effect of the pulse-jet baghouse. Two different cleaning types, (1) high initial tank pressure and one bag cleaning; and (2) low initial tank pressure and two consecutive bag cleanings, are used to compare the bag-cleaning performance in this study. It is found that the cleaning effect increases with the initial tank pressure. However, the cleaning intensity (overpressure) does not increase with the nozzle diameter. There exists an optimum nozzle diameter to achieve higher cleaning intensity and a better cleaning effect. This phenomenon results from the small volume of the baghouse compartment in this study. If an industrial size baghouse was used, it suggests that a nozzle diameter larger than 13 mm and initial tank pressure greater than 2.5 kg/cm^2 should be adopted to achieve a higher cleaning effect. Between the two cleaning types, type 2 is found to be more effective to clean the bag and the energy consumption for compressed air is reduced significantly from type 1. Therefore, type 2 bag cleaning is suggested to be a better method to clean the baghouse.

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Introduction

Pulse-jet fabric filters are used widely for collecting fly ash from combustion sources because of their high air to cloth (A/C) ratio and low cost. When the pressure drop across the fabric bag is greater than a designated value in a pulse-jet baghouse, a short burst of compressed air is discharged from a nozzle into the filter bag to increase the pulse pressure within the bag. The sudden increase of pressure in the bag leads to the acceleration of the bag cloth and creation of reverse air flow through the bag, resulting in the removal of dust cake (Bakke 1974; Ravin et al. 1988); Morris et al. 1991. Pulse-jet baghouses for control of particulate emissions of coal- and oil-fired boilers are successfully applied throughout the world (Dean and Cushing 1988; Blythe et al. 1991; Bustard et al. 1992). In this study, a pilot-scale baghouse is used to demonstrate the cleaning effect for an oil-fired boiler.

Some investigators (Lanois and Wiktorsson 1982; Bustard et al. 1992) have compared the cleaning performance of three commonly used pulse-cleaning designs: low- (LP), intermediate- (IP), and high-pressure (HP) baghouses. In the LP configuration, the tank pressure reaches approximately 12–30 psi (83.7–206.7 kPa) and no Venturi injector is installed at the bag top. In the HP configuration, a Venturi injector is installed at the bag top to induce secondary airflow. It was found that the LP system design without a Venturi injector requires lower cleaning energy for an equivalent cleaning efficiency.

Humphries and Madden (1983) found that particles will redeposit on the bag after cleaning when on-line cleaning is utilized. This phenomenon reduces the bag-cleaning efficiency. Therefore, two cleaning types are used in this work: Type 1, in which the bag is cleaned only once at high initial tank pressure, and Type 2, in which the bag is cleaned twice in succession at low initial tank pressure. The cleaning effect and energy consumption are compared to search for the most suitable cleaning type.

The cleaning effects of a pulse-jet baghouse are greatly influenced by the design and operating parameters such as nozzle diameter, Venturi type, initial tank pressure, and filtration velocity (Sievert and Löffler 1985; Morris et al. 1991; Lu and Tsai 1996). Therefore, the effects of filtration velocity, initial tank pressure, and nozzle size on the cleaning performance of the pulse jet are also investigated in this study.

Literature Review

Filtration Performance

In the filtration process, the pressure drop is a common measure for evaluating the filtration performance. When the dust accumulates on the fabric to form a dust cake, the filter drag is described by the basic filtration equation (Donovan 1985)

$$\frac{\Delta p}{v_f}=S_f=S_E+K_2(w-w_R)=S_E+K_2w_0 \tag{1}$$

$$\Delta p=(S_E+K_2w_0)v_f=R_fv_f \tag{2}$$

where Δp = pressure drop across the filter bag; v_f = filtration velocity; K_2 = specific resistance coefficient of the dust cake; S_f = filter drag; S_E = effective drag; w = mass areal density of the

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dust cake; w_R = residual dust areal mass density; w_0 = just the dust mass areal density added during the filtration cycle rather than the total mass areal density; and R_f = filter's final resistance coefficient.

Dennis and Klemm (1980) proposed that the filter drag for a single pulse-jet unit be described by the relationship

$$S_f = S_E + (K_2)_c w_c + K_2 w_0 \tag{3}$$

The new term added in Eq. (3) is $(K_2)_c w_c$, which represents the drag contribution of the cycling portion of the dust mass areal density on the fabric, where $(K_2)_c$ = specific resistance coefficient for the cycling fraction of the total dust mass areal density that is alternately dislodged and redeposited on the fabric; and w_c = cycling portion of the dislodgeable dust mass areal density.

Dennis et al. (1981) rewrote Eq. (3) as

$$\Delta p = (p_E)_{\Delta w} + K_2 w_0 v_f = (p_E)_{\Delta w} + C K_2 v_f^2 \Delta t = R_f v_f \tag{4}$$

where the areal density of freshly added dust, w_0, during the filtration interval Δt is expressed as $C v_f \Delta t$. C is the dust inlet concentration. The variable $(p_E)_{\Delta w}$ is defined as the effective residual pressure loss. $(p_E)_{\Delta w}$ can be obtained from the intercept of a linear extrapolation of the pressure-time curve on the pressure axis. The slope of the pressure-time curve equals $C K_2 v_f^2$, and K_2 is easily obtained from the slope when the inlet dust concentration and filtration velocity are constant. The similarity between Eq. (4) and the basic filtration equation [Eq. (2)] is obvious and, in the limit of negligible w_c, Eq. (4) becomes identical to the basic filtration equation. However, Eq. (4) can be applied to on-line pulse-jet filtration.

