Meteorology

UNIT-2

Meteorology:

→ The study of charactoristics of weather elements and science of atmosphere is known as "meteorology"

→ the parameters of meteorology is of great impo rtance in transport, diffusion & natural cleansing of pollutants in atmosphere.

→ Therefore, the information of meteorology is neccessary in planning control measures for air pollution and locating the industry.

mateorological factors influencing AP

→ Primary factors

(a) Temperature
(b) wind direction & speed
(c) mixing Height
(d) Atmospheric Stability

→ secondary factors

(a) Humidity
(b) Precipitation
(c) visibility
(d) solar radiation

Lapse rate :

The temperature of the well mixed air above 300m gets decreased by increase increase in altitude

→ This vertical temperature gradient is called as "Lapse rate".

Atmospheric Lapse rate :

→ It is also known as Environmental lapse rate

→ It is defined as the reduction of air temp. with increasing altitude.

→ In the lower regions of the atmosphere, the decrease in temperature with altitude occurs at a uniform rate of 3.5°F (1.94°c) Per 1000 feet (304m) of altitude.

→ Atmospheric lapse rate depends on conductive heating, adiabatic expansion & compression all of which causes the cooling of air as it moves up in the atmosphere & warming of air as it descends downwards in the atmosphere.

Types of Atmospheric Lapse rate

① Dry adiabatic lapse rate

② wet / saturated adiabatic lapse rate

(i) Dry adiabatic lapse rate:

→ In this type, for every 100 m increase in altitude, there is 1° celsius of cooling of air (i.e 1°c/100m, 10°c/km or 5.5°F/1000 feet)

→ thus, when dry air rises to 300m, it will cool by 3°

→ when it descends 300 m, it will regain its original temperature as its temperature rises by 3°.

→ As air rises up, it cools to the point when condensaation begins & clouds are formed.

(ii) wet/saturated ALR

→ Air saturated with water carries as much moisture as it can hold at a particular temperature.

→ This is called saturated air and has wet/saturated adiabatic lapse rate of 0.5°c per 100m, 5°c/km or 3.3°F/1000 feet

Super adiabatic lapse rate :

→ when the prevailing Environmental lapse rate is greater than adiabatic lapse rate then the Environmental lapse rate is known as "super-adiabatic lapse rate".

→ In this case, the rising of air will always remain warmer and less denser than the surrounding environment.

→ This leads to accelration of air particles to move up.

→ During the mixing of air pollutants, the atmospheric condition is said to be unstable and dispersion of pollutants will be quick and minimizes the intensity of pollution

→ By adopting this method, effective dispersion of pollutants and less rate of ~~pollutants~~ ~~or~~ pollution can be achieved.

Sub-adiabatic lapse rate :

→ when the prevailing Environmental lapse rate is less than adiabatic lapse rate then the Environmental lapse rate is known as sub-adiabatic lapse rate.

→ In this case, the rising of parcel of air cools more quickly then the surrounding environment i.e, air is denser than the surroundings and hence it will not be able to rise up to higher heights.

→ the atmospheric Condition is said to be stable in nature where, it is not favour-able for Effective dispersion of pollutants.

→ Due to the stable atmosphere, the rate of pollution will be higher where as rate of dispersion of pollutants gets reduced.

Atmospheric stability:

→ the temperature of the well mixed air above 300m gets decreased by increase in altitude

→ This vertical temperature gradient is known as "Lapse rate" and the value given is the Normal lapse rate

→ During the occurrence of negative lapse rate, the lighter warmer air at higher level covers a dense cold stratum of air at ground level. This process is called "Inversion".

→ During inversion, the vertical movement of air is stopped and below the inversion layer, the pollution will be concentrated.

→ Due to which the temperature is stable during temperature inversion & small amount of mixing takes place.

→ under such conditions pollutants in the air do not disperse.

wind direction & speed

-> The direction & speed of surface winds govern the drift and diffusion of air pollutant discharged near the ground level.

