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Effect of varying cycle time interval and aerosol pre-charge on filtration performance of polyester media

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Present study embodies filtration characterization of two nonwoven needle-felt polyester filter materials, viz. PTFE coated and without coated media. The materials have been assessed using flyash aerosol under varying time intervals (6, 9 and 12 min) at different inlet dust densities (50, 90 and 150 g/m^3). The flyash particles are charged prior to their deposition over the filter media using a three phase parallel plate box pre-charger at two different levels of pre-charge, viz. 4 kV and 8 kV along with 0 kV. Results reveal that the filtration performance for PTFE coated material is better under all conditions. However, an enhanced filtration performance in terms of particle emission and pressure drop is noted at increased pre-charge level and higher cyclic interval. It may also be noted that the level of improvement in filtration behavior for both the materials has been better at initial level of pre-charge from 0 kV to 4 kV. However, the cumulative behavior of all the factors is also found significant.

Keywords: Aerosol pre-charge, Cycle time, Dust charge, Dust concentration, Filtration performance, Particulate emission, Polyester, Pressure drop

1 Introduction

The researches pertaining to the effect of aerosol charge on filter media performance has been documented to a large extent[1,2]. In one of the related researches, Humphries *et al*[3]. analyzed that pre-charging of dust can lead to decrease in the flow resistance of fabric filters used for filtration. Further, occurrence of severe back corona was observed under the relative humidity level of 5%. This led to poor charging of particles and very little improvements in the filter performance. However, for relative humidity in range from 5% to 40% very little or no back corona was noticed, leading to effective pre-charging and cleaning of filter media. During another study, Lamb *et al*[4]. investigated the cause of the reduction in pressure drop using three separate mechanisms. The first mechanism being formation of more porous dust cake, due to deposition of dust in the regions of low packing density of the fabrics. Second mechanism was the attraction of dust particles to the bag wall, acting like a precipitator. This led to relatively greater dust cake thickness near the entrance of the bag. Further, the third mechanism involved attraction of particles to bag electrodes. The results revealed a significant effect of dust pre-charging on the second and third mechanism, leading to enhance the filtration performance.

In one of the other relevant studies, Joseph *et al*.[5] analyzed the effect of dust pre-charging on conventional bag filters. The rate of pressure drop was observed to reduce about half to that of without charge. The capturing efficiency of sub-micron particles was improved, due to the repellent forces between charged particles and charge on the dust cake. Further, during another study, Dutta *et al*.[6-8] characterized the filtration performance in terms of particulate emission, pressure drop and power consumption of different conductive filter materials on pilot and flat based test rigs at varying dust pre-charge levels and densities. A significant effect of dust charge was observed on each parameter in case of all the investigated material.

Van Osdell *et al*.[9] also tried to electrostatically enhance the process of fabric filtration which resulted in the lowering of pressure drop and increase in the collection efficiency, when compared with the conventional process. Incorporation of the dust pre-charger before fabric filter leads to reduction in the dust penetration, formation of dust cake which has

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increased porosity and non-uniform deposition of dust on a filter surface. This reduced the penetration of dust and the collection efficiency increases. Further, Kwetkus[10] performed experiments on fly ash under ambient conditions and also at high gas temperatures of 130^{0}C by installing a corona pre-charger in front of a pilot sized pulse jet filtration plant. The electrostatic charges on the dust particles were measured behind the pre-charger and corresponding effects of the pre-charger, and triboelectric charge were measured and evaluated. On the basis of these experiments, conclusion was drawn that the pre-charging of particles has a significant effect on collection efficiency and pressure drop behavior.

During another study, Bologa *et al.*[11] characterized filter materials by pre-charging of aerosol as a mechanism of gas cleaning and removal of sub-micron particles. A reduction in sedimentation of fly ash on inner walls of the gas duct was observed. Further analysis revealed that through charging, concentration of the particles was reduced by 95%. Another experimental study of electrostatically augmented air filter was conducted by Lee *et al.*[12] using a corona pre-charger for dusts and tobacco smoke. Filtration efficiency, pressure drop across the filter and particle concentration were measured. The study concluded that the use of pre-charger leads to decrease in pressure drop and improved collection efficiency. In a recent study, Javorek *et al.*[13] reviewed various particle separation system designs practiced at commercial level. Basically three popular systems were reviewed, viz. electrically energized filter, hybrid electrostatic filter and hybrid ESP. It was summarized that the dust charging has a certain role in achieving enhanced filtration behavior of media.

