UNIT V

ENERGY, ECONOMIC AND ENVIRONMENTAL ISSUES OF POWER PLANTS

Power tariff types, Load distribution parameters, load curve, Comparison of site selection criteria, relative merits & demerits, Capital & Operating Cost of different power plants. Pollution control technologies including Waste Disposal Options for Coal and Nuclear Power Plants.

5.1 INTRODUCTION

In all fields of industry economics plays an important role. In power plant engineering economics of power system use certain well established techniques for choosing the most suitable system. The power plant design must be made on the basis of most economical condition and not on the most efficient condition as the profit is the main basis in the design of the plant is to bring the cost of energy produced to minimum.

Among many factors, the efficiency of the plant is one of the factors that determine the energy cost.

5.2 TERMS AND DEFINITIONS

1. **Connected Load.** The connected load on any system, or part of a system, is the combined continuous rating of all the receiving apparatus on consumer's premises, which is connected to the system, or part of the system, under consideration.

2. **Demand.** The demand of an installation or system is the load that is drawn from the source of supply at the receiving terminals averaged over a suitable and specified interval of time. Demand is expressed in (kW), kilo volt-amperes (kVA), amperes (A), or other suitable units.

3. **Maximum demand or peak load.** The maximum demand of an installation or system is the greatest of all the demands that have occurred during a given period. It is determined by measurement, according to specifications, over a prescribed interval of time.

4. **Demand factor.** The demand factor of any system, or part of a system, is the ratio of maximum demand of the system, a part of the system, to the total connected load of the system, or of the part of the system, under consideration, expressing the definition mathematically,

$$\text{Demand factor} = \frac{\text{Maximum demand}}{\text{Connected load}}$$

5. **Load factor**. The load factor is the ration of the average power to the maximum demand. In such cases, the interval of maximum load and the period over which the average is taken should be definitely specified, such as a "half-hour monthly" load factor. The proper interval and period are usually dependent upon load conditions and upon the purpose for which the load factor is to be used. Expressing the definition mathematically,

$$\text{Load factor} = \frac{\text{Average load}}{\text{Maximum demand}}$$

6. **Diversity factor.** The diversity factor of any system, or part of a system, is the ratio of the maximum power demands of the subdivisions of the system, or part of a system, to the maximum demand of the whole system, or part of the system, under consideration, measured at the point of supply. Expressing the definition mathematically,

$$\text{Diversity factor} = \frac{\text{Sum of individual maximum demands}}{\text{Maximum demand of whole system}}$$

7. **Utilization factor.** The utilization factor is defined as the ration of the maximum generator demand to the generation capacity.

8. **Plant capacity factor.** It is defined as the ratio of actual energy produced in kilowatt hours 9kWh) to the maximum possible energy that could have been produced during the same period. Expressing the definition mathematically,

$$\text{Plant capacity factor} = \frac{E}{C \times t}$$

Where E = energy produced (kWh) in a given period.

C = capacity of the plant in kW, and

t = total number of hours in the given period.

9. Plant use factor. It is defined as the ration of energy produced in a given time to the maximum possible energy that could have been produced during the actual number of hours the plant was in operation. Expressing the definition mathematically,

$$\text{Plant use factor} = \frac{E}{C \times t'}$$

Where t' = actual number of hours the plant has been in operation.

10. Types of load.

(i) **Residential load.** This type of load includes domestic lights, power needed for domestic appliances such as radios, television, water heaters, refrigerators, electric cookers and small motors for pumping water.

(ii) **Commercial load.** It includes lighting for shops, advertisements and electrical appliances used in shops and restaurants etc.

(iii) **Industrial load.** It consists of load demand of various industries.

(iv) **Municipal load**. It consists of street lightning, power required for water supply and drainage purposes.

(v) **Irrigation load**. This type of load includes electrical power needed for pumps driven by electric motors to supply water to fields.

(vi) **Traction load.** It includes trams, cars, trolley, buses and railways.

11. **Load curve**. A load curve (or load graph) is a graphic record showing the power demands for every instant during a certain time interval. Such a record may cover 1 hour, in which case it would be an hourly load graph; 24 hours, in which case it would be a daily load graph; a month in which case it would be a monthly load graph; or a year (8760 hours), in which case it would be a yearly load graph.

12. **Load Duration curve.** A load duration curve and the corresponding chronological load curve in order of descending magnitude. This curve is derived from chronological load curve.

13. **Dump Power.** This term is used in hydroplants and it shows the power in excess of the load requirements and it is made available by surplus water.

14. **Firm Power.** It is the power which should always be available even under emergency conditions.

15. Prime Power. It is the power which may be mechanical, hydraulic or thermal that is always available for conversion into electric power.

16. **Cold reserve.** It is that reserve generating capacity which is not in operation but can be available for service.

17. **Hot reserve.** It is that reserve generating capacity which is in operation but not in service.

18. **Spinning reserve.** It is that generating capacity which is in connected to the bus and is ready to take the load.

5.3 POWER TARIFF TYPES

INTRODUCTION

The cost of generation of electrical energy consists of fixed cost and running cost. Since the electricity generated is to be supplied to the consumers, the total cost of generation has to be recovered from the consumers. Tariffs or energy rates are the different methods of charging the consumers for the consumption of electricity.

It is desirable to charge the consumer according to the maximum demand (kW) and the energy consumed (kWh). The tariff chosen should recover the fixed cost, operating cost and profit etc. incurred in generating the electrical energy.

OBJECTIVES

1. Recovery of cost of capital investment in generating equipment, transmission and distribution system.
2. Recovery of the cost of operation, supplies and maintenance of the equipment.
3. Recovery of cost of material, equipment, billing and collection cost as well as for miscellaneous services.
4. A net return on the total capital investment must be ensured.

REQUIREMENTS

1. It should be easier to understand.
2. It should provide low rates for high consumption
3. It should be uniform over large population.
4. It should encourage the consumers having high load factors.
5. It should take into account maximum demand charges and energy charges.
6. It should provide incentive for using power during off-peak periods.
7. It should provide fewer charges for power connecting than lighting.
8. It should have a provision of penalty for low power factors.
9. It should have a provision for higher demand charges for high loads demanded at system peaks.
10. It should apportion equitably the cost of service to the different categories of consumers.

GENERAL TARIFF FORM

A large number of tariffs have been proposed from time to time and are in use. They are all derived from the following general equation:

$$z = a.x + b.y + c$$

Where,

z = total amount of bill for the period considered,

x = maximum demand in kW,

y = energy consumed in kWh during the period considered,

a = Rate per kW of maximum demand, and

b = energy rate per kWh.

c = constant amount charged to the consumer during each billing period. This charge is independent of demand or total energy because a consumer that remains connected to the line incurs expenses even if he does not use energy.