-> If the wind speed is more at or near the source of pollution then the pollutants rapidly carried away from the source.

-> the dispersion of pollutants will not exist at the same concentration but will rapidly diluted with greater volumes of air.

-> If the wind speed is low, pollutants tend to be concentrated near the source

-> such light winds persists for long period leads to greater increase in concentration of pollutants

-> The Effect on motion of the Contaminants due to wind direction and speed can't be assumed in rough terrain.

-> Hills may deflect the air flow either horizontally, vertically or both.

-> The amount of deflection depends on the vertical stability of the atmosphere.

→ In valleys, the pollutant carried by a wind tend to flow either up or down the valley, following its meanderings.

→ wind speed helps in estimating the travel time of a pollutant from source to the receptor.

Wind direction Recorder

→ The National Environmental Engineering research institute (NEERI) has developed some devices for measuring the meteorological variables

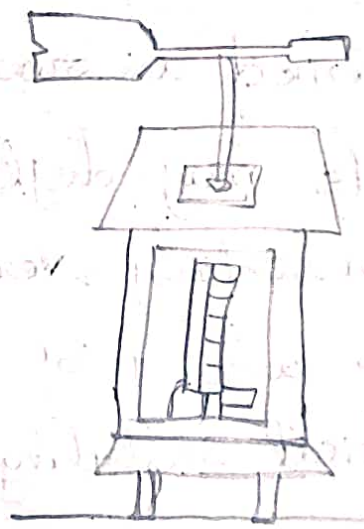
→ The WDR patented by NEERI is a simple one which employs the conventional wind vane to sense the direction.

→ It is automatic & operated mechanically without any power supply.

→ It continuously records on an attached chart

→ There are 4 main types of wind vanes for measuring direction

1. Flate plate vane
2. splayed vane
3. Aerofoil vane
4. Running avg. anemograph



WDR

wind speed Recorder

-> Instruments for measuring wind speed are called anemometers.

-> Instruments for recording wind speed are called anemographs.

-> The rate of rotation of the shaft to which the cups are attached indicates the wind speed and is transmitted to a recorder

-> The NEERI has developed & patented a wind speed recorder.

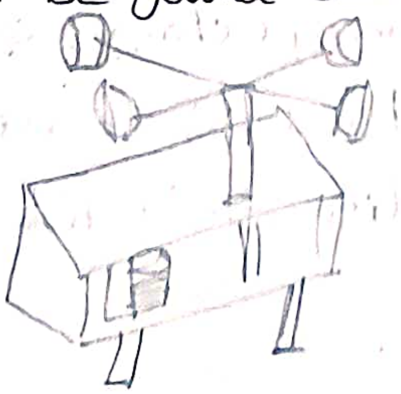
-> In the instrument, a 4 cup rotor is employed to sence the wind.

-> The motion of the cup is transfered after reducing its speed by a greater system to the pen which makes a continuous rise & fall impression on chart paper.

-> this rate of rise or fall is ∝ to the wind speed.

-> This gives 24-hr record in one setting.

-> wind speed @ a particular time & the avg wind speed can be found out from this record.



WSR

Wind turbulence

→ It refers to rapid fluctuations in wind velocity

→ The atmosphere does't flow smoothly but has seemingly random, Erratic motion

→ The turbulence caused by 2 factors

→ ① Due to frictional force occuring b/w the moving air & the Earth surface

→ ② Due to drastic thermal gradients, which Cause air to move rapidly upward & downwards.

→ Causes of Turbulence

→ ① mechanical turbulence :- Induced by vertical Shear from horizontal flow

② Thermal turbulence :- Induced by convection of heated air.

mechanical turbulence

→ Eddies are small less variable in size

→ high frequency (changes over time period of sec)

→ typically found in lowest km of atmosphere and in discrete patches or layers.

Thermal turbulence

-> eddies are large and variable in size
-> low frequency (changes over minutes)
-> the larger the eddy, the longer the dissip-ation time.

