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Analysis of Pulse-jet Cleaning of Dust Cake from Ceramic Filter Element

Keywords: Ceramic Filter, Patchy Cleaning, Hot Gas Cleaning, Pulse-jet Cleaning System

Introduction

Release of accumulated dust from the rigid candle filter surface has been extensively studied both theoretically and experimentally, especially for the case of pulse jet type cleaning[1)~16)]. However, it is still unclear which is the most effective parameter to the release of accumulated dust.

In this study, behaviors of released dust and pressure inside and outside the filter element were observed very precisely. Based on the observation, a simple model correlating between momentum acting on released dust, pressure and, shear and tensile stresses has been proposed. Then its validity was discussed by comparing calculated and experimental results.

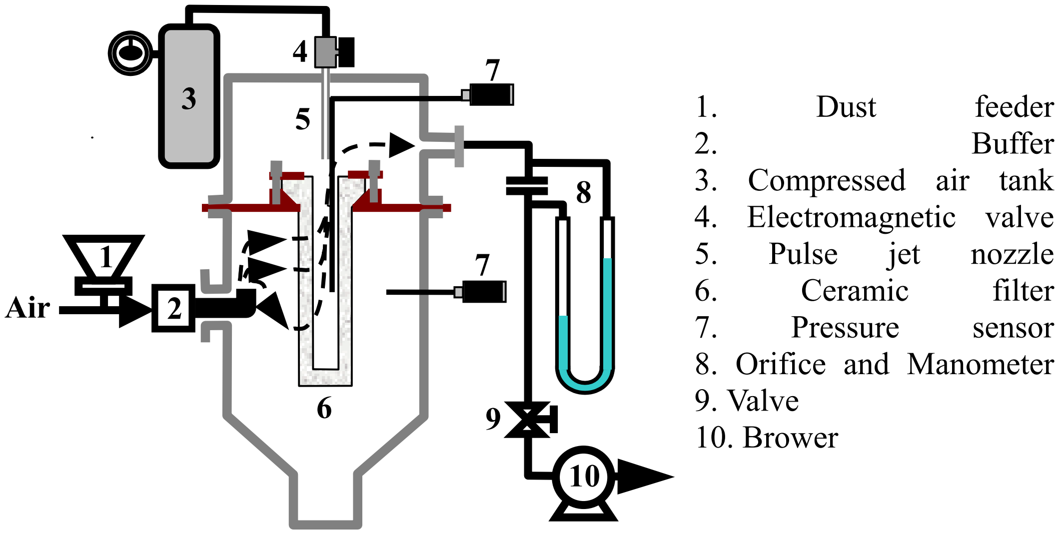
Objective

To establish a dust release model, information needed is shape, size, thickness, periphery length of released dust after release and pressure acting on dust cake. Hence, the motion of released dusts and pressure behavior were monitored at different locations of the element and at various cleaning conditions by using a high speed video camera and a pressure sensor with high frequency. Then, releasing efficiency and projected area, thickness of released dusts and the periphery length of the released dust flakes was measured.

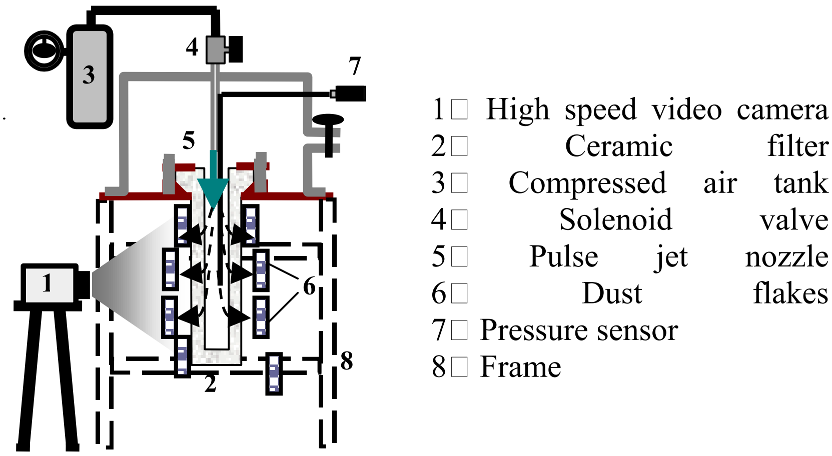
Based on the experimental results, the shear and tensile stresses acting on the dust was evaluated and compared with the proposed model.

