

## Effects of PTFE-coated membrane on polyester needle-punched filter media for the control of industrial air pollution

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Physical and chemical properties of aerosol, filter media properties, aerosol composition, dust cake properties, construction of filter unit, dew point and temperature are the parameters that affect the filtration performance during the control of industrial air pollution. No comprehensive experimental study has been reported on the effect of varying cleaning cycle times on the filtration performances, and no emission study at the clean side was conducted using PTFE-coated membrane on polyester needle punched filter media. In this experimental work, we are studying the filtration performances and characterization of emitted particles with varying cleaning cycle times in a pulse jet filtration system with membrane-coated media. The particulate emissions in terms of  $PM_{2.5}$  and  $PM_{10}$  are substantially lower, when using a coated membrane on filter media. Mass concentration and number concentration in downstream emission is also lower for filter media using PTFE membrane on needle felt nonwovens fabric media. Filtration efficiency is higher for filter media with PTFE coated than without PTFE membrane coating. PTFE membrane-coated media fabric exhibits lower residual pressure drop ( $\Delta P$ ), which ultimately enhances the filter media life, more energy saving and better control on emissions. The downstream  $D_{10}$ ,  $D_{50}$ , and  $D_{90}$  particles values are much higher in non-PTFE membrane-coated filter media. Overall, it is observed that fabric filter media with PTFE membrane, arrests a higher proportion of the fine particles, which causes lesser impacts on human health by industrial air pollution. Hence, the membrane-coated filter media (i.e. membrane separation) effectively controls the fine particles emission at downstream side/clean side.

**Keywords:** Emitted particles characteristics, Filtration efficiency, Industrial air pollution control, Particulate emission, PTFE membrane coated polyester

### Introduction

Many human activities are very closely related to manufacturing and development processes, leading to a rise in air pollution as they generate a lot of pollutants. Industrial processes emit not only harmful gases like carbon monoxide (CO), carbon dioxide (CO<sub>2</sub>), sulphur dioxide (SO<sub>2</sub>), nitrogen oxides (NO<sub>2</sub>), and fly ash but also emit volatile organic compounds which have adverse impacts on the health of an individual and lead to ozone layer depletion and the green house effect. Air filtration is essential in removing these pollutants, especially in all manufacturing process industries, to control industrial air pollution. Pulse-jet filtration (PJF) is a designated efficient technology for controlling air pollution by industrial emissions. PJFFs are primarily accepted by industries like power generation, chemical, steel, cement, food, pharmaceutical, municipal incineration, and municipal waste recycling; in the filtration process, particles deposited and form cake on the outer surface of the filter bags, with the rise in pressure drop. So, filter bags must be periodically

regenerated, usually by pulse-jet cleaning. Cleaning of cakes involves injecting high-pressure back pulse air (3–7 bar) into the filter bags for a very short time (50–150 ms) and cleaning back pulse air injection origins rapid expansion of the filter bags and dislodgement of a cake from surface of the filter media. The filter unit designed must have a high-performance level and be cost-effective to be economically viable. The dust particles easily caught on the surface or inside the pores in filter media<sup>1,2,3,4</sup>. Particle size smaller than the size of the pores of the filter media are caught on the fibers' surface by interception, inertial impaction, electrostatic particle capture mechanism or Brownian diffusion<sup>5</sup>. As high numbers of particles are collected, the filter media's pores are blocked, and the pressure drop value across the filter media increases. To reduce the pressure drop, most filters are cleaned using reverse airflow, pulse-jet cleaning, and mechanical shaker methods<sup>6,7</sup>. Pulse-jet filtration is portrayed as one of the most proficient innovations in maintaining mechanical contamination over the globe. Pulse-jet fabric filters

(PJFFs) are broadly utilized in force age, burning, substance, steel, concrete, food, drug, metal working, and carbon dark industries. Needle punch filter media provide higher filtration efficiency at relatively lower pressure drop. Due to greater flexibility and versatility in construction, needle felts are an ideal alternative for filtration. Regular needle-punched nonwoven textures had an impediment in filtration since they neglected to fulfil the ecological norms. The texture is commonly adequate for gathering enormous particles ( $>5 \mu\text{m}$ ). Be that as it may, it is not similarly successful for smaller, submicron-sized particles. The design of filter elements depends upon the following factors: Fabric materials types, their finishes and other details like filter element dimension and fabrication. Recent work has investigated the design of pulse-jet bag houses for fine particle collection<sup>8-12</sup>. For the proper functioning of the fabric filters, the selection of proper fabric is one of the primary factors. A variety of common fibers like natural cotton, wool, etc. or artificial fabrics like polyester, acrylic, polypropylene, polyamides, glass, aramid, polytetrafluoroethylene (PTFE), etc., are being used for the manufacturing of filter bags<sup>13</sup>. Some finishing treatments are applied to filter fabrics to improve filtration ability and properties such as flame-retardant, anti-static, thermal and chemical resistance<sup>14,15</sup>. Felted fabrics, i.e. nonwoven materials, are used with high-energy cleaning and saving systems such as pulse-jet cleanings. The felted fabric filters are generally 2 to 3 times thicker than woven filters. The felted filters depend less on the initial dust deposits to collect fine particles than woven filters. Felted fabrics are not used in highly humid conditions, especially in the case of hygroscopic particles, because these particles absorb moisture and thus become sticky. Clogging or blinding could result in such situations<sup>16-19</sup>. PTFE membrane can be used on filter media for all emissions and cost optimization. In this experimental work, both PTFE-coated membrane and non-coated polyester needle-