Determination

-> It is based on no. of factors including

① temp
② Air density
③ Pressure
④ Humidity

-> the simplest model for turbulence is the "Turbulence intensity (T_I) model"

$$T_I = \frac{\sigma}{V_{avg}}$$

where T_I = Turbulence intensity measured as the overall level of turbulence

σ = standard deviation of the avg wind speed

V_{avg} = avg wind velocity

Wind Rose

→ The design of any class of diagrams for showing the wind direction distribution experienced at a particular location over a considerable period is known as "wind rose"

→ Generally, it consists of a circle from which 8 or 16 lines emerge

→ when the length of each line increases then the frequency of the wind also increases

→ If the length of each line decreases then then the frequency of the wind also decreases from that particular ~~location~~ directions.

→ The frequency of calm conditions is entered in center.

→ There are various types of wind rose constructions.

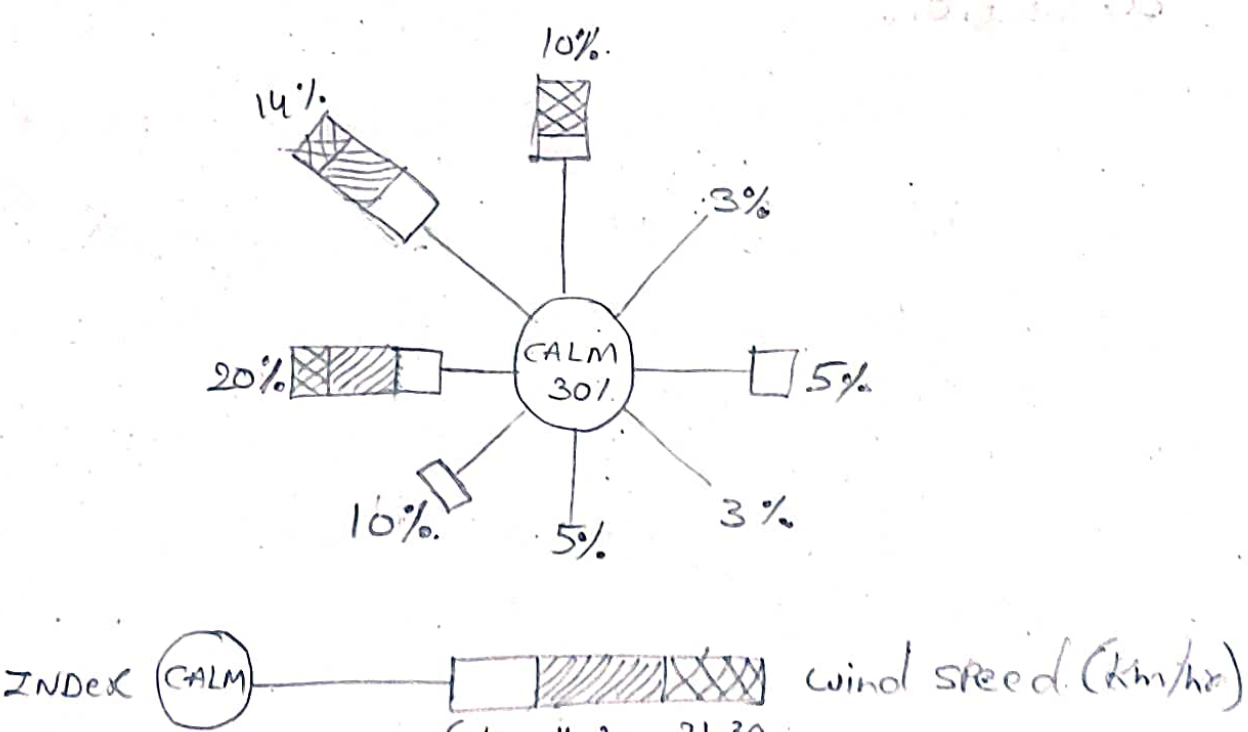
→ Some of them associate wind direction with other meteorological conditions and some show the wind speed range from each direction.