Although from the previous studies the benefit of aerosol charge and the impact of dust density on filtration behavior of materials is well documented, but due to continuous dust deposition over the filter media surface during filtration, the frequency of pulsing changes which further affects the filtration behavior of the media. Hence, pulsing cycle time is vital parameter and requires a thorough investigation, as till date there has been no study reported on analyzing the cumulative effect of dust charge and pulse cycle time on filtration behavior of filter material. The present study has therefore been undertaken to analyze the effect of varying dust charge, pulse cycle time, dust densities and their interaction on filtration behavior of PTFE coated and non-coated filter media.

2 Materials and Methods

2.1 Materials

Two different types of polyester needle punched nonwoven filter fabrics, viz. without coated and PTFE coated materials, have been investigated for filtration parameters on pilot plant pulse jet test rig at varying pre-charge levels and dust concentrations. The PTFE (Teflon) coating was applied over the base material (polyester nonwoven) using padding method. The technical specifications of the materials are represented in Table 1.

2.2 Experimental Setup

The experimental setup is illustrated in Figs 1 (a) and (b). Emission parameters, such as downstream mass and number concentration, were detected through particle sensor PALAS GmBH (Promo 2000) working on the principle of light scattering spectrometer. During filtration, dust laden dirty gas enters from outside to inside of the bag, which are held open by interior metal cages. The clean air passes through the bags while the dust gets deposited on the exterior surface of the filter bags. This deposition leads to the formation of a layer of dust on the external surface of the bag, called as “dust cake” and this helps to maintain high filtration efficiency. One negative aspect of formation of dust cake is the increase in pressure drop. As industrial filter bags encounter high values of dust concentration, as a result there occurs periodical regeneration of dust particles after pulse cleaning.

Pulse cleaning involves injecting high pressure back pulse air (3 – 7 bar) into filter bags for a very short time of about 50 – 150 ms. This pulse causes sudden expansion of the filter media and drives deposited particles to fall into dust hopper. Cleaning of bags is carried out via online mode. During pulse cleaning, the particles retained by the filter bags are to

Table 1 —Technical specifications of materials

Physical properties	Non-coated media	PTFE coated filter media
GSM, g/100 cm^2	502-509	504
Thickness, mm	1.9-2	1.95
Bursting strength, kg/cm^2	44-46	52
Air permeability at 20mm WC, m^3/m^2/min	21.27	6.66
Strength, N/mm	23.35	22.4
Elongation-at-break, %	41.83	40.82
Packing density, %	55	75
Fibre diameter, µm	12.5	12.5