punched filter media, are used to see the advantages, especially for media life and emission quality.

## Experimental Section

### Materials

Two different types of filter media fabrics, needle-punched nonwoven filter media and PTFE-coated nonwoven filter media have been used for testing. The specifications of the media fabric samples are given in Table 1.

### Filter media testing

#### Parameters of flat filter media test rig

1. Dust concentration:  $100 \text{ g/m}^3$
2. ACR(Air to cloth ratio): 1 m/min
3. Pulse pressure: 2 bar
4. Dustused: Fly ash ( $0.2-10 \mu\text{m}$ )
5. Pulse duration: 50 ms
6. Filter area:  $900 \text{ cm}^2$

**Testing conditions:** According to ISO standards (ISO-11057)

- 1 Conditioning Phase: 5 h study at 1000 pa.
- 2 Ageing Phase: Particulate efficiency after 1000 and 2500 cycle intervals at 5 s.
- 3 Stabilizing Phase: 5 h study at 1000 pa.
- 4 Measuring Phase: 2 h study at 1000 pa.

### Experimental set-up and conduct of the experiment

Experimental tests were performed on an industrial-based flat test rig, as shown in Fig. 1 (Process line diagram) and Fig. 2 (Machine in the laboratory). Emission parameters were observed from PALAS GmbH (Model Promo, 2000), which works on the principle of a light scattering spectrometer. The filter media were tested using fly ash dust with a face velocity of 2m/min, dust concentration of  $100 \text{ g/m}^3$ , air-to-cloth ratio of 1m/min, tank pressure of 2 bars and valve opening time of 50 ms. Each experiment was carried out in four phases: Conditioning, ageing, stabilizing, and

Table 1 — Technical specifications of the needle-punched nonwoven filter media

S. No.	Physical properties	Sample I	Sample II
1	GSM ( $\text{g/m}^2$ )	575	575
2	Thickness (mm)	2.1	2.1
3	Tensile strength (kgf)	MD- 110	MD- 110
4	Air-permeability (at $1/\text{dm}^2.\text{min}$ ) at 20 mm w/c)	160	160
5	Media fibre fineness (Denier)	2.5	2
6	Pore sizes of media (micron)	51.36	36.36
7	Punching density (Punches/ $\text{cm}^2$ )	350	350
8	Functional finish	PTFE Membrane	Non-PTFE Membrane

Sample I: PTFE Coated membrane needle punched polyester nonwoven filter media

Sample II: Non-PTFE coated membrane needle punched polyester nonwoven filter media

