

Chapter Two: Air pollution

Air pollution

Air pollution can be defined as a substance or substances (gaseous, liquid, or solid) released in to the ambient air by human being and it is not a part of atmosphere or its concentration is higher than the nature level for a sufficient time which affects the life of human, plant and animal condition life or the property in short term or long term and consequently cause environmental damages.

Air pollutions perspective

Air pollution may occur on three scales related to public health; micro ,meso and macro. Indoor air pollution results from products used in construction materials, inadequacy of general ventilation, and geophysical factors that may result in exposure to naturally occurring radioactive materials. Industrial and mobile sources contribute to **meso-scale** air pollutant that contaminates the ambient air that surrounding us outdoors.

Macro-scale effects include transport of ambient air pollution over large distances (countries to states, and nations) and global impact. Examples of Macro-scale impacts include acid rain and ozone pollution. Global impacts of air pollutions result from sources that may potentially change the upper atmosphere. Examples include depletion of the ozone layer and global warming. While Micro and Macro- scale effects are of concern, our focus will predominately be on meso-scale air pollution (few hectares up to size of a city and country boundaries).

Classification of Pollutants

Air pollutants are plenty; each one has its own special characteristics. Based on that, pollutants have to be classified by some criteria. The classification permits to study these pollutants in subgroups and makes on the basis of some characteristic of interest or concern and also provides an ordering which makes air pollution control programs easier, so the classification of air pollutants may be done based on:

1. Pollutants exposure into the atmosphere.
2. The physical characteristics of the pollutant.
3. The chemical molecular composition of the pollutants.

1- Pollutants exposure into the atmosphere.

This classification contains two categories:

- **Primary pollutants**

The pollutant emits directly to the air and produced as a result of combustion of fuels and production of industrial sector and vehicles producing carbon components.

- **Secondary pollutants.**

Secondary pollutants produced due to reaction of primary pollutants in the air. Some of this reaction needs the solar energy through a process called photochemical. An example for this reaction is Ozone formation from nitrous components in the presence of sunlight.

2- Physical characteristics of the pollutant.

This classification contains two categories:

- **gaseous**

Most air pollutants are existing in gaseous state (90%) and they act like air and do not settle or condense over long term period and transported by wind.

- **Particulate.**

Particulate pollutants are presence in the form of fine solids or liquids. They settled down quickly and affect lives and property near the source. The lighter and finer particles moving away from the origin of emissions place.

3- Chemical molecular composition of the pollutants.

This classification contains two categories:

- **Organic**

Organic pollutants contain carbon and hydrogen and its components.

- **Inorganic.**

Most of encountered pollutants are inorganic which they are pollutants do not contain carbon components excluding carbon oxides, like CO and CO₂, and carbon disulfide.

4- The effect of the pollutant on the health and the environment.

4.1- Effect of human Health

- Most sources of air pollution include carbon Dioxide, ozone, nitrogen dioxide, sulfur dioxide and particulate matter. WHO states 2.4 million people die each year from causes of air polluted components. Causes of illness associated with air pollutant are:

- a- Respiratory system
- b- Difficulty in breathing, wheezing, coughing.
- c- Cardiac diseases.
- d- Irritation of the eyes.

4.2-Effect on plants

Air pollutants stand a barrier against growing the plant especially Ozone injures the cells of the chloroplast condensed and the cell walls collapses.

4.3- Effects on animals

Studies showed fluorides have caused crippling skeletal damage to cattle in areas where fluoride fall out or absorbed by plants. Also poisoning associated with Ozone, photochemical oxidants, and lead pollutants recorded.

4.4- Effects on Economy

Economic losses are associated with

- a- Air pollutant effect on properties, equipment's.
- b- Sulfur pollution attacks Copper and Zink coatings.
- c- Cloth fabric weakened.
- d- Corrosion of Paints, arts
- e- Cleaning needs to remove erosion, dusts from building, vehicles and properties.

4.5- Effects on Climate

- a- Reduces the common visibility.
- b- Reducing the amount of solar radiation (lightening).
- c- Variation of the climate, rainfall disturbance due to global warming.

Air pollution sources

Air pollution might be:

1. Fuel combustion (exhaust emission of vehicles)
2. Smoke from a chimney and cigarettes.
3. Fly ash from Power plant.
4. Dusts from road usage and desert storms.
5. Smoke from eruption of Volcanoes.
6. Smoke results from forest fire and burning sold wastes disposal.

The Atmosphere composition

Atmosphere is one of the four components of the Earth's ecosystem (the other three are biosphere, hydrosphere, and lithosphere), it is a mixture of gases covers the Earth's surface. 99% of its mass is concentrated in the attitude of 20 miles from the earth's surface. The majority of the gases percentage is nitrogen (about 78%) and oxygen (about 21%). The remained 1% includes argon, carbon, helium, methane, neon, sulfur dioxide, water vapor, and xenon.

Atmosphere strata

1- Troposphere layer

- It is the first layer tangent to the Earth's surface with height 16km.
- Contain 75% of total air volume of the Atmosphere.
- The temperature is decreases with an average of 6.5° for each 1000 m
- There is air movement due to the changes in the Earth's surface temperature and different pressure layers.
- Sunlight penetrates this layer to warm the ground and water surfaces.
- This layer is ended in the boundary called tropopause when the temperature is started to increase.

The cold session in this layer serves the environmental to be stable as the water cannot vapor only in a very small amount which is not noticeable (5ppm)

2- Stratosphere layer

- Thickness of this layer extends up to 50km
- It is associated with non-movement of the air and very few water evaporation and Ozone layers are increases but with lower concentration.
- Reason of increasing the temperature is the absorption of ultraviolet rays to form Ozone. The temperature reaches 270°
- This layer is ended in the boundary called by stratopause and the temperature starts to decrease.

3- Mesosphere layer

- Starts at altitude 50km up to 80 km.
- The temperature starts to decrease and reaches 270° .at upper boundary
- No water exists in this layer, only Ozone.
- The density of air is serves reactions to form photochemical process.
- This layer is ended in the boundary called by mesopause and the temperature starts to decrease.

4- Thermosphere layer

- This layer is overlying the mesopause extend to 1000km.
- The temperature increases significantly (1000° C at altitude 1000km) due to breaking the gases molecules by universal rays and the energy converted to heat.

