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Effect of leaks on performance of a fabric filter in pulse jet cleaning assisted filtration system

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Study embodies assessment of outlet emission in the baghouse exhaust while hole appears on filter due to pyrophoric particles during hot gas filtration or damages due to cages. As it is difficult to study full-scale baghouse, flat PTFE coated polyester filter fabric has been tested in the present study. Experimental research has been carried out to observe and understand the emission behavior of leaks throughout the filtration time. After stabilization of media, the effect of three independent parameters has been used for the study of hole diameter, position of hole and face velocity. The behavior of emitted particles has been studied based on the data generated during online particle measurement system. The experiment leads to the inferences that with increase in hole size, the rate of outlet emission increases but in different manner. Smaller diameter hole does not make prominent effect to position with the face velocity. At all level of hole size, progressive increase in emission and peak pressure have been observed with the face velocity.

Keywords: Fabric filter, Leaked filter media, Needle felt filter fabric, Nonwoven, Outlet emission, Polyester, Poly-tetrafluoroethylene, Pulse-jet cleaning

1 Introduction

Filtration of dust-laden gases is of prime importance in coal-fired power plants, municipal waste combustion systems and many other industrial processes. Fine particles emission with an aerodynamic diameter of < 2.5μm is considered to be a major cause of adverse health effects ranging from the human respiratory tract to extra-pulmonary organs[1]. One of the most efficient methods for removing solid particulate contaminants from gas streams is filtration through fabric media. This is because, the fabric filter is capable of capturing submicron particles as small as 0.5 μm and can also remove a substantial quantity of those particles as small as 0.01 μm. Fabric filters, integrated with pulse jet cleaning, are most popularly used to control the particulate matter emission and to recover the valuable particles in many industries.

In industrial filter operation, the fabric filter performance can deteriorate due to a variety of causes, such as thermal erosion, mechanical stress through repeated flexing, chemical attack, abrasion, etc. Fabric damage can also be reflected in terms of occurrence of hole of 0.5 – 4 mm diameter due to variety of reasons, such as poorly welds or improperly seated gaskets, missing bolts, as well as damaged filter bag or may be due to pyrophoric particles during hot gas filtration[2]. During hot gas filtration, therefore, lot of technical intervention is needed for avoiding bag failure. Pinholes or leaks are the common problems in hot gas filtration caused by hot particles. This will lead to increase the outlet dust emission in the atmosphere. The degree of such failures can be as minor as a pinhole leak or as major as a fully involved baghouse fire[3]. In industry, these bags are normally in large numbers and due to sensory limits, there is no individual online sensor to check the leakage of each filter bags considering the economic aspect. These leaked or failed bags can increase the outlet emissions levels, which leads to environmental pollution and directly affects the industrial norms.

It may be noted that previous work done with leakage on filter bag performance is very limited. In one of the previous studies, irrespective of the leak position, a linear dependency of the clean gas concentration to the leak diameter has been found[4]. In another research, it has been found that the bigger pinholes decrease the collection efficiency, whereas higher filter face velocities increase the collection efficiency of filter media[5]. However, studies regarding the effect of position of varying diameters of holes on

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the performance of filter media at different face velocities have not been reported till date. Present study, therefore, embodies detailed study of the aforementioned factors on the filtration performance of media filter.

2 Materials and Methods

Nonwoven needle felt filter fabric made up of polyester with poly-tetrafluoroethylene (PTFE) membrane surface treated fabric (Table 1) was used. As it is difficult to execute test in baghouse filter,experiment has been conducted on laboratory set up (Fig. 1) using flat base filter media.It may be noted that the testing of flat media can provide the behaviour of media performance in full-scale baghouse. The test rig consists of the following parts, such as dust feeder assembly, upstream and downstream chamber, humidity and temperature sensing probe, online dust analyser probe, differential pressure tapings, pulsing nozzle and temporary storage tank, specimen window, specimen frame, damping sheet, pre-filter, High efficiency particulate air (HEPA) filter, suction arrangement, etc. Feeding of dust at predetermined constant rate is accomplished by a dust feeder assembly. The whole set-up is divided into two parts by test specimen, i.e. upstream and downstream. Two pressure sensors are provided on either side of the test specimen to measure the pressure differential across the filter media. The emitted dust (not retained by the media) is filtered through pre-filter and HEPA filter. The downstream side is connected with online particle size analyzer ‘PROMO 2000’ (light-scattering aerosol spectrometer) for detailed analysis of emitted dust particles.