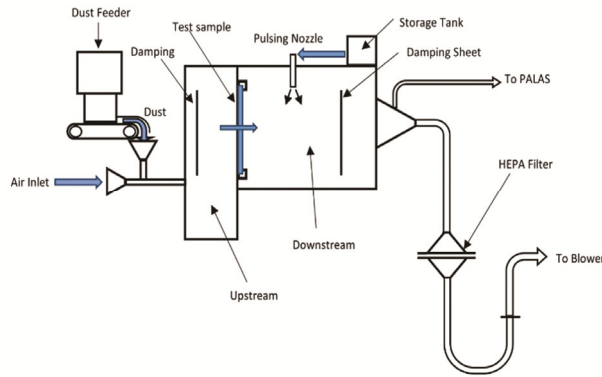


Fig. 1 — A schematic diagram of pulse jet flat media filtration test rig

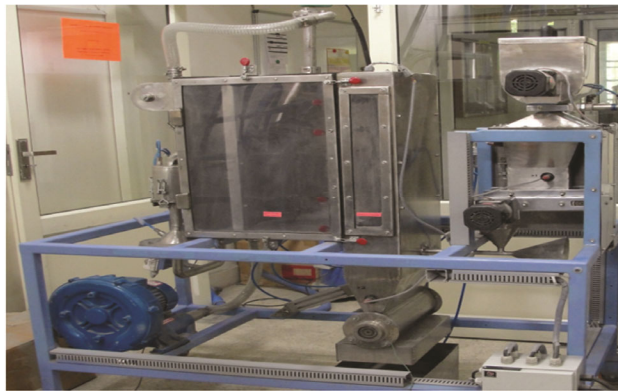


Fig. 2 — Pulse jet flat media filtration test rig

final measuring phase. The conditioning phase was carried out for 5 h at 1000 pa. After completion of the conditioning phase, the ageing phase was carried out for 1000 and 2500 cycles intervals at 5 s, the stabilizing phase was carried out for 5 h at 1000 pa, and the final measuring testing phase was carried out for 2 h at 1000 pa. The emission values, i.e., number and mass concentrations, were taken at each testing phase. The media performance emission data and differential residual pressure drop are taken for each testing phase, and peak pressure drop (Pa) is tested for the conditioning and ageing phase only<sup>20,21</sup>.

**Results and Discussion**

This experimental study tested polyester needle-punched nonwoven filter media and polyester needle-punched PTFE-coated nonwoven filter media at different phases and constant dust concentration on a flat pulse jet filtration test rig. Performances of filter media based on filtration efficiency, differential pressure behaviour, and downstream particle emissions were analyzed for both materials, and a comparative study was conducted. Accordingly, Table 2 shows the performance data at 1000 cycles for PTFE-coated material, Table 3 shows the data at 2500 cycles for PTFE-coated material, and Table 4 shows the data at 1000 cycles for non-PTFE-coated

Table 2 — Performances of polyester needle-punched PTFE samples (1000 cycles)

Performance Parameters	Conditioning	Ageing (1000 cycles)	Stabilizing	Measuring	Overall
PM <sub>2.5</sub> (µg/m <sup>3</sup> )	243	276	259	282	319
PM <sub>10</sub> (µg/m <sup>3</sup> )	537	563	553	579	602
Peak pressure drop (Pa)	1000	-	1000	1000	1000
Residual pressure drop (Pa)	249	282	270	302	324
Particles mass concentration (mg/m <sup>3</sup> )	0.65	0.7	0.62	0.64	0.75
Number concentration (P/cm <sup>3</sup> )	652	698	680	729	767
Filtration efficiency (%)	99.991	99.976	99.989	99.96	99.993
D <sub>10</sub> Particles	0.86	0.91	0.89	0.94	0.92
D <sub>50</sub> Particles	1.11	1.19	1.15	1.21	1.20
D <sub>90</sub> Particles	1.34	1.43	1.39	1.45	1.44

Table 3 — Performances of polyester needle-punched PTFE membrane samples (2500 cycles)

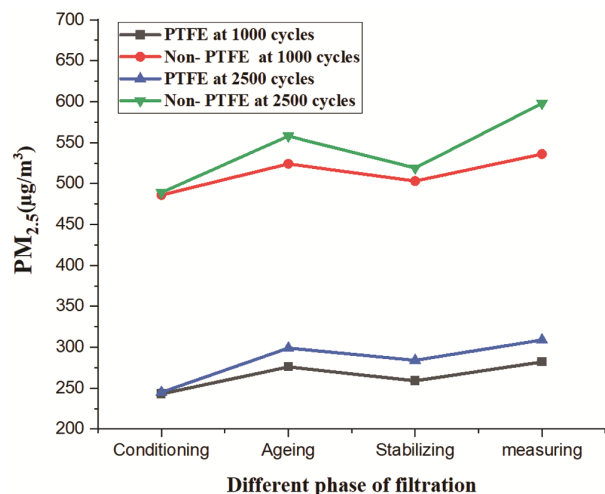
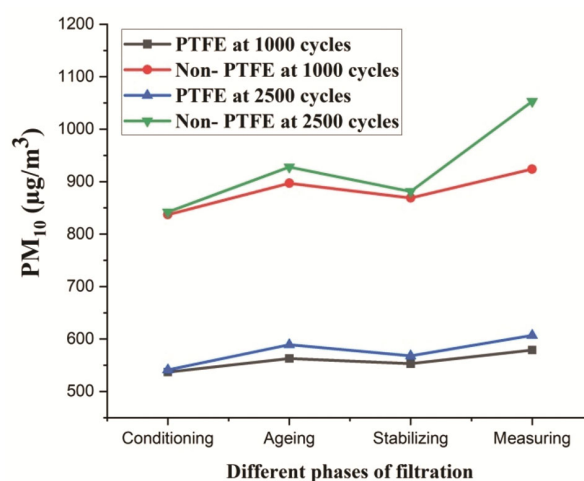
Parameters	Conditioning	Ageing (2500 cycles)	Stabilizing	Measuring	Overall
PM <sub>2.5</sub> (µg/m <sup>3</sup> )	245	299	284	309	348
PM <sub>10</sub> (µg/m <sup>3</sup> )	541	589	568	607	664
Peak pressure drop (Pa)	1000	-	1000	1000	1000
Residual pressure drop (Pa)	253	306	289	327	343
Mass concentration (mg/m <sup>3</sup> )	0.7	0.75	0.65	0.8	0.9
Number concentration (P/cm <sup>3</sup> )	654	752	693	797	835
Filtration efficiency (%)	99.990	99.973	99.98	99.971	99.992
D <sub>10</sub> Particles	0.87	0.94	0.92	1.1	0.96
D <sub>50</sub> Particles	1.12	1.20	1.17	1.22	1.21
D <sub>90</sub> Particles	1.36	1.46	1.41	1.48	1.47