→ The construction of wind rose can be carried out from the data achieved over a given period of time such as a particular month / season / a year

→ During the construction of wind roses, the mateorological convention are required to keep in view that the direction of wind referes to the direction from which the wind is blowing.

→ The preparation of wind rose diagram is carried out using suitable scale to represent lines & diferent speeds of wind.

→ The observations related to wind speed below 1 km/hr are recorded as CALM



Wind rose types

1) Precipitation wind rose
2) smoke windrose
3) sulphur dioxide wind rose
4) Hydrocarbon wind rose

→ Instead of wind speed, the parameters of Precipitation, smoke, SO_2, HC etc are attached to the wind direction.

→ These are known as "pollution Roses".

Uses of Wind rose diagram

→ It is used to analyse the wind data

→ To obtain the most suitable runway direction.

measurement of mateorological variables

1) wind direction Recorder
2) wind speed recorder
3) Humidity measurement
4) Temperature measurement
5) solar radiation measurement

Humidity measurement :

-> Humidity can be measured by using "whirling psychrometer".

-> It is one of the simplest & most reliable instruments

-> It comprised of 2 thermometers

-> One with a wet cloth surrounding the bulb is known as wet bulb

-> The Dry bulb & wet bulb are whirled in the air & the temp. of the both bulbs are noted

-> The relative humidity of the air can be found from the temp difference b/w the dry bulb & wet bulb thermometers.

→ other instruments that can be used for measuring Humidity are;

1) Hair Hygrometer
2) Infra-red Hygrometer

Temperature measurement:

→ A common Instrument for measurement of temp. is the thermometer.

Types of thermometer

1) mercury thermometer – depend on thermal expansion
2) Bimetalic thermometer – Based on the differential expansion of two metals
3) Electrical resistance thermometer – is based on the variation in the electrical resistance of metalic wire with change in temp.
4) Thermo couple – is based on the electrical current which flows when 2 electrical conductors made of 2 different metals are joined together.

-> However, A thermometer must be shielded from radiant energy to obtain readings accurately.

-> Proper aspiration is also neccessary to avoid the stagnation of the air inside the radiation sheild.

-> NEERI has developed a motor aspirated radiation shielded temp. sensor for temp. inversion studies.

Solar radiation measurement

-> The following are the instruments used to measure solar radiation

1) Pyrheliometer
2) solarimeter
3) Chemical actinometer

Plume Behaviour :

Plume :

It refers to the path & extent in the atmo-sphere of the gaseous effluents released from a source, usulally stack.

Behaviour :

It depends on localized air stability

→ Effluents from tall stacks are often injected to an effective height of several hundred metres above ground because of the cumulative effects of buoyancy & velocity on plume rise

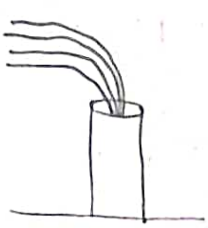
→ Diurnal variations in the atmospheric stability and long term variations also have influence on plume behaviour.

Types of plume behaviour :

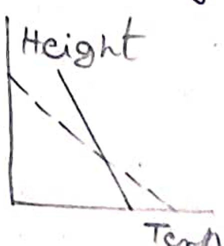
1) Coning :

→ It is cone shaped type of plume

→ It takes place in a near neutral atmosphere (adiabatic condition) when the wind velocity is greater than 32 km/h



Coning



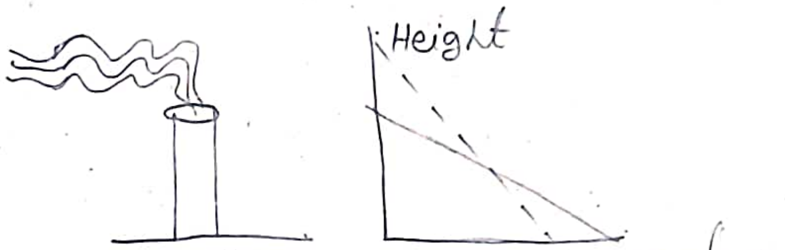
2) Looping

-> It is a wavy shaped type of plume

-> It occurs in a highly unstable atmosphere because of rapid mixing

-> The plume gets dispersed rapidly with the help of degree of turbulence

-> If the plume reaches the ground, high concentrations may occur near to the stack.



