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Comparative analysis of residual pressure drop behavior between electrostatically assisted flat based and pilot pulse jet filter unit using conductive filter media

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The present study aims at comparing the pressure drop behavior of three different needle-punched polyester conductive materials, viz. PTFE coated media, stainless steel fibre blended with PET media and stainless steel fibre scrim media. This comparison is done on a laboratory-based electrostatically assisted pulse-jet flat media test rig with the pilot filter unit, which is closer to the industrial set-up. The materials are investigated using fly ash aerosol, pre-charged at three different levels of charge, viz. 4 kV, 8 kV and 12 kV. The interpretations reveal that the flat media test rig is observed to exhibit lower residual pressure drop for all the investigated materials.

Keywords: Conductive filter media, Correlation behavior, Dust charge, Dust concentration, Residual pressure drop

1 Introduction

During filtration, a filter media is subjected to degradation due to many reasons of damage, such as aerodynamic, mechanical, chemical and thermal, which affect its life. Besides, there are various factors, such as the construction of filter media, operating conditions, temperature and humidity, on which the life of filter media is dependent. In the case of hot gas filtration, filter media's life is affected due to high temperature. While in normal conditions, the filter media life is dependent upon the extent of its clogging. In one of the studies[1], the ageing behavior of cleanable filter media at varying filtration velocity and cycle time according to VDI 3926 standard was studied. An extreme increase in pressure drop was reported after a certain ageing time and a cumulative effect of the operating parameters on the increased pressure drop was observed.

In another research[2], the cleaning mechanism of filter bags supported by rigid rings was analyzed. It was reported that the degree of cleaning is not the same along the length of the filter bag, as the acceleration on the filter media at the time of pulsing is higher on the top section, and it gradually reduces along its length. Further, the patchy cleaning behavior of filter media at the industrial and laboratory level was also compared[3], and the findings show a close agreement between them. In one of the recent studies[4], the cleaning behavior of pleated filter cartridges by designing a novel colliding pulse-jet cleaning method was studied. A considerable improvement in cleaning performance of filter materials was observed. Another latest study[5] shows the effect of particle size and pressure drop using pleated cartridge filter. It was reported that for the same particle size, both average and residual pressure drops are reduced with the decrease of maximum pressure, but both the number of pulse-jet cleaning and the average dust emission concentration are increased, which lowers the dust collection efficiency.

Some of the previous researches[6-8] have reported an enhanced filtration performance of filter materials through charging the aerosol particles. The progress on cleaning and regeneration of $PM_{2.5}$ filter media was also analyzed[9]. The wet-cleaning characteristics and regeneration performance of novel washable $PM_{2.5}$ filters, including super hydrophobic, electrostatically enhanced, metal–organic framework composite, and microchannel monolith filters, were evaluated and summarized. It was concluded that cleaning and

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regeneration characteristics should be integrated into the design of high-efficiency and low-resistance filter materials to develop more practical reusable $PM_{2.5}$ filter media. Khirouni *et al.*[10]. investigated the use of precoating technique to overcome the cleaning difficulties caused by the clogging of metallic nanoparticles. Experimental results highlighted the increase in collection efficiency and dust holding capacity using precoating. The cleaning efficiency was significantly improved from 10 % without precoating to 90 % with precoating. Clogging/unclogging cycles showed that the use of precoating allowed stabilizing the filtration process. Another study[11] reports the performance of a two-stage indoor air filtration system with a focus on main-stage filter media selection. The mechanism that causes a shortened service life of cellulose main-stage filter with the presence of a pre-stage filter was explored in detail and was found to be associated with the special particle loading behavior of conventional cellulose media.

However, there has been no comprehensive study on comparative analysis of laboratory and industrial situations. Hence, the present study aims at analyzing the pressure drop behavior of filter media. This was investigated on flatbed test rig and pilot filter unit by analyzing the rate of increase in residual pressure drop with the increasing filtration cycle time using flyash aerosol. It may also be added that the flatbed test rig represents the laboratory situation, whereas the pilot filter unit is more close to the industrial situation. Hence, how the material behavior changes occur at a scaled up level has been studied in the present investigation. The aerosol particles were charged through negative DC voltage at three levels, viz. 4 kV, 8 kV and 12 kV. Generally, at the industrial scale, filter media is assumed to be at its final stage, after which replacement is necessary. However, in certain industries, the said value is progressively changed to 1500 pascal for achieving a longer duration of media use at the cost of higher energy.

