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A Review on Conventional and Advanced Techniques to Reduce Airborne Particulate Matter from Air

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Abstract: The aim of this study is to develop a efficient method of controlling the emissions of particulate matter(PM) using innovative system as a control device. Removal of airborne particulate matter is necessary to protect our environment from pollution as PM is one of the most harmful inhaled pollutants. It is generic term to classify air pollutants comprising of suspended particles in air, varying in composition and size, resulting from various anthropogenic activities. Industrial facilities, Power plants, vehicles, incinerators, dust and fires are the major source of particulate matter. Airborne PM is also responsible for a number of effects aside from human health, such as alterations in visibility and climate. Therefore, to save the environment from the harmful effects of particulate matter conventional techniques such as cyclones separators(CS), Electrostatic precipitator (ESP), wet scrubbers, Cloud chamber scrubber (CCS), fabric filter etc and the advanced technique of smog tower are studied in this review paper. All the conventional techniques are efficient upto 99% but the latest invention gives the most promising removal efficiency upto 99% along with remarkable removal of particulate matter.

Keywords: Airborne PM, ESP, CCS, CS, SMOG Tower.

I. INTRODUCTION

Air pollution control techniques employed to reduce or eliminate the emission into the atmosphere of substances that can harm the environment or human health. The control of airborne particulate matter is necessary because these are small enough to enter into the lungs and cause health problems. Both nitrogen oxides and sulphur oxides are associated with the formation of particulate matter, but other processes can contribute to their formation. Aside from health concerns, particulates cause reduced visibility and haze when released in the atmosphere. Particulate matter (PM) is one of the most important air pollutants in environment. It is almost entirely biological and organic. It is a complex mixture of micrometric particles and liquid droplets made up of organic soot (VOCs) as well as inorganic particles as soil, dust, metals and acids (nitrates and sulphates)[4]. These particles vary greatly in size, composition, and origin. PM is emitted from both natural and anthropogenic sources, and its components are both primary (directly emitted) and secondary (formed in the atmosphere). Direct natural emissions come from wildfires, sea spray, and re suspension of organic matter such as leaf litter. Based on size, particulate matter is often divided into two main groups. The coarse fraction contains the larger particles with a size ranging from 2.5 to 10 µm (PM_{10} - $PM_{2.5}$). The fine fraction contains the smaller ones with a size up to 2.5 µm ($PM_{2.5}$). The particles in the fine fraction which are smaller than 0.1 µm are called ultrafine particles. Most of the total mass of airborne particulate matter is usually made up of fine particles ranging from 0.1 to 2.5 µm. Ultrafine particles often contribute only a few percent to the total mass, though they are the most numerous, representing over 90% of the number of particles.

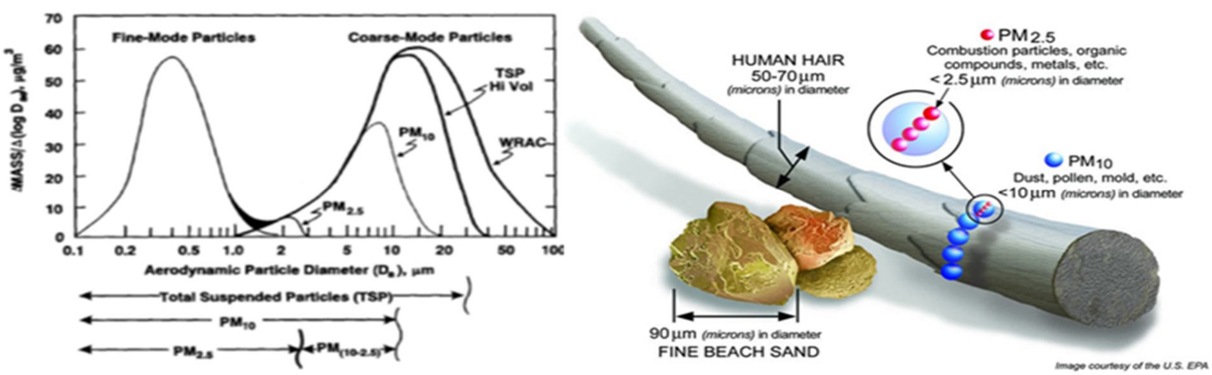

Fig. 1 – Size distribution of particulate matter
Source- Mauro Capocelli et al[4]