Height Km

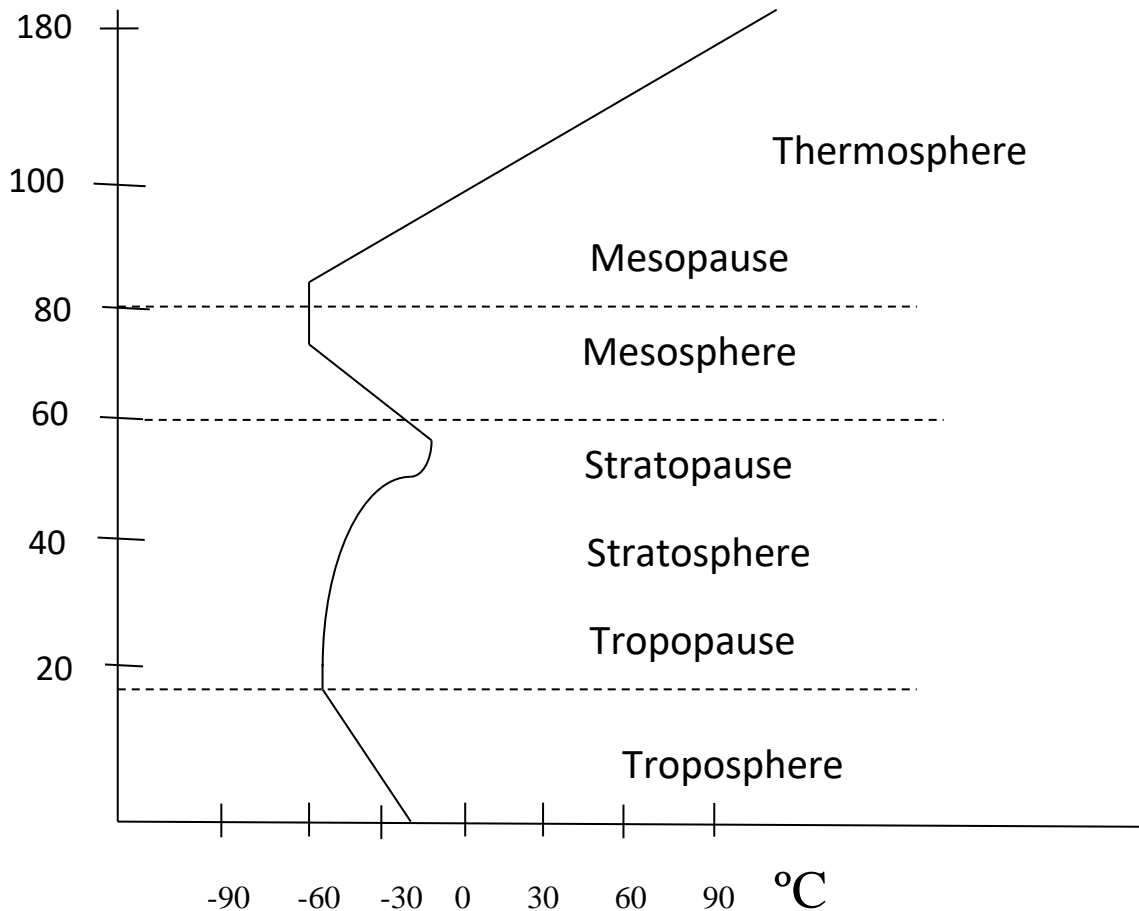


Fig.1 Temperature and atmosphere profile

Air pollutions standards

Environmental Protection Agency (EPA) established the national Ambient Air Quality standards (NAAQS) for the outdoor air that normally surrounding us (see Table 1). EPA calls pollutants listed in Table 1 *criteria pollutants* because they were developed on health-based criteria.

Criteria air pollutants is a term used internationally to describe air pollutants that have been regulated and are used as indicators of air quality and categorized in six contexts as below:

1. Carbon monoxide
2. Nitrogen oxides
3. Ozone
4. Sulfur dioxide
5. Particles
6. Lead

EPA established regulations for hazardous air pollutants (HAPs) using a risk-based approach. Also EPA established a HAPs emissions control program based on technology for 189 chemicals in 1990 (see page 26, text book "Introduction to EE by Macenzie et al 2008) and subsequently modified As of July 2005 there were 188 HAPs.

Table-1: National Air Ambient Quality Standards (NAAQS)

Criteria Pollutant	Standard type	Concentration		Average period or method	Allowable exceedances ^a
		$\mu\text{g}/\text{m}^3$	ppm		
CO	Primary	10,000	9	8-hour average	once per year
	Primary	40,000	35	1-hour average	once per year
Lead	primary and Secondary	1.5	N/A	Maximum arithmetic mean measured over a calendar quarter	
NO ₂	Primary and Secondary	100	0.053	Annual arithmetic mean	
Ozone	Primary and Secondary	235	0.012	Maximum hourly average ^b	once per year
Ozone	Primary and Secondary	157	0.08	8-hours average	^c
Particulate matter (PM ₁₀) ^d	Primary and Secondary	150	N/A	24- hourly average	one day per year
	Primary and Secondary	50	N/A	Annual arithmetic mean	^e
(PM _{2.5})	Primary and Secondary	65	N/A	24- hourly average	^e
		15	N/A	Annual arithmetic mean	^{f,g}
SO ₂	Primary	80	0.03	Annual arithmetic mean	once per year
	Primary	365	0.14	Maximum 24-hours concentration	
SO ₂	Secondary	1.300	0.5	Maximum 3-hours Concentration	once per year

^a Allowable exceedances may actually be an average value over a multi-year period.

^b The 1-hour NAAQS will no longer apply to an area one year after the effective date of the designation of that area for 8-hour ozone NAAQS. For most areas, the date of designation was June 2004.

^c Average fourth highest concentration over 3-year period.

^d Particulate matter standard applies to particles with an aerodynamic diameter $\leq 10 \mu\text{m}$.

^e Three-year average of 98th percentile 24-hour concentration.

^f Three-year average of weighted annual mean.

^g EPA has proposed to lower the daily average PM_{2.5} to $35 \mu\text{g}/\text{m}^3$ while leaving the existing annual standard unchanged at $15 \mu\text{g}/\text{m}^3$. The clean Air scientific Advisory (CASAC) recommended that the annual average standard be set between $13 \mu\text{g}/\text{m}^3$ and $14 \mu\text{g}/\text{m}^3$ and that 24-hour standard be set between $30 \mu\text{g}/\text{m}^3$ to $35 \mu\text{g}/\text{m}^3$. The final rule will be issued by September 2006).