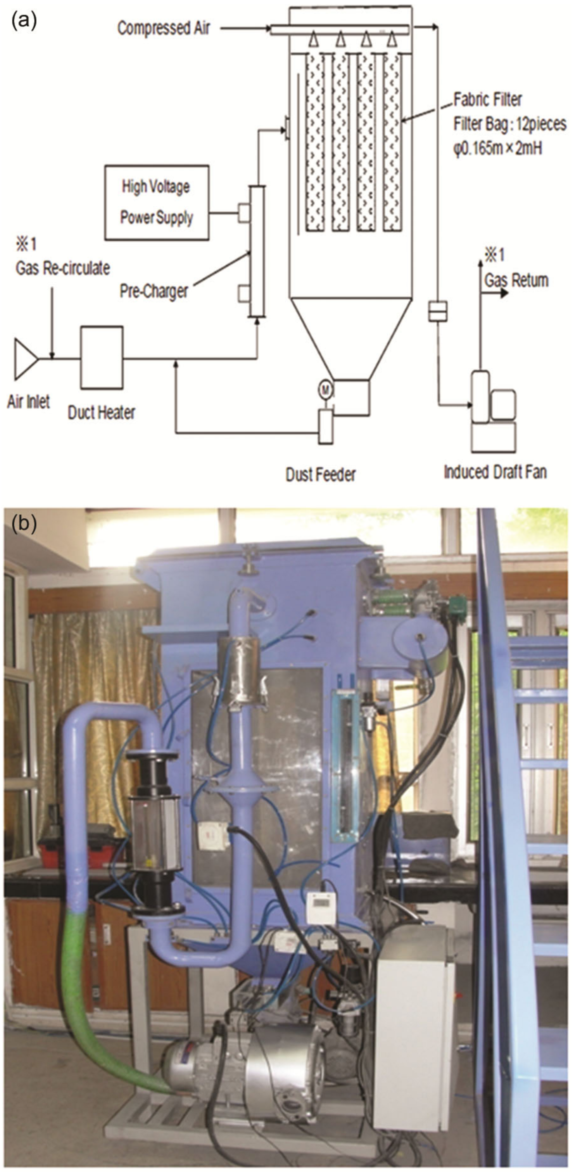

Fig. 1 — (a) Schematic diagram of filtration pilot plant and (b) actual image of pilot plant test rig

be removed either at upper limit of the pressure drop or at a pre-set filtration time. Properties of dust cake depends on different factors, such as filtration velocity, dust concentration, etc.

Filter media were tested using fly ash dust following ISO11057 filtration standard with face velocity of 2m/min, dust concentration of 50, 90 and 150 g/m^3 respectively, tank pressure of 2-3 bars and valve opening time of 50 ms. Each experiment was carried out in two phases, viz. stabilization phase and final testing phase. Initial Phase was carried out for 60 cycles and filter media was cleaned every time with a cleaning pulse after every 20 min. After completion of all the cycles, samples were stabilized and final test phase was carried out for 2 h and cleaning was done at different cycle times. The values of emission i.e. number concentration and mass concentration were taken at final testing phase of 2 h. The emission data are taken for final phase of measuring. This is because filtration process is transient in nature and does not depend completely on filter fabric, but also on particles trapped within and primary cake layer on surface of the fabric. Further, it is to be added that industrial cement dust ‘fly ash’ has been used as aerosol; a fine powder distributed over 0.1 - 10µm. The distribution of aerosol is illustrated in Fig. 2.

2.3 Experimental Design

In the present work, three experimental factors at three different levels were used to investigate using Box-Behenken design. The influence of static charge (0, 4 and 8 kV), dust concentration (50, 90 and 150 g/m^3) and cycle time (6, 9 and 12 min) on filtration performance was studied. The 0 kV charge level was taken so as to compare the results with and without charging of particles. Dust concentrations were selected to see the results at moderate and high

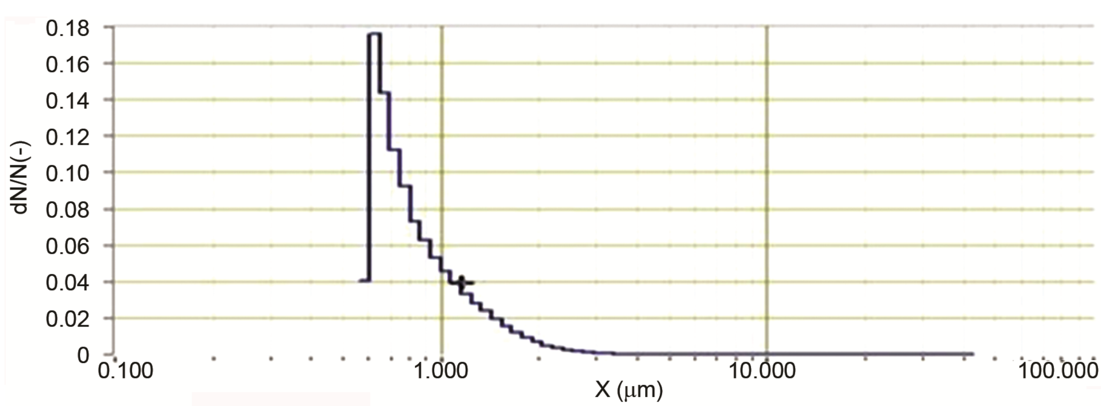

Fig. 2 — Flyash particle size distribution

concentrations. The experimental layout is shown in the Table 2.

It may be noted that the experimental runs were randomized. Reason for randomization is to attain effective statistical analysis through unbiased estimation of impact of factors and for validity of the inference drawn.