VARIOUS TYPES OF TARIFFS:

The various types of tariffs are:

1. Flat demand rate.
2. Straight meter rate.
3. Block meter rate.
4. Hopkinson demand rate (two-part tariff)
5. Doherty rate (three-part tariff)
6. Wright demand rate

FLAT DEMAND RATE:

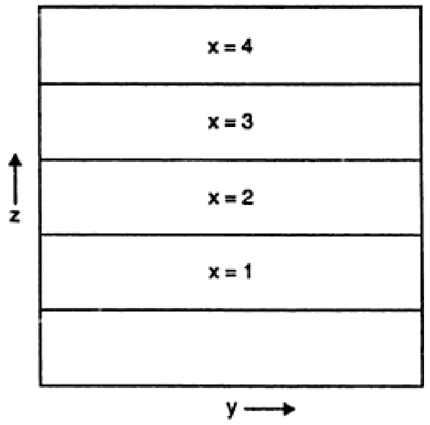


Fig 5.1 Flat demand rate

The flat demand rate is expressed as follows:

$$Z=ax$$

i.e., the bill depends only on the maximum demand irrespective of the amount of energy consumed. It is based on the customer's installation of energy consuming devices which is generally denoted by so many kW per month or per year. It is probably one of the early systems of charging energy rates. It was based upon the total number of lamps installed and a fixed number of hours of use per year. Hence the rate could be expressed as a price per lamp or unit of installed capacity.

Now-a-days the use of this tariff is restricted to signal system. street lighting etc., where the number of hours are fixed and energy consumption can be easily predicted. Its use is very common to supplies to irrigation tubewells, since the numbers of hours for which the tubewell feeders are switched on are fixed. The charge is made according to horse power of the motor installed.

In this form of tariff the unit energy cost decreases progressively with an increased energy usage since the total cost remains constant. The variation in total cost and unit cost are given in Fig 5.1

By the use of this form of tariff the cost of metering equipment and meter reading is eliminated.

STRAIGHT METER RATE

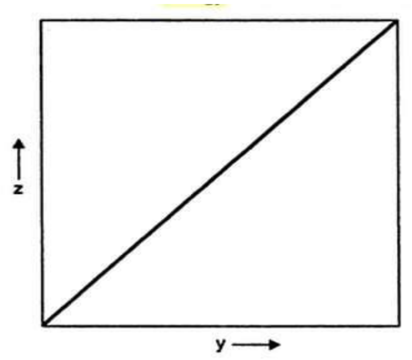


Fig 5.2 Straight meter rate

The straight meter rate can be expressed in the form:

$$Z=b.y$$

This is the simplest form of tariff. Here the charge per unit is constant. The charges depend on the energy used. This tariff is sometimes used for residential and commercial consumer. The variation of bill according to the variation of energy consumed in shown in Fig 5.2

Advantage. Simplicity

Disadvantages.

1. The consumer using no energy will not pay any amount although he has incurred some expenses to the power station.
2. This method does not encourage the use of electricity unless the tariff is very low.

BLOCK METER RATE

In order to remove the inconsistency of straight meter rate, the block meter rate charges the consumers on a sliding scale. The term ‘block’ indicates that a certain specified price per unit is charged for all or any part of such units. The reduced prices per unit are charged for all or any part of succeeding block of units, each such reduced price per unit applying only to particular block or portion thereof.

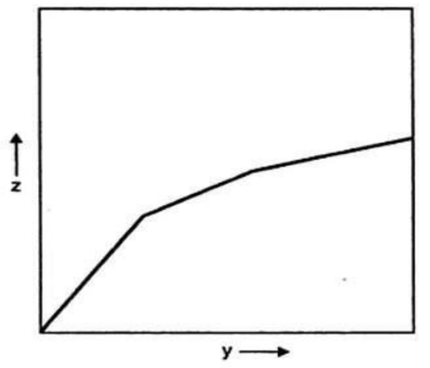


Fig 5.3 Block meter rate

The variation of bill according to this method is shown in Fig 5.3.

The block meter rate accomplishes the same purpose of decreasing unit energy charges with increasing consumption as the step meter rate without its defect. Its main defect is that is lacks a measure of the customer’s demand.

This tariff is very commonly used for residential and commercial customers. In many states of India, a reverse form of this tariff is being used to restrict the energy consumption. In this reverse form the unit energy charge increases with increase in energy consumption.

HOPKINSON DEMAND RATE (two-part tariff)

This method charges the consumer according to his maximum demand and energy consumption. This can be expressed as,

$Z=a+by$

This method requires two meters to record the maximum demand and energy consumption of the consumer. The variation of z with respect to y taking x as parameter is shown in Fig 5.4

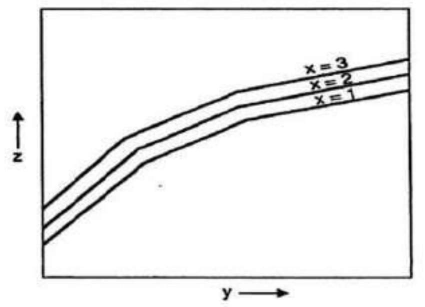


Fig 5.4 Hopkinson demand rate (two-part tariff)

This form of tariff is generally used for industrial customers.

DOHERTY RATE (three-part tariff)

When the Hopkinson demand rate is modified by the addition of a customer charge, it becomes a three charge rate or Doherty rate. It was first introduced by Henry L.Deoherty at the beginning of 20^{th} century. It consists of a customer or meter charge, plus demand charge plus any energy charge. This is expresses as follows:

$$Y=ax+by+c$$

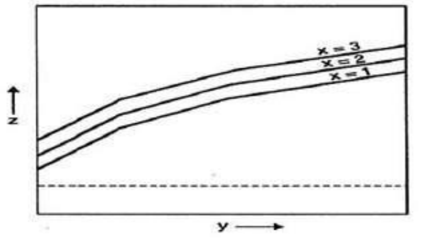


Fig 5.5 Doherty rate (three-part tariff)

Many people consider that theoretically this is an ideal type of rate. As it required two meters, is it better suited for industrial than for residential customers.

The Doherty rate is sometimes modified by specifying the minimum demand and the minimum energy consumption that must be paid for, if they are less than the minimum values specified. In this manner the customer charge is incorporated with the demand and energy component.

WRIGHT DEMAND RATE

This tariff was introduced by Arthur Wright (of England) in 1896. This rate intensifies the inducements by lowering both the demand and energy charge for a reduction in maximum demand or other words an improvement in load factor. This rate is usually specified for industrial consumers who have some measure of control over their maximum demands.

The rate is modified by stating a minimum charge which must be paid if the energy for the billing period falls below the amount by such charge. For allowing fair returns some adjustment in the rate forms are provided. Some of them are:

(i) Higher demand charges in summer
(ii) Fuel price adjustment to provide a rate change when fuel prices deviate from the standard.
(iii) Wage adjustment
(iv) Tax adjustment
(v) Power factor adjustment
(vi) Discount to be given to the customers for prompt payment of bills.