When the filtration process reaches a steady state, the effective residual pressure loss and specific resistance coefficient of the dust cake will remain constant (Dennis and Hovis 1984). For constant filtration velocity and inlet dust concentration, a lower effective residual pressure loss represents a longer filtration time and a better cleaning effect. The magnitude of $(p_E)_{\Delta w}$ is related to the cleaning energy. In this study, the effective residual pressure loss is used as an index to evaluate the bag-cleaning effect.

Effects of Bag-Cleaning Parameters

Many different bag-cleaning parameters such as pressure impulse, peak pressure, pulse overpressure, and fabric acceleration in the fabric bag have been claimed to be responsible for dust cake release by different investigators (Dennis et al. 1981; Ellenbecker and Leith 1981; Humphries and Madden 1983).

When the pressure drop exceeds a preset value, the dust cake must be removed by pulse-jet cleaning. A critical pulse-jet cleaning energy exists beyond which bag cleaning improves only slightly. Dennis et al. (1981) predicted that an acceleration of $200g$ is required to achieve complete dust dislodgment during pulse-jet cleaning. However, Morris's experiment (1984) demonstrated that the pulse-jet fabric system can operate steadily when the acceleration ranges from only $30g$–$60g$. From Bustard et al.'s observation (1992), an acceleration of $100g$–$200g$ is necessary to dislodge dust effectively. Kligel and Löffler (1983) pointed out that when the air pressure impulse in the fabric bag is greater than 50 Pa·s, dust removal efficiency does not increase further. The pressure impulse (PI) is defined as the integral of pressure versus time over a pulse duration, or $\mathrm{PI} = \int_0^{T_{\mathrm{pd}}} p(t)\,dt$ (T_{pd} = pulse duration). Humphries and Madden (1983) found that there is a minimum pulse pressure of about 0.3 kPa in the fabric bag that removes about 60% of the dust cake. Increasing the pulse pressure beyond this minimum value results in only a slight increase in the amount of dust dislodged. Sievert and Löffler (1989) also showed that it is necessary to reach a critical static overpressure of 400–500 Pa at all locations along the length of a bag in order to achieve a good fabric cleaning efficiency. The overpressure is defined as the pulse pressure inside the bag minus the pulse pressure outside the bag. For fly-ash particles, Lu and Tsai (1998) found that the critical cleaning average pulse overpressure is 500–600 Pa.

In this study, the peak pulse overpressure, average pulse overpressure, and pressure impulse are used as indices of cleaning intensity to evaluate the pulse-jet cleaning effect.

Experimental Method

A schematic diagram of the pilot-scale pulse-jet baghouse for testing the performance of filtration and bag cleaning is shown in Fig. 1. The system consists of a compressed air reservoir, diaphragm valves, air blow tubes, nozzles, fan, baghouse compartment, and air cooler. The compressed air tank volume was 0.08 m^3, and the blow tube diameter was 8.3 cm. In this work, no Venturi injectors were used in the baghouse. Inside the baghouse compartment, two 1.5-m-long and 130-mm-diameter fabric bags made of polyester with acrylic coating were installed. The bags were supported by cylindrical cages. The volume of the compartment was 0.54 m^3. A flow rate control device including an orifice, a pressure transducer (Model R22-01505, MODUS Instruments, Inc.), and a control valve was set downstream of the baghouse to measure the air flow rate during filtration and maintain a constant filtration velocity for each test. The dust of an oil-fired boiler was fed into the baghouse from the boiler through the air cooler. The sulfur content of the oil is about 0.5% by weight. The temperature of the airflow containing dust at the boiler outlet plenum was about 150°C. The temperature and relative humidity of waste gas inside the baghouse were 68–73°C and 78–86%, respectively. The dust mass concentration inside the compartment was determined by a filter holder during filtration. The mass median aerodynamic diameter (MMAD) and geometric standard deviation (σ_g) of emission dust from the oil-fired boiler inside the compartment were measured using a multiorifice uniform deposition impactor (MOUDI) cascade impactor (Model 100, MSP Inc., St Paul, Minn.) to be 1.3 μm and 2.2, respectively. The MOUDI was not connected directly to the stack. A sample tube with heating belt was inserted into the compartment of the baghouse and connected to the MOUDI. The sampling tube was heated to avoid the water vapor condensing inside the sampling tube and MOUDI.

During filtration, the pressure drop Δp across the bag and the volume flow rate Q_f were measured continuously. The pressure drop versus time curve can be used to determine the effective residual pressure loss $(\Delta P_E)_{\Delta w}$, and the specific resistance coefficient K_2 of the dust cake. After attaining a pressure drop of 4 in. H_2O (996 Pa), the diaphragm valve opened and the compressed air was injected into the bag from the nozzle to remove the dust accumulated on the bag. The dislodged dust dropped into the hopper and was removed by the rotary valve. The filtration velocity, initial tank pressure, and nozzle diameter were varied for the pulse-jet cleaning system to obtain different operating conditions. In order to determine the cleaning conditions inside the bag when the compressed air was released, it is necessary to measure the pulse pressure at various positions along the bag head. For this reason, high-frequency pressure transducers (Model R22-01505, MODUS Instruments, Inc., Clinton, Mass.) were installed on the bag. The pulse pressure was measured at three positions located at