Approach

1. Experiment
   (1) Behavior of the released dust flakes
   (2) Pressure behavior inside and outside of the filter element
2. Estimation of impulse and momentum
   (1) Description of the dust release dynamics
   (2) Momentum of released dust
   (3) Impulse due to the pulse-jet
   (4) Estimation of impulse for dust release



(a) During the filtration



(b) At the cleaning

Fig. 1 Schematic diagram of experimental setup

Project Description

Fig.1 shows a schematic diagram of the experimental setup for observation of cleaning process. Candle type ceramic filter (SiC, ID 40mm, OD 60mm, length 300mm, permeability 6.5 x 10^{-12} m^2) was installed at the center of the housing (ID 300mm, length 700mm) vertically as Fig.1(a). All experimental runs are performed at room temperature and around 60% relative humidity. Pulse-jet cleaning system consists of a compressed air reservoir with 6-liter volume, a solenoid valve and a nozzle (9mm ID x 450mm long). The nozzle is centrally placed with a distance of 10mm above the open end of the filter element. Flyash test particles (x_{50}=1.7μm, σ=1.9, ρ=2500kg/m^3) are fed by a table feeder and are dispersed by compressed air at 0.8g/min. Flyash particles were captured on the filter at the filtration velocity of 3m/min until pressure drop due to the accumulated dust becomes 3600Pa. After the filtration, thickness of deposited dust layer on the filter surface was measured by a laser displacement sensor.

Then the filter housing was replaced with a frame as Fig.1(b) and the compressed air (100, 200 and 300kPa) was injected for 220ms to release accumulated dust on the outer surface of the filter. Dust was released by injecting compressed air impulsively inside the filter and then pressure difference behavior and motion of released dust cake were monitored by a piezo-type pressure sensor and a high speed video monitor, respectively.

To see the influence of packing density of dust layer, two types of packing condition as consolidated and non-consolidated dust were tested. The consolidation was carried out by flowing clean air at 5m/min until pressure difference does not change.

Results

(1) Behavior of the released dust flakes

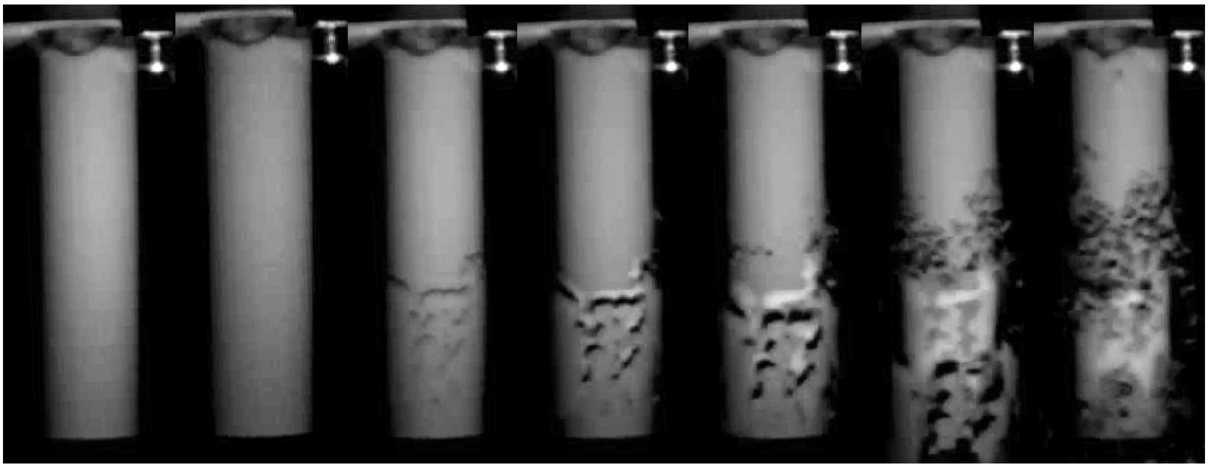
Fig.2 and Fig.3 show release behavior of the accumulated dust as images from the high-speed video camera monitoring the filter element at the pulse-jet cleaning. Concerning the releasing pattern, very clear difference was observed depending on pre-consolidated and non-consolidated dust, i.e., when captured particles were released without pre-consolidated condition, release first took place almost instantaneously at the lower section of the filter, and then release area expands to higher section for all tested cleaning cleaning pressures. Shape and size of released dust flake were mostly large and vertically strip shape at the beginning but it got smaller afterwards.

