PART III

23

Diesel Electric Power Plants

23.1. INTRODUCTION

Since the invention of diesel engine at the end of the nittenth century, this engine has found increasing applications either as continuous or as a peak source of electric power due to its excellent qualities in respect of economy of operation.

Diesel electric plants in the range of 2 to 50 MW capacity are used as central stations for small supply authorities and works and they are universally adapted to supplement hydro-electric or thermal stations where stand-by generating plants are essential for starting from cold and under emergency conditions.

In many countries, the demand for diesel electric plants is increased for electric power generation because of difficulties experienced in construction of new hydraulic plants and enlargement of old hydro-plants. A long-term planning is required for the development of thermal and hydroplants which cannot keep the pace many times with the increased demand by the people and industries.

The diesel units used for electric generation are more reliable and long-lived piece of equipment compared with other types of plants. In Denmark, a 15 MW unit was in existence as far back as the early 1900s. The 20 MW set of four engines is available in Belgium which was established long back. The present trend is to increase the unit capacity, and unit capacity of 40 to 100 MW is expected by the end of this century. In some countries like Iran, few power plants work with diesel engines to supply large network where prices of fuel are in favour of adopting diesel-plants.

With the rapid development of electric generation by other sources after independence made diesel plants to disappear from field as their generation cost was considerably high. Many small units in the range of 1 to 5 MW were used in India before independence to take the localised load as to supply electricity to small industrial units or district towns.

The diesel plants are more efficient than any other heat engines of comparable size. It is cheap in first cost. It can be started quickly and brought into the service. It can burn a fairly wide range of fuels. Its manufacturing periods are short and, therefore, a diesel station may be rapidly extended to keep pace with load growth by adding generating units of suitable sizes.

With such a formidable list of merits to its credit, it does not monopolise the power production market. Because, there are definitely some hurdles in the way of adopting these units for power generation as well as other power plants are in good competition with this unit.

It is sometimes possible to generate power very cheaply where use can be made of existing civil engineering works such as navigation or irrigation canals by introducing micro-hydro power plants, particularly low siphon units using bulb-propeller turbines. The thermal plants are favoured where cheap solid fuels or combustible waste products are cheaply available which can be burnt in boilers. The gas turbine power plants for continuous power generation are superior than diesel where fuel is very cheap, as at refinery or where load factors are very low. All these rivals to the diesel plant can be attractive where they are favoured by the right conditions.

The diesel engine will provide the most economic means of generating electricity on small scale particularly where there is no convenient site for micro-hydro plants and cheap fuels are not available and load factors are considerably large.

In the Southern states of India, especially in Karnataka and Tamil Nadu, the power cut has become a regular continuous feature from the last 15 years. Power cut of 55% to 75% is experienced by the Industry in the states which has cost lot to the manufacturers of cotton mills consuming bulk industrial power. The only solution to tide over the difficulties is to instal Diesel Generating Sets. This is already done by many individual mill owners in Coimbatore.

23.2. FIELD OF USE

The diesel electric power-plants are chiefly used in the fields mentioned below.

1. **Peak load plant.** The diesel plants are used in combination with thermal or hydro-plants as peak load plants. This plant is particularly preferable as peak load plant as it can be started quickly and it has no standby losses as in the case of thermal plants where boilers always must be kept hot.

2. **Mobile plants.** Mobile diesel plants mounted on skids or trailers can be used for temporary or emergency purposes such as for supplying power to large civil engineering works for supplementing electricity supply systems that are temporarily short of power.

3. **Stand-by Units.** This can be used as a standby unit to supply part load when required. For example, this can be used with hydro-plant as stand-by unit. If the water available is not sufficient due to reduced rainfall, a diesel station supply power in parallel with hydro-station. The use is made temporarily till the water is available to take the full load.

4. **Emergency plant.** The plants used for emergency purposes are also standby units, normally idle but are used where power interruption would mean financial loss or danger in key industrial processes, tunnel lighting and operating rooms of hospitals. They are also used for telecommunication and water supply under emergency conditions.

