# ISSUES AND CHALLENGES IN INDUSTRIAL FILTRATION

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***Abstract:*** *The environmental issue has become a major subject in the last few decades affecting science and technology throughout the world due to the serious environmental impacts caused by industrial air pollution. Consequently, pulse jet filtration has become the preferred choice all around the world. Researchers are continuously striving for new concepts of more energy-efficient and compact particulate collector which can meet future emission limits and operating requirements. The system can also satisfy stringent emission norms and if required, it can be embedded with new technique for simultaneous control of particulate and gaseous pollutants. In the recent past, stress is also being given to having control over the source to reduce or eliminate waste, and finally, on waste management. Prevention is frequently more cost-effective than control. The paper discusses all these methodology toward sustainability in the perspective of effective control of industrial air pollution.*

***Keywords:*** *Industrial air pollution, Pulse jet filtration, Pollutants Control, Sustainability*

## 1. Introduction

Gas cleaning is of prime importance in many process industries to control the particulate matter emission and to recover the valuables particles. The emissions of particulate matter are variable with particle concentration range from <1 g/m$^3$ to more than 250 g/m$^3$ and size of particles are predominantly very fine (0.1–25 μm). In generalities through sustainable development, the degree of particulate control normally found in fabric filter is unheard of in any other type of filter of similar duty. In one of the structural embodiment, fabric filtration technique is embedded with pulse-jet cleaning system. In past decade, use of industrial bag filters operated in the principle of pulse-jet filtration has got rapid surge as it prove to be most efficient and versatile. Pulse-jet fabric filters are widely used in many industries like solid- fuel- fired power generation, bulk solid processing and plasma - aided manufacturing etc. Pulse jet filtration process can be considered as one of the most sustainable technology worldwide.

During filtration, a positive effect is associated with greater filtration efficiency due to cake filtration, and on the other hand, a negative effect is associated with increased pressure drop. Since industrial filters encounter high-dust density (more than 250 g/Nm$^3$), pressure drop increases steadily with time. Therefore, filter bags must be periodically regenerated, usually by pulse-jet cleaning. This operation involves injecting high-pressure back-pulse air (3–7 bar) into the filter bags for a very short time (50–150 ms). Back pulse dislodges dust cake from filter surface and then filtration process continued regularly so called on-line cleaning. Figure 1 shows the schematic view of pulse-jet filtration process. A typical set-up for pulse jet filtration system is shown in the Figure 2.

It may be added that there are many variants of filter media design apart from more commonly used bag filter; such as cartridge filter, envelope filter, and ceramic filter. Further basic unit design can also be different for different industry; however basic mechanism remains the same. Pulse-jet filtration process can be conceived as most sustainable technology because of the many reasons such as satisfying stringent emission norms, flexibility of operations under different industrial situations, control of particulate and gases simultaneously, energy efficient strategies and simple operation (Figure 3).

In the recent past, stress is also being given to have control at source to reduce or eliminate waste. Efforts are also required to reshape the technological approach to pollution control and prevention. Prevention is frequently more cost effective than control. In many cases, a control system alone is not able to cope with the situation; prevention has also become a major aspect of research. Pollution prevention includes equipment or technology modifications, process or procedure modifications, reformulation or redesign of products, substitution of raw materials etc. In practice, no waste signifies eliminations of treatment and also the system without disposal, - a potential environmental threat. In spite of many developments on this area, there is continuous striving for improving the ways of industrial pollution control.ter elements.

