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Impact of progressive pulse cleaning pressure on polyester filter media performance using pulse jet filtration test rig

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The effect of progressive pulse cleaning pressure (2 bar to 3.5 bar) on filtration behaviour of two different polyester needle-punched nonwoven filter materials, viz. PTFE finished and without finished media has been studied at varying dust densities using flyash aerosol. The filter materials have been investigated on a flatbed filtration test rig based on cleaning at a fixed peak pressure drop of 1000 Pascal for an equal number of test cycles during the first three phases (conditioning, ageing and stabilizing phase) and further for the final measuring phase of four hours. The particulate emission and residual pressure drop behaviour are found to be significantly less in the case of PTFE-coated material under all the operating conditions. However, a significant difference among all levels of progressive pulse pressure has been found for both the examined materials.

Keywords: Needle-punched fabric, Nonwoven filter, Particulate emission, Polyester, Progressive pulse cleaning, PTFE finish, Pulse jet filtration, Residual pressure drop

1 Introduction

The studies pertaining to the filtration performance analysis in terms of emission and pressure drop of varying filter materials have been conducted to a large extent. In one of the relevant studies[1], the ageing behaviour of cleanable filter media at varying filtration velocity and cycle time according to the 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. During 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 behaviour of filter media at the industrial and laboratory level was compared[3], where a close agreement in results between them was found. In one of the recent research[4], the cleaning behaviour of pleated filter cartridges by designing a novel colliding pulse-jet cleaning method was studied. A considerable improvement in the cleaning performance of filter materials was noticed. During another latest study[5], the effect of particle size and pressure drop was studied using a pleated cartridge filter. It was reported that for the same particle size, both average and average 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. It may also be added that some of the previous researches[6-8] have reported an enhanced filtration performance of filter materials through charging the aerosol particles. However, its effect on filter media life is yet to be studied at the industrial level. Another experimental study of electrostatically augmented air filters was conducted by Lee *et al.*[9] using a corona pre-charger for dust and tobacco smoke. Filtration efficiency, pressure drop across the filter and particle concentration were measured. The study concluded that the use of a pre-charger leads to a decrease in pressure drop and improved collection efficiency.

Although there have been numerous reports defining the behaviour of varying filter materials in terms of pressure drop and emission, the effect of progressive pulse cleaning pressure with respect to increasing filtration time is yet to be studied.

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Since the aforementioned aspect is vital in determining the actual cleaning behaviour of filter media, it requires a thorough investigation. In view of this, the current study is undertaken to analyze the behaviour of materials with progressive pulse cleaning pressure.

2 Materials and Methods

The experiments were carried out using two types of filter materials, viz. polyester needle-punched fabric with a PTFE finish and without a finish. The PTFE finish was applied through the padding method. It may further be added that the base material for the application of the PTFE finish was different and specifications of the base fabric is playing an important role in filtration. The material specifications are represented in Table 1. Industrial cement dust 'fly ash' has been used as an aerosol, a fine powder distributed over 0.1-10 µm. The distribution of aerosol is illustrated in Fig. 1.

Test conditions used are: face velocity 2 m/min; dust concentration 100 and 150 g/m^3; pulse jet tank pressure 3 bar at first three stages; valve opening time 50ms; filter area 900cm^2; and cleaning pulse at 1000 Pa differential pressure at the media during first three stages. All tests were performed as per the ISO-11057 standard and the operating parameters are represented in Table 2.