For a fixed amount of an ideal gas kept at a fixed temperature, pressure and volume are inversely proportional.^[3]

is constant. For comparing the same substance under two different sets of condition, the law can be usefully expressed as

$$P_1V_1 = P_2V_2.$$

This law describes how a gas expands as the temperature increases; conversely, a decrease in temperature will lead to a decrease in volume. For comparing the same substance under two different sets of conditions, the law can be written as:

$$\frac{V_1}{T_1} = \frac{V_2}{T_2} \quad \text{or} \quad \frac{V_2}{V_1} = \frac{T_2}{T_1} \quad \text{or} \quad V_1T_2 = V_2T_1.$$

Units of Measure

The three basic units of measures used in reporting air pollution data are:

1. micrograms per cubic meters ($\mu\text{g}/\text{m}^3$) for measuring concentration
2. Parts per million (ppm) for measuring concentration.
3. Micrometer (μm) for particle size.

Converting ($\mu\text{g}/\text{m}^3$), ppm

ppm is a volume ratio, we may write

$$\text{ppm} = \frac{V_p}{V_a}$$

To determine the value of V_p

The conversion between ($\mu\text{g}/\text{m}^3$) and ppm is based on the fact that at standard conditions ($T=273^\circ$ Kelvin and $P= 101.325$ KPa). From Universal gaseous law:

$$P \times V_p = n \times R \times T,$$

n number of Moles of molecules, R gas constants $8.314 \text{ JK}^{-1} \text{ mol}^{-1}$, V_p Volume of pollutant m^3

$$V_p = \frac{nRT}{P}$$

$$n = \frac{(M_p)mass\ in(gm)}{(GMW)Molar\ mass\ (gm.mole)}$$

$$V_p = \frac{M_p}{p} \times RT, \text{ For standard conditions (273° Kelvin and 101.325 KPa) and R gas constants } 8.314\ J/K$$

$$V_p = \left\{ \frac{M_p(gm)}{GMW} \right\} \times 22.414\ L/gm \dots\dots\dots (1-0)$$

GMW is the gram molecular weight of the pollutant. For readings made at temperatures and pressures other than standard conditions, the standard volume, 22.414L/gm must be corrected. We use the ideal gas law to make the correction.

$$22.414L/gm \times \frac{T_2}{273\ K} \times \frac{101.325\ KPa}{P_2} \dots\dots\dots (1-1)$$

Where T_2 and P_2 are the absolute temperature and absolute pressure at which the readings were made.

Since ppm is a volume ratio, we may write

$$ppm = \frac{V_p}{V_a} \dots\dots\dots (1-2)$$

Where V_a is the volume of air in cubic meters at the temperature and pressure of the reading. We then combine Equations (1-0), (1-1) and (1-2) to form Equation (1-3)

$$ppm = \frac{M_p}{GMW} \times 22.414 \times \frac{T_2}{273K} \times \frac{101.325KPa}{P_2} \dots\dots\dots(1-3)$$

Where M_p is in μg . The factors converting μg to g and L to millions of L cancel one another. Unless otherwise stated, it is assumed that $V_a = 1.00\ m^3$.

Abbreviation:

- M_p is Mass of pollutants (μg)
- n number of Moles of molecules
- R_{gas} constants $8.314 \text{ JK}^{-1} \text{ mol}^{-1}$
- GMW is gram Molecular weight of the pollutant
- T_2 is absolute temperatures (k) in Kelvin { $K = C + 273$ }
- P_2 is absolute pressure (KPa)
- $\forall a$ is assum

Example;

A one-cubic-meter sample of air was found to contain $80 \mu\text{g}/\text{m}^3$ of SO_2 . The temperature and pressure were 25°C and 103.193 KPa when the air sample was taken.

What was the SO_2 concentration in ppm?

Solution:

First we must determine the GMW of SO_2 . From the chart (inside front cover, text book "Introduction to EE by Macenzie et al 2008), and

$$1. \quad \text{Find GMW of } \text{SO}_2 = 32.07 + 2(16.00) \\ = 64.07$$

$$2. \quad \text{We must convert the temperature to absolute temperature. Thus,} \\ 25^\circ + 273 \text{ K} = 298^\circ \text{ K.}$$

$$3. \quad \text{Use equation (1-3) to find ppm value}$$

$$\text{ppm} = \frac{\frac{M_p}{\text{GMW}} \times 22.414 \times \frac{T_2}{273\text{K}} \times \frac{101.325\text{KPa}}{P_2}}{\forall a \times 1000\text{L}/\text{m}^3}$$

$$\text{ppm} = \frac{\frac{80 \mu\text{g}}{64.07} \times 22.414 \times \frac{298}{273} \times \frac{101.325}{103.193}}{1.00\text{m}^3 \times 1000\text{L}/\text{m}^3}$$

$$= 0.03 \text{ ppm of } \text{SO}_2$$

Main air pollutants

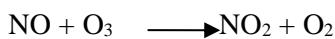
1. Carbon monoxide CO (inorganic gaseous)

Carbon monoxide is a colorless, odourless and tasteless gas that the most abundant of the criteria pollutants and its lethal to humans within few minutes at concentrations exceeding 5,000 ppm.

CO produced rather than CO₂ from incomplete burning of carbon in any based fuels includes petrol, diesel and wood. 70% of CO results from mobile sources especially motor vehicles, also produced from cigarettes. CO reacts with hemoglobin in the blood to form carboxyhemoglobin has a great connection for CO than it does with Oxygen. The effects of CO are very clear on people with heart and chronic pulmonary disease. We should note here that the average concentration of CO inhaled in cigarette smoke is 200 to 400 ppm.

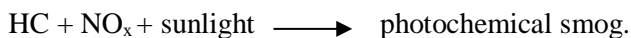
2. Nitrogen oxides- NO_x

Compounds of Nitrogen gaseous include Nitric oxide (NO), Nitrogen dioxide (NO₂), Nitrogen trioxide (NO₃), Nitrous oxide (N₂O), and Nitrogen pentoxide (N₂O₅). Also several types of Nitrogen acids include Nitrous acid (HNO₂) and Nitric acid(HNO₃).Nitrogen compounds are produced from combustion of fossil fuels, oil, coal, timber.Most of NO_x emissions are in the form of NO which rapidly converts to NO₂ in the presence of O₂or O₃as shown below:



NO is heavier than air and it is soluble in the water.

Furthermore, NO₂ react with organic compounds to produce Acetyl Nitrates (PAN) or with hydrocarbons (HC) in the presence of sunlight to produce smog.