5.4 LOAD DISTRIBUTION PARAMETERS (Types of load)

A device which taps electrical energy from the electric power system is called a load on the system. The load may be resistive (e.g., electric lamp), inductive (e.g., induction motor), capacitive or some combination of them. The various types of load on the power system are:

(i) Domestic load
(ii) Commercial load
(iii) Industrial load
(iv) Municipal load
(v) Irrigation load
(vi) Traction load

Domestic load. Domestic load consists of lights, fans, refrigerator, heaters, television, small motors for pumping water etc. Most of the residential load occurs only for some hours during the day (i.e., 24 hours) e.g., lighting load occurs during night time and domestic appliance load occurs for only a few hours. For this reason, the load factor is low (10% to 12%).

Commercial load. Commercial load consists of lighting for shops, fans and electric appliances used in restaurants etc. This class of load occurs for more hours during the day as compared to the domestic load. The commercial load has seasonal variations due to the extensive use of air conditioners and space heaters.

Industrial Load. Industrial load consists of load demand by industries. The magnitude of industrial load depends upon the type of industry. Thus small scale industry requires load up to 25kW, medium scale industry between 25kW and 100kW and large-scale industry requires load above 500kW. Industrial loads are generally not weather dependent.

Municipal Load. Municipal load consists of street lighting, power required for water supply and drainage purposes. Street lighting load is practically constant throughout the hours of the night. For water supply, water is pumped to overhead tanks by pumps driven by electric motors. Pumping is carried out during the off-peak period, usually occurring during the night. This helps to improve the load factor of the power system.

Irrigation load. This type of load is the electric power needed for pumps driven by motors to supply water to fields. Generally this type of load is supplied for 12 hours during night.

Traction load. This type of load includes tram cars, trolley buses, railways etc. This class of load has wide variation. During the morning hour, it reaches peak value because people have to go to their work place. After morning hours, the load starts decreasing and again rises during evening since the people start coming to their homes.

5.5 LOADCURVE

The curve showing the variation of load on the power station with respect to time is known as a load curve.

The load on a power station is never constant; it varies from time to time. These load variations during the whole day (i.e., 24 hours) are recorded half-hourly or hourly and are plotted against time on the graph. The curve thus obtained is known as daily load curve as it shows the variations of load w.r.t time during day. Fig 5.6 shows a typical daily load curve of a power station. It is clear that load on the power station is varying, being maximum at 6 P.M in this case. It may be seen that load curve indicates at a glance the general character of the load that is being imposed on the plant. Such a clear representation cannot be obtained from tabulated figures.

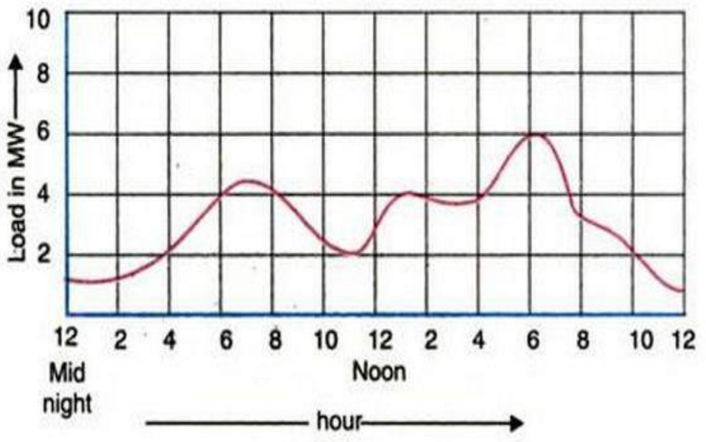


Fig 5.6

The monthly load curve can be obtained from the daily load curves of that month. For this purpose, average * values of power over a month at different times of the day are calculated and then plotted on the graph. The monthly load curve is generally used to fix the rates of energy. The yearly load curve is obtained by considering the monthly load curves of that particular year. The yearly load curve is generally used to determine the annual load factor.

Importance. The daily load curves have attained a great importance in generation as they supply the following information readily:

(i) The daily load curve shows the variations of load on the power station during different hours of the day.

(ii) The area under the daily load curve gives the number of units generated in the day.

Units generated/day = Area (in kWh) under daily load curve.

(iii) The highest point on the daily load curve represents the maximum demand on the station on that day.

(iv) The area under the daily load curve divided by the total number of hours gives the average load on the station in the day.

$$\text{Average load} = \frac{\text{Area (in kWh) under daily load curve}}{24\ \text{hours}}$$

(v) The ratio of the area under the load curve to the total area of rectangle in which it is contained gives the load factor.

$$\text{Load factor} = \frac{\text{Average load}}{\text{Max. demand}} = \frac{\text{Average load} \times 24}{\text{Max. demand} \times 24}$$

$$= \frac{\text{Area (in kWh) under daily load curve}}{\text{Total area of rectangle in which the load curve is contained}}$$

(vi) The load curve helps in selecting * the size and number of generating units

(vii) The load curve helps in preparing the operation schedule ** of the station.

*For instance, if we consider the load on power station at mid-night during the various day of the month. It may vary slightly. Then the average will give the load, mod-night on the monthly curve.

*It will be shown in that number and size of the generating units are selected to fit the load curve. This helps in operating the generating units or near the point of maximum efficiency.

** It is the sequence and time for which the various generating units (i.e. alternators) in the plant will be put in operation.

5.6 COMPARISON OF SITE SELECTION CRITERIA

PRINCIPLES OF POWER PLANT DESIGN

The following factors should be considered while designing a power plant:

1. Simplicity of design

2. Low capital cost
3. Low cost of energy generated.
4. High efficiency
5. Low maintenance cost
6. Low operating cost
7. Reliability of supplying power
8. Reserve capacity to meet future power demand.

LOCATION OF POWER PLANT

Some of the considerations on which the location of a power plant depends are:

1. Centre of electrical load
2. Nearness to the fuel source
3. Availability of water
4. Type of soil available and land cost.

Centre of electrical load

The plant should be located where there are industries and other important consumption places of electricity. There will be considerable advantages in placing the power station nearer to the center of the load.

- There will be saving in the cost of copper used for transmitting electricity as the distance of transmission line is reduced.
- The cross-section of the transmission line directly depends upon the maximum current to be carried. In case of alternating current the voltage to be transmitted can be increased thus reducing the current and hence the cross-section of the transmission line can be reduced. This will save the amount of copper.
- It is desirable now to have a national grid connecting all power stations. This provides for selecting site which has other advantages such as nearer to fuel supply, condensing water available.

Nearness to the fuel source

The cost of transportation of fuel may be quite high if the distance of location of the power plant is considerable. It may be advisable to locate high thermal power plants at the mouth of the coal mines.

Lignite coal mines should have centralized thermal power station located in the mines itself as this type of coal cannot be transported.

Such type of power stations could be located near oil fields if oil is to be used as a fuel and near gas wells where natural gas is available in abundance.

