36

Instrumentation and Control

36.1. Importance of Measurement and Instrumentation in Power Plant. 36.2. Measurement of Water Purity. 36.3. Gas Analysis, O_2 and CO_2 Measurements. 36.4. Measurement of Smoke and Dust. 36.5. Measurement of Moisture in Carbon Dioxide Circuit. 36.6. Nuclear Measurements.

36.1. IMPORTANCE OF MEASUREMENT AND INSTRUMENTATION IN POWER PLANT

The instruments are used in power plants for a number of reasons as to operate the power plant most efficiently. Instruments furnish accurate information for guidance to safe, continuous and proper plant operation. The information given by the recording units from the control room helps to direct its operation so as to achieve the best performance possible and furnish data for calculation so that results may be compared from time to time. These may be used to check on the internal condition of equipment and indicate when and where maintenance or repair is needed. This also helps to an operating crew to detect appreciable deviation from normal. The functions of instruments to be performed are listed below :

(1) Operating guidance. (2) Performance calculations. (3) Maintenance and repair guidance. (4) Economical supervision, and (5) Cost allocation.

The instruments used in modern power plants include the pressure and temperature measurements of steam and water, the flow measurement, CO_2 indicator, air flow recorder, draft gauge, vacuum gauge, flue-gas thermometer, fuel meter, watt-hour meter and many others. The installation of recording type instruments to aid operating supervision will depend on the extent to which it is necessary for the superintendent to have a check record on the work of his staff.

With the introduction of modern type of steam power plants, there is tendency towards remote control of power plant equipment. The use of computer has opened a new era for the successful control and operation of power plants.

Only important instruments which are used in power plants are discussed in this chapter.

36.2. MEASUREMENT OF WATER PURITY

The impurities enter into the feed water circuit mostly through the condenser by way of leaky tubes. The cooling water for condenser may be obtained from the sea or rivers contaminated by dye-works and acid or sewage works. Priming, corrosion, and excessive scaling of tubes in the boilers are troubles likely to result from concentration.

In thermal power plants, the water should be of purest form and contaminants should be kept to minimum to avoid serious troubles. If the concentration of impurities exceeds certain limit in high pressure boilers, these may cause scale formation, corrosion and cracking of metallic parts of the plant.

The electrical conductivity of water is used for determining the content of salt in feed water, steam and condensate. The conductivity of water is a measure of the ability of water to conduct an electric current. Pure water is highly resistant to the passage of an electric current. In other words, its conductivity is very low. With the addition of mineral salts, acids, or alkalies to pure water, they dissociate into positive and negative ions. These, in turn, increase conductivity in proportion to the number of ions present. Therefore, conductivity can be used as a test to determine the amount of total dissolved solids in water.

Conductance is measured in ohms or reciprocal of ohms. One mho is the conductance of a substance through which one ampere of current flows at potential difference of one volt. This measurement is usually made with a conductivity meter calibrated to read in micro-mhos which is 10^{-6} of a mho and is more convenient to use when dealing with low conductivities associated with water treatment. It has been recommended that for 100 bar power-plants, the conductivity of water should not exceed 0.3 micro-mho/cm^3 at 20°C. The idea of its extreme purity can be had by the fact that the best public water supply has a conductivity of about 30 to 40 and distilled water has a conductivity of 6 micro-mhos/cm^3.

The conductivity meter used is basically an electric measuring device. A wheatstone bridge shown in Fig. 36.1 serves as the measuring circuit. The temperature sensitive resistance R_t provides temperature compensation (if the temperature exceeds above 20°C). The conductivity cell immersed in the water sample forms the unknown resistance in one leg of the bridge. The change in solution conductivity changes its resistance R_x. The amplifier then actuates a balancing motor which immediately reacts to move the slider on R_4 to a new position of balance. The instrument pen moves a corresponding amount to record the new conductivity value.

Where the nature and composition of the impurity is variable, it is not practicable to calibrate the instrument in terms of the impurity and scale is usually calibrated in terms of the conductivity units. The interpretation of the readings being left to the chemist.

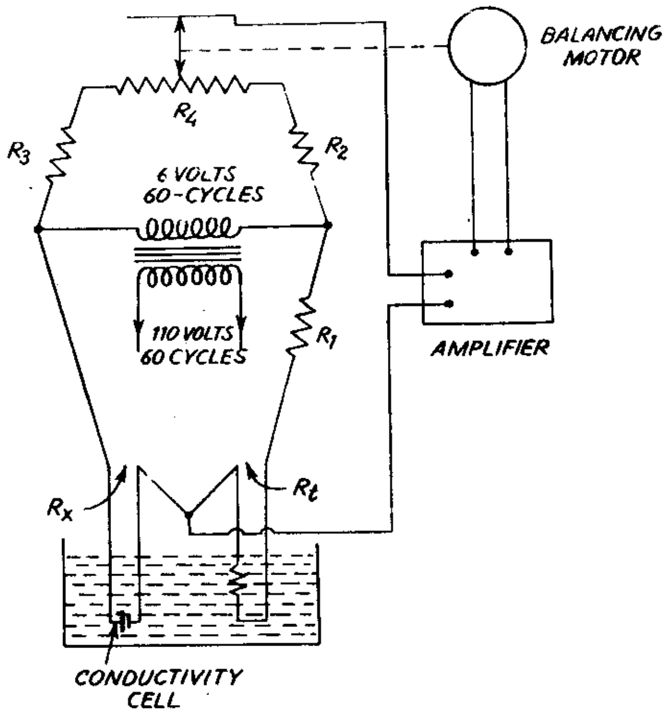


Fig. 36.1. Simplified electric circuit used to measure the conductivity (dissolved impurities) of water.

The conductivity measurement performs many useful jobs in the power plant :

1. The purity of the steam leaving the boiler may be determined by measuring the conductivity of a condensed steam sample. This also determines the carry-over of boiler water in steam to the superheater and turbine. Excessive carry over may cause the failure of superheater tubes and loss of turbine efficiency.

In this method, the steam coming out of boiler is passed through the pressure reducing valve and cooling coil and fed to the 'dionic' meter which gives a continuous record of the electrical conductivity and so of the purity of the condensed steam.

2. The conductivity of feed water to determine total dissolved solids is also helpful in adjusting the blowdown rate. Usual chemical methods for this determination are time-consuming and complicated. The conductivity test procedure is quick and simple. Special techniques are not needed therefore routine tests can be run in a matter of minutes by the plant operator.

Some typical values of conductivity obtained with 'Dionic Meter' are listed as follows :

Type of Water	*Units in micro-mhos/cm^3 at 20°C*
Distilled water	6
Condensate of boiler feed	0.9 to 5
Cooling water	—
Tidal water	550 to 1200
Estuary	1000 to 55000
Water towers	3000 to 4000
Sea water	50,000
Public water supply	34 to 420

It is a general practice to test for condenser tube leakage when the 'dionic' figure exceeds 4 units.

(*a*) **Dissolved Oxygen Recorders.** The presence of dissolved oxygen in feed water is fully responsible for the corrosion of boiler tubes and impairs the performance of the condenser. The deaerating system is included in the plant circuit to reduce the concentration of oxygen but it is always difficult to eliminate the dissolved oxygen entirely from the system. It is always necessary that the value of dissolved oxygen should be kept below 0.1 c.c. per litre. The chief causes of increase in oxygen content in feed water are leaky valves and defective seals on pumps. An equipment is always used to record the percentage of oxygen in feed-water and indicate with the help of alarm when the level exceeds above allowable value.

An oxygen recorder commonly used is shown in Fig. 36.2.

The feed-water to be analysed enters the cooler *A* through pressure reduction valve as shown in figure where its temperature is reduced to 20°C. Then it passes through a constant head device *B* which maintains the correct water flow through an orifice situated in a water jacket *C* surrounding a Katharometer. The water then flows through *D* where it comes in intimate contact with H_2-gas. Some of the H_2 gas is dissolved in water and part of the oxygen is given up. The H_2-gas is generated in the electrolytic cell *E*, passes through one side of Katharometer and then flows through compensator. The second side of Katharometer is exposed to the gas in the chamber.

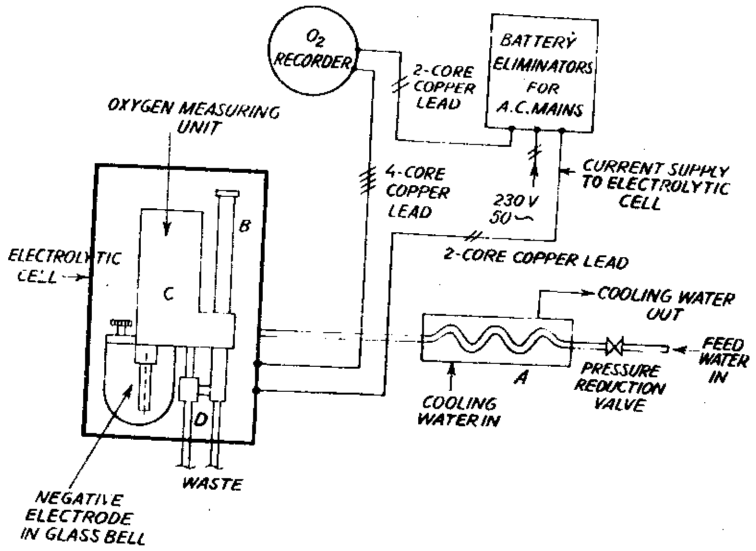


Fig. 36.2. Measurement of dissolved oxygen in feed water.

The Katharometer consists of four-platinum spirals mounted in cells in a central metal block and connected together to form a Wheatstone bridge. Two of the cells are open to the pure hydrogen and two of the gas from the contact chamber. The spirals are heated by an electric current and when the same gas surrounds all four, then they attain the same temperature and there is no deflection of the galvanometer in the indicator. If one pair is exposed to H_2 and other pair to the mixture of H_2 and O_2 in the contact chamber, the temperatures of two pairs of spirals will differ and the deflection will be shown on the galvanometer. This deflection is directly proportional to the oxygen in mixture and proportional to the oxygen dissolved in water as the oxygen in mixture in contact chamber is proportional to the oxygen dissolved in the feed water passing through the chamber. The scale of the galvanometer is calibrated to read directly the dissolved oxygen content of the feed water.

(*b*) **Measurement of pH (Potential of Hydrogen) value of water.** The term pH is used to indicate the degree of acidity or alkalinity of a solution as mentioned earlier in Chapter No. 19. Its value is measured on a pH scale just as temperature is measured on the scale of a thermometer.

The value of 7 on pH scale represents the pH of a neutral solution (pure water). If the substance has a pH greater than 7 (7 to 14) the solution becomes increasingly alkaline and if it drops below 7 and approaches zero, the solution becomes increasingly acidic. The pH value then is simply a number between 0 and 14 on a scale that depicts the degree of acidity or alkalinity of a solution.

The pH number mentioned above is derived from the expression

$$\text{pH} = \log_{10}\left(\frac{1}{\text{H}^+}\right)$$

The concentration of H_2 ions is expressed in moles per litre. All water solutions of acids and bases owe their chemical activity to the relative hydrogen (H^+) and hydroxyl (OH^-) ion concentrations. In water, the equilibrium product of these two concentrations is a constant 10^{-14} at 25°C. Hence, if the concentrations of H^+ and OH^- ions in pure water at 25°C are equal, H^+ is 10^{-7} and pH is the $\log_{10}$ $(1/10^{-7}) = 7$.

The pH scale covers a 0 to 14 range for both acid and alkaline solutions. Pure water (pH = 7) is neutral. Increase in its acidity boosts its hydrogen-ion concentration and causes pH value to fall below 7. Similarly, increase in alkaline solution concentration raises the pH above 7.

The scale forming and corrosive tendencies of a water are greatly influenced by pH value. Low pH (acidic) favours corrosion of metallic equipment coming in contact with the water. High pH (alkaline) may precipitate calcium carbonate from solution to form scale on the surfaces of pipelines, boiler tubes, condensers and heat exchange equipments.

To overcome the scale forming and corrosive properties of water, its pH value is controlled by chemical treatments as discussed in Chapter No. 19. The pH value of feed water is controlled at a minimum value of 10.5. This is high enough to prevent corrosion and at the same time allows precipitation of the various scale forming salts.

In general, the analysis of any given water is incomplete unless the pH has been determined. The pH is also a valuable tool in interpreting the scale forming and corrosion tendencies of the water. The pH value of water is generally measured by electrometric meter which is an electrical equipment.

Electrometric Method of pH Measurement. The principle of this instrument is described below.

Every metal has a tendency to go into the solution of its salt in the form of positive ions. In other words, each metal has got certain particular solution pressure which pushes the molecules of metals in the form of positively charged ions into the solution. This pressure causing the flow of positive metal ions is called electrolytic solution tension. When the metal is dipped into the solution of its own salts, the metallic ions in solution also exert osmotic pressure. The equilibrium condition is reached when osmotic pressure balances the electrolytic solution tension. Thus the difference in potential between the metal electrode and solution containing the metal ions depends on the difference between electrolytic solution tension and osmotic pressure. The electrode potential (potential at metal electrode solution boundary) of metal immersed in a solution at a given temperature is given by

$$E = E_0 + \frac{0.0001982\ (T + 273)}{n} \cdot \log_e (a)$$

where E_0 = Electrode potential when its active ion concentration in solution is equal to unity.

T = Temperature in °C

n = Valency of the ion

a = Active concentration of metallic ions in grammatical equivalent per litre.

In practice, only the potential difference is measured and therefore the pH meter always has two elements. A measuring element, the potential of which depends on the hydrogen ions concentration and a comparison element, the potential of which remains always constant. Two such elements are electrically connected to form a galvanic system and by measuring e.m.f. of this system, we can find out the active concentration of the hydrogen ions in solution and its pH value. Electrometer is used for measuring potential difference between the two electrodes.

The measurement of pH of water is carried out by means of glass electrode and reference electrode which are dipped into a solution and the e.m.f. is measured by the pH meter.

When a glass membrane forms the boundary between two solutions of different pH values, a voltage is developed across the membrane thickness, which obeys the law.

$$E = \frac{RT}{F}\,(\text{pH}_s - \text{pH}_x) \times 2.303$$

where pH_s is the pH value of a known solution and pH_x is the pH value of a solution to be determined. R and F are the chemical and physical constants and T is the absolute temperature. The voltage developed is temperature dependent, being 58 mV/pH at 20°C rising 73 mV/pH at 100°C. It is, therefore, necessary to calibrate the electrode assembly using buffer solutions of known pH as sample.

When a glass surface is dipped in a solution containing hydrogen ions, it also develops electro-potential proportional to hydrogen-ion concentration in the solution. Therefore, glass electrode can be used for measuring hydrogen ion concentration or the pH of the solution.

The sole purpose of the reference electrode is to establish a stable electrical connection via the sample solution to the outside of the pH sensitive membrane of the glass electrode. Due to the asymmetric behaviour of inner and outer layer of the pH sensitive membrane, an asymmetry potential is developed.

An electrical circuit using the above principle and glass electrode for measuring the pH value of water is shown in Fig. 36.3.

This circuit is a combination of electrometer and potentiometer. The potential of the glass (or other) electrode is opposed by an adjustable known voltage supplied by a potentiometric circuit. When these two voltages are equal, there will be no voltage on the grid and this is indicated by a very sensitive metre in the circuit. The electrode voltage is equal to the voltage indicated on potentiometric dial.

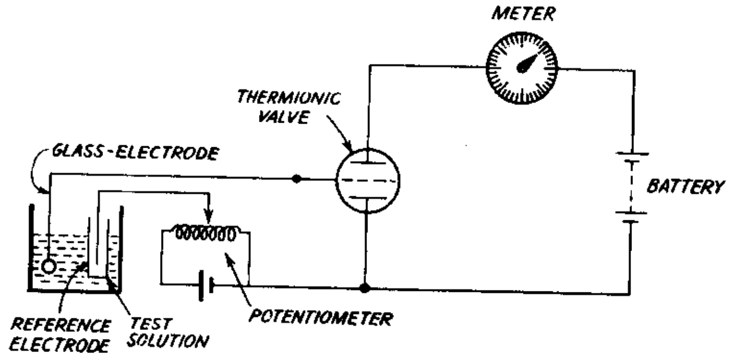


Fig. 36.3. (*a*) Electric circuit diagram for measuring the pH of the solution.

The glass electrode gives accurate results when the pH of the solution to be tested is up to 9. Above this value of pH, it gives results which are higher than the results given by hydrogen electrode. This is known as alkali error and it is considerably large at pH 12 to 13. Therefore, the glass-electrodes cannot be used in strongly alkaline solutions. The other electrodes which are in use are calomel electrode and antimony electrode.

Accessory Unit for pH and Redox Potential Measurements

The pH value or the redox potential of liquids can be measured continuously using recent *Siemens M 54110 unit.* The unit has an input stage electrically isolated from the main amplifier so that electrodes with high internal resistance or ion-sensitive electrodes can be connected.

Measuring the pH value means determining the hydrogen ion concentration of a solution as an indicator of its acidity or alkalinity. When measuring the redox potential, the reduction or oxidation force of a solution is determined.

Fig. 36.3 (*b*). Instrument for measuring pH value or redox potential of liquids.

36.3. GAS ANALYSIS, O_2, CO_2 AND CO MEASUREMENTS

The purpose of gas analysis is to determine the concentration of one or more components of a gas mixture. In steam power plants, the object of gas analysis is to keep the concentration of CO_2 and O_2 as minimum as possible therefore constant recording of these components in exhaust gases is necessary. The recording of these components helps to improve the efficiency of steam generation.

The common types of analysers used for the measurement of CO_2 and O_2 are described below :

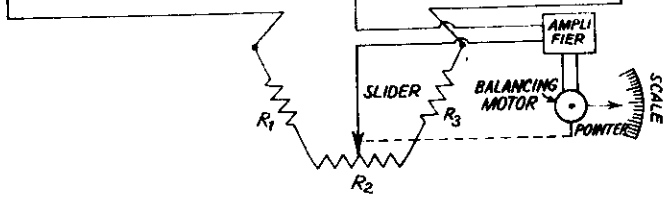


Fig. 36.4. Electrical circuit for the measurement of CO_2 content in the gases.

(A) The Measurement of CO_2 by thermal conductivity measurement. The proportion of various constituents of flue gases can be determined by measuring its thermal conductivity as the gases differ in their ability to conduct the heat. If the thermal conductivity of air is considered 1 at 0°C, then the thermal conductivity of CO_2, H_2, N_2 and O_2 are 0.585, 7.35, 1.015 and 1.007 respectively.

The most common method used for measuring CO_2 content in flue gases is shown in Fig. 36.4. This consists of hot wire thermal conductivity gas analysis cell. It consists of two chambers, each containing a wire filament as shown in figure. The gas is passed through one chamber whose conductivity is to be measured and other chamber is filled with a reference gas like air and sealed.

The platinum wire elements are passed through the cells as shown in figure and form a wheatstone bridge circuit. Under normal working conditions, these elements are heated by the bridge current. The temperature of the filament in the measuring chamber rises as the thermal conductivity of the gases passing around it decreases, as the heat of the filament cannot be carried by the gases. Thus the temperature, and hence the resistance, of the two platinum wire elements changes, and unbalances the bridge and provides an unbalanced voltage which is proportional to the percentage of CO_2 present in the flue gases. This unbalanced voltage can be used for measuring the percentage of CO_2 in flue gases.

Errors which would arise from variation in temperature of the gas have to be compensated and this is usually done by inserting another resistance in the circuit (not shown).

If appreciable H_2 is present in flue gases then the reading of CO_2 based on thermal conductivity of CO_2 content of the gases may be inaccurate. This type of instrument relies on the fact that the proportion of H_2 present is small and constant.

Another important consequent of the gas is water vapour, the thermal conductivity of which is approximately same as for CO_2. Therefore, the effect of variation in water vapour should be eliminated by either drying or saturating the gas sample before analysis.

(A) Magnetic Wind Method Measurement of Oxygen in Flue Gases. The flue gas analysis is an important tool to detect the efficient use of fuel. In past, this analysis has been limited to the determination of CO_2% in the flue gases. But with improved technique, it is now possible to detect and record % of O_2 continuously. Since % of O_2 is more reliable and fundamental guide to the % of excess air for combustion, the tendency is towards the wider use of O_2 analysis in steam raising plant.

Most industrial equipment of this nature makes use of the magnetic properties of gases for its operation. All gases are influenced by a magnetic field, either seeking the weakest part of the field-dimagnetic gases or strongest part of the field-paramagnetic gases. Most gases are dimagnetic, the two notable exceptions are O_2 and nitric oxide which are strongly paramagnetic but nitric oxide is very much less paramagnetic than oxygen. Provided the properties of flue gases do not vary within wide limits and gases do not contain appreciable amount of nitric oxide, this magnetic phenomenon can be used for the determination of the percentage of O_2 to a high degree of accuracy.

The types of instruments used are two, ***magnetic wind type*** or ***force type***. Both are described below :

The analyser used for measuring the O_2 content in flue gases works on the principle of paramagnetic properties of O_2. Oxygen is the only paramagnetic component in the flue gases. It has very high magnetic permeance compared with other gases.

