UNIT V
Air pollution

Unit of measurement

Concentrations of air pollutants are commonly expressed asthe mass of pollutant per Unit volume of air mixture, as mg/m3, µg/m3, ng /m3

Concentration of gaseous pollutants may also be expressed as volume of pollutant per million volumes of the air plus pollutant mixture (ppm) where 1ppm=

0.0001 % by volume. It is sometimes necessary to convert from volumetric units to mass per unit volume and vice versa.

The relation ship between ppm and mg/m3 depends on the gas density, which in turn depends on:™Temperature, Pressure, Molecular weight of the pollutant

The following expression can be uses to convert of between ppm and mg/m3 at any temperature or pressure.

Simply multiply the calculated value of mg/m3 by 1000 to obtain µg/m3. The constant 22.4 is the volume in liter occupied by 1 mole of an ideal gas at

standard concentration (0c and 1 atm.). One 14 mole of any substance is a quantity of that substance whose mass in grams numerically equals its molecular

weight

Sources and Classification of pollutants

Air pollution may be defined as any atmospheric condition in which certain substances are present in such concentrations that they can produce undesirable

effects on man and his environment. These substances include gases (SOx, NOx, CO, HCs, etc) particulate matter (smoke, dust, fumes, aerosols) radioactive

materials and many others. Most of these substances are naturally present in the atmosphere in low (background) concentrations and are usually considered to

be harmless. A particular substance can be considered as an air pollutant only when its concentration is relatively high compared with the back ground value

and causes adverse effects.

Air pollution is a problem of obvious importance in most of the world that affects human, plant and animal health. For example, there is good evidence that

the health of 900 million urban people suffers daily because of high levels of ambient air sulfur dioxide concentrations. Air pollution is one of the 6 most

serious environmental problems in societies at all level of economic development. Air pollution can also affect the properties of materials (such as rubber), visibility, and the quality of life in general. Industrial

development has been associated with emission to air of large quantities of gaseous and particulate emissions from both industrial production and from

burning fossil fuels for energy and transportation.

When technology was introduced to control air pollution by reducing emissions of particles, it was found that the gaseous emissions continued and caused

problems of their own. Currently efforts to control both particulate and gaseous emissions have been partially successful in much of the developed world, but

there is recent evidence that air pollution is a health risk even under these relatively favorable conditions.

In societies that are rapidly developing sufficient resources may not be invested in air pollution control because of other economic and social priorities.

The rapid expansion of the industry in these countries has occurred at the same time as increasing traffic from automobiles and trucks, increasing demands

for power for the home, and concentration of the population in large urban areas called mega cities. The result has been some of the worst air pollution

problem in the world.

In many traditional societies, and societies where crude household energy sources are widely available, air pollution is a serious problem because of

inefficient and smoky fuels used to heat buildings and cook. This causes air pollution both out door and indoors. The result can be lung disease, eye

problems, and increased risk of cancer.

The quality of air indoors is a problem also in many developed countries because buildings were built to be airtight and energy efficient. Chemicals produced

by heating and cooling systems, smoking and evaporation from buildings materials accumulate indoors and create a pollution problem.

The health effects of ambient air pollution have been difficult to document with certainty until recent years. This is because of methodological problems in

assessing exposure, other factors that cause respiratory disease (such as cigarette smoking, respiratory tract infections, and allergies), and the difficulty

of studying such effects in large populations.

Recently, however, a series of highly sophisticated and convincing studies from virtually every continent have demonstrated that air pollution has a major effect on human health. Respiratory symptoms are the most common adverse health effects from air pollution of all types. Following Table presents a summary

of major health effects thought to be caused by community air pollution. Respiratory effects of air pollution, particularly complicating chronic bronchitis,

may place an additional strain on the heart as well.
Air pollution is associated with increased risk of death from heart disease and lung disease, even at levels below those known to be acutely toxic to the

heart. Mucosal irritation in the form of acute or chronic bronchitis, nasal tickle, or conjunctivitis is characteristic of high levels of air pollution,

although individuals vary considerably in their susceptibility to such effects.

The eye irritation is particularly severe, in the setting of high levels of particulates (which need to be in the respirable range described and may be quite

large soot particles) or of high concentrations of photochemical oxidants and especially aldehydes.

There is little evidence to suggest that community air pollution is a significant cause of cancer except in unusual and extreme cases. However, emissions

from particular sources may be cancer-causing. Examples of cancer associated with community air pollution may include point-source emissions from some

smelters with poor controls that release arsenic, which can cause lung cancer. Central nervous system effects, and possibly learning disabilities in

children, may result from accumulated body burdens of lead, where air pollution contributes a large fraction of exposure because of lead additives in

gasoline.

These health effects are better characterized for populations than for individual patients. Establishing a relationship between the symptoms of a particular

patient and exposure to air pollution is more difficult than interpreting the likely health effects on an entire community. It is important to understand

that these pollutants are seasonal in their pattern. Both ozone and sulfates, together with ultra fine particulates, tend to occur together during the summer

months in most developed areas. Ozone, oxides of nitrogen, aldehydes, and carbon monoxide tend to

occur together in association with traffic, especially in sunny regions. Some pollutants, such as radon, are only hazards indoors or in a confined area.

Others are present both indoors and outdoors, with varying relative concentrations.

Classifications of Air Pollutants

Air pollutants can be classified as

a. Criteria Pollutants

There are 6 principal, or “criteria” pollutants regulated by the US-EPA and most countries in the world:

- Total suspended particulate matter (TSP), with additional subcategories of particles smaller then 10 µm in diameter (PM10), and particles smaller

than 2.5 µm in diameter (PM2.5). PM can exist in solid or liquid form, and includes smoke, dust, aerosols, metallic oxides, and pollen. Sources of PM include

combustion, factories, construction, demolition, agricultural activities, motor vehicles, and wood burning. Inhalation of enough PM over time increases the

risk of chronic respiratory disease.

- Sulfur dioxide (SO2). This compound is colorless, but has a suffocating, pungent odor. The primary source of SO2 is the combustion of sulfur-

containing fuels (e.g., oil and coal). Exposure to SO2 can cause the irritation of lung tissues and can damage health and materials.

- Nitrogen oxides (NO and NO2). NO2 is a reddish-brown gas with a sharp odor. The primary source of this gas is vehicle traffic, and it plays a role in

the formation of tropospheric ozone. Large concentrations can reduce visibility and increase the risk of acute and chronic respiratory disease.

- Carbon monoxide (CO). This odorless, colorless gas is formed from the incomplete combustion of fuels. Thus, the largest source of CO today is motor

vehicles. Inhalation of CO reduces the amount of oxygen in the bloodstream, and high concentrations can lead to headaches, dizziness, unconsciousness, and

death.

- Ozone (O3). Tropospheric (“low-level”) ozone is a secondary pollutant formed when sunlight causes photochemical reactions involving NOX and VOCs.

Automobiles are the largest source of VOCs necessary for these reactions. Ozone concentrations tend to peak in the afternoon, and can cause eye irritation,

aggravation of respiratory diseases, and damage to plants and animals.