Table 1 — Material specifications

Parameter	Without PTFE finish polyester filter media	PTFE finish filter media
Weight, g/m^2	512	496
Thickness, mm	1.88	1.84
Air permeability, L/dm^2/min	190	203
Bursting strength, kg/cm^2	24	32
Tensile strength, kgf		
MD	84	82
CD	88	84

Table 2 — Operation Parameter

Phase	Operation parameter	Value
Measuring	Loading cycle	30
	Pulsing duration	50 ms
	Pressure drop to start pulse jet	1000 pa
Ageing	Loading cycle	2500
	Pulsing interval	20 s
	Pulsing duration	50 ms
Stabilizing	Loading cycle	10
	Pulsing duration	50 ms
	Pressure drop to start pulse jet	1000 pa
Measuring	Loading cycle Time	4 hr
	Pulsing duration	50 ms
	Pressure drop to start pulse jet	1000 pa

2.1 Experimental Setup and Plan

The experimental setup is shown in Fig. 2. The test rig is composed of 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 a pressure-based method at a peak pressure level of 1000 Pa through a pulsing time of 50 milliseconds. The downstream side has been attached to an online particle size analyzer 'Promo 2000' to analyze the emitted particles. The experimental plan followed is shown in Table 3. The dimension of the flat specimen is 50 cm in length and 18 cm in width.

3 Results and Discussion

3.1 Effect on $PM_{2.5}$ Emission

The effect of varying progressive pulse pressure on $PM_{2.5}$ emission and number concentration has been represented in Table 4 for both materials. It is to be noted that $PM_{2.5}$ refers to the aerosol particle size having diameter smaller than 2.5 microns. It is

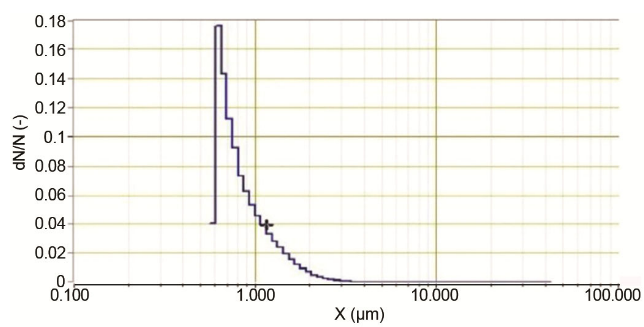

Fig. 1 — Flyash particle size distribution

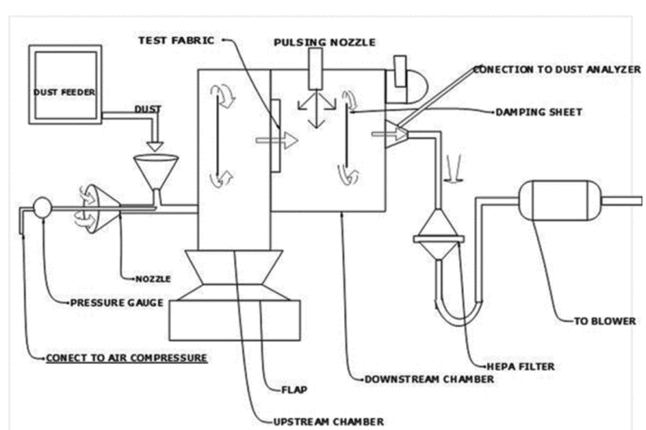

Fig. 2 — Experimental setup

Table 3 — Experimental plan for testing of polyester needle-punched filter media

Fabric type	Dust concentration g/m^3	Cleaning intensity (kPa) for measuring stage			Replication	
					First	Second
PTFE finished	100	3.0	3.0	3.0	1	2
	150	3.0	3.0	3.0	3	4
Without PTFE	100	3.0	3.0	3.0	5	6
	150	3.0	3.0	3.0	7	8
PTFE finished	100	2.0	2.5	3.0	9	10
	100	2.0	2.5	3.0	11	12
Without PTFE	150	2.0	2.5	3.0	13	14
	150	2.0	2.5	3.0	15	16
PTFE finished	100	2.5	3.0	3.5	17	18
	100	2.5	3.0	3.5	19	20
Without PTFE	150	2.5	3.0	3.5	21	22
	150	2.5	3.0	3.5	23	24

Table 4 — Results of $PM_{2.5}$ and number concentration at different pulse cleaning