2 Materials and Methods

The polyester needle punched conductive filter materials have been taken for the present investigation. The material specifications are presented in Table 1. The investigation of materials was carried on two different types of laboratory-based pulse jet set-ups, viz. flat media set-up embedded with pre-charger where the filter media is in flat rectangular form (Fig. 1), and pilot filter unit where

Table 1 — Material specifications

Material	Fabric mass g/m^2	Thickness mm	Air permeability $m^3/m^2/min$	Fibre length mm	Blend ratio %	Punches per cm^2
Polytetrafluoroethylene coated filter media	520	2.3	8	51	100 % PET	450
Stainless steel fibre blended with polyethylene terephthalate media	518	2.3	15	51	60 % PET with 40% stainless steel fibre	450
Stainless steel scrim media	505	2.1	12	51	5 % of stainless steel fibre in scrim with 95 % polyethylene terephthalate fibres	450

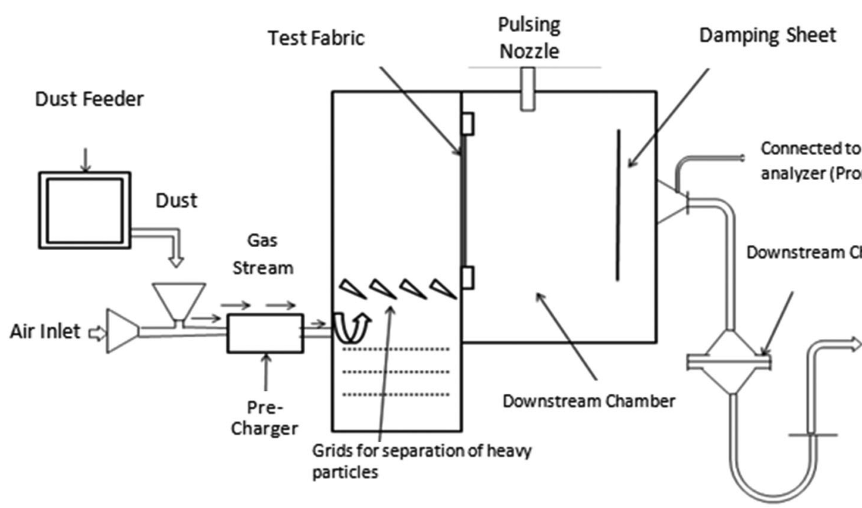

Fig. 1 — Experimental set-up of flat media test rig

the media is in cylindrical bag shape (Fig. 2). Generally, the filter materials are tested at laboratory scale in flat form, and at the industrial level the shape of filter media is in cylindrical bag form. Hence, for the present case, the pilot filter unit is closer to the real-time industrial situation. Therefore, the reason for characterizing the ageing performance of filter materials on the two set-ups is to analyze how the behavior of the materials changes at a scaled-up level.

In flat media rig, the set-up comprises a dust feeder for uniform dust feeding followed by a pre-charger installed to charge the aerosol particles. A dust layer is created on the surface of filter media during filtration. This dust layer is dislodged from time to time on pressure-based method at a peak pressure level of 1000 Pa through a pulsing time of 50 ms. The downstream side has been attached to an online particle size analyzer 'Promo 2000', to analyze the emitted particles. The standard followed was ISO 11057, and the aerosol used was fly ash. The experimental plan followed for both set-ups is shown further. The dimension of the flat specimen is 50 cm in length and 18 cm in width.