- Lead (Pb). The largest source of Pb in the atmosphere has been from leaded gasoline combustion, but with the gradual elimination worldwide of lead in

gasoline, air Pb levels have decreased considerably. Other airborne sources include combustion of solid waste, coal, and oils, emissions from iron and steel

production and lead smelters, and tobacco smoke. Exposure to Pb can affect the blood, kidneys, and nervous, immune, cardiovascular, and reproductive systems.

b. Toxic Pollutants

Hazardous air pollutants (HAPS), also called toxic air pollutants or air toxics, are those pollutants that cause or may cause cancer or other serious health

effects, such as reproductive effects or birth defects. The US-EPA is required to control 188 hazardous air pollutants

Examples of toxic air pollutants include benzene, which is found in gasoline; perchlorethlyene, which is emitted from some dry cleaning facilities; and

methylene chloride, which is used as a solvent and paint stripper by a number of industries.

c. Radioactive Pollutants

Radioactivity is an air pollutant that is both geogenic and anthropogenic. Geogenic radioactivity results from the presence of radionuclides, which originate

either from radioactive minerals in the earth‟s crust or from the interaction of cosmic radiation with atmospheric gases. Anthropogenic radioactive emissions

originate from nuclear reactors, the atomic energy industry (mining and processing of reactor fuel), nuclear weapon explosions, and plants that reprocess

spent reactor fuel. Since coal contains small quantities of uranium and thorium, these radioactive elements can be emitted into the atmosphere from coal-

fired power plants and other sources.

d. Indoor Pollutants

When a building is not properly ventilated, pollutants can accumulate and reach concentrations greater than those typically found outside. This problem has

received media attention as “Sick Building Syndrome”. Environmental tobacco smoke (ETS) is one of the main contributors to indoor pollution, as are CO, NO,

and SO2, which can be emitted from furnaces and stoves. Cleaning or remodeling a house is an activity that can contribute to elevated concentrations of

harmful chemicals such as VOCs emitted from household cleaners, paint, and varnishes. Also, when bacteria die, they release endotoxins into the air, which

can cause adverse health effects31. So ventilation is important when cooking, cleaning, and disinfecting in a building. A geogenic source of indoor air

pollution is radon32.

Other classifications

Air pollutants come in the form of gases and finely divided solid and liquid aerosols.

Aerosols are loosely defined as “any solid or liquid particles suspended in the air” (1).

Air pollutants can also be of primary or secondary nature. Primary air pollutants are the ones that are emitted directly into the atmosphere by the sources

(such as power-generating plants).

Secondary air pollutants are the ones that are formed as a result of reactions between primary pollutants and other elements in the atmosphere, such as

ozone.

Types of pollutants

Sulfur Dioxide

Sulfur dioxide was a serious problem in air pollution in the earliest days of industrialization. It has been the major problem in reducing or acidifying air

pollution during the period of rapid economic growth in many countries. In 1953, Amdur et al. studied the effects of sulfur dioxide on humans and found that,

at least in acute exposures, concentrations of up to 8 ppm caused respiratory changes that were dose dependent. (This is one of the first studies to use

physiological measurements as an indication of the effects of air pollution.) Later studies revealed that the main effect of sulfur dioxide is broncho

constriction (closing of the airways causing increased resistance to breathing) which is dose dependent, rapid, and tended to peak at 10 minutes (Folinsbee,

1992). Persons with asthma are particularly susceptible and in fact asthmatics suffer more from the effects of sulfur dioxide than does the general public.

Persons with asthma who exercise will typically experience symptoms at 0.5 ppm, depending on the individual.

Sulfate, the sulfur-containing ion present in water, remains a major constituent of air pollution capable of forming acid. Sulfate itself appears to be

capable of triggering broncho constriction in persons with airways reactivity and it is a major constituent of ultrafine particulates. There are other acid

ingredients in air pollution, such as nitric acid, but less is know about them. These acids, though, cause a phenomenon known as acid rain, with their

emission into the air by industry and motor vehicles.

Because of their small size and tendency to ride along on particulates, acid aerosols such as sulfur dioxide, sulfates and nitrogen dioxide tend to deposit deeply in the distal lung and airspace. They appear to provoke airways responses in an additive or synergistic manner with ozone. They have also been

implicated in causing mortality in association with ultra fine particulates.

SO_2 and sulfates are the principal chemical species that cause acid precipitation. They may be transported long distances in the atmosphere away from their

source and result in acidification of water and soils.

Nitrogen Dioxide

Nitric oxide (NO) is produced by combustion. Nitrogen dioxide (NO_2), which has greater health effects, is a secondary pollutant created by the oxidation of

NO under conditions of sunlight, or may be formed directly by higher temperature combustion in power plants or indoors from gas stoves. Levels of exposure to

nitrogen dioxide that should not be exceeded (WHO guideline levels) are respectively 400 µg/m3 (0.21 parts per million (ppm) for one hour and 150 µg/m3
(0.08 ppm) for 24 hours.

The direct effects of nitrogen oxide include increased infectious lower respiratory disease in children (including longterm exposure as in houses with gas

stoves) and increased asthmatic problems. Extensive studies of the oxides of nitrogen have shown that they impair host defenses in the respiratory tract,

increasing the incidence and severity of bacterial infections
after exposure. They have a marked effect in reducing the capacity of the lung to clear particles and bacteria.

NO_2 also provokes broncho-constriction and asthma in much the same way as ozone but it is less potent than ozone in causing asthmatic effects. Despite

decades of research, however, the full effects of NO_2 are not known. Known human health effects are summarized below:

Particulates matter

Particle matter in the air (aerosols) is associated with an elevated risk of mortality and morbidity (including cough and bronchitis), especially among

populations such as asthmatics and the elderly. As indicated, they are released from fireplaces, wood and coal stoves, tobacco smoke, diesel and automotive

exhaust, and other sources of combustion. The US Environmental protection Agency (EPA) sets a standard of 265 µg/m3 in ambient air, but does not have a

standard for indoor air levels. Usual concentrations range from 500 µg/m3 in bars and waiting rooms to about 50 µg/m3 in homes. In developed countries,

tobacco smoke is the primary contributor to respirable particles indoors.

Particulate matter (PM 10)

Larger particulates, which are included in PM10 (particulates 10 µm and smaller) consist mostly of carbon-containing material and are produced from

combustion; some fraction of these are produced by wind blowing soil into the air. These larger particulates do not seem to have as much effect on human

health as the smaller particulates.

Particulate matter (PM 2.5)

In recent years we have learned a great deal about the health effects of particles. As noted above, particulates in urban air pollution that are extremely

small, below 2.5 µm in diameter, are different in their chemical composition than larger particles. Particulates in the fraction PM2.5

(2.5 µm and below) contain a proportionately larger amount of water and acid forming chemicals such as sulfate and nitrate, as well as trace metals. These

smaller particulates penetrate easily and completely into buildings and are relatively evenly dispersed throughout urban regions where they are produced.

Unlike other air contaminants that vary in concentration from place to place within an area, PM2.5 tends to be rather uniformly distributed.

PM2.5 sulfate and ozone cannot be easily separated because they tend to occur together in urban air pollution. Recent research strongly suggests that at

least PM2.5 and sulfate, and probably ozone as well, cause an increase in deaths in affected cities. The higher the air pollution levels for these specific

contaminants, the more excess deaths seem to occur on any given day, above the levels that would be expected for the weather and the time of year. Likewise,

accounting for the time of the year and the weather, there are more hospital admissions for various conditions when these contaminants are high. Ozone,

particularly, is linked with episodes of asthma, but all three seem to be associated with higher rates of deaths from and complaints about lung disease and

heart disease. It is not yet known which is the predominant factor in the cause of these health effects, and some combination of each may be responsible for

some effects. Although the effect of air pollution is clearly present in the statistics, air pollution at levels common in developed countries is probably

much less of a factor in deaths and hospital admissions than the weather, cigarette smoking, allergies, and viral infections. However, the populations

exposed to air pollution are very large, and even if only 5% of all excess deaths during a one-week period are related to air pollution in a major city, a reasonable estimate, this means that thousands of deaths could be prevented. One unexpected finding of this research is that the effect of particulate air

pollution on deaths and hospital admissions is continuous from high levels to low levels of exposure. In other words, there is no obvious level below which

the public is clearly protected, and even at low levels of air pollution, some excess deaths still seem to occur. At first, it was thought that these deaths

represented sick people who would soon die anyway. If this were true, one would expect there to be fewer deaths than expected when air pollution levels

returned to normal or below normal, but a careful study of the death rate during and just after periods of high air pollution levels does not seem to show

this. At the much greater levels encountered in many developing countries, the effect is likely to be proportionately greater. There are many factors at work

that complicate such studies in developing countries. The very high rates of respiratory disease during the winter among even non smokers in some northern

Chinese cities, for example, has been attributed to air pollution and this is likely to be true, however, cigarette smoking, indoor air pollution from coal-

fired stoves, crowded conditions and the risk of viral infections may also be important factors.