Table 1 — Technical specifications of polyester filter fabric

Parameter	Value
Thickness, mm	2.13
Stiffness, N	73.5
Tensile strength, daN	162
Area density, g/m^2	514
Air permeability, $l/100cm^2/min$	150
Finish type	PTFE membrane

In filtration, test data are more relevant when the material is stabilized. Therefore, fabric sample (area 900 cm^2) was first stabilized according to ASTM 2008 standard using 10000 cycles in conditioning phase and 10 cycles in stabilization phase, afterward final measuring phase is carried out for one hour. To study the effect of leakage on emission behaviour, punching of filter media was made after stabilizing the filter sample only. The flat media was first removed after stabilization phase and again it was installed after punching hole. Three different diameters of circular hole (1 mm, 2 mm and 4 mm) were selected on the filter fabric on the basis of change in circular area of hole (4 times difference in area from one hole to subsequent larger hole). Hole area is directly linked with the extent of air flow through the bag filter affecting emission and pressure differential across the bag. Circular holes are made at

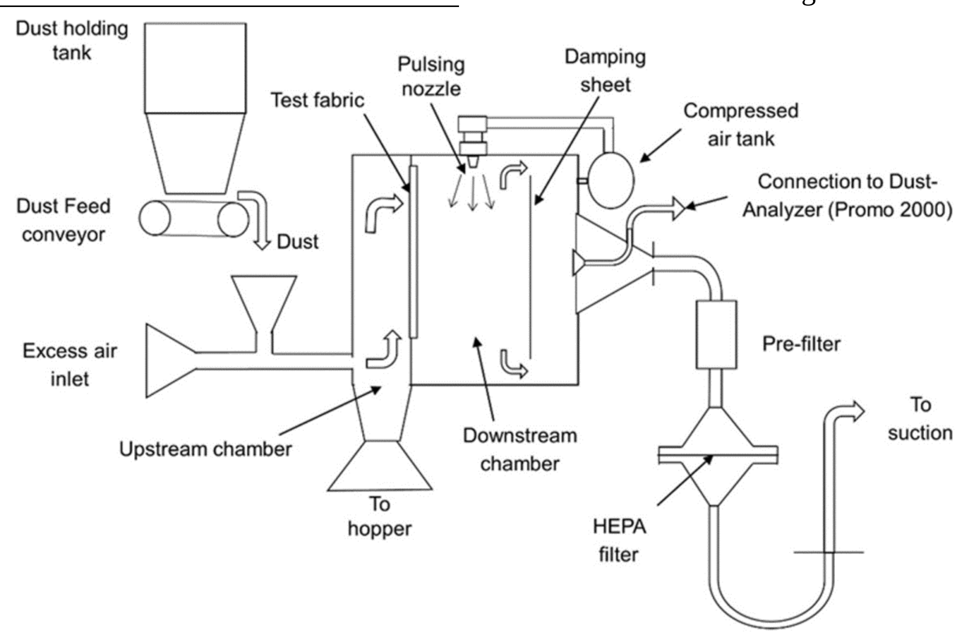

Fig. 1 — Schematic diagram of pulse-jet filtration test rig

two different positions [Fig. 2(a)] on the filter media by using hole punching machine.Figure 2(b) shows the punched hole in actual fabric. The detail working conditions of the experiment are given hereunder.

2.1 Test Sequences and Conditions at Stabilizing Phase

Test sequences and Conditions at stabilizing phase based on ASTM 2008 are given below:

- Conditioning of media (10000 cycles with cleaning pulse at time duration 5.
- Stabilizing of media (10 cycles with cleaning pulse at 1000 Pa).
- Face velocity of 2 m/min, dust concentration of 150 g/m^3, pulse jet tank pressure of 200 kPa and valve opening time of 50 ms.

