

# **A CASE STUDY ON ENVIRONMENTAL AIR POLLUTION AND CONTROL METHODS**

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## **ABSTRACT**

*This paper deals with analysis of different devices used to remove particulate matters. Gravitational settlers are found to be least effective for separation of particulate matters and fabric filters are most effective since it separates particles with sizes less than 1  $\mu\text{m}$ . Different classes of environmental pollution are discussed. Present pollution status of Indian metropolitan cities is briefly explained. It is observed that pollution due to thermal power plants reduces the dissolved oxygen in water as a result it creates suffocation of plants and animals. Health impacts of air pollution results mainly due to carbon mono oxide, which combines with haemoglobin to reduce the amount of oxygen which enters in human body. Different diseases like asthma and chronic obstructive pulmonary are also pointed out in this paper.*

**Keywords:** *Collection Efficiency, Cyclone Separators, Dust, Particulates, Pollution.*

## **I. INTRODUCTION**

Presence of matter [gas, liquid, solid] or energy [heat, noise, radiation] whose nature, location, or quantity directly or indirectly alter characteristics of processes of any part of the environment and causes [or has the potential to cause] damage to the condition, health, safety, or welfare to animals, humans, plants, or property [1]. We know that, a living organism cannot live by itself. Organisms interact among themselves. Hence, all organisms, such as plant, animals and human beings, as well as the physical surrounding with whom we interact, form a part of our environment. All these constituents of the environment are dependent upon each other. Thus, they maintain a balance in nature.

### **1.1 Classification of Environmental Pollution**

Environmental pollution can be classified as air pollution, water pollution, soil pollution and noise pollution [2]. Air pollution is the introduction into atmosphere of chemical, particulates or biological material that cause discomfort, disease or death of human, damage other living organism such as food crops, or damage the natural environment or built environment. There are different source of air pollution such as natural and man-made.

Water is said to be polluted when there is any physical, biological or chemical change in water quality that adversely affects living organisms or makes water unsuitable for use. Sources of water pollution are mainly factories, power plants, coal mines and oil wells situated either close to water source or away from sources they discharge pollutants directly or indirectly in to water sources like. River, lakes, water streams etc.

Soil contamination or soil pollution is caused by the presence of anaerobic chemicals or other alteration in the nature soil environment it is typically caused by industrial activity, agriculture chemicals or improper disposal of waste.

The word noise may be from the Latin word *nauseas*, which means disgust or discomfort the source of most outdoor or noise worldwide is mainly construction and transportation system, including motor vehicle noise, aircraft noise and rail noise.

## 1.2 Reason of Pollution

The ultimate cause of pollution is human action to nature.

### 1.2.1 Human activity

Industries for various human needs –directly and indirectly, Agriculture for food production and industrial needs, Health care for health of human beings and animals, Transport for mobility of human beings, Dowelling for settlement in city or villages, Energy for various direct human needs and industrial needs. All of them contribute to pollution in one way or other and therefore cause miseries All of them are aimed to be part of human welfare programmers [3].

### 1.2.2 Industries

A vast array of industries can cause pollution chemical to popular perception that only a chemical industry can cause pollution IN same industry pollution is out rightly visible. In others, it may be invisible, indirect.

**Table-1 Industry and pollution**

| Type of industry                                    | Type of pollution                 |
|-----------------------------------------------------|-----------------------------------|
| Manufacture of chemicals, medicines                 | Water pollution air pollution     |
| Paper industry                                      | Water pollution air, solid, sound |
| Sugar industry                                      | Water, air, solid,                |
| Electrical application and electric good industries | Solid and air pollution           |
| Petroleum based industries                          | Water and air pollution           |
| Power plants, cement, steal and other moves based   | Air, water, solid pollution       |