Russia will supply 9300 kW diesel generating set to the Heavy Engineering Corporation, Ranchi, to overcome the chronic power shortage faced by the plant.

5. **Nursery station.** When the diesel plant is used to supply the power to a small town in the absence of main grid and which can be moved to another area which needs power on a small scale when the main grid is available is known as "Nursery Station".

The main grid cannot extend to every corner of the country till there is enough load. Many times the extension of grid is not possible due to the constructional difficulties as in Assam. Diesel unit of small capacity can be installed to supply the load to a small town during the process of development and it can be removed to another required place till the main grid for tapping the power is available.

6. **Starting stations.** The diesel units are used to run the auxiliaries for starting the large steam plants.

7. **Central stations.** This can be used as central station where the capacity required is small (5 to 10 MW). The limit is generally decided by the cost of the plant and local conditions regarding the availability of fuel and water, space requirements and non-availability of the grid.

Small supply units for commercial purposes and public utilities *e.g.*, cinema hall, hospital and municipalities are commonly used in practice.

23.3. DIESEL ELECTRIC PLANTS

The essential components of diesel electric plants are shown in Fig. 23.1. It consists of the following components :

1. **Engine.** This is the main component of the plant which develops required power. The engine is generally directly coupled to the generator as shown in Fig. 23.1.

2. **Air-filter and supercharger.** The function of the airfilter is to remove the dust from the air which is taken by the engine.

The function of the supercharger is to increase the pressure of the air supplied to the engine to increase the power of the engine. The superchargers are generally driven by the engines.

3. **Exhaust system.** This includes the silencers and connecting ducts. The temperature of the exhaust gases is sufficiently high, therefore, the heat of the exhaust gases many times is used for heating the oil or air supplied to the engine.

4. **Fuel system.** It includes the storage tank, fuel pump, fuel transfer pump, strainers and heater. The fuel is supplied to the engines according to the load on the plant.

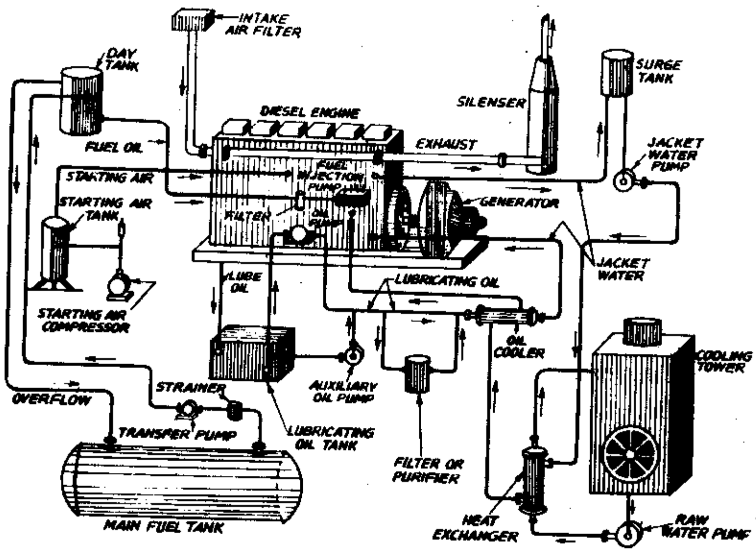


Fig. 23.1. General layout of diesel power plant.

5. **Cooling system.** This system includes water circulating pumps, cooling towers or spray ponds and water filtration plant. The purpose of cooling system is to carry the heat from the engine cylinder to keep the temperature of the cylinder in safe range and extend its life.

6. **Lubrication system.** It includes the oil pumps, oil tanks, filters, coolers and connecting pipes. The function of the lubrication system is to reduce the friction of moving parts and reduce the wear and tear of the engine parts.

7. **Starting system.** This includes compressed air tanks. The function of this system is to start the engine from cold by supplying the compressed air.