When dust layer was pre-consolidated, which means accumulated dust layer became denser structure, for cleaning pressure of 100 and 200 kPa, small amount of release of short and circular dust pieces was observed at the central part of the filter and this continued for a while forming patchy cleaning pattern. Then released area expanded to the lower and higher section. This was understood because of insufficient cleaning force against dense and thus strongly cohered layer. However, at the cleaning pressure of 300kPa, i.e., applying sufficiently strong releasing pressure, almost the similar release pattern was observed for non-consolidated condition. At the regions where dust flakes are released at small amount and size, dust is not released effectively, and results patchy cleaning. Patchy cleaning may occur when adhesive force of dust flake is relatively large compare to the impact of cleaning air.

Fig.4 shows properties of released flakes estimated from video image analysis of dust release. Size and shape of the released dust flake has larger value of project area and periphery length for higher cleaning pressure or lower porosity of dust layer. Also released area and periphery at each location along the filter were shown in Table 1 and 2, respectively.

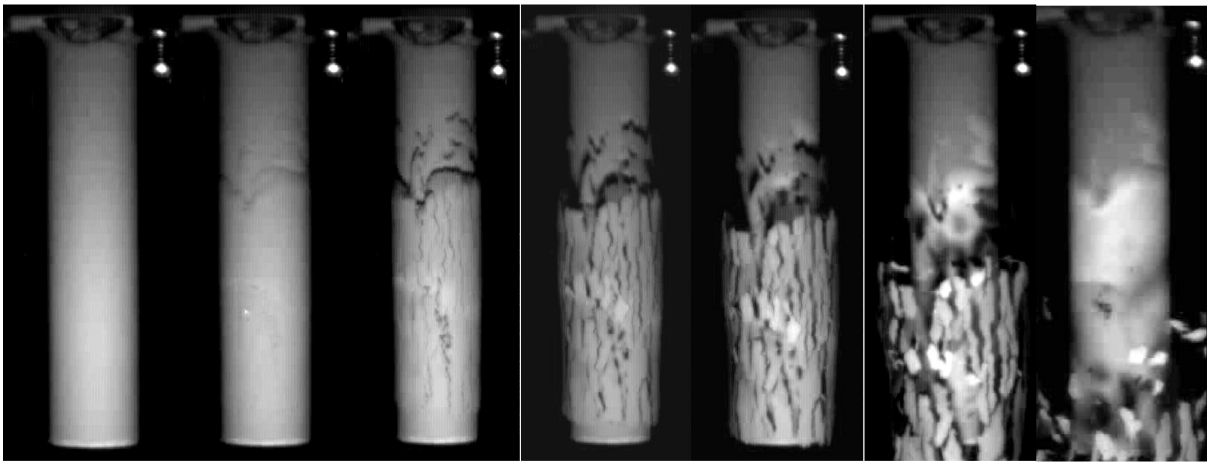
(2) Pressure difference

Fig.5 shows the time behavior of pressure difference between inside and outside the filter Δp at 5 different locations along the filter axis. Δp increased with time but increasing rate got larger at lower part of the filter and also at higher cleaning pressure. However, Δp did not changed so much in the lower section of the filter for tested cleaning pressures. From the video images, start time of dust release is about 10ms after the injection under the tested condition. Δp at 10ms is in its rapid increasing period and the value is less than a half of maximum pressure difference suggesting that cleaning efficiency of dust would not increase by extension of injecting period.



