Chapter One

Air Pollution Control

**Definition:** Air pollution is the presence of substances in air in sufficient concentration and for sufficient time, so as to be, or threaten to be injurious to human, plant or animal life, or to property, or which reasonably interferes with the comfortable enjoyment of life and property.

- It is an increasing problem in all countries
- It is increased with population and industrial activities
- It has huge economical effects

There are many air pollution disasters such as Dinora, Loss angelis, London, Belgium, Meuse river vally, India, Tschernobil

**Pollutant Sources:**

1. Stationary sources, factories, industries
2. Movable, cars, automobiles

They are classified as:

1. Man made, 2. natural processes.

Pollutants are also defined as:

1. primary pollutants resulting from combustion of fuels and industrial operations and
2. secondary pollutants, those which are produced due to reaction of primary pollutants in the atmosphere. (FOG, photochemical smog)

The ambient air quality may be defined by the concentration of a set of pollutants which may be present in the ambient air we breath in. These pollutants may be called criteria pollutants.

Emission standards express the allowable concentrations of a contaminant at the point of discharge before any mixing with the surrounding air.
Automobiles, industries and thermal power plants are the major sources of air pollutants from human activities. It may be mentioned here that pollution is caused not only by the activities of man but also by natural processes. For example:

1. Volcanic eruptions release large amounts of gases and particulate matter in the air
2. Forest fires release CO$_2$ and smoke
3. Decomposition of plant and animal residue
4. Pollen grains, storms
5. Methane gas

However, the contribution from these natural processes is within tolerable limits. On the other hand, the contribution from man-made sources is much larger.

**Types of Air Pollutants**

On the basis of particle size, there are three major categories of air pollutants: gaseous pollutants, particulate pollutants and aerosols.

1. Gaseous pollutants consist of atoms, molecules and include harmful gases, which can freely mix with air without settling down. Some examples of gaseous pollutants of air are carbon monoxide, carbon dioxide, sulphur dioxide, hydrogen sulphide, nitrogen oxides and hydrocarbons.

2. Particulate pollutants include finely divided solids as well as liquids having particle size from $10^{-4}$ to $10^{-3}$ cm. Particulates are harmful to the living as well as non-living things. The examples of particulate pollutants in the air are: dust, smoke, clouds, fumes, mist, spray and smog.

3. Aerosols are suspensions of fine particulate matter in the air. Aerosols have particle size smaller than particulates. Their particle size ranges from $10^{-7}$ cm to $10^{-4}$ cm. Aerosols can be either liquid or solid particles. They are small enough to remain suspended in the atmosphere for long periods of time. Smoke, fine dust, fog, clouds are examples of aerosols.

Particulates and aerosols serve as collectors of chemically active sulphur oxides, nitrogen oxides, ozone, hydrocarbons and other pollutants and are serious health hazards.

**Pollutants Sources**

<table>
<thead>
<tr>
<th>Name</th>
<th>Source</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Suspended particulate Matter, SPM</strong>&lt;sup&gt;a&lt;/sup&gt;</td>
<td>Automobile, power plants, boilers, Industries requiring crushing and grinding such as quarry, cement.</td>
</tr>
<tr>
<td>---------------------------------------------</td>
<td>-----------------------------------------------------------------------------------------------------</td>
</tr>
<tr>
<td><strong>Chlorine</strong></td>
<td>Chlor-alkali plants</td>
</tr>
<tr>
<td><strong>Fluoride</strong></td>
<td>Fertilizer, aluminum refining</td>
</tr>
<tr>
<td><strong>Sulphur oxides,</strong></td>
<td>Power plants, boilers, sulphuric acid manufacture, ore refining, petroleum refining</td>
</tr>
<tr>
<td><strong>Lead</strong></td>
<td>Ore refining, battery manufacturing, automobiles.</td>
</tr>
<tr>
<td><strong>Oxides of nitrogen,</strong></td>
<td>Automobiles, power plants, nitric acid manufacture, and also secondary pollutant</td>
</tr>
<tr>
<td><strong>Peroxyacetyl Nitrate PAN</strong></td>
<td>Secondary pollutant</td>
</tr>
<tr>
<td><strong>Formaldehyde</strong></td>
<td>Secondary pollutant</td>
</tr>
<tr>
<td><strong>Ozone</strong>&lt;sup&gt;a&lt;/sup&gt;</td>
<td>Secondary pollutant</td>
</tr>
<tr>
<td><strong>Carbon monoxide</strong>&lt;sup&gt;a&lt;/sup&gt;</td>
<td>Automobiles</td>
</tr>
<tr>
<td><strong>Hydrogen sulphide</strong></td>
<td>Pulp and paper, petroleum refining.</td>
</tr>
<tr>
<td><strong>Hydrocarbons</strong></td>
<td>Automobiles, petroleum refining</td>
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<tr>
<td><strong>Ammonia</strong></td>
<td>Fertilizer plant</td>
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<tr>
<td><strong>Volatile organic Compounds, (VOC)</strong></td>
<td>Automobiles, petroleum refining, Waste decomposition</td>
</tr>
<tr>
<td><strong>Smoke</strong></td>
<td>Volcanies, industries, forest fires</td>
</tr>
<tr>
<td><strong>Radioactive</strong></td>
<td>Laboratories, hospitals, nuclear industries</td>
</tr>
</tbody>
</table>