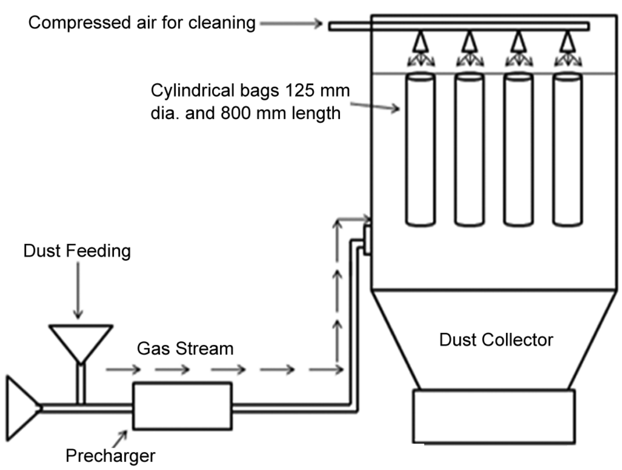

Fig. 2 — Experimental set-up of pilot filter unit

For the pilot filter unit, the mechanism is similar to that of flat media test rig. However, unlike flat media set-up, the filter media, in this case, is in cylindrical bag form. Table 1 represents the specification of materials investigated on both set-ups. The dimensions of each bag are 125 mm diameter and 800 mm height.

The testing conditions are: inlet face velocity (2 m/min), air-to-cloth ratio (2), inlet dust concentrations (50 g/m³ and 150 g/m³), tank pressure (2 bar), valve opening time (50 ms), total filtration area (0.09 m^2) for flat media test rig and (0.65 m^2) for tubular based set-up, and pulsing at 1000 Pa differential pressure drop, and charge levels at 4 kV, 8 kV and 12 kV as well as without charge with 2 replicas for each test.

The testing sequence is given below:

- conditioning 30 cycles, cleaning pulse at 1000 Pa
- ageing 2500 cycles with a cleaning cycle at 20 s stabilizing 10 cycles, cleaning pulse at 1000 Pa
- measuring for 2 h at 1000 Pa (pressure based cleaning)

The raw dust distribution of fly ash used for filter media characterization is represented in Fig. 3.

3 Results and Discussion

3.1 Correlation Behavior of Residual Pressure Drop

The interpretations reveal that the flat media test rig exhibits lower residual pressure drop for all the investigated materials. This is because, the entry of air

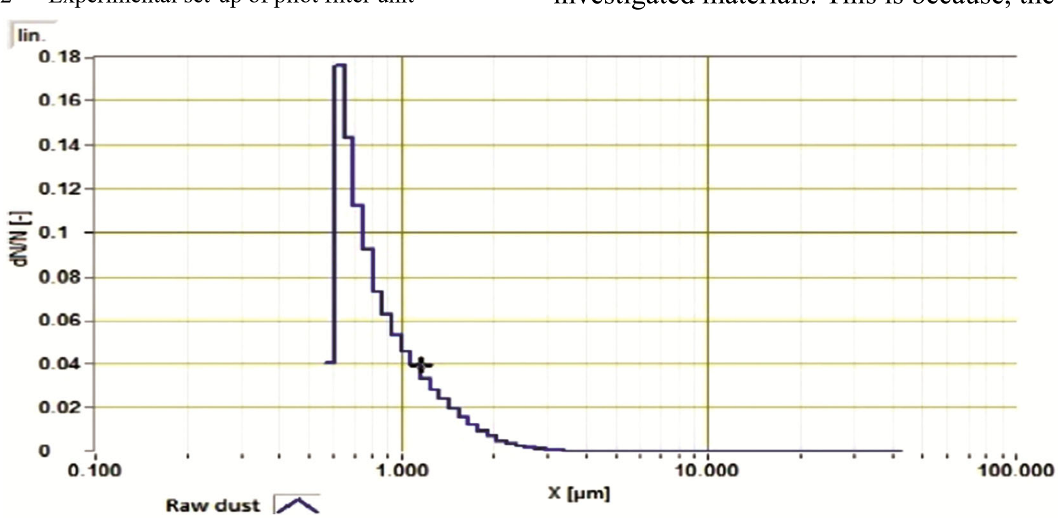

Fig. 3 — Raw dust distribution

is from one side and due to smaller height of the flat media the regulation of air is relatively uniform throughout its surface, resulting in better dust dislodgement. However, due to the longer height and broader dimension of the pilot filter media, the dust deposition along its length is not same due to unsteady air flow dynamics. The outer to inner air flow across the bag (pilot filter media) will be higher at the top near to the collar, and it will gradually reduce along the bag's length. Therefore, non-uniform deposition of dust over the pilot media surface becomes inevitable. The aerosol passes through the least resistance path; hence the inadequate cake formation at certain places over the pilot media can lead to higher emission.It may also be added that, as a result of long length, the dust dislodgement from pilot filter media due to the gravitational effect becomes a possibility prior to cleaning.