3 Results and Discussion

Performance on the basis of filtration efficiency, differential pressure behaviour and downstream emissions have been analyzed for both the materials and also their comparative study has been conducted.

3.1 Effect on Particle Emission

The effect of dust concentration and charge level on $PM_{2.5}$ emission is represented through surface plots (Fig. 3). It has been found that there is a drop in emission of around 75% using PTFE coated media as compared to non-PTFE for non-charged condition. With the rise in charge level from 0 kV to 8 kV, it can be noted that there is a decrease in emission value of about 25% for both materials, suggesting that by charging aerosol particles surface filtration pre-dominates. The values in the figures represent average values of two experiments. The contribution of each factor and regression equation has been represented through Tables 3 and 4 respectively. It may be noted that the effect of charge is higher in the case of PTFE coated material, and this can be ascribed due to the benefit of coating over the said material assisting in enhanced surface filtration in case of charged state. However, the cumulative effect of charge with cycle time is found to be more for the non-coated media. This can be attributed to the fact that the non-coated media does not have the benefit of

Table 2 — Experimental design for non-coated and PTFE coated filter sample

Run order	Standard	Charge level kV	Dust concentration g/m^3	Cycle time min
1	1	0	50	9
2	14	4	90	9
3	8	8	90	12
4	4	8	150	9
5	13	4	90	9
6	11	4	50	12
7	5	0	90	6
8	7	0	90	12
9	15	4	90	9
10	12	4	150	12
11	9	4	50	6
12	3	0	150	9
13	10	4	150	6
14	6	8	90	6
15	2	8	50	9

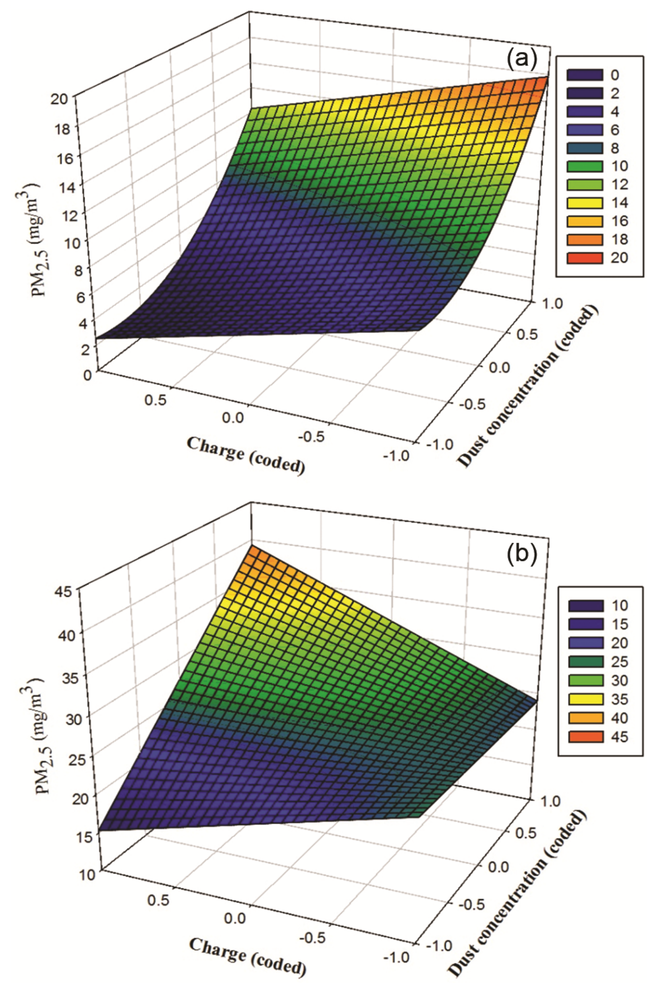

Fig. 3 — Effect of charge and dust concentration on $PM_{2.5}$ (a) PTFE coated and (b) non-PTFE coated

Table 3 — Per cent contribution of different factors on $PM_{2.5}$ emission

Fabric	A-Dust concentration, %	B-Charge %	C-Cycle time %	Dust concentration × cycle time (A×C), %	Dust concentration × charge (A×B), %	Charge × Cycle time (B × C), %
PTFE coated	28	15	18	15	6	13
Non-coated	21	7	26	4	14	17

A—Dust concentration, B—Charge and C—Cycle time.