**Table-2 Pollutants Concentration**

| Pollutants                           | Average time            | Concentration                               |
|--------------------------------------|-------------------------|---------------------------------------------|
| Sulphur dioxide [SO <sub>2</sub> ]   | Annual average 24 hours | 60 µg/m <sup>3</sup>                        |
| Oxide of nitrogen [NO <sub>2</sub> ] | A.A.24 hours            | 60 µg/m <sup>3</sup>                        |
| Suspended particulate matter         | A.A 24 hrs              | 140 µg/m <sup>3</sup> 200ug 1m <sup>3</sup> |
| Carbon monoxide                      | A.A 24 hrs              | 0.75µ g/m <sup>3</sup>                      |
| Carbon monoxide                      | A.A 24 hrs              | 2. µg/m <sup>3</sup> 4.0 µg/m               |

## 1.3 Pollution Control Devices

Dust collection systems, scrubbers, sewage treatment, industrial wastewater treatment, vapour recovery systems are some of the pollution control devices.

Electrostatic precipitator are operated at 12,000-30,000 volts applies across two spaced electrodes. At the applied voltage gas molecules ionize in between the electrodes. Suspended particulate contain in the moving air steam collide with the charged ions which in turn get charged and move toward oppositely charged electrodes. At the electrodes the charged particles deposit and lose their charge. Both solid and liquid aerosols can be collected in electrostatic precipitators [4].

A cyclone is a vertical cylinder attached with an inverted cone at the bottom. It has no moving part. The particulate laden gas is introduced through a tangential inlet into the cylinder at high velocity which imparts a whirling motion to the gas by generating a centrifugal force. Centrifugal force acting on particle in a spinning gas steam is greater than the gravitational force. The particle laden gas undergoes a spiralling motion directed toward the cone. The vortex enough centrifugal forced to throw the particle radially toward the wall of cone. At the bottom of the one the gas flow, reverse the direction to form an inner vortex spiralling upward until it exits from the cone.

## 1.4 Present Pollution Status of Indian Metropolitan Cities

The United Nations reported in 1994 that Kolkata, Mumbai and Delhi were among the most polluted [air pollution] cities in the world [5]. WHO (world health organization) also reported that out of the 7 cities in the world with serious air pollution, 5 were located in Asia-Kolkata, Mumbai, Delhi. Kolkata core, with an area of 104 sq. km. and a population of 4 million has a record of severe air pollution during winter season. The cities are comparatively clean during rainy season (July to October) due to heavy rainfall and also during summer (April to June) when high winds blow away the pollutants. Ambient air quality monitoring in major Indian cities has been conducted since 1978 by National Environmental Engineering Research Institute (NEERI), Nagpur and central pollution Control Boards (CPCB) under National Ambient Air Quality Monitoring (NAAQM) Programmes. The database has been generated since 1978 for the cities – Ahmadabad, Chennai, Delhi, Hyderabad, Jaipur, Kanpur, Kochi, Kolkata, Mumbai and Nagpur. The urban environmental issues arise from failure to provide the basic amenities to urban population. Accumulation of huge solid wastes [1000 tonnes per day at Kolkata] enhance the water pollution hazards – this along with air pollution and noise pollution pose severe health hazards for the urban population. Industries produce environment hazards everywhere. they consume 37 % of the world's energy and emit 50% of the world's CO<sub>2</sub>, 90% of SO<sub>x</sub> and almost all the chemicals now threatening O<sub>3</sub> layer with depletion. In developed country, energy is being used more efficiently and expected rate of increase of energy consumption is only 1.3 % a year the energy needed to produce a single unit of Gross Domestic Product (GDP) has declined by 29% since 1970 [6]. Natural gas is being used as fuel in cars in several countries in reducing Italy where 3lakh cars run on compressed natural gas (CNG). Major efforts have been made in developed countries in reducing petrol consumption by 50% of the amount used two decades ago. Auto emissions have also been cleaned up. Use of lead free petrol has curtailed lead emission lead emission by 87% during 1976-1978.

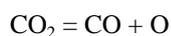
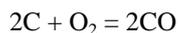
## 1.5 Pollutants Present in Atmosphere

Pollutants present in atmosphere are Carbon Monoxides, Nitrogen Oxides, Hydrocarbons and Photochemical Smog, Sulphur dioxide and Particulates.