Further, during the cleaning operation, the flow of air (inner to outer) through the pilot media is less at the top, and also the top section of the bag filter (pilot media) is in close proximity to the pulsing nozzles[2]. The intensity of pulsing becomes higher at the top of the pilot media, and it decreases gradually as the purge air moves downward.Hence, the top section experiences intense shaking, which gradually reduces along the length of the bag. Therefore, the degree of cleaning is not same along the pilot media height, leading to patchy cleaning, and higher residual pressure drop. Also, a strong correlation for residual pressure drop between the two test rigs can be observed (Fig. 4). Figure 5 exhibits the behavior of residual pressure drop for all the materials with rising charge levels from 0 kV to 12 kV. The performance of materials in terms of residual pressure drop is found similar to that of emission, as the said values are noted to be the least for PTFE coated media in both the test rigs, followed by stainless steel fibre blended with PET media and stainless steel fibre scrim media. During emission, the contribution of charge on the PTFE coated material is found to be the least among all the materials. However, in the case of residual pressure drop, the contribution of charge for the PTFE coated media is found to be higher than those of the other two materials (Table 2). This can be attributed to a higher level of reduction in particle depth of penetration (Table 3) and (Fig. 6) at 4 kV charge from the uncharged condition in the case of PTFE coated media as compared to the non-coated

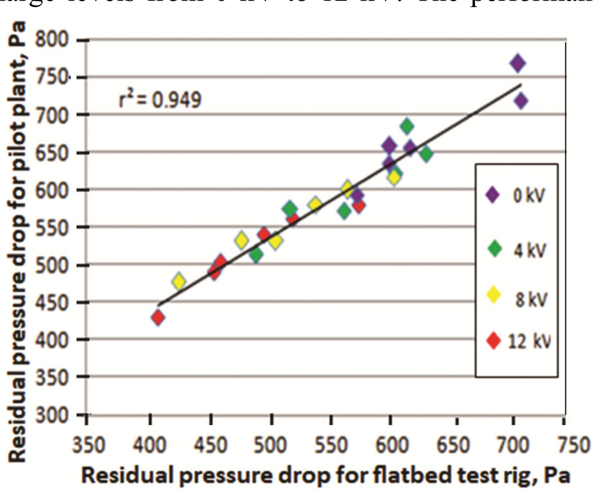

Fig. 4 — Correlation behavior of residual pressure drop between flat and pilot test rig

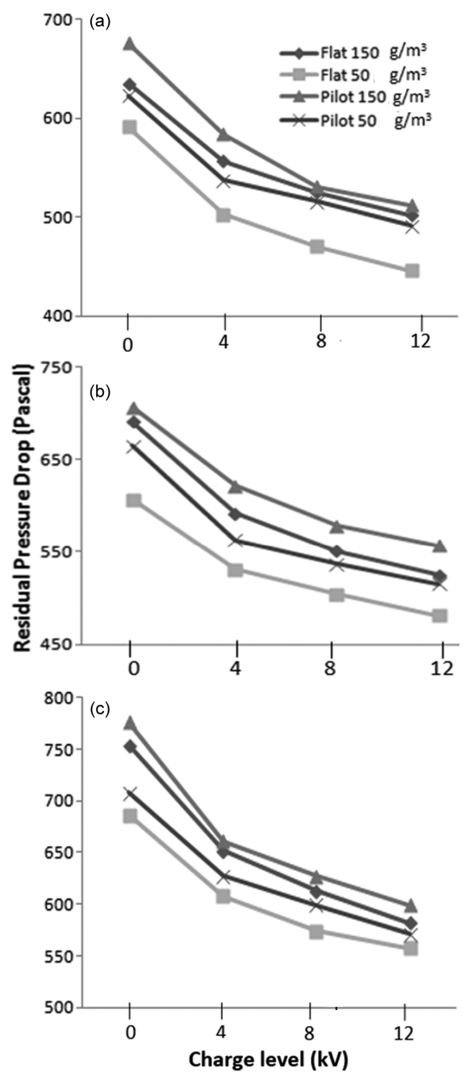

Fig. 5 — Behavior of residual pressure drop (a) PTFE coated media (b) stainless steel fibre blended with PET media and (c) stainless steel fibre scrim media