There remains much more work to do to understand this problem, but the essential message seems clear: at any level, particulate air pollution and possibly

ozone are associated with deaths, and both are clearly associated with hospital admissions and health risks.

Hydrocarbons

Most hydrocarbons such as aliphatic and salicylic hydrocarbons are generally biochemical inert at ambient levels and thus present little hazards. Aromatic

hydrocarbon such, on the other hand

are biochemical and biologically active are more irritating to mucous membranes compounds like benzo(a) Pyrene are known to be potent carcinogens. HCs are

included among the criteria air pollutants, chiefly because of their role as catalysts in the formation of photochemical smog.

Lead

Lead is the best studied of these trace metals. It is known to be a highly toxic substance that particularly causes nerve damage. In children, this can

result in learning disabilities and neurobehavioral problems. An estimated 80 – 90% of lead in ambient air is thought to be derived from the combustion of leaded petrol. Due to its effects on the behavior and learning abilities of children even at low levels of exposure, efforts throughout the world are

directed at removing lead from gasoline. The WHO guidelines value for long-term exposure to lead in the air is 0.5 –1.0 µg/m3 /year).

Influence of meteorological phenomena on air quality

Meteorology specifies what happen to puff or plume of pollutants from the time it is emitted to the time it is detected at some other location. The motion of

the air causes a dilution of air pollutant concentration and we would like to calculate how much dilution occurs as a function of the meteorology or

atmospheric condition.

Air pollutants emitted from anthropogenic sources must first be transported and diluted in the atmosphere before these under go various physical and

photochemical transformation and ultimately reach their receptors. Otherwise, the pollutant concentrations reach dangerous level near the source of emission.

Hence, it is important that we understand the natural processes that are responsible for their dispersion. The degree of stability of the atmosphere in turn

depends on the rate of change of ambient temperature with altitude.

VERTICAL DISPERSION OF POLLUTANTS

As a parcel of air in the atmosphere rises, it experiences decreasing pressure and thus expands. This expansion lowers the temperature of the air parcel, and

therefore the air cools as it rises. The rate at which dry air cools as it rises is called the dry adiabatic lapse rate and is independent of the ambient air

temperature. The term adiabatic means that there is no heat exchange between the rising parcel of air under consideration and the surrounding air. The dry

adiabatic lapse rate can be calculated from the first law of thermodynamics (1°C per 100m). As the air parcel expands, it does work on the surroundings.

Since the process is usually rapid, there is no heat transfer between the air parcel and the surrounding air.

Saturated adiabatic lapse rate, (Γs)
Unlike the dry adiabatic lapse rate, saturated adiabatic lapse rate is not a constant, since the amount of moisture that the air can hold before condensation

begins is a function of temperature. A reasonable average value of the moist adiabatic lapse rate in the troposphere is about 6°C/Km.

Example

An air craft flying at an altitude of 9 km draws in fresh air at - 40°C for cabin ventilation. If that fresh air is compressed to the pressure at sea level,

would the air need to be heated or cooled if it is to be delivered to the cabin at 20°C.

Solution

As the air is compressed, it warms up it is even easier for the air to hold whatever moisture it may have, had .so there is no condensation to worry about

and the dry adiabatic lapse rate can be used, At 10°C per km, compression will raise the air temperature by

10x9=90°C making it -40+90°c=50°C

It needs to be the air conditioned The air in motion is called wind, air which is rushing from an area of high pressure towards an area of low pressure. When

the weather-man reports the wind to us he uses a measuring system worked out in 1805 by Adoniral Beaufort. For example, a

“moderate breeze” is a wind of 13 to 18 miles an hour. Obviously air quality at a given site varies tremendously from day to day, even though the emissions

remain relatively constant. The determining factors have to do the weather: how strong the winds are, what direction they are blowing , the temperature

profile , how much sun light available to power photochemical reactions, and how long it has been since the last strong winds or precipitation were able to

clear the air. Air quality is dependent on the dynamics of the atmosphere, the study of which is called meteorology

Temperature lapse rate and stability

The ease with which pollutants can disperse vertically into the atmosphere is largely determined by the rate of change of air temperature with altitude. For

some temperature profiles the air is stable, that is, air at a given altitude has physical forces acting on it that make it want to remain at that elevation.

Stable air discourages the dispersion and dilution of pollutants. For other temperature profiles, the air is unstable. In this case rapid vertical mixing

takes place that encourages pollutant dispersal and increase air quality. Obviously, vertical stability of the atmosphere is an important factor that helps

determine the ability of the atmosphere to dilute emissions; hence, it is crucial to air quality. Let us investigate the relationship between atmospheric

stability and temperature. It is useful to imagine a “parcel” of air being made up of a number of air molecules with an imaginary boundary around them. If this parcel of air moves upward in the atmosphere, it will experience less pressure, causing it to expand and cool. On the other hand, if it moves dawn ward,

more pressure will compress the air and its temperature will increase. As a starting point, we need a relationship that expires an air parcel‟s change of

temperature as it moves up or down in the atmosphere. As it moves, we can imagine its

temperature, pressure and volume changing, and we might imagine its surrounding adding or subtracting energy from the parcel. If we make small changes in

these quantities, and apply both the ideal gas law and the first law of thermodynamics, it is relatively straightforward to drive the following expression.

Let us make the quite accurate assumption that as the parcel moves, there is no heat transferred across its boundary, that is, that this process is adiabatic

The above equation gives us an indication of how atmosperic temperature would change with air pressure, but what are really interested in is how it changes

with altitude .To do that we need to know how pressure and altitude are related. Consider a static column of air with a cross section A, as shown in figure.A

horizontal slice of air in that column of thickness dZ and density

ρ will have mass ρAdZ. If the pressure at the top of the slice due to the weight of air above it is

P(Z+dZ), then the pressure at the bottom of the slice ,P(Z) will be P(z+dz)plus the added weight per unit area of the slice it self:

The negative sign indicates that temperature decreases with increasing altitude. Substituting the constant g =9.806m/s2, and the constant –volume specific

heat of dry air at room temperature, Cp 1005J/kg. 0C in (2

.6) yields

ATMOSPHERIC STABILITY

The ability of the atmosphere to disperse the pollutants emitted in to it depends to a large extent on the degree of stability. A comparison of the adiabatic

lapse rate with the environmental lapse rate gives an idea of stability of the atmosphere. When the environmental lapse rate and the dry adiabatic lapse rate

are exactly the same, a raising parcel of air will have the same pressure and temperature and the density of the surroundings and would experience no buoyant

force. Such atmosphere is said to be neutrally stable where a displaced mass of air neither tends to return to its original position nor tends to continue

its displacement

When the environmental lapse rate (-dT/dz.)Env is greater than the dry adiabatic lapse rate,Γ the atmosphere is said to be super adiabatic. Hence a raising

parcel of air, cooling at the adiabatic rate, will be warmer and less dense than the surrounding environment. As a result, it becomes more buoyant and tends

to continue it‟s up ward motion. Since vertical motion is enhanced by buoyancy, such an atmosphere is called unstable. In the unstable atmosphere the air

from different altitudes mixes thoroughly. This is very desirable from the point of view of preventing pollution, since the effluents will be rapidly

dispersed through out atmosphere. On the other hand, when the environmental lapse rate is less than the dry adiabatic lapse rate, a rising air parcel becomes

cooler and denser than its surroundings and tends to fall back to its original position. Such an atmospheric condition is called stable and the lapse rate is

said to be sub adiabatic. Under stable condition their is very little vertical mixing and pollutants can only disperse very slowly. As result, their levels

can build up very rapidly in the environment. When the ambient lapse rate and the dry adiabatic lapse rate are exactly the same, the atmosphere has neutral

stability. Super adiabatic condition prevails when the air temperature drops more than 1°C /100m; sub adiabatic condition prevail when the air temperature

drops at the rate less than 1°c/100m

Inversion

Atmospheric inversion influences the dispersion of pollutantsby restricting vertical mixing. There are several ways by which inversion layers can be formed

.One of the most common types is
the elevated subsidence inversion, This is usually associated with the sub tropical anti cyclone where the air is warmed by compression as it descends in a

high pressure system and achieves temperature higher than that of the air under neath. If the temperature increase is sufficient, an inversion will result

- It lasts for months on end
- Occur at higher elevation
- More common in summer than winter

The subsidence is caused by air flowing down to replace air, which has flowed out of the high-pressure region

Radiation Inversion

The surface of the earth cools down at night by radiating energy toward space. On cloudy night, the earth‟s radiation tends to be absorbed by water vapor,

which in turn reradiates some of that energy back to the ground. On the clear night, however, the surface more readily radiate energy to space, and thus

ground cooling occurs much more rapidly. As the ground cools, the temperature of the air in contact with the ground also drops. As is often the case on clear

winter nights, the temperature of this air just above the ground becomes colder than the air above it, creating an inversion. Radiation inversions begins to

form at dusk .As the evening progresses, the inversion extends to a higher and higher elevation, reaching perhaps a few hundred meters before the morning sun

warms the ground again, breaking up the inversion.

Radiation inversion occurs close to the ground, mostly during the winter, and last for only a matter of hours. They often begin at about the time traffic

builds up in the early evening, which traps auto exhaust at ground level and causes elevated concentration of pollution for commuters. With out sunlight,

photochemical reactions can not takes place, so the biggest problem is usually accumulation of carbon monoxide (CO). In the morning, as the sun warms the

ground and the inversion begins to the break up, pollutants that have been trapped in the stable air mass are suddenly brought back to earth in a process

known as fumigation. Fumigation can cause short lived high concentrations of pollution at ground level.

Radiation inversions are important in another context besides air pollution. Fruit growers in places like California have long known that their crops are in

greatest danger of frost damage on winter nights when the skies are clear and a radiation inversion sets in. Since the air even a few meters up is warmer

than the air at crop level, one way to help protect sensitive crops on such nights is simply to mix the air with large motor driven fans.

The third type of inversion, know as advective inversion is formed when warm air moves over a cold surface or cold air. The inversion can be a ground based

in the former case, or elevated in the latter case. An example of an elevated advective inversion occurs when a hill range forces a warm land breeze to

follow at high levels and cool sea breathes flows at low level in the opposite direction.

TOPOGRAPHICAL EFFECTS

In large bodies of water the thermal inertia of the water causes a slower temperature change than the near by land. For example, along an ocean coastline and during periods of high solar input, the daytime air temperature over the ocean is lower than over the land. The relative warm air over the land rises and

replaced by cooler ocean air. The system is usually limited to altitudes of several hundred meters, which of course, is where pollutants are emitted. The

breeze develops during the day and strongest in mid after noon. At night the opposite may occur, although, usually not with such large velocities. At night

the ocean is relatively warm and the breeze is from the cooler land the warmer ocean. The on shore breeze is most likely in the summer months, while the

off-shore land breeze more likely occur in winter months. A second common wind system caused by topographical effect is the mountain - valley wind. In this

case the air tends to flow down the valley at night Valleys are cooler at higher elevation and the driving force for the airflow result from the differential

cooling. Similarly, cool air drains off the mountain at night and flows in to the valley. During the day light hours an opposite flow may

occur as the heated air adjacent to the sun warmed ground begins to rise and flow both up the valley and up the mountain slopes. However, thermal turbulence

may mask the daytime up-slope flow so that it is not as strong as the nighttime down - slope flow. Both the sea breeze and the mountain valley wind are

important in meteorology of air pollution. Large power stations are often located on ocean costs or adjacent to large lakes. In this case the stack effluent

will tend to drift over the land during the day and may be subjected to fumigation.

Wind velocity and turbulence

The wind velocity profile is influenced by the surface roughness and time of the day. During the day, solar heating causes thermal turbulence or eddies set

up convective currents so that turbulent mixing is increased. This results in a more flat velocity profile in the day than that at night. The second type of

turbulence is the mechanical turbulence, which is produced by shearing stress generated by air movement over the earth‟s surface. The greater the surface

roughness, the greater the turbulence. The mean wind speed variation with altitude is the planetary boundary layer can be represented by a simple empirical

power.

In practice, because of the appreciable change in wind speed with altitude, a wind speed value must be quoted with respect to the elevation at which it is

measured. This reference height for surface wind measurement is usually 10 meters

Atmospheric turbulence is characterized by different sizes of eddies. These eddies are primarily responsible for diluting and transporting the pollutants

injected in to the atmosphere. If the size of the eddies is larger then the size of the plume or a puff then the plume or the puff will be transported down

wind by the eddy with little dilution. Molecular diffusion will ultimately dissipate the plume or the puff. If the eddy is smaller than the plume or the

puff, the plume or the puff will be disperse uniformly as the eddy entrains fresh air at its boundary.

Plume behavior

The behavior of a plume emitted from an elevated source such as a tall stack depends on the degree of instability of the atmosphere and the prevailing wind

turbulence.

Classification of plume behavior

1. Looping: it occurs under super adiabatic conditions with light to moderate wind speeds on a hot summer after noon when large scale thermal eddies are

present. The eddies carry portion of a plume to the ground level for short time periods, causing momentary high surface concentration of pollutants near the

stack. Thus the plume moves about vertically in a spastic fashion and the exhaust gases disperse rapidly

2. Conning: It occurs under cloudy skies both during day and night, when the lapse rate is essentially neutral. The plume shape is vertically

symmetrical about the plume line and the major part of the pollutant concentration is carried down -wind fairly far before reaching the ground level.

3. Fanning: occurs when the plume is dispersed in the presence of very light winds as a result of strong atmospheric inversions. The stable lapse rate

suppresses the vertical mixing, but not the horizontal mixing entirely. For high stacks, fanning is considered a favourable meteorological condition because

the plume does not contribute to ground pollution.

4. Fumigation: here a stable layer of air lies a short distance above the release point of the plume and the unstable air layer lies below the plume

.This unstable layer of air causes the pollutant to mix down -wind toward the ground in large lumps, but fortunately this condition is usually of short

duration lasting for about 30 minutes Fumigation is favored by clear skies and light winds, and it is more common in the summer seasons.

5. Lofting : The condition for lofting plume are the inverse of those for fumigation , when the pollutants are emitted above the inverse layer , they

are dispersed vigorously on the up ward direction since the top of the inversion layer acts as a barrier to the movement of the pollutants towards the ground

6. Trapping: occurs when the plume effluent is caught between two inversion layers. The diffusion of the effluent is severely restricted to the unstable

layer between the two unstable layers.