Exposure to NO₂ is reddish brown in concentrated form and gives a brownish yellow tint in at lower concentrations. At 5 ppm it has a strong sweetish odor and if exposure to 5 ppm for 15 minutes results in cough and irritation of the respiratory tract. The average NO₂ concentration in tobacco smoke is approximately 5ppm.

Example

Compute the annual production of NO₂ from 210000 vehicles in a certain city, the emission of NO₂ rate is 2.2 g/km per vehicles. Assume the annual travel is 24000 km per vehicles.

Solution

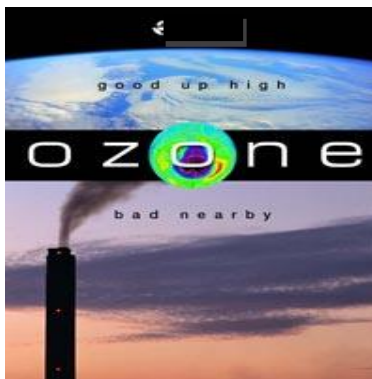
$$\text{Each vehicle produces } \frac{24000}{1000} \times 2.2 = 52.8 \text{ kgNO}_2$$

$$\text{For 210,000 vehicles } 52.8 \text{ kg} \times \frac{210000}{1000} = 11088 \text{ tonesNO}_2$$

3 – Ozone – O₃

However Ozone is classified as secondary pollutant, it is also considered as a “criteria pollutant” because of its association with urban smog. As a result of serious reaction occurs Ozone produced from Nitrogen oxides and various hydrocarbons in the presence of sunlight in a process called (photochemical oxidants).

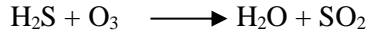
While ozone in the stratosphere protects earth from harmful UV radiation, ozone on the ground is hazardous to human health. Ground-level ozone is formed when vehicle emissions containing nitrogen oxides (primarily from vehicle exhaust) and volatile organic compounds (from paints, solvents, and fuel evaporation) interact in the presence of sunlight. The irradiation of air containing hydrocarbons and oxides of Nitrogen leads to oxidation of NO to NO₂, oxidation of HCs and formation of O₃. The presence of Ozone in the Stratosphere provides a barrier to ultraviolet (UV) radiation but when reaches lower atmosphere (troposphere) in terms of chemical reaction production it is considered lethal for human. Ozone can irritate the lining of the nose, airways and lungs, associated with pains in eyes, ears, and throat cough and throat.

**4 – Sulfur dioxide – SO₂**

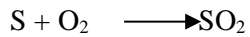
Sulfur dioxides may be both primary and secondary pollutants. Power plants, industry, volcanoes, and oceans emit SO₂, SO₃, and SO₄ directly as primary pollutants. In addition, biological decay process and some industrial sources emit H₂S which is oxidized to form secondary pollutants SO₂. 99%, of SO₂ in air comes from human through

combustion of fuel and industrial activities. SO₂ is invisible and has a nasty, sharp smell and affects the health through pains in eyes, ears, and throat cough and throat. Its affect are appears within 15 minutes of exposure.

The most important oxidizing reaction for H₂S appears to be one involving ozone:



The combustion of fossil fuels containing sulfur yields sulfur dioxide in direct proportion to the sulfur content of the fuel:



In generally it is assumed 5% of the sulfur in the fuel goes up in the ash.

Example

A certain coal is burned at a rate of 50 kg/min, if the analysis of the coal shows sulfur content of 2.5%, what is the annual rate of emission of SO₂, if 5% of the sulfur in the fuel goes up in the ash?

Solution

$$S_{in} = 50 \text{ kg/min} \times \frac{2.5}{100} = 1.25 \text{ kg/min}$$

For one year

$$S_{in} = 1.25 \times 60 \times 24 \times 365 = 65,7000 \text{ kg/year}$$

Since 5% in the input goes up to the ash, so

$$S_{ash} = S_{in} \times 0.05$$

$$S_{ash} = 65,7000 \times 0.05 = 32,850 \text{ kg/year}$$

$$S_{SO_2} = S_{in} - S_{ash}$$

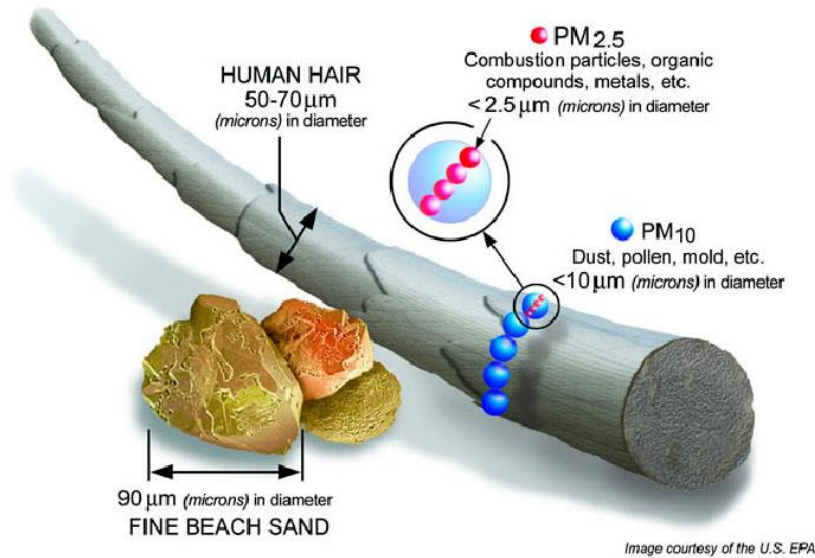
$$S_{SO_2} = 65,7000 - 32,850$$

$$S_{SO_2} = 62,415 \text{ kg/year.}$$

5 – Particles

Particles include dust, dirt, smoke, soot, ... etc. Some particles are large enough or dark to be seen as soot or smoke, while others are so small they can only be detected by microscope.

Particle can be generated and emitted in to ambient air directly in nature like in volcano eruptions, dust storm and from man-made activities includes vehicles emissions and industrial processes)electrical generation, incinerators and stone crushing).



6 – Lead

Volcanic activities and airborne soil are the primary natural sources of atmosphere lead. Smelters and refining processes, as well as incineration of lead-containing wastes, are major point sources of lead, also recycling of batteries and paints contain lead also considered one of the point sources. Approximately 70 to 80 percentage of the lead that used to be added to gasoline was discharged to the atmosphere. Lead is a soft metal that is found in air in the form of very small particles. The allowable percentage of lead is $0.1 \mu\text{g}/\text{m}^3$.