8. **Governing system.** The function of the governing system is to maintain the speed of the engine constant irrespective of load on the plant. This is done generally by varying fuel supply to the engine according to load.

23.4. TYPES OF DIESEL ENGINES USED FOR DIESEL POWER PLANTS

The diesel engines are generally classified as four-stroke engines and two-stroke engines.

The four-stroke engine developes power after every two revolutions of crank shaft whereas two-stroke engine developes power with each revolution of crank shaft. Generally, two-stroke engines are favoured for diesel power plants for the advantages described later.

Duel Fuel Engines. In duel fuel engines, gas and oil both are used as fuels for the engines. The gas is used as main fuel and oil is used as helper for ignition.

In the duel fuel engine, the air and gas are taken in during suction stroke. The pressure of the mixture is increased during compression stroke. Near the end of the compression stroke, the pilot oil is injected into the cylinder. The compression heat first ignites the pilot oil and then gas mixture. The further actions of the engine are similar to the diesel engine. The air-gas ratio is comparatively higher in duel fuel engines compared with gas engines.

There is keen interest in the diesel power plants to use the duel fuel engines for better economy and proper use of available gaseous fuels in the country. The gas may be a waste product as in the case of sewage treatment installations or oil fields where the economic advantage is self-evident. With the wider availability of natural gas, the duel fuel engines may become an attractive means of utilising gas as fuel at off-peak tariffs for the generation of electrical energy.

Advantages and disadvantages of two-stroke engines over four-stroke engines. For comparing the merits and demerits of two-stroke engines over four-stroke engines, the size and speed of the engines are considered same.

Advantages. 1. Theoretically, a two-stroke engine develops twice the power of four-stroke engine at the same speed. The actual power developed is 1.7 to 1.8 times of the power developed by 4 stroke engines. This is because, some of the power is used for compressing the air in crank case and effective compression stroke is less than four-stroke engine for the same stroke.

2. The two-stroke engine is much lighter and more compact, and occupies less floor area for the same power developed.

3. The turning moment of two-stroke engine is more uniform than four-stroke engines. This ability of the engine reduces the size of the flywheel required. This further requires lighter foundations and reduces the installation cost to a greater extent.

4. It provides mechanical simplicity and, therefore, gives higher mechanical efficiency.

5. The starting of two-stroke engines is much easier than four-stroke engine.

6. The capital cost of the plant with two-stroke engines is considerably less.

Disadvantages. 1. The thermodynamic efficiency of two-stroke engine is less than four-stroke as the effective compression ratio is less than the four-stroke engine of the same dimensions.

2. The cooling of the engine presents difficulty as the quantity of heat removed per minute is large. Oil cooling of the piston is necessary as there is possibility of overheating the piston due to firing in each revolution.

3. The lubricating oil consumption is more as the operating temperatures are higher.

4. The scavenging is not complete particularly in high speed engines (above 1000 r.p.m.) as very short time is available for scavenging and hence the fresh charge is highly polluted. The pollution reduces the thermal efficiency of the engines.

The field for the two-stroke C.I. engines is only diesel electric stations because its use is justified over four-stroke engines if the engines are built for large output purpose.

23.5. THERMODYNAMIC CYCLES AND CYCLE ANALYSIS

The diesel engines work on diesel cycle. The theoretical diesel cycle for four-stroke and two-stroke engines having the same dimensions and same maximum pressure are shown in the thermodynamics book by the same authors.

The indicated mean effective pressure of the cycle and ideal thermal efficiency are given by the following expressions

$$p_m = (P_a \rho) \cdot \frac{\gamma \rho^{\gamma-1} (R-1) - (R^\gamma - 1)}{(\rho - 1)(\rho \gamma - 1)}$$

$$\eta_{th} = 1 - \frac{1}{R^{\gamma-1}} \left[\frac{(\rho^\gamma - 1)}{\gamma(\rho - 1)} \right]$$

The power developed by the engine is given by

$$\text{B.P.} = \text{I.P.} \times \eta_m = \frac{p_m LA \cdot n}{1000} \times \eta_m = \frac{2\pi NT}{1000} \text{ kW}$$

where n is the number of working strokes

$$n = N \text{ (for two-stroke engines)}$$

$$n = \frac{N}{2} \text{ (for four-stroke engines)}$$

where N is the r.p.s. of the engine.