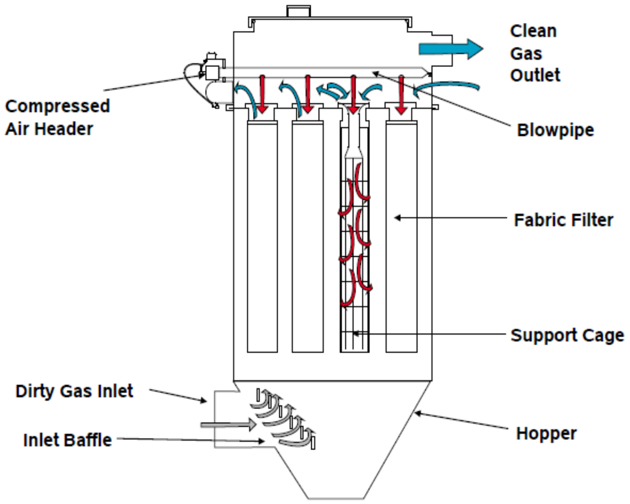



Figure 1: A schematic view of pulse-jet filtration process

Figure: 2 A typical set-up of pulse jet fabric filtration system

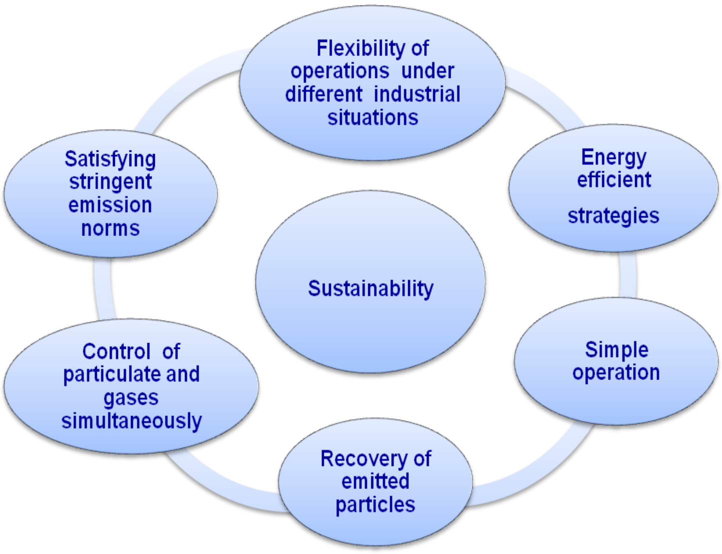


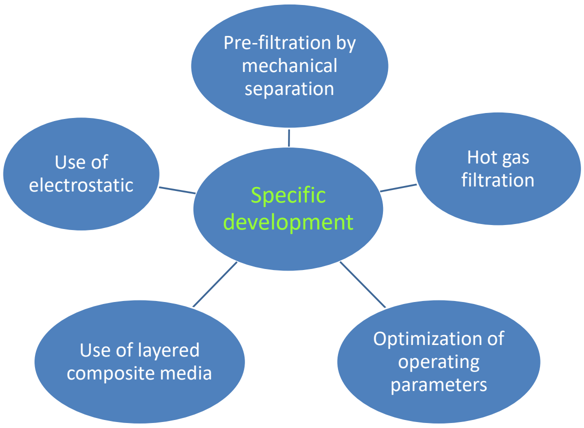

Figure 3: Sustainability issues of pulse jet filtration process

## 2. Issues and challenges

Technical challenges behind the development can be enlisted as follows;

a. Satisfying filtration efficiency at lower pressure drop and energy efficient strategies: Requirement for lower $PM_{2.5}$ emission which necessitate smaller pore sizes, whereas it will also lead to higher differential pressure. It is also important to note that the filtration requirements vary depending on the nature of aerosol. The media efficiency required for carbon black will probably not be needed for wood shavings. The energy used by the downstream exhaust fan accounts for 60–80% of the baghouse total operation costs and, therefore, a stable and low range of differential pressure (ΔP) is useful. Broadly there are many energy efficient strategies. This involves improved energy efficient system design, judicious selection of filter media, setting of operating parameters at the optimum level, hot air filtration etc (Figure 4).