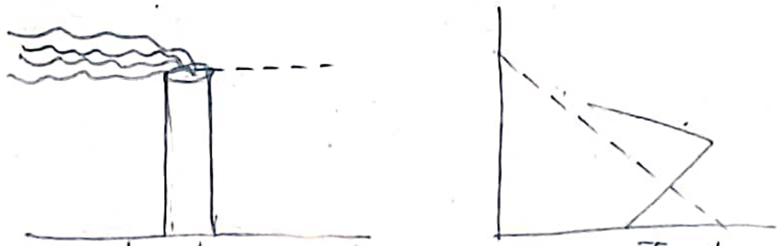
Looping

3) Lofting

-> It occurs when there is a strong lapse rate above a surface inversion.

-> The diffusion in this condition is rapid upward, but downward diffusion does't penetrate the inversion layer

-> Under such conditions, the emissions will not reach the ground / surface

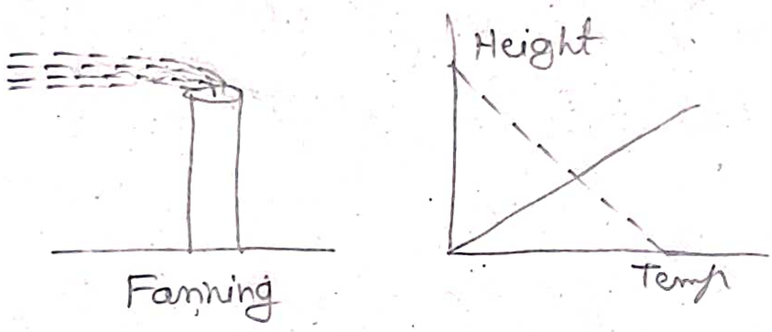


Lofting

4) Fanning

→ It is a type of plume emitted under extrem inversion condition.

→ In this condition, the plume will spread horizontally thus it is difficult to predict the concentrations at ground level

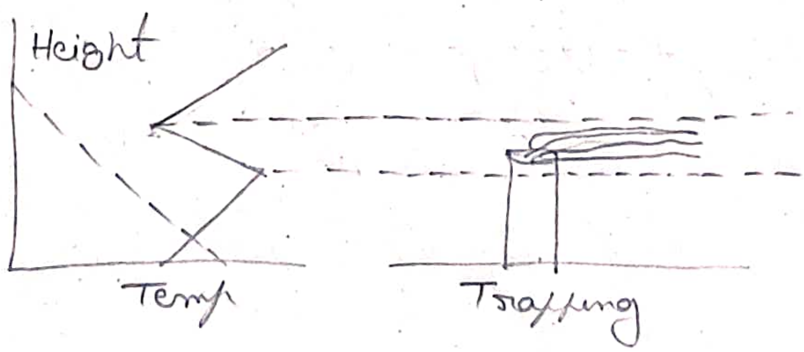


5) Trapping

→ This type of plume is caught in between inversions

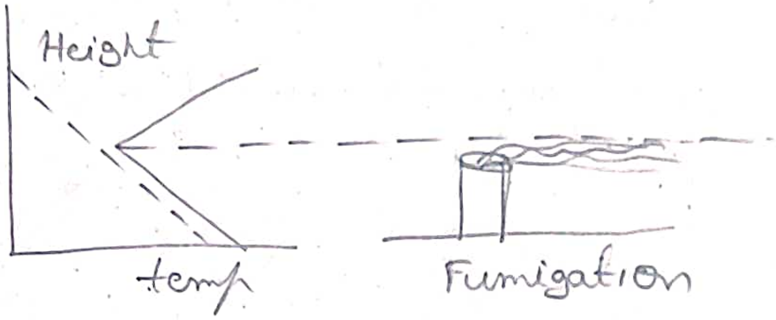
→ It is very critical from the point of ground level concentrations of pollutants

→ It can diffuse only upto a limited vertical height.