The brake thermal efficiency of the engine is given by

$$\eta_b = \frac{\text{Brake power (kW)}}{m_f \times C.V.}$$

where m_f is the mass of fuel used in kg per sec and C.V. is the calorific value of fuel in kJ/kg. Other notations carry usual meaning.

23.6. DIFFERENT SYSTEMS OF DIESEL POWER PLANT

(1) **Fuel Storage and Fuel Supply System.** The fuel storage and supply arrangement generally depend on the type of fuel, size of plant and type of engine used and so on.

The supply system is generally classified as (*a*) Simple suction system and (*b*) Transfer system.

In a simple suction system, the oil is taken by a suction pump driven by engines from service tank located a few cm below the engine level. Such pump delivers constant volume of fuel, therefore, an overflow line is required back to the tank. This system is used for small capacity plant.

In transfer system, the motor driven pump takes the oil from main storage and supply to the day-storage tank. The oil from day-storage tank flows under gravity to the engine pump. This type of system is shown in Fig. 23.2 and it is generally preferred for medium size or big size power plants.

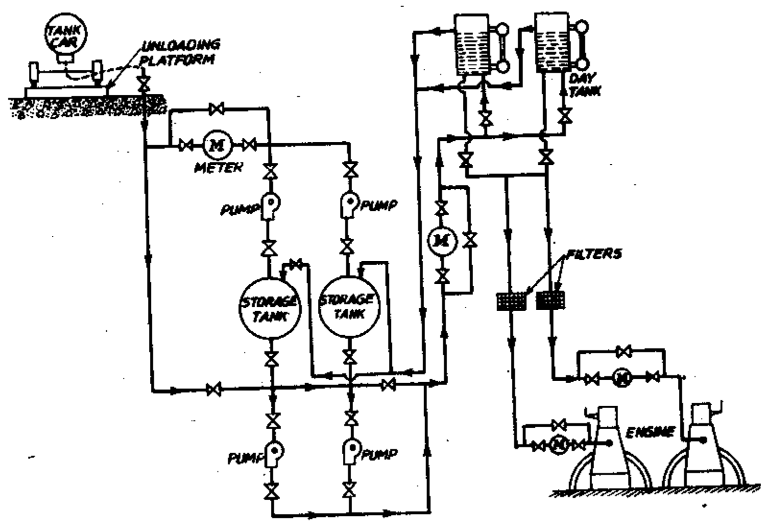


Fig. 23.2. Fuel storage and supply system.

The location of storage tank above ground or below ground depends upon local conditions. Each of them has specific advantages. The overground tanks have the advantages of detecting the leak easily, low maintenance and easy cleaning. On the other hand, underground tanks have the advantage of reduced fire hazards.

The heating requirement depends upon the climatic conditions and viscosity of the fuel used. If the heating is required, then it is generally done in the storage tank by passing the hot jacket water through a coil dipped in the storage tank.

Injection of Fuel into the Engine. The functions of the fuel injection system are to meter small amount of oil, inject into the cylinder at proper time, atomize and mix with the air. The efficiency of the engine depends upon the proper mixing of fuel with air. Mixing becomes more difficult with an increase in speed and increase in cylinder diameter.

Presently, in all didesel power plants "solid injection" is used. The fuel at a pressure of 100 to 200 bar is injected through nozzle into the compressed air which also helps to atomise the oil.

The common methods which are used for fuel injection system are individual pump, common rail and distributor system.