Table 2 — Contribution percentage for residual pressure drop derived from two-way ANOVA

Factor	PTFE coated		Stainless steel fibre blended with PET		Stainless steel fibre scrim	
	Flat based test rig	Pilot filter unit	Flat based test rig	Pilot filter unit	Flat based test rig	Pilot filter unit
Charge, kV	43.11	48.84	38.09	43.17	36.33	41.21
Dust concentration, g/m^3	34.81	25.07	37.78	39.48	35.98	28.42
Charge Xdust concentration	18.34	22.68	18.72	22.61	23.41	27.31

Table 3 — Depth of penetration for pilot filter unit, mm

Filter media	Depth of penetration, mm							
	0 kV		4 kV		8 kV		12 kV	
	50 g/m^3	150 g/m^3	50 g/m^3	150 g/m^3	50 g/m^3	150 g/m^3	50 g/m^3	150 g/m^3
PTFE coated	1.83	1.85	0.76	0.97	0.64	0.82	0.54	0.71
Stainless steel fibre blended with PET	2.06	2.08	1.09	1.27	0.76	0.91	0.61	0.79
Stainless steel fibre scrim	2.09	2.09	1.25	1.62	0.96	1.01	0.68	0.83

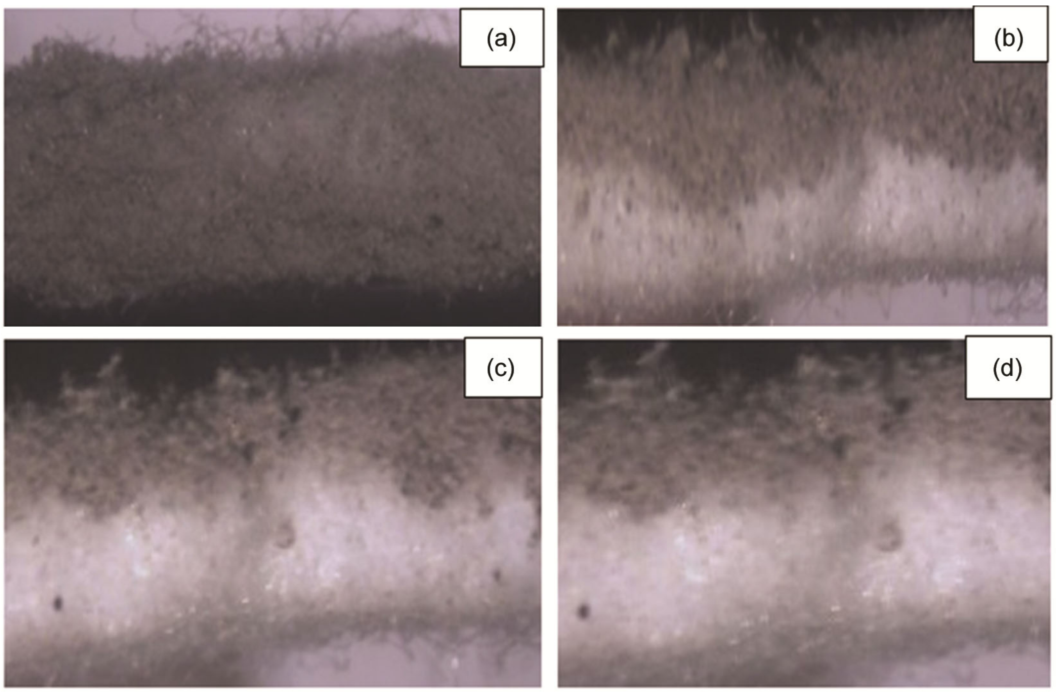

Fig. 6 — Depth of aerosol penetration (a) 0 kV, (b) 4 kV, (c) 8 kV and (d) 12 kV

materials. As the coating over the PTFE coated media is non-sticky, the primary cake layer formation over its surface will be relatively less.