6) Fumigation :

→ It is a phenomenon in which pollutants that are aloft in the air are brought rapidly to ground level when the air destabilizes.



Plume Rise :

→ Gases that are emitted from stacks are often pushed out by fans

→ As the turbulent exhaust, gases exit the stack they mix with ambient air.

→ The mixing of ambient air into the plume is called "Entrainment".

→ As the plume entrains air into it, the plume diameter grows as it travels downward.

→ These gases have momentum as they enter the atmosphere.

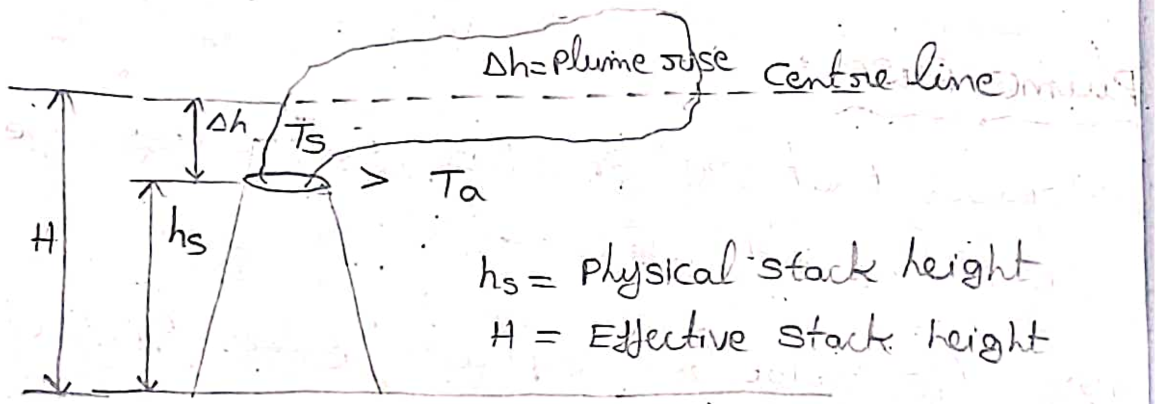
→ Often these gases are heated & are warmer than the outdoor air.

→ In these cases the emitted gases are less dense than the outside air & are therefore buoyant.

→ A Combination of gases momentum & buoyancy causes the gas to rise

→ This is refered to as "plume rise" and allows air pollutants emitted in this gas stream to be lofted higher in the atmosphere.

→ Since the plume is higher in the atmosphere and at a further distance from the ground, the plume will disperse more before it reaches ground level.



→ The stack height is an Imp factor in determining the pollution level @ a given location.

→ The "effective height" of stack is the sum total of stack height & plume rise beyond the stack ~~height~~ exit.

→ The plume rise depends on many factors like

1) Exit velocity
2) wind speed
3) Stack dia
4) Plume temp.
5) Lapse rate

Estimation of Plume rise :

→ Several formulas are available to predict the plume rise (Δh) from stacks.

→ most of the formulas are empirical in nature as the theory has't been developed adequately.

1) IS Formula :

→ The Bureau of Indian Standards has suggested that the following Brigg's formula be used to compute plume rise for practical use (IS: 8829).