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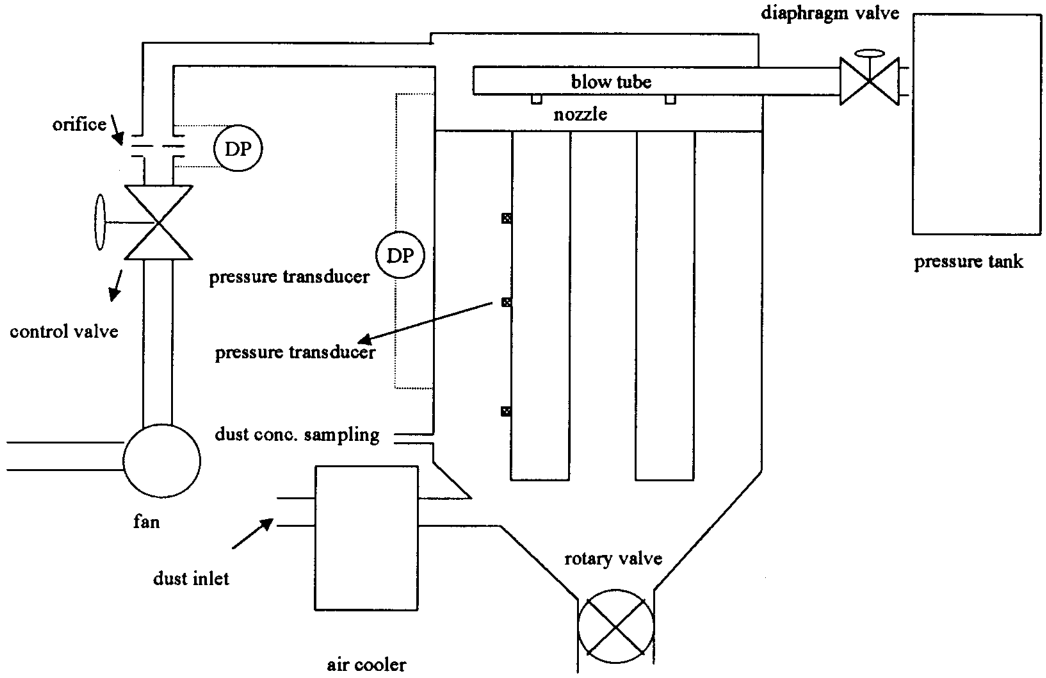

Fig. 1. Schematic diagram of pilot-scale pulse-jet baghouse

20, 100, and 140 cm from the bag opening. The pulse pressure was recorded by computer during the bag-cleaning period.

All tests were performed at a constant filtration velocity. When the pressure drop across the fabric reached 4 in. H_2O (996 Pa), the bag cleaning was initiated and the pulse pressure inside and outside the bag were recorded by the pressure transducers. Before the pilot-scale test, the baghouse was set to run for about 50 h. The design and operation conditions are shown in Table 1.

Table 1. Design and Operation Parameters of Pulse-Jet Baghouse Used in this Study

Parameter	Value
Design and operation parameters	
Number of bags	4
Bag length	1.5 m
Bag diameter	130 mm
Bag fabric	Polyester with acrylic coating
Ventury	No Venturi
Number of nozzles	4
Nozzle diameter d_n	8, 13, and 20 mm
Distance between nozzle and venturi S	72 mm
Filter operating condition	
Temperature of waste gas	68–73°C
Relative humidity of waste gas	78–86%
Dust	Emission dust of oil-fired boiler, MMAD≒1.3 μm, $\sigma_g = 2.2$
Filtration velocity v_f	4–8 cm/s
Inlet dust concentration C	30.2–53.7 mg/m^3
Cleaning pulse duration T_{pd}	300 ms
Initial tank pressure p_{tk0}	1.0–6.0 kg/cm^2

Results and Discussion

Filtration Curve of Pilot-Scale Test

The filtration cycle of the long-term test is shown in Fig. 2. The operation conditions are $p_{\mathrm{tk0}} = 2-6$ kg/cm^2, $v_f = 4.0$ cm/s, and $d_n = 13$ mm. It is found that the baghouse works well in this study. The specific dust cake resistance coefficient K_2 can be obtained from this filtration curve by fitting the linear portion of the data from Eq. (2), and the effective residual pressure loss $(P_E)_{\Delta w}$ can be obtained from the intercept of the linear portion of the curve. Fig. 3 shows the linear portion of the filtration curve when the baghouse operates at $d_n = 13$ mm, $p_{\mathrm{tk0}} = 3.0$ kg/cm^2, $v_f = 4.3$, 6.0, and 8.0 cm/s, respectively. The calculated K_2 values are 5.13, 4.45, and 4.17 N·min/g·m (307,888, 267,479, and