PLUME DISPERSION

Dispersion is the process by which contaminants move through the air and a plume spreads over a large area, thus reducing the concentration of pollutants it

contains. The plume spreads both horizontally and vertically. If it is gaseous, the motion of the molecules follows the low of gaseous diffusion The most

commonly used model for the dispersion of gaseous air pollutants is the Gaussian, developed by Pasquill, in which gases dispersed in the atmosphere are

assumed to exhibit idea gas behavior

The Gaussian plume model

The present tendency is to interpret dispersion data in terms of the Gaussian model. The standard deviations are related to the eddy diffusivities

Estimation of δyandδz

The values of δyandδz have been shown to be related to the diffusion coefficient in the y and z directions .As might be expected, δy and δz are functions of

down wind distance x from the source as well as the atmospheric stability conditions. Based on the experimental observation of the dispersion of plumes,

pasquill and Gifford have devised a method for calculating, δy and δz of the spreading plume from knowledge of the atmospheric stability. Six categories of

the atmospheric stability; A through F, were suggested and these are shown in the table 2.1 as a function of wind and solar radiation

Plume rise

Generally, effluent plumes from the chimney stacks are released in to the atmosphere at elevated temperatures. The rise of the plume after release to the

atmosphere is caused by buoyancy and the vertical momentum of the effluent. Under windless conditions, the plume rises vertically but more often it is bent as a result of the wind that is usually present. This rises of the plume adds to the stack an additional height H, such that the height H of the virtual

origin is

obtained by adding the term H, the plume rise, the actual height of the stack, Hs. The plume center line height H = Hs + H is known as the effective stack height and it is this height that is used in the Gaussian plume calculations.
Plume rise

Estimation of plume rise

1. Buoyant plumes

In the case of buoyant plumes, the influence of buoyancy is much greater than the influence of vertical momentum. Such plumes are usually obtained when the

release temperatures are more than 50 c greater than ambient atmospheric temperatures.
2. Plume rise under stable and calm conditions

When there is little or no wind, the bending of the plume is negligible small and it rises to some height where the buoyancy force is completely dissipated.

The recommended equation for such a situation is

3. Non- buoyant plumes

For sources at temperature close to the ambient or less than 50 ° C above ambient and having exit speed of at least 10m/sec, the following equation can be

used

AIR POLLUTION CONTROL

Pollution control equipment can reduce emissions by cleaning exhaust and dirty air before it leaves the business. A wide variety of equipment can be used to

clean dirty air. DNR engineers carefully study and review how these controls may work and the methods and requirements are put into a permit - a major duty

performed by the DNR.

Process Controls

There are other ways to reduce emissions besides using pollution control equipment--prevent emissions to begin with. Air quality permits help minimize,

reduce or prevent emissions as much as possible by placing requirements on how things are done.

Permits can specify the quantity, type, or quality of fuel or other substance used in a process. For example, a permit might specify the maximum percent of sulfur that can exist in the coal to

reduce sulfur dioxide emissions. A permit may specify the quantity of volatile chemicals in paint, solvent, adhesive or other product used in large quantity

during manufacturing. Permits can also help reduce the impact of emitted pollutants on local air by specifying smokestack height and other factors.

Engineers can also set combustion specifications to minimize emissions. For example, to help reduce nitrogen oxide formation, the combustion conditions in

the furnace can be altered. The flame temperature can be lowered or raised, the amount of time air remains in the combustion chamber can be altered, or the

mixing rate of fuel and air can be changed. These options are often reviewed, studied and best choices made depending upon cost, plant design and many other

variables.

GRAVITY SETTLING CHAMBERS

This is a simple particulate collection device using the principle of gravity to settle the particulate matter in a gas stream passing through its long

chamber. The primary requirement of such a device would be a chamber in which the carrier gas velocity is reduced so as to allow the particulate matter to

settle out of the moving gas stream under the action of gravity. This particulate matter is then collected at the bottom of the chamber. The chamber is

cleaned manually to dispose the waste.

The gas velocities in the settling chamber must be sufficiently low for the particles to settle due to gravitational force. Literature indicates that gas

velocity less than about 3 m/s is needed to prevent re-entrainment of the settled particles. The gas velocity of less than 0.5 m/s will produce good results.

Curtains, rods, baffles and wire mesh screens may be suspended in the chamber to minimize turbulence and to ensure uniform flow. The pressure drop through

the chamber is usually low and is due to the entrance and exit losses.

The velocity of the particles in the settling chamber can be obtained by Stokes‟ law as follows:

$Vs = (g(rp – r) D2) / 18 \mu$

Where,

D = Diameter of the particle. g = acceleration due to gravity rp = density of the particle

r = density of the gas µ = viscosity of the gas

The advantages of settling chambers are:

i) low initial cost,

ii) simple construction,

iii) low maintenance cost,

iv) low pressure drop,

v) dry and continuous disposal of solid particles,

vi) use of any material for construction, and

vii) temperature and pressure limitations will only depend on the nature of the construction material.

The disadvantages of this device are

i) large space requirements and

ii) only comparatively large particles (greater than 10 micron) can be collected.

Because of the above advantages and disadvantages, settling chambers are mostly used as pre-cleaners. They are sometimes used in the process industries,

particularly in the food and metallurgical industries as the first step in dust control. Use of settling chambers as pre-cleaners can also reduce the

maintenance cost of high efficiency control equipment, which is more subject to abrasive deterioration.

CYCLONES:

Settling chambers discussed above are not effective in removing small particles. Therefore, one needs a device that can exert more force than gravity force

on the particles so that they can be removed from the gas stream. Cyclones use centrifugal forces for removing the fine particles. They are also known as

centrifugal or inertial separators.

The cyclone consists of a vertically placed cylinder which has an inverted cone attached to its base. The particulate laden gas stream enters tangentially at

the inlet point to the cylinder. The velocity of this inlet gas stream is then transformed into a confined vortex, from which centrifugal forces tend to

drive the suspended particles to the walls of the cyclone. The vortex turns upward after reaching at the bottom of the cylinder in a narrower inner spiral.

The clean gas is removed from a central cylindrical opening at the top, while the dust particles are collected at the bottom in a storage hopper by gravity.

The efficiency of a cyclone chiefly depends upon the cyclone diameter. For a given pressure drop, smaller the diameter, greater is the efficiency, because

centrifugal action increases with decreasing radius of rotation. Centrifugal forces employed in modern designs vary from 5 to 2500 times gravity depending on

the diameter of the cyclone. Cyclone efficiencies are greater than 90% for the particles with the diameter of the order of 10 μ. For particles with diameter

higher than 20 μ, efficiency is about 95%.

The efficiency of a cyclone can be increased by the use of cyclones either in parallel or in series. A brief explanation of both arrangements is given below:

Multiple Cyclones:

A battery of smaller cyclones, operating in parallel, designed for a constant pressure drop in each chamber. The arrangement is compact, with convenient

inlet and outlet arrangements. They can treat a large gas flow, capturing smaller particles.

Cyclones in series:

Two cyclones are used in series. The second cyclone removes the particles that were not collected in the first cyclone, because of the statistical

distribution across the inlet, or accidental re-entrainment due to eddy currents and re-entrainment in the vortex core, thus increasing the efficiency.

The advantages of cyclones are:

i) low initial cost,

ii) simple in construction and operation,

iii) low pressure drop,

iv) low maintenance requirements,

v) continuous disposal of solid particulate matter, and

vi) use of any material in their construction that can withstand the temperature and pressure requirements.

