Indian Journal of Fibre & Textile Research
Vol. 46, September 2021, pp. 269-274

Energy consumption analysis of electrostatically assisted flat and tubular based filtration test rigs using polyester conductive media

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Received 8 July 2020; revised received and accepted 2 May 2021

In current study, the energy utilized by two types of laboratory based electrostatically assisted pulse jet filtration set-ups, viz. flat media test rig and tubular based test rig has been analyzed and compared. Three types of polyester nonwoven conductive filter media viz. polytetraflouroethylene coated media, stainless steel fibre blended with polyethylene terephthalate media and stainless steel scrim media have been characterized on both setups at three levels of aerosol charge, viz. 4 kV, 8 kV, 12 kV and without charge. The results reveal a significant drop in energy utilization ranging from 20% to 35% at pre-charge levels for both setups. Among all three materials, polytetraflouroethylene coated material is known to perform the best in both test setups. The contribution of compression energy in total power consumption is found to decrease in tubular based setup. However, the total energy consumption has been found to be the lower for flat media test rig.

Keywords: Compressor energy, Conductive filter media, Energy for charge, Fan energy, Polyester nonwoven, Polytetraflouroethylene, Total energy utilization

1 Introduction

Reduced power utilization has developed into a foremost priority for global industrial sectors over the years. In order to minimise power consumption and attain improved sustainability in filtration industries, different systems have been designed and practised globally[1-4]. One of the designs, which has gained popularity in recent years, is aerosol pre-charger embedded with pulse jet system[5,6]. Previous studies investigated the filtration characteristics of conductive filter media on pulsejet system assisted with pre-charger [7, 8]. However, till date no study has been reported on energy consumption behaviour of different types of conductive filter materials, although it can be an important aspect for any industry using fabric filter. During the mentioned research[7,8] four kinds of conductive filter materials, viz. PTFE coated media, stainless steel fibre blended with

PET media, stainless steel scrim media and carbon filament scrim media, were characterized at three levels of dust pre-charging, viz. 4 kV, 8 kV, 12 kV and without charge using fly ash dust. Among all materials, the performance in terms of particle capture and controlled residual pressure drop was found to be the best for PTFE coated media. The cleaning of materials was done on pressure based method. Although residual pressure drop signifies power utilized by the system, but it is just a relative parameter and does not comprise the other aspect of energy like compressed energy due to pulsing and dust pre-charging, hence considering all the aspects it becomes important to get the holistic view while calculating energy. It may also be added that, till date no comprehensive study has been reported on the above related aspect. In light of that, the present study is undertaken to analyze the change in energy consumption behaviour of the conductive materials from flat media test rig to the tubular based set up which is more close to the real time industrial situation.

2 Materials and Methods

The present study characterizes the power consumption behavior for three types of conductive filter media viz. PTFE coated media, stainless steel fibre blended with PET media and stainless steel scrim media at three different levels of dust pre-charging viz. 4 kV, 8 kV, 12 kV and without charge. The investigation of materials was done on two different types of laboratory based pulse jet setups, viz. flat media set-up embedded with pre-charger where the filter media is in flat rectangular form

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(Fig. 1) and tubular based set up where the media is in cylindrical bag shape (Fig. 2).

For flat media rig, the set-up comprised a dust feeder for uniform dust feed 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 time to time on pressure based method at peak pressure level of 1000 Pa through a pulsing time of 50 milliseconds. The emission results were captured by an online particle size analyzer 'Promo 2000' connected to downstream which works on the principle of light-scattering aerosol spectrometer system. The downstream side is attached to an online particle size analyzer 'Promo 2000', connected at the downstream side to analyze the emitted particles. The ISO 11057 standard was followed and the aerosol used was fly ash. Table 1 shows the material specifications followed for both setups. For all the filter media such as PTFE coated, S S fibre blended with PET and S S scrim, the dust inlet concentration level was kept 150 g/m^2 using 2 replica at 0, 4, 8 and 12 kV charge levels. The flat

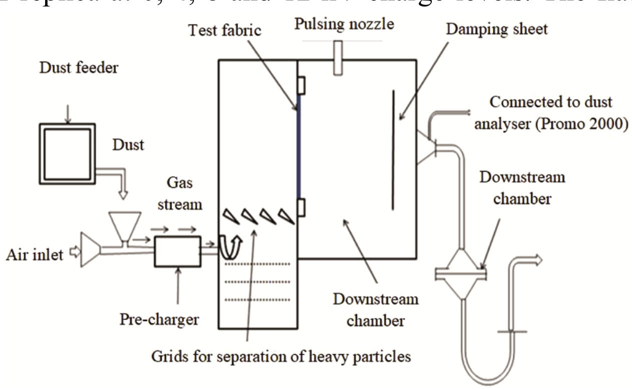

Fig. 1 — Experimental set-up of flat media test rig[7,8]