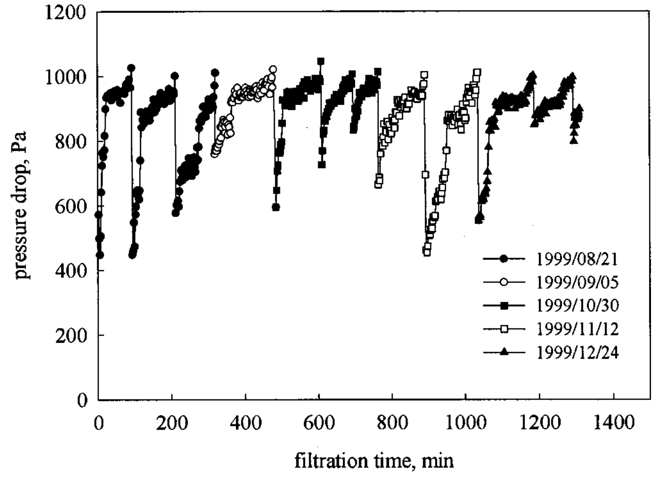

Fig. 2. Filtration cycle of long-term test

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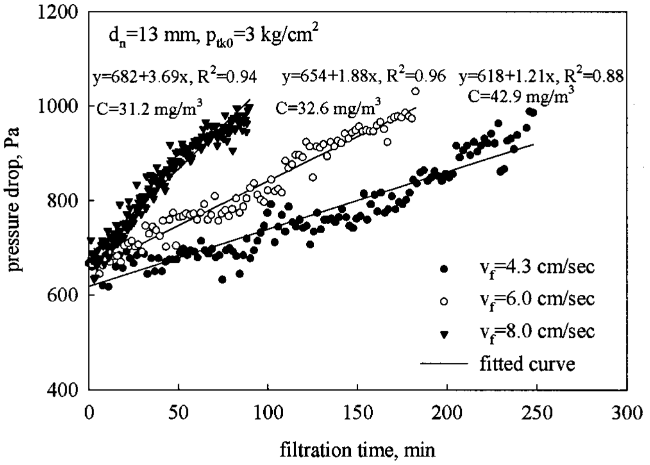

Fig. 3. Linear portion of filtration curve for filtration velocity when baghouse operates at $d_n = 13$ mm, $p_{tk0} = 3.0$ kg/cm^2

250,200 s^{-1}), respectively. Similar experimental data were obtained for different initial tank pressures for the bag cleaning.

The relationship between K_2 and filtration velocity obtained from filtration at $d_n = 13$ mm is

$$K_2 \ (\mathrm{s}^{-1}) = 1.53 \times 10^5 V^{0.33} \tag{5}$$

for the emission dust of an oil-fired boiler (MMAD = 1.3 μm) where the units of K_2 and V are s^{-1} and cm/s, respectively.

The curve of Eq. (5) can be represented by $\hat{K}_2 = aV^b$, and the number of samples is $n = 8$. If we take the logarithms of both sides of Eq. (5), it becomes

$$\log(\hat{K}_2) = \log a + b \log V \tag{6}$$

The equation can be rewritten as $\hat{Y} = \hat{\beta}_0 + \hat{\beta}_1 X$, where $\hat{Y} = \log(\hat{K}_2)$, $\hat{\beta}_0 = \log a$, and $\hat{\beta}_1 = b$. The slope ($\hat{\beta}_1$) and intercept ($\hat{\beta}_0$) of the regression line can be obtained by the method of least squares.

The confidence intervals of the regression line are desired. For a straight-line regression, the corresponding confidence interval for $\mu_{Y|X_0}$, the expected value of Y at X_0 is given by the formula (Kleinbaum et al. 1988)

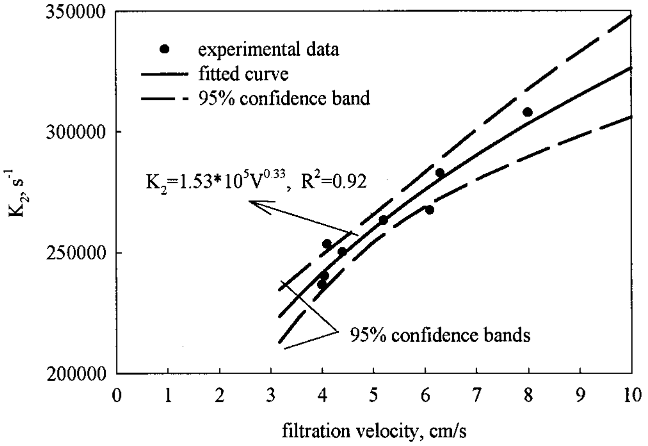

Fig. 4. Relationship between filtration velocity and K_2

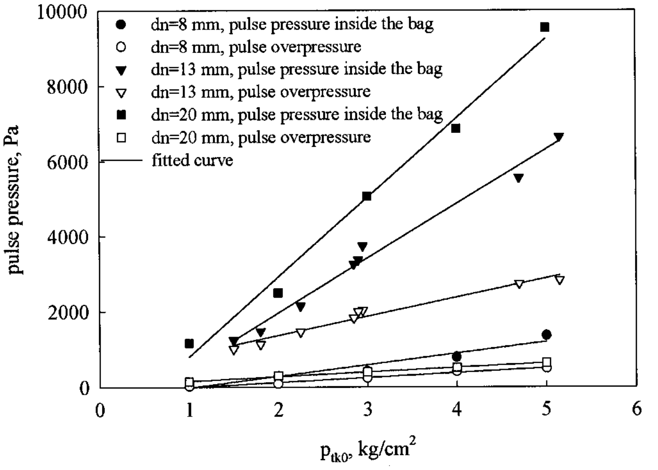

Fig. 5. Influence of initial tank pressure and nozzle diameter on average pulse overpressure and pulse pressure inside bag

$$Y_{X_0} \pm t_{n-2,1-\alpha/2} S_{\hat{Y}_{X_0}} \tag{7}$$

$$S_{\hat{Y}_{X_0}} = S_{Y|X}\sqrt{1/n + (X_0 - \overline{X})^2/(n-1)S_X^2} \tag{8}$$

where $Y_{X_0} = \hat{\beta}_0 + \hat{\beta}_1 X_0$ = predicted value of Y at X_0; $S_{\hat{Y}_{X_0}}$ = estimate of the standard deviation of Y_{X_0}; $S_{Y|X}$ = estimate of variance of Y; $\overline{X}$ = average of X; and S_X^2 = variance of X.