In any case it has been seen that it is cheaper to transmit electricity than to transport fuel. Hence the power plant should be located neared the fuel supply source.

Availability of water

The availability of water is of greater importance than all other factors governing station location. Water is required for a thermal power station using turbines for the following two purposes:

(i) To supply the make-up water this should be reasonably pure water.

(ii) To cool the exhaust system. This cooling process is done in case of diesel engines too. For bigger power stations the quantity of this cooling water is tremendous and requires some natural source of water such as lake, river or even sea. Cooling towers could be used economically as the same cooling water could be used again and again.

Only a part of make-up water for cooling will then be required. For small plants spray pounds could sometimes be used. It is economical to limit the rise in cooling-water temperature to a small value (between 6º and 12ºC), and to gain in cycle efficiency at the expense of increased cooling water pumping requirement.

Type of soil available and land cost.

While selecting a site for a power plant it is important to know about the character of the soil. If the soil is loose having low bearing power the pile foundations have to be used.

Boring should be made at most of the projected site to have an idea of the characters of the various strata as well as of the bearing power of the soil. The best location is that for which costly and special foundation is not required.

In case of power plants being situated near metropolitan load centers, the land there will be very costly as compared to the land at a distance from the city.

LAYOUT OF POWER PLANT BUILDING

The following points should be taken care of which deciding about power plant building and its layout:

1. The power plant structure should be simple and rugged with pleasing appearance.
2. Costly materials and ornamental work should be avoided.
3. The power plant interior should be clean, airy and attractive.
4. The exterior of the building should be impressive and attractive.
5. Generally the building should be single storeyed.

6. The layout of the power plant should first be made on paper, the necessary equipment well-arranged and then design the covering structure. In all layouts, allowances must be made for sufficient clearances and for walkways. Good clearance should be allowed around generators, boilers, heaters, condensers etc. Walkway clearances around hot objects and rapidly moving machinery should be wider than those just necessary to allow passage. Also the galleries in the neighborhood of high tension bus bars should be sufficient as the space will permit.
7. Provision for future extension of the building should be made.
8. The height of the building should be sufficient so that overhead cranes could operate well and the overhauling of the turbines etc. is no problem. Sufficient room should be provided to lift the massive parts of the machines.
9. Each wall should receive a symmetrical treatment in window openings etc.
10. The principal materials used for building the power plant building are brick, stone, hollow tiles, concrete and steel.
11. In case of a steam power plant, there are distinct parts of the buildings viz., boiler room, turbine room and electrical bays. Head room required in the boiler room should be greater than in the other. Ventilation in boiler room presents greater difficulty because of heat liberated from the boiler surfaces. The turbine room is actually the show room of the plant. Mezzanine flooring should be used in the power plant. The chimney height should be sufficient so as to release the flue gases sufficiently high so that the atmosphere is not polluted and the nearby buildings are not affected.
12. The foundation of a power plant is one of the most important considerations. For this the bearing capacity of the sub-soil, selection of a working factor of safety and proportioning the wall footing to economical construction should be well thought of and tested. The pile foundations may have to be used where the soils have low bearing values.
13. In any power plant machines foundation plays an important part. The machine foundation should be able to distribute the weight of the machine, be plate and its own height over a sage subsoil area. It must also provide sufficient mass to absorb machine vibrations.
14. Sufficient room for storage of fuel should be provided indoor as well as outdoor so as to ensure against any prolonged breakdown.

5.7 CAPITAL AND OPERATING COST OF DIFFERENT POWER PLANTS (COST ANALYSIS)

The cost of a power system depends upon whether:

(i) An entirely new power system has to be set up, or
(ii) An existing system has to be replaced, or
(iii) An extension has to be provided to the existing system. The cost interalia includes:

1. Capital or Fixed cost. It includes the following:

(i) Initial cost
(ii) Interest
(iii) Depreciation cost
(iv) Taxes
(v) Insurance

2. Operational cost. It includes the following:
   (i) Fuel cost
   (ii) Operating labour cost
   (iii) Maintenance cost
   (iv) Supplies
   (v) Supervision
   (vi) Operating taxes.

CAPITAL COST OF FIXED COST

Initial cost

Some of the several factors on which cost of a generating station or a power plant depends are:

(i) Location of the plant
(ii) Time of construction
(iii) Size of units
(iv) Number of main generating units
(v) Overhead charges which will include the transportation cost, stores and storekeeping charges, interest during construction etc.
   - To reduce the cost of building, it is desirable to eliminate the superstructure over the boiler house and as far as possible on turbine house also.
   - The cost on equipment can be reduced by adopting unit system where one boiler is used for one turbo-generator. Also by simplifying the piping system, and elimination of duplicate system such as steam headers and boiler feed headers. The cost can be further reduced by eliminating duplicate or stand-by auxiliaries.
   - When the power plant is not situated in the proximity to the load served, the cost of a primary distribution system will be a part of the initial investment.

Interest

All enterprises need investment of money and this money may be obtained as loan, through bonds and shares or from owners of personal funds. Interest is the difference between money borrowed and money returned. It may be charge at a simple rate expressed as % per annum or may be compounded, in which case the interest is reinvested and adds to the principal, thereby earning more interest in subsequently years.

Even if the owner invests his own capital the charge of interest is necessary to cover the income that he would have derived from it through an alternative investment or fixed deposit with a bank. Amortization in the periodic repayment of the principal as a uniform annual expense.

Depreciation

Depreciation accounts for the deterioration of the equipment and decrease in its value due to corrosion, weathering and wear and tear with use. It also covers the decrease in value of equipment due to obsolescence. With rapid improvements in design and construction of plants, obsolescence factor is of enormous importance. Availability of better models with lesser overall cost of generation makes it imperative to replace the old equipment earlier than its useful life is spent. The actual life span of the plant has, therefore, to be taken as shorter than what would be normally expected out of it.

The following methods are used to calculate the depreciation cost:

(i) Straight line method
(ii) Percentage method
(iii) Sinking fund method
(iv) Unit method

(i) **Straight line method.** It is the simplest and commonly used method. The life of the equipment or the enterprise is first assesses as also the residual or salvage value of the same after estimated life span. This salvage value is deducted from the initial capital cost and the balance is divided by the life as assessed in years. Thus, the annual value of decrease in cost of equipment is found and is set aside as depreciation annually from the income. Thus, the rate of depreciation is uniform throughout the life of the equipment. By the time the equipment has lived out its useful life an amount equivalent to its net cost is accumulated which can be utilized for replacement of the plant.

(ii) **Percentage method**. In this method the deterioration in value of equipment from year to year is taken into account and the amount of depreciation calculated upon actual residual value for each year. It thus, reduces for successive years.

(iii) **Sinking fund method**. This method is based on the conception that the annual uniform deduction from income for depreciation will accumulate to the capital value of the plant at the end of life of the plant or equipment. In these methods, the amount set aside per year consists of annual installments and the interest earned on all the installments.