- Change in overall design of filter unit. Pre-filtration by mechanical means is widely adopted. There is also possibility of combination of cyclone and fabric filtration mechanism.
- Use of hybrid filter in which electrostatic precipitator may be used in line or may be embedded with fabric filtration system.
- Use of membrane at the upstream side of fabric as a composite. Due to the extreme thickness (12–75 µm) of the membrane, it is essential to combine it with a suitable substrate either by special adhesives or, where appropriate, by flame bonding. One most popular micoporous PTFE membrane is chemically inert and can withstand high temperature ($260^0$C).
- Use of layered fabric concept where finer denier fibres or even nano fibres can be used at the upstream side of fabric. Fine fibres can be produced using different process. Fibres such as bi-component fibres, which have large number of island fibres, can be formed and could be useful in making finer denier fibre fabrics. However, manufacturing of nanofibres at commercial and economical scale has not yet been realized.




b. Fibres offering high temperature resistance: High process temperatures, much above $300^0$C while beneficial for cycle efficiencies, impose severe limitations on the type of filter media to be used and also mechanical durability and corrosion resistance of components in the gas cleaning unit. The application of conventional high-temperature filter materials in the temperature range of $250^0$C and higher is substantially restricted. For example common fibre material used in pulse jet filter range from Homopolymer acrylic (Dralon-T) at temperature less than $140^0$C, Poly-phenylene-sulphide (Ryton), Aramid (Nomex) etc. up to a temperature of about $200^0$C and Polyimide (P84) and teflon at temperature of about $250^0$C. The most efficient way of separating particles at high temperature (up to $1000^0$C) is to use ceramic filters (rigid/flexible).

c. Optimizing operating parameters

d. Size of filter unit

e. Longer filter life

f. Fibre offering more chemically and hydrolytic resistance with/without temperature.

g. Development of suitable sorbent to control gaseous emission

h. Development of new technique for simultaneous control of particulate and gaseous pollutants.

i. Challenges to reuse the filter bags after its life time.

In the recent past, stress is also being given to having control over the source to reduce or eliminate waste, and finally on waste management. Prevention is frequently more cost-effective than control.

In order to achieve the objective of control of industrial air pollution through sustainable development, a large number of different strategies and system changes would be needed to be implemented today. These strategies and system changes include:

• Use of pulse jet filtration in industries as pulse jet filtration can meet the stringent particulate emission limits regardless of variation in the operating conditions. Fabric filters can be designed to collect particles in the sub-micrometer range with 99.9 % control efficiency. For satisfying stringent emission norms, in many cases, industry is opting for retrofitting of the existing ESP casing with pulse jet fabric filters.

• Proper selection of fiber material from the pool of fibers depending on filtration requirement, physical characteristics of the dust, chemical composition of the dust, chemical composition of the gas, operating temperature, mode of operation etc. Apart from fiber material, fiber fineness, cross-sectional shape, and above all, structure of nonwovens, its degree of consolidation have significant impact on the performance of filter media.

• Control of particulate and gases simultaneously by new technologies, viz. combined use of fabric filters with sorbent injection systems, use of catalytic filters, technology based on non-thermal plasma (NTP).

• For sustainability of development, one of the main issues is energy-efficient system. Apart from optimizing operating parameters, designing of filter media is important. Energy-efficient strategies encompass hybrid filtration and hot gas filtration.

• Recovery of industrial waste is also an effective way of controlling industrial air pollution since the industrial waste can be used for the value addition in a new product. Industrial filtration process in sequential manner could arrest finer particles at the last stage by fabric filters. The finer particles are more expensive. It can be recycled or can be used effectively in some other manufactured product.

• The positive impact on the environment is impossible without a dramatic reduction in three things: pollution, materials consumption, and energy consumption. Prevention is frequently more cost-effective than control. Prevention through change in process can involve the strategies such as change in process philosophy and change in plant operations. These strategies include advanced combustion technologies such as circulating fluidized-bed (CFB) technology, integrated gasification combined cycle (IGCC), flue gas desulphurization (FGD), coal washing, ammonia injection, dust suppression techniques etc.