Table 4 — Regression equation for $PM_{2.5}$ emission

Fabric	Regression equation	R^2	Standard error
PTFE media	$6.815 + 4.88 \times A - 2.78 \times B - 2.75 \times C - 2.23 \times A \times C + 3.37 \times A^2 + 1.9 \times C^2$	0.94	0.45
Non-PTFE media	$26.02 + 5.59 \times A + 1.27 \times B - 4.79 \times C + 6.40 \times A \times B$	0.62	1.56

A—Dust concentration, B—charge and C—cycle time

coating; hence the agglomerated charged particles will assist in achieving relatively higher level of improved surface cake formation for the said material as compared to the coated media.

The $PM_{2.5}$ emission follows a reducing pattern for both filter media with an increase in dust charge level. Emission value for PTFE-coated filter media is less at charge levels as compared to that for normal polyester media. It can also be noted that as the charge level rises from 0 kV to 4 kV, the rate of decrease in emission is higher as compared to the increase in levels from 4 kV to 8 kV, which indicates that as the charge level increases there comes a saturation point where the effect of charge nullifies. Further, it has also been analyzed that for 0 kV charge, the emission value difference is almost 75% for both filter media; with an increase in charge level the difference reduces to 65 % for 8 kV. This is due to the effect of charge causing agglomeration of particles, which, in result, restricts fine particles to pass into the clean air.

Likewise, the downstream PM_{10} also follows a similar trend, but the difference in emission level for both filter media is around 74% at 0 kV and with an increase in charge level, the difference reduces to 30% for 8 kV, which is almost 50% less as compared to $PM_{2.5}$ values. This is because heavy particles after agglomeration form a bigger cluster and thus will be easily captured by the filter media. It can be observed that with an increase in charge level, the amount of $PM_{2.5}$ in ratio to PM_{10} reduces to almost 14%, which indicates that charging effect is beneficial in preventing fine particles to penetrate through filter media.

Similarly, it can also be observed that mass concentration reduces almost at an equal rate with increase in charge levels for both filter media. The effect of charge on aerosol particles aids to surface collection of particles on filter media, which, in result, allows very little mass of aerosol particles to seep through to clean air. The number of particles at downstream reduces linearly with increase in charge level. The effect of charge on aerosol particles aids to a surface collection of particles on filter media, which, in result, allows very few number of aerosol particles to seep through to clean air. However, for D_{10}, D_{50} and D_{90} values which represent the diameter size of particles, no particular trend has been observed. Filtration efficiency for PTFE-coated media has been found to be better for both charged and non-charged condition, which is obvious as the emission is less for PTFE media.

Further, it has also been noted that at lower dust concentration (50 g/m^3), for same cycle time the emission is approximately 50% lower as compared to higher dust concentration (150 g/m^3) for non-charged condition. This is because at lower dust concentration (at 50 gm/m^3), absolute number of very fine particles presence will be less at upstream chamber and at higher dust concentration (at 150 gm/m^3), such dust particles are expected to be much higher. Another fact to be noted is that the emission of particle mainly takes place at the time of pulsing where high pressure purge of air acts upon the fabric. The pores of fabric opens up and there is expansion of the filter bag which leads to passage of particles in the clean air stream. Also, there is always a chance of regeneration. Pulsing also widens the pores of media for every minute time, which increases the chance of direct penetration, resulting in seepage of particles through the filter media. More the number of small particles in the upstream, the more will be the penetration of particles by direct penetration and seepage, leading to higher emission at downstream. For charged condition, the emission is 70% less for lower dust concentration as compared to higher dust concentration; this is as a result of particles getting ionized and causing agglomeration and thus reducing the seepage through media.