### 1.5.1 Carbon Monoxides [CO]

It is a colourless, odourless, and tasteless gas. It is 96.5% as heavy as air and is not soluble in water. The basic chemical reaction yielding CO are

Incomplete combustion of fuel or carbon-containing compounds –



### 1.5.2 Nitrogen Oxides [NOx]

Nox represents composite atmospheric gases, nitric oxide and nitrogen dioxide. Which are primarily involved in air pollution. NO is a colourless gas, odourless gas, but NO<sub>2</sub> has a reddish – brown colour and pungent suffocating odour [7].



### 1.5.3 Hydrocarbons and Photochemical Smog

Natural sources, particularly trees, emit large quantities of hydrocarbons in the atmosphere. CH<sub>4</sub> is the major naturally occurring hydrocarbons emitted into the atmosphere. It is produced in considerable quantities by bacteria in the anaerobic decomposition of organic matter in water, sediments and soil. It has been estimated that anthropogenic sources [human activities] contribute about 15% of the hydrocarbons emitted to the atmosphere each year. An approximate break-up of global hydrocarbons is given as Petroleum -55%, Coal-3.3%, Wood - 2.2%, Incinerators and refuse burning- 28.3%, Solvent evaporation -11.3% [8].

### 1.5.4 Sulphur dioxide [SO<sub>2</sub>]

It is a colourless gas with a pungent odour. It is produced from the combustion of any sulphur bearing material. SO<sub>2</sub> is always accompanied by a little SO<sub>3</sub>. The mixture is denoted by –



Under normal humid conditions of the atmosphere, SO<sub>3</sub> invariably reacts with water vapour to form droplets of H<sub>2</sub>SO<sub>4</sub>.

### 1.5.5 Particulates

Small solid particulates and liquid droplets are collectively termed particulates. These are present in the atmosphere in fairly large numbers and sometimes pose a serious air-pollution problem [9]. The most important physical property is size. Particulates range in size from a diameter of 0.0002 micron to a diameter of 500 micron with lifetimes varying from a few seconds to several months.

## 1.6 Pollution due to Thermal Power Plants

Natural gas is frequently combusted in gas turbine as well as boiler. The waste heat from a gas turbine can be used to raise steam, in a combined cycle plant that improves overall efficiency. Power plants burning coal,

fuel, oil or natural gas are often called fossil-fuel power plants. Some biomass – fuelled thermal power plants have appeared also. Non – nuclear thermal power plants, particularly fossil fuel plants, which do not use co – generation are sometimes referred to as conventional power plants [10].

## 1.7 Effects of Thermal Pollution

The warm temperature reduces the level of dissolved oxygen in water. The decrease in DO can create suffocation of plants and animals such as fish, amphibians, copepods, which give rise to anaerobic conditions. With the constant flow of high temperature discharge from industries, there is a huge increase in TOXINS that are being regurgitated into the natural body of water. These toxins may contain chemical and radiation that may have harsh impact on the local ecology and make them susceptible to various diseases. A dent in a biological activity in water may cause significant loss of biodiversity. Changes in the environment cause certain species of organisms to shift their base to some other place while there, could be a significant number of species that may shift in because of warmer waters.

## II. PROBLEM IDENTIFICATION

### 2.1 Harmful Effect of Pollution

It affects respiratory system of organisms and causes pneumonia etc. carbon monoxide emitted from motor vehicles and cigarette smoke affect nervous system. Due to depletion of ozone layer, radiation reaches earth UV radiation causes skin cancer, damage to eyes and system of body. Acid rain also results of air pollution. Some rain of also result of air pollution also causes air pollution. The greenhouse gases, such as carbon dioxide [CO<sub>2</sub>] and methane [CH<sub>4</sub>] trap the heat radiated from earth. This leads to an increase in earth temperature. Some toxic metals and pesticides also cause air pollution. Human beings become victims of various water borne diseases, such as typhoid, cholera, dysentery, jaundice etc. The presence of acids/alkalizes in water destroys the microorganisms, thereby hindering the self – purification process in the rivers or water bodies. Agriculture is affected badly due to polluted water; marine eco-systems are affected adversely. The sewage waste promotes growth of phytoplankton in water bodies, causing reduction of dissolved oxygen. Poisonous industrial wastes present in water bodies affect the fish population and deprives us of one of our sources of food. It also kills other animals living in fresh water.