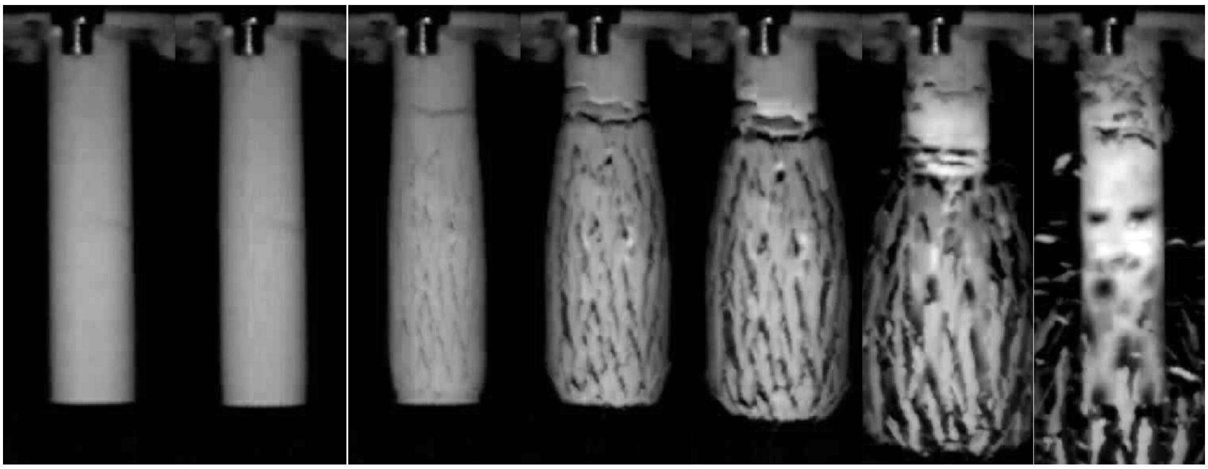
t=10ms 12.5ms 25ms 55ms 77.5ms 120ms 180ms