2.2 Test Conditions at Measuring Phase

- Face velocity at three level (1.5 m/min, 2 m/min and 2.5 m/min), hole diameter (1 mm, 2 mm and 4 mm) and hole position (top and bottom)
- Results are based on one hour of measuring phase.
- Peak pressure has been defined as the highest pressure drop between one hour of measuring phase.

2.3 Test Dust

Industrial dust 'Fly Ash' is used to conduct the experiments. Fly ash is fine powder distributed over 0.5-10µm. Particle size characteristics of raw dust at upstream side is D_{10}= 1.39µm, D_{50}= 3.27µm and D_{90}= 5.88µm based on cumulative size distribution. These above-mentioned diameter values show the 10, 50 and 90 % of particles having diameter less than the values of D_{10}, D_{50} and D_{90} respectively.

3 Results and Discussion

In the present study, the effect of leaks on emission behaviour of dust particles and pressure differential across the media has been studied. To compare the results of leaked filter media, fresh filter media (without hole) was tested at same operation parameters. Direct penetration and seepage of dust particles is very prominent in fresh filter media at time of cleaning pulse[6]. This can be ascribed due to more through pores in the filter media at the beginning. After stabilization of media, these open pores are closed by dust particles and primary cake layer builds up on the filter surface. Therefore, the above phenomenon has less impact on outlet emission. It is found that with the increase in face velocity, emission is linearly increased across the filter media. The media without hole shows very less outlet emission than the leaked filter media and also shows relatively small change in emission with the increase in face velocity.

Figure 3(a) shows that, as the hole appears, significant change in filtration parameter ($PM_{2.5}$) is observed. Linear increase in the emission can be seen with the increase in face velocity for without hole filter media. The sharp increase in the emission can be

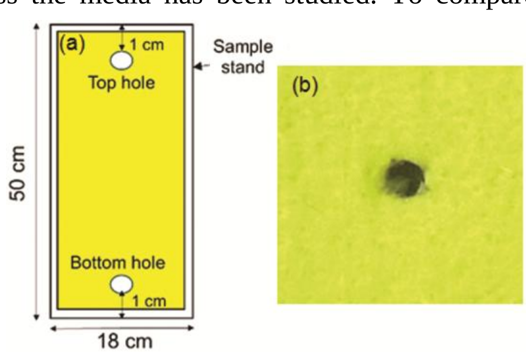

Fig. 2 — Schematic view of hole on filter sample (a) position of holes and (b) hole on filter fabric

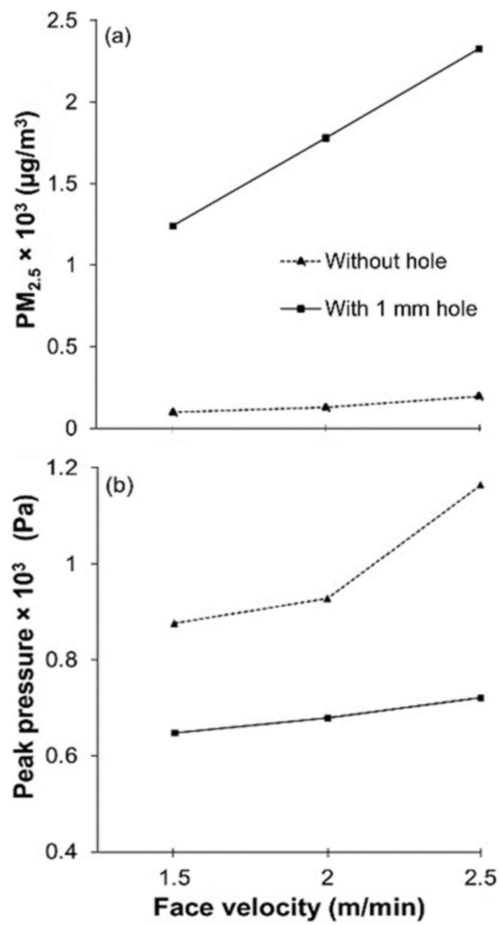

Fig. 3 — Effect of face velocity on (a) $PM_{2.5}$ and (b) peak pressure betweenwithout hole and 1 mm hole filter media

seen for leaked filter media at higher level of face velocity. It is due to the least resistant area of leaked surface which is very prone to straight through movement of dust particles in downstream side at higher filter face velocities.Figure3(b) shows progressive higher pressure values for filter media of without hole with the increase in face velocity. However, for leaked media, the change in peak pressure is quite small with the increase in face velocity.