The disadvantages of cyclones include:

i) low collection efficiency for particles below 5 – 10 μ in diameter,

ii) severe abrasion problems can occur during the striking of particles on the walls of the cyclone, and

iii) a decrease in efficiency at low particulate concentration.

Typical applications of cyclones are:

i) For the control of gas borne particulate matter in industrial operations such as cement manufacture, food and beverage, mineral processing and

textile industries.

ii) To separate dust in the disintegration operations, such as rock crushing, ore handling and sand conditioning in industries.

iii) To recover catalyst dusts in the petroleum industry.

iv) To reduce the fly ash emissions.

The operating problems are:

i) Erosion: Heavy, hard, sharp edged particles, in a high concentration, moving at a high velocity in the cyclone, continuously scrape against the wall and

can erode the metallic surface. ii) Corrosion: If the cyclone is operating below the condensation point, and if reactive gases are present in the gas stream,

then corrosion problems can occur. Thus the product should be kept
above the dew point or a stainless steel alloy should be used. iii) Build – up: A dust cake builds up on the cyclone walls, especially around the vortex

finder, at the ends of any internal vanes, and especially if the dust is hygroscopic. It can be a severe problem.

ELECTROSTATIC PRECIPITATORS:

Electrostatic precipitators (ESP) are particulate collection devices that use electrostatic force to remove the particles less than 5 micron in diameter. It

is difficult to use gravity settlers and cyclones effectively for the said range of particles. Particles as small as one-tenth of a micrometer can be removed

with almost 100% efficiency using electrostatic precipitators.

The principle behind all electrostatic precipitators is to give electrostatic charge to particles in a given gas stream and then pass the particles through

an electrostatic field that drives them to a collecting electrode.

The electrostatic precipitators require maintenance of a high potential difference between the two electrodes, one is a discharging electrode and the other

is a collecting electrode. Because of the high potential difference between the two electrodes, a powerful ionizing field is formed. Very high potentials –

as high as 100 kV are used. The usual range is 40- 60 kV. The ionization creates an active glow zone (blue electric discharge) called the „corona‟ or „corona

glow‟. Gas ionization is the dissociation of gas molecules into free ions.

As the particulate in the gas pass through the field, they get charged and migrate to the oppositely charged collecting electrode, lose their charge and are

removed mechanically by rapping, vibration, or washing to a hopper below.

In summary, the step by step process of removing particles using ESPs is:

i) Ionizing the gas.

ii) Charging the gas particles.

iii) Transporting the particles to the collecting surface.

iv) Neutralizing, or removing the charge from the dust particles.

v) Removing the dust from the collecting surface.

The major components of electrostatic precipitators are:

i) A source of high voltage

ii) Discharge and collecting electrodes.

iii) Inlet and outlet for the gas.

iv) A hopper for the disposal of the collected material.

v) An outer casing to form an enclosure around the electrodes.

The ESP is made of a rectangular or cylindrical casing. All casings provide an inlet and outlet connection for the gases, hoppers to collect the precipitated

particulate and the necessary discharge electrodes and collecting surfaces. There is a weatherproof, gas tight enclosure over the precipitator that houses

the high voltage insulators.

Electrostatic precipitators also usually have a number of auxiliary components, which include access doors, dampers, safety devices and gas distribution

systems. The doors can be closed and bolted under normal conditions and can be opened when necessary for inspection and maintenance. Dampers are provided to

control the quantity of gas. It may either be a guillotine, a louver or some such other device that opens and closes to adjust gas flow.

The safety grounding system is extremely important and must always be in place during operation and especially during inspection. This commonly consists of a

conductor, one end of which is grounded to the casing, and the other end is attached to the high voltage system by an insulated operating lever.

The precipitator hopper is an integral part of the precipitator shell and is made of the same material as the shell. Since ESPs require a very high voltage

direct current source of energy for operation, transformers are required to step up normal service voltages to high voltages. Rectifiers convert the

alternating current to unidirectional current.

Types of electrostatic precipitators:

There are many types of ESPs in use throughout the world. A brief description of three different types is given below:

A) Single stage or two stage:

In a single stage ESP, gas ionization and particulate collection are combined in a single step. An example is the "Cottrell" single-stage precipitator.

Because it operates at ionizing voltages from 40,000 to 70,000 volts, DC, it may also be called a high voltage precipitator. It is used extensively for heavy

duty applications such as utility boilers, large industrial boilers and cement kilns.

In the two-stage precipitator particles are ionized in the first chamber and collected in the second chamber. For example, "Penny"– the two stage

precipitator uses DC voltages from 11,000 to 14,000 volts for ionization and is referred to as a low voltage precipitator. Its use is limited to low inlet

concentration, normally not exceeding 0.025 grains per cubic feet. It is the most practical collection technique for many hydrocarbon applications, where the

initial clear exhaust stack turns into a visible emission as vapor condenses.

B) Pipe type or Plate type:

In the pipe type electrostatic precipitators, a nest of parallel pipes form the collecting electrodes, which may be round, or square. Generally the pipe is

about 30 cm in diameter or less. Most commonly a wire with a small radius of curvature, suspended along the axis of each pipe, is

used. The wires must be weighted or supported to retain proper physical tension and location, electrically insulated from the support grid and strong enough

to withstand rapping or vibration for cleaning purpose. The gas flow is axial from bottom to top.

The pipe electrodes, may be 2-5 m high. Spacing between the discharge electrode and collecting electrode ranges from 8-20 cm. Precipitation of the aerosol particles occurs on the inner pipe walls, from which the material can be periodically removed by rapping of pipes or by flushing water. The pipe type

precipitator is generally used for the removal of liquid particles.

In the plate type precipitators the collection electrodes consist of parallel plates. The discharge electrodes are again wires with a small curvature.

Sometimes square or twisted rods can be used. The wires are suspended midway between the parallel plates and usually hang free with a weight suspended at the

bottom to keep them straight. Discharge electrodes are made from non-corrosive materials like tungsten, and alloys of steel and copper. The gas flow is

parallel to the plates.

The plates may be 1-2 m wide and 3-6 m high. The parallel plates should be at equally spaced intervals (between 15 and 35 cm). The collection of the aerosols

takes place on the inner side of the parallel plates. The dust material can be removed by rapping either continuously or periodically. The dust particles

removed fall into the hopper at the base of the precipitator.

Collection electrodes should have a minimum amount of collection surface, bulking resistance, resistance to corrosion and a consistent economic design.

Plate type precipitators are horizontal or vertical, depending on the direction of the gas flow. Gas velocities are maintained at 0.5-0.6 m/s in these

precipitators. They‟re used for collection of solid particulate.

C) Dry and Wet Precipitators:

If particulate matter is removed from the collecting electrodes, by rapping only, it is known as a dry precipitator. If, on the other hand, water or any

other fluid is used for removal of the solid particulate matter, then it is known as a wet precipitator. In general, wet precipitators are more efficient.

However, it is the dry type plate precipitators that are predominantly used.

Efficiency:

Generally, the collection efficiency of the electrostatic precipitator is very high, approaching 100%. Many installations operate at 98 and 99% efficiency.

Some materials ionize more readily than others and are thus more adapted to removal by electrostatic precipitation.

Acid mists and catalyst recovery units have efficiencies in excess of 99%. However, for materials like carbon black, which have very low efficiencies due to very low collection capacity, by proper combination of an ESP with a cyclone, very high efficiencies can be achieved. The gas entering the ESP may be pre-

treated (i.e., removing a portion of particulate) by using

certain mechanical collectors or by adding certain chemicals to the gas to change the chemical properties of the gas to increase their capacity to collect on

the discharge electrode and thus increase the efficiency.