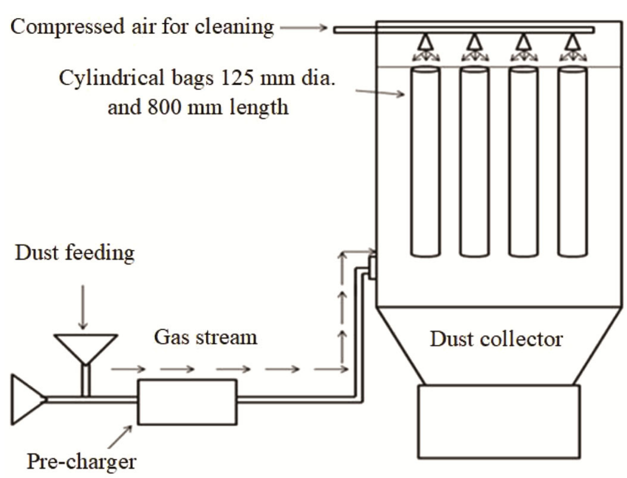

Fig. 2 — Experimental set-up of tubular based test rig

specimen dimension is kept as 50 cm length and 18 cm width.

For tubular based setup, the mechanism is similar to that of flat media test rig. However unlike flat media setup, the filter media for tubular setup is in cylindrical bag form. The dimension of each cylindrical bag is kept as 125 mm diameter and 800 mm height.

Testing conditions are given below :

- Inlet face velocity :2 m/min
- Air to cloth ratio :2
- Inlet dust concentration :150 g/m^3
- Tank pressure :3 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
- Pulsing at 1000 Pa differential pressure drop

Testing sequences are 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 total energy consumed for 2 h of measuring phase was calculated using power consumed for suction of gas, i.e. the fan energy, air compression required for media cleaning at the time of pulsing and energy utilized to charge the dust particles[9].

The fan energy was calculated using the measured pressure drop, total filtration time and gas flow rate. The energy consumed for media cleaning was obtained by estimation of compressed air requirement. Energy for dust charging has been calculated by using the voltage and current applied to the pre-charger[9, 10]. The equations for calculating energies of fan, compressor and charge are given below:

$$\text{Energy of fan(Kwh)} = \frac{q \times dp \times t}{\eta \times 1000} \quad \dots (1)$$

Table 1 — Material specification

Material	Fabric mass g/m^2	Thickness mm	Air permeability m^3/m^2/min
PTFE coated filter media	550	2.3	8
S.S fibre blended with PET media	550	2.3	15
S.S scrim media	500	2.1	12

$$\text{Energy of compressor (kWh)} = \frac{N \times (P2 - P1) \times V\text{reservoir}}{(1-n)} \times 2.778 \times 10-7 \quad \ldots (2)$$

$$\text{Energy of charge (kWh)} = V \times I \times t \times 2.778 \times 10^{-7} \quad \ldots(3)$$

where q is the air flow rate (m^3/s) ; ŋ, the fan efficiency (%) considered as 85% ; N, the number of cleaning pulses; $P1$, the air pressure in reservoir just before cleaning (Pa); $P2$, the air pressure in reservoir just after cleaning (Pa); $V_{reservoir}$, the volume of reservoir (m^3); N, the exponent of polytrophic process considered as 1.33; V, the voltage applied (volt); I, the current (ampere) ; t, the operating time (s); and dp, the pressure drop (mmH_2O).

Pressure drop values for final 2 h of measuring phase have been considered for calculations, as shown below:

Total energy consumption (E_{Total}), kWh = Energy consumption of fan (E_{Fan}), kWh + energy consumption of compressor ($E_{Comp.}$), kWh + energy consumption of charge (E_{Charge}), kWh ..... (4)

Energy required to charge the dust for tubular based setup has been calculated by proportionally scaling up the current (I) required per gram with rise in amount of inlet dust (g/min). The current required for charging per gram of dust is 0.002 Ampere/min. For flat media test rig, the amount of inlet dust is 27 g/min, and therefore the current required per minute has been 0.054 Ampere, while for tubular based setup the amount of inlet dust has been 195 g/min, requiring the total current per minute to be 0.39 Ampere.