(a) Cleaning pressure 100kPa



t=10ms 12.5ms 25ms 55ms 77.5ms 120ms 180ms

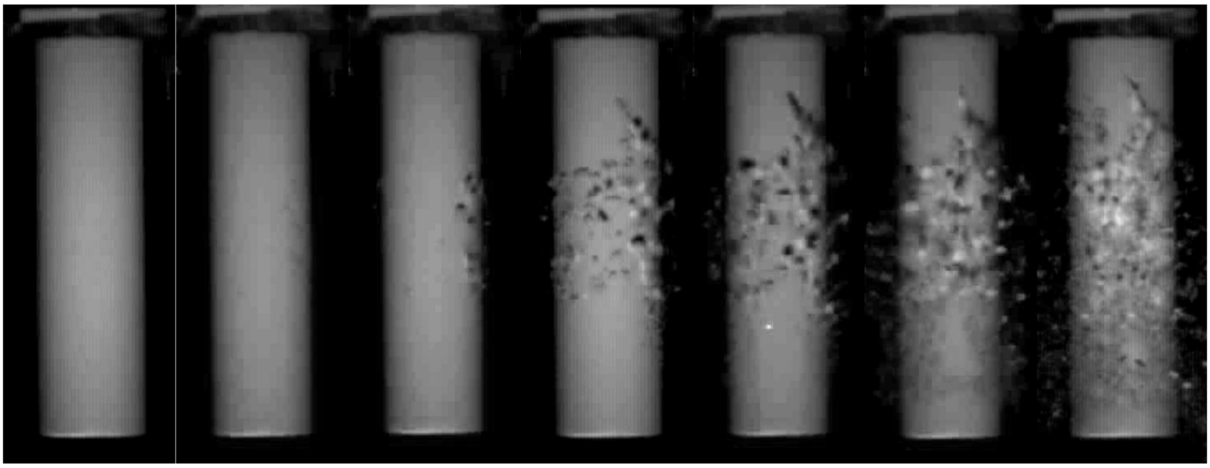
(b) Cleaning pressure 200kPa



t=10ms 12.5ms 25ms 55ms 77.5ms 120ms 180ms

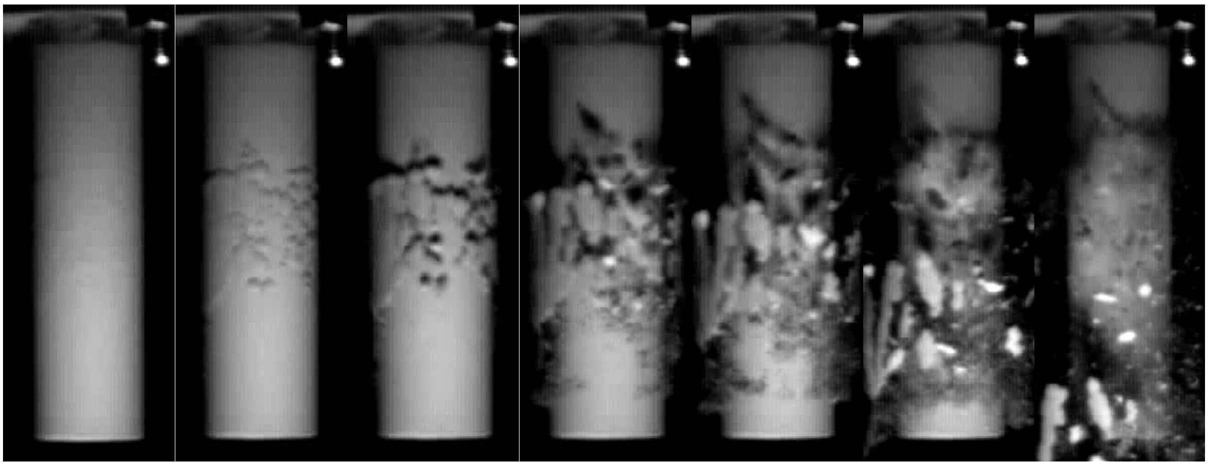
(c) Cleaning pressure 300kPa

Fig.2 Release behavior of non-consolidated dust



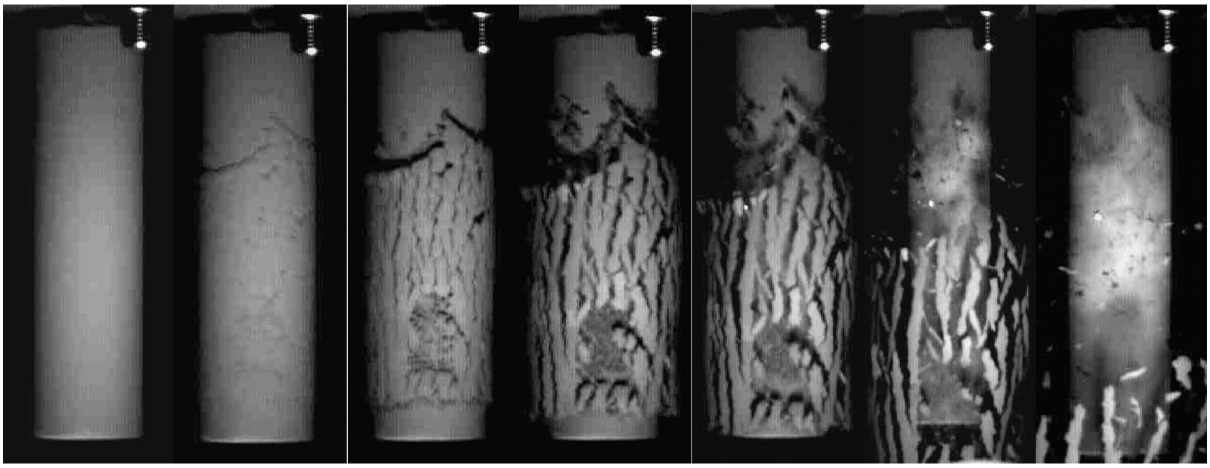
t=10ms 12.5ms 25ms 55ms 77.5ms 120ms 180ms