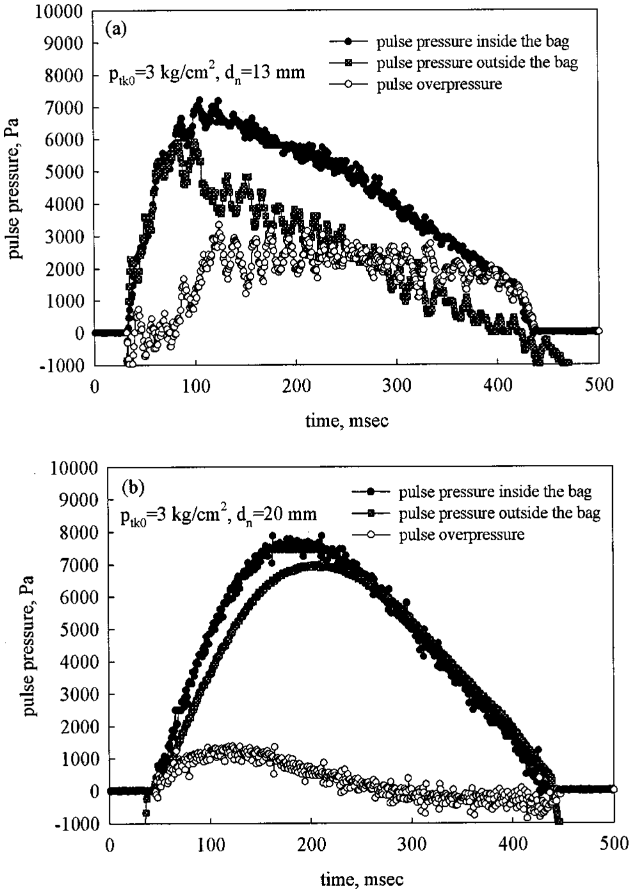

Fig. 6. Pulse pressures inside and outside bag during bag cleaning at $p_{tk0} = 3$ kg/cm^2 and $d_n =$ (a) 13, (b) 20 mm.

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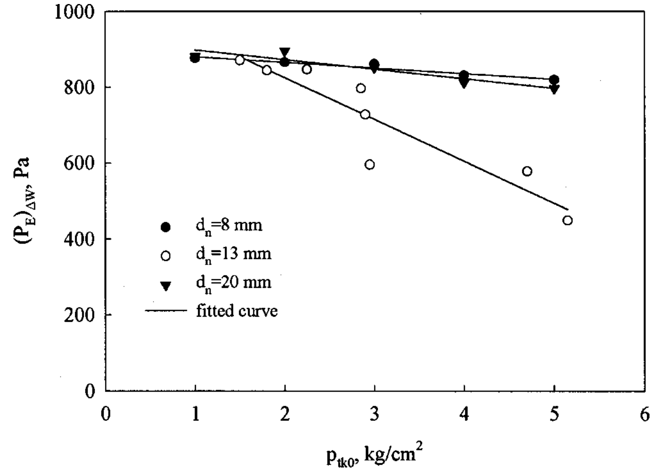

Fig. 7. Influence of initial tank pressure on effective residual pressure loss for different nozzle diameters

By using the previous formulas, the fitted curve and 95% confidence intervals of the K_2 value are shown in Fig. 4. In a previous study of a pilot-scale pulse-jet baghouse (Tsai et al. 2000), the relationship between K_2 and filtration velocity for fly ash of a coal-fired boiler and limestone were described as

$$K_2\ (\mathrm{s}^{-1})=2.24\times10^5V^{0.66},\quad \text{fly ash of coal-fired boiler (MMAD}=6.0\ \mu\text{m)}$$

$$K_2\ (\mathrm{s}^{-1})=4.75\times10^5V^{0.44},\quad \text{limestone (MMAD}=2.6\ \mu\text{m)}$$

The K_2 values reported previously are compared with the confidence intervals of the K_2 value of this work. For example, the K_2 values of fly ash of a coal-fired boiler and limestone at $V=4$ and 6 cm/s are 559,252, 874,178 and 730,850, 1,044,913 s^{-1} [calculated from the regression curve of Tsai et al. (2000)], respectively. For $\alpha=0.05$, the corresponding 95% confidence intervals of K_2 values at $V=4$ and 6 cm/s are (234,250,249,225) and (268,910,283,279), respectively. It is found that the K_2 values of previous work are outside the 95% confidence interval bands; therefore the K_2 value of this work is different from the values reported previously.

It is seen that the influence of filtration velocity on the specific cake resistance coefficient for larger particles is larger than for smaller particles. Previous research also pointed out that the K_2 value will increase by about 20% when the filtration velocity increases from 5 to 12 cm/s (Ellenbenbecker and Leith 1981). The higher filtration velocity also makes the baghouse blind easily. Therefore, the filtration velocity of 4 cm/s is used in the following discussion.

Influence of Initial Tank Pressure and Nozzle Diameter on Bag Cleaning

Fig. 5 shows the influence of initial tank pressure and nozzle diameter for bag cleaning on average pulse overpressure p_{ov} and average pulse pressure inside the bag, p_{in}. The p_{in} for bag cleaning is the absolute pressure inside the bag and results from the burst of high-pressure compressed air from the compressed air reservoir. The average overpressure is the driving force for bag cleaning, which is defined as the average of the pulse pressure inside the bag minus the pulse pressure outside the bag. It is seen that both the average pulse overpressure and the pulse pressure inside the bag increase with the initial tank pressure. The relationships between the average pulse overpressure and p_{in} and initial tank pressure are almost linear. Therefore, increasing the initial tank pressure is the most convenient way to increase the cleaning effect.