Excess of PM emission in environment is harmful for public, plants and animals. Exposure to elevated levels of PM has long been associated with adverse human health impacts, and is a major source of morbidity and mortality worldwide and many cases, inhaling PM can negatively affect human health because these are easily deposited in the respiratory tract and lungs. The typical range of PM sizes deposited in the path from the nose to the lungs are as follows: 7.0–11 µm in the nose, 4.7–7.0 µm in the pharynx, 3.3–4.7 µm in the trachea, 1.1–3.3 µm in the bronchial tubes, and less than 1.1 µm in the alveolus inside the lung[14].

Due to environmental concerns, most industries are required to operate some kind of air filtration system to control particulate emissions. These systems include inertial collectors (cyclonic separators), fabric filter collectors (baghouses), electrostatic filters used in facemasks, wet scrubbers, and electrostatic precipitators. All these are the conventional method of removing air pollutants along with these there is an advanced methodology of treating air by filtration known as SMOG TOWER.

II. CONVENTIONAL METHODS OF TREATING AIR

A. *Cyclones Separator*

Cyclone separators provide a method of removing particulate matter from air or other gas streams at low cost and low maintenance. Cyclones are basically centrifugal separators, consists of an upper cylindrical part referred to as the barrel and a lower conical part referred to as cone. They simply transform the inertia force of gas particle flows to a centrifugal force by means of a vortex generated in the cyclone body. The particle laden air stream enters tangentially at the top of the barrel and travels downward into the cone forming an outer vortex. The increasing air velocity in the outer vortex results in a centrifugal force on the particles separating them from the air stream. When the air reaches the bottom of the cone, it begins to flow radially inwards and out the top as clean air/gas while the particulates fall into the dust collection chamber attached to the bottom of the cyclone.