The magnetic permeance of paramagnetic gases decreases with an increase in temperature. The gas molecules near the heated body in the magnetic field lose part of their magnetic properties and are pushed out of the magnetic field by cooler molecules. The temperature of cooler molecules entered in the magnetic field where heated body is situated, is increased and in turn, they are also pushed out of magnetic field by other molecules. In this way, a convection flow known as 'Magnetic Wind' is created which cools the heated body. The magnetic wind increases with an increase in O_2 content in the flue gases and cooling of the heated body is intensified. The temperature change of heated body alters its electric resistance which indicates the concentration of O_2 in the gas mixture. Therefore, the O_2 content can be measured by measuring an electric resistance of the heated body which can be one of the arms of Wheatstone bridge.

The electric circuit used for O_2 measurement using the magnetic wind type principle is shown in Fig. 36.5.

This instrument aspirates the gas into the measuring cell through an annulus with an horizontal bypass tube as shown in figure.

This by-pass tube has two identical adjacent platinum windings on the outside which are connected into a Wheatstone Bridge circuit and become heated by the application of voltage across the bridge.

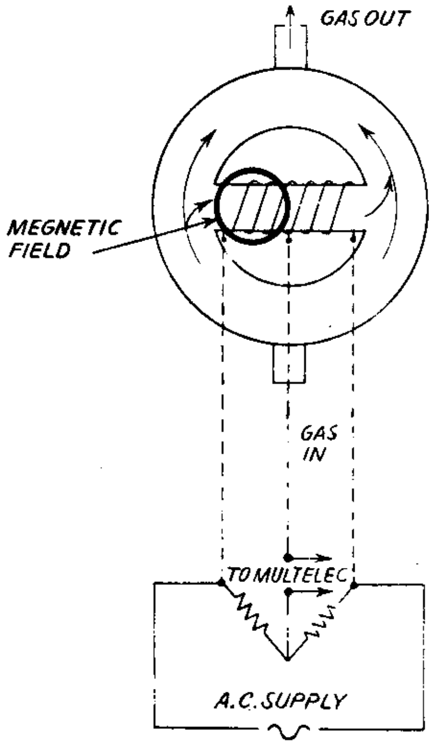


Fig. 36.5. Paramagnetic Oxygen Analyser.

One of these windings is cut by an intense magnetic field provided by a large permanent magnet. When the sample of flue gas enters into the cell, O_2 is drawn into the by-pass by virtue of its paramagnetic properties. It is heated by the winding which reduces the magnetic susceptibility of the gas. Cool O_2 from the gas of higher susceptibility is drawn in the tube displacing the hot gas which passes along the tube back into the annulus. This 'magnetic wind' causes differential cooling of the two windings and by the change of resistance with temperature unbalances the bridge. The resulting unbalanced e.m.f. is measured by a standard potentiometer recorder and is proportional to the oxygen content of the sample.

(*b*) **Dissolved Oxygen Probe.** The new EIL model 8012 dissolved O_2 probe now available from Kent Instruments (Australia) Private Limited gives a direct read-out of dissolved O_2 concentration in ppm on a conventional pH/mV meter.

It comprises an O_2 sensor capsule (a silver/lead galvanic cell) connected to a miniaturised circuit within the probe body. This circuit converts the current output of the capsule, produced by the electro-chemical reduction of O_2 diffusing into it from the sample, to a millivolt signal compatible with the input requirements of the pH/mV meter. The circuit is powered from four tiny rechargeable nickel/cadmium cells contained within the probe body and the probe cable serves the dual function of connecting the probe in operation to the pH/mV meter and of connecting the probe when not in use to the battery charging unit. The cells can be recharged without removing them from the probe. Automatic temperature compensation is carried out by means of a thermistor mounted on the probe stem close to the sensor capsule.

The adjustable control at the top of the probe body is used to calibrate the probe and metre combination.

Westinghouse Oxygen Analyser. It provides instantaneous and actual oxygen measurement in the heart of combustion system. No sampling system is required with this analyser. It can be installed right in the gas stream to provide continuous monitoring of combustion unit as shown in Fig. 36.6. It has no moving parts so there is hardly any chance of its breakdown. Its corrosion-resistant stainless steel construction allows it to be used with any fuel.

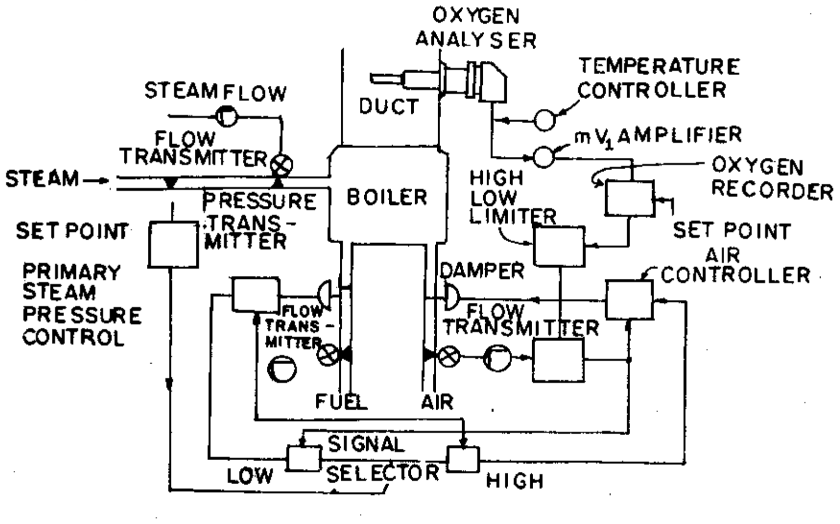


Fig. 36.6. Westinghouse oxygen Analyser.

Similar zirconia oxygen analyser with self-cleaning sample loop, flame trap, purgeable sensor enclosure and thermal shock absorber is manufactured in India by Taylor Instruments Co., 14-Mathura Road, Faridabad. It is claimed that the monitoring is done in less than five seconds after exposing the analyser to the gases. The circuit diagram of the analyser is shown in Fig. 36.7.

CO-Measurement. The monitoring of CO is direct measurement of completeness of combustion, regardless of the flue gas O_2 content. Substantial fuel saving can be achieved by reducing excess air in the

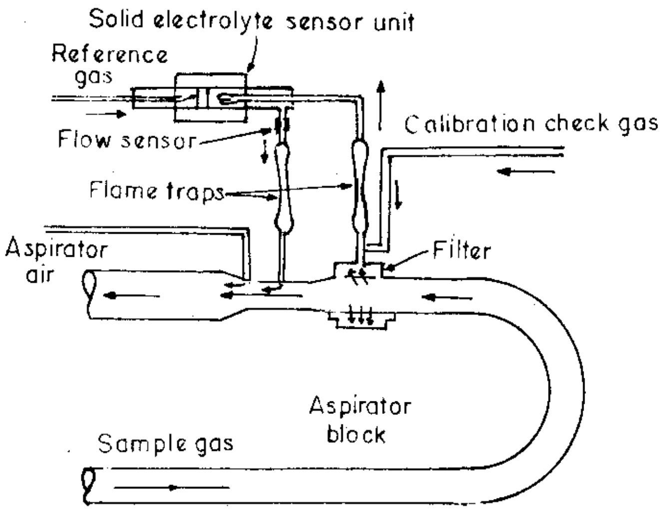


Fig. 36.7. Zirconia O_2 Analyser.

furnace and thus in the stack gas. The largest amount of heat loss in the boiler (7-14%) is contained in dry stack-gases. This heat loss is directly proportional to the stack gas temperature and the excess air (air/fuel ratio). By carefully controlling this ratio, the boiler can operate with an average of 30% less air. This results in a 6% less heat loss in overall.

The classical method of estimating the correct A : F ratio is to measure O_2 in the flue gases. However, air leaks, a common malady in boilers using induced draft fans, have disproportionate effect on the recorded O_2 analyser (5% infiltration of air near O_2 analyser can cause it to read 95% high). On the other hand, CO in flue gas can be measured in ppm concentrations, well within the range of today's CO analysers. CO is *only formed in the flame envelope* of the burners. Therefore, the traces of CO provide a direct measurement of fuel burning systems performance and efficiency.

It can be seen from Fig. 36.8 that, as the proper A : F ratio is reached, there is a sharp increase on the CO Vs excess air. By operating boilers at this break-point (which is 100-250 ppm of CO), excess air is minimised and fuel usage is reduced. This range for control is independent of fuel being used (coal, oil or gas). The point at which the CO curve starts to rise rapidly, is coincident with the maximum of the thermal efficiency curve and corresponding to minimum total heat loss. The heat loss reaches a minimum as CO level approaches minimum. This break point is very well defined, acting like a on-off switch. Added advantage is, with the reduction of excess air, less O_2 is available for the oxidation of SO_2 to SO_3 and thus the formation of H_2SO_4 is greatly reduced.

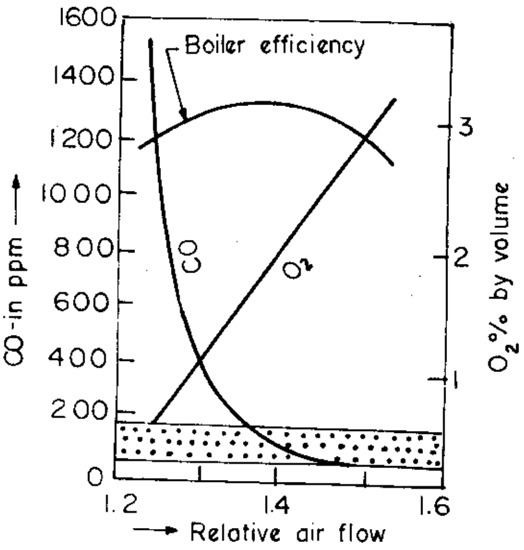


Fig. 36.8.

The main components of a system used for CO-analyzer are shown in Fig. 36.9. This works on the principle of non-dispersive infra-red adsorption and is suitable for all biatomic molecules. The principle of the apparatus is based on molecular specific absorption of bands of infra-red radiation.

The different radiation intensities, depending on the gas concentration are first converted in the receiver chamber into flow pulses and then into electrical signals.

The system first shoots beams of infrared and visible light through the gases in the smoke stack as shown in Fig. 36.9. A molecule of a particular gas hungrily absorbs light energy at particular wavelengths. By comparing the original intensities of the beams (I_0) with the amount of light that reaches the detector (I), the analyser determines the relative amounts of CO in the gases. The resulting signal is amplified and transmitted to the control room. The concentration of the gas is measured in terms of the ratio as log (I/I_0). Therefore, any light level change, darking of the window, scattering of particulates or water droplets in the gas stream, effects both I and I_0 equally, and maintains the ratio unchanged.

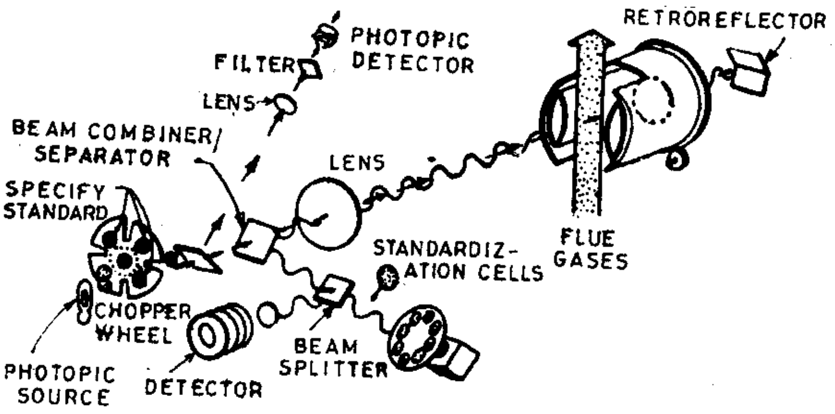


Fig. 36.9. CO-Analyser.

The analyser can be mounted directly in the furnace duct, downstream of economiser, air heater or precipitator and measures the gas all the way across the duct. Sapphire windows protect the components from corrosive flue gas. Most analysers incorporate an air purge system to remove build-up dirt on the source and detector windows.

This apparatus can detect all gases which have absorption bands in the infra-red spectrum as CO, CO_2, NO and all hydro-carbons.

Some analysers provide simultaneous analyses in the infrared, ultraviolet and visible portions of the spectrum. This multichannel capacity allows not only CO and CO_2 measurements for combustion control but also compliance monitoring for SO_2, NO_x to satisfy the environmental regulations.

36.4. MEASUREMENT OF SMOKE AND DUST

The importance of measuring smoke density with addition of suitable alarms and recorders is now increasing because of the smoke nuisance. Sometimes back, the measurement of smoke dust was ignored but modern combustion units have grown tremendously in size producing several million cubic metre of combustion products per minute. The emission control regulations are also imposed by various governmental agencies and therefore it has become essential to control the emission of particulates in stack gases.

The methods used for measuring the smoke and dust carried with exhaust gases are described below :

(*a*) **Photo-cell Type Smoke Metres.** In this type of metre, the obscuration principle of smoke to the light is used to measure the smoke density. A focused light beam through the chimney is passed on a photo-cell and the variations in the signal of the photo-cell circuit are measured. The variation of the obscuration of the light source due to the smoke and dust in the gases is measured. The indicator is scaled in percentage obscuration.

Such type of circuit is shown in Fig. 36.10.

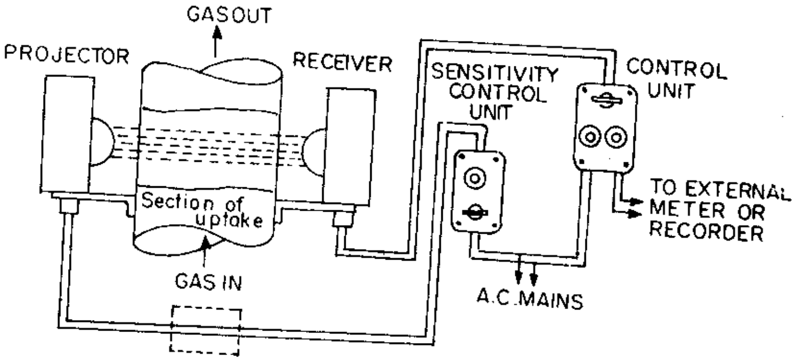


Fig. 36.10. Photo-cell principle for smoke density measurement.

The recorders and alarms can be fitted so that a continuous record of smoke emission is provided and the boiler plant operators are warned if this exceeds a predetermined level.

The major problem with this type of metre is the fouling of projector and receiver lenses by smoke and dust. It has been experimentally determined that the dust will not be deposited at the end of the tube at right angle to the dust if the ratio of the length to the diameter is minimum 4 : 1 for coarser particles and 16 : 1 for fumes and smoke. Therefore, in order to keep the lens windows clean for long period of operation, it is necessary to mount the lamp and photo-cell units on extension tubes with the possibility of their length being varied from 4 : 1 to 16 : 1 ratio.

To install the equipment, two holes of 5 to 10 cm in diameter are required on opposite sides of the stack. If possible, a position should be chosen at a point in the duct where the suction exists so that surrounding air will be drawn to the duct, pass the glasses protecting the lenses and so keep them clean.

(*b*) **Reflected Light Dust Monitor.** In this metre, the reflected light from the dust particles is measured instead of recording the light absorbed by dust. The arrangement of the circuit diagram is shown in Fig. 36.11. A simple lamp and a photo-cell are mounted side by side. A light from the lamp is beamed into the dust through a suitable opening. Some of this light is reflected back on the photocell. The indication of reflected light varies with variation of the dust quantity in the gas. If the dust size remains constant, then the instrument can be calibrated on a weight basis.

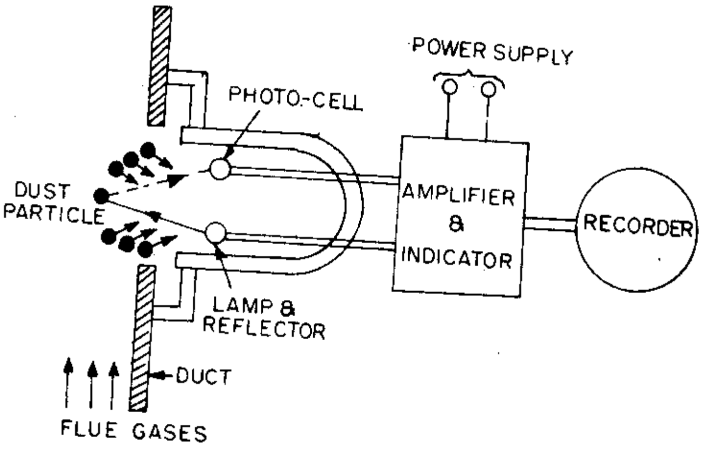


Fig. 36.11. Reflected light dust-recorder.

The advantages of this metre are that it has no problem of alignment and it is relatively free from corrosion due to absence of components with the duct.

36.5. MEASUREMENT OF MOISTURE IN CARBON DIOXIDE CIRCUIT

The presence of moisture in gas circuit of nuclear reactor will accelerate corrossion in the circuit and pressure vessel. It has an adverse effect on the performance of fuel element and considerably reduces the effective operation. Therefore, it is necessary to limit the moisture content of CO_2 and to record continuously the gas circuit moisture content in order to detect any boiler tube leaks and alert the operator by providing suitable alarm.

The arrangement of the components used for the purpose is shown in Fig. 36.12.

The infrared gas analyser is commonly used to measure moisture in CO_2. A continuous sample of CO_2 is obtained by connecting the analyser across the gas circulators to induce gas flow through the system.

The analyser consists of a comparator system which detects the difference in infrared radiation intensity passing through the reference tube of dry CO_2 and the sample tube of reactor CO_2 drawn from the gas circuit. Nichrome twin heaters are mounted as infrared sources which are 'chopped' by an electrically driven fan so that regular discrete amounts of infrared radiation are directed into the two tubes through calcium fluoride, pressure retaining windows depending upon the moisture content in the gas to be compared by the condenser diaphragm unit. For unequal infrared heating of condenser unit gas, a pulsed pressure differential is created across the diaphragm.

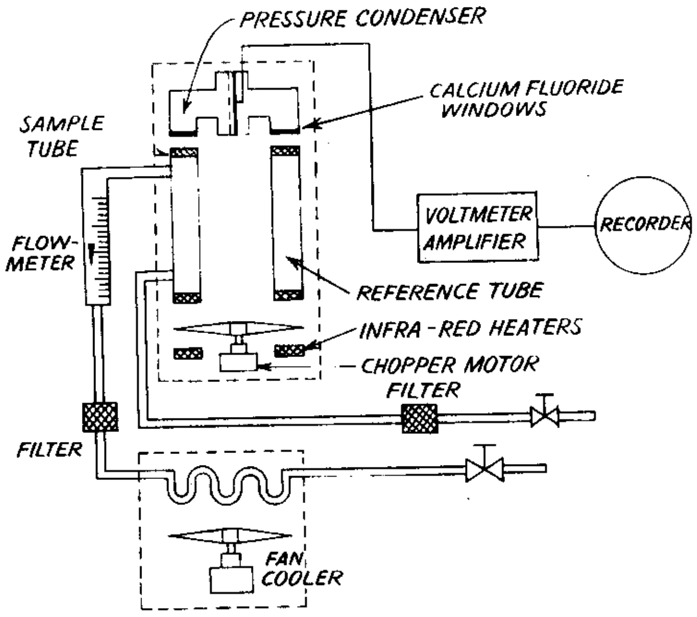


Fig. 36.12. Measurement of moisture in CO_2 circuit of a reactor.

A perforated plate mounted close to the diaphragm completes the condenser which can be suitably connected to obtain an electrical signal which is further amplified. The amplifier can provide local indication and an output for a recorder. Careful siting and installation of the analyser is essential because of its sensitivity to temperature and vibration.

36.6. NUCLEAR MEASUREMENTS

Fuel Leak Detection. The fissile fuels used in nuclear reactors necessarily canned in materials which have structural stability and are compatible with the fissile fuel. Base fuel elements are not used because the fission products released during operation will enter the coolant and produce sidespread contamination with a resultant radiation hazard.

In the event of a fault occurring in the canning material due to structural defect or corrosion, a leak of fission products may occur which may cause contamination and health hazard. Therefore an equipment is provided to detect fuel element leaks at an early stage of development. The faulty fuel element can be discharged from the core before any serious damage occurs.

The problem of detecting the nuclear radiation in large power reactors is more difficult as the number of fuel channels used is as large as 3000. The leak of radiation is generally detected by detecting the fission products carried with the coolant.

The following two methods are commonly used for nuclear radiation detection.

(1) Detection by Gamma Activity of the Fission Products. The presence of fission products in the coolant may be detected by measuring the gamma-activity of the coolant. This is not a very satisfactory method if a high degree of sensitivity is required on account of the large γ-background due to activated impurities in the coolant. In this case, the leak will pass undetected until the emission of fission products is large enough to indicate a γ-activity in excess of the normal background. The sensitivity can be improved by a method in which the activity of the fission products alone is determined.

(2) Detection by Gaseous Fission Product Acitivity. A number of radioactive gaseous fission products are produced during the fission process and their presence in the coolant may be used for the detection of leaky fuel element.

A large number of isotopes of krypton and xenon occur as a result of radio-active decay. These formed isotopes further decay with β-emission to form isotopes of rubidium and caesium which are also β-active. Advantage of this particular method is that the daughter products rubidium and caesium are solids. Therefore, it is possible to extract the krypton and xenon gases by careful filtering from other impurities in the coolant circuit and allow them to decay to solid daughter products. Then the β-activity of the daughters is then measured in order to detect the presence of fission products in the coolant circuit.