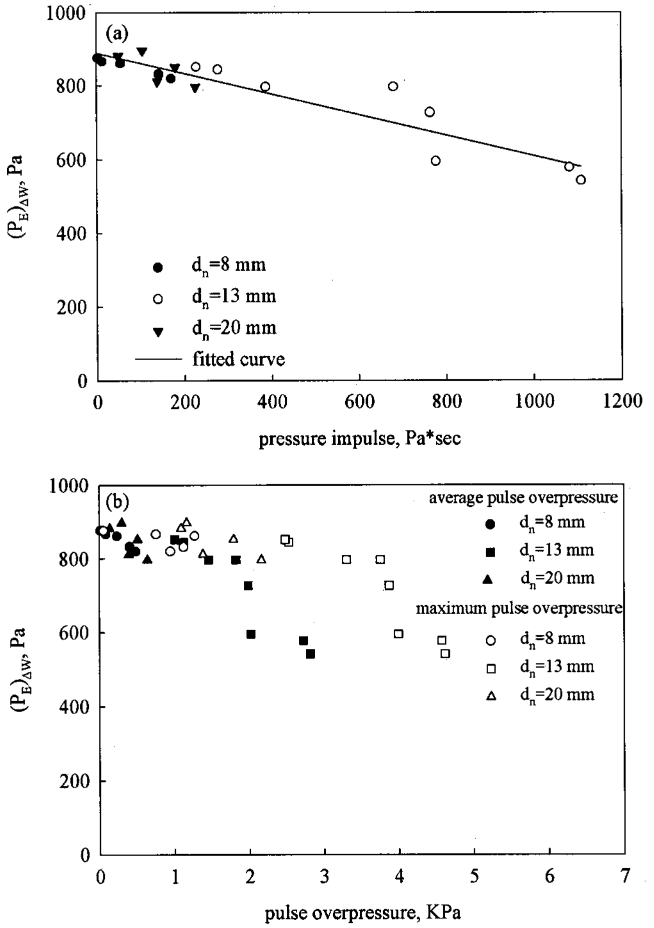

Fig. 8. Effects of (a) pressure impulse on cleaning effect for different nozzle diameters; (b) maximum and average pulse overpressure on cleaning effect for different nozzle diameters

It is also found from this figure that the average pulse pressure increases with the nozzle diameter, since a larger nozzle diameter will discharge more compressed air. However, the average pulse overpressure does not show this trend, so there exists an optimal nozzle diameter (13 mm) to achieve the higher pulse overpressure. This phenomenon can be explained by Fig. 6, which shows the pulse pressures inside and outside the bag at $p_{tk0}=3$ kg/cm^2, the difference being the pulse overpressure. It is seen from Figs. 6(a and b) that the pulse pressure outside the bag is very large for $d_n=20$ mm and results in lower pulse overpressure. In this study, the volume of the baghouse compartment is about 0.54 m^3. The suction flow rate of waste gas by the fan is 5.9 m^3/min. When an initial tank pressure of 3 kg/cm^2 is used, the discharged mass flow of compressed air from the nozzle can be computed by (Kayser and Shambaugh 1991)

$$\dot{M}_{\text{isen}}=Ap_{tk0}\left[\frac{\gamma M_W}{R_gT}\left(\frac{2}{\gamma+1}\right)^{(\gamma+1)/(\gamma-1)}\right]^{1/2},\quad p_{\text{com}}/p_{tk0}<\theta \tag{9}$$

where $\dot{M}_{\text{isen}}$ = isentropic, adiabatic mass flow rate of discharge compressed air; A = area of the nozzle; p_{com} = pressure inside the

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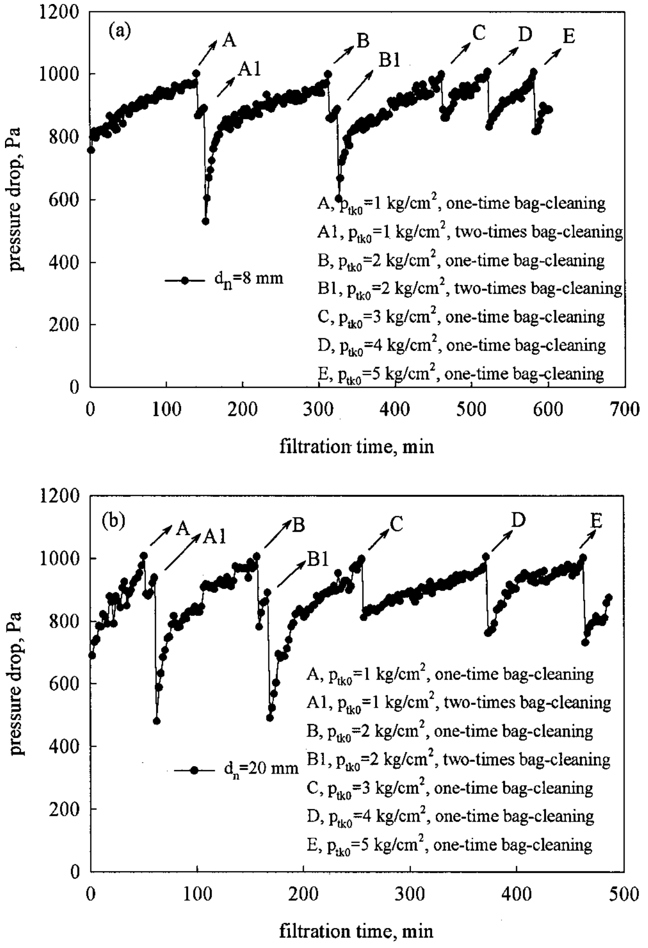

Fig. 9. Filtration curves for two operating conditions: $d_n =$ (a) 8 and (b) 20 mm

compartment just before bag cleaning; M_W = molecular weight of air; R_g = universal gas constant 8,314 J/kgmol·K; γ = heat capacity ratio; and θ = pressure ratio 0.528. When the ratio of $p_{\mathrm{com}}/p_{tk0} < 0.528$, the gas velocity at the nozzle becomes sonic.