Dust concentration, g/m^3	Filter media type	At 3 bar (C1)	At 2 to 3 bar (C2)	At 2.5 to 3.5 bar (C3)
		$PM_{2.5}$ Emission (µg/m^3)		
100	PTFE finish	7.75	8.52	7.16
		7.33	8.88	7.13
	Without PTFE	17.86	18.75	16.55
		17.60	18.91	16.48
150	PTFE finish	10.84	12.33	10.73
		11.8	12.21	10.86
	Without PTFE	24.75	26.54	23.75
		28.95	30.96	25.95
		Number Concentration (P/cm^3)		
100	PTFE finish	24.66	32.66	23.63
		26.64	32.56	24.59
	Without PTFE	70.56	75.32	60.96
		71.36	78.37	63.31
150	PTFE finish	33.47	42.13	31.06
		38.55	45.75	32.21
	Without PTFE	118.91	128.31	116.7
		119.54	127.35	114.13

analyzed that for every case irrespective of dust concentration level and filter media type, the progressive pulse pressure from 2.5 bar to 3.5 bar is more effective and shows better relative results. This can be ascribed due to a higher pulsing impact at 2.5-3.5 bar. Furthermore, the cycling interval between two subsequent pulsing will be more, which will result in lower regeneration of dust over the media surface, therefore the penetration to the downstream will be comparatively less and eventually the overall $PM_{2.5}$ emission value will be less. It is also noted that PTFE-finished filter media with lower dust concentrations reveals a lower $PM_{2.5}$ emission value. This low emission value is due to proper cake formation on the surface of filter media and efficient dislodging of dust as the finish enhances the surface property of filter media. Also, at lower dust concentrations the number of inlet particles will be less and hence, loading on filter media will be relatively lower.

Further inference reveals maximum $PM_{2.5}$ emission from 2 bar to 3 bar, irrespective of dust level concentration and filter media type. This is because at comparatively lower pulse pressure the impact of pulsing is not much intense. Therefore, the residual pressure drop is much higher and the set pressure drop is reached quite frequently, as a result, the number of pulsing cycles increases and the re-deposition of dust becomes higher. This leads to the possibility of more particles penetrating through the filter media towards clean air, hence emission becomes higher. At 3 bar pulse pressure, the $PM_{2.5}$ emission is higher than that of 2.5-3.5 bar progressive pulse pressure; however, it is relatively lower than that of 2-3 bar progressive pulse pressure. This can be attributed to the fact that during all the previous filtration phases the filter media has been subjected to the same pulse pressure as that in the measuring phase. Therefore, the emission data was consistent during the measuring phase. The residual pressure and cyclic intervals are constant as compared to progressive pulse pressures.

It is also noted that, at constant pulse pressure, the $PM_{2.5}$ emission increases for both the investigated materials. PTFE finished filter media reveals twice lower particulate values for both dust densities as compared to without finished filter media. The percentage change of $PM_{2.5}$ emission with increasing dust concentration is higher in the case of without a PTFE finished filter media at different pulse pressure. The application of PTFE finish enhances the surface property of filter media by providing a bridging effect over the surface which prevents the penetration of smaller particles into inner layers, this is because the number of pores and pore size gets reduced. It may also be added that the finished material has improved airflow than non-finished filter media, which is responsible for efficient and proper filter cake formation. Further, it is to be noted that the behaviour of PM_{10} emission with progressive pulse pressure has been found similar to $PM_{2.5}$ emission.

ANOVA analysis has been carried out to analyze the effect of each factor on $PM_{2.5}$ emission and the same has been represented in Table 5. The surface finish has a prominent role during the filtration process among all the factors. During pulsing, the pores get wide and open for a short time, as an effect of high-pressure cleaning pulse air. In such case, direct penetration and seepage take place through the opening up of pores, which causes straight through of the particles into the clean air side. But in the case of without PTFE finished filter media, there will be non-uniform pore sizes and chances of seepage of the dust through the filter media become higher.