**a- Criteria pollutants**
Factors Affecting Reaction Rate

1- Concentration of the reactants
2- Amounts of moisture
3- Degree of photoactivation
4- Presence of some metals like Fe, Mg, work as a catalyst or provide a surface for the reaction
5- Meteorological conditions
6- Local topography and geography

Units
Air pollution is expressed either as ppm or microgram µg/m³
1 ppm = 1 volume of pollutant/(10^6 volume of air plus pollutant)
1 ppm = 0.0001% by volume
For solid pollutants it is usual to use µg/m³, i.e mass/volume.

At 25°C, 298K and 1 atmosphere, 101326 kpa:

\[
\frac{\text{pollutant mass}}{\text{volume of air}} = \frac{\rho_p V}{V_{\text{air}}} \quad \text{(1)}
\]

\[
P V = nRT = \frac{\text{wt}}{\text{MW}} \cdot R \cdot T
\]

\[
P V = \frac{\text{PMW}}{\text{RT} \rho_p} = 1
\]

Multiply equation 1 by 1:

\[
\frac{\text{pollutant mass}}{\text{volume of air}} = \frac{\rho_p V_p P \cdot MW}{V_{\text{air}} \cdot RT \rho_p}
\]

\[
\frac{\text{pollutant mass}}{\text{volume of air}} = \frac{V_p P \cdot MW}{V_{\text{air}} \cdot RT}
\]

For 1 atm., T = 298K, R = 0.08208(atm.m³)/(kg. Mole.K)
\[
\frac{\text{pollutant mass}}{\text{volume of air}} = \frac{V_p \cdot MW}{V_{air} \cdot 24.5}, \text{multiply by } 10^9 \text{ to convert kg to mg and divide by } 10^6 \text{ to convert to ppm}
\]

\[
\frac{\mu g}{m^3} = \text{ppm} \cdot MW \cdot \frac{1000}{24.5}
\]

For same conditions but 0°C the constant 24.5 becomes 22.41

**Ex:** Certain gas contains 1.5% by volume of CO, find the concentration in mg/L, and µg/L

1% = 10000 ppm
1.5% = 15000 ppm

\[
\mu g/m^3 = 15000 \times (16+12) \times 1000/24.5 = 17.1 \times 10^6
\]

\[
= 17.1 \times 10^6 \times (1/1000)(mg/\mu g)/(1/1000)(L/m^3) = 17.1 \times 10^6 mg/L
\]

**Example**

Calculate SO₂ concentration in flue gas when one mole of C₇H₁₃ containing 1% sulphur is burnt in presence of stochiometric amount of oxygen.

**Solution**

First we write stochiometric equation for combustion:

C₇H₁₃ + 1 0.25O₂ = 7 CO₂ + 6.5 H₂O

Since O₂ is supplied through air which also contains nitrogen and in air each mole of oxygen is accompanied by 3.76 mole N₂, for 10.25 mole O₂, 38.54 mole N₂ will be supplied. Therefore we may write:

C₇H₁₃ + 1 0.25O₂ + 38.54 N₂ = 7 CO₂ + 6.5 H₂O + 38.54N₂

Therefore quantity of flue gas at STP is = 45.54 mole

22.4 L = 1 mole

45.54 mole = 45.45*22.4/1 = 1020 L

Since one mole C₇H₁₃ = 7 x 12 + 13 x 1 = 97 g, sulfur contents of fuel = 97 x 0.01 = 0.97 g.

1 mole of sulfur plus one mole of oxygen produce 1 mole of sulfur dioxide and the molecular weight of sulfur = 64 which is the same of oxygen, therefore 1 gram of sulfur react with 1 gram of oxygen.

Therefore SO₂ produced = 1.94 g or 1940 mg/mole of fuel.