Apparently, the subsequent secondary layer deposition will take a relatively long time. Therefore, the pulsing interval will be higher than that of the non-coated materials, resulting in a lower residual pressure drop. Further, it is also noted that the non-coated materials are subjected to early clogging, and also the number of pulses is higher as compared to the PTFE coated media. The drop in the number of pulses from 0 kV to 4 kV charge has been higher for PTFE coated media, as the improvement has been higher in this case. It may also be added that the role of charge and interaction behavior between dust and charge appears to be more in the pilot filter unit in case of all the materials; however, the interaction behavior between dust and material as well as charge and material is observed to be prominent in flat media test rig. This can be as cribbed to relatively uniform deposition of dust over the flat media surface, resulting in better cumulative effect with its surface as compared to the pilot media surface, where the level of uniform deposition is not up to the extent similar to flat media test rig.

It has been observed that the material taking a longer time to dissipate charge exhibits lower residual pressure drop (Table 4). This is because, as the

Table 4 — Charge dissipation test result

Media	Half decay time, s		
	4 kV	8 kV	12 kV
PTFE coated media	9.2	11.4	12.8
Stainless steel fibre blended with PET media	6.8	8.1	10.9
Stainless steel fibre scrim media	4.9	7.2	9.2
Carbon fibre blended with PET media	4.1	6.7	8.1
Carbon filament scrim media	3.3	4.5	5.9

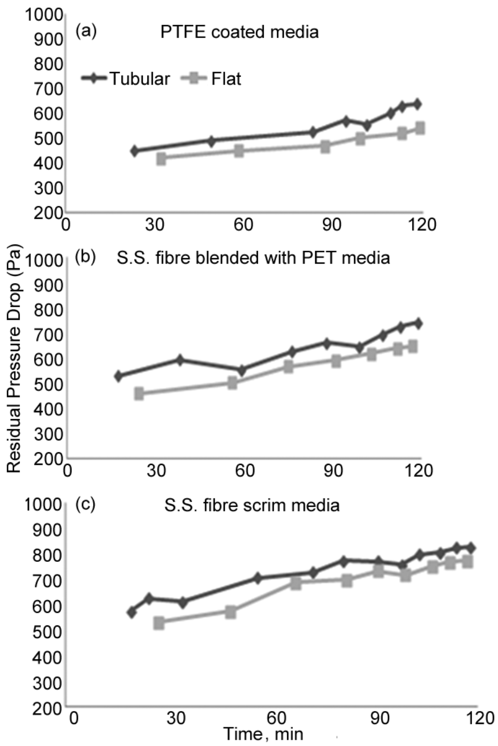

Fig. 7 — Residual pressure drop trend with time for different filter media (without charge)

charged particles get deposited over the media's surface, during charge dissipation, the agglomerated particles break and loosen up. More dissipation time suggests that agglomerated particles loosen slowly, which delays the particles to trespass into the inner layer, and the particles remain on the surface of media for a relatively more extended period, resulting in lower depth of penetration. Therefore, the residual pressure drop reduces.

3.2 Residual Pressure Drop Behavior with Time

To understand how long a filter media can sustain under a certain filtration condition, it becomes a priority to analyze the change in the behavior of materials with time in terms of residual pressure drop. In view of that, the residual pressure drop behavior of the materials with time for the measuring phase is compared for both the test rigs. Figure 7 represents the behavior of all materials without charge. It is observed that PTFE coated media exhibits the lowest pressure drop values throughout the phase in both test rigs, followed by stainless steel fibre blended with PET media and stainless steel fibre scrim media.

As already stated, PTFE coated media has been advantageous in providing a uniform dust cake deposition over the surface, as the coating pores have a relatively small pore size. This results in the smooth removal of dust from the media surface at the time of cleaning. This enables a large amount of dust to be removed from the media surface, leading to reduced residual pressure drop. Besides, the time interval between two subsequent pulses is increased, and relatively reduced number of pulses is resulted during the filtration phase. As stainless steel fibre blended with PET media and stainless steel fibre scrim media do not have the benefit of coating; as a result, the dust particles are more prone to penetrate inside the media core due to larger pore size, as compared to the coated material. This has been evident from the depth of penetration results as discussed earlier. More dust penetration within the media core is responsible for uneven removal of aerosol from the media surface during pulsing; hence a large proportion of dust remains on the surface. This results in a relatively higher pressure drop and reduced time interval between the subsequent pulses. Finally, a stage comes when the pulsing becomes too frequent due to blocking of pores, known as the clogging stage. It can be observed from Fig. 7 that the residual pressure drop trend has been much consistent for flat media test rig in case of all materials, and also the values are lower than pilot filter unit throughout the phase. Besides, the initial pulsing is noted to be earlier for the pilot filter unit, and the numbers of pulses are more as compared to that for the flat media test rig. This can be attributed to the longer height of the pilot media resulting in relatively improper dislodgement of dust as discussed under section **3.1**.