It is very important to take into consideration not to use paints with lead-based paint in the renovation of old houses which contribute in the indoor pollutant can be a significant source of lead indoors. People can absorb lead during storm outbreak and swallowed through breathing which causes pain in Muscles and Joints.

7- Volatile organic compounds-VOCs

VOCs- are organic chemicals that can vapor at room-temperature conditions due to a low boiling point, which causes large numbers of molecules to evaporate or sublime from the liquid or solid form of the compound and enter the surrounding air. An example is formaldehyde, with a boiling point of $-19\text{ }^\circ\text{C}$ ($-2\text{ }^\circ\text{F}$), gradually exiting from (paint varnishes, and wax) contents and spread out into the air. VOCs- include ethylene oxide, phenol, benzene, carbon tetrachloride. Many are precursors for photochemical oxidants and react with NO_x and O_2 with sunlight to produce smog and aerosol pollution. It was found that the concentrations of many VOCs are significantly higher indoors

(up to ten times higher) than outdoors. VOCs causes eye, nose, and throat irritation; headaches, loss of concentration, nausea; damage to liver, kidney, and central nervous system.

8 – Hydrocarbons-HCs

Hydrocarbons are one of VOC species emission. They are organic compounds present in the atmosphere as a trace gas and contain only carbon and hydrogen typically in the petroleum products. HCs play very important role in the reactive condition in the troposphere layer in terms of photochemical air pollutant and it is clear in formation of ozone. Among HCs methane take a somewhat special position due to high ambient mixing ratio. The major man-made hydrocarbons include traffic organic, chemical production, transportation and processing of crude oil and distribution of natural gases.

Example

Compute the HC discharged from a population of 850000 if 164000 vehicles travel 18000 km/annum and emitting 1gm/km. The consumption per capita of oil-based paint is 2 liter/annum and contains 1200gm/liter. The HC per capita from dry cleaning solvent is 750gm/annum.

Solution

1- HC content from vehicles movement:

$$\frac{164,000 \times 18,000 \times 1}{1000000} = 2,952 \text{ tones}$$

2- HC content from paint:

$$\frac{85,0000 \times 2 \times 1,200}{1000000} = 2,040 \text{ tones}$$

3- HC content from solvents:

$$\frac{85,0000 \times 750}{1000000} = 637.5 \text{ tones}$$

Total amount of HC = 2,952 + 2,040 + 637.5 = 5,629.5 tones

$$\frac{5,629.5 \times 1000}{850,000} = 6.623 \frac{kg}{capita} / \text{annual}.$$

9 – Smog

Smog is a type of air pollution; the word "smog" was coined in the early 20th century by Londoners before World War 1 to describe the combination of smoke and fog that account for much of their weather. It produced from the

burning of coal and fuel associated with the availability of sunlight and the presence of fine particles and calm wind. Fog decreases the sight distances due to deducting sunlight radiation. Fog effects on human health especially when it continuing for several days, most side effects are associated with problems in the respiratory system notably those related to bronchial causes.

10 – Fly ash

Fly ash used to describe the particulate matter carried in the effluent gases from furnaces burning fossil fuels. The components of fly ash vary considerably, but all fly ash includes silicon dioxides of iron, calcium, and magnesium and heavy metals like lead, arsenic, cobalt, and copper. Also cement and fuel plants and railways produce fly ash. Fly ash affects on the ground and surface water quality when the ash enters the drainage system and leads to block and clog the trenches. Fly as especially the fine particles will remain and stands suspend in the ambient air leading to serious health problems (respiratory system).

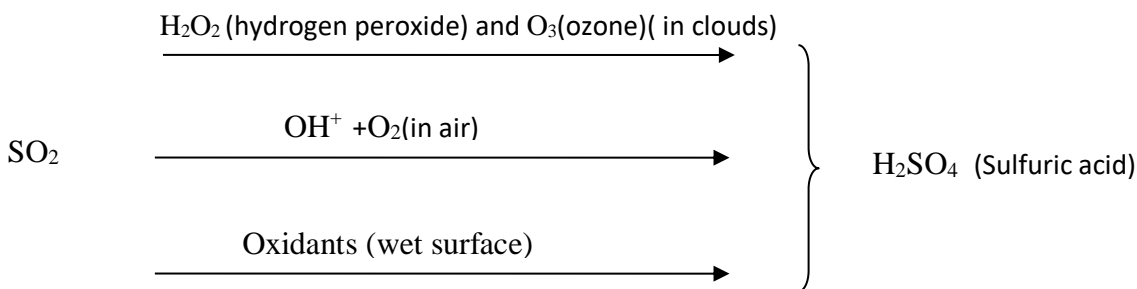
Economically we can benefit from the collected ash in the controlled equipment devices in producing raw materials for manufacturing bricks.

11 – Chlorofluorocarbon-CFC

Chlorofluorocarbons-CFCs (known as Freon) are non-toxic, non-flammable. CFC composed form fluorine atoms, carbon atoms and chlorine atoms. CFCs nowadays involved in different types of daily live materials like refrigeration and air conditioners, as solvents in cleaners, fire extinguishers, and as propellants in aerosols. It is well known the impact of CFS on destruction of ozone layer (ozone depletion) in the stratosphere, the terrible matter is the long lifetime of this gases which stay in the atmosphere about 20 t0 100 years.

Acid rain

Unpolluted rain is naturally acidic because SO₂ and CO₂ from the atmosphere dissolves to a sufficient extent to form carbonic acid. The common PH for rainwater is about 5.6, Chemical reactions in the atmosphere convert VOCs to acidic compounds and associated oxidants. (see Figure 1)



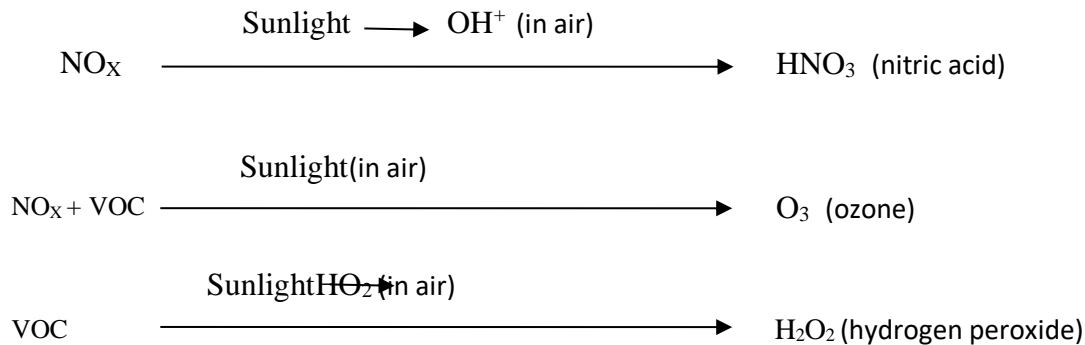


Figure 1 : Acid rain process

Acid rain affects the aquatic life, damage to crops, forests and properties and construction materials and eventually affects human health.