2. **Air-supply System.** A large diesel engine power plant requires considerable amount of air as 4 to 8 m^3/kW-hr. The air contains lot of dust and, therefore, it is necessary to remove this dust from air before entering into the cylinder which would otherwise cause excessive wear in the engine. An air-supply system of a diesel power plant begins with an intake located outside the building provided with filters. The filters used may be oil-impingement, oil-bath or drag type depending upon the dust type and dust concentrations in the air.

In many parts of western countries, the outside air temperature may reach such a level that it causes misfiring at low loads on the plant. Under such circumstances, the air intake system needs heating and necessary heating of air is provided by using the heat from the exhaust gases.

3. **Exhaust System.** The following points should be taken into consideration for the design of exhaust system of a big power plant.

(*a*) The noise should be reduced to a tolerable degree.

(*b*) It should be exhausted well above the ground level to reduce the air pollution at breathing level.

(*c*) The pressure loss in the system should be reduced to minimum.

(*d*) The vibrations of exhaust system must be isolated from the plant by use of flexible exhaust pipe.

(*e*) A provision should be made to extract the heat from exhaust if the heating is required for fuel oil heating or building heating or process heating.

In many cases, the temperature of the exhaust gases under full load conditions may be of the order of 400°C. With the recovery of heat from hot jacket water and exhaust gases and its use either for heating oil or buildings in cold weather increase the thermal efficiency to 80%. Nearly 40% of the heat in the fuel can be recovered from the hot jacket water and exhaust gases. The heat from the exhaust can also be used for generating the steam at low pressure which can be used for process heating. Nearly 2 kg of steam at 8 bar pressure can be generated per kW per hour, when the mass of exhaust gases can be taken as 10 kg/kW-hr.

4. **Water-cooling system.** If the engines are not properly cooled, the temperature existing inside engines would disintegrate the film of lubricating oil on the liners and wrapping of valves and pistons takes place. The proper cooling of the engine is absolutely necessary to extend the life of the plant. Therefore, exit temperature of the cooling water must be controlled. If it is too low, lubricating oil will not spread properly and wearing of piston and cylinder takes place. If it is too high, the lubricating oil burns. Therefore, the maximum exit temperature of the water is limited to 70°C.

Constant cooling water flow rate rises the exit water temperature with the increase in load or vice versa when inlet water temperature is constant. Therefore, a control on the flow of cooling water is necessary according to the load conditions on the plant.

A common water cooling system used in diesel plant is shown in Fig. 23.3.

The water which is not soft will cause deposits at temperature of about 50°C. Therefore, it is necessary to soften the water before entering into the system and to prevent the growth of algae which may reduce the heat transfer due to fouling.

The cooling water is treated with 3 ppm Calgon to control the scaling in the different parts of the system and it is also chlorinated once per shift upto 6 ppm to prevent algae growth which would cause the rapid tube fouling. For inhibiting corrosion, 300 ppm of sodium chromate is also added. Generally, the quantity of cooling water required is 35 to 60 litres per kW per hour.

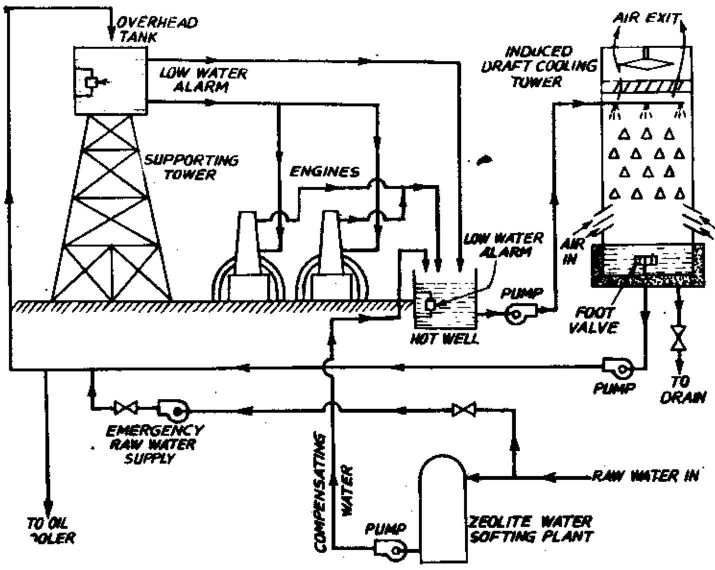


Fig. 23.3. Cooling water system using water softing plant and cooling-tower.