The gaseous fission products from the stream of coolant are first removed and allowed to enter a precipitation chamber where the solid daughter products are produced. These products are collected on a wire in the precipitation chamber by maintaining a high voltage between the wire and chamber. The activity collected on the wire is then measured. Such system is described below :

The arrangement of the components is shown in Fig. 36.13. The precipitation chamber consists of a metal cylinder with a thin metal wire passing through its centre and insulated from the cylinder. The cylinder potential is kept 4 kV positive with respect to the wire. The gas from each sample channel is passed through the precipitation chamber for 25 seconds and the produced daughter products (rubidium and caesium) are collected on the wire. These isotopes are positively charged and therefore are collected on the wire. At the end of the sampling period, the wire is rapidly moved out of the precipitation chamber and into a hole in phosphor and photomultiplier system. A beta-sensitive phosphor is used and the photo-multiplier output is amplified to operate a rate-meter. The presence of β-active materials on the wire is detected by determining the integrated count over a period equal to the gas sampling period.

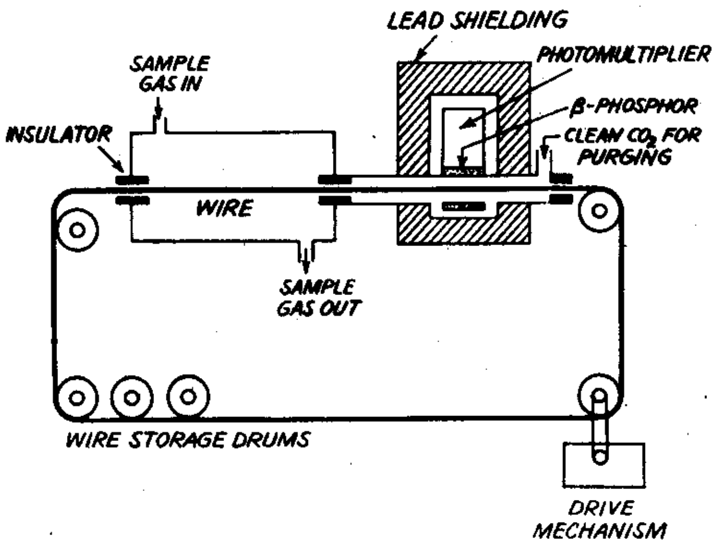


Fig. 36.13. Precipitator chamber and detection system.

The precipitator wire passes over a system of pulleys back through the precipitator chamber. Sufficient time must be allowed before particular part of wire re-enters the chamber to allow for complete decay of the deposited active products. The half-life of rubidium and caesium is in minutes and their activity is reduced by a factor within 20 minutes. A reduction factor of 100 is achieved by making the wire about 20 metres long.

A typical-cooled reactor will have nearly 3200 fuel channels and it would be quite difficult and uneconomical to monitor each channel for the presence of fission products continuously. To avoid this a small pipe is fitted at the top of each channel in such a way that a gas sample is picked up from each channel. The sampling pipes (carrying 1% of coolant) are brought out of the reactor vessel and shielding and are connected together into groups. The combined gas sample from these groups is then passed to a selector valve controlling a large number of groups. This valve selects each group of channels in sequence and allows the gas sample to pass to a precipitation chamber. The gas coming out of the precipitation chamber is then returned to the main gas circuit or pressure vessel via a compressor to maintain the pressure of the gas circuit. Such an arrangement is shown in Fig. 36.14.

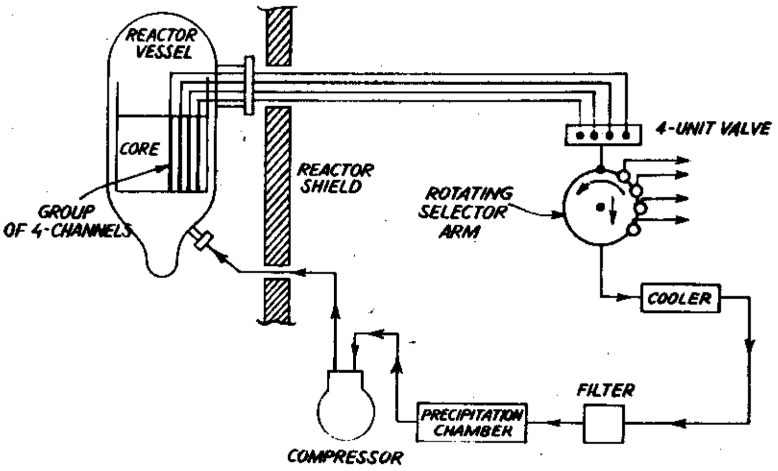


Fig. 36.14. Gas sampling arrangement.

Measurement of Neutron Flux. The instruments commonly used for the measurement of neutrons flux are of two types. Neutrons are ejected in both instruments by the ionisation produced as a result of the interaction of the thermal neutrons with boron producing α-particles as per the reaction given below :

$$_5B^{10} + {}_0n^1 \rightarrow {}_3Li^7 + {}_2He^4.$$

(1) Ionisation Chamber Method. A typical ionisation chamber is shown in Fig. 36.15. It consists of two concentric cylindrical aluminium electrodes contained in an aluminium gas-tight container. The inner surface of the outer electrode and outer-surface of the inner electrode are coated with boron and the container

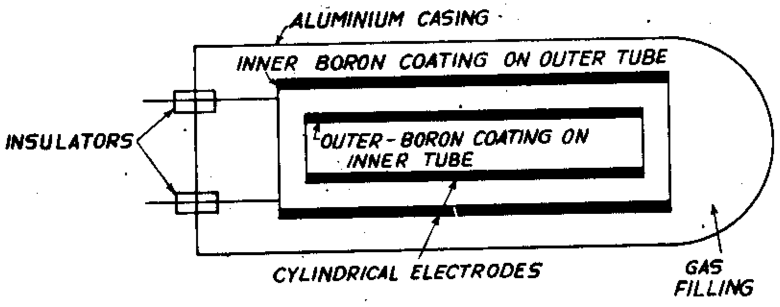


Fig. 36.15. Typical Ionisation chamber.

is filled with hydrogen or argon. An alternate scheme utilises boron trifluoride gas in the container with uncoated electrodes. The neutron sensitivity of the ionisation chamber is dependent upon the area of the boron coating, the degree of enrichment of the boron with the isotope boron 10 and the gas pressure within the container.

The difficulty faced for measuring the neutron flux is the presence of a large γ-background. The sensitivity to γ-rays may be reduced by the use of a suitable gas in the container (hydrogen is best). The γ-sensitivity is further reduced in ionisation chambers using coated electrodes, enriched boron and with reduced gas pressure.

(2) Pulse Counter. The most commonly used pulse counter in reactor instrumentation is the boron trifluoride proportional counter. This is used for measuring small neutron fluxes in the range where the currents produced in ionisation-chamber system are too small for measurement. The principle of proportional counter is to produce pulses as a result of irradiation and to use pulse amplification technique to obtain a measurable signal. A typical BF_3 counter is shown in Fig. 36.16.

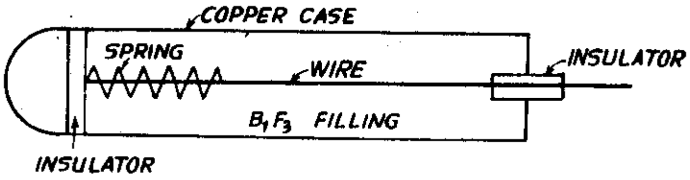


Fig. 36.16. Typical BF_3 filled Pulse Counter.

It consists of a copper tube forming one electrode and a fine insulated wire at centre of the tube, forming the other electrode held at high voltage. The tube is filled with BF_3 gas. The central wire is maintained at a high voltage to ensure that secondary ionisation occurs and a large pulse is obtained.

A neutron sensitivity of the order of 3 counts/sec will be achieved up to a maximum counting rate of the order of 10^4 to 10^5 counts/sec.

The pulse height obtained due to neutrons is found to be approximately 100 times that due to γ-rays and so by suitable pulse height discrimination, the effect of γ-rays may be completely eliminated.

Dosimeters. The instrument used for measuring the radiation intensity is known as dosimeter. These are generally divided into two types ; survey dosimeter used for measuring radiation intensity inside and outside the building and personal dosimeter designed for measuring radiation doses received by individual worker.

Survey Dosimeter. The arrangement of the components of this instrument is shown in Fig. 36.17. It consists of an ionization chamber whose current is proportional to the intensity of incident γ-radiation. The chamber current is amplified and measured by an ammeter which may be directly calibrated in dose rate units as roentgents per hour. The reading of this dosimeter permits one to determine how long it is possible to work in a certain room without facing a health hazard.

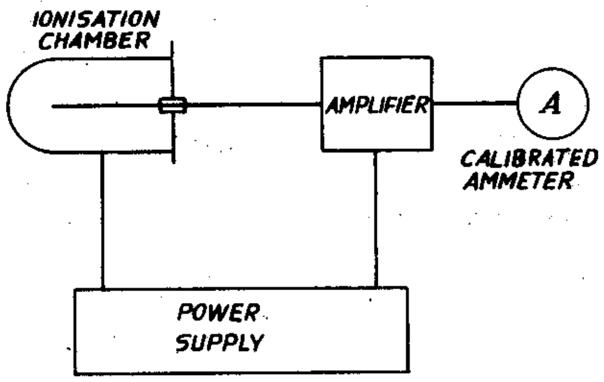


Fig. 36.17. Block diagram of survey dosimeter.

Fountain Pen Dosimeter. This type of dosimeter is used for measuring the radiation doses received by the worker.

Principle. If we charge an electroscope, the thin metal leaves suspended from the central electrode will be mutually repulses and then will slowly approach each other due to loss of charge by leakage. In case of a well insulated central electrode, the charge is maintained for many days. If the electroscope is affected by γ-rays, the air inside it is ionized and becomes conductive. As a result, the charge leaks away much sooner. The irradiation dose is gauged by the amount of the charge loss which is determined by the charge in the distance between the leaves.

In actual instrument, the leaves are replaced by two lightly stretched fibres whose position can be observed through a simple microscope, the electroscope body is made in the shape of a fountain pen which is generally attached to the breast pocket. The arrangement of this type of dosimeter is shown in Fig. 36.18.

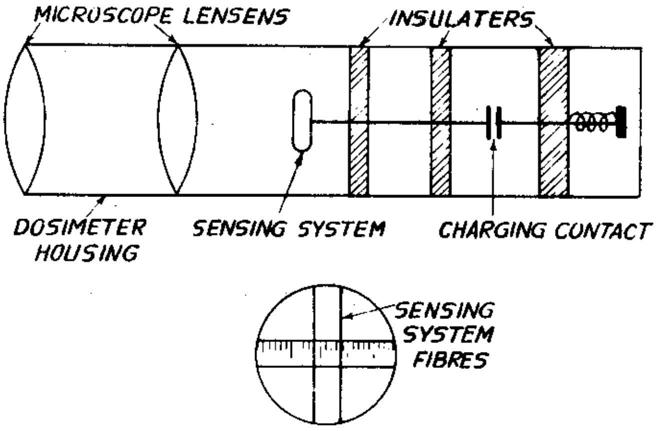


Fig. 36.18. Fountain Pen Type Dosimeter.

At the beginning of the shift, the dosimeter is charged from a high voltage battery. Due to mutual repulsion, the fibres will take up extreme opposite to radiation, the fibres gradually come close together. Since the instrument scale is calibrated directly in roentgens, the position of the fibres at any instant will indicate the irradiation dose received from the beginning of the working day.

The measuring range of the dosimeter depends on the bulge of the fibres and can be made equal to 0.3γ over the whole scale. This means that under normal irradiation (not over 0.05γ per working day) the dosimeter requires charging only once a week.

EXERCISES

36.1. How do you define the water purity used for power plant ? Draw an electrical circuit used to measure the dissolved impurities in water and explain its working.

36.2. Why oxygen level in the water is maintained low ? Draw a circuit used to measure the dissolved O_2 in the water.

36.3. What is pH value ? What is its importance for the feed water used in power plant ?

36.4. Draw an electric circuit used to measure pH value of feed water and explain its working with basic principle.

36.5. What do you understand by paramagnetic effect ? How it is used to measures O_2 in the exhaust gases ? Explain the working of O_2 meter with a neat sketch.

36.6. Draw an electric line diagram to measure CO_2 in the flue gases and explain its working.

36.7. What do you understand by photocell ? Draw a line diagram of smoke meter and explain its working.

36.8. What factors are measured in Nuclear power plants which are responsible for nuclear hazard ?

36.9. Draw a neat line diagram of a circuit to analyse the gas for nuclear radiation.

36.10. What do you understand by Dosimeter ? Draw a line diagram of a Dosimeter and explain its working.

□□□

37

Pollution and its Control

37.1. INTRODUCTION

The purpose of this chapter is to introduce the readers with the sources polluting the atmosphere. The electric power demand is continuously increasing and it is expected that the demand would be doubled after every 7 to 10 years and the pollution of the environment would be rapid in the coming years. The electric utilities are currently faced with simultaneous demand for increased power, and the demand for the elimination of all the objections attributed to hydro-electric power, fossil fuels and nuclear energy.

The main pollutants from the thermal plants are dust and objectionable gases like CO, CO_2, SO_2, NO_2 and many others. The ash is also a problem as it also emits heat to the atmosphere as well as small diameter pollutants carried by the air. The pollution from the thermal plant is also large quantity of heat discharged to the atmospheric air and water used for condensing the steam.

The pollution from the nuclear power plants is radioactive waste in form of gases, liquids and solids whose radioactive property may remain number of years. The dumping and leakages of these wastes are the major problems in nuclear power plants.

The pollution problem is mainly faced by the developed countries like U.S.A., U.K., Japan and France and positive steps have already been taken by the Governments to reduce the pollution effects. An increased concentration of man's activity into any area is another cause of air pollution. In USA, 50% of the total emissions are released over less than 1.5% of the country's area. No doubt, presently the percentage of pollution by electric plants is considerably less (15% of total) but it is estimated that the source of pollution will increase rapidly as the power demand increase is very very rapid.

37.2. AIR AND WATER POLLUTION BY THERMAL POWER PLANTS

The environmental pollution by thermal power plants using fossil fuels poses a serious health hazard to modern civilization. Air pollution by thermal plants is a contributing factor in the cause of various respiratory diseases and lung cancer and causes significant damage to the property in addition to causing annoyance to the public.

The thermal power plants burning conventional fuels (coal, oil or gas) contribute to air pollution in a large measure. The combustible elements of the fuels are converted to gaseous products and non-combustible elements to ash. The common gaseous products of interest are sulphur dioxide, nitrogen oxide, carbon dioxide and carbon monoxide, and large quantities of particulate materials as fly ash, carbon particles, silica, alumina and iron oxide.

The energy industries are one of the largest sources of environmental pollution. A 350 MW coalfired station emits about 75 tons of SO_2, 16 tons of nitrogen oxide, and 5 tons of ash per day if no safeguards are adopted. All steam generating plants also discharge nearly 60% of heat produced back to the atmosphere irrespective of the fuel used.

Due to large emissions from the thermal power plants, air pollution has become an international problem. This problem is mainly faced by 11 countries in the world which share 80% of the world's fossil-fired generating capacity. Emissions from their power plants have grown to a point where we and all of them now must think for controlling the pollution contributing to a common atmosphere.

Many countries have unique air pollution problems. These are due to fuel characteristics, unfavourable topographical conditions, concentration of power plants in limited area and high population densities.

The production capacities of 11 countries which share 80% world-electric generation are given in Tables I and II. The major pollutants given off by fossil fuel combustion are particulates, SO_2 and other gases and it will be sufficient to discuss about these pollutants.

The amount of particulates and gases emitted per year in U.S.A. are listed in Tables III and IV which is sufficient to understand the seriousness of the problem.

It is clear from Table I that U.S.A. produces 39% of the world's electric power and emits nearly 20 million tons of SO_2 per year. Therefore, the major problems with the thermal power plants are to remove particulates and SO_2, which cause health hazards. The principal air pollutant from oil-fired power plant is SO_2. The oil fuels used in world power plants contain the sulphur in the range of 2 to 5%. However, the high energy to weight ratio of oil reduces its net contribution of SO_2 with respect to coal. On the emission basis, 2.7% sulphur coal and 4% sulphur oil are equivalent.

The sulphur dioxide is of immediate concern among the different pollutants. The SO_2 is oxidised slowly in the atmosphere to sulphur trioxide and it further combines with water to form H_2SO_4. The H_2SO_4 is highly irritating to the upper respiratory tract. The H_2SO_4 even in minute quantities can penetrate deep into lungs and can cause damage. The acid mist can also cause extensive damage to vegetation and forestry.

TABLE I

Electric and Industrial Power Generation of 11 Countries

Country	*Total production kWh × 10^9*	*Thermal production kWh × 10^9*	*Thermal capacity MW (e)*
U.S.A.	1317.32	1092.4	239353
Russia	556.9	469.2	106914
Japan	237.2	168.2	32421
U.K.	196.2	191.0	53573
West Germany	172.2	156.0	40904
Canada	165.6	32.9	9613
France	111.6	66.5	18020
Italy	93.5	50.8	14158
East Germany	56.7	55.7	10855
Poland	47.4	46.5	10560
Czechoslovakia	35.7	32.0	8050
Total	2990.2	2361.2	544421

As per the data published by U.S.A. Public Health Service, the permissible maximum concentrations of SO_2 at ground level are 0.05 to 0.08 ppm for 24 hours, 0.12-0.2 ppm for 1 hour and 0.1-0.5 ppm for 5 minutes respectively. The maximum expected ground level concentration of SO_2 should be such that it does not exceed the level which might result in injury to the population and agriculture.

TABLE II

Total Fuel Consumption for All Purposes in 11 Countries

Country	*Coal tons × 10^6*	*Lignite tons × 10^6*	*Fuel oil coal tons equivalent × 10^6*	*Gas in $m^3 \times 10^6$*
U.S.A.	439.1	1.3	202.7	1262.5
Russia	197.4	236.4	117.3	378.5
Japan	76.3	0.1	69.4	12.8
U.K.	163	—	49.3	31.2
West Germany	97.4	29.6	59.7	33.6
Canada	21.7	0.6	29.8	85.0
France	60.3	1.8	39.0	23.3
Italy	12.8	1.1	41.4	24.0
East Germny	11.0	72.6	3.0	3.8
Poland	97.7	7.2	3.1	12.4
Czechoslovakia	25.7	42.8	3.9	8.9
Total	1202.4	393.5	618.6	1876

The primary source of SO_2 in the atmosphere is the combustion of bituminous coal and residual oil fuel. The sulphur content in the U.S. coal varies from 0.5 to 6% whereas that in Indian coals varies from 0.2 to 2%. Presently, the only effective control of SO_2 emission is the use of fuels (coal and oil) containing lower percentage of sulphur. The use of fuel oil containing more than 2.5% sulphur by weight is now prohibited in some countries. For the use of present coal containing high sulphur percentage requires either removal of SO_2 from exhaust gases or desulphurisation of fuel before use.

The sulphur dioxide is main pollutant from thermal power plants. 65% of total SO_2 emitted into atmosphere was only from thermal plants in U.S.A. The use of coal is going to increase throughout the world in coming few decades so control of SO_2 is going to be more difficult problem.

Another gas pollutant is nitric oxide (NO) which is not a very toxic gas by itself and does not play any harmful role in the atmosphere. But it oxidises to nitrogen dioxide (NO_2) as a result of series of chain reactions which is highly irritant to the lung. Nitrogen oxide further decomposes into nitric oxide and atomic oxygen in the presence of sunlight. The formed atomic oxygen combines with the atmospheric oxygen to form O_3 which is highly irritating and responsible for many health hazards.

TABLE III

Total U.S.A. Air Pollution by Source—1966

Source	*Tons per year*	*Percent of total*
Industry	23×10^6	16.8
Power Plants	20×10^6	14.1
Motor vehicles	86×10^6	60.6
Space heating	8×10^6	5.6
Refuse disposal	5×10^6	3.5

TABLE IV

Emission of Different Pollutants in U.S.A. Per Year

Pollutant	*Tons per year*
CO	66×10^6
Oxides of N_2	6×10^6
Hydro carbons	12×10^6
SO_2	20×10^6
Lead compounds	19×10^6
Particulates	1×10^6

The maximum permissible limit of nitrogen oxide is 0.05 to 0.1 ppm. Exposure to 2 or 3 ppm of nitrogen oxide for a couple of hours causes chronic fibrotic changes in pulmonary tissues. These gases cause pulmonary oedema and interfere in the respiratory passages at higher concentrations. The concentration of nitrogen oxides in the exhaust depends upon amount of excess air supplied, method of firing and furnace configurations.

The thermal plants contribute substantially to CO_2 emissions. The concentration of CO_2 could have long range effects on the welfare of the world population. The CO_2 is added in the atmosphere at a rate of 6000 million tons per year. This pollutant may modify the heat balance of the atmosphere and could cause uncontrolled change in climate.

The burning of fossil fuels is believed to be largely responsible for 10% increase in CO_2 in the atmosphere in the present century. The global consequences of CO_2 are not fully understood but there is concern that its accumulation in the atmosphere, as use of fossil fuels continues to grow without adequate environmental controls, may have a *green-house effect*, causing irreversible and dangerous changes in the world climate. Severe climate changes could turn fertile land into deserts or melt the polar ice cap, raising the global sea level 5 to 10 m. The implications and control of CO_2 need priority study. These samples of environmental issues as yet unresolved, however, indicate the uncertainties in trying to evaluate acceptability and the future market of coal. Like many other forms of energy, it has high social costs which cannot be measured in economic terms.