Emission values reveal better results at larger cycle time. This can be attributed to the fact that at larger cycle time the pulsing interval is higher. Hence, the rate of pulsing is less frequent as compared to lower cycle time, which indicates less frequent regeneration and opening of pores of filter media. This results in comparatively reduced seepage through the media which can be observed clearly from the graphs. From the coded design, it can be analyzed that, from the emission responses, the effect of dust concentration is having highest weightage for both media. The reason for less weightage of dust concentration and charge on non-PTFE media may be due to the variation in relative humidity. According to studies, at higher relative humidity, effect of charging of dust is reduced, and as a result of it the emission is more. Higher humidity also varies in the dust feed rate, which affects emission results. Another point to be noted is that the variation in emission of PTFE membrane filter media and non-PTFE filter media can be due to the charge on PTFE filter media itself. Studies have shown that PTFE media also possesses small amount of charge, as a result of which the charged dust particles agglomerate easily and emission is greatly reduced. Table 4 represents the regression equation for various responses in case of both the filter materials.

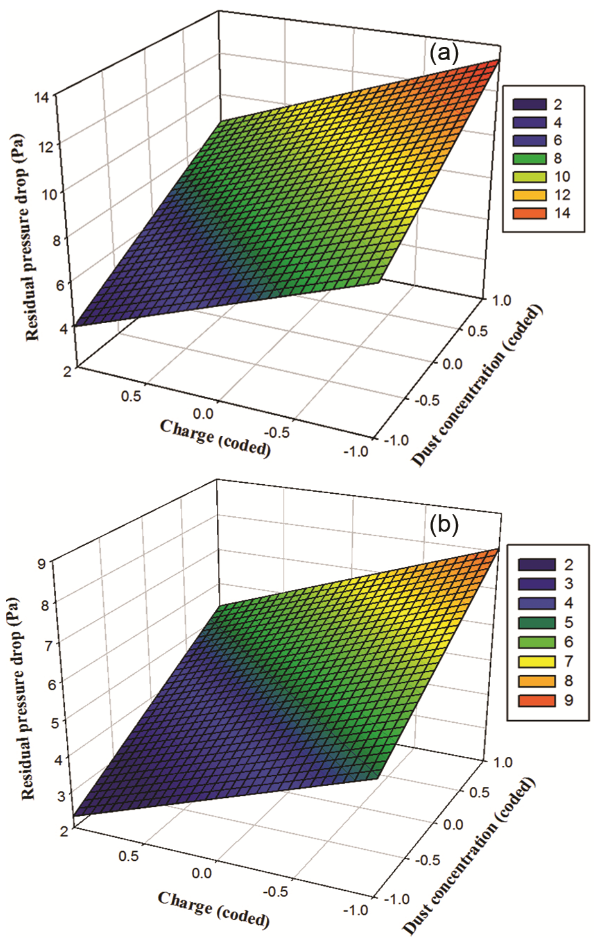

Fig. 4 — Effect of dust concentration and charge on residual pressure (a) non- PTFE filter fabric and (b) PTFE filter fabric

3.2 Effect on Pressure Drop

The effect of dust charge and dust concentration for both the materials has been represented in Fig. 4. It has been found that PTFE membrane filter media shows gradual increase in peak pressure and residual pressure drop. Further, it also shows a relatively slow increase in pressure values. It can be due to the effect of coating, facilitating the proper primary cake formation on the surface of filter fabric in the upstream side, which helps in proper dust dislodgement during regeneration pulse. It has also been noted that PTFE coated media reveals better surface filtration rather than depth filtration due to coating, which also supports during regeneration pulse for cleaning of filter fabric. However, Non-PTFE filter graph reveals steep increase in pressure values. When filter fabric is stabilized, all the pores of filter fabric are chocked off and depth filtration gets started. It offers firm rise in pressure values. Non-PTFE filter graph also gives random surge in pressure values. It is due to the uncontrollable cleaning or patchy cleaning of non-PTFE filter fabric, because untreated fabric offers improper and thick cake formation over the surface of filter fabric in upstream side after stabilization. It can also be seen the that increase in pressure value for PTFE filter is lesser than the non-PTFE filter. It can be due to re-entrapment of dust after regeneration pulse is more in case of non-PTFE filter fabric. The regression equation for varied parameters and contribution of each factor is represented through Tables 5 and 6 respectively. It

Table 5 — Regression equation for varied filtration parameters

Fabric	Filtration parameters	Regression equation	R^2	Standard error
PTFE media	Peak pressure	20.6 + 5.62 × A -6 × B + 6.38 × C	0.75	0.45
	Residual pressure	5.2 + 1.5 × A – 1.38 × B + 1.38 × C	0.61	1.56
Non-PTFE media	Peak pressure	27.41 + 11.25 × A -7.5 × B + 5.25 × C	0.66	0.38
	Residual pressure	8.67 + 2.63 × A - 2.38 × B + 1.5 × C	0.73	0.51

A—Dust concentration, B—charge and C—cycle time.