• Alternative raw materials and fuels should be used to reduce pollutant source by reducing or eliminating the hazardous materials that enter the production process.

• Waste utilization, segregation, and disposal can be a simple and effective pollution prevention technique applicable to a wide variety of wastes generating from the industries. Recycling and reuse can lead to reduction in waste, landfill, or dumping and associated site degradation, substitution for virgin resources and reduction in associated environmental costs of natural resource exploitation.

• Coprocessing is a proven sustainable development concept that reduces demands on natural resources, reduces pollution, and landfill space, thus contributing to reducing the environmental pollution. The substitution of raw materials or fuel has often been used successfully as a method of atmospheric pollution control when the contaminant being eliminated from the fuel or raw material is not essential to the process.

The industrial air pollution control emerges into a very effective gas cleaning methods, belong in basic the requirements for atmospheric environmental activities, as well as into the processes of production of new high-tech materials and machine design. The new results of aerosol filtration science will have an important impact on further environmental and technological developments. Through environmental control not only particulate matter are separated, but also various harmful gaseous matters are suppressed. A survey of limit concentrations for emission of and for exposure to a number of pollutants is given in Table 12 [15]. The table shows that there are very large differences between the ratios of emission and exposure limit concentrations for individual pollutants. As an example, the limit concentration for particulate matter is set at 10 mg $Nm^{-3}$, whereas the MAC (Maximum Admissible Concentration in work spaces) value is 125 µg $Nm^{-3}$. The ratio between both values is 80. On the other end of the scale is mercury where the concentration limits for exposure and emission are identical, i.e. 50 µg $Nm^{-3}$. The reason for the large difference of the emission limits between mercury and the other toxic compounds is not clear. The above ratio will be more when the dispersion phenomena occurring during the emission of a flue gas into the atmosphere are taken into account. The flue gas from waste incinerators undergoes very rapid dispersion and dilution after leaving the incinerator stack. It follows that the maximum mercury concentration in the ambient air will remain at least five to six orders of magnitude below the lowest MAC value and that public health will not be threatened. On the other hand, the environmental impact of the sophisticated treatment of the flue gases for mercury control comprises an increased amount of hazardous waste, the operation of more complicated treatment processes and the risks of the handling of an inflammable material such as active carbon. Future studies must address the above issue very carefully considering the other pollutants such as $SO_2$, $NO_x$, furan, dioxin etc, than mercury alone [15]. It is also very important to develop technology for prevention of emission, the act relating to closed substance cyclic waste management and environmentally compatible disposal of waste covering the areas of avoidance, recycling and disposal of waste.

Table 12 Emission and exposure limits for various pollutants [15]

| Pollutants | Emission limit (EM) | Exposure limit (EX) | Ratio (EM/EX) |
|---|---|---|---|
| Particle matter | 10 mg/$Nm^3$ | 125 µm/$Nm^3$ (24 h) | 80 |
| $SO_2$ | 50 mg/$Nm^3$ | 125 µm/$Nm^3$ (24 h) | 400 |
| HCℓ | 10 mg/$Nm^3$ | 8 mg/$Nm^3$ (5 ppm) | 1.25 |
| CO | 50 mg/$Nm^3$ | 10 mg/$Nm^3$ (8 h) | 5 |
| Hg | 50 mg/$Nm^3$ | 50 mg/$Nm^3$ (8 h) | 1 |

Nevertheless with the increasingly stringent emissions regulations of fine particulates and air toxics, pulse jet fabric filters have become an attractive particulate collection option for utilities. Pulse jet fabric filters (PJFFs) can meet stringent particulate emission limits (over 99.99%) regardless of variation in operating conditions [279]. The increasing popularity of pulse-jet system is also due to on-line cleaning application, often no compartmentalization, outside collection which allows the bag maintenance in a clean and safe environment. However, more stringent air-pollution laws, specially when using waste derived fuels are drawing more attention to the off-gas cleaning facilities, usually bag filters. Pulse-jet fabric filtration system can cope with most industrial gas cleaning problems economically and efficiently. Filtering of hot gases before heat exchanging, catalytic oxidation in combination with bag filters, electrostatic precipitator in fabric filter with conductive filter media, dry scrubbing to blind the gaseous components, filtration with very fine difficult particulates are just some of the uses. A relatively new technology but one which is being increasingly applied in high temperature air pollution control is the use of low density ceramic filters in filter plant [280].

