Effects of the Overall Length and *OD* on Opposing-pulse-jet Cleaning for Pleated Filter Cartridges

Quanquan Wu^{1,2}, Jianlong Li^{1,2*}, Daishe Wu¹, Da-Ren Chen^{2*}

¹ Key Laboratory of Poyang Lake Environmental and Resource Utilization, Ministry of Education, School of Resources, Environmental and Chemical Engineering, Nanchang University, Nanchang 330031, China

² Particle Laboratory, Department of Mechanical and Nuclear Engineering, Virginia Commonwealth University, Richmond, VA 23294, USA

ABSTRACT

Opposing-pulse-jet technology has been proposed as a solution for regenerating filtration media by minimizing the incomplete cleaning of pleated filter cartridges. In this study, we investigated the effects of a pleated filter cartridge's overall length and outer diameter (*OD*) on the performance of opposing-pulse-jet cleaning via numerical modeling. For each pleated filter cartridge, the delay time, Δt (defined as the delay in launching the secondary nozzle), was varied to analyze the intensity and the uniformity of the static pressure distribution in the core of the cartridge. It was found that two opposing jet flows collided much more intensely in the core when the length of the overall cartridge, *L*, was short, and the *OD* was small. For a given *L*, the pressure pulse's performance was maximized by varying Δt . The pulse intensity and uniformity in the filter core can be represented as a bimodal (double-peaked) function of Δt . In general, the pulse intensity was greater when $\Delta t > 0$ s than when $\Delta t < 0$ s (when the secondary jet was launched before the primary jet).

Keywords: Dust collector; Filter cartridge; Opposing pulse jet; Cleaning quality; Length; Diameter.

INTRODUCTION

Dust collectors have been applied in various industrial settings for the control of particulate emission over the decades in order to meet the gradually more stringent dust emission regulation. A fabric collector is the most efficient and versatile among all the types of collectors. In the fabric collector, dust-laden airflow passes through a fabric filtration element and dust cake quickly grows on the air entrance surface of the fabric element. Because of the advantage of large filtration area in unit space, pleated filter cartridges are recently favored over baghouse filters (Zhang and Wang, 2011; Chen and Chen, 2017a, b; Chen *et al.*, 2017). The pressure drop across the filter element increases with the growth of dust cake. To save the energy consumption of air movers, the periodical cleaning of the fabric filter element is required to regenerate the filtration media. One of online techniques for the regeneration of filter elements, named as *reverse pulse-flow/jet cleaning*, is to apply pressurized air flow, preferred to be pulsed, in the opposite direction of filtration flow (Tien, 2012; Tarleton, 2015). Pleated filter cartridges

however have less elasticity than baghouse filters because of the fabric material, pleated structure and having large surface area to be cleaned. As a result, the issue of incomplete cleaning was more serious when using pleated filter elements as compared to using baghouse filters (Li *et al.*, 2015; Chen and Chen, 2017a). The quality of the cleaning gets worse when filtering dust in humid air (e.g., in the underground mine tunnels) or sticking dust (e.g., the carbon black dust in rubber plants) (Li *et al.*, 2017; Li *et al.*, 2019a, b).

Various methods have been proposed to improve the effectiveness of reverse pulse-jet cleaning for pleated filter cartridges. To effectively transfer more dynamic pressure into static pressure from the cartridge opening to its inside, Shim *et al.* (2017) investigated a dual-slit injector to achieve better cleaning performance and to considerably increase the cleaning interval. Chen and Chen (2016, 2017b) proposed a new cleaning scheme using multiple pulse jets in one cleaning cycle to improve the cleaning performance without the increase of compressed gas tank pressure. The multi-pulsing jet cleaning increased the number of cleaning actions and local medium acceleration at the top sections of pleated filter cartridges. Chen and Chen (2017a) further investigated an annular-slit nozzle for the reverse pulse-jet cleaning and found it could produce a favorable effect on the local cleaning efficiency by significantly increasing the local filter pressure drop at the top sections of pleated filter cartridge. The optimization of pulse-jet cleaning performance via the variation of the

* Corresponding author.