Table 4 — Performances of polyester needle-punched non-PTFE membrane samples (1000 cycles)

Parameters	Conditioning	Ageing (1000 cycles)	Stabilizing	Measuring	Overall
PM <sub>2.5</sub> (µg/m <sup>3</sup> )	486	524	503	536	612
PM <sub>10</sub> (µg/m <sup>3</sup> )	837	897	869	924	1023
Peak pressure drop (Pa)	1000	-	1000	1000	1000
Residual pressure drop (Pa)	404	457	424	487	503
Mass concentration (mg/m <sup>3</sup> )	1.2	1.4	1.2	1.5	1.7
Number concentration (P/cm <sup>3</sup> )	1360	1690	1478	1712	2472
Filtration efficiency (%)	97.569	96.80	97.40	96.78	99.23
D <sub>10</sub> Particles	1.22	1.48	1.34	1.54	1.49
D <sub>50</sub> Particles	1.63	1.96	1.83	2.11	1.98
D <sub>90</sub> Particles	2.10	2.72	2.42	2.93	2.81

Table 5 — Performances of polyester needle-punched non-PTFE samples (2500 cycles)

Parameters	Conditioning	Ageing (2500 cycles)	Stabilizing	Measuring	Overall
PM <sub>2.5</sub> (µg/m <sup>3</sup> )	489	558	519	598	748
PM <sub>10</sub> (µg/m <sup>3</sup> )	842	928	881	1053	1262
Peak pressure drop (Pa)	1000	-	1000	1000	1000
Residual pressure Drop (Pa)	407	499	471	509	566
Mass concentration (mg/m <sup>3</sup> )	1.4	1.6	1.3	1.7	1.9
Number concentration (P/cm <sup>3</sup> )	1378	1842	1498	1896	3481
Filtration efficiency (%)	97.58	96.76	97.36	96.42	98.89
D <sub>10</sub> Particles	1.23	1.61	1.48	1.82	1.78
D <sub>50</sub> Particles	1.65	2.17	1.91	2.71	2.59
D <sub>90</sub> Particles	2.11	3.11	2.59	3.43	3.16

Fig. 3 — PM<sub>2.5</sub> at different phases of filtrationFig. 4 — PM<sub>10</sub> at different phases of filtration

material. Lastly, Table 5 shows the data at 2500 cycles for non-PTFE coated material.

#### PM<sub>2.5</sub> and PM<sub>10</sub> emissions

It is observed that media fabric types significantly impact the emissions from Table 2-5 and Figs 3-8. It is observed that polyester filter fabric (With treatment) exhibits lower emissions than polyester fabric (Without treatment) for both cycles of the ageing phase, viz. 1000 and 2500 cycles. Due to the small pore size of the coated material, the particles are facilitated with improved surface filtration. As a result, the particles are prevented from seeping

through the inner layer of the filter media, leading to reduced particulate emission. PM<sub>2.5</sub> and PM<sub>10</sub> particle values increased after the ageing phase but decreased after the stabilization phase due to the stabilization of filter media. Values again increased during the measuring phase for both samples but were higher without coating fabric due to more penetration of particles.

#### Particle mass concentration and number concentration

Particle mass concentration of the particles refers to the mass of the particles emitted per cubic meter. From the mass concentration study (Figs 9-11), it has