(a) For hot effluents with heat release of the order of 10^6 cal/s or more

$$\Delta h = 0.84 (12.4 + 0.09 h) \frac{Q_H^{1/4}}{\bar{u}}$$

where; Q_H = Heat release in Calories/second

h = Stack height (m)

$\bar{u}$ = wind speed (m/s)

(b) For not very hot releases & which can be counted as momentum sources above

$$\Delta h = \frac{3 W_o D}{\bar{u}}$$

where; W_o = Efflux velocity (m/s)

D = Stack exit dia

2) Moses & Carson formula

$$\Delta h = C_1 \frac{V_s d}{\bar{u}} + C_2 \frac{Q_h^{1/2}}{\bar{u}}$$

where; Δh = Plume rise (m)

V_s = Stack exit velocity (m/s)

$\bar{u}$ = wind speed (m/s)

d = stack dia (m)

Q_h = Heat emission rate (K cal/s)

C_1 & C_2 = Plume rise regression coefficients which depends on atmospheric stability

a) unstable condition — $C_1 = 3.47$, $C_2 = 5.15$

b) neutral condition — $C_1 = 0.35$, $C_2 = 2.64$

c) stable condition — $C_1 = -1.04$, $C_3 = 2.24$

Stack Height:

→ The Height of the stack & height of plume rise above the stack plays a major role in the ground level concentration expected on the down wind side.

→ The actual stack height (H) is easy to determin while effective stack height (He) is quite difficult to estimate

→ For a given stack height, the concentration at ground level decreases with increase in wind velocity.

→ However there is a "Critical velocity" when the ground concentration attains its max value which is given by

$$C_m = \frac{M.K}{H^2} \sqrt[3]{\frac{1}{V.A_T}}$$

where; C_m = max concentration of pollutants on ground level.

H = Stack height

M = mass of the pollutant gases discharged per unit time

V = Volume of the pollutant gases discharged per unit time

A_T = Difference in temp of stack gases & surrounding air

K = Constant which depend on factors such as.

1) Horizontal & vertical mixing of Pollutants in the air

2) Settling velocity of Polluting substances

3) Discharge characteristics of the gases from stack.

→ The Empirical formula for the stack height Emitting max concentration of Pollutants is given as;

$$C_{max} = \frac{AFMm}{H^2}\left(\frac{n}{V.t}\right)^{1/3}$$

where;

C_{max} = max concentration of pollutants

A = coefficient depends upon atmospheric condition
200 - for Indian conditions

F = coefficient, depends upon dust precipitation efficiency, ranges from 0.8 to 0.95

M = quantity of flue gases (g/s)

m = coefficient depends upon velocity of flue gases

H = stack height (m)

n = no. of emitting sources

V = volume of gases leaving the stack (m^3/s)

t = Difference in temp b/w flue gases & atmospheric temp at the top of the stack.

1) A factory uses 200000 l of furnace oil (specific density 0.97) per month. If for one million litres of oil used per year, the particulate matter emitted is 3.0 tonnes per year, SO_2 emitted is 59.7 tonnes per year, NO_x emitted is 7.5 tonnes per year, HC emitted is 0.37 tonnes per year & CO emitted is 0.52 tonnes per year. Calculate the height of the chimney required to be provided for safe dispersion of the pollutants.

As per Central Board for prevention & control of water pollution, New Delhi, the chimney height can be calculated by using $H = 74 (Q)^{0.27}$

where Q = Particulate matter emission (tonnes/hour)
H = Chimney height (m)

Sol

Given; The particulate emission = 3 t/million litre of oil / year

$200000 \times 12 = 2400000$ l/year
$= 2.4$ million l/year

$\therefore$ Total Particulate emission $= 2.4 \times 3 = 7.2$ t/year
$= \frac{7.2}{300 \times 24}$ tonnes/hour

(Assume 300 working days & 24 hours/day)

→ Now $H = 74 \left(\frac{7.2}{300 \times 24}\right)^{0.27}$

$H = 11.47$ m

→ The height of the chimney for effective dispersion of SO_2 is to be calculated as per the formula

$H = 14 (Q)^{0.3}$ → (given in Sec. 19.5)

where Q = SO_2 emission (kg/h)
H = Chimney height (m)

$\therefore Q = 59.7 \times 2.4 = 144$ t/year $= 20$ kg/h

$\therefore H = 14 (20)^{0.3} = 34.4$ m

$\therefore$ Adopt a Height of 34.4 m

Note :-
Since the emission of SO_2 is much more than that of NOx, CO & HC. so calculation of stack height is