Tel.: 1-804-828-2828; Fax: 1-804-827-7030

E-mail address: dchen3@vcu.edu

(with only the primary nozzle). However, various factors, for examples, the cartridge design variables and operational parameters, that will influence the performance in the opposing-pulse-jet cleaning were difficult to explore by the experiments.

NUMERICAL MODELING

A typical computational domain is shown in Fig. 1. The computational domain used for this modeling is deduced from the test system described in the work (Li *et al.*, 2019b). The experimental dust collector has the filtration chamber dimensions of 1225 mm (width) $\times$ 750 mm (depth) $\times$ 1550 mm (height) with only one pleated filter cartridge installed

vertically. Due to axisymmetric configuration of pleated filter cartridges, one district pleat was used in our modeling. To keep the axisymmetric feature, the box-type filtration chamber was simplified as a cylindrical one keeping the same cross-sectional area in the horizontal plane. The round inlet and outlet for the experimental filtration chamber was also modeled as annular ones with the same opening areas as the round ones.

The primary cleaning nozzle (with the diameter of 24 mm) is installed over the opening of pleated filter cartridge. The secondary cleaning nozzle, which is the same type and size as the primary one, is placed at the base of pleated cartridge. The filter cartridge studied in the previous experiment has the length L of 660 mm and outer diameter OD of 320 mm. To investigate how the cartridge length and diameter affects the cleaning performance of the opposing-pulse-jet process, the length and diameter of pleated cartridges were varied: $L = 1000, 1350, 1700, 2000, 2300$ mm, and $OD = 160, 200, 260, 350$ mm, respectively (referenced but not limited to Chinese standard JB/T 10341-2014; MIIT, 2014). The pleat height and number were kept the same as the experiment one. The media thickness and permeability were kept as 0.6 mm and $2.0 \times 10^{11} \text{ m}^{-2}$, respectively.

ANSYS Meshing R.19.0 was applied to generate hexahedral meshes in the computational domain. Among all the studied ones, the case with the cartridge having $L = 660$ mm and $OD = 160$ mm had the minimal number of ~ 0.08 M elements and the one with $L = 2300$ mm and $OD = 320$ mm had the maximal number of ~ 0.43 M elements. ANSYS Fluent R.19.0 was used to calculate the flow and pressure fields in the computational domain. The flow and pressure fields during the media regeneration phase of the filtration system was assumed to be unsteady, compressible and turbulent. The realizable $k-\varepsilon$ model was elected for turbulent flow modeling. The detail of realizable $k-\varepsilon$ program can be found in the Fluent Theory Guide (ANSYS Inc., 2018a). The flow in the porous media in ANSYS Fluent are modeled by the addition of a momentum source term to Navier-Stokes equations (ANSYS Inc., 2018b).

The boundary conditions applied in this study are also given in Fig. 1. The pressure inlet boundary condition was applied at the inlets of two nozzles. For all cases in our study were assumed to conduct under the so-called “offline” cleaning mode (i.e., without the filtration phase occurred in the practical operation of dust collector). Under the above cleaning, the pressure at the dust collector top inlet and bottom outlet were close to the ambient pressure. The pressure boundary condition was also applied at the top inlet and bottom outlet of the dust collector. The reference pressure of 101.325 kPa was set at the dust collector inlet. The no-slip condition was applied for all solid walls with a standard wall function for the turbulent flow modeling. The time step size was set at 0.0002 s.

The transient pressure for the cleaning nozzles was specified using a user-defined function (UDF). The pressure value for the primary nozzle inlet in the modeling was obtained from the experiment study of opposing-pulse-jet cleaning with the pulse duration of 0.05 s and no delay time, $\Delta t = 0$ s (Li et al., 2019b). The fitted function of the nozzle inlet pressure P (kPa) with the time t (s) was:

$$P = \begin{cases} 0, & t < 0.0020 \\ 29.06 \cdot \sin(130.899 \cdot t - 1.833) + 29.06, & 0.0020 \leq t < 0.0264 \\ -204.00 \cdot t + 63.518, & 0.0264 \leq t < 0.9860 \\ 21.72 \cdot \cos(98.175 \cdot t - 9.621) + 21.72, & 0.0986 \leq t < 0.1300 \\ 0, & 0.1300 \leq t \end{cases} \quad (1)$$

The pressure value for the secondary nozzle was set the same as the primary one. The time to delay the launch of jet from the secondary nozzle (Δt , defined as the delay time) was varied in the range of -0.150 to $+0.150$ s. Note that a negative value in the delay time refers to the fact that the secondary jet will be initiated earlier than the primary jet. For the convenience, the time to initiate the first cleaning jet (either from the primary or secondary nozzle) was set at $t = 0.002$ s.