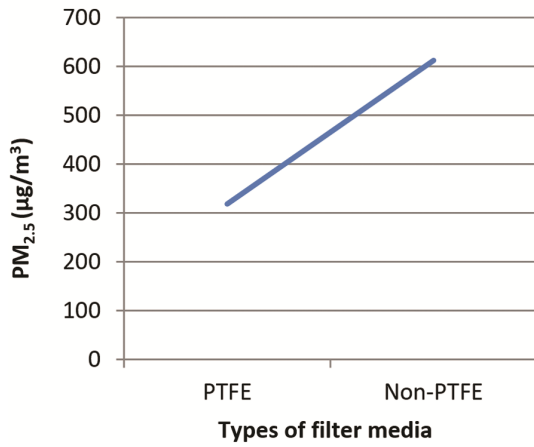


Fig. 5 — Overall PM<sub>2.5</sub>, ageing phase at 1000 cycles

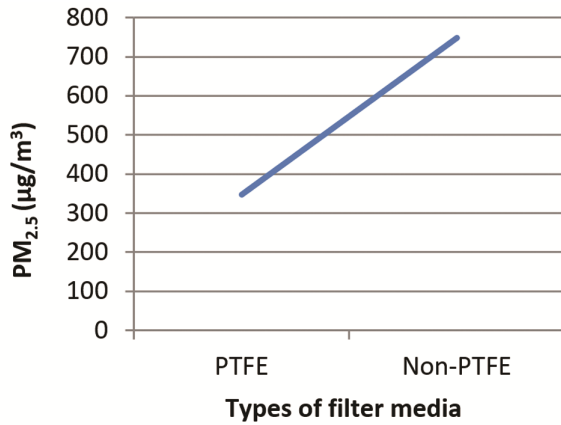


Fig. 6 — Overall PM<sub>2.5</sub>, ageing phase at 2500 cycles

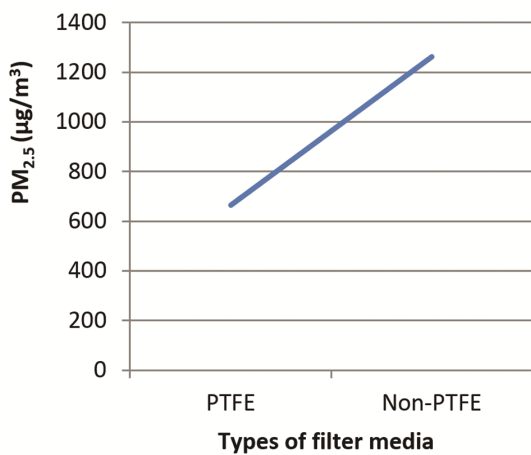


Fig. 7 — Overall PM<sub>10</sub>, ageing phase at 1000 cycles

been observed that polyester filter fabric (with PTFE treatment) gives a lower *C<sub>m</sub>* value than polyester filter fabric (without treatment) due to excellent dust cake release and little particulate penetration of the

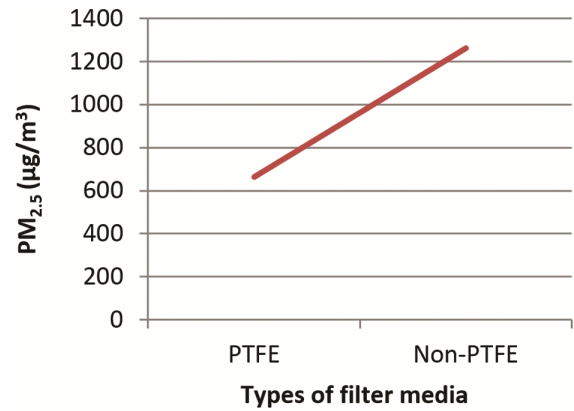


Fig. 8 — Overall PM<sub>10</sub>, ageing phase at 2500 cycles

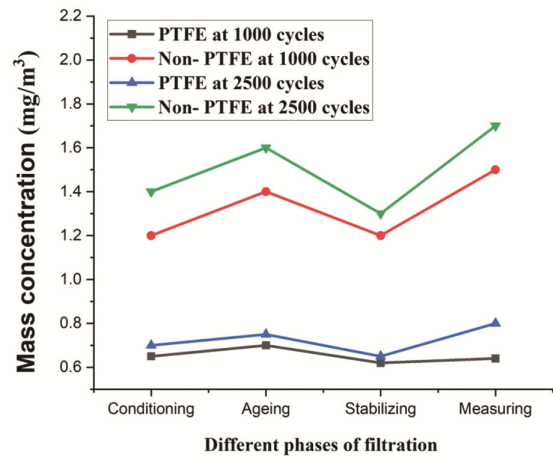


Fig. 9 — Mass concentration at different phases of filtration

coating. Dust cake release during the ageing phase is less and gives a higher value of mass concentration, but during stabilizing, the value of mass concentration decreases due to better cake release, and again, it slightly increases due to less cake release.

The particle number concentration indicates the number of particles present per cubic centimeter downstream. From Table 2-5 and Figs 12-14, it has been observed that both fabric types and dust concentration impact the emitted number of particles per cubic cm of the filter fabric during the filtration process, but fabric type has a significant influence. It is found that membranes act as the primary factor for dust collection. A dust cake only minimizes collection efficiency and cake pressure or thickness. Hence, it has been observed that the concentrations downstream of polyester filter fabric (with PTFE membrane) are much less than those in polyester filter fabric (without membrane).