3.1 Effect on Various Filtration Parameters at Leaked Filter Media

3.1.1 Effect on $PM_{2.5}$

Figure 4 presents downstream emission of leaks in terms of mass concentration ($PM_{2.5}$). Results of dust emission for 1 mm diameter of hole is least compared to 2 mm and 4 mm hole diameters. As the diameter of hole increases, outlet emission also increases as expected. However, it is interesting to note that, when diameter of hole changes from 1 mm to 2 mm (four times higher area ratio), the increase in emission ratio rises around five times at top position and six times at bottom position of hole. On comparing emission of 4 mm hole with 2 mm hole (four times higher area ratio), the increase in emission ratio rises only around two times at top position and three and a half (3.5) times at bottom position of hole. The above results indicate that bottom position of hole is very sensitive to emission. It is ascribed due to the flow of aerosol with respect to fabric. In industry as well as in test rig, flow of aerosol is from bottom to the top of the filter media. Therefore, bottom position of hole gets earlier exposure of dust laden air, resulting in higher emission at bottom position as compared to top position.

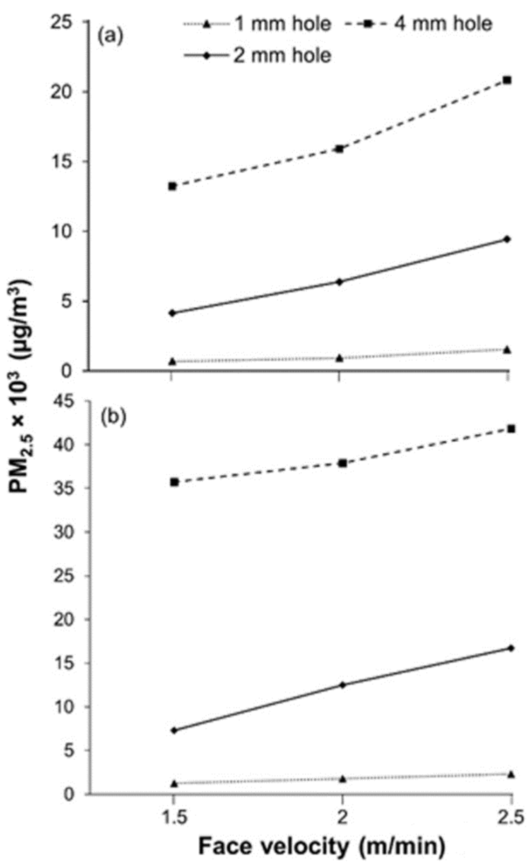

Fig. 4 — Effect of face velocity and hole size on $PM_{2.5}$ at (a) top and (b) bottom positions of hole

Further observation suggests that the increase in hole size governs the flow pattern and emission in different way. Change in emission of leaked filter media can be found very different as compared to without leaked filter media [Fig.3(a)]. Rate of increase in emission between top and bottom position of 1 mm hole shows very small change. This is presumably due to the reason that the cake formation takes place earlier over the smaller holes which clogs the filter surface and hence cake filtration takes place. These results confirm that the emission at smaller size hole will not be affected significantly with the change in position of hole. On the other hand, the rate of increase in emission at 4 mm hole is very significant by changing the position of holes.

Table 2 shows the analysis of variance (ANOVA) at 0.05 level of significance. It shows contribution of individuals as well as interaction effect of leaked parameters on the emission. The diameter of hole shows a major contribution of 69.23%, whereas the position of holes shows contribution of around 12.92%. There is also significant interaction effect between hole diameter and position of hole, which shows notable contribution (13.75%) of outlet emission. It signifies that the larger diameter of holes (2 mm and 4 mm) behaves differently at top and bottom position and makes prominent effect on