### 2.2 Health Impacts of Air Pollution

Air pollution is a major environmental health problem affecting the developing and the developed countries alike. The effects of air pollution on health are very complex as there are many different sources and their individual effects vary from one to the other. It is not only the ambient air quality in the cities but also the indoor air quality in the rural and the urban areas that are causing concern. In fact in the developing world the highest air pollution exposures occur in the indoor environment

Some of these gases can seriously and adversely affect the health of the population and should be given due attention by the concerned authority. The gases mentioned below are mainly outdoor air pollutants but some of them can and do occur indoor depending on the source and the circumstances.

Carbon monoxide combines with hemoglobin to decrease the amount of oxygen that enters our blood through our lungs. The binding with other hemo proteins causes changes in the function of the affected organs such as

the brain and the cardiovascular system, and also the developing foetus. It can impair our concentration, slow our reflexes, and make us confused and sleepy. Sulphur dioxide in the air is caused due to the rise in combustion of fossil fuels. It can oxidize and form sulphuric acid mist. SO<sub>2</sub> in the air leads to diseases of the lung and other lung disorders such as wheezing and shortness of breath.

## 2.3 Diseases Caused by Air Pollution

While the most visible consequences of air pollution is smog, the effects of this environmental problem are more devastating than what simply meets the eye. Breathing in these chemicals daily is damaging the body causing serious health problems. Below read about some diseases caused by air pollution.

Although asthma may not be directly caused by air pollution, asthma attacks can be triggered by high levels of air pollution. The health condition asthma can also be caused by air pollution. A pollutant such as sulphur dioxide causes the constriction of smaller airways in the lungs and makes breathing harder even for healthy people. With someone prone to asthma attacks, this constriction can set off a serious and life-threatening attack. In fact, asthma attacks set off by pollutants are one of the largest causes of air pollution related death in Europe and in North America.

## 2.4 Environmental Problem

### 2.4.1 SMOG

Smog is a type of air pollutant. The word "smog" was made in the early 20<sup>th</sup> century as a portmanteau of the words smoke and fog to refer to smoky fog. The word was then intended to refer to what was sometimes known as pea soup fog, a familiar and serious problem in London from the 19<sup>th</sup> century to the middle 20<sup>th</sup> century. This kind of smog is caused by the burning of large amounts of coal within a city; this smog contains soot particles from smoke, sulfur dioxide and other components.

### 2.4.2 Coal

Coal fires, used to heat individual buildings or in a power-producing plant, can emit significant clouds of smoke that contribute to smog.

### 2.4.3 Transportation emissions

Traffic emissions – such as from trucks, buses, and automobiles – also contribute. Airborne by-products from vehicle exhaust systems cause air pollution and are a major ingredient in the creation of smog in some large cities. The major culprits are from transportation sources are carbon monoxide [CO], nitrogen oxides NO and NO<sub>x</sub>, volatile organic compounds, sulphur dioxide and hydrocarbons.

### 2.4.4 Photochemical smog

Photochemical smog was first described in the 1950s. It is the chemical reaction of sunlight, nitrogen oxides and volatile organic compounds in the atmosphere, which leaves airborne particles and ground-level ozone. This noxious mixture of air pollutants can include the following aldehydes, nitrogen oxides, such as nitrogen dioxide, peroxyacyl nitrates, tropospheric ozone, volatile organic compounds. All of these harsh chemicals are usually highly reactive and oxidizing. Photochemical smog is therefore considered to be a problem of modern industrialization.