As regard overall design of filter unit, there exists lot of variation in the construction depending on manufacturer and application needs. Although some advanced filter such as hybrid technology has come into place for specific applications; but more commonly an existing ESP may be completely converted into a fabric filter at conventional filter velocities (0.9 to 1.4 m/min) as an 'ESP/FF conversion', or a brand new 'standalone fabric filter' is built. This decision is typically made based on site or schedule constraints. Further choosing different classes of pulse-jet filter (LPHV/MPML/HPLV) is a matter of application needs, operating and maintenance cost, easy installation etc. In pulse-jet filters, one of the basic requirements is to minimize the operation cost. The energy used by the fan accounts for 60-80% of the baghouse operation costs [171] and therefore, a stable and low differential pressure makes it worth considering investing in highly developed filter unit. This involves improved system design, judicious selection of filter media and setting of operating parameters at the optimum level.

During pulse-jet filtration, regulation of pressure drop is accomplished through optimizing the impulse used and extent of cleaning of filter media in each cycle. Cleaning should not damage the bag filter while allowing filtration process to operate at a steady and lowest possible pressure drop. It is also necessary to conserve the dust layer up to a certain extent to ensure good filtration efficiency and in cases help in absorbing gas on dust cake of specific properties. It may be noted that filter media has to be designed/selected based on application. The various filter media proposed for same application can have different flow rate characteristics and air cleaning efficiencies. The most effective way to determine the correct media for the application and dust is through testing. Acquiring emission and pressure data along with particle size analysis before and after filtration while filter media is run through a small scale simulation is useful to determine the effectiveness of filter. It is also important to note that the filtration requirements vary depending on nature of aerosol. The media efficiency required for carbon black will probably not be needed for wood shavings [99].

Apart form satisfying stringent emission requirement at varied situation, filter media should have many other properties such as resistance to temperature and chemical environment, dimensional stability, resistance against flexing fatigue and abrasion etc depending on application type. The filter media should be deigned also to minimize the inevitable changes in pressure loss and face velocity during cyclic operation of filtration and dedusting. Designing of filter media is therefore primarily aimed at enhancing its life while maintaining the emission requirement. However, most of the cases, life of the filter is limited by trapping of pores by small dust particles influenced by structure of filter media, filtration velocity and/or damage caused by pulse cleaning. Deciding air to cloth ratio is one of the most critical tasks for overall system design and successful running of filtration operation.

In the development of industrial filter media, a common approach is enhancing surface filtration. Although meanwhile basic nonwoven structure has been improved significantly, further enhancement of surface filtration is often accomplished by various means such as using membrane or coating; or employing fine fibres, trilobal/multilobal fibres at the upstream side of layered nonwoven fabric etc. Out of the several techniques, membrane filters become more common for controlling fine particulates. Notwithstanding use of PTFE filter membrane increases the cost of the product. There is also need of looking at their mechanical strength and thus their lifespan. Even small membrane damages will allow dust penetration into the fabric, followed by further delamination and will cause increases in the pressure differential. Higher dust loads, uneven gas distribution, excessive cleaning pressure, incorrectly sized cages or, in some cases, carelessness during installation will lead to membrane defects and consequently performance failures. One of the major challenges is the development of strong membrane without affecting permeability characteristics. The membrane represents probably the fastest growing part of the filtration media market. The future will undoubtedly see more advanced products of this type, leading to structures that are efficient in particle capture, provide longer filter life and also capable of performing under more chemically and thermally challenging environments. All of these benefits translate into operational cost savings and better environmental pollution control.