As an approximation, neglecting the volume of oxygen consumed in production of SO₂, concentration of SO₂ = 1940 mg/1020 L = 1902 mg/m³, at STP.
Or $1920 \times \frac{273}{298} = 1742 \text{mg/m}^3$

**Automobiles**
In urban areas automobiles form a significant source of a number of air pollutants, namely, particulates, NOx, hydrocarbons, carbon monoxide, and lead. These pollutants are produced when fuel is burnt under less than ideal conditions. Non-uniform oxygen supply within the combustion chamber and lower flame temperature leads to incomplete combustion releasing CO, HC and unburnt particles in the exhaust. Tetraethyl lead, $(\text{C}_2\text{H}_5)_4 \text{Pb}$, is added to petrol as anti-knock additive. Where such petrol is used lead is emitted in the exhaust fumes as inorganic particulates.

**Industrial sources**
Only two sources are discussed here as illustrative examples.

**Cement manufacture**
Raw materials include lime, silica, aluminum, and iron. Lime is obtained from calcium carbonate. Other raw materials are introduced as sand, clay, shale, iron ore, and blast furnace slag. The process consists of mining, crushing, grinding, and calcining in a long cylindrically shaped oven or kiln. Air pollutants can originate at several operations as listed below.

<table>
<thead>
<tr>
<th>Source</th>
<th>Emission</th>
</tr>
</thead>
<tbody>
<tr>
<td>Raw material crushing, grinding</td>
<td>Particulates</td>
</tr>
<tr>
<td>Kiln and cooling Particulates, CO, SO$_2$, NOx, HC</td>
<td></td>
</tr>
<tr>
<td>Product grinding and packaging Particulates</td>
<td></td>
</tr>
</tbody>
</table>

**Sulphuric Acid Manufacture**
Sulphuric acid is produced from sulphur, which is burnt to obtain SO$_2$. Sulphur dioxide is converted to trioxide in the presence of vanadium pentaoxide catalyst. The sulphur trioxide is absorbed in recycling concentrated sulfuric acid. Unreacted SO$_2$ escapes with the flue gas. New large plants now use double conversion double absorption (DCDA) process realizing above 99 percent efficiency.

**Example**
A 250 T/d double conversion double absorption DCDA sulphuric acid plant burns 82T/d sulphur in the manufacturing process. Flue gas containing 350 ppm SO$_2$ is discharged at the
rate of 35 Nm³/s, What is the percent recovery of sulfur in the product.

Solution:
350 ppm SO₂ = 350*64/24.5 = 916 mg/Nm³
Therefore SO₂ discharged with flue gas:

\[
\frac{916 \text{ g SO}_2}{35 \text{ Nm}^3} \cdot \frac{3600 \text{ s}}{1 \text{ hr}} \cdot \frac{1 \text{ kg}}{10^6 \text{ mg}} \cdot \frac{1000 \text{ kg}}{1 \text{ T}} = \frac{7.77 \text{ T}}{d}
\]

The quantity of sulphur in 2.77 T/d SO₂ is
2.77 T x 32 g S
--------- x --------- = 1.38 T/d
d 64 g SO₂
Therefore sulphur recovery = (82-1.38)/82 = 98.3%
Note: DCDA plants are expected to give better than 99% recovery. Therefore the reason for poor performance should be investigated and corrected.

Particulate Matters:
It is a term employed to describe airborne solid and liquid particles larger than single molecule (0.0002 micron = 0.2 nanometer) but smaller than 50 micron.

1 Micron = (1/10000)cm
- It have a life time in suspension ranging from few seconds to several months.
- Below 0.1 micron undergo random Browninian motion and greater than 20 micron is removed by gravity or inertial processes.
- Particulate is used interchangeably with aerosol which is a dispersion of solid or liquid matter of microscopic size in gaseous media less than 1 micron.

It is a small discrete mass of solid or liquid

Dust
It is a solid particle larger than colloidal size capable of temporary suspension in air. It does not flocculate and diffuse but settle
Sand 20-2000 micron
micron

pulverized coal 3-400

Dust fall
It refers to particle of sufficient size that they fall quickly. They are measured by dust fall or Jars. (weight/area), 30 ton/sq. mile – typical

Fly ash
It is finely divided particles of ash entrained in flue gas

An Asian dust cloud during the spring of 2001. The dust cloud was generated by high winds over China’s Gobi Desert
Fume: Particles formed by condensation or chemical reaction with a diameter less than 1 micron
Mist
Dispersion of small liquid droplets of sufficient size to fall from air
Smoke
Small gas borne particles resulting from combustion
Soot
An agglomeration of carbon particles

Composition and shape of soot