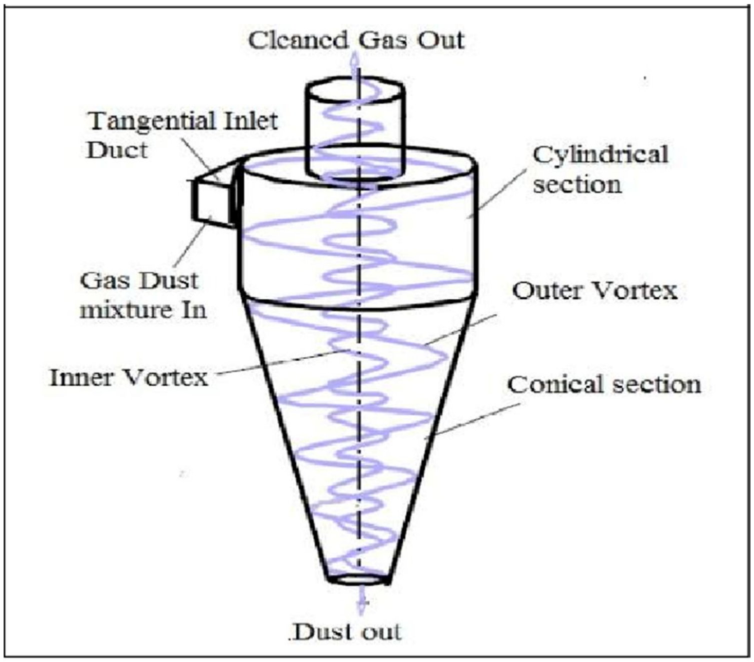

Fig. 2- Schematic diagram of cyclone separators
Source- Snehal s. gawali et al

Cyclone collectors can be designed for many applications, and they are typically categorized as high efficiency, conventional (medium efficiency), or high throughput (low efficiency). High efficiency cyclones are likely to have the highest-pressure drops of the three cyclone types, while high throughput cyclones are designed to treat large volumes of gas with a low-pressure drop. Each of these three cyclone types has the same basic design. Different levels of collection efficiency of a cyclone collector is related to the pressure drop across the collector. This is an indirect measure of the energy required to move the gas through the system. The pressure drop is a function of the inlet velocity and cyclone diameter.ficiency and operation are achieved by varying the standard cyclone dimensions. These simple devices are used to primarily control particles over PM_{10} (pre-cleaners for more expensive final control devices such as fabric filters or electrostatic precipitators); high efficiency cyclones can be designed to be effective even for $PM_{2.5}$. The main advances of classical separation chambers are kept in these conical arrangements.

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B. Electrostatic Precipitator

An electrostatic precipitator (ESP) removes particles from a gas stream by using electrical energy to charge particles either positively or negatively. The charged particles are then attracted to collector plates carrying the opposite charge. The collected particles may be removed from the collector plates as dry material (dry ESPs), or they may be washed from the plates with water (wet ESPs). ESPs are capable of collection efficiencies greater than 99 percent. An ESP is primarily made up of the following four components: gas distribution plates, discharge electrodes, collection surfaces (either plates or pipes) and rappers. The gas distribution plates consist of several perforated plates which help maintain proper flow distribution of the entering gas stream. The discharge electrodes are divided into fields. Most ESPs have three or four fields in series; however, very large units may have as many as fourteen fields in series. Discharge electrodes are energized by a single transformer-rectifier (T-R) set power supply. The energized electrodes create ions that collide with the particles and apply the electrical charge to the particles contained in the incoming gas stream. The collection plates or pipes provide the collection surfaces for the charged particulate matter. The rapping system is responsible for removing the collected particulate matter from the collection surfaces. The primary indicators of the performance of ESPs are the particulate matter outlet concentration, which can be measured with a particulate matter continuous emissions monitoring system (CEMS), opacity, secondary corona power, secondary voltage (voltage across the electrodes), and secondary current (current to the electrodes). Other indicators of performance are the spark rate, primary current, primary voltage, inlet gas temperature, gas flow rate, rapper operation, and number of fields in operation. In 2006 Javorek et al [12], have realized a comprehensive review of the wet ESP state-of-the-art for gas cleaning (mainly dust or smoke particles). In a single stage ESP, the charging and discharging (collecting at the electrode) take place in one device while in a two stage ESP, charging and removal of the particles occur in separate electric fields (and consequently separate chambers). The two stage ESP is common for small waste gas streams (<90000 Nm^3/h) characterized by a high concentration of micrometric and sub-micrometric particles (e.g. smoke or oil mist) [4].