The CO is injurious to the human health as it combines with haemoglobin in the red blood corpuscles and thus interferes with their normal function of supplying oxygen to the blood tissues. The 5% of the body's haemoglobin becomes inactive if body is exposed for one hour to a concentration of 120 ppm. This leads to dizziness, headache and lassitude to the human beings and animals.

The quantities of pollutants emitted by 400 MW plant for different fossil fuels are listed in Table V.

As mentioned earlier the other pollutants from thermal plants using coal or powdered coal as fuel are carbon, silica, iron oxide and large quantities of fly ash. The best type 400 MW plant emits 10 tons of fly ash per day, whereas a plant using poor coal could emit 10 tons of fly ash per hour. Nearly 3 million tons of fly ash are emitted per year by 30 odd thermal plants in India and it is expected that this will increase to 8 million tons per year by the end of this decade.

The quantity of fly ash emitted depends upon the ash content of the coal, the type of burner and the equipment used to control the fly ash. The ash content of U.S. coal lies between 7 to 17% whereas the ash content of Indian coal varies from 3 to 42%.

The thermal power plants are the contributors for SO_2, NO_x and aerosols is shown in Fig. 37.1.

The use of air cleaning equipment has reduced the particulate emission considerably from coal-fired plants. The efficiency of 95% of cyclone collector combined with electrostatic precipitator is very common nowadays. No doubt, this reduction in fly ash emission increases the cost of the plant. The cleaning equipment required for 400 MW plant costs nearly 1.5 crores of rupees and running cost of the cleaning equipment is 0.5 to 0.6 mils/kW-hr, 10% of the plant operating costs.

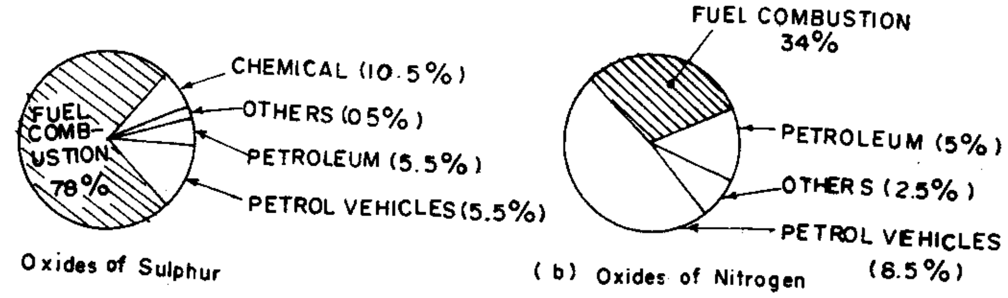
TABLE V

	Annual release in Lbs from 400 MW plant using emission control equipment of 97.5%		
	Coal	*Oil*	*Natural Gas*
Fuel used annually	9.2×10^5 tons (3.5% sulphur and 9% ash)	6.97×10^8 litres (1.6% sulphur content)	7.7×10^{10} litres
Pollutants			
Aldehydes	4.6×10^4	1.03×10	2.72×10^4
Oxides of nitrogen	1.84×10^7	1.91×10^7	1.06×10^7
Oxides of Sulphur	1.22×10^8	4.64×10^7	1.08×10^4
Carbon monoxide	4.6×10^5	7.36×10^3	Negligible
Hydrocarbons	1.84×10^5	5.88×10^5	Negligible
Particulates	3.96×10^5	6.4×10^5	4.08×10^5

Different Pollutants and their Effects on Human Health and Vegetation. Air constitutes about 80% of man's daily intake by weight. We breathe about 22000 times a day, inhaling about 16 kg of air. It is, therefore, essential that the air around us should be as clean as possible, at least it should not be hazardous to the human health.

The world health organization defines air pollution as "limited to situations in which the outdoor ambient atmosphere contains materials in concentration which are harmful to man and his environment".

The atmosphere surrounding the power plants is contaminated by SO_2 (thermal and gas turbine power plants, burning oil or coal containing high percentage of S), NO_x (thermal plants using coal and gas turbine



(a) Oxides of Sulphur

(b) Oxides of Nitrogen

(a)

(b)

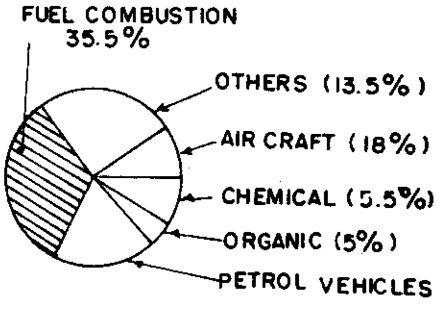
Fig. 37.1.

plants using oil), H_2S (gas turbine plants using gas as fuel), CO and CO_2 (thermal and gas turbine plants) in addition to nuclear radiations in case of nuclear power plants.

The particulates carried by the exhaust gases and ash (containing many hazardous elements) are another nuisance to the human health.

All these pollutants have injurious effects on the human health and vegetation in some form or the other when their limit exceeds above a particular level as discussed earlier.

The main pollutants are NO_x and SO_2 with particulates. NO_x forms smog known as Los Angeles Smog and Smog formed by SO_2 is known as London Smog. The effects of both are listed in Table VI.



(c) Particulates or Aerosls

(c)

Fig. 37.1.

TABLE VI

Characteristics	*Photo-chemical* (O_3 + *PAN*) Los Angeles Smog	(SO_2 + *particulate*) London Smog
Major fuel involved	Petroleum	Coal and petroleum products
Principal constituents	O_3, NO_2 and organic Products	SO_2 and particulate
Type of Reaction	Photo-chemical	Thermal
Time of Max Occurrence	Mid-day	Early morning
Principal effects	Eye Irritation	Lung cancer and coughing From 5—9 Dec. 1952, 4000 people died in London due to London smog.
Visibility	0.8 to 1.6 km	Less than 100 m.

The effects of different pollutants on the human health are summarised in Table VII.

1. Control of Particulates. Majority of the thermal power plants use one of the following mechanical arresters for the removal of solid particles ; wet scrubbers, fabric filters and electro-static precipitators.

Ash from oil burning plants is objectionable due to many reasons. About 95% of the fly ash under 2 microns in diameter are difficult and costly to remove. This ash carries metal aerosols such as iron, aluminium, vanadium and nickel which are harmful to the health. The metallic aerosols are catalysts in photo-chemical formation of smog. An incomplete combustion in oil-fired plants forms carbon smut which absorbs H_2SO_4 and becomes acid smut and causes a severe nuisance around the power plant. In contrast, ash from pulverised coal is larger in diameter and contains small amounts of active aerosols. Therefore, to control the pollution of air due to coal burnt plants is easy and less costly than oil burnt plants.

TABLE VII

Pollutant	$\mu g/m^3$	*Effects*
SO_2	115	*On Man*—suffocation, irritation of throat and eyes, respiratory, asthma, lung cancer. *On Vegetation*—destruction of sensitive crops and reduced yield. *On Materials*—corrosion. NO_2 in the presence of hydrocarbon (HC) and sunlight causes photo-chemical smog containing O_2 and peroxy acetylnitrate known as Los Angeles Smog.
NO_x		*On Man*—irritation, bronchitis, oedema of lungs.
H_2S		*On Man*—irritation, diseases of bone, mottling of teeth, respiratory disease. *On Vegetation*—destruction of crops. *On Animals*—fluorosis in cattle grazing.
CO	15	*On Man*—poisoning cardiovascular diseases, increased accident liability.
Particulates [Dust fume mist and soot (0.1—10μ size)]	100	*On Man*—respiratory diseases like sillcosis (cough, cold, sneezing), asbestosis. *On Material*—soiling and corrosion. The particulate and SO_2 together is known as London Smog.

It is economically feasible to obtain a very high degree of pollution control over particles which are larger than 2 to 3 microns. High efficiency removal of particulates is expensive. To increase the efficiency of the precipitator from 90 to 99% requires approximately double the size of precipitator and requires double power input. The particulate removal is the major problem (as cost is concerned) in-power plants using pulverised fuel. Pollution control activities vary widely from country to country. Australia has a unique particulate pollution problem and aggressive programme for its solution. Most Australian coal contains low sulphur and high ash. Therefore, the problem is flyash control. Government of Australia and Industry groups have undertaken progressive programmes in coal cleaning and electrostatic precipitator design.

Particulate matter removal is also considered a serious problem in areas such as Silesian region of Poland where high level of pollution is aggravated by fly ash due to concentrations of power plants. The particulate removal problem is most serious in Czechoslovakia as the ash content in coal is as high as 60%. It is estimated that the country produces 6 to 7 times as much flyash per capita as U.S.A.

Irrespective of all steps taken to remove the particulates from gases before letting to stack, 1% is always discharged to the atmosphere. The only method left to control the dust within the allowable limit is to increase the height of chimney so that the dispersion will be on the larger area thus reducing concentration.

The particulates affect global and local weather conditions by blocking the path of sun rays which cause the drop in earth temperature and cause fog and rains which aggravates the problem of visibility. This requires more light as visibility drops cause further pollution, further rains and further reduction in visibility.

The details of mechanical and electrical equipments used for the removal of particulates are already discussed in Chapter 12.

(2) Control of Sulphur Oxides. To prevent the emission of sulphur into atmosphere is most important as it is harmful to the health. Every preventive measure is taken by different countries throughout the world to prevent the emission of sulphur into atmosphere.

There are two basic approaches to the problem. First is to remove the sulphur compounds from the fuel (coal or oil) before burning and second is to remove sulphur dioxide from the flue gases. To use low sulphur content fuel is the only commercially proved means to control SO_2 emissions but several countries have developed better methods for flue gas cleaning.

The commony three types of processes, wet scrubbing, solid absorbent and catalytic oxidation are used to remove SO_2 from the flue gases leaving the boiler. The wet scrubbing with line and limestone slurry is used by U.S.A., Sweden, Japan, England, Germany and many other countries. Other methods are in development stages and also used by few power companies of Japan and Germany. It has been found that to remove SO_2 from flue gases instead of removing sulphur from coal is more economical.

Most of the development work to desulphurise the oil fuel has been done in U.S.A. Recently Japan has invested heavily in low sulphur oil processes. One is already in operation and many are under construction. The sulphur reducing plants reduce the sulphur content of oil from 2.5% to 1.5%.

Newly developed method of hydrogen treatment reduces the sulphur content even below 1%. Hydrogen treatment converts sulphur to hydrogen sulphide which is then isolated by absorption in suitable chemicals.

Great amounts of air pollutants are produced with coal combustion than any other fuels. Therefore, research is continued on converting coal to cleaner and more convenient gaseous and liquid fuels. Three different processes for producing gas from coal are in development stages. Hygas pilot plant at Chicago is now ready to produce the gas. The CO_2 acceptor process plant designed for handling 50 tons lignite per day is working for producing gas at Rapid City in South Dakota from 1971. A two-stage supergasification plant for gas production is established in Western Pennsylvania. A pilot plant in Princeton at New Jersey has started operating for the production of synthetic petroleum, fuel gas and solid char from coal.

Modern Methods to Control SO_2. Enough has been discussed in Chapter 16 concerning wet scrubbers and electrostatic precipitators for controlling the SO_2 emission to atmosphere.

To prevent air pollution with SO_2 at ground level, tall chimneys are installed to disperse flue gases so that SO_2 concentraton at ground level should not exceed an objectionable limit (0.5 mg/m^3). Many regions of the advanced countries have reached the limit and it is not possible to maintain the SO_2 level below objectionable with increasing power demand. All developed countries are searching for most efficient methods, for improving fuels used in power generation and for the removal of SO_2 from the flue gases.

The advisable methods of preventing air pollution with SO_2 are different for gaseous, liquid and solid fuels. It is advisable to remove H_2S from natural gas before burning it. The technology of this purification of natural gas has been introduced on an industrial scale in a number of countries.

A solution has been proposed to obtain low sulphur oil from high sulphur oil by chemical treatment at oil refineries. This solution is costly one and hardly used in practice. Gasification of high sulphur oil under pressure involving subsequent heat recovery and removal of H_2S from products of gasification to obtain elementary sulphur and combustion of the purified products of gasification in boiler or gas turbine is also assumed to be viable.

It is wrongly believed that purification in scrubbers can appreciably decrease sulphur content in flue gases. The scrubbers with water which contains no alkalies does not remove more than a small fraction of SO_2 contained in the flue gases. When spraying water contains alkali compounds of calcium, the absorption of SO_2 increases, however, the probability of formation of deposits of calcium sulphates on the surface of scrubbers and in pipes increases which disrupts normal operation of the equipment. Therefore, scrubbers cannot be regarded as universally accepted plants for removing SO_2 from flue gases. The considerable decrease in temperature of the clean gases as they pass through the scrubber deteriorates the dispersion ability of the gases, is one of the main reasons why scrubbers are not more extensively used to clean the flue gases.

Dry Method. The circumstances forced investigators to search for dry methods of removing SO_2. The simplest of them is combining SO_2 with powdered lime-stone.

The lime-stone ($CaCO_3$) is added to the coal before it is pulverised, twice the stoichiometric quantity. The pulverised mixture of fuel and $CaCO_3$ is fed into the combustion chamber. In the presence of high temperature in the furnace, the $CaCO_3$ dissociates into CO_2 and CaO and while CaO moves together with combustion products, it reacts with SO_2 to form calcium sulphate.

$$CaCO_3 = CaO + CO_2$$
$$CaO + SO_2 = CaSO_3$$

The sulphates and unreacted CaO are precipitated in the ash precipitating plant. This requires the higher capacity precipitator to take an extra load of CaO and $CaSO_3$ in addition to the normal pollutants.

When $CaCO_3$ is added to the fuel, a part of the CaO formed reacts with silica and other components of mineral parts of the fuel and therefore loses a considerable ability of absorbing SO_2. In addition, heating to temperature of 1500°—1600°C in the furnace leads to loss of activity of CaO and and decreases absorption of SO_2. Therefore, the present trend is separate pulverisation of lime-stone and fuel and feeding the powdered lime-stone into the zone of lower temperature of about 1200°C. This is more preferable when the power plant uses high sulphur oil as fuel. With combustion of coal, this involves installation of additional pulverisers and overcoming difficulties associated with uniform distribution of powdered limestone over the cross-section of the boiler gas passeges.

The rate of reaction between CaO and SO_2 depends on temperature as shown in Fig. 37.2. This shows that maximum reaction rate takes place at about 950°C and decreases at higher and lower temperatures. Thus most intense absorption of SO_2 by CaO takes place in the superheater region where the gases hardly stay for about one second at this temperature. Therefore, there is no time for the reaction to be completed over a so short time and flue gases contain abundant CaO along with SO_2. This makes necessary to increase the quantity of CaO considerably compared with stoichiometric quantity in order to attain atleast 50% removal of SO_2. The main shortcoming of this method lies in this difficulty.

With deliberate addition of lime-stone to fuel, the formation of deposits on the boiler heating surfaces will be faster than without adding lime-stone. The formation of deposits causes a decrease in steam output of boilers and accounts for higher flue gas temperatures. Free CaO in the ash and slag complicates the operation of ash removal. At the same time, addition of lime-stone to fuel almost completely eliminates the danger of acid corrosion of the cold end heating surfaces and considerably extends the region of use of ash in the national economy. The process of electrostatic precipitation with addition of $CaCO_3$ to fuel does not become more complicate.

The use of this method is at premature stage and its economical and operational justification are yet to be established. Work on reducing the cost of gas purification by this method should be directed at increasing the degree of fineness of $CaCO_3$ and at increasing the time of contact of gases with $CaCO_3$ at a temperature at which the intensity of reaction is maximum and at finding the methods of the most efficient use of the wastes.

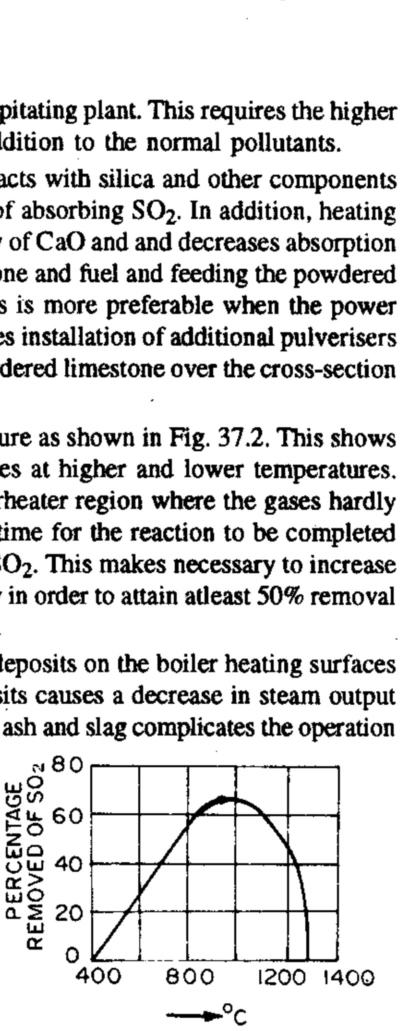


Fig. 37.2. Effect of temperature on the reaction of CaO and SO_2 for the removal of SO_2

(3) Control of Nitrogen Oxides. Incomplete combustion contains harmful gaseous substances such as CO and hydro-carbons. Main causes of incomplete combustion assuming correct burning conditions and sufficient surplus air can be a low reaction temperature or too short a reaction time in the combustion chamber. Higher flame temperatures and longer retention times in the main reaction zone of the combustion chamber have a favourable influence on combustion and reduction in the content of CO going with exhaust gases.

Nitrogen oxides are another harmful and objectionable group of pollutants emitted from the power plants. A boiler of 170 tons/hr steam generating capacity discharges 2.2 tons of nitrogen oxides to atmosphere per day and 950 tons/hr capacity discharges 57 tons per day. These figures are sufficient to *emphasise* the *severity* of air pollution from nitrogen oxides. NO_x is formed in high temperature zones of combustion chamber from N_2 and O_2 of the air. High temperatures favour NO formation. Therefore, NO can thus be said to be the indicator of good and stable combustion. The contradictory behaviour of both *pollutants* (CO and NO) with respect to temperature and retention time has the effect that measures aimed at reducing NO_x emission normally raise the CO content.

With high temperature combustion of gaseous or liquid fuel, the pollution of the atmosphere by solid particles, CO and SO_2, can be kept minimum by suitable organization of the combustion process : burning gas with excess air, choice of optional length and diameter of the furnace chamber, correct stabilization of the flame etc. However, these measures do not lead to a reduction in the release of NO_x since they are present in the combustion products in appreciable quantities even with good combustion conditions and when there are no unburnt gases.

The methods which are commonly used to reduce the emission of NO_x from thermal and gas turbine plants are discussed below.

(*a*) **Reduction of Temperature in Combustion Zone.** A method of decreasing temperature by an injection of steam (in gas turbine plant) and a method of simultaneously decreasing temperature and concentration of O_2 by recirculation of furnace gases (in thermal power plant) into the combustion zone are commonly used for decreasing NO_x concentration. It has been observed that the influence of recirculation at low loads is less appreciable but owing to a decrease in temperature in the flame core through a decrease in load, the NO concentration decreases by a factor 1.5 to 2. Recirculation of 23% of gases into the furnace of the boiler at operational equivalence ratio of 1.02 and rated load lowers the concentration of NO_x by nearly 30%.

Edison company has developed a two-stage combustion system for burning gas in which burners are installed in the lower zone of the furnace and operate with equivalence ratio of 0.85 (equivalence ratio is the ratio of actual A : F ratio to stoichiometric A : F ratio) while the quantity of secondary air supplied to the upper zone of the furnace is 21% of that theoretically required for complete combustion. The disadvantage of this system is the higher CO content in the products and special measures should be taken to afterburn the CO at the end of furnace.

(*b*) **Reduction of Residence Time in Combustion Zone.** A reduction in time of residence of the combustion products in high temperature zone for the purpose of reducing the NO is ensured by burning the fuel under conditions close to stoichiometric often in conjunction with recirculation of the combustion products and further rapid cooling of the flow of combustion products. By this method, NO_x is reduced to 150-200 ppm. This method is one of the most promising methods since it enables one, together with the lowering of the NO_x formed, to reduce to a minimum the contents of CO_2, SO_2, formaldehyde and hydrocarbons in the combustion products.

(*c*) **Increase in Equivalence Ratio in the Combustion Zone.** One of the effective methods for decreasing NO_x in the exhaust is to carry out the combustion in the equivalence ratio of 1.6 to 1.8 and ensuring at the same time intensification of inter-mixing in the front zone of the combustion chamber. Intensification of the process of inter-mixing at $\phi > 1.6$ makes it possible to decrease local maximum temperature as well as to decrease the time for burning out the fuel. This reduces the formation of NO_x because an increase in burning out time of fuel appreciably increases the yield of NO_x.

(*d*) **NO_x Removal Technique for Power Stations.** A firm in Japan has developed an *in-furnace* for NO_x removal process for thermal power plants. In this process, NO_x produced by combustion of fuel in the main burner receives a strong reduction action through the radical species (hydro carbon, CO, carbon) which are produced by pyrolysis of the fuel from NO_x removal fuel injector, thus reducing NO_x into N_2 inside the high temperature furnace.

This process requires neither NH_3, nor catalyst as compared to other conventional NO_x removal processes. There is no drop in the boiler's efficiency nor increase in operational cost.

The arrangements for removal of NO_x using NH_3 injection and in-furnace arrangement described above are shown in Fig. 37.3 and Fig. 37.4.

