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Air Filtration Technology- A Comprehensive Review

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Abstract— Industries and vehicles are primary contributors for air pollution. Particle matter ($PM_{2.5}$ & PM_{10}) are a major concern nowadays. Few of the hazardous health effects of particulate matter are insomnia, asthma, heart diseases, stroke, lung cancer, etc. These are triggered by the increased levels of air pollution. $PM_{2.5}$ also reduces the life span of outdoor electronic equipment's. There exist many techniques for achieving breathable air, other than reforestation, air purification is another viable option. Air purifiers have played a vital role in producing clean air and reducing the occurrence of the hazardous health issues in humans. In this paper a study of the effects of polluting contaminants, $PM_{2.5}$ & PM_{10} are done, along with a study of the different existing air filtration technologies and the review of some of the analysis of air filtration techniques.

Index Terms— Air pollution, Air purifiers, ANSYS, CFD, Chemisorbent media, ESP, Plasma, HEPA, $PM_{2.5}$, PM_{10}

1 Introduction

Due to the increase in population, many forests are being cleared in order to utilize the land for agriculture, buildings and industries. Increase in transportation usage, pesticides for agricultural purposes, industrial waste and many other causes the discharged of harmful pollutants to the environment which eventually led to the exponential increase in pollution. Pollution is defined as the introduction of contaminants into the natural environment, that causes adverse vexing effect to the planet. Pollution can be caused by the contamination of air, water and land.

The air pollutants are substances which causes air pollution. There are number of ways to prevent air pollution, one of the ways of achieving this is by eradicating the source of pollutants. Eradication of the source is achieved by eliminating processes which produces the pollutants. Pollutants such as Carbon Dioxides (CO_2), Carbon monoxides (CO), Nitrogen oxides (NO_x), Particle matter ($PM_{2.5}$ & PM_{10}), etc. are emitted by the vehicles. The emission of these pollutants is through combustion of the fuels in vehicles. In order to eradicate the source many present researchers and companies are changing the energy sources from fuel combustion to electricity. Introduction of electric vehicles & hybrid vehicles are done to eradicate these pollutants.

Thermal power plants are also responsible for the introduction of air pollutants such as Nitrogen oxides (NO_x), Sulphur Dioxides (SO_2) etc. These sources again need to be eradicated. In order to eradicate these sources, the thermal plants can be replaced by nuclear plants.

Eradication of the source is very effective but the replacements are costly. It takes time in order to completely change the internal combustion vehicles to electrical & hybrid vehicles and the thermal power plants to nuclear power plants.

Another way is to reduces the introduction of pollutants into the environment. This can be done by improving the emission standards such as by updating engines from BS4 to BS6. Industries should also process the disposal of pollutants. This method doesn't completely eradicate but reduces the pollutants.

Another method is by stopping nature's destruction such as reducing deforestation. Another way is by filtering the pollutants wherever necessary. By the instalments of air filter at the source of air pollution is more. This method is effective for current situation and it is also countering and removing the pollutants from the sources.

Air pollution is contamination of particles in the atmosphere which causes harmful effect to the surroundings. Poor indoor air quality (IAQ) cause many problems for human beings such as asthma and pulmonary inflammation [1]. The air pollutants are CO2, CO, NOx, NH3, SO2, CH4, CFC's and particulate matters. These particulate matters are particles like dust, soot and other particles that are mixed together or suspended separately and are hazardous to the environment. They vary in sizes (microns). They are PM2.5 and PM10. PM2.5 causes increase in the incidence of various respiratory diseases and resident mortality rates, as well as increase in the energy consumption in heating, ventilation, and air conditioning systems [2].

Children, elderly and others are most vulnerable to potential indoor air pollution health effects because they spend more time in the home environment. Reduction in particulate matter and allergens result in reducing symptoms and in certain cases, preventing disease progression across all age groups, including the elderly and the children [5]. In order to avoid these particulate matters from affecting the humans. Population is recommended to limit exposure to air pollution and call to the authorities to create an index of pollution related to health and they concluded to remain indoors, wear a qualified mask and minimize the duration or intensity of outdoor activities [3]. Another method is using air filter; they are the life savers [4].

Using air filters (HEPA) airborne indoor fungal levels and particulate matter are reduced up to 70% and 38% respectively [6]. Usage of air filters also helps in improving thermal comfort, acoustic impact and other aspects [7].