3.2 Effect on Particle Number Concentration

The effect of progressive pulse cleaning on particle number concentration has been represented in Table 4 for both materials. It is observed that at lower dust concentrations, there are more numbers of coarser particles as compared to that at higher dust concentrations. This may be due to the relatively early blocking of pores at higher dust concentrations as compared to that at lower dust concentrations during the conditioning phase, thus restricting coarser particles to pass through. Also, the dust layer formation is observed earlier in high dust concentration, which also helps in restricting coarser particles at progressive pressure trends.

Further inferences reveal that at a constant pressure of 3 bar (C1), the number concentration value has changed by 44% at lower dust concentrations for finished material. In the case of without PTFE finish filter media, the number concentration value changes to 68%. However, at progressive pulse

Table 5 — ANOVA for $PM_{2.5}$ emission and particle number concentration at different pulse cleaning

Source	SS	Degree of freedom	MS	F	%C
		$PM_{2.5}$ emission			
Dust concentration (DC)	243.270	1	243.270	133.800	18.75
Finish type (FT)	960.768	1	960.768	528.428	74.08
Pulse pressure (PP)	20.634	2	10.317	5.674	1.65
DC×FT	46.010	1	46.010	25.306	3.54
DC×PP	0.420	2	0.210	0.116	0.032
FT×PP	3.060	2	1.530	0.841	0.23
DC×FT×PP	0.871	2	0.436	0.240	0.067
Error	21.818	12	1.818		
Total	1296.851				
		Particle number concentration			
Dust concentration (DC)	5502.48	1	5502.48	1932.45	16.91
Finish type (FT)	23877.04	1	23877.04	8385.53	73.32
Pulse pressure (PP)	583.93	2	291.97	102.54	1.81
DC×FT	2532.58	1	2532.58	889.43	7.77
DC×PP	3.53	2	1.77	0.62	0.01
FT×PP	14.32	2	7.16	2.51	0.04
DC×FT×PP	17.13	2	8.56	3.01	0.05
Error	34.17	12	2.85		
Total	32564.7				

pressure from 2 bar to 3 bar (C2), the number concentration value changes by 35% at lower dust concentrations for finished material. In the case of without PTFE finish filter media, the change is noted to be 64%. Further, for progressive pulse pressure from 2.5 bar to 3.5 bar (C3), the number concentration value changes by 29% at lower dust concentrations of finished media. In the case of without PTFE finish filter media, the change has been 88%.

Table 5 represents the overall effect of the variance of number concentration at different pulse pressure at two different filter media and two different dust concentrations. Among all the factors, the finish type is having maximum impact on particle number concentration. This can be ascribed due to a similar reason as discussed for $PM_{2.5}$ emission under section **3.1**.

3.3 Effect of on Residual Pressure Drop

Residual pressure drop trend with filtration time at 100 g/m^3 dust concentration has been represented in Figs 3(a), (b) & (c) for 3 bar, 2-3 bar and 2.5-3.5 bar progressive pulse pressures respectively. It is observed that PTFE-finished filter media have less residual pressure drop throughout the filtration cycle time as compared to those without PTFE-finished filter media for all the progressive pulse pressures. For 3 bar, the PTFE-finished filter media reveals lower residual pressure drop and also the pressure trend is more schematic for PTFE finished media as compared to without PTFE finished filter media. The reason for this can be ascribed due to the additional advantage of the properties of finish on the surface of filter media. The finish facilitates proper cake formation on the surface of the media, which results in the efficient release of dust reducing lower pressure drop and also dust re-deposition after pulsing on the media surface will be less. Thus, dust penetration into the inner layer of media must be lower as compared to without finish media. Lower penetration will lead to a more gradual trend of pressure.