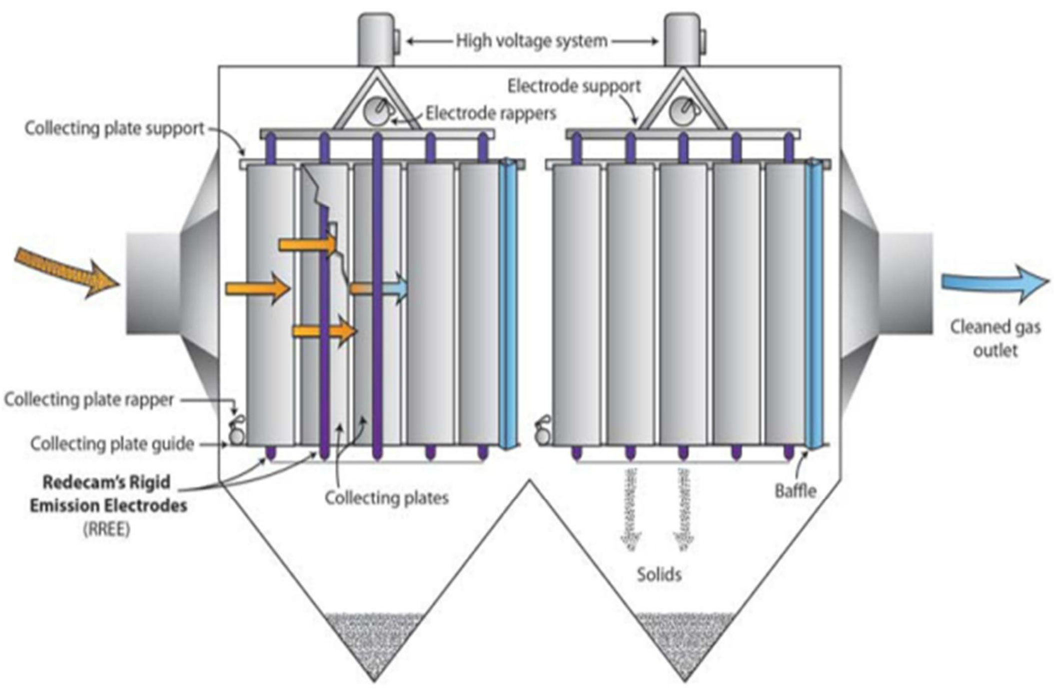

Fig 3- Image of electrostatic precipitator
Source- Mauro Capocelli et al [4]

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C. Wet Scrubber

Wet scrubbers (WS) realize the interception of PM through the direct contact with liquid droplets. WS can assembled with variable geometries to each of which optimized in a specific gas flow rate; in relation to the contact dynamics they are arranged in the form of spray towers, packed bed scrubber and Venturi scrubbers. This last realizes the acceleration of the gas stream in a throat to atomize the scrubbing liquid and to improve gas-liquid contact .

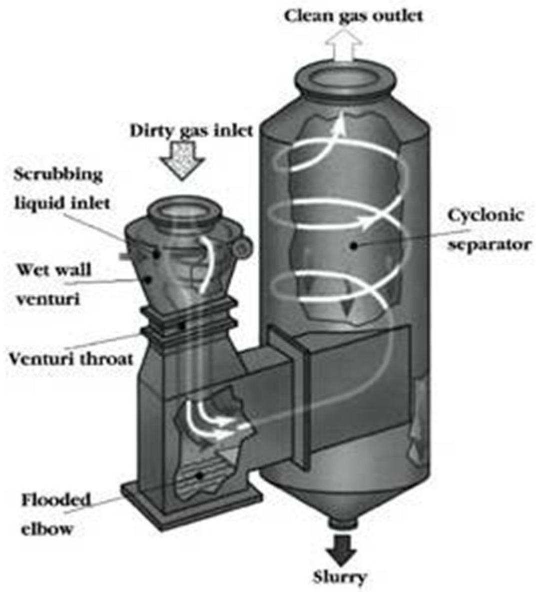

Fig. 4 – Schematic view of a Venturi Wet Scrubber
Source- Mauro Capocelli et al [4]

Liquid scrubbers are used in case of removal/recover of flammable and explosive dusts as well as treatment of gaseous compounds. Furthermore, WS as the advantage to cool and supersaturate the gas stream leading to particle scrubbing by condensation. WS can operate at medium/high collection efficiency and low cost. On the other hand, the main disadvantages of WS are the risk of corrosion and freezing, the generation of a liquid by-product and the low particle collection efficiency in the 0.1-2μm range[4].