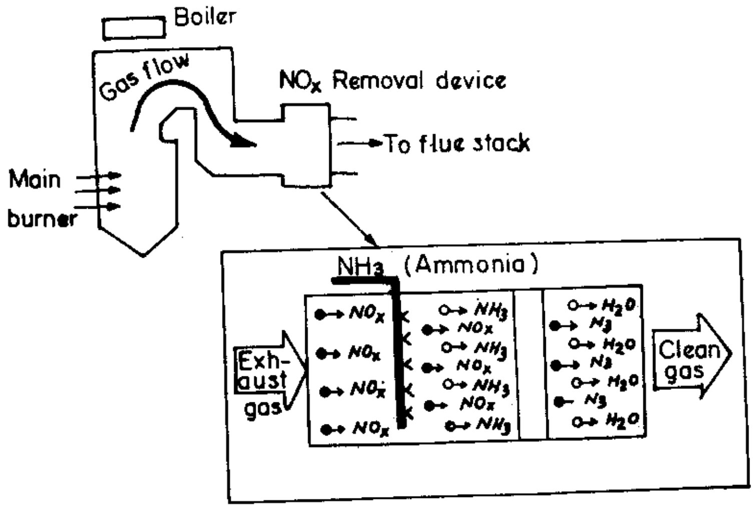


Fig. 37.3.

The gaseous pollutant emissions from coal combustion in Thermal Power Plants in India during the year 1978-79 are listed in the table given below. The data given is sufficient to indicate the effects of these pollutants on the environment.

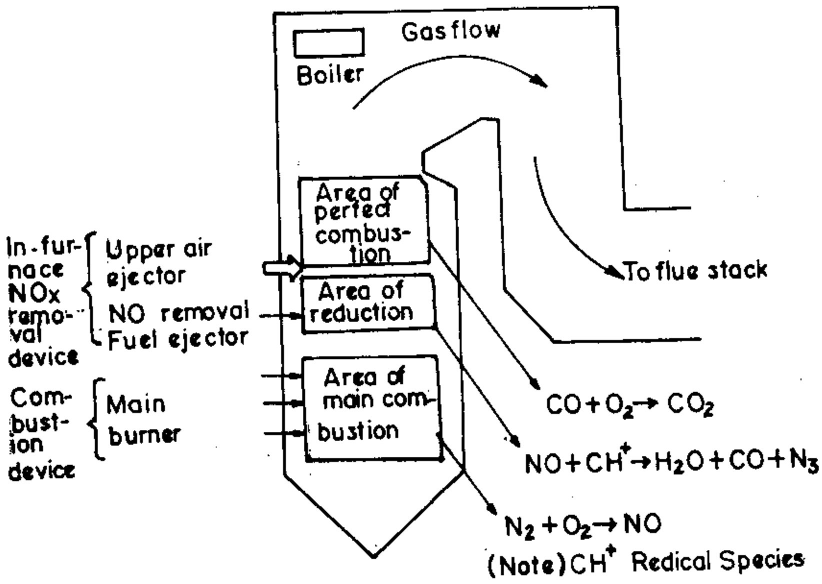


Fig. 37.4.

Pollutant	SO_2	NO_x	CO	Hydro-Carbons	Aldehydes	Arsenic/ Antimony
Quantities in (tons)	1086,000	260,000	6,500	2,600	65	572

37.3. WATER POLLUTION BY THERMAL PLANTS AND ITS CONTROL

Another equally serious problem is the water pollution caused by thermal plants. The water pollution is caused by discharging hot condenser water and water discharged into the river carrying the ash of the plant. The discharge of polluted water causes hydrological and biological effects on the surrounding ecology. The biological study should determine the types of aquatic organisms in the area and their adaptability to the environmental variations.

Thermal pollution of water is very important for the fish cultivation as their growth is very susceptible to the temperature changes.

Another important constituent in the discharge of cooling water is residual chlorine as chlorine or sodium hypochlorite is used to prevent fouling of the condensers.

Another serious problem associated with the discharged water is the ash carried by the water. The ash gets spread over the large cultivated area along the path of the river and affects the agricultural growth very much. This is because the ash has high alkaline characteristics which are injurious for the growth of many agricultural products. The ash destroys the fertility of the land for ever. Such phenomenon was badly experienced when the ash from Koradi thermal power station in Maharashtra was discharged in the river.

The waste water from water demineralization plant contains large quantities of chlorides of Ca, Mg, Na and K. This waste water is channelled out to some river or to an ash pond along the fly ash. On the way to river or ash pond, these salts percolate in the nearby soil and make the ground water salty. In the ash pond, the situation is worse as there is continuous accumulation of these salts and the pond reaches a saturation level of these salts. The process of salt saturation in the pond is further accelerated by solar evaporation of the water. The wells on the area covering a few kilometres from the ponds become salty and polluted water from these wells becomes harmful for human consumption as well as for irrigation purposes.

Discharging these salts with the waste water aggravates the pollution problem but also loses them, even though, their recovery is simple and economical.

The waste water can be treated first with lime to precipitate magnesium hydroxide and then with soda ash to get precipitated calcium carbonate and the resulting sodium chloride solution can be reused for regeneration in softeners. The above-mentioned reactions are listed below.

$$MgCl_2 + Ca(OH)_2 = Mg(OH)_2 \downarrow + CaCl_2$$

$$CaCl_2 + Na_2CO_3 = CaCO_3 \downarrow + 2\,NaCl.$$

The main use of magnesium is in the manufacture of refractories required for steel plant. The refractories imported by India costs 10 crore per year. The recovery of Mg $(OH)_2$ may help in this direction. The recovered $CaCO_3$ can be used in chemical, paint, paper and many other industries. The arrangement of the system is shown in Fig. 37.5.

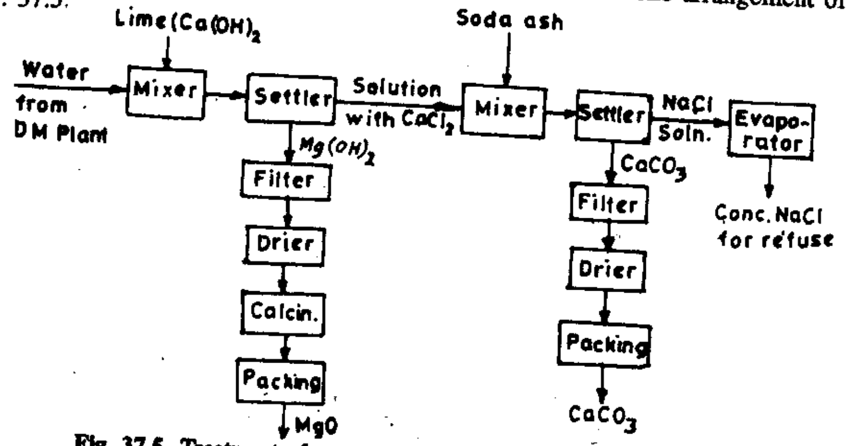


Fig. 37.5. Treatment of waste water from DM-plant to control the water pollution.

Uncommon Salt Pollution from Dabhol Power Plant in Kokan (Maharashtra) (Ist stage of 225 MW)

In this plant, sea water is used for cooling purposes and same water is recycled passing through cooling waters. As sea water contains large amounts of salts and these are thrown out into the atmosphere through the cooling towers. These salts from the atmosphere again enters into the surrounding drinking waters. The salt concentration in a drinking water should not be 16 units in 100 milliliter but it is observed that the sources of drinking water around the plant contains 400 to 4000 units. It is also concluded that such a high level of salts in drinking water came through cooling tower.

It is also estimated that the salts emitted through tower will be only 0.25 gms/min but present level is 200 to 300 times higher than estimated. With the present level of salt emitted through cooling tower will spread over 100 km from the power plant. The salts emitted contains potassium chloride, magnesium chloride and sodium sulphate. These salts in atmosphere can create trouble in breathing and cause cough, bronchities, pheumonia and asthama. In addition to this, 90 m^3 of salt water per second thrown out into the atmosphere through cooling water will destroy crops of mango, cashewnut and rice around 20 km area.

The drinking water contained 180 units of salts as well as bacteria which are similar to the bacteria found in human urine. This is only possible if the chloronation in the tower is not sufficient to kill the generating bacteria. Therefore, it is essential to take necessary steps to prevent all these odd and unexpected problems cropped up.

Another problem faced, with this power plant is the emission level of SO_2 and NO_x. The level of these gases is found 10-times greater than safe level. This is because the height of chimney is only 50 m compared with minimum required height as per the rule is 220 m. Therefore, it is also necessary to take steps now only to avoid such heavy pollution.

37.4. ACID RAINS

Approximately, 15 million tons of particulate, 25 million tons of SO_2 and 20 million tons of NO_x are emitted into atmosphere per year from man-made sources as given in the following table :

Emission Source	*Particulate %*	*SO_2%*	*NO_x%*
Power Plant Boilers	24	69	33
Industrial Boilers	6	8	10
Commercial	4	5	5
Industrial Sources	47	13	2
Transportation	9	5	50
Miscellaneous	10	—	—

These emissions cause health problems, reduce visibility and contribute to the acid rain problems significantly.

Acid rain and problems of acidity of rivers and lakes in Scandinavian countries, particularly Norway, has been known for many decades. In Norway, it has been the practice for many years to introduce lime stone into rivers to increase the alkalinity of rivers and lakes.

Acid rain is another menace created by the thermal power plants. The three constituents of flue gases which mainly affect acidity of the rains are CO_2, SO_2 and NO_x. The SO_2 emitted to atmosphere combines with water and forms H_2SO_4 and similarly NO_x forms HNO_3. During the rainy season, the acid formed in the atmosphere falls on the ground. The effect of this rain is to increase the acidity of the lake, well water and flowing rivers. If the acidity increases above a particular level ($pH < 5$), the fish population dies totally when $pH = 5$ and less. In 1978, West Virginia had stormy rains as sour as the juice of lemon and its pH was 2.3. In New York, a park 70 lakh acres in area having more than 200 lakes, all are dead due to acidic rains. The population of fishes in Sweden and Norway has almost become nil for the same reason. It is also estimated that the number of such lakes will be 50,000 by 2000 A.D. in Canada. USA burns lot of coal and oil containing high sulphur and acid rains are experienced by Canada.

CO_2 in the atmosphere causes rain to be acidic but only to a very limited extent. pH of rain due to CO_2 is about 5.6. If all SO_2 and NO_x due to combustion of fossil fuels were removed, the pH would be 4.7 to 4.9 due to natural emissions of SO_2 and NO_x. In areas where acid rain is occurring, the pH of rain can be as low as 3.5.

Acidity of rain is frequently no higher near to the areas where the greatest emissions of SO_2 occur (near power stations). This may be because the SO_2 in the atmosphere must first be converted by photo chemical oxidation to SO_3 before it causes acid rain. SO_2 is oxidised to SO_3 at 3 to 4% per hour in mid-day but only 1% at an average per 24 hours. The SO_3 reacts rapidly with moisture to form H_2SO_4. This acid may be removed by wet precipitation (acid rain) or by particulate dry deposition.

Emissions from UK must travel at least 1000 km to Scandinavia and the travelling time will be 1 to 2 days, most of the time over the sea. Only a very small per cent of oxides of sulphur produced in this country will reach Scandinavia.

Acidification of lakes has been reported from Norway and Sweden. The sulphate levels in Scandinavian water were rising at a rate alarming in increase in acidity—23% per year from 1965 to 1970 in the case of Lake Vanern and 8 to 12% per year in four other large rivers and lakes cited ($pH < 5$). Deterioration of forests has been reported from Central Europe (West Germany). The damage is in high elevation forest—over 600 to 1000 m above sea level.

The further detrimental effect of acid rains is the reduction of ground fertility and crop yield. There will be many bad effects on the overall biological life. Therefore, it is necessary to ban the emission of SO_2 into atmosphere from thermal power plants as its contribution is maximum. Therefore Government of USA has banned the use of high sulphur content coals and industries preventing the emission of SO_2 as per Government rules are rewarded giving lot of tax concession.

The bad effects of acid rains are listed below :

(1) Fishes from lakes die at $pH = 6.5$. The eggs of fishes do not fertilize and produce fish. The most distinct effect of this is the death of fishes in large number, its number reduces gradually and becomes zero. Such lakes are called as **Dead Lakes.** Because of this, the fishing occupation in Sweden and Norway has almost stopped. In New York park of 70 Lac. acres, nearly 200 lakes in this area are dead. By 2000, it is estimated that, the number of such lakes in Canada is estimated to be 50,000.

(2) Due to acid rains, the metals like Hg, Pb, in earth crust are gradually dissolved and are found in the body of fishes and enter into the body of human beings and causes many dieases.

(3) The concentrated acid rains can completely destroy the agricultural potential of the land.

Parts of Scandinavia in Europe are potentially susceptible, since they combine granitic geology and shallow soils with high rainfall and location not sufficiently remote from the industrial centres of north-west Europe.

(4) Acid rain is a worldwide concern. It was reported in 1983 that as much as 35% of the Black Forest in West Germany had been damaged by acid rains.

(5) The acid rain also damages national monuments and building. Such effect is already identified on Tajmahal.

The problem of acid rain is becoming more complex because the countries who are the cause of these rains are different while those experiencing the rains are different. For example, America burns impure coal and acid rains are experienced by Canada.

Worldwide, emissions of sulfur dioxide and oxides of nitrogen continue to climb. These pollutants cause economic, environmental, and aesthetic harm, as well as damage to human health. The oxides of sulfur form particulates and reduces atmospheric visibility, degrading recreational values. Oxides of nitrogen help to form ozone, a principal constituent of urban smog. Concentrated in urban area, sulfur dioxide and smog cause lung damage and raise many respiratory diseases. But even when these pollutants are widely dispersed, they pose a significant environmental threat through the formation of acids that precipitate as rain, snow, or in other forms.

Acid precipitation has altered the chemistry of tens of thousands of lakes and streams to the point where they can no longer support life. It is implicated in damage to crops and forests in many areas of the world, among them China, North and South America, Africa and nearly 50 million hectares of forest in Europe alone. It can also help to mobilize toxic metals from soil, sediments, and even drinking water. It is, in short, a major indirect cost attributable to the use of fossil fuels.

Coal, being the most carbon-intensive fossil fuel, accounts for 43 per cent of annual global carbon emissions and burning the entire coal reserve would release three trillion tonnes of carbon into the atmosphere—five times more than the safe limit for averting serious climatic disruptions.

The London smog resulted from coal-burnt smoke with high sulphur content which lead to the production of high concentration of sulphuric acid in fog droplets. The acidic droplets, along with high density smoke, inhibit normal functioning of lungs resulting in symptoms including chest constriction, difficulty in breathing, headache, nausea, vomiting and irritation in eyes, ears, nose and throat.

Suggesting reduction of huge subsidies on coal in many countries that encourage its use, the report says India and China jointly account for about ten per cent of the total annual global coal subsidies.

"Hastening coal's declining use is imperative if climate change is to be slowed in the next century."

Thirteen countries continue to depend on coal for at least one quarter of their total energy.

These include the U.S. and Denmark in the industrialised world which depend on coal for 53 and 74 per cent of their electricity respectively.

China, where acid hazes cause annual damage worth U.S. $14 billion, has more than halved its coal subsidy rates—a move which led to a 5.2 per cent drop in its coal consumption 1997. Belgium, France, Japan, Spain and the U.K. have also halved their coal use.

The use of coal, which was earlier dubbed as "the bridge to the future", experienced a 2.1 per cent global drop last year (1998).

Pollution levels in Delhi are comparable to the infamous 1952 London smog that claimed 4,000 lives, according to the Washington-based Worldwatch Institute. It says similar levels exist in Beijing and many other cities.

Stressing the need to globally phase out coal as a fuel source because of its high-polluting potential. The report says, an acid haze over the Indian Ocean is reducing wheat yield in India.

Process Influencing Acid Rains

The man-made air-borne materials like SO_2 and NO travel hundreds of kilometres depending upon the direction of wind and its velocity Fig. 37.6 shows the processes occurring during the transport. As the

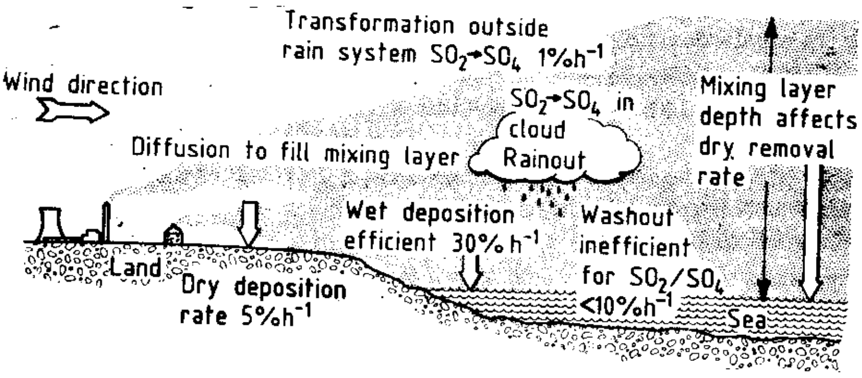


Fig. 37.6. Processes occurring during transport.

cloud of material is carried along the wind, it is diluted by dispersion both in horizontal and vertical directions. Vertical dispersion is largely confined within the turbulent boundary layer of the atmosphere which is hardly 1000 m. Horizontal dispersion continues indefinitely.

If Q denotes the fraction of gases from a source remaining air borne after time, t, then Q = 1 when $t = 0$ and Q satisfies the following equation

$$\frac{dQ}{dt} = -(K_w\theta + K_d + K_t) \cdot Q$$

where K_w, K_d and K_t denote the rate of removal of the gases by three atmospheric processes.

K_w is the rate of removal in rain and $\theta = 1$ when it is raining otherwise zero.

K_d is the rate of removal by dry deposition at the earth's surface.

where $K_d = \frac{\text{Deposition velocity}}{\text{Depth of pollutant cloud}}$

The value of $K_d = 10^{-5}$/sec or 4% per hour.

The rate of removal is dependent on the nature of underlying surface, the height at which the pollutant is mixed and type of pollutant.

K_t is the rate of removal of the pollutant by chemical conversion as

$SO_2 \rightarrow SO_3$. This is caused mainly by photo-chemical reactions in the atmosphere (in the presence of solar radiation). K_t = 1% per hour for SO_2.

However, in dry condition, the rate of conversion from $SO_2 \rightarrow SO_3$, K_t is much less than K_d thus, in the absence of rains, SO_2 is depleted at the rate of 5% per hour mainly by dry deposition. After 20 hours of transport, $\frac{1}{e}$ or 37% of the emission is still air borne. At a air speed of 7 m/sec, this fraction of the emitted material will travel at least 500 km and therefore, most countries in Europe will at same time or other during the year have an influence on their nearest neighbours.

The greatest rate of dry deposition generally occurs near to a source and dry deposition is proportional to the ground-level concentration. Thus, for most countries, the largest contribution to deposition is from their own sources.

Removal of gases during raining is known as wet deposition and strongly affects the concentration of air-borne material such as SO_2. On the annual basis, away from the vicinity of the source, the rate of removal by wet deposition is comparable with the rate of removal by dry deposition. Rainfall is clearly episodic and therefore K_w is much greater than K_d during raining. Clearly, wet deposition depends on the duration and frequency of precipitation along the path of air mass.

It is obvious that each country in Europe pollutes every other country to some extent and this is where the role of mathematical modelling is of great importance. Only by modelling, it is possible to assess how much of the pollution received in one country due to the sources in another.

British emission of SO_2 in 1984 was over 4 million tonnes of SO_2 per year which makes Britain one of the largest emitters in Europe (65% comes from power plants). The SO_2 emission was about 6 million tonnes in 1970 per year and then it is decreased in the last 15-years. The period of greatest increase in Europe was from World War-II until the oil crisis in 1973, during which time, the European SO_2 emission doubled through the use of oil and emission of NO_x trebled.

37.5. THERMAL POLLUTION BY THERMAL AND NUCLEAR POWER PLANTS

The Government of U.S.A. is facing a problem to meet the increasing demand of power. A difficulty has been faced in siting the steam power plants due to heavy thermal pollution by fossil and nuclear power stations. It is estimated that the power demand in the coming 30 years would increase surprisingly high with increase in pollution and the problem in finding acceptable sites for the new plants is becoming difficult and more difficult.

It is approximately estimated that nearly 40 million kJ of heat is rejected per minute by a thermal plant to the environment through condenser water and exhaust gases. This tremendous discharged heat to the atmosphere has created a great problem in locating the power plants.

It is predicted that a significant change in number of sites and average power generating capacity at site in U.S.A. is expected to occur over the next 20 years as given in table below. By 1990, approximately 90 new sites for fossil plants and 165 new sites for nuclear plants, each of 500 MW capacity, will be added in the present capacity of the nation. And by the end of century ; total 500 plants (300 fossils + 200 nuclear) each of 500 MW capacity will be added to increase the total capacity of the nation to 1352000 MW.

The major problem faced is the effect of discharge of large quantities of heated water into the aquatic environment. The problem is further aggravated for nuclear power plants. Because, the nuclear plant discharges essentially all of its heat to the environment while fossil fuel discharge from 10 to 15% of its heat directly to atmosphere. As a result, a light water nuclear plant discharges nearly 50% more heat to condenser water than a comparable size of fossil fuel plant.

The heated water can have the following undesirable adverse effects :

1. The increased temperature of water reduces the maximum oxygen-carrying capacity of the system with simultaneously increasing biological and biochemical oxygen demands within the system.

2. Metabolic rates for aquatic organisms as fish increase with temperature so that their oxygen requirements also rise. In addition to this, fish growth is specially sensitive to the temperature during spawning or embryo-development, so that species reproduction can be effectively terminated, although adult fish remains unaffected.