The dust cake on the entrance surface of pleated cartridges was not considered in this modeling to focus our research on exploring the action of opposing jets in the cleaning process. The deformation of filtration media in the cleaning process was also neglected.

Our model in the case of $L = 660$ mm and $OD = 320$ mm was verified by the comparison of calculated static pressure with the measured one in the core of pleated filter cartridge (Li et al., 2020).

RESULT AND DISCUSSION

Effect of Filter Length

(1) On the Evolution of Static Pressure

Shown in Fig. 2 is the evolution of static pressure contour and flow streamline when the opposing-pulse-jet cleaning was operated with the delay time $\Delta t = +0.025$ s. The filter cartridges under the study have the overall length $L = 660, 1350, 2000$ mm, and outer diameter $OD = 320$ mm. At the start of the primary jet, the flow entered into the core of pleated cartridge moving towards its base. At the same time, the same jet flow drove the surrounding air moving into the cartridge core. As the secondary jet nozzle initiated, the secondary jet flow impinged with the primary one in the cartridge core. The flow impinging position moved upward from the cartridge base due to the continuous operation of the secondary jet and then stopped temporarily in the region near $\sim 2/3$ of the pleated cartridge length (measured from its base). The cleaning-flow impingement ended when the primary flow stopped.

By examining the cleaning-flow impingement location in all the shown cases with different cartridge lengths, it is found that the cleaning-flow collision time was very close, from $t = \sim 0.04$ s to ~ 0.12 s. The static pressure contour evidenced a relative high pressure (more than ~ 500 Pa) was developed in a narrow core region in the case with a short cartridge ($L = 660$ mm; Fig. 2(a)) compared to the high pressure in other cases. At the time $t = 0.085$ s, when the position of flow collision was relatively steady, the high-pressure region (marked in dashed box in Fig. 2(a)) occupied $\sim 1/3$ of the cartridge length. While, in the case with the cartridge having

$L = 1350$ mm (Fig. 2(b)), the high-pressure region occupied $\sim 1/2$ of the cartridge length while the static pressure in the region was lower than that in the case with the one having $L = 660$ mm. For the case of the cartridge having $L = 2000$ mm (Fig. 2(c)), the high-pressure region occupied $\sim 3/5$ of the cartridge length and the static pressure was even lower than that in the case of $L = 1350$ mm. It is thus concluded that more filter surface of pleated cartridges could be covered as

the overall length of pleated cartridges was increased while keeping the cartridge *OD* constant although the static pressure in the high-pressure region was reduced (given the assumption of the same cleaning-flow rate).

(2) On the Pressure Evolution at Selected Observation Points

Shown in Fig. 3 is the transient pressure evolution at nine

Fig. 2. Evolution of static pressure contours and flow streamlines when the opposing pulsed-jet cleaning was operated with $\Delta t = +0.025$ s, filter length (a) $L = 660$ mm, (b) 1350 mm, (c) 2000 mm, and filter outer diameter $OD = 320$ mm. (Continue)

Fig. 2. (Continued).

observation points, P1–P9, selected in the pleated cartridges with the overall length $L = 660, 1350, 2000$ mm while keeping the outer diameter $OD = 320$ mm (when the opposing-pulse-jet cleaning was operated at various delay times Δt). Also shown in Fig. 1, the selected P1–P9 points are located at the middle of inner filtration surface, and evenly distributed in the distance between P1 and P9 (in the longitudinal direction). The P1 is located at 100 mm from the cartridge opening and the P9 is located at 100 mm above the cartridge base.