(a) Cleaning pressure 100kPa



t=10ms 12.5ms 25ms 55ms 77.5ms 120ms 180ms

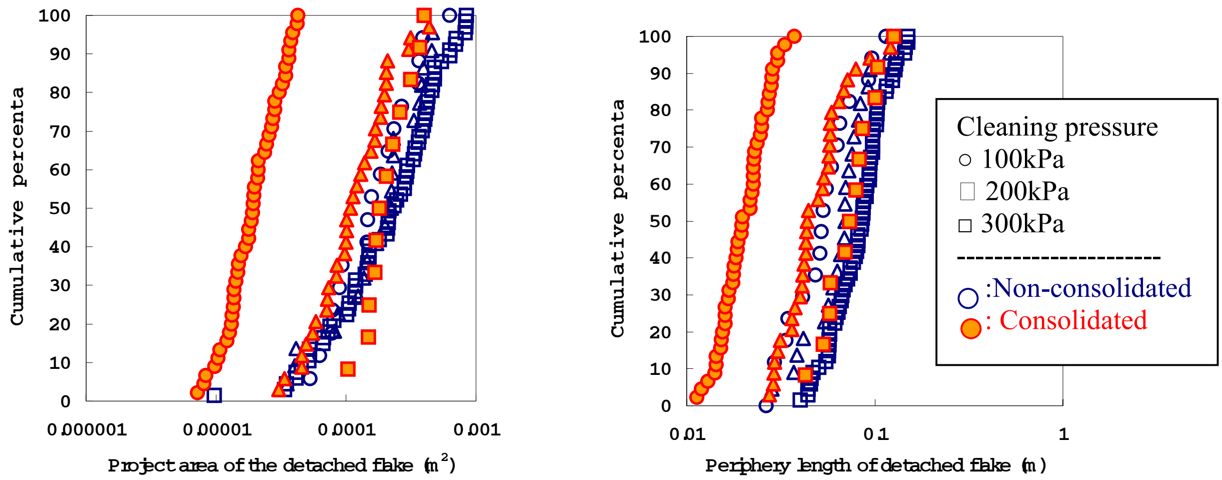
(b) Cleaning pressure 200kPa



t=10ms 12.5ms 25ms 55ms 77.5ms 120ms 180ms

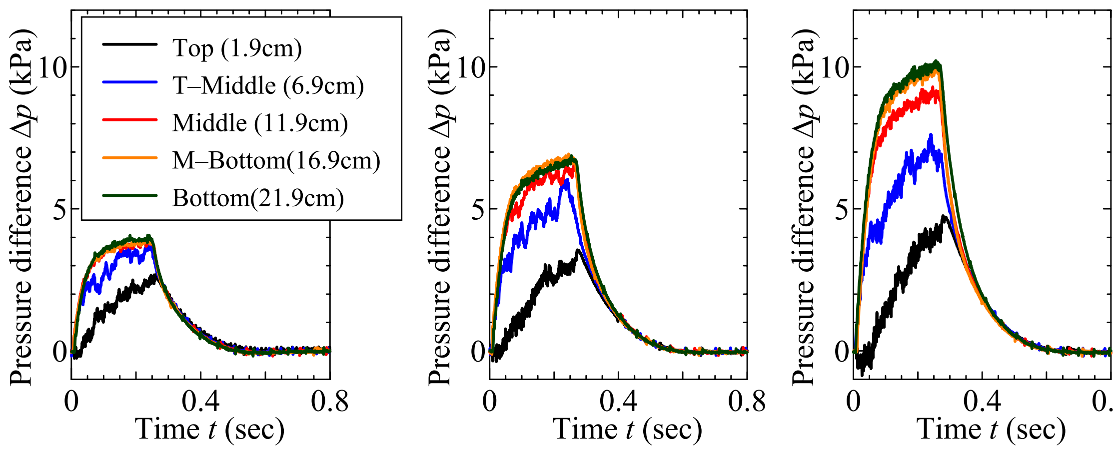
(c) Cleaning pressure 300kPa

Fig.3 Release behavior of consolidated dust



(a) Project area (b) Periphery length

Fig.4 Properties of released flakes



(a) 100kPa (b) 200kPa (c) 300kPa

Fig.5 Time dependence of pressure difference between both sides of the filter element at the different positions

Table 1 Project area S

Cleaning Pressure(kPa)	Condition	S (m^2/ -10^{-3})				
		Top	T-middle	Middle	M-bottom	Bottom
100	Non-consolidated	-	-	7.5	7.5	9.4
	Consolidated	-	3.9	3.4	1.8	-
200	Non-consolidated	-	9.4	9.4	9.4	9.4
	Consolidated	-	4.0	8.1	6.2	-
300	Non-consolidated	9.4	9.4	9.4	9.4	9.4
	Consolidated	-	1.7	6.2	1.1	-