U.S. Electrical Utility Power Statistics Relating to Population and Energy Consumption

—	*1950*	*1968*	*Estimated 1980*	*Predicted 2000*
1. Population (millions)	152	202	235	320
2. Total power capacity (millions of kW)	85	290	600	1352
3. kW capcity per person	0.6	1.4	2.5	4.5
4. Power consumed per person per year in kW-hr	2000	6500	11500	25000
Total consumption (kW-hr)	325 Billion	1.3 Trillion	2.7 Trillion	8 Trillion
Nuclear power capacity % of total	0	< 15%	25%	69%

3. Effects of temperature on critical segments of the food chain result in eliminating lower members of the chain or preypredator relations of species may be significantly altered.

Louis Committee for an environmental information recently shocked the people with its prediction that waste heat from nuclear power plants would raise the water temperature of the annual fresh water run-off of the entire contiguous of U.S.A. 20°C by the year 2000.

It is, therefore, necessary to take the advance steps to use this tremendous discharged thermal energy before the development of power generating capacity of the nation.

37.6. RADIOACTIVE POLLUTION OF ENVIRONMENT BY NUCLEAR POWER PLANTS

The major obstacle to immediate effective use of nuclear power is the threat to the biological environment from radioactive waste produced by present fission reactors. Such waste remains toxic and active to man and plant for as long as 600 years. It has been already experienced that the waste from the Windscale power station (U.K.) on British cost has raised the radioactivity in the Irish sea to the point, embryo fishes display deformed back bones.

Senator Graval warns about AEC's projection of 600 nuclear fission plants being constructed over the next 30 years, these plants would produce about as much long lived radioactivity as 500,000 Hiroshima bombs. If just one-tenth of one percent of it escaped into the atmosphere, its environmental contamination is equivalent to such 500 bombs per year. No doubt, proper disposal would prevent any such escape of radioactivity but the potential is there for human error.

The major problem in the nuclear plant is not the emitted radioactivity during operation but radioactivity carried with the waste and its retention for a long time. The major problem faced is the disposal of highly radioactive nuclear waste in the form of solid, liquid and gaseous without any injury to the atmosphere. The preservation of waste for a long time, hundreds of years, creates lot of difficulties and requires huge capital. This problem will aggravate the situation mainly by the end of century as the nuclear power production of the world would be 60% of total (4300 × 10^3 MW).

The non-condensable radioactive gases produced during the operation of reactor are passed first through a hold-up line where it is filtered and retained for 30 minutes before mixing with exhaust air and discharging through a tall stack. The height of the stack required for nuclear plant is atleast 2.5 times as tall as any nearby buildings. The permissible rates of discharge of radioactivity through the stack depends upon meteorological parameters like wind speed and direction, temperature and humidity at the site. The permissible limit as recommended by International Commission on Radiological Protection for Population Exposure is 500 millirems per year.

An international symposium organized by Gottlieb Duttweiler Institute for Economic and Social Studies at Ruschikon highlighted the present tendency of the public controversies about the energy and environment to illustrate the contention that technology can no longer be considered alone, but that the consequences of its application, particularly nuclear power, are of general public interest.

It is said in the conference that we have extracted and used energy sources in environmentally damaging ways. Further, we have developed and supported technologies which are going to destroy the surrounding environment more than to contribute to the quality of life.

Schumacher put forth the danger of nuclear power development before the people in the words of Dr. Edward D. David (U.S.A.'s President's adviser) that "one has a queasy feeling about something they have to say underground and be pretty well sealed off for 25000 years before it is harmless". His main criticism was that the proposition to replace thousands of million tons of fossil fuels every year by nuclear energy means to solve the fuel problems by creating an environmental and ecological problem. It further means solving one problem (fuel shortage) by shifting it to another sphere creates infinitely bigger problem. He further points out that the future scientists and engineers will be able to devise safety rules and precautions of such perfections that the using, transporting, processing and storing radioactive waste will be made entirely safe.

Many others were in favour of nuclear power saying that it is even more safe than fossil power plant as environment pollution is concerned. H.J. Dunster stated that the impact of nuclear power generation on environment is even less than that of conventional generation and thus nuclear power made a positive contribution to environmental cleanliness.

Radio-chemical analysis of fly ash sample obtained from the combustion of pulverised coal and fuel oil have indicated that the fossil fuel plants discharge relatively large quantities of radioactive material into the atmosphere than nuclear plants of comparable size. A 400 MWe thermal plant using coal as fuel would emit 11.2 millicuries of radiation to the atmosphere which is larger than nuclear plant of the same capacity.

It was concluded at the end of meeting that "Our best hope today for meeting the nation's growing demand for economical and clean energy lies with the fast breeder reactors, because of its highly efficient use of nuclear fuel. The breeder reactor could extend the life of our natural uranium fuel from decades to centuries with far less impact on the environment than the conventional power plants".

The favourable operating experience of nuclear power plants in the control of environmental pollution has come as a boon to mankind faced with the serious problem of environment pollution.

The present experience of the nuclear radiation effect on the mankind shows that not a single instance of injurious effects has been observed in individuals whose exposure has not exceeded the recommended maximum permissible limits. This shows that the criteria for general population exposures to radiation from nuclear power reactors are reasonable and acceptable.

37.7. NOISE POLLUTION AND ITS CONTROL

The creation of noise creates the pollution by increasing the sound level of the atmosphere. It is estimated that the environmental sound level is doubling in loudness after every 10 years. The increase in sound level of the atmosphere is not the major problem presently but desirable sound level is essential in power plants and every step should be taken to reduce the sound level of the power plants to a tolerable level.

Heavy noise environment has extremely unpleasant effects on people exposed to them. Continuous exposure to noise level above 100 dB has adverse effect on hearing ability within a short time. Therefore, in world energy conference of 1971, a study of noise suppression in thermal power plants occupied a major percentage of the seminars conducted.

The main sources of noise in a power plant are turbo-alternators, fans and power transformers. The simple soundproofing system consists of adequate insulation of the turbine body and piping, with a dash pot on the air-inlet to the fans. A moderate treatment includes a complete casing for turbo-alternator. An intensive treatment includes building around the turbine group and fans and complete sound-proofing of the transformers and switch gears.

Table 37.1 gives the noise levels of different individual equipments for different types of sound-proofing systems. Using these values of individuals, the total noise level of a group of equipments can be calculated. The reduction in the sound-level with the increase in distance from the source of noise is given by the following empirical relation.

TABLE 37.1

Noise Level of Power Plant Equipments with Various Methods of Sounding-proofing

Different Equipments with different Sound Proofing	*Noise level in db and plant capacity in MW*			
	500-MW	*600-MW*	*800-MW*	*1000-MW*
Turbo-alternators				
(1) Without sound-proofing	124	127	130	132
(2) With moderate proofing	111	112	112	113
(3) With medium proofing	101	102	103	104
(4) With intensive proofing	96	97	97	98
I.D. and F.D. Fans				
(1) Without sound-proofing	138	139	140	142
(2) With moderate proofing	108	109	110	112
(3) With medium proofing	98	99	100	101
(4) With intensive proofing	93	94	94	95
Power Transformers				
(1) Without sound-proofing	107	110	120	120
(2) With moderate proofing	101	102	104	104
(3) With intensive proofing	96	97	97	95

A (reduction in noise level in decibels) = $10 \log_e (\pi L^2)$ where L is the distance in metres from noise source.

The tolerable sound level and time of exposure are equally important in the design of allowable noise level in power plant. The working hours of the worker must be reduced in a highly noised area. 90 decibels of a sound level is considered maximum tolerable level for 8 hours exposure. The noise level in more than 50% power plants in U.S.A. is above 90 decibels. The length of exposure versus tolerable noise level for the workers is shown in Fig. 37.7.

Presently, enough attention has been given in many developed countries to reduce the noise level in the power-plants to the tolerable level.

The curves derived from hearing tests as shown in Fig. 37.8 made on workers show that within 10 years, over 10% of employees subject to 8 hours a day of 95-dB noise level will suffer from hearing impairment and that of 40 years, 20% will be affected to the same extent by the noise level of 92-*dB*.

37.8. METHOD SUGGESTED TO REDUCE POLLUTION

The following methods are suggested for developing the power generating capacity without pollution to the atmosphere :

1. It is suggested that the tidal power must be developed in the coming years which is free from pollution.

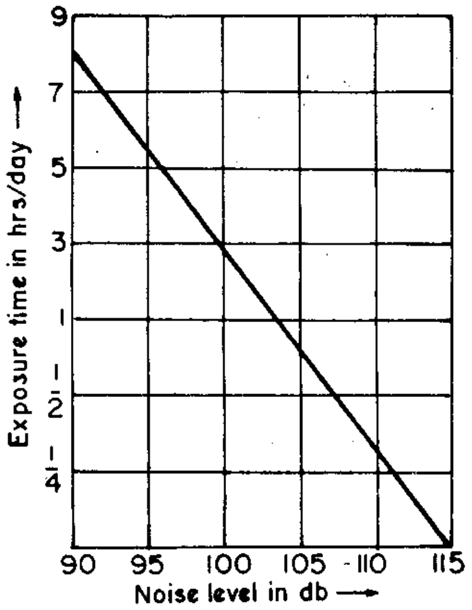


Fig. 37.7. Tolerable hours in a day for different noise levels.

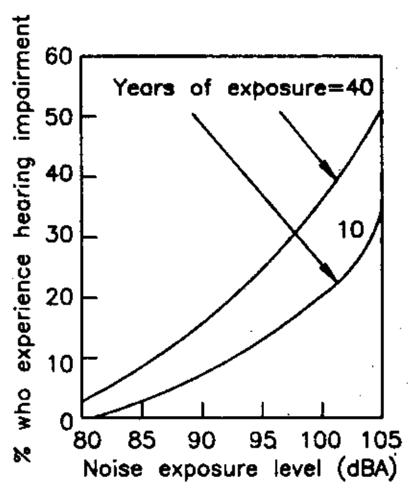


Fig. 37.8.

2. F.P. Rogers has suggested that it would be more safe to set the nuclear power plants underground. This definitely preserves the environment. There would be lot of difficulties in excavation, concreting, roof lining, structural supporting, lowering the reactor equipments and many others. But even then it is suggested that locating the power plant underground would be profitable in the long run.

3. It has been already seen that the thermal discharges to the environment are common from fossil and nuclear fueled power stations. Significant quantities of particulates and gases from fossil-fueled system, small quantities of radioactive gases from nuclear, have an impact upon an environment. These problems of pollution are mitigated by off-shore siting of power plants. Off-shore siting of power stations also isolates the plants from earthquakes and provides the thermal enhancement of the water to increase recreational and commercial values. No doubt, off-shore location requires new design consideration and floating platforms in the sea increasing the capital cost of the plant.

4. It was proposed that the thermal pollution of the atmosphere and the generation cost of the plant can be reduced by using the low grade energy exhausted by the steam. The ideal use for enormous quantity of residual energy from steam power plants requires large demand with unity power factor.

Particularly in U.S.A., many uses of energy are available in winter, but not in summer therefore finding large scale valuable uses of thermal energy is the key for developing beneficial uses.

It is estimated that the total energy used in U.S.A. for air-conditioning is equivalent to the total energy used for heating the offices and residences. The low grade energy exhaust by the thermal plants is not readily usable for air-conditioning purposes. It is possible to use this energy by stopping the expansion of steam at a temperature of 95°C to 100°C and use of this energy can be made to drive an absorption refrigeration system such as lithium bromide water system. This will be a definite positive answer to reduce the thermal pollution of environment otherwise caused by burning extra fuel to run the absorption refrigeration system in summer or to run the heating systems in winter.

Further use is suggested as open field irrigation, soil heating with warm water and better cultivation of the fishes in a slightly warm water. In short, a combination of uses could consume all heat from a large thermal power station, making conventional cooling unnecessary and reduce the generating cost with minimum thermal pollution of the atmosphere.

5. It is also proposed to use the sun energy for the production of power which is absolutely free from air-pollution.

37.9. STANDARDIZATION FOR ENVIRONMENTAL POLLUTION

With fast industrialization and rapid development of the power industry, protection of natural environment and rational use of natural resources have acquired prime importance today as the pollution from these sources has threatened and challenged the human existence on this planet.

With increasing power generation and that also in a concentrated area, U.S.A. Government has already formulated rules and regulations for the emission of pollutants to the atmosphere by different industries. Incentives are also provided to industries for emitting less and penalties are also made to the industries emitting more.

For formulating the rules for emissions, a comprehensive programme of standardization in the field of environment protection is necessary. The standardization also varies from country to country as well as from place to place as it depends upon the surrounding air velocity, temperature, humidity, population density, atmospheric dispersion characteristics and many other factors. Field experimentation is very essential to establish such standards of emissions.

The programme of standardization should cover protection and rational use of water resources, mineral wealth, land, protection of atmosphere and improvement of land use.

Standardization in this area is mainly concerned with the public health parameters of environment quality. Normal values of these parameters determine the limits of unaffected human existence and serve as the basis for calculating the normal rates of noxious matter emissions, primarily into air and water. These calculations must also take into account the factors like intensity of self-purification, possibility of diluting the exhausts, techniques of exhaust neutralization and damage from environmental pollution at the time of preparing code.

The relevant standards specify the general requirements for chemical analysis and properties of water of aquatic objects and contain tables of maximum permissible concentrations (MPC) of noxious compounds. The general requirements comprise parameters that characterize the content of suspended and floating matter, odour, taste, colour, temperature, mineral composition (for domestic water only) and pH value.

The quantities of contaminants discharged with effluents are determined separately for each enterprise and drain, taking into consideration the MPC for the compounds, the category of water use granted, the background contamination of the object, the practicability of mixing and diluting the effluents and the process of self-purification.

Standardization in the field of atmospheric protection are the ratings for exhaust emissions in air depending on the composition and concentration of the emissions, sources of pollution and specific local conditions as well as provisions for protection against noxious emissions and methods of analysis, means of control and techniques of neutralization of emissions.

USA Government has established a very wide code for air, water and ground pollutant emissions. The (former) USSR Ministry approved the MPC values for more than 200 pollutants. This standardization establishes rules for determining and controlling harmful emissions with due consideration to the hygienic, economic and ecological requirements. The standard defines the maximum permissible emission (MPE) for each source of atmospheric pollutant. These values are always found on the basis of health requirements and normal methods of establishing contamination of surface air layers which is a function of weather conditions, surface relief and location of the area.

Source Neeri Survey 1971

City	*Particulate in air* ($\mu g/m^3$)	SO_2 ($\mu g/m^3$)	*City*	*Particulate annual average* ($\mu g/m^3$)	*Particulate Maximum* ($\mu g/m^3$)
Calcutta	340.7	32.88	New York	124	252
Bombay	240.8	47.11	Washington	72	216
Delhi	601.1	43.43	Chicago	114	273
Madras	100.9	8.38	Buffalo	117	1321
Kanpur	543.5	15.97	Hanolulu	33	74
Nagpur	261.6	7.71	California	113	235
Ahmedabad	306.6	10.66	Virginia	174	684
Hyderabad	146.2	5.06	Birmingham	128	329

The particulate and SO_2 emissions of a few Indian and Foreign cities are listed in the table which will give an idea to the readers whether such codes are necessary or not in India. The problem of pollution is not very serious in this country as most of pollutants are below specified standards of the other countries except in a few big industrial towns.

600 tons of pollutants with 60 tons of SO_2 are emitted per day in Calcutta which is sufficient to give an idea for its seriousness. The dust fall rate in Calcutta is 1.10 to 40 tons/km^2/month whereas in USA this range is 4.5—400 tons/km^2/month.

Pollution Index

Environmental pollution has made the sky a virtually overloaded sewer, fertile land, a wasteland and a river, a poisonous sink. We breathe from this sewer, drink from this sink, fall sick and die under the fatal illusion of progress.

The pollutants are many as SO_2, NO_x, H_2S, CO and dust. The effects of each on human life are diversified. Therefore, the Govt. has put restrictions on the pollutants emitted by all industries. The common pollutant among all is SO_2 and its effects are more serious than others. Therefore, the effects of all other pollutants are converted into equivalent effect of SO_2 and the sum is made which is called equivalent effect of SO_2.

The threshold values of pollutants present in the air are added and expressed in terms of SO_2 threshold value. This value is taken as "**Zero-Pollution**" (A_0) that means this amount of pollution has no adverse effects on animals and plants. Similarly, the excessive values of all polluting gases present in air are added and expressed in terms of SO_2 threshold value. This

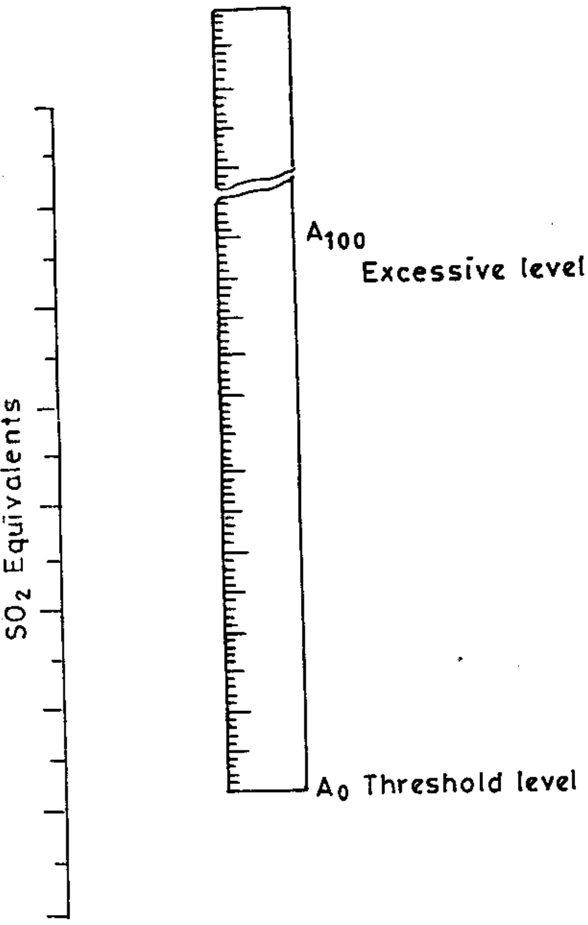


Fig. 37.8. Indexing the air pollution intensity

value is taken as **"Excessive Pollution"** (A_{100}). This value can cause the maximum possible damage to the animals and plants at that place. Now A_0 and A_{100} is divided into 100 equal parts (as effect of each is linear as shown in Fig. 37.9) and one part out of 100 is taken as **"Unit of Air-Pollution"**. The values of different pollutants in different ranges are listed in following table.

The first 20 units (A_0 to A_{20}) is permissible level for residential area, hospitals and schools. The next 20 units (A_{21} to A_{40}) is permissible for markets, railway stations and bus-stops. The units A_{41} to A_{60} are permissible for small scale industries. Above A_{60}, it is for industrial estates, where the person is permitted to spend only 8-hours a day beyond which it causes bad effect on the health. This type of Index is simple to understand like °C which expresses the hotness at a place instead of ppms.

The indexing of the air pollution intensity on the scale A_0 and A_{20} and equivalent SO_2 is shown in Fig. 37.10.

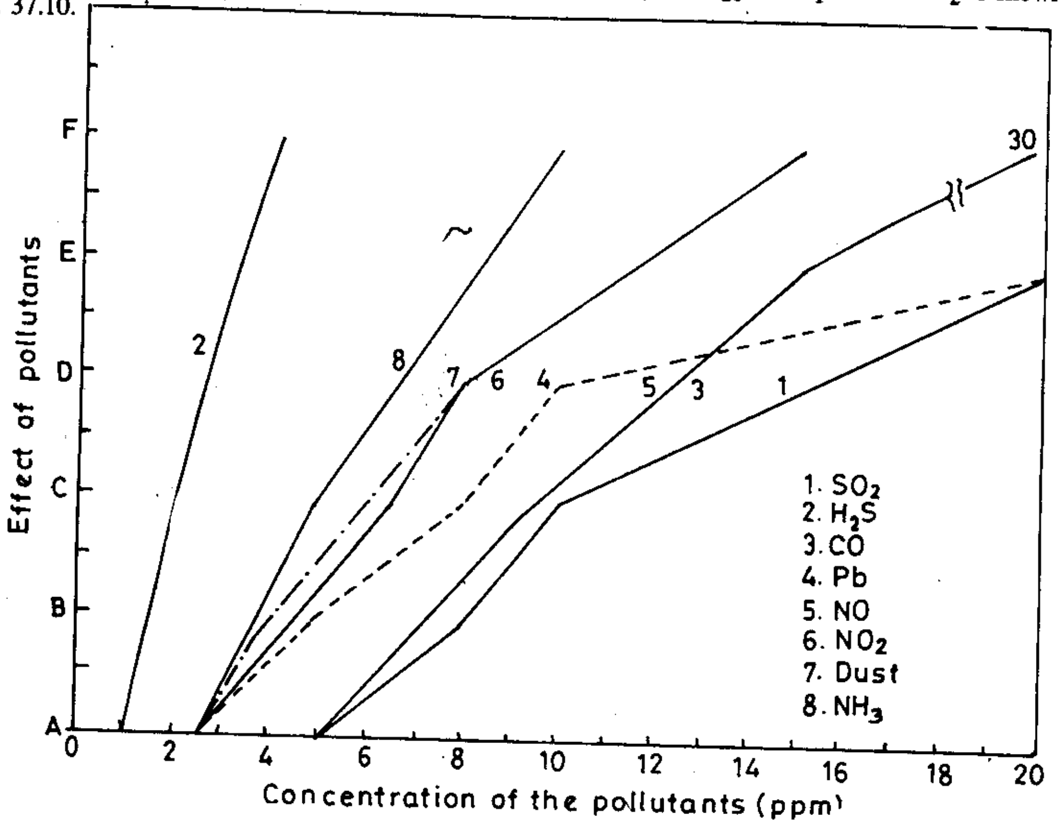


Fig. 37.10. Bio-chemical effects of air pollutants.