Table 6 — Contribution for varied filtration parameters

Fabric	A-Dust concentration, %	B-Charge %	C-Cycle time %	Dust concentration × cycle time (A×C), %	Dust concentration × charge (A×B), %
PTFE Media	36	21.33	16	8	15
Non-PTFE coated media	41	17	13.5	6	19

is observed that the effect of dust concentration has been the highest among all the factors in case of non-coated materials. However, the impact of other two factors, viz. charges and cycle time, has also been found to be significant. This indicates that the coating over the filter material is neutralizing the effect of dust density.

The peak and residual pressure drop trend for both the investigated materials are represented from Fig 5. It is observed that the dust concentration is having a significant impact on residual pressure drop behavior. The pulsing is executed on time based method, and hence its effect has been relatively less as compared to pressure based method. At higher dust concentration, pressure drop is noted as higher in case of both the materials. This can be attributed to the presence of greater number of small particles in the upstream, which leads to depth filtration, affecting the life of media. These particles can enter the clean air stream during pulsing. Also some particles remain trapped inside the structure of media, thus reducing the pore size and porosity of filter media and leading to increase in the residual pressure drop level.

Further inferences reveal that, charge level also has a significant impact on residual pressure. With the rise in charge level from 0 kV to 8 kV, a considerable reduction in the residual pressure drop trend is noted. However, the relative impact of cycle time is found less than those of the dust concentration and charge level. With lower cycle time, the pulsing is more frequent, and as a result of it the residual pressure drop values are lower as compared to higher cycle time. It can also be observed that dust concentration and charge have greater values of interaction as compared to dust concentration and cycle time. Thus, emission and pressure drop are influenced more by dust concentration and charge level as compared to cycle time. However, each factor and their cumulative effect on residual and peak pressure is found to have a significant impact.

It may also be added that the pressure drop trend for PTFE coated material is found to be much stable as compared to the non-coated material in case of both charged and uncharged conditions. This can be ascribed due to the effect of coating, facilitating improved dust cake formation on the media surface, thereby leading to smooth dislodgement of the dust during pulsing in the case of PTFE coated material. Hence, the particle penetration and seepage are restricted to large extent. However, for non coated material the surface pores will be relatively large. Hence, the particle depth penetration and seepage are comparatively higher, leading to increased pressure drop.

Further, it has also been noticed that the pressure drop trend with time is steadier in case of pre-charged condition as compared to without charge. This can be attributed to the effect of charge, causing agglomeration of dust particles[6,7], thereby providing a bridging effect over the filter media surface. This results in improved surface filtration, leading to reduced pressure drop. The cross-sectional images of investigated PTFE-coated material are illustrated in Fig. 6 for both levels of charge as well as without charge. It is observed from the image that the level of particle depth of penetration is relative lower in case of higher pre-charge level. This can be due to the effect of agglomeration due to charge, facilitating surface filtration and easy dislodgement of dust cake during pulsing. A similar trend is noticed for the without coated material also.