Under the opposing-pulse-jet cleaning, three events were observed resulting in the increase of static pressure at all the observation points in a pleated filter cartridge. One event is due to the initiation of the first jet flow (either from the primary or secondary nozzle, as illustrated in Fig. 3(a)). Another event is due to the air accumulation in the cartridge core, resulting from the continuous operation of cleaning flow. The other one is due to the impingement of two jet flow under a suitable delay time operation. Note that, in some cases, the first event might not be visible in the static pressure plot given in Fig. 3. It is because of the merging of the first and second events.

In the time period of only one nozzle jetting (either the primary jet only or the secondary jet only), continuous gradients of static pressure were found along the filter length in the case of short cartridge. However, more observation points were found to stay approximately the same pressure in the case of long cartridges. For examples, in Fig. 3(a4), during the period of time $t = 0.18\text{--}0.25$ s under the delay time operation of $\Delta t = -0.150$ s (i.e., in the period that only the primary nozzle was jetting), the static pressure continuously increased along all the points (P1–P9) in the case of the pleated cartridge having $L = 660$ mm. Under the same operation condition, the static pressure was increased from P1 to P5 and from P1 to P3, and kept approximately constant for the points P5–P9 and for the points P3–P9 in the cartridges of $L = 1350$ and 2000 mm, respectively. The above trend was also found during the period of time $t = 0.05\text{--}0.10$ s under the operation of delay time $\Delta t = -0.150$ s (i.e., only the secondary nozzle was jetting) and during the period of time $t = 0.05\text{--}0.10$ s under the delay time operation of $\Delta t = +0.075$ s (i.e., only the primary nozzle was jetting).

Fig. 3. Transient pressure evolution on inner surface of pleated cartridges when the opposing pulse-jet cleaning was operated at different delay time for pleated cartridges having the overall length (a) $L = 660$ mm, (b) 1350 mm, (c) 2000 mm while retaining the overall outer diameter $OD = 320$ mm.

During the time of only primary nozzle jetting, the pressure along the inner filter surface of pleated cartridge was found to decrease with the increase of the cartridge overall length. For example, at the time $t = 0.20\text{--}0.25$ s under the $\Delta t = -0.150$ s operation, the maximal pressure occurred at the point P9 with the pressure of $\sim 600\text{--}700$ Pa for the cartridge of $L = 660$ mm. The maximal pressure was located at the points P5–P9, and the points P3–P9 with the value of $\sim 450\text{--}500$ Pa, and $\sim 400\text{--}450$ Pa for the filter cartridges having $L = 1350$ and 2000 mm, respectively. The similar trend was observed during the period of time $t = 0\text{--}0.50$ s under the operation of

$\Delta t = -0.150$ s, and during the period of time $t = 0.03\text{--}0.08$ s under the operation of $\Delta t = +0.075$ s.

During the time of only the secondary nozzle jetting, the static pressure in a portion of observation points turned from the negative to positive value (relative to the reference pressure). For example, during the time $t = 0\text{--}0.12$ s and under the delay time operation $\Delta t = -0.150$ s, the static pressures at all the observation points were negative for the pleated cartridge of the overall length $L = 660$ mm (except the positive pressure at the very brief initial time). Note that the negative value in the static pressure simply means that the

pressure in the jet-flow collision phase was less than the reference one and its absolute value is positive. However, under the same operational condition, the static pressure was positive at the points P1–P4, and P1–P6 in the cases of pleated cartridges of $L = 1350$ and 2000 mm, respectively.

Under the delay time $\Delta t = -0.150$ s operation, it can be found that, when the jetting from the secondary nozzle launched, the primary cleaning jet has not yet been started, thus the impinging of the primary and secondary jet flows is not possible. Comparing the positive pressure evolution while only the primary nozzle was jetting among the cases of cartridges with different overall length, it revealed that the positive pressure decreased with the increase of overall cartridge length. For example, the peak pressure was ~ 750 Pa for the cartridge of $L = 660$ mm, and it decreased to ~ 550 and ~ 450 Pa in cases of cartridges of $L = 1350$ and 2000 mm, respectively. The similar observation on the positive pressure could also be found in the case with the delay time operation of $\Delta t = +0.075$ s.