Table 1. Analysis of some Air Pollutants

Sl. No.	Name of the Pollutants	(in ppms)					
		A	B	C	D	E	F
1.	SO_2	5.0	8.0	10.0	—	200	300
2.	H_2S	10.0	15.0	20.0	—	—	40.0
3.	CO	50.0	70.0	90.0	—	—	300.0
4.	Pb	0.25	0.50	0.80	1.0	2.0	3.0
5.	NO	5.0	7.0	10.0	12.0	15.0	40.0
6.	NO_2	25.0	45.0	65.0	80.0	—	150.00
7.	Dust	0.25	0.40	0.60	0.80	—	1.5
8.	NH_3	25.0	—	50.0	—	—	100.0

(A) Threshold values, (B) Mild effects need no treatment, (C) Mild effects need some treatment, (D) Permissible limit, (E) Irreversible effects, (F) Excessive limit :

EXERCISES

37.1. What are the basic elements exhausted with the flue gases which are hazardous for human health ? What are the effects of SO_2, NO_x and hydrocarbons on the human and crop lives ?

37.2. What are the different methods used to control SO_2 in the flue gases ? Explain any two.

37.3. What are the different methods used to control NO_x in the flue gases ? Explain any two.

37.4. Method used to control NO_x increaases CO in the flue gases. What is the reason ? What method is used to control both ?

37.5. What do you understand by acid rains ? What are the reasons for this ? How they are controlled ?

37.6. What do you understand by London smog and Los Angeles Smog ? Which is more serious and why ?

37.7. What do you understand by thermal pollution ? Explain the bad effects of thermal pollution.

37.8. What do you understand by noise pollution ? Explain the methods adopted to reduce the noise pollution.

37.9. What are the basic radioactive pollutants ? What are their bad effects on human and vegetation life ?

37.10. Explain the different methods adopted to control the nuclear pollution.

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38

Green House Effect and Its Control

38.1. INTRODUCTION

The pollution caused by thermal power plants and nuclear power plants to the earth atmosphere was considered seriously for last four decades and handled very effectively by providing many advanced methods to remove and control poisonous gases and particulates from the exhaust. The effect of CO_2 was never considered so seriously as thought during the current decade as it has no harmful effect on the human health or biological life. Otherway, the presence of CO_2 was considered essential for the O_2 balance on the earth.

Even though, CO_2 has no ill-effects on human or biological health of the earth, its present trend of increase in atmosphere has created a great threat to the human being for his survival as its major impact on the earth is the commonly known as Green House Effect (Increasing the temperature of the earth surface slowly).

The present time is also the most appropriate time for correcting the most serious mistake made during 20th century which has posed a serious threat to some of the most cherished values of humankind and in some cases to the very survival of most forms of life on the earth.

Rapid industrialisation world-wide has adversely affected the atmosphere with the CO_2 concentration, arising mainly from combustion of fossil fuels, increasing steadily over the past four decades. We have understood now, the damage which we have made to our living atmosphere for our more and more comfort and now we have reached to a stage to consider the measures to be taken immediately to stop further damage.

The earth has entered a period of climatic change that is likely to cause widespread economic social and environmental dislocation over the next century if emissions of heat trapping gases are not reduced. The undesirable global climate change is indeed in progress and that at least some of the warming is due to human action, specifically by burning coal, oil and wood for power generation, transport and cooking.

Without any doubt, the 20th century has been catastrophic from the point of view of environment. For the first time in the earth history, planet level threats have emerged as a result of man's own actions. Two major threats are Global Warming and Depletion of Ozone (O_3) layer. Of these, the second one is much easier to tackle as it involves only a few specific gases to be controlled whereas in meeting the first threat, drastic reduction in overall energy consumption (which is responsible for CO_2 emission in atmosphere) is inmediately required.

*The effects of CFCs on the depletion of O_3 layer and its effects on global warming is detected and effective measures are already taken to phase out CFCs by safe group of refrigerants by the year 2010 partly and by the year 2050 fully.

The scientists suggest that by doubling the green house gases (CO_2 and CFCs) can increase the earth temperature by 0.5 to 5°C by trapping global heat. It is also concluded that industrial nations will do little to stop CO_2 from increasing because stabilising CO_2 concentration even at double of today's level (350 ppm) over the next 100 years can be attained only if emissions eventually drop substantially below the 1990 level (335 ppm). This is partly because, these gases remain in the atmosphere for many, many years. CO_2 accounts for 70% of all so called green house effects. And if increase in CO_2 in atmosphere is continued, it could cause the earth to warm up a few degrees (5°C) which is enough to cause serious climate and social problems. The water level may go up by 3 m in Newyork, Losangles, Bombay and Bangladesh and will have difficult time in coming future.

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*There is separate chapter on this topic in the book "Refrigeration and Air-conditioning" by the same author and interested readers are advised to refer that book for further details.

Increasing trend of CO_2 in the atmosphere has definitely posed some serious problems before the environmental scientists :

(*i*) The first question is, how much CO_2 will be added to the atmosphere in future years and at what rate by burning the fossil fuels and clearing the forests ? These human activities have already increased CO_2 in atmosphere by 1.5%.

(*ii*) Second question is, whether the increase in CO_2 will cause an important global rise in average temperature and other changes in the world climate ?

(*iii*) The third question is, whether the possible climate changes due to increase in CO_2 in the atmosphere would have major consequences on human life ?

The answer to all three questions is yes and therefore, it has become essential to take steps to curb the CO_2 increase in atmosphere to maintain the comfortable human life on the earth.

The environment is now one of the fastest growing areas in terms of career opportunities, albeit for all the wrong reasons—the growing importance of an environmental engineer, pollution control specialist or an environmental lawyer is quite comparable to that of a doctor in the midst of an epidemic. Growing levels of industrial effluents, stricter pollution control laws and increasing industrial activity, are now making environmental professionals indispensable in the manufacturing sector.

At the industrial level, environmental engineering is one of the more lucrative areas. An environmental engineer works at preventive as well as curative levels on pollution control. Depending on the raw materials and production process, the residuals of a manufacturing activity, in the form of processed wastewater, atmospheric waste, unutilised materials, emissions, sludge and solid waste at various stages, need to be handled and minimised. The environmental engineer's job profile involves assessing the environmental impact of a particular manufacturing activity, devising system packages for industrial clients, manufacture and maintenance of pollution control equipment, evolving 'low or no waste technologies' and modification of the manufacturing system itself, with the view to optimise resource use and minimise waste and ecological damage. He ensures that a plant meets standards set by the central and state pollution control boards, ISO standards and environmental laws. Consultancy firms, conducting studies on environmental impact assessment, pollution level analysis, and air, soil and water quality, also employ environmental engineers.

Another related area is energy engineering, which among other things involves developing energy-efficient technologies, and non-conventional energy sources, nuclear reactor engineering, Bio-mass energy, wind power and solar energy systems, power generation and system planning, as alternatives to conventional electrical power.

38.2. CO_2 AND ITS ROLE IN THE BIOLOGICAL LIFE

Atmosphere is made of N_2 and O_2 with small percentages of other gases as CO_2, NO_x, CH_4, O_3 and man-made gases as chlorofluoro carbons (CFCs). Very small percentages of these gases determine to a large extent the effects on own planet. However, they all are presently undergoing rapid changes in their atmospheric concentrations as a result of human activities. The two problems created by their changes are Green House Effect (responsible for the increase in global temperature) and statospheric O_3 depletion which has created a life threatening by exposing the earth to ultraviolet radiations.

CO_2 is not considered a toxic gas. It is not even considered a pollutant but its presence in atmosphere is considered essential for photosynthesis and production of O_2 which is most essential requirement of human life. However, higher concentration of CO_2 produces respiratory problems, and carboxyhimoglobin in blood and deprives brain from O_2.

CO_2 is colourless and odourless gas that does not support combustion but it is one of the most important ingredients of the planets' biosphere. Exchanged between plants and animals, air and sea, at a rate of hundreds of billions of tons per year CO_2 arises from and helps to sustain the life on Earth. Carbon, one of the components, is the very essence of life. It comprises the backbone of all organic molecules, of which all living things are made. It combines with O_2 which provides animals with the energy needed to drive their

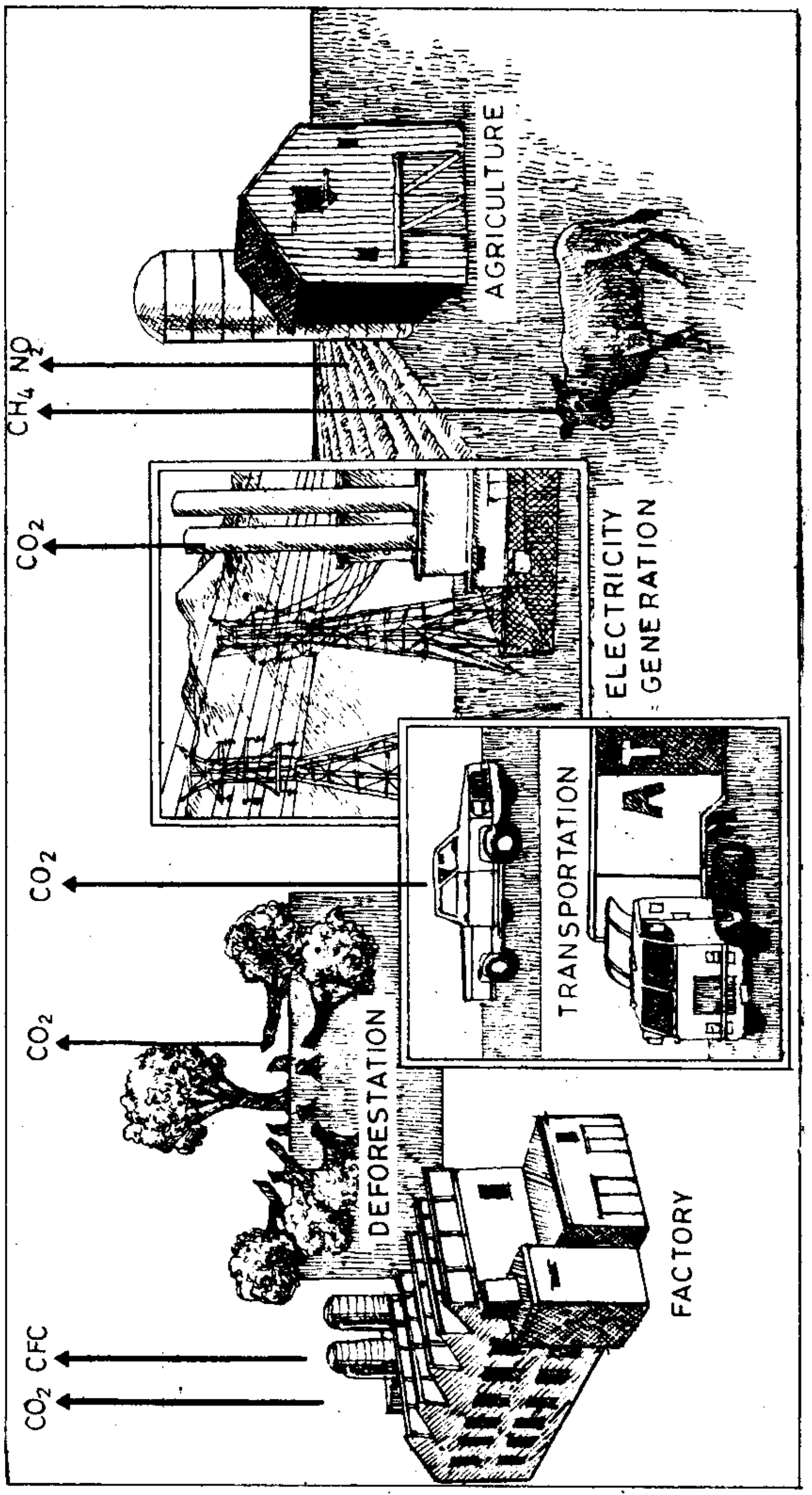


Fig. 38.1. CO_2-emission from man made sources.

biological processees. The gas itself is exhaled into the atmosphere and in turn is taken in by plants, which use the molecules, plus H_2 from water, to take carbohydrates for building new tissue.

CO_2 is only 0.03% of the atmosphere by volume (or 2.25 trillion tons). Its heat trapping quality is partly responsible for the climate that has been so hospitable to life on earth.

The quantity of CO_2 emitted naturally and by manmade causes are listed below.

Natural causes	*Amount tons/year*	*Manmade causes*	*Amount (tons/year)*
Organic decay	2×10^{12}	Combustion (power plants)	2×10^{10}
Volcanoes	1×10^{12}	Industry	2×10^{6}
Respiration	1×10^{12}		

Total $(A + B)$ steady state $= 3 \times 10^{12}$ tons/year (325 ppm)

The man-made causes of increasing CO_2 in air are shown in Fig. 38.1.

It is obvious that CO_2 contribution is mainly by natural causes, even then, the power plant and transport combustion also contribute significantly. Therefore, the CO_2 is continuously increasing in the atmosphere as it was 312 ppm in 1940, 318 ppm in 1960 and expected to be 350 ppm by 2000.

The level of CO_2 in the atmosphere is maintained steady state by photosynthesis which reduces CO_2 and increases O_2 in the atmospheric air. The photosynthesis is a process which is carried out by the green plants by absorbing CO_2 and moisture in the air and convert them in O_2 and organic matter in the presence of sunlight.

There must be sufficient green plants to absorb generated CO_2 and convert into O_2 but when the CO_2 emitted rate is higher and number of green plants is decreased, then the CO_2 steady state condition is achieved at higher concentration in the air and this is what is happening because of increasing demand of power worldwide and large cut-outs of forest trees because of increased rural population who use wood as basic fuel for them.

The present CO_2 emission into atmosphere is 5700 crore of tons per year from man-made causes and forest area only in India is shrinking at a rate of 1.5 lac hectors per year (the major dams construction is responsible for only 12% and remaining is 88% by other causes). This scene is very panic as both are equally responsible to increase CO_2 percentage in air. Therefore, there is demand to reduce the power requirement and increase the forest area by artificial plantation. Many measures are already in process throughout the world to reduce CO_2 by different methods which will be discussed at the end of this chapter.

38.3. WHAT IS GREEN HOUSE EFFECT

In many countries, where sun energy is not easily available, for the cultivation of fruits and vegetables, is made available for their growth through green house effect. The term *Green House* was first brought into use by Swedish Scientist Swante Arhensum in 1896.

A green house, as shown in Fig. 38.2 (*a*) is a house made of complete glass where the vegetables are cultivated. In this house, the solar energy at shortwave radiation enters inside through the glass as glass is almost (80-90%) transparent to short wave radiations. This shortwave radiation when strikes the inner earth surface of the green house, converts into heat-longwave radiation. This longwave radiation is again reflected back into atmosphere from the inside surfaces but it cannot go out as the glass restricts the longwave radiation going out and traps the heat. This trapped heat (which should not have happened without glass) contributes to the warming of glass house and provides energy for the growth of plants. This trapped energy essential for the growth of plants keeps the plants green. Therefore, this effect is known as Green House effect. The earth surrounding atmosphere behaves just like glass and keeps the earth green. Therefore, this effect is also popularly known as Green House effect.

Warming of the atmosphere and subsequently the earth surface warming takes place because of green house effect. The atmosphere contains radiatively active substances like CO_2, water vapour and other trace gases that contribute towards the warming up.

In bodies without an atmosphere, like moon, the sun facing side is unbearably hot because the radiation from the sun strikes it directly and heats its surface. The dark side is bitterly cold because, the heat it catehes during the "*day*" is lost in "*night*". But on earth, the thick blanket of atmosphere (nearly 200 km) prevents heat from escaping to space. Actually, the atmosphere is almost transparent to shortwave radiation and therefore all short wave solar energy (95% lies in between 0.4 to 8μ wavelength) reaches the earth. This radiation is converted into heat-longwave radiation which is then re-radiated. These longwave radiations cannot get through the atmosphere as easily as shortwave radiation. It remains trapped by the air and this trapped heat which contributes to the general warming of the earth and creates temperature conditions conductive to the human and biological life. The earth green house effect is shown in Fig. 38.2 (*b*).

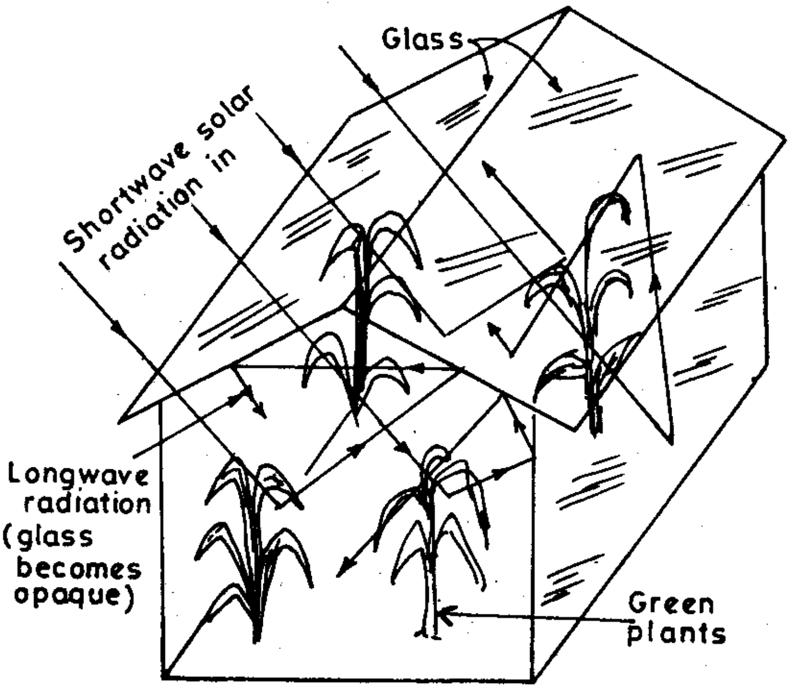


Fig. 38.2 (*a*) Green House.

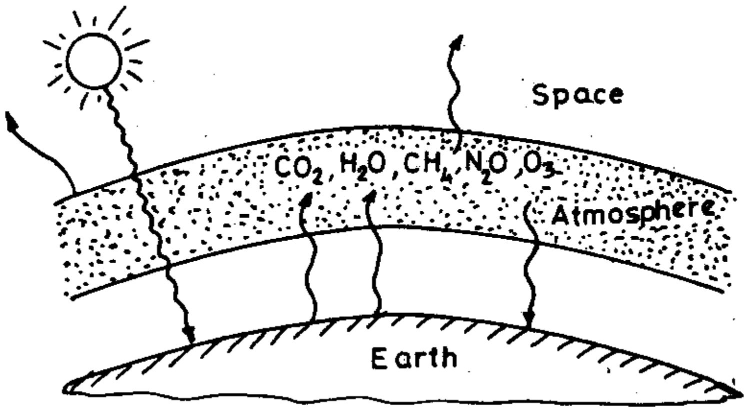


Fig. 38.2. (*b*) Greenhouse gases trap long wavelength energy from the earth's surface, heating the atmosphere, which, in turn, heats the earth.
(Earth as a greenhouse)

In the process of green house effect, the visible light comes in as it would have, if there was no atmosphere. But, the atmospheric gases transparent in the visible part of the solar spectrum tend to be opaque in the longer infrared part of the spectrum. The thermal radiation in the infrared is impeded from getting out, resulting in the blanketing of the earth in the infrared spectrum but not in the visible part of the spectrum.

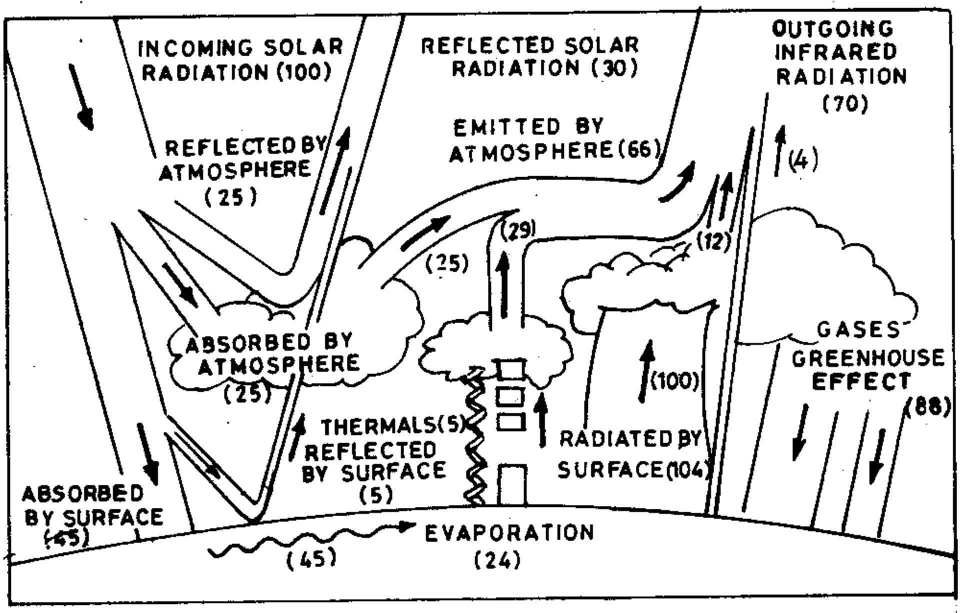


Fig. 38.3. Solar radiation and greenhouse effect.