D. Cloud Chamber Scrubber

The Cloud Chamber Scrubber (CCS) treats $PM_{2.5}$, fine, submicron, ultrafine, and condensable particulate as well as PM_{10} and more coarse particles. It is new cleaning systems to remove particles from flue gas and the optimization of the existing technologies in order to improve the particle capture of submicronic particles [1]. Simultaneously, all soluble acid and caustic gases are removed at the same high levels as conventional scrubbers. Different charging and spraying configurations are possible and PM can be charged either negatively or positively with opposite polarity droplets. A commercial application of this interesting technology is the Cloud Chamber Scrubber (CCS) by Tri-Mer Corporation [21]. The CCS is a major advance in multi-pollutant control devices. It is composed of three zones: preconditioning chamber (a) for the removal of coarse particles and humidity/temperature adjustment; cloud generation vessel (b) for the removal of neutral and negative submicronic particles; second cloud generation vessel (c) with negatively charged droplets so that neutral and positive particles are captured. Afterwards treated air flows through a mist eliminator, before discharge (particles between 0.1 and 2.5 μm) [4]. It will proven submicron performance at efficiencies typically greater than 99%.[20] I has Capability to capture particles even smaller than 0.1 micron. it requires only 10 watts per 1000 cfm to charge the water droplets, plus moderate pump power for water recirculation, hence energy efficient. It also removes any gas that can be treated by a wet scrubber, including hydrogen chloride (HCl), sulfur dioxide (SO_2), ammonia (NH_3), and hydrogen sulfide (H_2S). Mostly it is used for diesel emission control. CCS wet scrubber technology works by passing the dirty gas stream through a chamber containing a “scrubbing cloud” of high-density, charged water droplets. Inside the wet scrubber, billions of charged droplets rapidly interact with the particles in the process stream. When a particle and a droplet pass within 20 microns, electrical forces cause the particle (being less massive by orders of magnitude) to be pulled into the droplet. Each individual water droplet becomes a particle collector. The droplets collect particles as they interact with the process gas stream, then fall into the sump. Captured particles agglomerate within the sump, settle out, and are removed as low volume slurry from the bottom.

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Relatively clean water from the top of the sump is re-circulated to the charging grid, where it is recharged, completing the cycle. A low concentration of particulate does not affect the ability to charge the water, so relatively clean water from the top of the sump is filtered for very coarse particles and re-circulated to the charging nozzles. Several factors are involved with optimizing the effectiveness of a particular Cloud Chamber application. These include droplet size, droplet charge, particle size, particle charge, particle retention time, and electric field effect. For each application, a simulation can be run to analyze these factors, along with expected inlet loading, gas type and concentration. Gases to be treated, if any, are taken into consideration. Simulations help determine the ideal system configuration in terms of recirculation flow, gas-to-cloud contact time, and vessel size. Advanced real time particle measurement is used during start-up to fine-tune parameters.

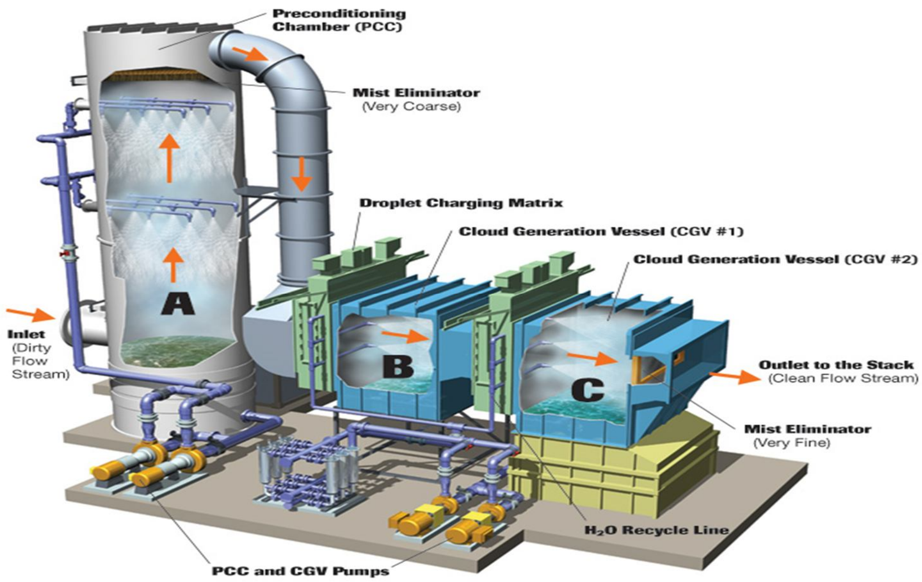

Fig. 5- Schematic diagram of cloud chamber scrubber
Source- Mauro Capocelli et al [4]