As regard overall system design, there are some unique developments have taken place over the past decades. There are several hybrid filters based on combination of cyclone/electrostatic mechanism fitted with pulse-jet bag filtration system has been developed. Advanced hybrid particulate collector, combines the best features of ESPs and baghouse, providing major synergism between the two collection methods, both in the particulate collection step and in the transfer of the dust to the hopper. There are also technological developments for simultaneous control of gaseous matter. Existing technology for gas cleaning at high temperature involves candle filters for removing solid contaminants and sorbents for removing fluid contaminants. For all combustion processes in the future, out of the available cleaning methods, rigid ceramic filters have emerged as a promising technology for cleaning of hot gases due to their resistance to attack by aggressive gases and high temperatures (e.g., in pressurised fluidised-bed combustion and gasification at temperatures up to 1000°C). The COHPAC system also shows promise for location on the hot-side of EPSs, by placing ceramic filter elements in the last ESP field. COHPAC has the potential to upgrade a utility's pollution control measures, most likely including $SO_2$ removal as well as reducing mercury and possibly $NO_x$ emissions. However, whole process should be cost-effective, and must compete with all the other options currently being evaluated. COHPAC could well offer a very interesting and cost-effective solution to future problems in coal-fired utilities. It appears that even up to the year 2015 coal-fired electric utilities will dominate the industry, followed by nuclear, hydro-powered, natural gas and oil-fired stations. Thus fabric filter technology based on the COHPAC system carries a good potential into the 21st century [281].

In spite of the fact that there is significant improvement in particulate filtration along with various sorbents and associated equipment over the past few years, there still seems to be a long way to go to achieve complete reliability of these systems which have never been tested successfully in a real integrated gasification (IG) based system environment. So far a robust and completely reliable technology has not been developed especially for gas cleaning over 600 °C to achieve higher efficiencies. As reported, most of these candle filters appears to have operated for a maximum period of 2700 h at 400°C and little longer period of about 15,000 h at lower temperature of 285°C in a coal gasification environment. The failing of the candle filters within a short period of operation leads to an uneconomical plant availability factor [282]. For longer filter life, it is important to determine the consistency in manufactured qualities. A dynamic characterization method is recommended as a nondestructive evaluation technique [283]. However, researchers in the area should be aware that there are certain fundamental limitations to improve the intrinsic material properties of candle filters, and therefore alternate routes involving operating conditions and process related changes should be explored to develop more reliable and efficient gas cleaning technology.

Pollution control strategies in developed countries continues to evolve in response to new and changing environmental regulations, new technologies, and even some new applications of proven technologies. Control of mercury emissions from coal-fired power plants is gaining increasing attention in several parts of world. Some of the future changes expected in the environmental regulations include tighter emissions regulations on $SO_2$, $NO_x$, $PM_{2.5}$, mercury control and air toxics such as lead, and cadmium. There is continual refining and upgrading of product offerings for $DeNO_x$ Selective Catalytic Reduction (SCR), pulse jet fabric filters and rigid discharge electrode ESPs. To provide a more complete product line of air pollution control technologies, an additional type of lime spray dryer absorber for Dry Flue Gas Desulfurization (DFGD), new Wet Electrostatic Precipitator (WESP) technologies and single tower In-situ Forced Oxidation Wet Flue Gas Desulfurization (IFO-WFGD) systems have also come up [284]. It may be added that use of non-thermal plasma is yet in laboratory scale; might show its potential in near future.

In line with the above, future development in pulse-jet filtration will encompasses the following areas;

- A more compact particulate collector
- A more energy-efficient particulate collector
- A device with a high particulate removal efficiency (99.99%) for all particle sizes including fine particles
- Development of suitable sorbent to control gaseous emission
- Development of new technique for simultaneous control of particulate and gaseous pollutants.
- Improve life of filter element

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