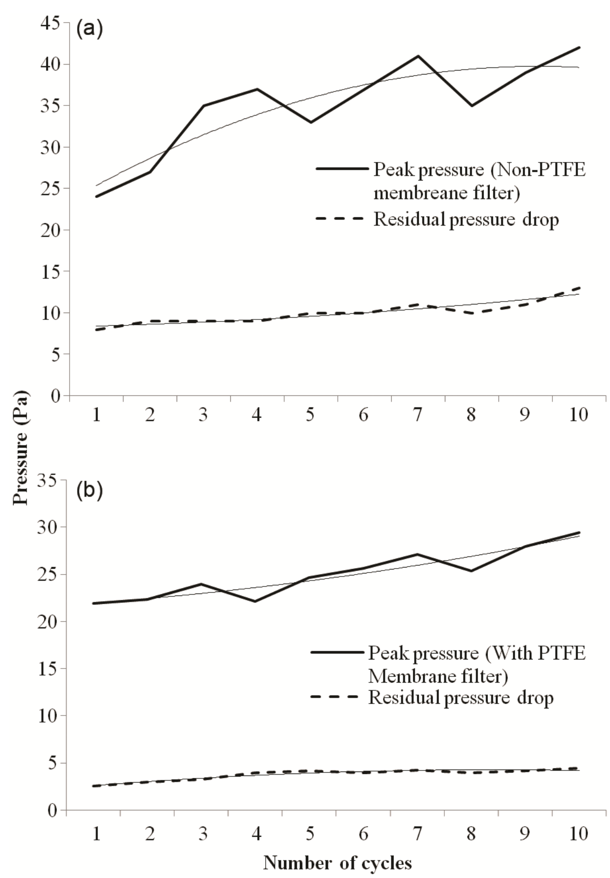

Fig. 5 — Peak and residual pressure drop trend at 4 kV charge (a) Non-PTFE filter media and (b) PTFE filter media

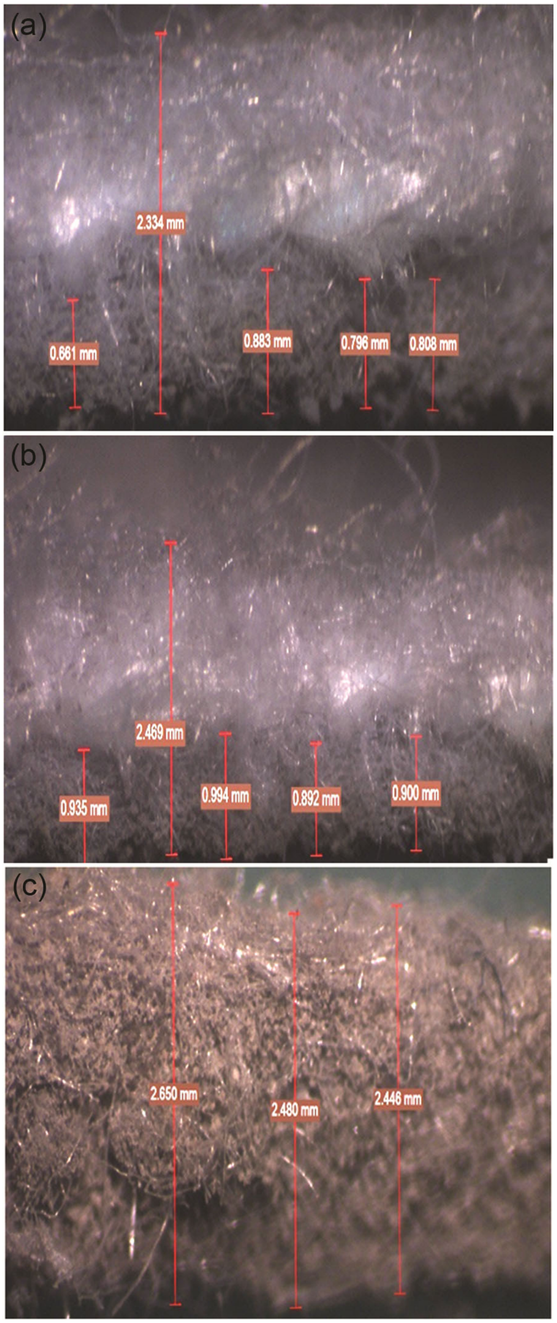

Fig. 6 — Cross-sectional image of investigated PTFE coated material (a) 8 kV charge, (b) 4 kV charge and (c) 0 kV charge

4 Conclusion

The investigation of filter materials reveals an enhanced filtration performance under charged conditions for both the examined materials. The coating over the material enables a relatively improved filtration performance of the PTFE media. Each factor is found to play a significant role in the material behavior. However, among all the factors the dust concentration is observed to make the highest impact in case of both emission and pressure drop. Further inferences reveal a relatively stable trend of residual pressure drop with time for the PTFE coated material under all the operating conditions. The residual pressure drop pattern for charged condition has been steadier as compared to uncharged condition. It may also be added that, besides significant contribution of each factor, the interaction behavior among all the factors has also been significant.

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