During the jet-flow impinging period (which can be found in the operation of delay time $\Delta t = -0.050, 0.000$ and $+0.075$ s), it is found that in general the achievable static pressure was higher than that during the period of one nozzle jetting only. The above is more obvious for the case with long cartridge. For examples, during the period of time $t = 0.07$ – 0.13 s and under the delay time operation of $\Delta t = -0.050$ s, the static pressure during the flow impingement were found to be 181, 296, and 309 Pa, which were higher than those in the time period without the flow impingement for the cartridges of $L = 660, 1350$ and 2000 mm, respectively. Also, during the time period $t = 0.08$ – 0.13 s and under the operation of $\Delta t = +0.075$ s, the static pressures were found $-146, 298$ and 366 Pa, which is again higher than that in time period with no flow colliding for the cartridges of $L = 660, 1350$ and 2000 mm, respectively.

(3) On the Pulse Intensity and Uniformity

The max. static pressures during the reverse pulse-flow cleaning are usually taken as the index to quantitatively

represent the cleaning performance (Yan et al., 2013; Li et al., 2015; Yan et al., 2018; Li et al., 2019a). The average and inverse of coefficient of variation (C.V., defined as the ratio of the standard deviation to the mean) of the peak static pressures could be adopted to represent the cleaning intensity and uniformity, respectively. Shown in Fig. 4 is the pulse intensity of opposing pulse jet under the variation of the delay time for the cartridges of overall length, $L, 660$ – 2300 mm.

The pulse intensity curve was found to be bimodal (i.e., its intensity first increased and followed with the decrease, and then increased and decreased again) with the variation of delay time Δt in all the cases of $L = 660$ – 2300 mm. Generally, the pulse intensity in the cases of $\Delta t \neq 0$ s were found to be higher than those in the case of $\Delta t = 0$ s (shown in Fig. 4). The above observation is primarily because of the location of jet-flow collision moved in the cartridge core. The pulse intensity decreased with the increase of overall cartridge length in the cases of $\Delta t \neq 0$. It is simply due to the enlargement of core volume with the increase of cartridge overall length, resulting in the weakening of the pressure buildup. Moreover, the pulse intensity under the delay time $\Delta t < 0$ s operation were lower than that under the $\Delta t > 0$ s operation. For examples, for the cartridge with $L = 660$ mm, the pulse intensity was 601 and 655 Pa when Δt was -0.050 s and $+0.050$ s, respectively. Also, for the cartridge with $L = 1350$ mm, the pulse intensity was 519 and 597 Pa when $\Delta t = -0.075$ s and $+0.075$ s, respectively. It is because, under the delay time $\Delta t < 0$ s operation, the secondary nozzle started first, a portion of the cleaning flow from the second nozzle was easy to leak off through the cartridge opening when the primary cleaning flow was launched. Under the operation of $\Delta t > 0$ s, the primary cleaning flow started first, the primary jet flow would not be easy to escape from the cartridge opening and could collide with the secondary jet flow in the full strength. It is also found that both peak pressure intensities (i.e., one in $\Delta t < 0$ and the other in $\Delta t > 0$) were decreased with the increase of the overall cartridge length and the effect was more pronounced in the case of $\Delta t < 0$. It is because the secondary jet flow could not entrain surrounding air effectively

Fig. 4. The pulse intensity of opposing pulse-jet as the function of the delay time for the pleated cartridges having the overall length L varied from 660 to 2,300 mm.

Fig. 5. The peak static pressure distribution on the filter inner surface in opposing cleaning mode (with their best Δt) and primary-jet-only cleaning mode with the filter length varying from 660 to 2300 mm.

due to the close cartridge base. Under the operation $\Delta t = 0$ s, the pulse intensity achieved for filter cartridges with long overall length (although the high-pressure region due to the jet flow colliding was enlarged, shown in Fig. 3) was actually greater than that achievable in short cartridges. The above observation is different from that under the operation of $\Delta t \neq 0$ s. It is because, under the operation of $\Delta t = 0$ s, the primary and secondary jet flow started and ended at the same time and the position of the jet collision was not moved.