The factors affecting the efficiency of electrostatic precipitators are particle resistivity and particle re-entrainment. Both are explained below:

A) Particle Resistivity :

Dust resistivity is a measure of the resistance of the dust layer to the passage of a current. For practical operation, the resistivity should be 107 and

1011 ohm-cm. At higher resistivities, particles are too difficult to charge. Higher resistivity leads to a decrease in removal efficiency. At times,

particles of high resistivity may be conditioned with moisture to bring them into an acceptable range.

If the resistivity of the particles is too low,(<10 ohm–cm), little can be done to improve efficiency. This is due to the fact that the particles accept a

charge easily, but they dissipate it so quickly at the collector electrode, that the particles are re- entrained in the gas stream. This results in low

efficiency.

Particle resistivity depends upon the composition of the dust and the continuity of the dust layer. Resistivity is also affected by the ESP operating

temperature and by the voltage gradient that exists across the dust layer.

B) Particle re-entrainment:

This is a problem associated with particle charging. It occurs primarily in two situations – due to either inadequate precipitator area, or inadequate dust

removal from the hopper. Re-entrainment reduces the precipitator performance, because of the necessity of recollecting the dust that had been previously

removed from the carrier gas. The problem can be overcome by a proper design of the ESP and necessary maintenance.

The advantages of using the ESP are:

i) High collection efficiency.

ii) Particles as small as 0.1 micron can be removed.

iii) Low maintenance and operating cost.

iv) Low pressure drop (0.25-1.25 cm of water).

v) Satisfactory handling of a large volume of high temperature gas.

vi) Treatment time is negligible (0.1-10s).

vii) Cleaning is easy by removing the units of precipitator from operation.

viii) There is no limit to solid, liquid or corrosive chemical usage.

The disadvantages of using the ESP are:

i) High initial cost.

ii) Space requirement is more because of the large size of the equipment.

iii) Possible explosion hazards during collection of combustible gases or particulate.

iv) Precautions are necessary to maintain safety during operation. Proper gas flow distribution, particulate conductivity and corona spark over rate must

be carefully maintained.

v) The negatively charged electrodes during gas ionization produce the ozone.

The important applications of ESPs in different industries throughout the world are given as below:

i) Cement factories:

a) Cleaning the flue gas from the cement kiln.

b) Recovery of cement dust from kilns.

ii) Pulp and paper mills:

a) Soda-fume recovery in the Kraft pulp mills.

iii) Steel Plants:

a) Cleaning blast furnace gas to use it as a fuel.

b) Removing tars from coke oven gases.

c) Cleaning open hearth and electric furnace gases.

iv) Non-ferrous metals industry:

a) Recovering valuable material from the flue gases.

b) Collecting acid mist.

v) Chemical Industry:

a) Collection of sulfuric and phosphoric acid mist.
b) Cleaning various types of gas, such as hydrogen, CO2, and SO2.

c) Removing the dust from elemental phosphorous in the vapor state.

vi) Petroleum Industry:

a) Recovery of catalytic dust.

vii) Carbon Black industry:

a) Agglomeration and collection of carbon black.

viii) Electric Power Industry:

a) Collecting fly ash form coal-fired boilers.

SCRUBBERS:

Scrubbers are devices that remove particulate matter by contacting the dirty gas stream with liquid drops. Generally water is used as the scrubbing fluid. In

a wet collector, the dust is agglomerated with water and then separated from the gas together with the water. The mechanism of particulate collection and removal by a scrubber can be described as a four-step process.

i) Transport : The particle must be transported to the vicinity of the

water droplets which are usually 10 to 1000 times larger.

ii) Collision :The particle must collide with the droplet.

iii) Adhesion :This is promoted by the surface tension property.

iv) Precipitation: This involves the removal of the droplets, containing

the dust particles from the gas phase.

The physical principles involved in the operation of the scrubbers are: i) impingement, ii) interception, iii) diffusion and iv) condensation. A brief

description is given below:

i) Impingement :

When gas containing dust is swept through an area containing liquid droplets, dust particles will impinge upon the droplets and if they adhere, they will be

collected by them. If the liquid droplet is approximately 100 to 300 times bigger than the dust particle, the collection efficiency of the particles is more,

because the numbers of elastic collisions increase.

ii) Interception:

Particles that move with the gas stream may not impinge on the droplets, but can be captured because they brush against the droplet and adhere there. This is

known as interception.

iii) Diffusion:

Diffusion of the particulate matter on the liquid medium helps in the removal of the particulate matter.

iv) Condensation:

Condensation of the liquid medium on the particulate matter increases the size and weight of the particles. This helps in easy removal of the particles.

The various types of scrubbers are:

i) Spray towers.

ii) Venturi scrubbers.

iii) Cyclone scrubbers.

iv) Packed scrubbers.

v) Mechanical scrubbers.

The simpler types of scrubbers with low energy inputs are effective in collecting particles above 5 – 10 µ in diameter, while the more efficient, high energy

input scrubbers will perform efficiently for collection of particles as small as 1 – 2 µ in diameter.

The advantages of scrubbers are:

i) Low initial cost.

ii) Moderately high collection efficiency for small particles.

iii) Applicable for high temperature installations.

iv) They can simultaneously remove particles and gases.

v) There is no particle re- entrainment.

The disadvantages of scrubbers are:

i) High power consumption for higher efficiency.

ii) Moderate to high maintenance costs owing to corrosion and abrasion.

iii) Wet disposal of the collected material.

The scrubbers are used in a variety of applications. Some of the situations are:

i) They‟re particularly useful in the case of a hot gas that must be cooled for some reason.

ii) If the particulate matter is combustible or if any flammable gas is present, even in trace amounts, in the bulk gas phase, a scrubber is preferred to

an electrostatic precipitator.

iii) Scrubbers can be used when there are waste water treatment systems available on the site, with adequate reserve capacity to handle the liquid

effluent.

iv) Scrubbers are also used when gas reaction and absorption are required simultaneously with particulate control.

FABRIC FILTERS:

Fabric filtration is one of the most common techniques to collect particulate matter from industrial waste gases. The use of fabric filters is based on the

principle of filtration, which is a reliable, efficient and economic methods to remove particulate matter from the gases. The air pollution control equipment

using fabric filters are known as bag houses.

Bag Houses

A bag house or a bag filter consists of numerous vertically hanging, tubular bags, 4 to 18 inches in diameter and 10 to 40 feet long. They are suspended with

their open ends attached to a manifold. The number of bags can vary from a few hundreds to a thousand or more depending upon the size of the bag house. Bag

houses are constructed as single or compartmental units. In both cases, the bags are housed in a shell made of rigid metal material. Occasionally, it is

necessary to include insulation with the shell when treating high temperature flue gas. This is done to prevent moisture or acid mist from condensing in the

unit, causing corrosion and rapid deterioration of the bag house.

Hoppers are used to store the collected dust temporarily before it is disposed in a landfill or reused in the process. Dust should be removed as soon as

possible to avoid packing which would make removal very difficult. They are usually designed with a 60 degrees slope to allow dust to flow freely from the

top of the hopper to the bottom discharge opening. Sometimes
devices such as strike plates, poke holes, vibrators and rappers are added to promote easy and quick discharge. Access doors or ports are also provided.

Access ports provide for easier cleaning, inspection and maintenance of the hopper. A discharge device is necessary for emptying the hopper. Discharge devices can be manual (slide gates, hinged doors and drawers) or automatic trickle valves, rotary airlock valves, screw conveyors or pneumatic conveyors).