From Eq. (9), the discharge mass flow rate of air from the nozzle can be calculated, and the volume flow rate of cleaning air at standard temperature and pressure (STP) can also be calculated. The calculated mass flow of compressed air from four nozzles during the cleaning period for $d_n = 20$, 13, and 8 mm is about 1.19, 0.50, and 0.19 kg/s, respectively. The volume flow rates at STP are about 0.99 (59.4), 0.41 (24.6), and 0.16 m^3/s (9.6 m^3/min) for $d_n = 20$, 13, and 8 mm, respectively. Therefore, the suction flow rate (5.9 m^3/min) cannot release the cleaning airflow immediately. The excess airflow accumulates inside the compartment (outside the bag). The small compartment volume (0.54 m^3) results in the excess air volume being converted to static pressure. This phenomenon causes the pulse pressure outside the bag for $d_n = 20$ mm to be significantly larger than that for $d_n = 13$ mm. Therefore, there must exist an optimal nozzle diameter to make the pulse overpressure achieve a maximum value in this study. A nozzle diameter of 13 mm can reach the maximum overpressure in this study. However, a larger compartment volume can reduce the conversion of excess airflow to pulse pressure outside the bag. Then the pulse overpressure will increase with the nozzle diameter.

Relationships between Index of Cleaning Effect and Cleaning Intensities

The effective residual pressure loss is used as an index of the cleaning effect and the average, maximum overpressure and pressure impulse inside the bag are recognized as the cleaning intensity in this study. Fig. 7 shows the influence of initial tank pressure on the effective residual pressure loss for different nozzle diameters. It is found that the bag-cleaning effect is best for $d_n = 13$ mm since the pulse overpressure for $d_n = 13$ mm is maximum. The next best value is for $d_n = 20$ mm, and the minimum value is for $d_n = 8$ mm. Therefore, the cleaning effect seems to increase with pulse overpressure.

Figs. 8(a and b) show the effects of pressure impulse and maximum and average pulse overpressure on the cleaning effect for different nozzle diameters. Figs. 8(a and b) display that the cleaning effect increases with pressure impulse and average and maximum pulse overpressure. It is seen from Fig. 8(a) that there seems to exist a critical pressure impulse at about 800 Pa·s. When the pressure impulse is greater than 800 Pa·s, the cleaning effect increases only slightly. This value is much larger than the result of Klingel and Löffler (1983) (50 Pa·s). Fig. 8(b) also shows a similar phenomenon. The critical average and maximum pulse overpressure are about 2 and 4 kPa, respectively. This is also much greater than the values of 400–500 Pa (Sievert and Löffler 1989) and 500–600 Pa (Lu and Tsai 1998). The reason for this is the high relative humidity and small particle size of dust particles in this study. When relative humidity is high and particle size is small, particles will adhere tightly to the bag and a higher cleaning force is needed to clean the dust cake.

Suggested Nozzle Diameter for Industrial Size Baghouse

In this work, the size of the pilot-scale baghouse is quite small (the compartment volume is 0.54 m^3). Therefore, the cleaning air accumulates inside the compartment (outside the bag) and is converted to static pressure. This phenomenon makes the pulse overpressure (pulse pressure inside the bag minus pulse pressure outside the bag) maximum at $d_n = 13$ mm. However, if the compartment volume increases to industrial size, the cleaning air will be released inside the compartment and the pulse pressure outside the bag will be reduced and approach zero. Therefore, the pulse overpressure will increase with the pulse pressure inside the bag. It is seen that the pulse pressure inside the bag increases with the nozzle diameter (see Fig. 5). Thus, the pulse overpressure and cleaning effect will increase with the nozzle diameter for an industrial size baghouse. From Fig. 8(b), it is seen that the cleaning effect increases only slightly when the pulse overpressure is larger than 2 kPa. If we assume the pulse pressure outside the bag will be reduced to zero for an industrial size baghouse, then the pulse overpressure will equal the pulse pressure inside the bag. From Fig. 5, the pulse pressure inside the bag can achieve 2 kPa for $d_n = 13$ mm at $p_{tk0} = 2.2$ kg/cm^2 and $d_n = 20$ mm at $p_{tk0} = 1.6$ kg/cm^2. The maximum pulse pressure inside the bag achieves only 1.4 kPa for $d_n = 8$ mm at $p_{tk0} = 5$ kg/cm^2. Therefore, it is suggested that the smallest nozzle diameter should be larger than 13 mm for an industrial size filter. However, the pulse pressure depends on the nozzle diameter and initial tank pressure. We suggest that $d_n > 13$ mm and $p_{tk0} > 2.5$ kg/cm^2 can be adopted for an industrial size filter.