Table 2 Periphery length l

Cleaning Pressure(kPa)	Condition	l (m)				
		Top	T-middle	Middle	M-bottom	Bottom
100	Non-consolidated	-	-	0.3	2.2	3.0
	Consolidated	-	3.3	2.2	3.0	-
200	Non-consolidated	-	3.2	2.3	2.7	2.4
	Consolidated	-	1.7	2.1	2.2	-
300	Non-consolidated	3.2	2.1	2.0	2.3	2.0
	Consolidated	-	3.1	2.4	2.7	-

Application

(1) Description of the dust release dynamics

Fig.5 schematically shows the mechanism and related parameters for dust release. When one dust flake is going to be split from the dust layer and be released from the filter surface, three types of stress are considered to be effectively working for the release of accumulated dust, i.e., normal stress resulted from pressure difference between both sides of the dust flake, tensile stress between the dust flake and the filter surface, and the shear stress work around the periphery of the released flake. The factors of released dust behavior such as reverse airflow rate, size and shape of the flake, and the kinetic momentum depends on balance of those stresses.

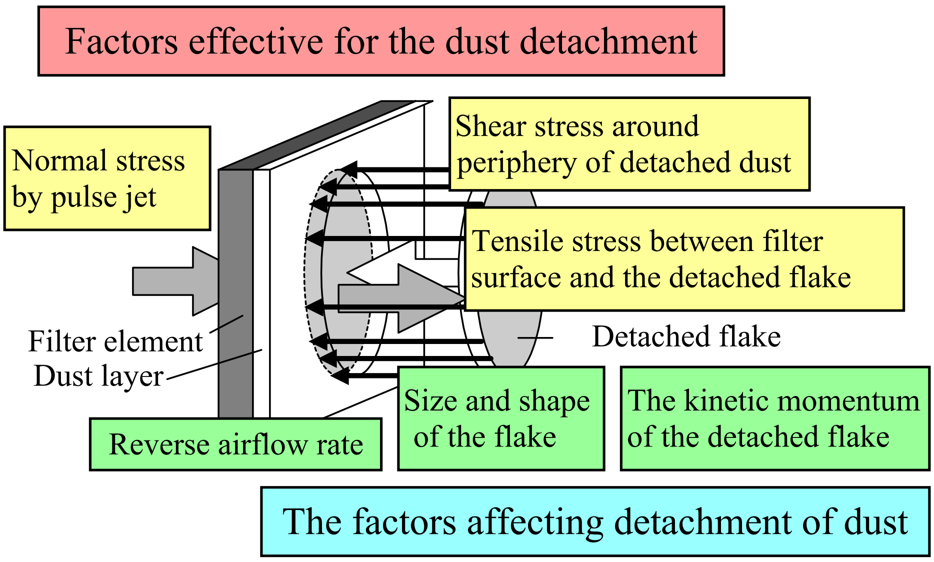


Fig.5 The mechanism and related parameters of dust release process

To investigate release of dust flakes, relationship among the factors is assumed based on the conservation law of momentum shown below.

$$\rho_d \cdot S \cdot t_d \cdot u_d = \int_0^t \Delta p_d \cdot S \cdot dt - F \cdot \Delta t \qquad (1)$$

Where ρ_d is apparent density of the accumulated dust, S is total project area of the released flake, t_d is thickness of the dust layer, u_d is the releasing velocity of the flake, Δp_d is the pressure difference between both sides of the dust layer, and Δt is the working time for release. F is the resistance force against the release and may be written as below.

$$F = \sigma \cdot S + \tau \cdot t_d \cdot l \qquad (2)$$

Where σ is the tensile stress, τ is the shear stress, and l is the periphery length of the flake. Left side of eq.(1) means momentum of the released flake, and the first term on the right side is the impulse due to the normal stress by pulse jet, and the second term is also the impulse due to adhesive force of the dust. Each parameter is estimated in follow subsections.