Let, A = Amount set aside at the end of each year for n years,
n = Life of plant in years,
S = Salvage value at the end of plant life,
i = Annual rate of compound interest on the invested capital, and
P = Initial investment to install the plant.

Then, amount set aside at the end of first year = A

Amount at the end of second year

$$= A + \text{interest on } A = A + Ai = A(1+i)$$

Amount at the end of third year

$$= A(1+i) + \text{interest on } A(1+i)$$
$$= A(1+i) + A(1+i)i$$
$$= A(1+i)^2$$

$\therefore$ Amount at the end of nth year = $A(1+i)^{n-1}$

Total amount accumulated in n years (say x)

= Sum of the amounts accumulated in n years

i.e.,
$$x = A + A(1+i) + A(1+i)^2 + \ldots\ldots + A(1+i)^{n-1}$$
$$= A\,[1 + (1+i) + (1+i)^2 + \ldots\ldots + (1+i)^{n-1}] \quad \ldots(i)$$

Multiplying the above equation by $(1+i)$, we get

$$x(1+i) = A\,[(1+i) + (1+i)^2 + (1+i)^3 + \ldots\ldots + (1+i)^n] \quad \ldots(ii)$$

Subtracting equation (i) from (ii), we get

$$x.i = [(1+i)^n - 1]\,A$$

$$\therefore \quad x = \left[\frac{(1+i)^n - 1}{i}\right] A$$

where, $x = (P - S)$

$$\therefore \quad P - S = \left[\frac{(1+i)^n - 1}{i}\right] A \quad \ldots(9.6)$$

or,
$$A = \left[\frac{i}{(1+i)^n - 1}\right](P - S) \quad \ldots(9.7)$$

(iv) **Unit method.** In this method some factor is taken as a standard one and depreciation is measured by that standard. In place of years equipment will last, the number of hours that equipment will last is calculated. This total number of hours is then divided by the capital value of the equipment. This constant is then multiplied by the number of actual working hours each year to get the value of depreciation for that year. In place of number of hours, the number of units of production is taken as the measuring standard.

OPERATING COST

The elements that make up the operating expenditure of power plant include the following costs:

(i) Cost of fuels
(ii) Labour cost
(iii) Cost of maintenance and repairs
(iv) Cost of stores (other than fuel)
(v) Supervision
(vi) Taxes

Cost of fuels. In a thermal station fuel is the heaviest item of operating cost. The selection of the fuel and the maximum economy in its use are, therefore, very important considerations in thermal plant design. It is desirable to achieve the highest thermal efficiency for the plant so that fuel charges are reduced. The cost of the fuel includes not only its price at the sire of purchase but its transportation and handling costs also.

In the hydroplants the absence of fuel factor in cost is responsible for lowering the operating cost. Plant heat rate can be improved by the use of better quality of fuel or by employing better thermodynamic conditions in the plant design.

The cost of fuel varies with the following:

(i) Unit price of the fuel
(ii) Amount of energy produced.
(iii) Efficiency of the plant

Labour cost. For plant operation labour cost is another item of operating cost. Maximum labour is needed in a thermal power plant using coal as a fuel. A hydraulic power plant or a diesel power plant of equal capacity requires a lesser number of persons. In case of automatic power station the cost of labour is reduced to a great extent. However labour cost cannot be completely eliminated even with fully automatic station as they will still require some manpower for periodic inspection etc.

Cost of maintenance and repairs. In order to avoid plant breakdown maintenance is necessary. Maintenance includes periodic cleaning, greasing, adjustments and overhauling of equipment. The material used for maintenance is also charged under this head. Sometimes an arbitrary percentage is assumed as maintenance cost. A good plan of maintenance would keep the sets in dependable condition and avoid the necessity of too many stand-by-plants.

Repairs are necessitated when the plant breaks down or stops due to faults developing in the mechanism. The repairs may be minor, major or periodic overhauls and are charged to the depreciation fund of the equipment. This item of cost is higher for thermal plants than for hydro-plants due to complex nature of principal equipment and auxiliaries in the former.

Cost of stores. The items of consumable stores other than fuel include such articles as lubricating oil and greases, cotton waste, small tools, chemicals, paints and such other things. The incidence of this cost is also higher in thermal stations than in hydro-electric power stations.

Supervision. In this head the salary of supervising staff is included. A good supervision is reflected in lesser breakdowns and extended plant life. The supervising staff includes the station superintendent, chief engineer, chemist, engineers, supervisors, store in-charges, purchase officer and other establishment. Again, thermal stations, particularly coal fed, have a greater incidence of this cost than the hydro-electric power stations.

Taxes. The taxes under operating head include the following:

(i) Income tax
(ii) Sales tax

(iii) Social security and employee's security.

5.8 POLLUTION CONTROL TECHNOLOGIES INCLUDING WASTE DISPOSAL OPTIONS FOR COAL AND NUCLEAR POWER PLANTS. (POLLUTION AND ITS CONTROL)

INTRODUCTION

All power production plants, invariably, pollute the atmosphere and the resulting imbalance on ecology has a bad effect. The pollution is inevitable in some cases and has to be minimized to the extent possible. This is being achieved by effective legislations all over the world.

The power plant pollutants of major concern are:

A. From fossil power plants:
   - (i) Sulphur oxide.
   - (ii) Nitrogen oxide
   - (iii) Carbon oxide
   - (iv) Thermal pollution
   - (v) Particulate matter

B. From nuclear power plants
   - (i) Radioactivity release
   - (ii) Radioactivity wastes
   - (iii) Thermal pollution

   Besides this, pollutants such as lead and hydrocarbons are contributed by automobiles.

POLLUTION FROM THERMAL-POWER PLANTS

The environment is polluted to a great extent by thermal power plants. The emission from the chimney throws unwanted gases and particles into the atmosphere while the heat is thrown into the atmosphere and rivers. Both these aspects pollute the environment beyond tolerable limits and now are being controlled by appropriate regulations. The types of emissions, effects and methods of minimizing these pollutions are discussed below.

The air pollution in a large measure is caused by the thermal-power plants burning conventional fuels (coal,oil or gas). The combustible elements of the fuel are converted to gaseous products and non-combustible elements to ash. Thus the emission can be classified as follow:

(1) Gaseous emission
(2) Particulate emission
(3) Solid waste emission

(4) Thermal pollution (or waste heat)

Gaseous emission and its control

The various gaseous pollutants are:

(i) Sulphur di-oxide
(ii) Hydrogen sulphide
(iii) Oxides of nitrogen
(iv) Carbon monoxide etc.