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Table 2. Effective Residual Pressure Loss and Energy Consumption of Bag Cleaning for different Bag-Cleaning Types

	$d_n = 8$ mm		$d_n = 20$ mm	
Cleaning type	Energy consumption (kJ)	Pressure drop after cleaning (Pa)	Energy consumption (kJ)	Pressure drop after cleaning (Pa)
$p_{\mathrm{tk}0} = 1.0$ kg/cm^2, one cleaning	4.0	876.5	8.1	881.5
$p_{\mathrm{tk}0} = 1.0$ kg/cm^2, two cleanings	8.1	530.4	16.1	480.6
$p_{\mathrm{tk}0} = 2.0$ kg/cm^2, one cleaning	5.7	866.5	16.2	781.9
$p_{\mathrm{tk}0} = 2.0$ kg/cm^2, two cleanings	11.4	602.6	32.4	490.5
$p_{\mathrm{tk}0} = 3.0$ kg/cm^2, one cleaning	7.3	861.5	20.3	811.7
$p_{\mathrm{tk}0} = 4.0$ kg/cm^2, one cleaning	8.9	831.7	24.3	769.4
$p_{\mathrm{tk}0} = 5.0$ kg/cm^2, one cleaning	11.3	819.2	29.2	747.0

Comparison of Cleaning Effect for Two Different Cleaning Types

It is found from the previous discussion that increasing the initial tank pressure is the most convenient way to increase the cleaning effect. However, the energy consumption of compressed air is also larger for higher initial tank pressure. Therefore, two operating conditions for bag cleaning are compared in this study: Type 1, where bag cleaning occurs once at high initial tank pressure, and type 2, where bag cleaning occurs twice at low initial tank pressure. The time between the two sequential pulses is about 5–10 s for type 2 bag cleaning. The filtration curves for the two operating conditions are shown in Figs. 9(a and b) for $d_n = 8$ and 20 mm, respectively. From the figures, it is found that the type 2 operating condition at low initial tank pressure can achieve a lower baghouse pressure drop after cleaning than type 1 operation at high initial tank pressure. The reason is that the first cleaning for type 2 will loosen particles adhered on the bag and the second cleaning will pulse the dust away from the bag. Therefore, the type 2 operating condition is much more effective for bag cleaning than type 1. Table 2 displays the energy consumption and pressure drop after cleaning for the two bag-cleaning conditions. It is found that the type 2 operating condition at low initial tank pressure ($p_{tk0} = 1$ and 2 kg/cm^2) can obtain a lower pressure drop and energy consumption than type 1 at high initial tank pressure ($p_{tk0} = 4$ and 5 kg/cm^2). Therefore, the type 2 operating condition can achieve a better cleaning effect with less energy consumption of compressed air.

Conclusions

A pilot-scale pulse-jet baghouse was used to control the particulate emission of an oil-fired boiler. Different filtration velocities, initial tank pressures, and nozzle diameters were chosen to evaluate the cleaning effect of the pulse-jet baghouse. In addition, two different cleaning conditions were used to compare the bag-cleaning performance in this study.

It is found that increasing the initial tank pressure is a convenient way to increase the cleaning effect. However, the pulse overpressure inside the bag does not increase with the nozzle diameter. There exists an optimum nozzle diameter to achieve higher cleaning intensity and better cleaning effect in this work. This phenomenon results from the larger excess air in the compartment for larger nozzle diameter; the small volume of the baghouse compartment converts the excess airflow to static pressure. Thus the overpressure cannot increase with the nozzle diameter. If an industrial size baghouse is used, the experimental data of this work suggest that a nozzle diameter larger than 13 mm and initial tank pressure greater than 2.5 kg/cm^2 should be adopted to achieve a higher cleaning effect. Between the two cleaning conditions, the type 2 operating condition can achieve a better cleaning effect with less energy consumption of compressed air than type 1. Therefore, bag-cleaning type 2 is suggested to be a better method to apply in bag cleaning for the pulse-jet baghouse.

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Notation

The following symbols are used in this paper:

A = area of nozzle (m^2);
C = dust concentration (mg/m^3);
d_n = nozzle diameter for bag cleaning (mm);
K_2 = specific resistance coefficient of dust cake (s^{-1});
$\dot{M}_{\mathrm{isen}}$ = isentropic, adiabatic mass flow rate of discharge compressed air (kg/s);
M_W = molecular weight of air (kg/kgmol);
p_{com} = pressure inside compartment just before bag cleaning (Pa);
$(p_E)_{\Delta w}$ = effective residual pressure loss (Pa);
p_{in} = average pulse pressure inside bag (Pa);
p_{ov} = average pulse overpressure (Pa);
p_{tk0} = initial tank pressure for bag cleaning (kg/cm^2);
R_f = filter's final resistance coefficient (Pa·s/cm);
R_g = universal gas constant 8,314 J/kgmol·K;
S_E = effective drag of residual dust (Pa·s/cm);
S_f = filter drag (Pa·s/cm);
S_X^2 = variance of X;
$S_{Y|X}$ = estimate of variance of Y;
$S_{\hat{Y}_{X_0}}$ = estimate of standard deviation of Y_{X_0};
t = filtration time (min);
v_f = filtration velocity (cm/s);
W = mass areal density of dust cake (g/cm^2);
W_R = residual dust areal density (g/cm^2);
W_0 = freshly accumulated dust areal density after cleaning cycle (g/cm^2);
X = independent variable of straight line;
$\overline{X}$ = average of X;
Y = dependent variable of straight line;
Y_{X_0} = predicted value of Y at X_0;

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$\hat{\beta}_0$ = estimated intercept of regression line;
$\hat{\beta}_1$ = estimated slope of regression line;
γ = heat capacity ratio;
Δp = filtration pressure drop (Pa); and
θ = pressure ratio 0.528.

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