The trend at 4 kV charge for all materials is represented in Fig. 8. It is observed that the pressure drop values for both test rigs are lower, and the trend is more consistent as compared to without charge throughout the phase. This can be ascribed due to the effect of charge on dust particles, causing them to agglomerate; as a result, the dust diameter becomes larger. The agglomerated particles facilitate a bridging effect over the pores of the media surface; as a result, the particles are prevented from penetrating inside the

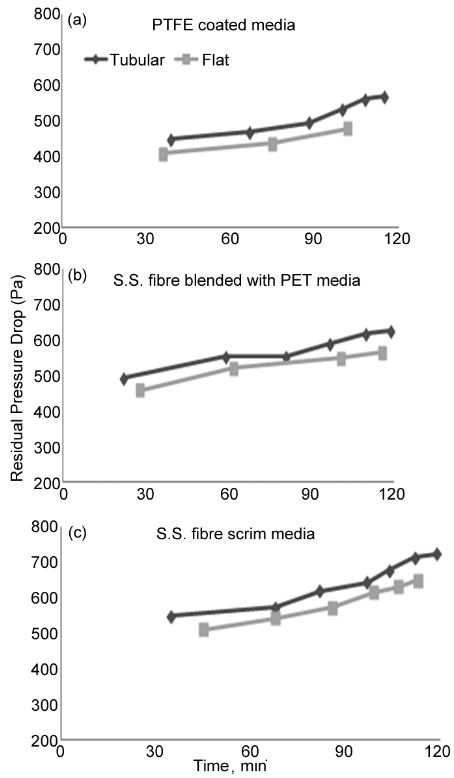

Fig. 8 —Residual pressure drop trend with time for different filter media at 4 kV

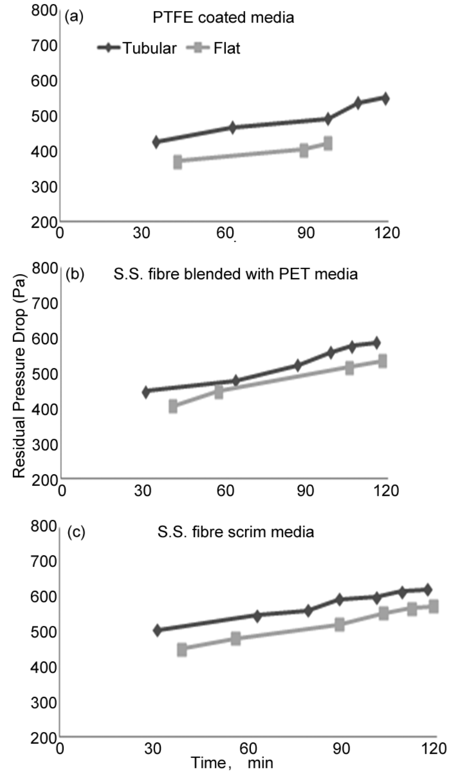

Fig. 9 — Residual pressure drop trend with time for different filter media at 8

core of media. Hence, the particles are dislodged relatively smoothly as compared to without charge, which leads to a relatively lower and consistent trend with the filtration time.