The effects of pollutants on environment are as follows:

S. No.	Pollutant	Effects		
		On man	On vegitation	On materials/animals
1.	SO_2	Suffocation, irritation of throat and eyes, respiration system.	Destruction of sensitive crops and reduced yield.	Corrosion.
2.	NO_2	Irritation, bronchitis, oedema of lungs.	—	—
3.	H_2S	Bare disease, repiratory diseases.	Destruction of crops.	Flourosis in cattle grazing.
4.	CO	Poisoning, increased accident-liability.	—	—

Removal of Sulphur dioxide (SO_2):

SO2 is removed by wet scrubbers as shown in Fig 5.7

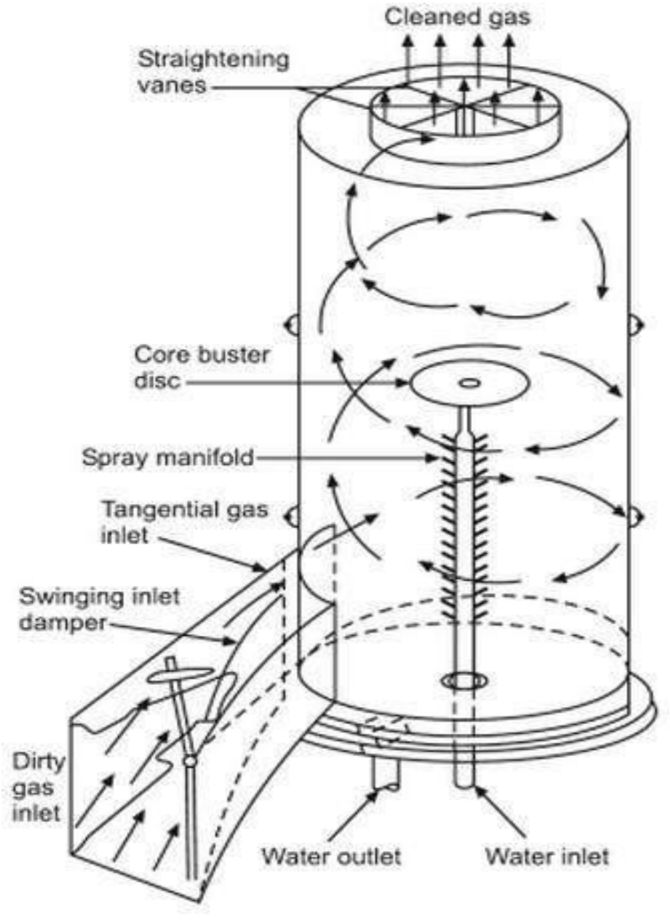


Fig 5.7 Wet scrubbers

- The gases to be cleaned are admitted tangentially into the scrubber which will also help in separating the particulate matters. Water spray absorbs these gases, and particulate matters which collect on the surface of the scrubber, are washed down by the water and this water is further treated, filtered and reused.
- The wet scrubbers also find application in chemical and grain milling industries
- The collection efficiency of scrubber is about 90%.

The following are disadvantages of using wet scrubbers:

1. The gases are cooled to such an extent that they must be reheated before being sent to the stack.
2. The pressure drops are very high.
3. Water used, after dissolving Sulphur oxides, will contain sulphuric and sulphurous acids which may corrode the pipelines and the scrubber itself, this water cannot be let out into the rivers for obvious reasons.

In power plants where high Sulphur content coal is the only source available, it is preferable to remove the Sulphur from the coal before it is burnt. This is done by coal washing which reduces the flyash as well as some Sulphur oxides in the flue gases. But the power plants employ "flue-gas desulphurization" (FGD) system similar to wet scrubber system. FGD can be of the following types:

1. The recovery or regenerative system.
2. Throw away or non-regenerative system. In this system the reactants are not recovered and the final products are Sulphur salts of calcium and magnesium.

Regenerative system:

Some of the regenerative systems are:

1. FW-Bergbau process
2. Wellman-Lord process
3. Wet magnesium oxide process

- In the fig 5.8 is shown the FW-Bergbau process. In this process, SO2 is removed by adsorption and Sulphur is collected as molten Sulphur.

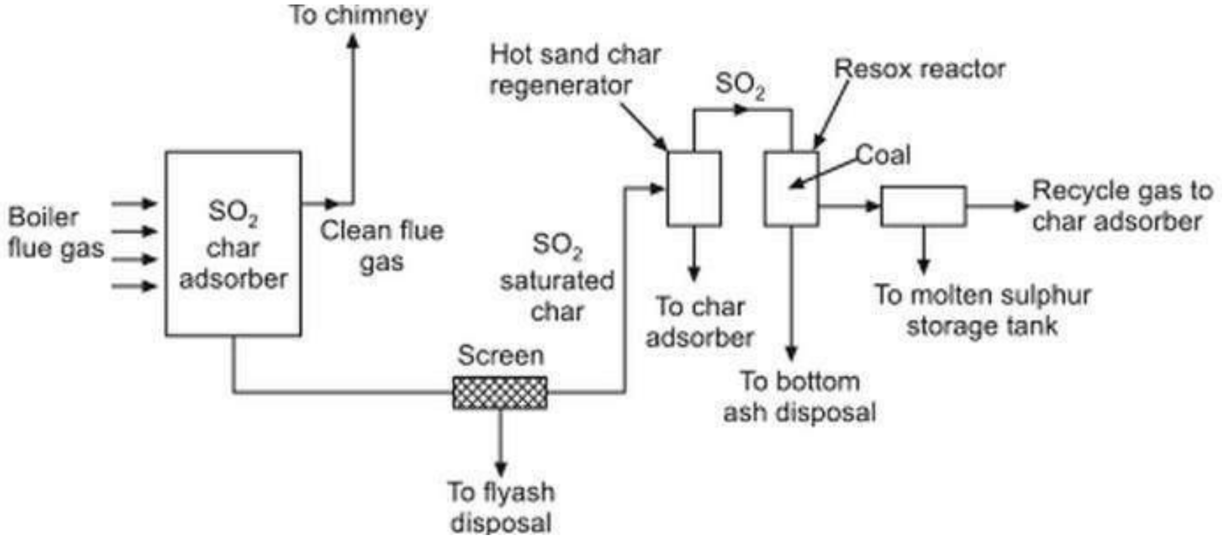


Fig 5.8 F.W Bergbau Forshung adsorption FGD regenerative system

- Fig 5.9 shows the Wellman-Lord FGD system. This system removes SO2 by absorption in sodium carbonate and SO2 is recovered as Sulphur or sulphuric acid products.