E. Fabric Filter

In a Fabric Filter (FF), waste gas is forced to pass through a tightly woven or felted fabric, collecting particulate matter on the fabric by sieving and other related mechanisms. Fabric filters can be in the form of sheets, cartridges or bags (the most common type) with a number of the individual filtering units housed together in a group. When low particles loads occur, filter collection efficiency is primary related to the filter pore size and length. High particulate loading forms a "cake" on the filter surface increasing the collection efficiency.

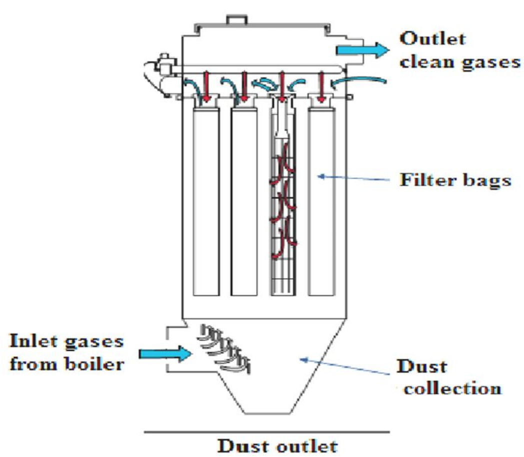

Fig 6- Schematic diagram of fabric filter
Source- Coal Fired Power Plants: Emission Problems and Controlling Techniques[11]

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Fabric filters are used, primarily, to remove particulate matter (and other hazardous air pollutants in particulate form such as metals) at moderate loads down to $PM_{2.5}$. This technology is useful to collect particulate matter with electrical resistivity either too low or too high for Electrostatic Precipitator, so they are suitable to collect fly ash from low-sulphur coal or fly ash containing high levels of unburnt carbon [2]. The cleaning intensity and frequency are important variables in determining removal efficiency (the dust cake provides an increased fine particulate removal) and the pressure drop across the fabrics (ΔP 100-500 mbar) and the consequent energy requirement (0.2-2 kWh/1000Nm3). Catalytic filtration is commonly adopted in the new generation of diesel particulate filters (DPF), for the automotive application. Commonly the oxidation catalyst and the particulate filter are combined and particles can be burnt off continually. The catalyst filter consists of an expanded polytetrafluoroethene membrane, laminated to a catalytic felt substrate. It is used to separate particulate and eliminate hazardous contaminants from the gaseous phase, such as dioxins and furans, but also aromatics, polychlorinated benzenes, polychlorinated biphenyls, volatile organic compounds and chlorinated phenols. The filtration efficiencies of DPF are > 99% for solid matter (globally > 90% considering a non-solid portion). These systems can be alternatively designed to trap a portion of the total particle load (e.g. the 70% instead of the 100%) in order to obtain a lower back pressure and a blocking risk [4].

III. MODERN TECHNOLOGY: SMOG TOWER

This is the new technique in the field of improving air quality by removing air pollutants.
Smog tower is a structure of concrete that has multiple layers of filters. The size of this structure would be 20-40 feet in height and 20 feet on each side. In total it requires a compound of around 30x30 meters. It sucks the smog particles. It captures and collects more than 75% of the $PM_{2.5}$ and PM_{10} air bound smog particles and releases clean air around. Tower with a 360 degree coverage coating an almost circular zone of clean air in its surrounding. It sucks the dirty air like a giant vacuum cleaner and works on ionisation technology[19]. Ion technology then filters it, before returning smog free air through the towers vents. By creating a field of ions, all the particles on the nano scale gets positively charged, therefore when the ground is negatively charged, they are dragged to the ground, and 75% more clean air is obtained. Carbon in the smog is positively charged ion and the negative ions are produced using negative ion generator through circuiting.This will attract the charged carbon to the ground in the form of impurities.They are then collected separately and the pure air is now sent out through the outlet at the top of the tower. its capacity would have the to clean 250,000 to 600,000 cubic meters of air per day. . This anti-smog tower works with the goal that it helps to decrease approx. 94% of airborne particle issues [15].