Indoor air pollution

People spend most of time indoor in their residential places than outdoor; especially people who live in urban, cold climates may spend more than 90% time indoors. In last decades the sources, concentrations and impact of air pollutants found which rose from conventional domestic residences. Also it was recognized sometimes indoor polluted more than outdoor. Many of the pollutants are the same one in the outdoor..Many people were died from improper operating of kerosene space heaters and furnace malfunctions as result of carbon monoxide emission. Also the effect of photocopy machines in spreading ozone. Indoor pollutant is varying during summer and winter.

Global climate change-Greenhouse gases

Global warming can be defined as the increasing of the average temperature of Earth's atmosphere year by year its projected continuation. Since the early 20th century, it was recorded that Earth's mean surface temperature has increased by about 0.8 °C (1.4 °F), associated with about two-thirds of this increase occurred after 1980. And it is furcated the average surface temperature is projected to increase by 1.4 to 5.8° C. The reason of this increasing in temperature it is primarily caused by increasing concentrations of greenhouse gases produced by human activities such as the burning of fossil fuels and deforestation, greenhouse gas (GHG) is a gas in an atmosphere that absorbs and emits radiation. GHG are relatively transparent to short-wave ultraviolet light the sun. They absorb and emit long-wave radiation at wavelengths typical of the earth and atmosphere. GHG are much like the glass on a green house(thus, the name green house gases). They let in short-waves (ultraviolet) radiation from the sun that heats the ground surface, but restrict the loss of heat by radiation from the ground surface. The more the GHG in atmosphere, the more effective it is in restricting the outflow of long-waves radiation.This process is the fundamental cause of the greenhouse effect.The primary greenhouse gases in the Earth's atmosphere are water vapour, carbon dioxide,

methane, nitrous oxide, and ozone. CO₂ has been identified as the major GHG because of its abundance and its strong absorption spectrum in the region where the earth emits of its infrared radiation.

Chapter Three: Air Pollution Control

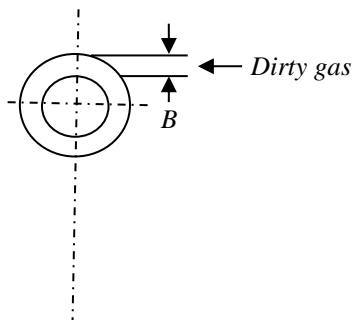
Control technologies selected based on environmental, pollutant type, engineering, and economic factors. The major controlling performance parameters are:

- 1- Particle size, weight, shape, distribution and velocity
- 2- Gas temperature, density and viscosity
- 3- Humidity level, PH and solubility
- 4- System pressure drop and mass transfer condition

1- Particulate pollutions

Cyclones are used for particle sizes diameter greater than 10 μ m. This is an internal collector with no moving parts. The particulate-laden gas is accelerated through a spiral motion, which imparts a centrifugal force to the particles. The particles hurled out of the spinning gas and impacts on the cylinder wall of the cyclone. They then slide to the bottom of the cone. Here they are removed through an airtight valving system. Cyclones are used widely for most types (medium to coarse size) for dust and primary collectors or pre-cleaners before the gas move to finer devices. Another reason for widespread usage of cyclone is low cost effective in terms of capital and operation costs.

The standard single-barrel cyclone will have dimensions proportional as showed in figure 1:



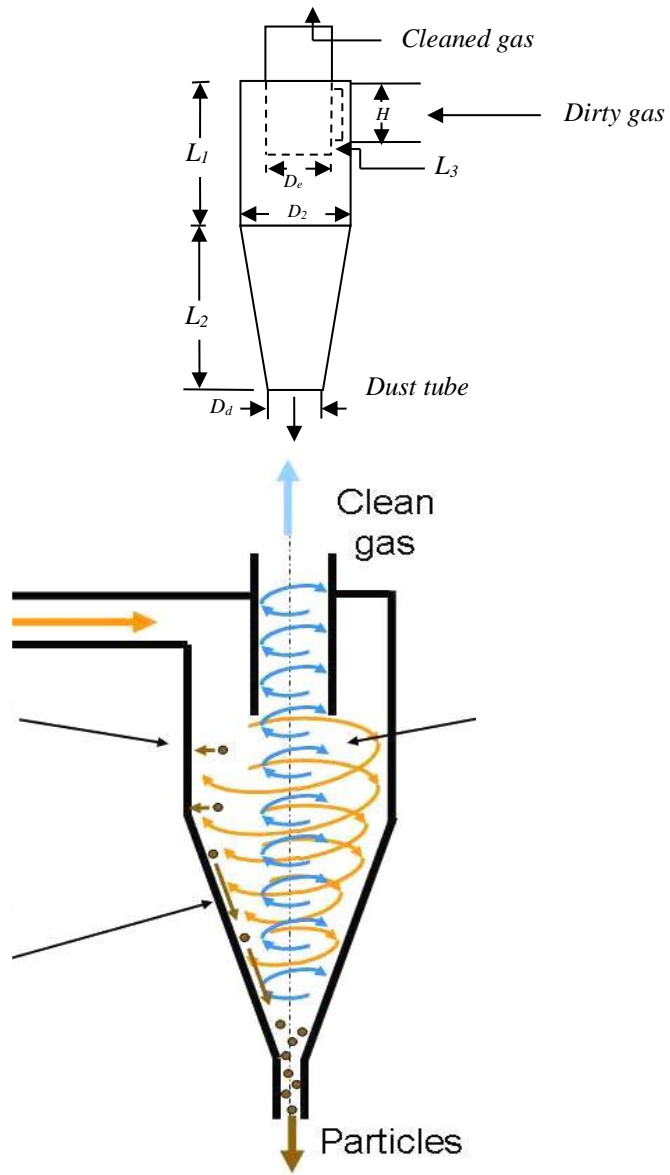


Figure 1 :Standard cyclone properties

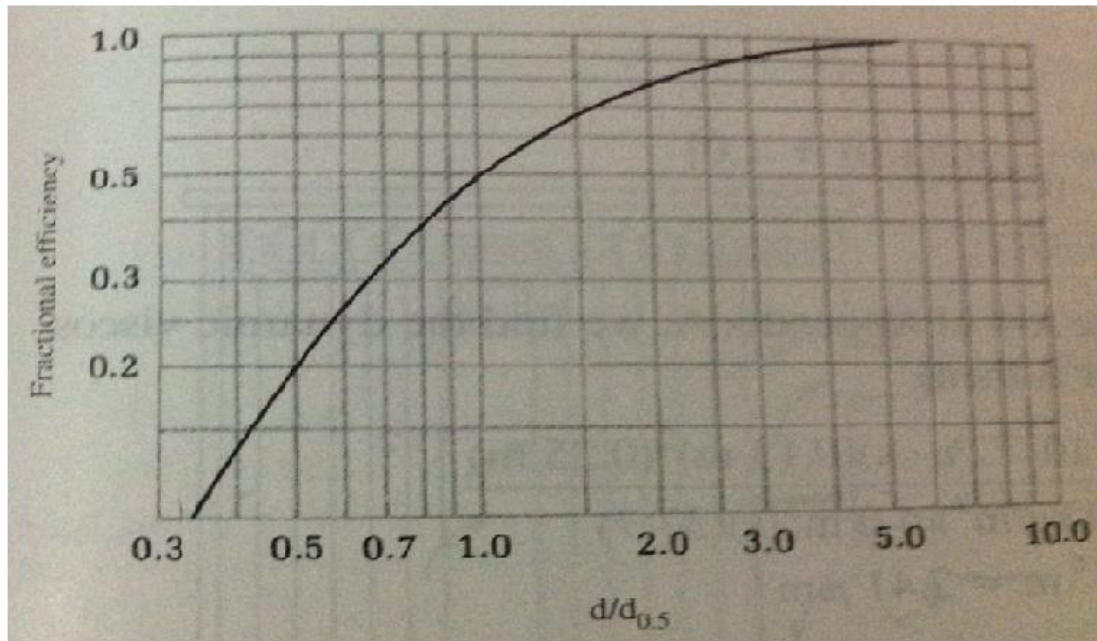


Figure 2: Empirical cyclone collection efficiency

Length of cylinder,	$L_1 = 2D_2$
Length of cone,	$L_2 = 2D_2$
Diameter of exit,	$D_e = 0.50 D_2$
Height of entrance,	$H = 0.50 D_2$
Width of entrance,	$B = 0.25 D_2$
Diameter of dust exist,	$D_d = 0.25 D_2$
Length of exist duct,	$L_3 = 0.125D_2$

The efficiency (of collection of various particle sizes (η)) can be determined from the empirical expression and graph (developed by Lapple)

$$d_{0.5} = \left[\frac{9\mu \times B^2 \times H}{\rho_p \times Q\dot{g} \times \theta} \right]^{1/2}$$

$d_{0.5}$ = cut diameter, the particle size for which the collection efficiency is 50%

μ = dynamic viscosity of gas, Pa.s

B = width of entrance, m

H = height of entrance, m

ρ_p = Particle density, kg/m³

$Q\dot{g}$ = gas flow rate, m³/s

θ = effective number of turns made in traversing the cyclone as defined in equation below;

$$\theta = \frac{\pi}{H} (2L_1 + L_2)$$

Where L_1 and L_2 are length of cylinder and cone respectively.

Example

Determine the efficiency of a standard cyclone having the following characteristics:

10 μ m in diameter, density of 800 kg/m³, cyclone barrel diameter 0.5 m, gas flow rate 4 m³/s. Temperature of the gas 25° C.

Solution

From the standard cyclone dimensions we can calculate the following:

$$B = 0.25 \times 0.5 = 0.13 \text{ m}$$

$$H = 0.5 \times 0.5 = 0.25 \text{ m}$$

$$L_1 = L_2 = 2.00 \times 0.5 = 1.0 \text{ m}$$

The number of turns is then (θ)

$$\theta = \frac{\pi}{H} (2L_1 + L_2)$$

$$\theta = \frac{\pi}{0.25} [2(1.0 + 1.0)] = 37.7$$

From the gas temperature and table A-4 of Appendix (page 980), we find the dynamic viscosity is 18.5 μ Pa.s, the cut diameter is then:

$$d_{0.5} = \left[\frac{9\mu \times B^2 \times H}{\rho_p \times Q_g \times \theta} \right]^{1/2}$$

$$d_{0.5} = \left[\frac{9 (18.5 \times 10^{-6} \text{ Pa.s}) \times (0.13 \text{ m})^2 \times 0.25}{(800 \text{ kg/m}^3) \times (4.0 \text{ m}^3/\text{s}) \times 37.3} \right]^{1/2}$$

$$d_{0.5} = 2.41 \times 10^{-6} \text{ m} = 2.41 \mu\text{m}$$

The ratio of particle size is

$$\frac{d}{d_{0.5}} = \frac{10 \mu\text{m}}{2.41 \mu\text{m}} = 4.15$$

From figure 2 we find that the collection efficiency is about 95 percent.

Filtration

When high efficiency control of particles smaller than $5 \mu\text{m}$ is desired, a filter may be selected as the control method. The hypothesis of filter action is only the gas and vary small particles can pass through it. Two types are in use:

- 1- Deep bed filter, resembles which consist of packing of fibers is used to intercept particles in the gas stream and it is very effective for air conditioning system which needs to clean gas continuously and provides low volumes.
- 2- Baghouse, it is preferable to be used in capturing dirty industrial gas with high volumes.

The performance of the filter is characterized by two parameters:

- 1- Particle collection efficiency
- 2- Pressure drop

The material which the fabric is made from should be have enough strength o resist to collapse at the maximum gas temperature expected and applied chemical compounds. The disadvantage of the fabric filter it is weakness when operate at high-temperature and may be the gases often have to be cooled before contacting the filter medium. The filter media commonly used are woven fabric, paper, plastic and ceramic fibers. Theefficiency of the filter depends on the filter media and the velocity of interchange of the filter; It is important to know the particle size distribution of the dust to allow to determine the proper filter media. The main parameters that should be considered are temperature, acidic, alkali, strength, moisture resistance and efficiency. Bag diameters for shaker and reverse air flow baghouses range from 15 to 45 cm. The bags may be up to 12m length, they are designed to shaken at periodic intervals, ranging from 30 minutes to more than two hours. The fundamental design parameter for baghouses is the ratio of the volumetric flow rate of the gas to be cleaned to the area of filter fabric. This ratio is called the *air-to-cloth ratio*. It has units of $\text{m}^3 \cdot \text{s} / \text{m}^2$ or $\text{m} \cdot \text{s}$.