3 Results and Discussion

It has been observed that among fan, compressor and charge, the energy consumption for fan is the highest in both test setups. Highest proportion of fan energy in overall power consumption is due to the reason of fan operating throughout the filtration process, as it does the suction of dust laden gas stream and directs it over the filter media surface. As subsequent layers of dust get deposited over the media surface, the fan energy goes on increasing. However, compressor energy is required during pulse cleaning, which operates for a very short period of time when the fixed peak pressure between upstream and downstream side of the filter media is achieved; hence its contribution is relatively less in overall energy consumption. Table 2 depicts the values of fan energy consumption for flat and tubular setups respectively. It is observed that fan energy is approximately 2-3 times higher in tubular based set up for all the materials. This can be attributed to larger amount of dust inlet for tubular based setup, which is about seven times higher than the flat media setup. Also larger filtration area for tubular based setup results in higher fan energy consumption. It can also be noted that with rise in dust pre-charge level from 0 kV to 12 kV the fan energy is decreased in both test setups for all materials. For flat media test rig the fan energy is observed to reduce by 44 - 55% from 0 kV to 12 kV charge, while for tubular based test rig the reduction has been ranging between 53% and 58%.

It can also be noted that the decrease in fan energy for both test rigs is higher with rise in dust charge level from 0 kV to 4 kV as compared to rise in charge from 4 kV to 8 kV and 8 kV to 12 kV respectively. This is because at uncharged condition there are more number of smaller aerosol particles in the gas approaching the media which inhibits uniform deposition of dust over the media surface and results in non-uniform cake formation. Due to large number of smaller particles there are chances that some of these particles may penetrate inside the media. Therefore, high fan energy is required to maintain a nominal flow throughout the surface of the media. While at 4 kV, there are less number of smaller particles expected in the gas steam due to the effect of pre-charging, causing the particles to agglomerate, and as a result the particle size gets larger which improves the deposition of dust over the pores on the media surface. This results in a uniform cake layer formation, and due to this an easy nominal gas flow can be maintained throughout the media surface at relatively lower fan energy.

Table 2 — Energy consumption of fan at various dust charge levels for both setup

Filter media	Energy consumption, kWh							
	0 kV		4 kV		8 kV		12 kV	
	Flat	Tubular	Flat	Tubular	Flat	Tubular	Flat	Tubular
PTFE coated	3.6	10.57	2.4	7.27	1.9	5.57	1.6	4.94
S.S. fibre blended with PET	4.9	12.98	3.5	10.17	3	8.07	2.7	6.57
S.S. scrim	6.5	16.95	4.8	11.89	4.1	8.86	3.6	7.26

Table 3 — Energy consumption of compressor

Filter media	Energy consumption, kWh							
	0 kV		4 kV		8 kV		12 kV	
	Flat	Tubular	Flat	Tubular	Flat	Tubular	Flat	Tubular
PTFE coated	1.18	2.9	0.96	2.1	0.85	1.8	0.80	1.4
S.S. fibre blended with PET	1.51	3.5	1.07	2.6	0.94	2.2	0.86	1.8
S.S. scrim	1.90	4.2	1.30	3	1.04	2.5	0.97	2

Effect of agglomeration will not be to the similar extent, as charge increases from 4 kV to 8 kV and further. This is because at 8 kV and further, the particle diameter of the agglomerated particle is likely to be larger as compared to that at 4 kV, which is expected to contribute in formation of a little better cake due to larger particles. Therefore, for 8 kV and further, energy required by the fan for maintaining a throughout optimum gas flow will be less compared to that at 4 kV but it will not be that much less as it gets reduced from without charge to charge at 4 kV. This is because for each charge level uniform surface deposition is already accomplished. For 8 kV and further, the cake deposition is expected to be little better, which can contribute in relatively reduced fan energy, but the level of reduction will not be that much higher. This also gives an indication that effect of charge is impactful only up to a certain limit.

Another notable point has been decrease in difference in emission between materials at higher pre-charging level as compared to that at uncharged condition. This indicates that pre-charging of aerosol is more effective for materials that exhibit relatively higher emission at without charge, as higher emission levels will likely to have more number of smaller particles. The effect of agglomeration is more impactful on smaller particles. This is found in agreement with the earlier study[5]. Therefore, at higher charge a large improvement can be observed. The rank wise performance of materials in terms of energy consumption is similar to the material performance in terms of emission and residual pressure drop for the reported studies[6,7]. Among all the materials the fan energy consumption has been found to be the least for PTFE coated filter media followed by stainless steel fibre blended with PET media and finally stainless steel scrim media which exhibits the highest energy consumption for fan.