Fig 7- Image showing the SMOG TOWER IN ROTTERDAM, 2015 [17]

According to the Ministry of Earth Sciences' SAFAR report, the AQI of Delhi was at 419 in November 2019, which is categorized as severe. In November 2019, the Supreme Court directed the Modi government and the Arvind Kejriwal led-Delhi government to draw up a comprehensive plan to install "smog tower" across the capital to deal air pollution. The Delhi experiment is being headed by the Indian Institute of Technology (IIT) Bombay in collaboration with IIT Delhi. The central pollution control board (CPCB) and the University of Minnesota are involved in the process. Therefore, Delhi has recently got the patent of the world's largest air purifier on JAN 3, 2020. The massive 20 feet tall air-purifier has been installed at South Delhi's Lajpat Nagar market. The device will be able to take in air from all 360 degree angles and can generate 1,300,000 cubic meters of clean air per hour. Although its capacity would have the to clean 250,000 to 600,000 cubic meters of air per day. This giant purifier will have 48 fans to keep the flow of clean air going. The manufacturer of this device claims that it could provide clean air to 75,000 people living in the 3 kilometer radius around it. This tower is inaugurated by the cricketer Gautam Gambhir. It is 20 feet tall and cylindrical in design. The tower will run on electricity. This smog tower sucks the polluted air like a giant vacuum cleaner with big inlet point, which is purified by the multiple layers before re-circulated into the atmosphere. To purify the air the highly effective H14 grade Highly Effective Particulate Arrestance (HEPA) filter would be used. This filter can clean up to 99.99% Particulate Matter (PM) present in the air with the help of pre-filter and activated carbon. A machine fixed inside the tower will remove nearly 80% of the particulate matter i.e. $PM_{2.5}$ and PM_{10}. It is also claimed to clean 80% of Particulate matter, $PM_{2.5}$ and PM_{10} and help in improving air quality within a circumference area of almost 500 to 750 metres.

IV. CONCLUSIONS

Air pollution control devices play an important role in controlling air quality to fulfill the standard criteria. Selecting the suitable devices by considering their limitations in various environmental and manufacturing conditions, alongside their costs imposing the industrial facilities is so essential. Monitoring the gas temperature, pressure drop, type and density of existing pollutants in outlet gas, economic parameters are very important to select control devices. The proper selection will result in reducing the operation costs, increasing efficiency in elimination of particulate matter pollutant and extending the service life of air pollution control devices. This study showed that there is so many techniques to improve air quality but we have to focus on the innovative and latest technique which provide proper selection, designing, operation and economic value. Cyclone separator, ESPs, wet scrubbers, fabric filter etc are useful for removing air pollutant upto 99% in efficiency but smog tower technique is useful in removing 99.99% particulate matter from the air. This anti-smog tower works with the goal that it helps to decrease approx. 94% of airborne particle issues. This converts coarse and ultrafine dust particles into coarse buildup.

Smog Free tower is not intended as a final solution but as a sensory experience of a clean future because advances show that this is a promising air-cleaning technology. They are promising because of their relatively high efficiency on micron particles at high airflow rates with economical initial and operational cost. At the current stage, they are not applicable for locations where submicron particles are the major concern but we can launch it for more polluted areas such as industrial areas. In our country, INDIA we can launch it in Kanpur, Sonbhadra, Ghaziabad like industrial areas where so many factories are established which are responsible for increasing air pollution. Surely, this will overcome the problem of air pollution at least in particular areas upto some extent.

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