In the case of 2-3 bar, the PTFE finish filter media depicts a better impact of progressive pulsing in the last 80 min. The filter media is tested for 240 min at equal intervals of 80 min at 2 bar, 2.5 bar and 3 bar respectively. From the graphs, it can be noted that as the pulsing pulse pressure increases from 2 bar to 3 bar, the residual pressure drop level decreases. This can be because, at lower pulse pressure the burst of air thrown during pulsing will be less, thus the impact of pulsing on the filter media will be lower. Therefore, the residual pressure level could not reach a sufficient lower level and the number of pulsing cycles is higher; with subsequent pulsing at 2 bar, the residual pressure drop increases very rapidly. This is due to continuous regeneration of dust after every pulsing. For the next 80 min at 2.5 bar, the residual pressure drop decreases rapidly and a gradual trend is followed thereafter. This is due to the higher impact of pulsing on filter media and less regeneration of dust, which will lead to less pulsing comparatively and less blockage of pores by dust particles. For the final 80 min at 3 bar, there is a slight

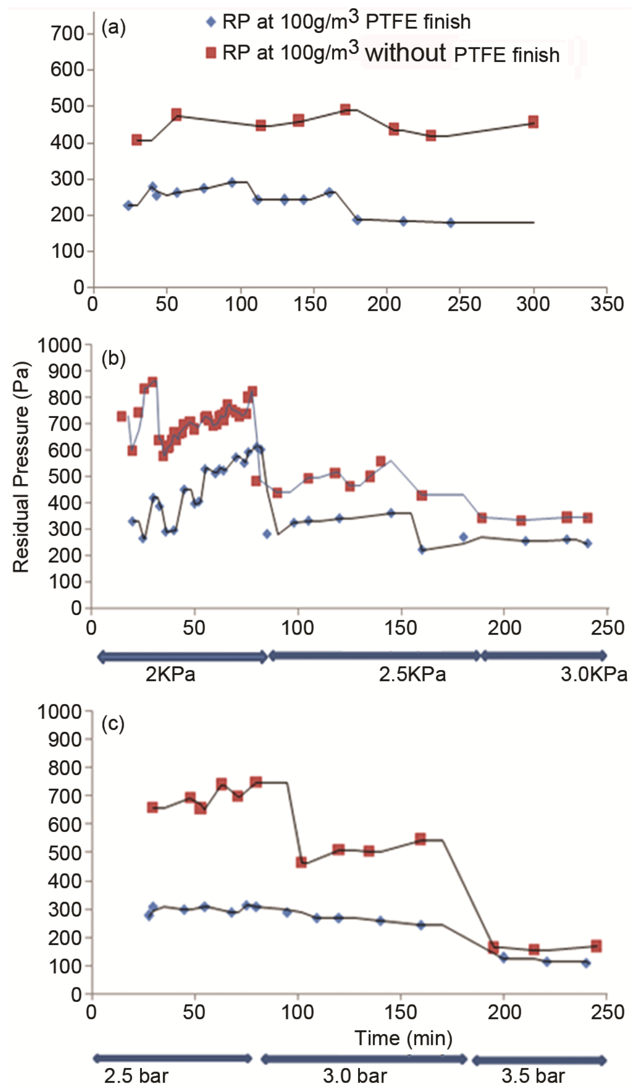

Fig. 3 — Residual pressure drop trend at 100 gm/m^3 (a) 3 bar, (b) 2-3 bar and (c) 2.5-3.5 bar

decrease in pressure drop found, the level of pressure drop reduced is not much because by this time much of the pores are blocked. Therefore, the pressure drop level could not reach an expected lower level. In a comparative analysis of two filter media (PTFE and without PTFE), PTFE finished filter media shows lower residual pressure drop than without PTFE filter media. The reason could be the same as for constant pulse pressure (3 bar). Further, in another case of progressive pulsing (2.5 bar to 3.5 bar), as the pulsing pulse pressure increases the residual pressure drop level increases. This could be because at higher pulse pressure the burst of air thrown during pulsing will be high, thus the impact of pulsing on the filter media will be less. Hence, the residual pressure level could not reach a sufficient lower level and the number of pulsing cycles is higher.