### 2.4.5 Natural causes

An erupting volcano can also emit high levels of sulphur dioxide along with a large quantity of particulate matter; two key components to the creation of smog. However, the smog created as a result of a volcanic eruption is often known as vogueto distinguish it as a natural occurrence. The radiocarbon content of some plant life has been linked to the distribution of smog in some areas. According to a study published in The Lancet, even a very small (5 µg) change in PM2.5 exposure was associated with an increase (18%) in risk of a low birth weight at delivery, and this relationship held even below the current accepted safe levels.

## 2.4.6 Ozone depletion

The Earth's ozone layer is mainly found in the lower portion of the stratosphere from approximately 20 to 30 kilometers above Earth. Ozone depletion describes two distinct but related phenomena observed since the late 1970s: a steady decline of about 4% per decade in the total volume of ozone in Earth's stratosphere (the ozone layer), and a much larger springtime decrease in stratospheric ozone over Earth's polar region. The latter phenomenon is referred to as the ozone hole. In addition to these well-known stratospheric phenomena, there are also springtime polar troposphere ozone depletion events. The details of polar ozone hole formation differ from that of mid-latitude thinning but the most important process in both is catalytic destruction of ozone by atomic halogens. The main source of these halogen atoms in the stratosphere is photo dissociation of man-made halocarbon refrigerants, solvents, propellants, and foam-blowing agents [CFCs, HCFCs, freons, halons].

## III. METHODOLOGY

### 3.1 Removal of Particles from Gas Streams

Particulate removal devices operate basically on the principle that a gas stream containing particles is passed through a region where the particles are acted on by external forces or caused to intercept obstacles, thereby separating them from the gas stream. When acted upon by external forces, the particles acquire a velocity component in a direction different from that of the gas stream.

### 3.2 Collection Efficiency

We define the collection efficiency  $\eta[D_p]$  of a device for particles of diameter  $D_p$  as

$$\eta[D_p] = 1 - \frac{\text{number of particles of diameter } D_p \text{ per m}^3 \text{ of gas out}}{\text{number of particles of diameter } D_p \text{ per m}^3 \text{ of gas in}}$$

The overall efficiency of the device based on particle number is

$$\eta = 1 - \frac{\text{number of particles per m}^3 \text{ of gas out}}{\text{number of particles per m}^3 \text{ of gas in}}$$

These efficiencies can be expressed in terms of the particle size distribution functions at the inlet and outlet sides of the device,

$$\eta[D_p] = 1 - \frac{\eta_{out} D_p}{\eta_{in} D_p}$$

Let us consider relationship between collection efficiency and particle size simply the collection efficiency. Other terms that are used for this quantity are the grade efficiency or the fractional efficiency. An important point on the collection efficiency curve is the size for which  $\eta = 0.5$ . The particle size at this point is called the cut size or the cut diameter

### 3.3 Settling Chambers

Gravitational settling is perhaps the most obvious means of separating particles from a flowing gas stream. A settling chamber is, in principle, simply a large box through which the effluent gas stream flows and in which particles in the stream settle to the floor by gravity. Gas velocities through a settling chamber must be kept low enough so that settling particles are not retained. The gas velocity is usually reduced by expanding the ducting into a chamber large enough so that sufficiently low velocities result. Although in principle settling chambers could be used to remove even the smallest particles, practical limitations in the length of such chambers restrict their applicability to the removal of particles larger than about 50  $\mu\text{m}$ .

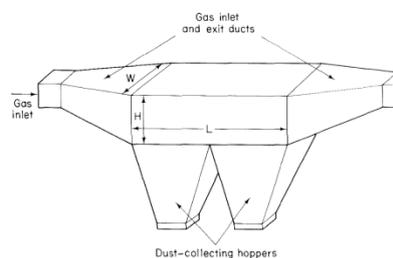


Fig. 1 Settling Chamber

### 3.4 Cyclone Separators

Cyclone separators are gas cleaning devices that utilize the centrifugal force created by a spinning gas stream to separate particles from a gas. A standard tangential inlet vertical reverse flow cyclone separator is shown in fig (1). The gas flow is forced to follow the curved geometry of the cyclone while the inertia of particles in the flow causes them to move toward the outer wall, where they collide and are collected. A particle of mass  $m_p$  moving in a circular path of radius  $r$  with a tangential velocity  $v_0$  is acted on by centrifugal force of  $m_p v_0^2 / r$ . At a typical value of  $V_0 = 10 \text{ m s}^{-1}$ ,  $r = 0.5 \text{ m}$ , this force is 20.4 times that of gravity on the same particle.