Filter Media

Woven and felted materials are used to make bag filters. Woven filters are used with low energy cleaning methods such as shaking and reverse air. Felted

fabrics are usually used with low energy cleaning systems such as pulse jet cleaning. While selecting the filter medium for bag houses, the characteristics

and properties of the carrier gas and dust particles should be considered. The properties to be noted include:

a) Carrier gas temperature

b) Carrier gas composition

c) Gas flow rate

d) Size and shape of dust particles and its concentration

The abrasion resistance, chemical resistance, tensile strength and permeability and the cost of the fabric should be considered. The fibers used for fabric

filters can vary depending on the industrial application. Some filters are made from natural fibers such as cotton or wool. These fibers are relatively

inexpensive, but have temperature limitations (< 212 F) and only average abrasion resistance. Cotton is readily available making it very popular for low

temperature simple applications. Wool withstands moisture very well and can be made into thick felts easily.

Synthetic fibers such as nylon, orlon and polyester have slightly higher temperature limitations and chemical resistance. Synthetic fibers are more expensive

than natural fibers. Polypropylene is the most inexpensive synthetic fiber and is used in industrial applications such as foundries, coal crushers and food

industries. Nylon is the most abrasive resistant synthetic fiber making it useful for applications filtering abrasive dusts. Different types of fibers with

varying characteristics are available in the market.

Fabric Treatment

Fabrics are usually pre-treated, to improve their mechanical and dimensional stability. They can be treated with silicone to give them better cake release

properties. Natural fibers (wool and cotton) are usually preshrunk to eliminate bag shrinkage during operation. Both synthetic and natural fabrics usually undergo processes such as calendering, napping, singeing, glazing or coating. These processes increase the fabric life and improve dimensional stability and

ease of bag cleaning.

a) Calendering:

This is the high pressure pressing of the fabric by rollers to flatten, smooth, or decorate the material. Calendering pushes the surface fibers down on to

the body of the filter medium. This is done to increase surface life, dimensional stability and to give a more uniform
surface to bag fabric. b) Napping:

This is the scraping of the filter surface across metal points or burrs on a revolving cylinder. Napping raises the surface fibers, that provides a number of

sites for particle collection by interception or diffusion. Fabrics used for collecting sticky or oily dusts are occasionally napped to provide good

collection and bag cleaning ease.

c) Singeing:

This is done by passing the filter material over an open flame, removing any straggly surface fibers. This provides a more uniform surface.

d) Glazing:

This is the high pressure pressing of the fiber at elevated temperatures. The fibers are fused to the body of the filter medium. Glazing improves the

mechanical stability of the filter and helps reduce bag shrinkage that occurs from prolonged use.

e) Coating:

Coating or resin treating involves immersing the filter material in natural or synthetic resin such as polyvinyl chloride, cellulose acetate or urea -

phenol. This is done to lubricate the woven fibers or to provide high temperature durability or chemical resistance for various fabric material.

Operation of a bag house:

The gas entering the inlet pipe strikes a baffle plate, which causes larger particles to fall into a hopper due to gravity. The carrier gas then flows upward

into the tubes and outward through the fabric leaving the particulate matter as a "cake" on the insides of the bags. Efficiency during the pre-coat formation

is low, but increases as the pre-coat (cake) is formed, until a final efficiency of over 99% is obtained. Once formed, the pre-coat forms part of the filtering medium, which helps in further removal of the particulate. Thus the dust becomes the actual filtering medium. The bags in effect act primarily as a

matrix to support the dust cake. The cake is usually formed within minutes or even seconds. The accumulation of dust increases the air resistance of the

filter and therefore filter bags have to be periodically cleaned. They can be cleaned by rapping, shaking or vibration, or by reverse air flow, causing the

filter cake to be loosened and to fall into the hopper below. The normal velocities at which the gas is passed through the bags at 0.4-1m/min. There are many

types of "filter bags" depending on the bag shape, type of housing and method of cleaning the fabric.

Efficiency:

The efficiency of bag filters may decrease on account of the following factors:

a) Excessive filter ratios - 'Filter ratio' is defined as the ratio of the carrier gas volume to gross filter area, per minute flow of the gas. Excessive

filter ratios lower particulate removal efficiency and result in increased bag wear. Therefore, low filter ratios are recommended. Therefore, low filter

ratios are recommended for high concentration of particulate.

b) Improper selection of filter media - While selecting filter media, properties such as temperature resistance, resistance to chemical attack and abrasion

resistance should be taken into consideration.

Operating Problems:

Various problems during the operation of a bag house are:

a) Cleaning -

At intervals the bags get clogged up with a covering of dust particles that the gas can no longer pass through them. At that point, the bags have to be

cleaned by rapping, shaking or by reverse air flow by a pulse jet.

b) Rupture of the cloth -

The greatest problem inherent in cloth filters is the rupture of cloth, which results from shaking. It is often difficult to locate ruptures and when they‟re found the replacement time is often considerable.

c) Temperature -

Fabric filters will not perform properly if a gross temperature overload occurs. If the gas temperature is expected to fluctuate, a fiber material that will

sustain the upper temperature fluctuation must be selected.
Also, whenever the effluent contains a reactive gas like SO2 which can form an acid whenever the temperature in the bag house falls below the dew point it

can create problems. Sometimes it may even be necessary to provide an auxiliary heater to make sure that the temperature in the bag house does not fall below

acid gas dew point.

d) Bleeding -

This is the penetration of the fabric by fine particles, which is common in fabric filtration. It can occur if the weave is too open or the filter ratio is

very high. The solution is to use a double layer material or a thick woven fabric.

e) Humidity -

This is a common and important problem, especially if the dust is hygroscopic. It would therefore be advisable to maintain moisture free conditions within

the bag house, as a precautionary measure.

f) Chemical attack -

This is another problem associated with fabric filters. The possibility of chemical attack due to corrosive chemicals present in the effluent. A proper

choice of fabric filter will avoid this problem.

Filter cleaning mechanisms:

The following mechanisms are used for cleaning the filters in a bag house:

i) Rapping

ii) Shaking

iii) Reverse air flow (back wash)

iv) Pulse jet

Multi-Compartment Type Bag House:

If the requirements of the process being controlled are such that continuous operation is necessary, the bag filter must be of a multi-compartment type to

allow individual units of the bag filter to be successively off-stream during shaking. This is achieved either manually in small units or by programming

control in large, fully automatic units. In this case, sufficient cloth area must be provided to ensure that the filtering efficiency will not be reduced

during shaking off periods, when any one of the units is off-stream.

The advantages of a fabric filter are:

i) High collection efficiencies for all particle sizes, especially for particles smaller than 10 micron in diameter.

ii) Simple construction and operation.

iii) Nominal power consumption.

iv) Dry disposal of collected material.

The disadvantages of a fabric filter are:

i) Operating limits are imposed by high carrier gas temperatures, high humidity and other parameters.

ii) High maintenance and fabric replacement costs. Bag houses are difficult to maintain because of the difficulty in finding and replacing even a single

leaking bag. Also as general rule, about 1/4th of the bags will need replacement every year.

iii) Large size of equipment.

iv) Problems in handling dusts which may abrade, corrode, or blind the cloth.

The applications of a fabric filter are:

Fabric filters find extensive application in the following industries and operations:

i) Metallurgical industry

ii) Foundries

iii) Cement industry

iv) Chalk and lime plants

v) Brick works

vi) Ceramic industry

vii) Flour mills

Cost:

A bag filter is comparatively expensive to install. Its power consumption is moderate. In most cases, the maintenance cost is high because the bags have to

be repaired or replaced regularly. The nature of the gas and the dust decide the frequency of such maintenance work.

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