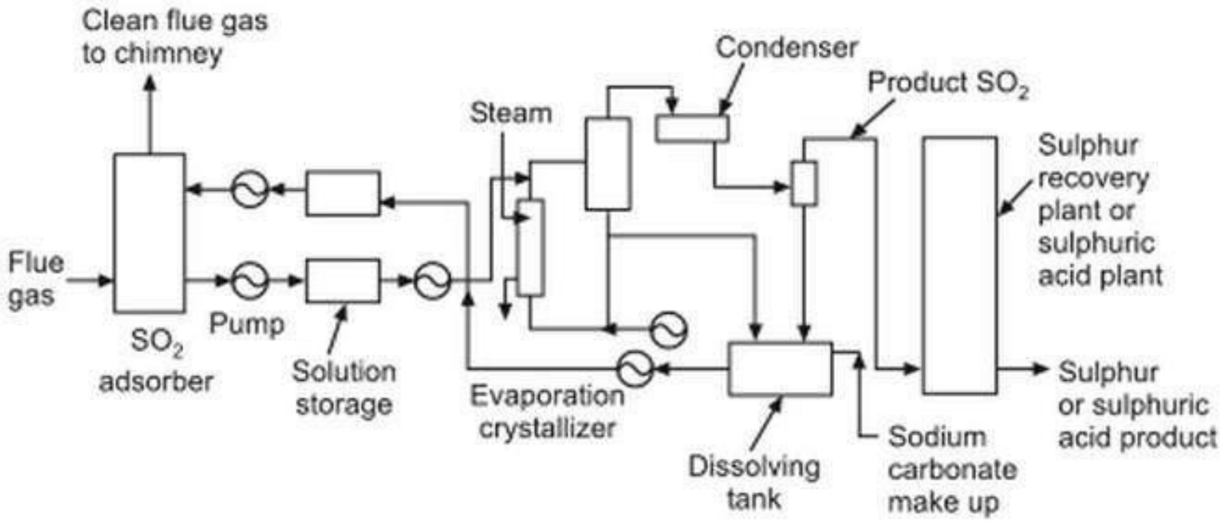


Fig 5.9 Wellman-Lord absorption FGD regenerative system

In non-regenerative systems the principal reactant is either lime or limestone. The slurry is made into sludge by adding flyash and other proprietary sludge additives and the sludge is disposed. These methods could prove a bit more expensive since no Sulphur or Sulphur product is recovered and the reactant is not generated as in the case of FB Bergbau process.

Emission of NO_X:

Nitrogen oxides are compounds of the elements nitrogen and oxygen, both of which are present in air. The combustion of fossil fuels in air is accompanied by the formation of nitric oxide (NO) which is subsequently partly oxidized to nitrogen dioxide (NO_2). The resulting mixture of variable combustion is represented by the symbol NO_x, where x has a value between 1 and 2. Nitro gen oxides are present in stack gases from coal, oil and gas furnaces (and also in the exhaust gases from internal combustion engines and gas turbines).

The following methods are commonly used to reduce the emission of NO_X from thermal (and gas turbine) power plants:

1. Reduction of temperature in combustion zone.
2. Reduction of residence period in combustion zone.
3. Increase in equivalence ratio in the combustion zone.

Particulate Emission and its control

The particulate emission, in power plants using fossil fuels, is easiest to control. Particulate matter can be either dust (particles having a diameter of 1 micron) which do not settle down or particles with a diameter of more than 10 microns which settle down to the ground. The particulate emission can be classified as follows:

Smoke: It composes of stable suspension of particles that have a diameter of less than 10 microns and are visible only in the aggregate.

Fumes. These are very small particles resulting from chemical reactions and are normally composed of metals and metallic oxides.

Flyash. These are ash particles of diameters of 100 microns or less.

Cinders. These are ash particles of diameters of 100 microns or more.

The above particulates, in any system of controlling the particulate emission, are to be effectively collected from the flue gases. The performance parameters for any particulate remover are called the collection efficiency defined as:

$$\text{[illegible]} = \frac{\text{[illegible]}}{\text{[illegible]}} \times 100$$

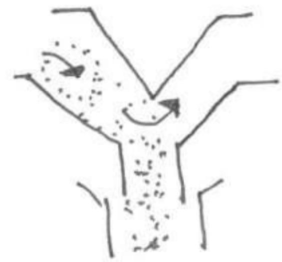
For different system the collector efficiency varies from 50 to 99%; for an electrostatic precipitator it is more than 90%.

Some collector systems, their efficiencies and their adaptability, are discussed in the following paragraphs:

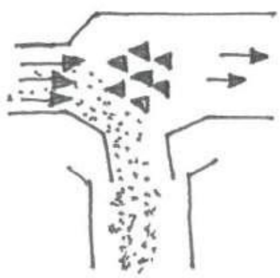
a. Cinder catchers

The cinder catchers are shown in fig 5.10

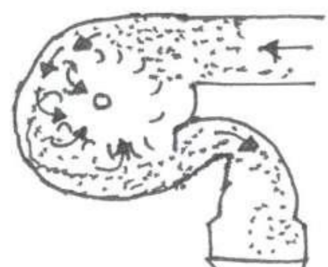
(a) sudden decrease in gas velocity



(b) sudden change in the direction of flow of flue gas.



(c) Impingement of flue gases on a series of baffle stops.



(d) cinder-vane fan

- Refer fig 5.10(a) sudden decrease in gas velocity makes the particulates separates and fall.
- Refer fig 5.10(b) a sudden change in the direction of flow of flue gas throws the particulates away and can be collected.
- Refer fig 5.10 (c) Impingement of flue gases on a series of baffle stops the particulate matter as shown. These are commonly used in stoker and small cyclone furnaces where crushed coal is burned rather than the very fine pulverized coal. The collection efficiencies of cinder catchers are from 50 to 75%.
- Refer Fig 5.10(d) the cinder vane fan uses the fan which imparts centrifugal force to the particulates and they are collected as shown. The efficiency is from 50 to 75%.

b. Wet scrubbers

- Wet scrubbers as described for removal of gases can also be used for removal of particulate matter; but the gases will have to be reheated before they are sent to the stack.
- The wet scrubbers are not commonly used to remove particulate matters,

c. Electrostatic precipitator

- An electrostatic precipitator is shown in fig 5.11. In this device a very high voltage of 30kV to 60kV is applied to the wires suspended in a gas-flow passage between two grounded plates.

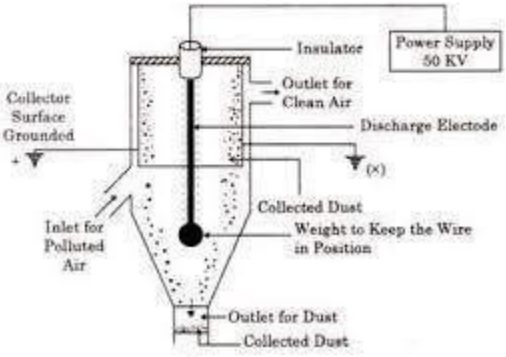


Fig 5.11 Electrostatic precipitator

- The particles in the gas stream acquire a charge from the negatively charged wires and are then attracted to the ground plates. The grounded plates are periodically rapped by a steel plug which is raised and dropped by an electromagnet and dust is collected in the hopper below:
- In this type of collector, care must be taken to see that large quantity of unburnt gases do not enter the precipitator. If such a mixture enters, power should be turned off; otherwise there could be explosion because of constant sparking between wires and plates.
- The collection efficiency is about 99%.
- Electrostatic precipitators are suitable for power plants where fly-ash content is high. Fly-ash having high electrical resistivity does not separate in the electrostatic precipitator. This problem can be solved by injecting Sulphur trioxide into the exhaust gas which improves the conductivity of fly-ash. This again poses a problem of discharging objectionable Sulphur trioxide into the atmosphere; this needs a wet scrubber after the electrostatic precipitator.

d. Baghouse filters

- Fig 5.12 shows a baghouse filter. Baghouse filters are found useful in removing the particulate matters where low Sulphur coal is used.