(2) Estimation of the momentum of released flakes $\rho_d \cdot S \cdot u_d \cdot t_d$

Table 3 shows the estimated value of the momentum of a released flake that has mean size at each position along the filter. As seen from Table 1, larger momentum is given to released flakes for larger cleaning pressure. However, momentum is much smaller for consolidated condition. Momentum seems to be available to evaluate a force for release of the flakes.

(3) Estimation of impulse for dust release $F \cdot \Delta t$

Table 4 shows the estimated value of the cleaning impulse. Δp_d was defined as the predicted pressure difference between both sides of the flakes, which is calculated from measured pressure difference of filter element with dust load and estimated pressure difference of filter element from the permeability till the time of the flakes began to be released. Table 3 shows the estimated value of $F \cdot \Delta t$ in eq.(1) at 5 different locations along the filter axis. The value of S and u_d were defined from image analysis. ρ_d was predicted by dust load and measured thickness of dust layer t_d.

Table 3 The estimated value of the momentum $\rho_d \cdot S \cdot u_d \cdot t_d$

Cleaning Pressure(kPa)	Condition	$\rho_d \cdot S \cdot u_d \cdot t_d$ (N·s)				
		Top	T-middle	Middle	M-bottom	Bottom
100	Non-consolidated	-	-	0.64	0.63	0.83
	Consolidated	-	0.31	0.44	0.66	-
200	Non-consolidated	-	0.26	0.47	0.95	0.80
	Consolidated	-	0.27	0.54	0.39	-
300	Non-consolidated	0.00	0.30	0.60	1.31	1.43
	Consolidated	-	0.17	0.62	1.10	-

Table 4 The estimated value of $\int_0^t \Delta p_d \cdot S \cdot dt$

Cleaning Pressure(kPa)	Condition	$\int_0^t \Delta p_d \cdot S \cdot dt$ (N□s)				
		Top	T-middle	Middle	M-bottom	Bottom
100	Non-consolidated	-	-	6.03	2.26	1.90
	Consolidated	-	0.02	0.10	0.05	-
200	Non-consolidated	-	0.56	0.21	0.32	0.23
	Consolidated	-	0.11	0.18	0.21	-
300	Non-consolidated	0.82	0.25	0.21	0.32	0.13
	Consolidated	-	0.25	0.21	0.32	-

Table 5 The estimated value of $F\cdot\Delta t$

Cleaning Pressure(kPa)	Condition	$F\cdot\Delta t$ (N□s/-10^{-3})				
		Top	T-middle	Middle	M-bottom	Bottom
100	Non-consolidated	-	-	5.40	1.64	1.07
	Consolidated	-	-0.29	-0.34	-0.62	-
200	Non-consolidated	-	0.30	-0.26	-0.63	-0.67
	Consolidated	-	-0.16	-0.35	-0.17	-
300	Non-consolidated	0.82	-0.05	-0.38	-0.98	-1.31
	Consolidated	-	0.09	-0.40	-0.77	-

$F\cdot\Delta t$ is considered as the value of impulse caused by cohesive and adhesive force of the dust against the normal force. However, most value of estimated momentum were larger than the cleaning impulse $\int_0^t \Delta p_d \cdot S \cdot dt$ that calculated values of impulse caused by adhesive force $F\cdot\Delta t$ were lower than zero. When the value of $F\cdot\Delta t$ has positive value, released time was larger than 0.05s. Since pressure difference or released time might be underestimated. The magnitude of $\int_0^t \Delta p_d \cdot S \cdot dt$ is so sensitive to time that the frame time of the video camera (0.0025s) may not be short enough.

The released flakes from consolidated dust are much smaller than them from non-consolidated dust. The difference will affect $F\cdot\Delta t$ by change of shear strength of the dust.

Future Activities

To investigate the dust release from the ceramic candle filter, high-speed video images of filter cleaning process are analyzed. Size and shape of released dust flakes strongly depend on the cleaning pressure and porosity of the dust layer.

We tried to express release mechanism of dust based on the conservation law of momentum. Impulse and momentum were estimated from properties of released flake by image analysis and measurement of pressure and dust layer thickness. However, the investigation is still not enough and further investigations about the relationship among these parameters are required.

Also, further discussion for best description for dust release is required. It is considered that there are several ways to describe the dust release such as the balance of force, momentum, and energy. It is still subject to be discussed.

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