Table 2 — ANOVA results for $PM_{2.5}$ emission and peak pressure

Source	% Contribution	
	$PM_{2.5}$	Peak pressure
Hole diameter	69.23	90.94
Position of hole	12.92	5.01
Face velocity	1.92	2.61
Hole diameter × position of hole	13.75	0.22
Hole diameter × face velocity	0.71	0.1
Face velocity × position of hole	0.02	0.09

emission, whereas presence of smaller size hole (1 mm or lower) does not make much of differences. Through ANOVA, it has also been found that the impact of face velocity is insignificant on the particle emission. It may be noted that ANOVA represents overall impact based on individual trend of data (Fig.4). Impact of face velocity is very prominent on larger holes, but it is quite small in case of smaller holes. It is due to the fact that smaller holes (up to 1mm) gather sufficient amount of dust particle due to initial air flow characterises. Till stabilization period, the dust layer is appeared to be quite stable even after repeated pulse cleaning. Hence, smaller holes are not causing much of problems at increased face velocity.

3.1.2 Effect on Peak Pressure

A comparative analysis of pressure drop values due to difference in hole diameters and its position can be seen in Fig.5. It has been observed that, peak pressure is higher for smaller hole diameter and lesser for larger hole diameter. Peak pressure is decreased in very small amount between 1 mm and 2 mm hole diameter, whereas it is decreased in large amount between2 mm and 4 mm hole diameter. It shows that smaller size of hole does not significantly affect change in peak pressure drop. From the peak pressure and cited emission results of $PM_{2.5}$, it is examined that, when outlet emission is found less, their respective pressure drop value is high for particular hole diameter. From Fig.5, it can also be noticed that in the measuring phase of one hour, peak pressure of 1000 Pa is never reached due to leaked filter media. Therefore, no cleaning pulse effect is observed during filtration operation.

The continuous increase in peak pressure is observed with the increase in face velocity. It is due to more number of particles available in the suspended air to clog the surface pores of leaked filter media with the increase in face velocity, which leads to increase in pressure drop. On the contrary, tendency of clogging of surface pores of media is reduced substantially with the increase in hole diameter, which leads to lower pressure drop. From Fig.5, pressure drop is reduced drastically at larger hole diameter. Also, in case of larger hole diameter, bottom position of the hole is more vulnerable and has lowest peak pressure.

Table 2 shows ANOVA at 0.05 level of significance. Hole diameter shows a major contribution around 90.94%. It is interesting to note that position of holes, face velocity, and interaction effect show less contribution percentage. Smaller holes achieve higher peak pressure; the aforesaid parameter decreases drastically at the larger size of holes.

3.2 Emission *vs* Pressure Drop Behaviour of Leaked Filter Media with different Face Velocities

For leaked filter media, both emission and peak pressure are simultaneously affected by hole size, position of hole and level of face velocity (Fig.6). It can be seen that the changes in emission and peak

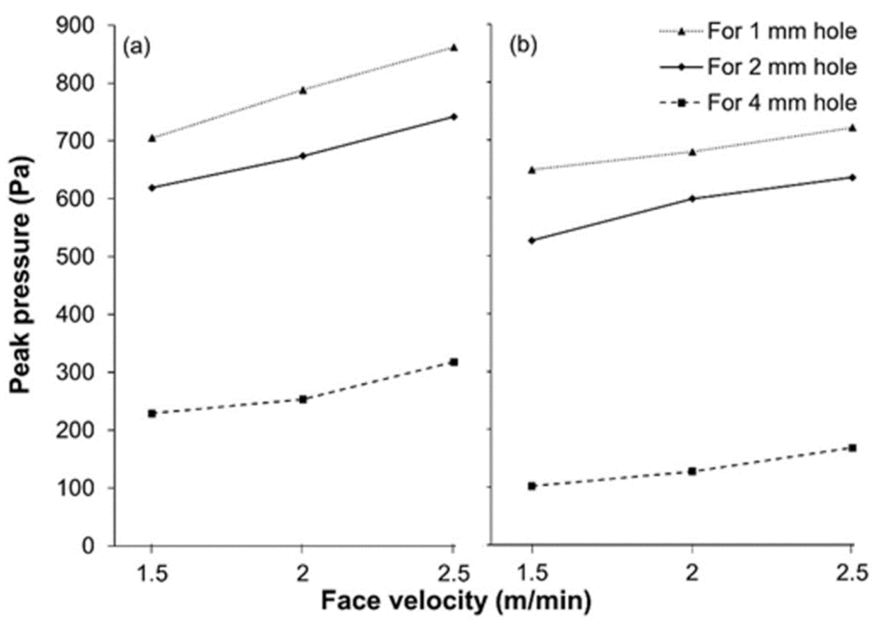

Fig. 5 — Effect on peak pressure at different positions of hole (a) top and (b) bottom