The values of energy utilized by compressor and charge for both test rigs at various pre-charging levels are represented in Tables 3 and 4 respectively. Compressor energy indicates energy utilized during cleaning. Likewise fan energy, the energy utilized for

Table 4 — Energy consumption of charge

Test rig	Energy consumption, kWh			
	0 kV	4 kV	8 kV	12 kV
Flat	0	0.43	0.86	1.29
Tubular	0	3.12	6.24	9.36

compressor has also been known to be approximately two times higher for tubular based setup. This can be due to larger filtration area for tubular based setup. In view of this, the discharge of air from the reservoir during pulsing is seven times higher than in flat media test rig, resulting in relatively more compressor energy. Apart from this, the number of cleaning cycles for tubular based test rig is comparatively higher. This is because, due to larger filtration area the number of pores will be relatively more on filter bag surface, as a result the chances of particle seepage to clean air and blinding of pores will be higher. Hence, the fixed peak pressure is achieved relatively quickly, thereby reducing the time between two subsequent pulses. Hence, the number of cleaning pulse increases.

The decrease in compressor energy for both test setups with rise in pre-charging level from 0 kV to 4 kV is found to be higher as compared to that from 4 kV to 8 kV and further. This is because, there are more number of fine particles in the gas stream at uncharged condition, which prevents smooth deposition of particles over the media surface, as large number of particles are likely to penetrate within the pores of media. Due to continuous penetration there comes a stage where all the pores get blocked, resulting in early clogging of media which leads to frequent pulsing and higher compressor energy requirement. While at 4 kV charge the effect of agglomeration causes a bridging effect over the media surface, as a result very few particles penetrate inside. Hence, the pulsing interval is increased which enables less compressor energy to be utilized. Similarly, for higher charge level also, the reason for reduced compressor energy is the effect of agglomeration of dust particles due to pre-charging. The performance of materials in terms of compressor energy is found to be in same order as that for fan energy utilization.

The total power consumption is represented in Figs 3 (a) and (b) for flat and tubular test rigs. The tubular setup is observed to consume approximately three times higher total energy than flat media test rig. However, the proportion of charge energy has been found to be higher for flat media test rig. This indicates that charge is more impactful in reducing

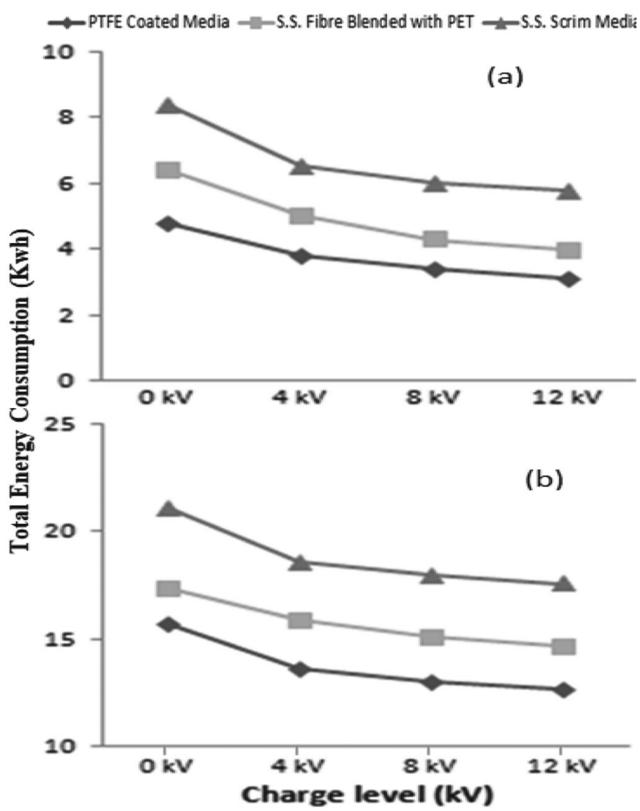

Fig. 3 — Total energy consumption for (a) flat media test rig, and (b) tubular based test rig

overall energy for flat media test rig. This is in agreement with the ANOVA results as shown in Table 5, where the contribution of charge is higher for flat media test rig. This can be attributed to relatively less amount of dust inlet and lower filtration area in flat media setup, as a result the chances of dust seepage and early blinding of pores reduce. Hence, smooth dislodgement of dust at the time of pulsing is resulted, thereby increasing the time between two subsequent pulses, leading to reduced compressor and fan energy consumption

The behavior trend from the graphs has been found similar to fan and compressor energy, as a sharp decrease is observed from 0 kV to 4 kV charge in both test rigs and thereafter stability in trend is noted from 4 kV to 12 kV. This can be due to the same reason as mentioned for fan and compressor energy. The material wise ranking for overall energy consumption has been PTFE coated filter media followed by stainless steel fibre blended with PET media and lastly stainless steel scrim media, which exhibits highest overall energy consumption in both test rigs. Also, a strong correlation between both test setups can be drawn, which is evident from Fig. 4.