There are many techniques to filter air. One of the techniques is by using nanotechnology. By using Nylon 6 nano filters using nanofibers of 80–200 nm in diameter [9], by using Ag nanowire percolation network [10] and many others. Although, these technologies are very efficient and accurate these technologies possess high cost. Another technology is by using ESP (Electrostatic Precipitator). These aren't as expensive as nano technology but they are theoretically considered as permanent; and the filtration e□ciency of the particles can achieve 82% to 94% and various relations [7]. The collection efficiency of ESP is 100% for particles of diameter more than 8, 5 and 4μm which is collected by collector plates, for wire potentials of 20, 25, and 30kV. For the constant inlet velocity, the collection efficiency increases with increase in particle diameter and wire potential [11]. Another technique is by using humidification where the dust particles get entrapped by the humidity and gets filtered [13]. Another technique is using hybrid of technologies like porous filter and ESP [12]. In order to find the dust concentration at a place method like laser scattering measurement is used. These devices are used to monitor the dust concentration like (PM2.5, PM10 and others) [8]. Another technology is by using electro spun nanofibers have been widely applied in various filtration devices, like vehicle cabin filters, personal respirators, indoor air cleaners, etc. Novel electro spun nanofibers are introduced using polymer membranes and Nanofibers. A number of techniques such as hybrid filters (use of electrostatic effects), composite filters (to enhance the physical and chemical properties). Introducing these techniques have created electro spun nanofibers with PM2.5 filter efficiencies up to 99.999% [19].

Many institutes such as WHO has taken procedures by giving guidelines to improve IAQ since 2014 [20]. Indian institutes such as CBCP are spreading awareness to people about the dangers faced due to exposure towards air pollution and the remedy to prevent air pollution [21,22].

2 Review on Filtration Techniques

Tables 1 show the different existing air filter technologies, its pros and cons. Table 2 show the detail review on analysis of different filtration techniques.

Table 1 Existing filter technologies

Air-cleaning technology	Targeted indoor air pollutant(s)	Mechanism(s) of action	Advantages	Disadvantages
Fibrous filter media [14], [15], [20]	Particles	Collection: Filter fibres capture particles • Mechanical filtration media rely on mechanical forces alone. • Electrostatically charged (electret) media use mechanical fibres with an electrostatic charge applied to collect oppositely charged particles, enhancing removal efficiency.	• If rated efficiency is high, they can have excellent removal capabilities for many particle sizes. • Mechanical media filters see improved efficiency with loading.	• Regular replacement is required. • Used particle filters can be a source of sensory pollution/odours. •High pressure drops on some fibrous media filters can negatively impact HVAC systems. •Electret media filters see reduced efficiency with loading.
Electrostatic precipitation (ESP) [13], [20]	Particles	Collection: Corona discharge wire charges incoming particles, which collect on oppositely charged plates.	• Can have high removal efficiency for a wide range of particle sizes. • Low pressure drops and minimal impacts on HVAC system. • Low maintenance requirements.	• Sometimes ESPs have high ozone and nitrogen oxide generation rates. • Efficiency typically decreases with loading and plates require cleaning. • High electric power draw requirements. • Expensive.
Ionizers (i.e., ion generators) [20]	Particles	Collection: Similar to ESP.	• Typically, low power draw requirements. • Quiet. • Low maintenance.	• Generates ozone. • Typically, low effectiveness because of very low airflow rates and clean air delivery rates (CADRs).
Ultraviolet germicidal irradiation (UVGI) [20]	Microbes	Destruction: UV light kills/inactivates airborne microbes.	• Can be effective at high intensity with sufficient contact time • Can be used to inactive microbes on cooling coils and other surfaces.	• Uncoated lamps can generate ozone. • Potential for eye injury. • Effectiveness increases with lamp intensity, which is typically low in residential UVGI air cleaners. • High electrical power draw requirements. • Inactivates but does not remove microbes.