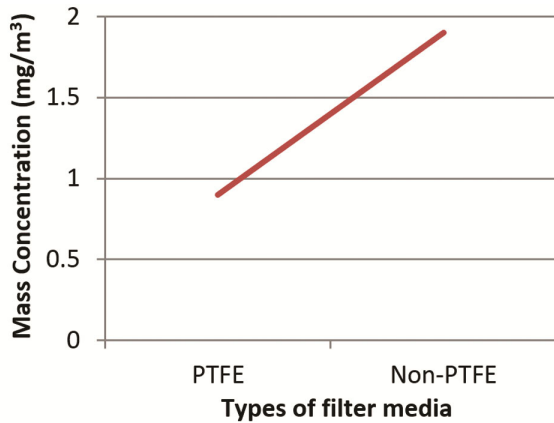


Fig. 10 — Overall mass concentration, the ageing phase at 1000 cycles

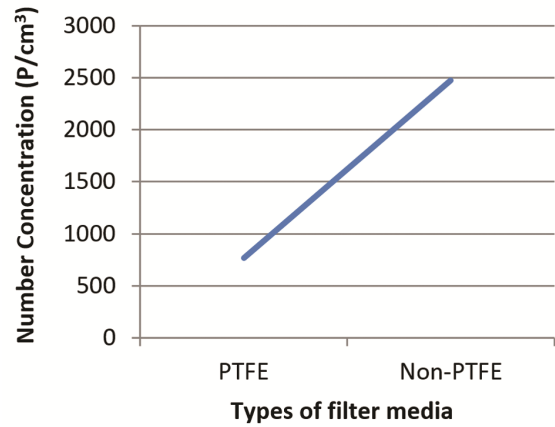


Fig. 13 — Overall number concentration, the ageing phase at 1000 cycles

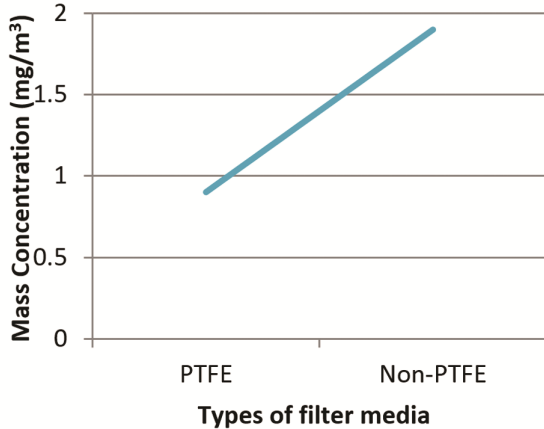


Fig. 11 — Overall mass concentration, the ageing phase at 2500 cycles

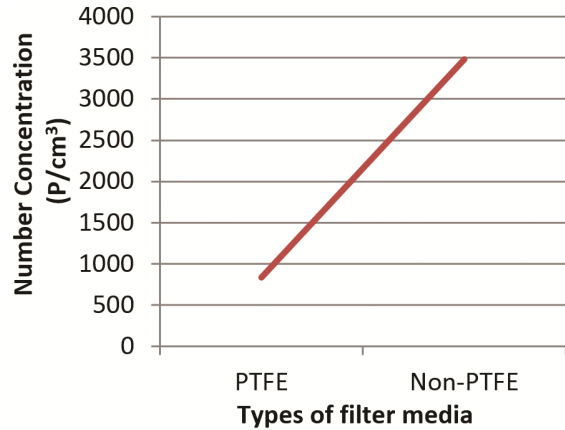


Fig. 14 — Overall number concentration, the ageing phase at 2500 cycles

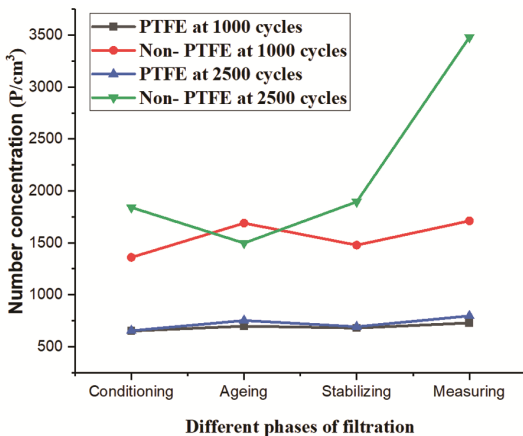


Fig. 12 — Number concentration at different phases of filtration

**Filtration efficiency**

The filtration efficiency (%) for the filter fabrics is calculated on a mass basis. The filtration efficiency is defined as the ratio of the amount of dust collected by the fabric to the amount of dust fed, as shown below:

Filtration Efficiency (%) = (Mass of dust collected by media fabric/Mass of dust fed) x 100.