The reduction in power consumption at pre-charging level is due to cumulative behavior of charge and material. It has been observed that each material is behaving differently. This difference in behavior is due to intrinsic behavior of material as their structural properties are different and also due to charge. As far as only charge is concerned two best materials, viz. PTFE coated media and stainless steel fibre blended with PET have been identified from analysis. Therefore, ANOVA for both test rigs has been carried out for full scale bag house considering these two materials, as showed in Table 5. The calculated

Table 5 — ANOVA findings for energy consumption of flat and tubular media test rigs between PTFE coated and PET blended with S.S. fibre media

Sources	S.S	d.f	Mean square	F_{cal}	$F_{tab.}$ At α=0.05	Contribution, %
			Flat media			
Material	2673	1	2673	125.08	5.31	47
Charge	1649	3	549.66	25.72	4.06	29
Interaction	1194	3	398	18.62	4.06	21
Residual	171	8	21.37	-	-	3
Total	5687	15				
			Tubular media			
Material	7581	1	7581	204.22	5.31	51
Charge	3567	3	1189	32.03	4.06	24
Interaction	3418	3	1139.33	30.70	4.06	23
Residual	297	8	37.12	-	-	2
Total	14863	15				

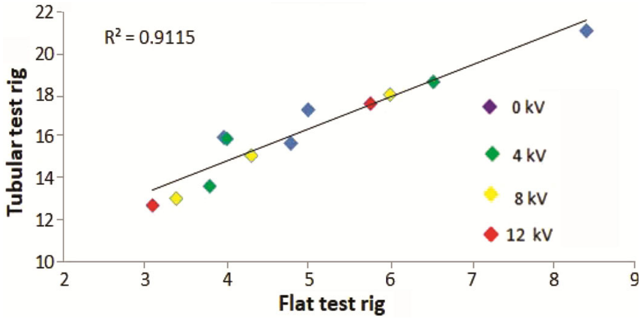

Fig. 4 — Energy consumption correlation between test rigs

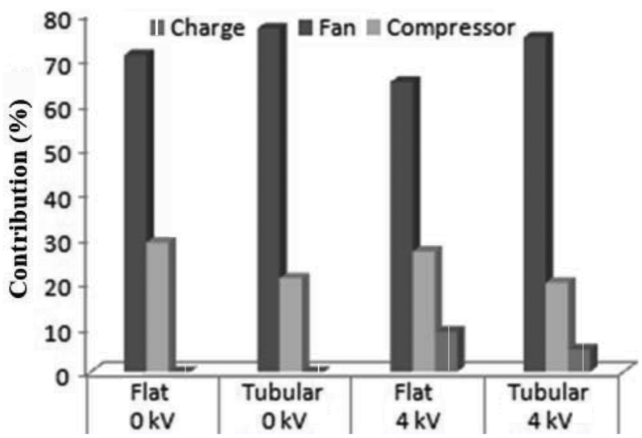

Fig. 5 — Proportionate contribution in total energy consumption at 0 kV and 4 kV charge for PTFE coated material

F value is higher than the table value in each case, which indicates that each factor and their interaction are having a significant impact on energy consumption results.

Another interpretation has been significant drop in the proportion of compressor energy for tubular based setup as compared to that for flat media test rig under both charged and uncharged conditions. As represented in Fig. 5 the proportion of compressor energy in tubular set up is 30%, while that for flat setup it is reduced to 21%. This can be related to the fact that larger filtration area requires higher suction energy for maintaining nominal flow of gas throughout the filter media as compared to smaller filter area.

4 Conclusion

In view of the above investigation, one of the important interpretations drawn has been the increased proportion of suction energy (fan) for tubular based setup. This has been explained on the basis of larger filter area for tubular based setup requiring higher suction energy for maintaining a nominal flow of aerosol throughout the filter bag surface. This indicates that for a full scale bag house the energy consumption by the suction unit will be the most prominent as compared to the other components (compressor and charge). All the factors, viz. material type, charge and their cumulative behavior are known to make a significant contribution in reducing energy consumption. However, the contribution of charge has been higher for flat media test rig. Among all the materials the performance of PTFE coated media is found to be the best in both test rigs as far as energy utilization is concerned.

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