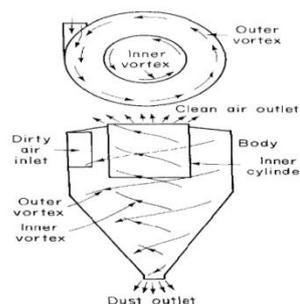
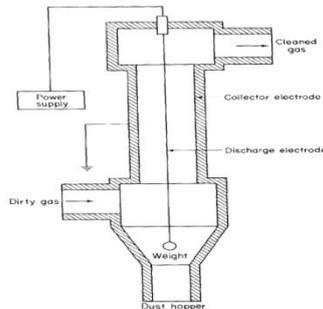


Fig. 2 Tangential inlet vertical reverse flow cyclone

### 3.5 Electrostatic Precipitation

Electrostatic precipitators are one of the most widely used particulate control devices, ranging in size from those installed to clean the flue gases from the largest power plants to those used as small household air cleaners. The basic principle of operation of the electrostatic precipitator is that particles are charged, and then an electric field is imposed on the region through which the particle-laden gas is flowing, exerting an attractive force on the particles and causing them to migrate to the oppositely charged electrode at right angles to the direction of gas

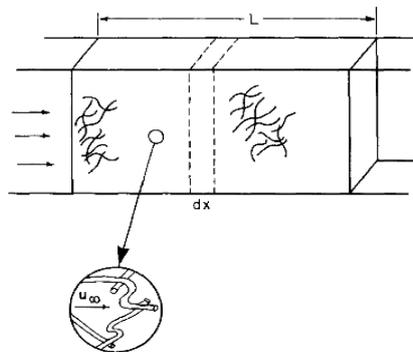
flow. Fig.(3) shows a cylindrical singlestage electrostatic precipitator. A wire serving as the discharge electrode is suspended down the axis of a tube and held in place by a weight attached at the bottom. The sides of the cylinder form the collecting electrode. The collected particles which form a layer on the collecting electrode are removed to the dust hopper by rapping the collecting electrode.



**Fig.3 Cylindrical single-stage electrostatic precipitator**

### 3.6 Collection Efficiency of a Fibrous Filter Bed

A fibrous filter bed is viewed as a loosely packed assemblage of single cylinders. Even though the fibres are oriented in all directions in the bed, from a theoretical point of view the bed is treated as if every fibre is normal to the gas flow through the bed. Since, as we have noted, the solid fraction of the filter,  $\alpha$ , is generally the order of only 10%, we assume, in addition, that each fibre acts more or less independently as a collector. Thus, to compute the particle removal by a filter bed, we basically need to determine the number of fibres per unit volume of the bed and then multiply that quantity by the efficiency of a single fibre.



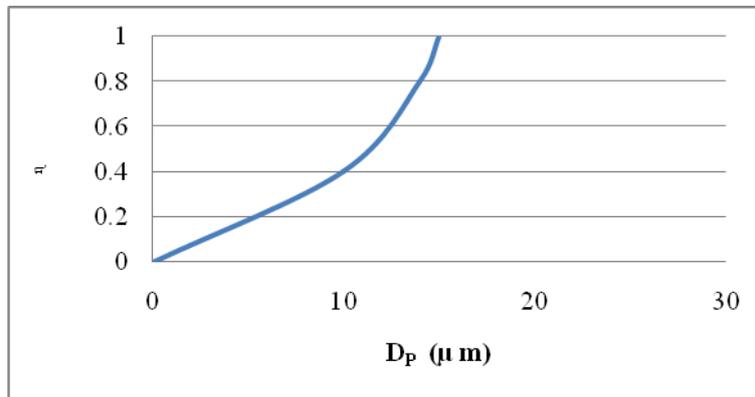
**Fig. 4 Filter bed composed of an assemblage of single fibers**