It is also found that the optimal delay time corresponding to the maximal pulse intensity changed with the overall cartridge length. The optimal Δt were +0.025, +0.038, +0.038, +0.050, +0.063 and +0.063 s in $L = 660, 1000, 1350, 1700, 2000$, and 2300 mm, respectively. It is primarily because the increased distance between two nozzles (as a result of the increase of overall cartridge length) requires increased time for the pressure buildup in the filter cartridge core (due to the start of the second jet flow).

Shown in Fig. 5 is the peak static pressure distribution on the inner filter surface in the “opposing” cleaning mode (under the optimal Δt) and “primary-nozzle jetting only” cleaning mode for the cartridges with the overall length varying from 660 to 2300 mm. It is evidenced that the static pressure at all observation points in the “opposing” cleaning mode were higher than those in the “primary-nozzle jetting only” mode. The obvious increase of static pressure was observed in the middle of the cartridge, and the less increase in the pressure in the region near the cartridge opening and base. Notice that, for the cartridges with the overall length $L \geq 1700$ mm, no obvious pressure increase in the “opposing” cleaning mode were found in the region with a distance less than 400 mm from the cartridge opening (compared to that in the “primary-nozzle jetting only” mode). It is because in the region close to the cartridge opening, which is far from the secondary nozzle, the energy is not easy to be accumulated even by the jet-flow impingement.

Shown in Fig. 6 is the pulse uniformity in the opposing-

pulse-jet cleaning as the function of delay time Δt for the cartridges with the overall length L from 660 to 2300 mm. Under the operation of $\Delta t < 0$ s, the pulse uniformity corresponded well with the pulse intensity, i.e., the greater the pulse intensity the higher the value of $C.V.^{-1}$ (representing better pulse uniformity). Under the delay time $\Delta t > 0$ s, the pulse uniformity corresponded well with the pulse intensity only for the cartridge with $L = 660$ mm and the pulse uniformity increased with the increase of Δt for the cartridges with $L = 1000$ – 2300 mm. The above finding is mainly due to the fact that the jet collision could not cover the region near the cartridge ends of long pleated cartridges. The pulse

Fig. 6. The pulse uniformity under the opposing pulse-jet cleaning as the function of the delay time for the pleated cartridges with the overall length varied from 660 to 2,300 mm.

uniformity was the worst for all cartridges when $\Delta t = 0$ s. It is because that the location of the jet collision would not move and pressure energy buildup could only cover a small section of the inner filter surface.

Effect of Cartridge Outer Diameter (OD)

(1) On the Evolution of Static Pressure

Shown in Fig. 7 is the evolution of static pressure contour and flow streamlines when the opposing-pulse-jet cleaning was operated at the delay time $\Delta t = +0.025$ s for the cartridges with $OD = 200$ and 350 mm while keeping $L = 660$ mm. For the comparison, the data of the cartridge with $L = 660$ mm and $OD = 320$ mm could be found in Fig. 2(a). For the cartridge with small OD , the jet-flow collision was more intensified (because of small core volume), covering more percentage area under high static pressure. As the OD

increased, the core volume of the cartridges increased, leading to less static pressure buildup and less area of the filter surface covered by the jet-flow collision.

Because the distance between the primary and secondary nozzles was kept the same in this part of study, the position for the jet-flow collision occurred in the location close to the middle of the cartridges with the increase of the cartridge outer diameter. For example, at the timing $t = 0.085$ s, the location of the jet-flow collision was at the distance of $\sim 2/5$ of the cartridge length from the opening of the cartridge having the $OD = 200$ mm. The jet collision location was nearly at the middle of the filter cartridge having the $OD = 350$ mm. It is because, for small OD cartridges, the pressure energy was quickly built up in the core region and the secondary jet flow required high energy to reach the core region.

Fig. 7. Evolution of static pressure contour and flow streamlines under the opposing pulse-jet cleaning with the delay time $\Delta t = +0.025$ s for pleated cartridges with the length $L = 660$ mm and outer diameters (a) $OD = 200$ mm, (b) $OD = 350$ mm.