As the circulation of water in the cooling system is concerned, these are generally divided into a single circuit system and double circuit system. These two systems are shown in Fig. 23.4 (*a*) and Fig. 23.4 (*b*).

The single circuit system may be subjected to corrosion in the cylinder jackets because of the dissolved

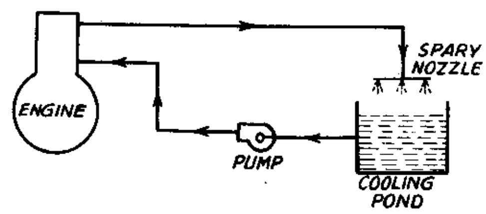


Fig. 23.4 (*a*). Single circuit cooling system.

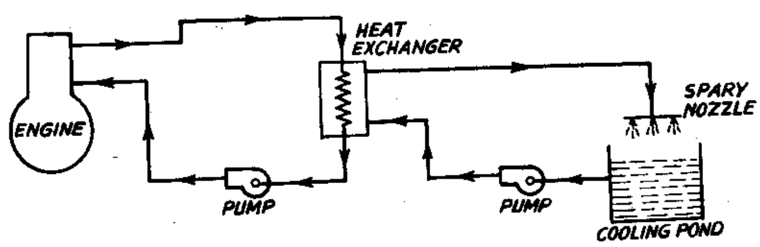


Fig. 23.4 (*b*). Double circuit cooling system.

gases in the cooling water. The double circuit system largely eliminates internal jacket corrosion but the corrosion may exist in the raw water circuit.

5. **Lubrication system.** The role played by the lubrication system in diesel power plant is more important than any other plant because of very high pressures and small clearance in these engines. The life of the engine, the overall efficiency of the plant and possible continuous service of the plant are dependent on the effectiveness of the lubrication system.

Main parts to be lubricated of a diesel engine are crankshaft, wrist pin bearings, bearings and all other moving parts. The lubrication of piston and cylinder is little different as special lubricant is required for this purpose as the lubricant has to operate under high pressure and temperature conditions.

The forced feed lubrication is generally used to lubricate all the parts. The general equipments which are used in lubrication system are pump, oil cleaners, oil coolers, storage, sump tanks and safety devices.

The friction losses of the engine will appear as the heating of the lubricating oil during its circulation through the engine. Generally, 2.5% of the fuel heat is given to the lubricating oil and it is necessary to remove this heat for proper functioning of the lubrication. This heat nearly amounts to 300 kJ/kW-hr. The lubricant oil is cooled in an oil cooler before supplying to the engine. The cooling is done by using the water from the pump of the cooling tower.

Another important problem of the lubrication system is to remove the impurities in the form of carbon particles, water and metal scrap carried by the oil during circulation. For this purpose, filters, centrifuges or chemical cleaning plants are used. The mechanical type of filters used are cloth bags, wood pads, paper pads and porous material pads. Many times, the oil from the engine is filtered by passing through the metal screen strainers and ultimate cleaning is accomplished by passing the oil through centrifugal cleaner. This is necessary in high capacity plant as the quantity of lubricating oil circulated is approximately two thousand litres per hour for 1 MW plant. The oil should be heated before passing through the cleaning system. This is necessary to increase the fluidity of the oil.

The cost of the lubricating oil in the diesel plant is considerable compared with other plants as the consumption is nearly 3 litres per 1000 kW-hr generated at full load conditions. Thus the lubricating oil consumption is nearly 1% of the fuel oil consumption. Well refined mineral oil is best suited for slow speed engines but specially treated oil is required for heavy duty and high speed engines.