From Table 2-5, it can be seen that fabric type significantly impacts filtration efficiency. Figs 15-17 show that polyester filter fabric (with PTFE treatment) has higher efficiency than polyester filter fabric (without treatment). Further, it was observed that filtration efficiency decreases in the case of polyester filter fabric (without treatment) is higher than for polyester filter fabric (with PTFE treatment).

**Pressure drop (ΔP)**

It is found from Figs. 18-20 that both factor dust concentration and fabric finish significantly impact the pressure drop. The graphs also revealed a comparative analysis of differential pressure drop values for the two types of fabric used in the experiment at the same dust concentration level. It is observed that the residual pressure drop for polyester

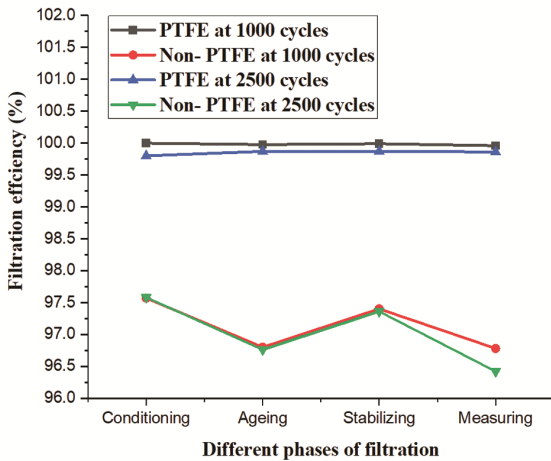


Fig. 15 — Filtration efficiency at different phases of filtration

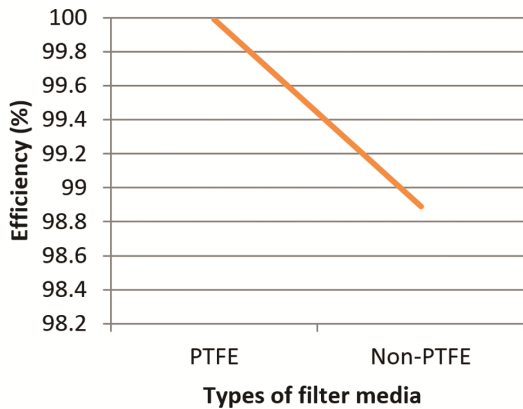


Fig. 16 — Overall filtration efficiency, ageing phase at 1000 cycles

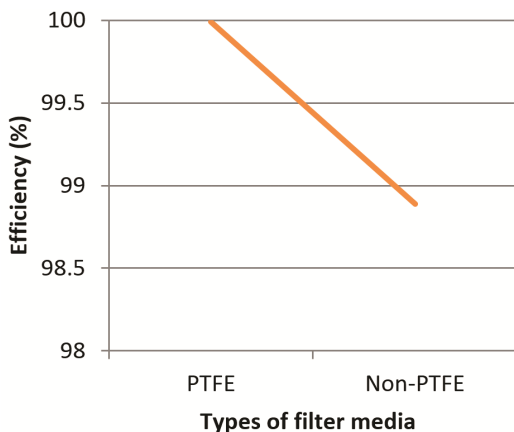


Fig. 17 — Overall filtration efficiency, ageing phase at 2500 cycles

filter fabric (without treatment) was higher than for polyester filter fabric (with PTFE membrane treatment). This may be due to easy cake releases from the finish of the PTFE-treated fabric. Filter media that releases dust more effectively will see less