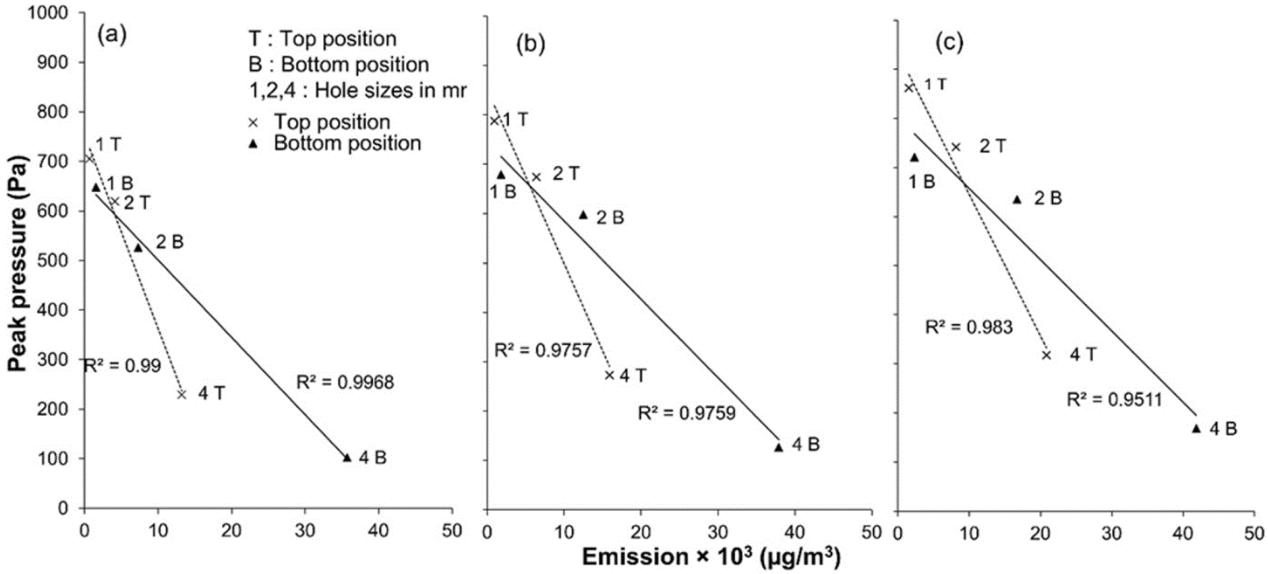

Fig. 6 — Relationship between emission and pressure drop in leaked filter media with varied face velocity (a) 1.5 m/min, (b) 2 m/min and (c) 2.5 m/min

pressure at smaller size holes are very insignificant. Smaller holes give higher peak pressure values along with lower outlet emission, whereas the larger hole shows very significant change in peak pressure and outlet emission. Peak pressure decreases drastically and outlet emission goes high enough.

In all the experimental test, it has been found that top position of hole gives higher peak pressure values with comparatively lower outlet emission. With respect to particular pressure drop at larger size of the hole, emission values are much higher in case of bottom position hole as compared to that in case of top position.

4 Conclusion

Based on the study on leaked filter media performance the following conclusions have been drawn:

4.1 Behaviour of leaked filter media is quite different for different hole sizes. As the leaked surface area increases four times (from 1 mm to 2 mm hole diameter), the increase in emission ratio becomes more than four times at both position of the hole, while it remains lesser than four times when the diameter of hole changes from 2 mm to 4 mm at both positions of the hole. However, the peak pressure decreases quite significantly with the increase in hole size.

4.2 Top position of holes gives lesser emission in comparison to bottom position throughout the experiment due to less exposure of dust laden air.

4.3 The smaller diameter of the hole does not make much of difference with the increase in face velocity.

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