The residual pressure drop trend at 3 bar, 2-3 bar and 2.5-3.5 bar at 150 g/m^3 dust concentration is represented in Figs 4(a), (b) & (c) respectively. In a comparative analysis of dust concentration levels, it is found that at higher dust concentrations (150 g/m^3), the residual pressure drop in the system increases with filtration time. This is because at a higher dust concentrations the inlet of dust particles will be much higher, thus there will be more loading on filter media and also the chances of particles seeping into the inner layer of filter media will be more and the pore will get blocked more quickly compared to the lower dust concentrations (100 g/m^3). However, for both the examined materials, the overall trend for both dust concentrations is noted to be similar in the case of all the progressive pulse pressure levels.

The average residual pressure drop values for both the investigated materials are represented in Table 6. It is observed that the PTFE finished media is exhibiting lower residual pressure drop under both dust densities and all progressive pulse pressure levels. This can be ascribed to the benefit of surface finish as discussed previously.

Figure 5 represents the effect of dust concentration on residual pressure drop on both the materials for 3 bar, 2-3 bar and 2.5-3.5 bar. It is observed that there is a significant difference between the dust concentration levels for all the pulse values. However, the overlapping in cases 2.5-3.5 bar is relatively higher. This indicates that at higher pulse pressure values the impact of dust concentration is decremental due to more thrust of blown air.

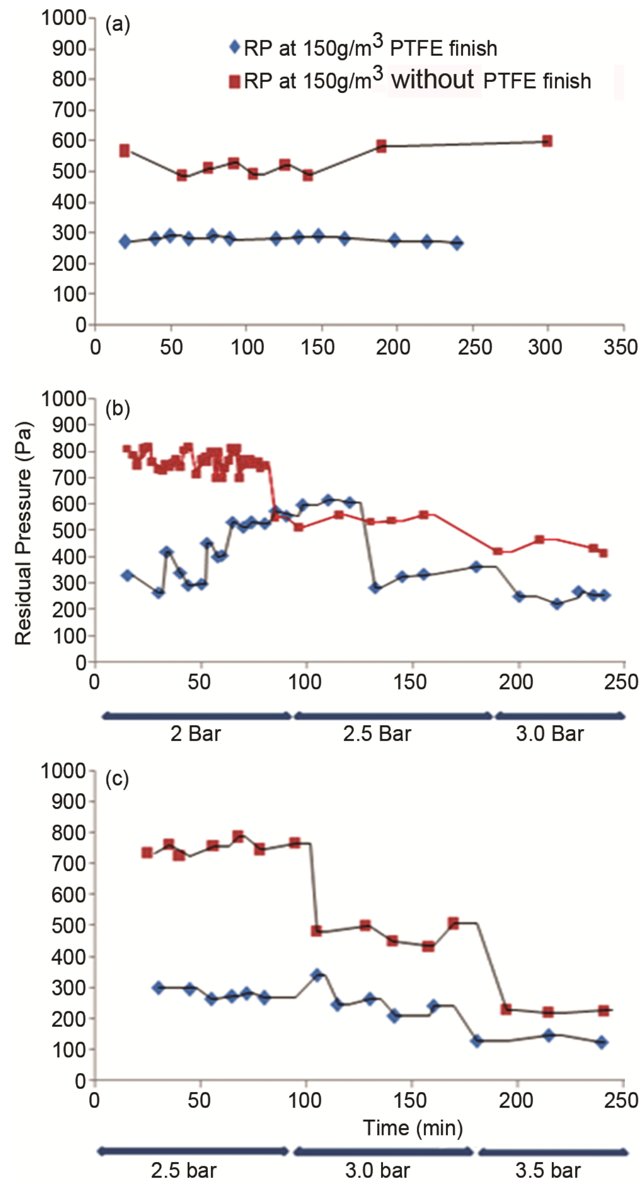

Fig. 4 — Residual pressure drop trend at 150 gm/m^3 (a) 3 bar, (b) 2-3 bar and (c) 2.5-3.5 bar