(2) On the Pulse Intensity and Uniformity

Shown in Fig. 8 is the average pulse intensity as the function of delay time Δt for the pleated cartridges varying the outer diameter OD from 160 to 350 mm. The bimodal trend on the average pulse intensity by varying the delay time Δt was found for all the studied filter cartridges. For all the studied case, the pulse intensity peaked in the range of $\Delta t = -0.100$ to -0.050 s and $\Delta t = +0.025$ to $+0.100$ s. For the cartridges with $OD \leq 260$ mm, the pulse intensity could reach 1000 Pa with a suitable Δt operation. For the ones with

Fig. 8. The average pulse intensity in the pleated cartridge core as the function of delay time for the pleated cartridges varying the OD from 160 to 350 mm.

$OD \leq 200$ mm, the pulse intensity could even reach 1500 Pa. However, the pulse intensity was ~ 400 Pa for the ones with $OD = 350$ mm. According to the previous cleaning work (Siefert and Löffler, 1989; Mukhopadhyay, 2010), the minimum pulse pressure to achieve a good fabric-cleaning efficiency is 400–500 Pa. Thus, the $OD = 350$ mm would be considered to exceed the upper limit for the pulse-jet cleaning studied and the OD upper limit shall be between 320 and 350 mm. In addition, the optimal delay time Δt was found to be $+0.025$ s, which is independent from the OD of the pleated cartridges.

The peak pressure distribution on the filter inner surface cleaned by the “opposing pulse jet” mode (under the optimal $\Delta t = +0.025$ s operation) and by the “primary-nozzle jetting only” mode for the pleated filter cartridges with the outer diameter $OD = 160$ –350 mm and overall length $L = 660$ mm are shown in Fig. 9. The static pressures were found to be increased when cleaned by the “opposing pulse jet” mode compared to that by the “primary-nozzle jetting only” mode for all the shown cartridges, more significantly for ones with small OD s.

Fig. 10 shows the pulse uniformity on the inner filter surface of pleated cartridges with the $OD = 160$ –350 mm under the opposing-pulse-jet cleaning. The pulse uniformities were obviously influenced by the delay time Δt for all the studied cartridges. The bimodal trend was found in the pulse uniformity curve by varying the delay time. For the viewpoint of pulse uniformity, the optimal delay time Δt was in the range of $+0.025$ – 0.100 s for the cartridges with $OD = 160$ –320 mm.

CONCLUSION

This parametric study numerically investigated the effect of the overall length, L , and the outer diameter, OD , of pleated

Fig. 9. The peak pressure distribution on the filter inner surface cleaned by the opposing pulse-jet mode (the optimal delay time $\Delta t = +0.025$ s) and by the primary-nozzle jetting only mode for the cartridges with the $OD = 160$ –350 mm while kept the overall length $L = 660$ mm.

Fig. 10. The pulse uniformity on inner filter surface as the function of delay time for pleated filter cartridges with the outer diameter OD varied from 160 to 350 mm when cleaned by the opposing pulse-jet method.

filter cartridges on an opposing-pulse-jet cleaning process operated with various delay times. We focused on the intensity and the uniformity of the static pressure distribution in the core of the cartridges. Our findings are summarized as follows:

1. The impingement of the primary and secondary jet flows with various L s and OD s:
 - a) The impingement of the flows from the primary and secondary nozzles intensifies when the filter cartridge possesses either a short L or a small OD .
 - b) The jet-flow collision generates a gradient of relatively high static pressure, which is concentrated in a small region of the cartridge core, covering a minor fraction of the filter's inner surface, for short pleated cartridges.
 - c) As the L increases, the static pressure generated by the jet-flow collision decreases while the cleaning area—the pressurized region—increases.
 - d) When the OD is small, the generated high-static-pressure gradient occupies the majority of the core space. As the OD increases (with a fixed L), both the intensity of the pressure and the size of the pressurized region decrease.
2. The delay time, Δt , significantly affects the opposing-pulse-jet cleaning of pleated filter cartridges with various L s and OD s:
 - a) Optimal cleaning performance can only be achieved when Δt falls within a suitable range of values.
 - b) The pressure pulse's intensity and uniformity can be depicted as a bimodal function of Δt . In general, the pulse intensity is greater when $\Delta t > 0$ s than when $\Delta t < 0$ s.
 - c) The optimal Δt increases with the L (when the OD is fixed). However, it remains consistent between cartridges of the same L with various OD s.

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