Among all materials, the trend for PTFE coated media is found the most consistent with filtration time. This can be attributed to the combined benefit of the surface coating and particle agglomeration due to charge on the pressure drop behavior. However, stainless steel fibre blended with PET media and stainless steel fibre scrim media do not have the benefit of coating. Therefore, the trend is relatively unsteady as compared to PTFE coated media, but due to the effect of charge, the behavior is more consistent as compared to without charge. This can be evident from the ANOVA results where the charge is known to make a significant contribution in case of both test rigs. Further, the trend for stainless steel fibre blended with PET media is observed to be consistent as compared to stainless steel fibre scrim media. This can be ascribed to the already stated charge dissipation test results, as discussed previously under section **3.1**. This can also be evident from the ANOVA results, where the charge is known to make a significant contribution in both test rigs.

Further, the trend for stainless steel fibre blended with PET media is observed to be consistent as compared to stainless steel fibre scrim media. This can be ascribed to the already stated fact of charge dissipation test results, as represented in Table 4. Longer dissipation time refers to delayed penetration of particles inside the media core as the particles lose charge relatively slowly; hence, the residual pressure drop trend is comparatively stable. The charge dissipation time for stainless steel fibre blended with PET media is higher than that for stainless steel fibre scrim media. Further inference reveals that likewise without charge, the trend for flat media test rig is found more consistent as compared to tubular based test rig at 4 kV charge; also, the number of cleaning pulses is found lower in the flat media test rig and the initial pulsing is delayed as compared to the pilot filter unit. The reason can be ascribed similar to, as stated for without charge.

Figures 9 and 10 depict the behavior at 8 kV and 12 kV charges. The trend for both test rigs remains constant as compared to without charge and 4 kV charge. This can be due to comparatively higher effect of agglomeration at 8 kV and 12 kV charges, allowing better surface deposition over the media surface. As a

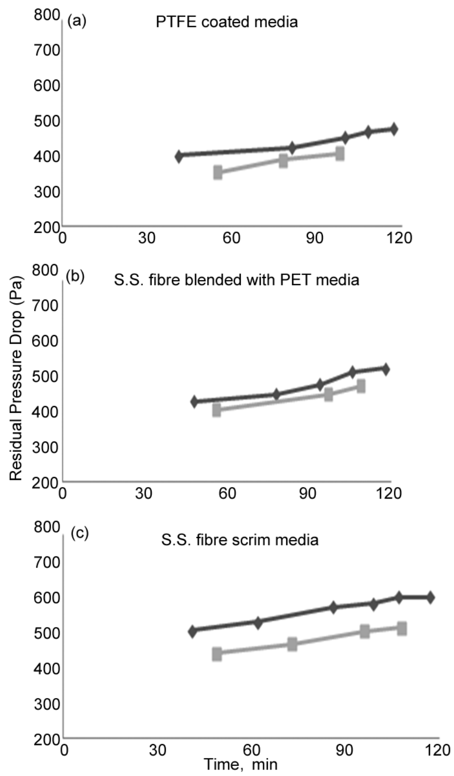

Fig. 10 — Residual pressure drop trend with time for different filter media at 12 kV

result, the particles are properly dislodged, reducing residual pressure drop with a consistent trend with time. Likewise without charge and 4 kV charge, the PTFE coated media exhibits the lowest pressure drop values throughout the filtration phase in both test setups among all the materials due to the reason as mentioned earlier. Also, the trend for flat media test rig remains consistent with time for 8 kV and 12 kV charge with delayed initial pulsing and the number of cleaning cycles is found lower as compared to the pilot filter unit, for the reasons as discussed earlier.

4 Conclusion

The investigation of conductive filter materials reveals a relatively higher residual pressure drop for the pilot filter unit at all levels of pre-charge and dust densities. Further, it is observed that the level of decrease in residual pressure drop for both the test rigs is higher at the initial charge levels from 0 kV to 4 kV, and the decrease is not significant from 4 kV to 12 kV charge. Further inference reveals a strong correlation between the test rigs for both emission and pressure drop. The residual pressure drop behavior with increasing time is observed to be more consistent for flat media setup, and the pulsing interval is higher for flat media test rig. The initial pulsing occurs earlier for the pilot filter unit as compared to flat media test rig under all levels of pre-charging as well as without charge, the number of cleaning cycles is also higher for pilot filter unit. Among all the filter materials, the trend for PTFE coated media has shown the most consistent behaviour in both test rigs with the lowest residual pressure drop values throughout the filtration phase, in contrast to stainless steel fibre blended with PET media and stainless steel fibre scrim media.

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