Table 6 — Results of residual pressure at different pulse cleaning

Dust concentration g/m^3	Filter media type	Residual pressure (Pa) At 3 bar	At 2 to 3 bar	At 2.5 to 3.5 bar
100	PTFE finish	241	368	252
		232	355	248
	Without finish	448	640	515
		452	652	535
150	PTFE finish	280	425	265
		283	431	271
	Without finish	475	705	554
		481	718	552

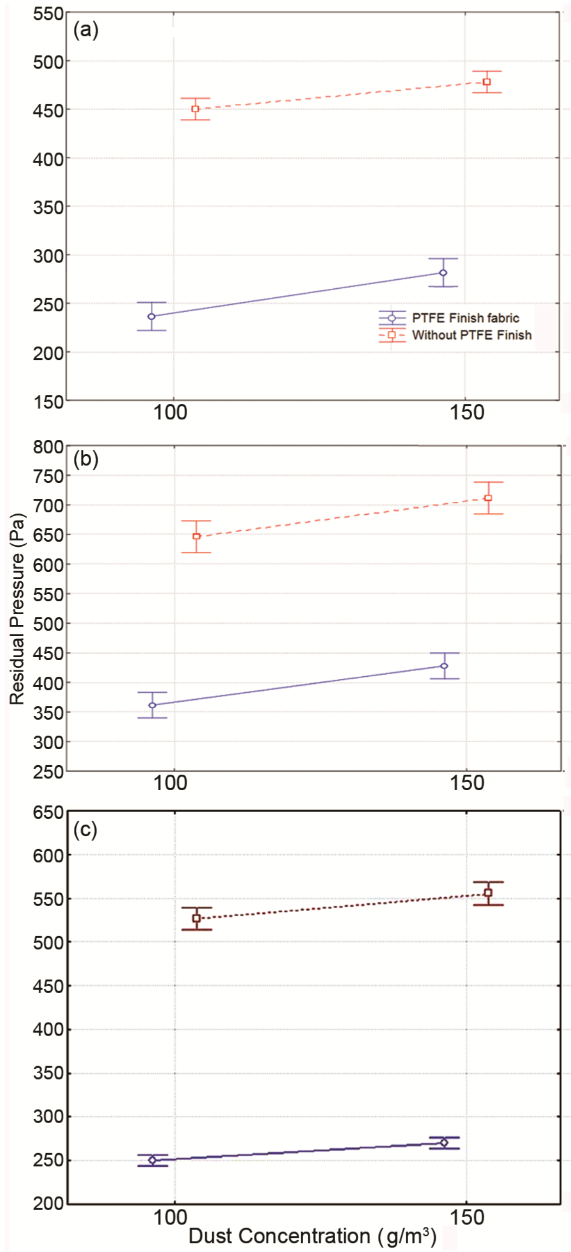

Fig. 5 — Effect of dust concentration and finish type on residual pressure (a) 3 bar, (b) 2-3 bar and (c) 2.5-3.5 bar

4 Conclusion

Based on the investigations and the effect of progressive pulsing at two dust concentrations on the performance of filter fabric in terms of emission, residual pressure drop and other factors, it can be conferred that the effect of progressive pulse cleaning has been better in the case of both dust concentrations and investigated filter materials as compared to constant pulse cleaning pressure. The PTFE finished media is revealing lower emissions compared to the without finished material under all the conditions. Further inference reveals the highest impact of finish type on emission among all the factors. It is also concluded that the variation in emission is relatively less for the finished media as compared to the unfinished material at higher dust concentrations in the case of progressive pulsing. The residual pressure drop trend is noted to be relatively steadier for the finished material and progressive pulse cleaning. However, for constant pulse pressure, a high variation in the residual pressure drop is observed, which may be due to patchy cleaning and the ageing effect.

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