Air-cleaning technology	Targeted indoor air pollutant(s)	Mechanism(s) of action	Advantages	Disadvantages
Adsorbent media [20]	Gases	Collection: Gases physically adsorb onto high-surface-area media (typically activated carbon).	• Potential for high removal efficiency for many gaseous pollutants in air cleaners with a sufficient amount of media for the application. • No by product formation.	• Regular replacement is required. • High pressure drops on some sorbent media filters can negatively impact HVAC systems. • Standard test methods are not widely used.
Chemisorbent media [20]	Gases	Collection: Gases chemically adsorb onto media coated or impregnated with reactive compounds.	• Potential for high removal efficiency for many gaseous pollutants. • Chemisorption is an irreversible process, meaning pollutants are permanently captured.	• Regular replacement is required. • Effectiveness of many consumer-grade systems is unknown. • High pressure drops on some sorbent media filters can negatively impact HVAC systems. • Different removal efficiency for different gases at different concentrations.
Catalytic oxidation [20]	Gases	Conversion: Most utilize photocatalytic oxidation (PCO) in which a high surface-area medium is coated with titanium dioxide as a catalyst; incoming gases adsorb onto the media and UV lamps irradiate and activate the titanium dioxide, which reacts with the adsorbed gases to chemically transform them.	• Can degrade a wide array of gaseous pollutants (e.g., aldehydes, aromatics, alkanes, olefins, halogenated hydrocarbons). • Can be combined with adsorbent media to improve effectiveness.	• Can generate harmful by-product such as formaldehyde, and acetaldehyde, and ozone. • No standard test methods. • Often relatively low removal efficiency for many indoor gases, but high. variability in removal for different gases • Lack of field studies to validate performance. • Catalyst often has a finite lifespan.
Plasma [20]	Gases	Conversion: Electric current is applied to create an electric arc; incoming gases are ionized and bonds are broken to chemically transform the gaseous pollutants.	• Can have high removal efficiency • Can be combined with other air cleaning technologies (e.g., PCO) to improve performance and minimize by product formation.	• By products are formed from many plasma technologies, including particles, ozone, formaldehyde, carbon monoxide, chloroform, nitrogen oxides, and a large number of other organic gases.

Table 2 Existing filter technologies Review

Study	Numerical and experimental study of pulse-jet cleaning in fabric filters.	Impact of water droplet and humidity interaction with soluble particles on the operational performance of surface filters in gas cleaning applications	Modeling and analysis of flow through an inlet duct in an electrostatic precipitator with optimum performance
Filtration technique	Fabric filters with pulse-jet cleaning system	Surface filters (mechanical filter type)	Flow through an Electrostatic precipitator
Working	The tests were conducted in the presence of a dust cake which was simulated by using special bags with low permeability. All tests were performed at room temperature and with the filter in off-line mode (without filtration flow). The unsteady Reynolds-averaged Navier–Stokes formulation (URANS) was considered for optimal computation. The commercial code STAR-CCM+ is used to simulate the complex flow in the pulse-jet cleaning system.	The filters were made of hydrophobic, oleo phobic polyester flat sheet media with a weight of 440 g/m^2, thickness of 1.4 mm and in circular shape with an active filtration area measuring 42.1 mm in diameter. Sodium chloride served as the test salt with a solubility of 358 g/l in water at 20^{o}C and atmospheric pressure. At 25^{o}C and atmospheric pressure, its deliquescence relative humidity (DRH) is 75.4% and its efflorescence relative humidity (ERH) is 48%. The structure of salt particles generation and formation of particles on the filter surface is analyzed using scanning electron microscope (SEM).	The analysis of ESP inlet duct has been performed using CAD software ANSYS 15.0 CFX. Triangular surface mesh is generated and used in the simulation to create the fluid domain. Analysis is done using CFX and meshing is done with triangular surface elements type. The entire domain is in the stationary frame of reference. The boundary conditions specified are mass flow rate at the inlet and static pressure at the outlet. The walls are defined no slip condition. The monitoring parameter is pressure for the entire case studies. Reference pressure used for simulation is 101.325 Pa and hence the static pressure at inlet is given as zero Pascal. The computational fluid analysis of CAD model has been done to calculate the pressure drop for different cases.
Result & Discussion	CFD model was used to investigate the jet behavior, the physics of subsonic/supersonic pulse-jet cleaning and the effect of the Venturi in relation to a typical pulse-jet cleaned fabric filter. Experimental pressure measurements were used as validation data for the 3D CFD model. The results of 3D CFD model jet alignment, pulse pressure inside the bags and the effect of the nozzle and Venturi design were obtained.	It was seen that the pressure drop increases at starting of filtration and during the exposure to liquid droplets when the total liquid content in the system is larger. As liquid droplets continue being collected on the fiber the pressure drop increases. SEM image shows that the no filter cake as formed on the filter surface. The almost round shape particles are attached to the fiber or to other particles without increase in humidity. It also shows that there is no penetration of salt particles through the filter.	The results show that with the incorporation of guide vanes and fillets at each corner, the following was obtained I. Reduction in pressure drop II. Reduction in turbulence III. Uniform distributions among streams IV. Minimized erosion of duct walls caused due to high velocity V. Reducing erosion of the duct walls results in the reduction of leakages in the ducts VI. Reduction of pressure drop across the duct saves the power consumption
Conclusion	In pulse-jet cleaned fabric filters the selection of nozzle and Venturi type is based on the cost evaluation of filter. This type of filtration technology has a significant amount of pressure drop and works effectively at low inlet velocity. The 3D CFD model of this filter produces optimal results using unsteady RANS simulation.	The exposure of soluble particles on a hydrophobic surface filter to both, high humidity only and to water droplets results in rearrangements of the particles on the face side of the filter. Using pressure drop recordings and SEM images taken after the experiments the two sets of experiments can be clearly distinguished. Further research needs to be carried on how fast the salt particles penetrate into the medium after direct contact with water droplets.	The incorporation of vanes and fillets improves the flow of the ESP inlet duct. Increase in the number of vanes at the bends decreases the pressure drop throughout the duct. This further reduces power consumption and increases the duct efficiency.