As a result, the earth surface temperature has to go up until the radiation which is leaking out in the infrared just balances the visible radiation that is coming in. Fig. 38.3 explains the greenhouse effect in terms of various radiation components. The numbers in the brakets are in terms of the percentage, each arrow represents relative to earth-average solar constant of 340 W/m^2.

However, if too much heat is held back, life can be endangered. Such a runaway "Green House Effect" occurs on venus which has an extremely dense CO_2 rich atmosphere. The surface temperature of the venus is 477°C. It is not because it is close to the sun, but it is because of the dense surrounding layer of CO_2 in its atmosphere.

If no green house effect existed on earth, the average temperature would be – 19°C well below the freezing point of water and hence, incompatible with any form of life as we know it. Most of the heat entered from sun into earth atmosphere is re-radiated but in the process, a delicate balance is maintained which keeps the earth surface at an average temperature of 15°C. It is obvious to understand how crucial the green house effect is in keeping us warm and comfortable. But too much of good thing can have the opposite effect, like on venus.

This green house effect has been working from the very birth of the earth. It has helped in the development of the environment over the earth. The animals, birds and vegetation all are tied up with each other as an ecosystem which has a self-ecological balance like human health. The excessive rise in population, excessive cutting of the forest and unlimited rise in power generation causes an imbalance of the ecosystem, naturally, such a significant imbalance rarely occurs. This kind of disturbance in the ecocycle is predicted like eruption of volcanos and floods. The nature has proved to be competent enough to restore back the fine ecological balance *but upto limited range.*

The CO_2 gas in the atmosphere is solely responsible for green house effect on the earth as it is transparent to short wavelength and *opaque* to long wave radiations. Its percentage in atmospheric air will definitely decides how much energy will be trapped into the surrounding atmosphere which is responsible for earth surface temperature. Higher % of CO_2 will trap more and increase the earth surface temperature slowly. Its immediate effect on increase in temperature may be slow as hardly 5°C within coming 100 years but its long term effects are serious and destructive and therefore, it is necessary to take due care before the atmosphere is so much damaged by the human activities.

CO_2 alters the earth's heat balance by acting one way screen as it is transparent to shortwave solar radiation and stops the back flow of heat from long wave radiations emitted from earth surface. This increases the earth surface temperature and this phenomenon is known as **Green House Effect.**

38.4. O_3 (OZONE) AS A GREEN HOUSE GAS

The economic and industrial progress of human being in the long run shows to have caused more harm to the nature and to himself than any good.

Progressive molestation of the nature under the name of development has left not a single sector of nature unpolluted. The most significant and dangerous effect of this pollution has gone too far and demands urgent attention and measures to curb it, is the earth's protective case—the O_3 layer. Ozone has protected the life on earth from the harmful ultra-violet rays since long. Today, it's thinning endangers the life on earth.

The main culprit for this is the increasing use of CFCs which are used on very large scale in refrigeration and air-conditioning industries.

Harm done is irrecoverable though late, recently steps have been taken to prevent future depletion of O_3 layer. In Montreal Protocol, all countries have agreed to bear the costs of switching over to CFCs substitutes to save O_3 layer. India has also signed the protocol in 1992. Accordingly USA has agreed to provide economical assistance of \$ 1.75×10^6 to India to phase out the use of ozone depleting CFCs.

The effect of O_3 in the outer atmosphere of earth has similar effect like CO_2 but the nature of effect is in different form and more serious. The most intensively studied Green House Gas (GHG) is CO_2 and the potential impact of an increase in its concentration has been widely discussed. However, other gases like chlorofluoro carbons (R-11 and R-12) can also significantly amplify the green house effect of CO_2.

The other important gases which are responsible for green house effect are R-11 and R-12, they are popular refrigerant used in refrigeration and air-conditioning industry. Their leakages in the atmosphere act with the O_3 layer and destroys the O_3 molecules.

The solar energy in the range of ultraviolet radiation wave length (which is highly injurious to the human and biological life) is retarted by the O_3 layer and prevents its entry through the atmosphere to the earth. With an extensive study, it has been established that the reactions between R-11, R-12 and O_3 destroys O_3 layer and it has already detected ozone-holes in the upper atmosphere of the earth as shown in Fig. 38.4 *(a)*. Therefore, the ultraviolate wavelength energy directly enters into the atmosphere (just like flowing water through a hole on the surface of a pot). This effect of pouring energy through these holes compared with the percolation of energy through CO_2 layer is more serious. These gases (R-11 and R-12) have greater growth rates, stay longer in atmosphere (hundreds of years) and so have greater green house effects than CO_2. For example, on molecular basis, the release of one CFC molecule has the same surface heating effect as the addition of 10,000 CO_2 molecules. The effect of CFCs is more serious than CO_2 but the total effect of CFCs on green house effect compared with CO_2 is (percentage wise) considerably less. Even then, enough care has been taken to wipe-out CFC's from the refrigeration industry by the end of 2020 by replacing the safe refrigerants. The purpose of this chapter is not to discuss the effect of CFCs on green house effect but devote more concerning CO_2 effect as the emission of CO_2 cannot be stopped but it can be reduced by adopting different methods.

The likely concentration trends of other GHGs (green house gases), and their effects are approximated in terms of an equivalent amount of CO_2 because they are radiatively similar to it. At present, the effect of other GHGs is approximately equivalent to an increase of 40 to 50 ppm of CO_2. During the next 50 years, the other GHGs will increase their effects relative to CO_2 through their greater growth rates, longer residence times, and their higher efficiencies. This would result in a green house situation equivalent to CO_2 doubling well before 2050. Therefore, preventive measures must also include controlling the emission of both CO_2 as well as other GHGs.

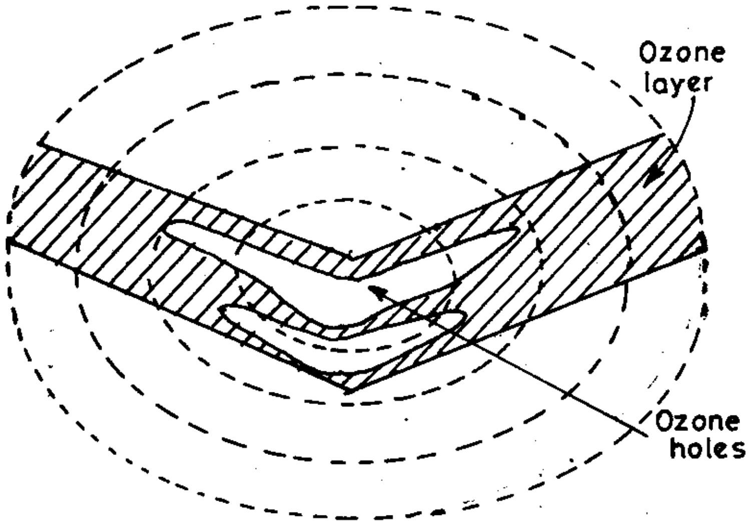
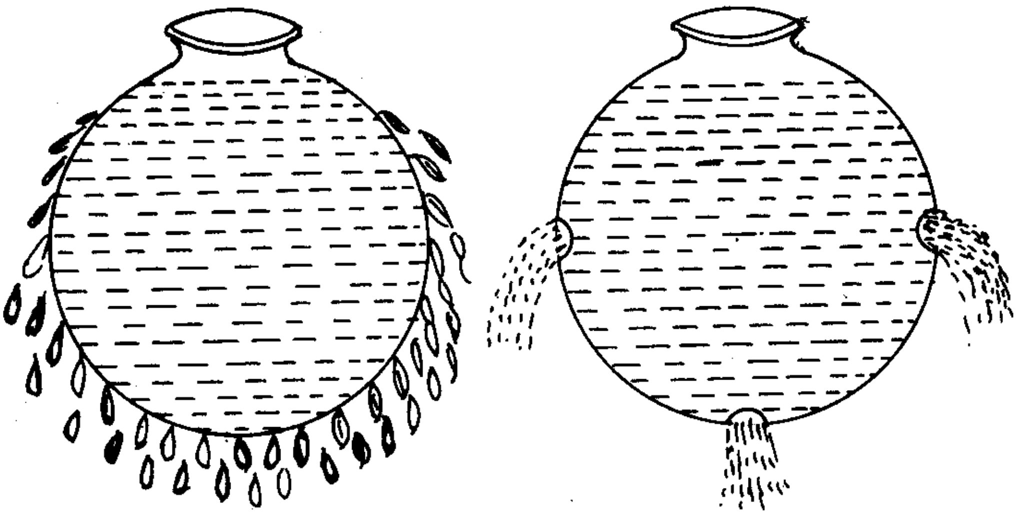


Fig. 38.4 (*a*) The Antarcnc Ozone Hole. The dramatic reduction discovered is shown here.



(*i*) Effect is similar to CO_2 (*ii*) Effect is similar to O_3

Fig. 38.4. (*b*)

The present percentage contribution to green house effect by different gases is shown in Fig. 38.5 and it is obvious that CO_2 contributes maximum to the global warming.

CFCs and CFC Substitutes and their effects on O_3-Depletion and Green House Effect

Substances	*Chemical Formula*	*O_3 Depletion Potential*	*Green House Strength*
CFC – 12	CCl_2F_2	0.90	1.00
HCFC – 22	$CHClF_2$	0.05	0.07
HCFC – 123	$CHCl_2CF_3$	0.15	0.10
HCFC – 124	$CHClFCF_3$	0.50	0.10
HFC – 125	CHF_2CF_3	0.00	0.20
HFC – 134 (*a*)	CFC_3HEF	0.00	0.10
HCFC – 141 (*b*)	CH_3CCl_2F	0.05	0.20
HFC – 152 (*a*)	CH_3CHF_2	0.00	0.10

Table I – Relative share of greenhouse gases responsible for global warming

Greenhouse gas	*Share in additional global warming (per cent)*
CO_2	50 (40 energy related, 10 other factors)
CFC	22
CH_4	13 (partly from fossil fuel exploitation)
O_3	7 (related to NO_x and CO emissions)
N_2O	5
H_2O	3 (stratospheric water vapour)

Table II – Greenhouse Gases in Earth's Atmosphere

Greenhouse gas	*Major sources*	*Total emissions per year (Millions of tons)*	*Average residence time in atmosphere*	*Approximate current concentration (PPB)*
Carbon dioxide (CO_2)	Fossil fuel combustion, deforestation	5,500	100 years	350,000
Methane (CH_4)	Rice fields, cattle, landfills, fossil fuel production	550	10 years	1,700
Nitrous oxide (N_2O)	Nitrogenous fertilizers, deforestation, biomass burning	25	170 years	310
Chlorofluora carbons	Aerosol sprays, refrigerants, foams	1	60 to 100 years	About 3 (Chlorine atoms)

The other gases listed in Table I are chemically far more efficient in absorbing infrared radiation than carbon dioxide. The combined warming effect of these trace gases will soon equal or exceed the effect from carbon dioxide alone [6-7].

There is a large group of natural ozone-cracking substances produced by algae, bacteria and plants. Methyl chloride and methyl bromide are the biggies together accounting for 20% of O_3-depletion. A whopping amount of methyl is generated by natural processes including biochemistry of salt-marsh plants, coastal ecosystems and breakdown of organic matter in soil.

Salt marshes are top producers, even though they constitute less than 0.1% of the global surface area, produces 10% of total atmospheric load of methyl chloride and methyl bromide.

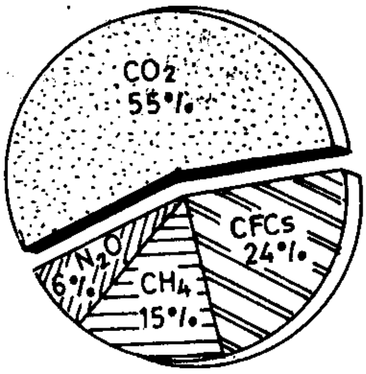


Fig. 38.5. Contribution to Green House Effect by different gases.

Ozone Hole

An ozone layer outside the atmosphere protects the earth from ultra violet rays radiated by the sun as it has high absorption capacity for these rays. Due to large use of CFCs during the last two centuries, the O_3 layer is becoming thinner and thiner as CFCs destroy the O_3 very rapidly. When this was detected by the scientists, the restriction has imposed on its use in 1987 as per Montreal Protocol and plan is adopted to phase out CFCs by 2010.

The O_3 from the atmosphere is eaten out by CFCs and creates a hole and such a hole was detected in 1985 over Antartic. The hole recently detected over South Pole covers nearly 1750 lacs of square kilometer which is three times the area of America. This hole has covered complete Antartica zone and also reached to South America. Such a huge hole was detected in 1998 which covered 1680 lacs of square kilometers. Such hole is expected everyyear but it takes very long time (15—20 years) to fill it up as production of O_3 is a very slow process.

The development of the hole which could extend from the Arctic to the British Midlands, follows a period of usually low temperatures combined with high levels of pollutants in the atmosphere—the ideal formula for O_3-destruction.

The effect of this is minimum over India but there is an Ozone dip.

38.5. THE OTHER GREEN HOUSE GASES (GHGs)

The water vapour and CO_2 are the main GHGs responsible for greenhouse effect. Any gas that absorbs in the infrared will help to reduce the loss of terrestrial radiation to outer space. However, absorption by water vapour and CO_2 is so strong that other gases will contribute little unless they absorb radiation in the range of 8 μm to 12 μm (the atmospheric window) where absorption by CO_2 and water is weak.

The most important trace gases that contribute significantly to the trapping of terrestrial radiation are CH_4, NO_x and CFCs (F-11 and F-12). Methane concentrations are only about 0.5% of CO_2 but it is 21 times as effective as CO_2, while CFCs are only one millionth of CO_2 but 15000 times more effective compared with CO_2.

Methane, currently at 1750 ppb is increasing by 1% annually and is expected to double in about 70 years. The sources of CH_4 emissions are rice paddies, waste disposal and oil recovery operations. Doubling methane would have about 15% of the warming effect of doubling CO_2.

NO_x, currently at 300 ppb is increasing at the rate of 0.25% per year. The main source is combustion. It is estimated that likely increase is about 20% by 2060 and will contribute about 4% to the total greenhouse warming.

The present concentrations of CFCs (F-11, 0.06 ppt and F-12, 0.14 ppt) contributes to global warming to about 0.2 W/m^2 or 12% of total. The trace gases combined now contribute to 50% of total green house effect. Even CFCs emissions are reduced, the green house effect may rise as F-11 have 80 years and F-12 have 1400 years lifetime. If the Montreal Agreement to reduce emissions to 80% of 1986 level from 1993 and to 50% from 1998 is fully implemented, CFCs are likely to contribute about 10% to greenhouse warming in 2060.

The percentage of GHGs and their effects towards greenhouse effect are listed in the table III below.

Table III – Major Greenhouse Gases and their Characteristics

Gas	*Atmospheric concentration (ppm)*	*Annual concentration increase (%)*	*Relative greenhouse efficiency ($CO_2 = 1$)*	*Current greenhouse contribution (%)*	*Principal sources of gas*
Carbon dioxide	351	0.4	1	57	Fossil fuels, deforestation
CFCs	0.00225	1	15,000	25	Foams, aerosols, refrigerants, solvents
Methane	1.675	1	25	12	Wetlands, rice, livestock, fossil fuels
Nitrous oxide	0.31	0.2	230	6	Fuels, fertilizer, deforestation

The different refrigerants green house effect (O_3 depletion potential) relative to F-11 is shown in Fig. 38.6.

The present refrigerants (F-11 and F-12) are going to be replaced by F-134 *a* and F-143 *a* which have very less warming effects compared with conventional refrigerants as shown in Fig. 38.6.

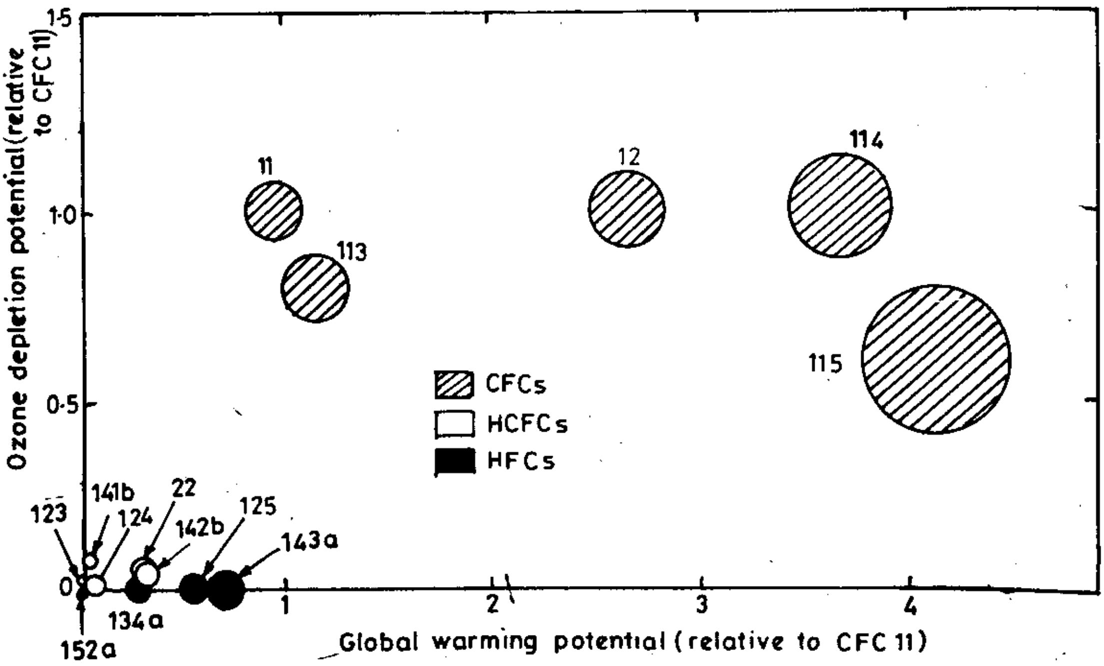


Fig. 38.6. Global warming potential and ozone-depletion potential for fully halogenated (CFCs), hydrochlorofluorocarbons (HCFCs), and hydrofluorocarbons (HFCs) measured relative to F-11 of the circles is proportional to atmospheric lifetimes.

38.6. TREND OF CO_2 INCREASE IN ATMOSPHERE

An assessment of the evolving greenhouse climate requires an estimation of the future trends in concentration of CO_2 and other GHCs. This is a hazardous undertaking because such trends depend on

Table IV – Overview of a selection of greenhouse gases influencing climate

Constituent	Principal anthropogenic sources	Principal sinks and removal processes	Atmospheric residence time	Global average mixing ratio in 1980	Possible increase from 1980-2030 (uncertainty range in 2030)	Potential influence or climate and surface temperature change
Carbon dioxide (CO_2)	Fossil fuels, deforestation, soil destruction	Ocean biosphere	6-10 Yr.	339 ppmv	339-450 ppmv (380-550 ppmv)	Warming in T. Cooling in S. $2 \times CO_2 \rightarrow 3 \pm 1.5°C$ global, 2 to 3 times greater at poles
Methane (CH_4)	Rice paddies, cattle raising, biomass burning, gas leakage, fossil fuels	Photochemical reaction with OH and NO_x. Soils in semi-arid climates, net CH_4-flux from T. to S. Reactions with OH and $O(^1D)$ in S.	9-10 Yr.	1.65 ppmv	1.65-2.34 ppmv (1.85-3.30 ppmv)	Direct and indirect greenhouse effect in T ; influence on chemistry in S. (source of H_2O, reaction with Cl and HCl-formation) $2 \times CH_4 \rightarrow 0.3°C$
Ozone (O_3)	Indirectly produced through photochemical reactions with other substances	Through oxidation of CO and NO under the influence of NO ; catalytic reactions with *e.g.* NO_x, Cl_x, HO_x in S.	30-90 dy(T.) 2 Yr. (S.)	0.02-0.3 ppmv (T.) 5-10 ppmv (S.) (at 30 km)	12.5 per cent increase in tropospheric O_3	O_3-production in T. leads to warming : $2 \times O_3 \rightarrow 0.9°C$
Nitrous oxide (N_2O)	Biomass burning, fossil fuels, artificial fertilizers	No major sink in T., photolysis and reaction with $O(^1D)$ to form NO in S.	165-185 Yr.	300 ppbv	300-375 ppbv (350-450 ppbv)	Greenhouse effect in T. impact on O_3-budget in S. $2 \times N_2O \rightarrow 0.3\text{-}0.4°C$
Chlorofluorocarbons ($CFCl_3$) (CF_2Cl_2)	Propellants, coolants, solvents	No known sink in T., sink in S. through photolysis	65 Yr. 110 Yr.	0.18 ppbv 0.98 ppbv	0.18-1.10 (0.5-2.0 ppbv) 0.28-1.80 (0.9-3.5 ppbv)	increase from 0.1 ppbv. $CFCl_3 \rightarrow 0.13°C$ $Cf_2Cl_2 \rightarrow 0.15°C$
T = Troposphere S = Stratosphere		ppmv = parts per million ppbv = parts per billion		2 × = doubling of concentration		