Example

An aggregate plant found to be in violation of particulate discharge standards. A mechanical shaker baghouse has been selected for particulate control. Estimate the number of bags required for a gas flow rate $20 \text{m}^3/\text{s}$, if each bag is 15 cm diameters and 12 m length. One- eighth of the bags are taken off for cleaning. The manufacture's recommended air-to-cloth ratio for aggregate plants is 0.010m/s .

Solution

$$Q = V \times A$$

$$A = \frac{Q}{V}$$

$$A = \frac{20 \text{ m}^3/\text{s}}{0.010 \text{ m/s}} = 2000 \text{ m}^2$$

Surface area for one bag = $\pi \times \text{Dia} \times \text{Length}$

$$= 3.14 \times 0.15 \times 12 = 5.656 \text{ m}^2$$

$$\text{Number of Bags} = \frac{2000 \text{ m}^2}{5.656 \text{ m}^2} = 353.6 \text{ bags consider } 354 \text{ ags}$$

$$\text{One-eighth of bags are off line} = \frac{354}{8} = 44.25 \text{ take } 44$$

$$\text{Total number of bags} = 354 + 44 = 398 \text{ bags.}$$

Use 400 bags (50 bags for one-eighth taken off for cleaning)

Liquid Scrubbing

When the particulate matter to be collected is wet, corrosive, or very hot, the fiber filter may not work. Liquid scrubbing might. Typical scrubbing applications include control of emission of talc dust, phosphoric acid mist, and open hearth furnace fumes. A high pressure liquid spray is applied to the gas passing through the washer, filter, venturi or other devices. During this process the gas will lose its temperature, cooled and cleaned. Water is used as spray. Simple spray chamber are used for relatively coarse particle sizes. For high efficiency removal of fine particles, combination of venturi scrubber is used followed by a cyclone apparatus.

The efficiency of scrubber collection can be determined by this equation:

$$\eta = 1 - e^{-KR\sqrt{\psi}}$$

Where:

η = Efficiency

K = Correlation coefficient m^3 of gas/ m^3 liquid

R = Liquid flowrate m^3 of gas

ψ = Inertial impaction parameter relates the particle and droplet sizes and relative velocities and defined by the equation below:

$$\psi = \frac{C \times \rho_p \times V_g \times (dp)^2}{18 \times dd \times \mu} \quad \text{where:}$$

C = Cunningham correction factor defined by the below equation:

$$C = 1 + \frac{6.21 \times 10^{-4}(T)}{dp} \quad (T = \text{absolute temperature, K) and } (d_p = \text{diameter of particle, } \mu\text{m})$$

ρ_p = Particle density, kg/m³

V_g = speed of gas at throat, m/s

d_d = diameter of droplet, m

μ = dynamic viscosity of gas, Pa.s

The C- Cunningham correlation factor accounts for the fact that very simple particles do not obey Stokes' law settling equation.

Example

Given the scrubber described below, write an expression for collection efficiency that is a function of particulate size. Assume the particles are fly ash with a density of 700kg/m³ and a minimum size of 10 μ m diameter.

Venturi characteristics:

Throat area = 1.00 m²

Gas flow rate = 94.4 m³/s

Gas temperature = 150° C

Liquid flow rate = 0.13 m³/s

Coefficient k = 200

Drop diameter = 100 μ m

dynamic viscosity of gas = 25.3 μ Pa.s

Solution

$$C = 1 + \frac{6.21 \times 10^{-4}(T)}{dp} = 1 + \frac{6.21 \times 10^{-4}(150+273)}{10} = 1 + 0.0263,$$

assume $C=1$, because of very small value of d_p for all particles greater than 10 μ m.

$$\psi = \frac{C \times \rho_p \times V_g \times (dp)^2}{18 \times d_d \times \mu} = \psi = \frac{1 \times (700 \text{ kg/m}^3) \times \left(\frac{94.40 \text{ m}^3}{\text{s}}\right) \left(1 \times 10^{-4} \frac{\text{m}^2}{\text{m}^2}\right) \times (dp)^2}{(18 \times 100 \times 10^{-6}) (25.2 \times 10^{-6} \text{ pa.s})}$$

$$\psi = 1.46 \times (dp)^2$$

$$\eta = 1 - e^{-KR\sqrt{\psi}}$$

$$\eta = 1 - e^{((-200) \times 1.38 \times 10^{-3}) \times (1.21 dp)}$$

$$\eta = 1 - e^{(-0.33 dp)}$$

Electrostatic Precipitation (ESP)

ESPs have applications in power plant, in cement plants, and in metallurgical, refining, and heavy chemical industries for the collection of fumes, dusts, and acid mists. Particles, in passing through a high voltage electrical field, are charged and then attached to a plate of opposite charge, where they collect. The accumulated materials fall into hopper where shake.

The gases treated may be cold or at a temperature as high as 1100° F, but 600° F or less is more common. EP are efficient for collection of particles less than 0.5µ in size, hence cyclone are better for the removal of larger particles and are used a head of precipitators.

The following equation is used for calculation of ESP.

$$\left[\frac{-AW}{Q\dot{g}} \right]$$

$$\eta = 1 - e$$

Where:

A = collection area of plates, m²

W = particle sedimentation velocity in an electric field, m/s

Qḡ = gas flow rate m³/s

W, is a function of the electrostatic force and it is calculated by the following equation:

$$W = \frac{q \times E_p \times C}{6\pi \times r \times \mu}$$

Where:

q = charge, coulombs (C)

E_p = collection field intensity, volts/m

r = particle radius, m

μ = viscosity of gas, pas.s

C = Cunningham correction factor

Example

Determine the collection efficiency at electrostatic precipitator described below for a particle size 154 µm in diameter, setting velocity of 0.184 m/s.

ESP specification:

Height = 7.32 m

Length = 6.1 m

No. of passages = 5

Gas flow rate 19.37m³/s

Solution

$$A = 7.32 \times 6.1 = 44.65 \text{ m}^2$$

Each plate has two collecting surfaces

No. of plates = No. of passages -1

No. of plates = 5-1 = 4

$$\text{Total area(A)} = 44.65 \times (4 \times 2) = 357.2 \text{ m}^2$$

$$\left[\frac{-AW}{Q\dot{g}} \right]$$

$$\eta = 1 - e$$

$$\eta = 1 - e^{\left[\frac{-(375.2 \times 0.184)}{19.73} \right]}$$

$$\eta = 0.964$$