### 3.7 Wet Collectors

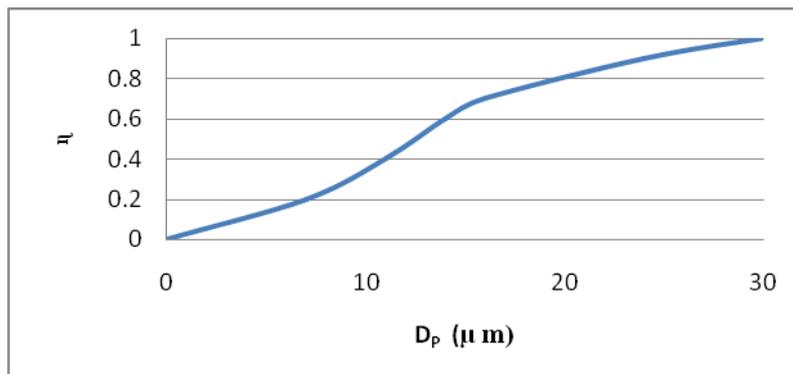
Wet collectors, or scrubbers, employ water washing to remove particles directly from gas stream.

## IV. RESULT AND DISCUSSION

### 4.1 Cyclone Collection Efficiency



**Fig. 5** Cyclone efficiency of laminar flow particle as the particle size increases the efficiency also increases so it can be said that efficiency is a function of particle size



**Fig.6** Cyclone efficiency of turbulent flow particle

The dirty gas enters at the top of the cyclone and is given a spinning motion because of its tangential entry. Particles are forced to the wall by centrifugal force and then fall down the wall due to gravity. At the bottom of the cyclone the gas flow reverses to form an inner core that leaves at the top of the unit. In a reverse-flow axial-inlet cyclone, the inlet gas is introduced down the axis of the cyclone, with centrifugal motion being imparted by permanent vanes at the top.

### 4.2 Efficiency of Electrostatic Precipitator

Overall efficiency of the electrostatic precipitator as a function of precipitator particle when particle size is kept constant and graph is drawn efficiency increases with increase in particle size .hence it can be concluded that the efficiency of ESP increases in particle size, and also Overall efficiency of the electrostatic precipitator as a function of precipitator length. When particle length is kept constant and graph is drawn efficiency increases with increase in particle length .hence it can be concluded that the efficiency of ESP increases with increase in particle length.