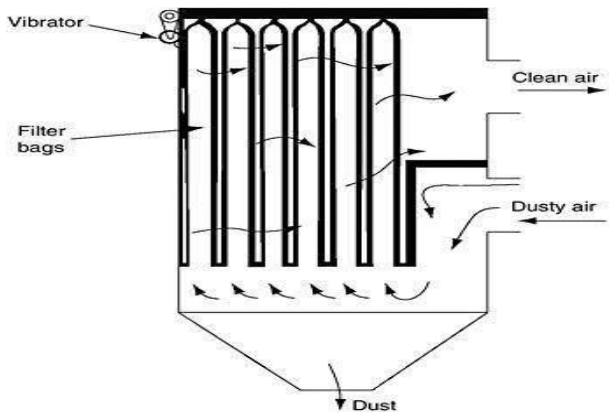


Fig 5.12 Baghouse filter

- The cloth filters cost about 20% of installation cost and last for 1.5 to 3 years.
- The baghouse filter is usually cleaned by forcing air in the reversed direction. They need large filter areas of about 6.5m2/MW of power generation. Hence the installation cost could be high.
- Although baghouse filters are expensive, yet they are being widely used in coal-fired systems.

Solid waste disposal

From the fossil fuel fired power plants considerable amount of solids in the form of ash is discharged. This ash is removed as bottom ash or slug from the furnace. The fossil fuel fired system also discharges solid wastes such as calcium and magnesium salts generated by absorption of SO_2 and SO_3 by reactant like lime stone.

Thermal pollution

Discharge of thermal energy into waters in commonly called “Thermal Pollution”.

Thermal power stations invariably will have to discharge enormous amounts of energy into water since water is one medium largely used to condense steam. If this heated water from condensers is discharged into lakes or rivers, the water temperature increases.

At about 35°C, the dissolved oxygen will be so low that the aquatic life will die. But in very cold regions, letting out hot water into the lakes or rivers helps in increasing the fish growth. But, in our country, such places are not many and hence, it is necessary that we minimize this thermal pollution of water. One of the regulations stipulates that a maximum temperature of water let out cab be 1°C above the atmospheric temperature. Thus the thermal power plants or any other industry has to resort to various methods of adhering to this regulation.

a. Thermal discharge index(TDI)

Thermal discharge index (TDI) is the term usually used in connection with the estimation of the amount of thermal energy released to environment from a thermal power plant. TDI of any power plant is the number of thermal energy units discharged to the environment of every unit of electrical energy generated.

$$TDI = \frac{\text{Thermal energy discharged to environment in } kW_{th\ units}}{\text{Electrical power output in } kW_{electrical}}$$

This index cannot be zero or else the plant violates the second law of thermodynamics; but this index should be as low as possible to improve the efficiency of the plant as well as to keep the pollution level low.

The thermal discharge index (TDI) is strongly dependent on the thermal efficiency of the plant.

b. How to reduce thermal pollution?

While considering the efficiency of the thermal plant, it is desirable that the water from a river or lake is pumped through the condenser and fed back to the source. The rise of temperature will be about 10°C which is highly objectionable from the pollution point of view. Hence, this waste heat which is removed from the condenser will have to be thrown into the atmosphere and not into the water source; in this direction following methods can be adopted:

1. Construction of a separate lake
2. Cooling pond
3. Cooling towers

Construction of a separate lake

Sufficientlylarge water storage in the form of a lake can be built and once-through cooling the condenser can be adopted. If the natural cooling of water from the lake is not sufficient, floating spray pumps can be employed.

This method improves the thermal efficiency of the plant but can prove expensive. Also, it may not always be possible to have a large enough lake artificially built.

Cooling pond

A cooling pond with continuously operating fountains can be adopted for smaller power plants. This will also serve as a beautifying feature of the power plant side.

Cooling towers

In order to throw heat into the atmosphere most power stations adopt the cooling towers. The hyperbolic shape given to the tower automatically induces air form the bottom to flow upwards and the water is cooled by coming in direct contact with the air. This is a natural convection cooling and is also called ‘wet-cooling tower’.

The overall efficiency of such plants will be lower than those of the plants adopting once-through cooling system. There will be considerable vapor flumes escaping from the cooling towers. Sometime, make-up cooling water may be scarce. In such cases, dry cooling tower can be adopted. Dry cooling towers are much more expensive than wet cooling towers.

All cooling towers, whether dry or wet, are expensive and add to the initial investment of the plant. Small plants can adopt mechanical-draft systems using induced or forced draft systems. This helps in avoiding height to the cooling towers. Thus, the initial cost is reduced but the maintenance costs of mechanical-draft systems are high.

POLLUTION FROM NUCLEAR POWER PLANTS

The various types of pollution from nuclear power plants are:

1. Radioactive pollution
2. Waste from reactor (solid, liquid, gases)
3. Thermal pollution

Radioactive pollution. This is the most dangerous and serious type of pollution. This is due to radioactive elements and fissionable products in reactor. The best way to abate is the radioactive shield around the reactor.

Waste from reactor. Due to nuclear reactor reaction nuclear wastes (mixtures of various Beta and Gamma emitting radioactive isotopes with various half-lives) are produced which cannot be neutralized by any chemical method.

If the waste is discharged in the atmosphere, air and water will be contaminated beyond the tolerable limits. Some methods of storage or disposal of radioactive waste materials are discussed below:

1. **Storage tanks.** The radioactive wastes can be buried underground (very deep below the surface) in corrosion resistance tanks locates in isolated areas. With the passage of time these will become stable isotopes.
2. **Dilution.** After storing for a short time, low energy wastes are diluted either in liquid or gaseous materials. After dilution, they are disposed off in sewer without causing hazard.
3. **Sea disposal.** This dilution can be used be adequately diluting the wastes and this method is being used by the British.

4. **Atmospheric dilution.** This method can be used for gaseous radioactive wastes. But solid particles from the gaseous wastes must be filtered out thoroughly since they are the most dangerous with higher half-lives.
5. **Absorption by the soil**. Fission products are disposed off by this method. The radioactive particles are absorbed by the soil particles. But this is expensive.
6. **Burying in sea.** Solid nuclear wastes can be stored is concrete blocks which are buried in the sea. This method is expensive but no further care is needed.