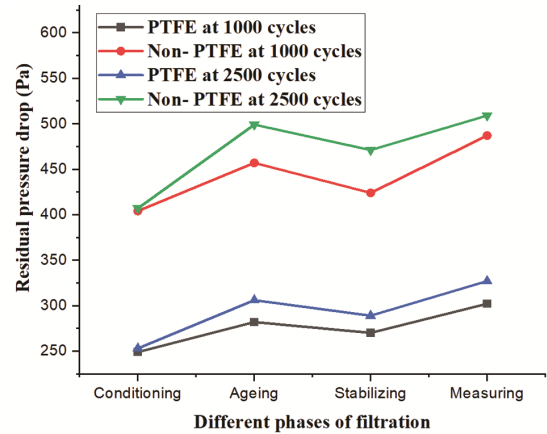


Figure 18 — Residual pressure drop at different phases of filtration

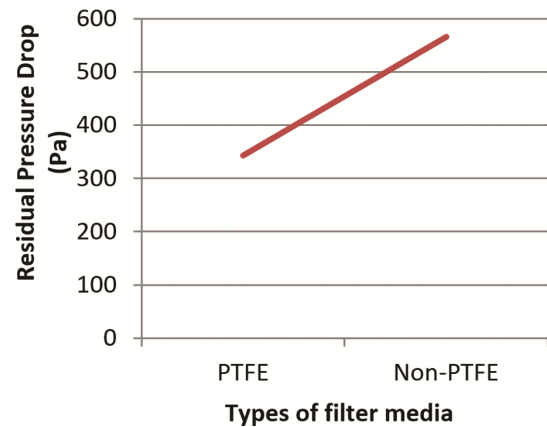


Fig. 19 — Overall residual pressure drops, the ageing phase at 1000 cycles

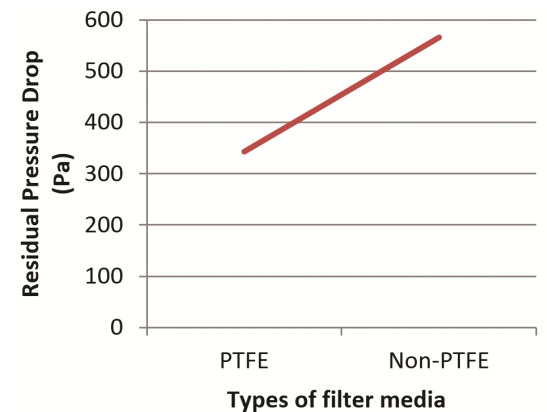


Fig. 20 — Overall residual pressure drops, the ageing phase at 2500 cycles

residual pressure drop, leading to a longer time between pulsing, a larger pulse cycle, potentially longer media life and energy savings. Also, when PTFE coating is adequate, it tends to deflect dust particles from direct abrasive contact on the media

surface. Therefore, fabric treated with PTFE also aids initial cake development and improves cake release properties.

After ageing, the peak pressure is reached more quickly in filter media without treatment than in PTFE-treated filter fabric. The filter media fabric without treatment also appears to have a higher residual pressure drop than the filter fabric with treatment. Most particles are separated due to depth filtration during the first filtration cycle. With further test time, the separation mechanism changed to a patchy cleaning mechanism inside the filter medium. During this time, inhomogeneous dust depositions occur in the filter medium, which causes the gas to flow through the filter medium with higher velocities at places where dust deposition is less. These places will preferably be filled with dust particles with an initially high-pressure drop, which increases at the beginning of the cycle. With the further continuation of filtration cycles, the dust layer deposition becomes more homogeneous, and a stabilized condition is obtained. The time interval during pulsing in the ageing phase is less, and the residual pressure drop is higher, but the time interval during pulsing at the stabilizing phase is slightly higher, leading to a decrease in residual pressure drop; the time interval for pulsing during the measuring phase, i.e. Slightly decreases, hence again increased value of residual pressure drop is obtained.

### Conclusion

Filter media fabric with PTFE membrane coating arrests fine particles due to less opening of pores, and media clogging is more in without PTFE coated filter media due to open structure. Hence, emissions in terms of  $PM_{2.5}$  and  $PM_{10}$  are substantially lower, when using PTFE-coated needle-punched polyester fabric as filter media compared to those without membrane-coated polyester fabric. Mass concentration and number concentration are lower for fabric treated with PTFE coating. Filtration efficiency is also higher for polyester filter media fabric with PTFE membrane coating than without PTFE coating; the coating facilitates and augments the surface filtration and very smooth dislodgement of particles during cleaning cycles. PTFE membrane-coated fabric exhibits lower residual pressure drop as compared to uncoated media fabric, and the time interval for pulsing (Pulse cycle) will be longer when the fabric is coated with PTFE. The energy requirement is also lower in PTFE-treated fabrics. PTFE-coated fabric gets stable (Ageing) earlier than without coating,

providing more consistent filtration for longer time. The life span of PTFE membrane-treated fabric will be higher, and hence, this saves money for filtration. Due to more pulsing, media clogging is more inside the filter media structure, as cycles increased from 1000 to 2500 during the ageing phase. The values of  $PM_{2.5}$ ,  $PM_{10}$ , mass concentration and number concentration also increase. Shaking is higher, and pore opening is more; hence, particles go downstream side, leading to particle seepage through the media, as the cleaning cycle time increases from 1000 to 2500 during the ageing phase. It is found that the residual pressure drop increases, and filtration efficiency decreases. Needle-punched nonwoven filter media (without PTFE membrane) showed higher downstream emission for  $D_{10}$ ,  $D_{50}$  and  $D_{90}$  particles. Polyester needle felt nonwoven filter media with a PTFE membrane arrests a higher proportion of fine particles, which in turn, provides for minimum impacts on human life during industrial air emissions. Hence, membrane-coated filter media effectively controls the emission of fine dust particles.

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