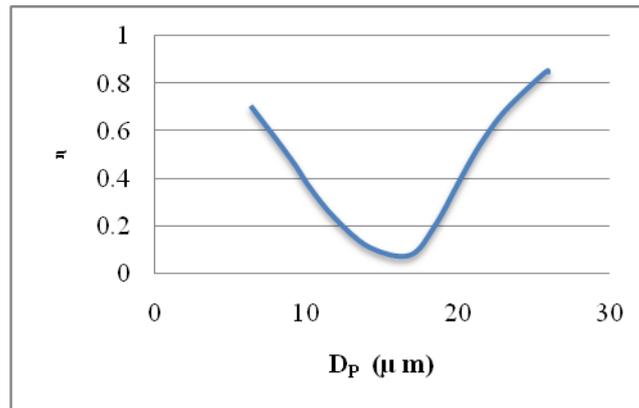


Fig. 7 Overall efficiency of the electrostatic precipitator

### 4.3 Efficiency Comparison

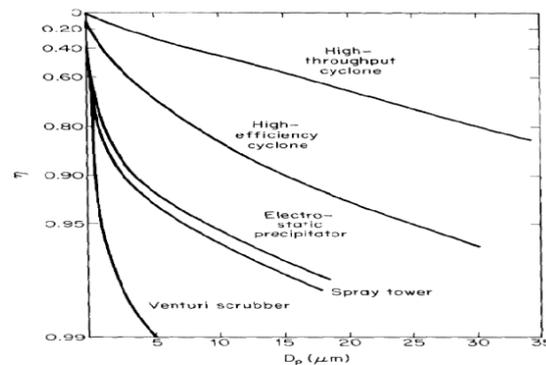


Fig. 8 Comparison of efficiencies

Collection efficiencies for gas cleaning devices hence from graph it is clear that venturi scrubber has highest efficiency of all due to high relative velocity of particle collect on the electrode. If the particles collected are liquid, then the liquid flows down the electrode by gravity and is removed at the bottom of the device. If the particles are solid, the collected layer on the electrode is removed periodically by rapping the electrode. Particle charging is achieved by generating ions by means of a corona established surrounding a highly charged electrode like a wire. The electric field is applied between that electrode and the collecting electrode this is the reason why the ESP's higher efficiency as shown in fig. (8).

### V. CONCLUSIONS

In this paper it is observed that gravitational settler can be used to separate the particles size greater than  $50 \mu\text{m}$  with efficiency more than 50%. It offers low pressure loss but requires much space. Cyclone separators are used with particle size in between  $5-25 \mu\text{m}$  with efficiency in between 50-90%. Wet collectors, spray towers are used to separate particles sizes varying in between  $2.5-10 \mu\text{m}$  with efficiency in between 80-99%. Electrostatic precipitator can be used to separate particles sizes less than  $1 \mu\text{m}$  with efficiency in between 95-99%. Fabric filtration are found to be most effective which can be used separate particles sizes less than  $1 \mu\text{m}$  with efficiency more than 99%.

The methods of dust separator discussed in this thesis are general and traditional methods and are used in most of the power plant methods can be found out and are very costly some other methods can be studied which are more cost effective and efficient. Methods of controlling pollution in thermal power plant are discussed in this thesis other methods used for controlling pollution can be future discussed like method used to control radioactive waste in nuclear power plant, method used to reduce pollution in manufacturing industry and the method used to reduce pollution in vehicle.

## REFERENCES

- [1]. Air pollution and infant health: Lessons from New Jersey Janet Currie\*, Matthew Neidell, Johannes F. Schmieder, *Journal of Health Economics* 28 (2009) 688–703
- [2]. Allison, Paul, 1982. Discrete-time methods for the analysis of event histories. *Sociological Methodology* XII, 61–98.
- [3]. Almond, Douglas, Kenneth, Chay, David Lee, 2005. The cost of low birth weight. *Quarterly Journal of Economics* 121, 1031.
- [4]. Basu, R., Woodruff, T.J., Parker, J.D., Saulnier, L., Schoendorf, K.C., 2004. Comparing exposure metrics in the relationship between Pm2 5 and birth weight in California. *Journal of Exposure Analysis and Environmental Epidemiology* 14 (5), 391–396.
- [5]. Barringer, Felicity, 2008. California sues EPA over denial of waiver. *The New York Times*, January 3. Bell, M., Ebisu, K., Belanger, K., 2007.
- [6]. Brauer, M., Lencar, C., Tamburic, L., Koehoorn, M., Demers, P., Karr, C., 2008. A cohort study of traffic-related air pollution impacts on birth outcomes. *Environmental Health Perspectives* 116 (5), 680–686.
- [7]. Chen, L., Yang, W., Jennison, B.L., Goodrich, A., Omaye, S.T., 2002. Air pollution and birth weight in northern Nevada 1991–1999. *Inhalation Toxicology* 14 (2), 141–157
- [8]. Wichmann HE, Mueller W, Allhoff P, et al. Health effects during a smog episode in West Germany in 1985. *Environ Health Perspect.* 1989;79:89–99.
- [9]. Keil U, Stieber J, Döring A, et al. The cardiovascular risk factor profile in the study area Augsburg: results from the first MONICA survey 1984/ 85. *Acta Med Scand Suppl.* 1988;728:119–128.
- [10]. Peters A, Döring A, Wichmann HE, Koenig W. Increased plasma viscosity during an air pollution episode: a link to mortality? *Lancet.* 1997; 349:1582–1587.