Study	Numerical simulation of the filtration process in fibrous filters using CFD-DEM method	Numerical study of the gas–solid flow characteristic of fibrous media based on SEM using CFD–DEM
Filtration technique	Fibrous Filter	Fibrous Filter
Working	The analysis was done using ansys and validated by comparing semi analytical models. The fibrous medium was modelled by using B-splines (NURBS) with random angles inside a cube. After one fibre is created the SVF is calculated and doesn't allow beyond certain value and then the next fibre is made and so on. CFD and DFM analysis was used to simulate the airflow, the motion of particles, and the interactions between particles fibers and fluid. The filtration efficiency and pressure drop of the filters were calculated and analysed in CFD-DEM and the results were validated by the semi-analytical models. In addition, the correlations between filtration performance and fiber structures, particle parameters and fluid properties were investigated.	The particle was made as soft sphere model which has the principle of change in momentum when contact collision occurs for CFD-DEM model. The Fluids are made in CFD-DEM by establishing the equations of motion of each particle according to newton second law of motion and adding the equations for conservation of momentum and continuity. The fiber was modelled by reconstruction from SEM, image processing using MATLAB reconstruction was done using both MATLAB and gambit software. The information like perimeter centroid and boundary conditions was extracted and based on those parameters the model was extracted. Boundary conditions and calculation conditions are designed.
Result & Discussion	The deposition of particles, behaviour of filter efficiency and pressure drop was found from different diameters and different SVFs.	Influence of particle characteristics and structural parameters on the particle deposition and agglomeration was found. Influence of the structural parameters on the pressure drop was found. Influence of the structural parameters on the filtration efficiency was found.
Conclusion	The particles that gets entrapped in the fibre, it gradually forms dendrites and gets deposited which blocks and reduce the inlet velocity. Increase of SVF, decrease of fibre diameter and decrease of inlet velocity increases the filter efficiency and makes the fluid turbulent and increases pressure drop because blockage of particles occurs. If the inlet velocity increases the filtration efficiency decreases.	With the increase in the filtration time, the deposition mass of the particles on the surface of the fibrous media increases. The pressure-drop increases with increasing filtration time under various conditions. The total pressure drop of the fibrous media increases with the fiber diameter. The filter efficiency decreases with increase in fiber cross section.

3 Conclusion

Clean air plays a vital role for better human health and environment. The air pollution issues in our society needs necessary precautions to be taken, mainly in the industry and transportation sector. Implementing proper policies for the transportation facilities and industries. By reducing deforestation and planting trees the production of fresh breathable air can be increased. By the instalments of air filter indoor and outdoor, the air pollution can be minimized. Thereby improving human health and environment. Natural ventilation, control at the source of pollutant emission and instalment air filters are the main three strategies to reduce indoor air pollutants. By integrating the existing air filtering technologies, they can overcome each other's weaknesses and produce better performance. The life cycle and overall performance of the multi-stage air filter is better compared to its individual air filtering technology.

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