The general outline of the lubrication plant used in diesel power plant is shown in Fig. 23.5.

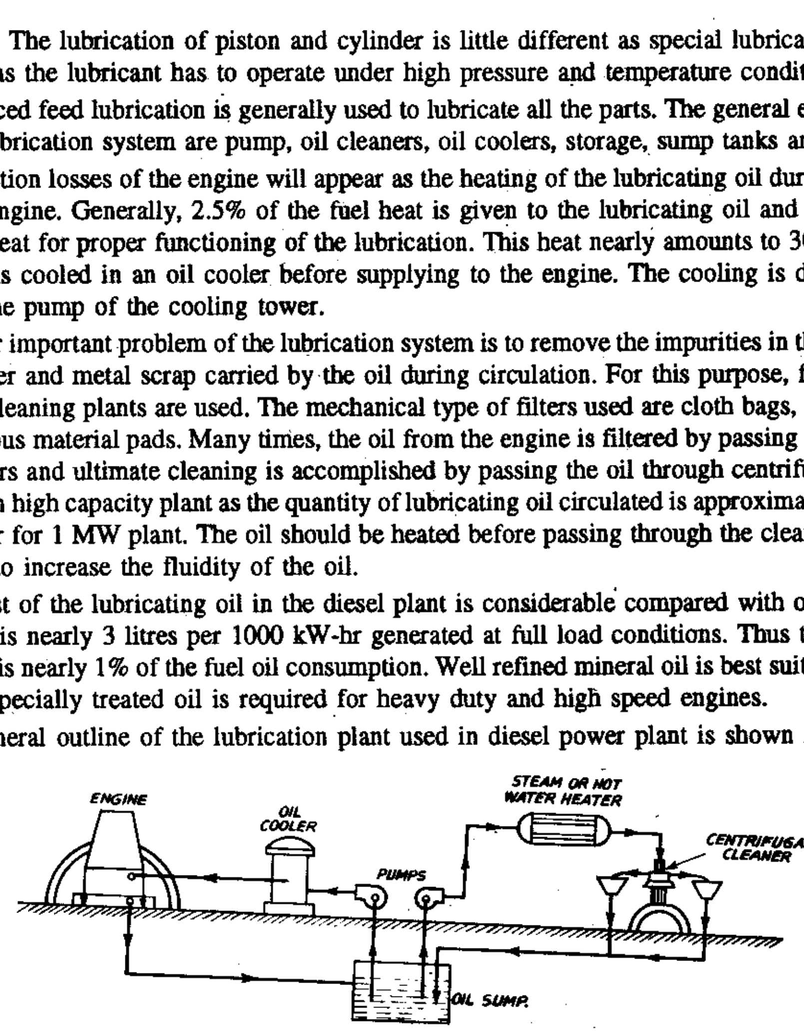


Fig. 23.5. Lubrication system having continuous centrifugal cleaning.

6. **Starting system.** It is difficult to start even smallest diesel engine by hand cranking as the compression pressures are extremely high. Therefore, some mechanical system must be used to start the engine. Generally, compressed air, electric motors and auxiliary gasoline engines are used for starting purposes. Compressed air system is commonly used in big diesel power plants.

Air starting system uses valve arrangement to admit pressurised air at about 20 bar to a few of the cylinders, making them to act as reciprocating air motors to turn the engine shaft. Admitting fuel oil to the remaining engine cyclinder helps the engine to start under its own power.

During normal working of the plant, the power from the main shaft is used to drive the compressor which accumulates air into the accumulators. Once the accumulators indicate the rated pressure, the compressors are automatically disconnected from the power shaft.

For automatic starting system, the ordinary air starting equipments are arranged to open in the correct sequence and close when the engine starts running. The automatic starting system is also used to prime the lubricating oil system and to start the automatic flow of the cooling water also.

7. **Governing system.** The governing of diesel engine is done by varying the quantity of fuel supplied

to the engine. Generally constant stroke with variable suction or variable bypass method is used to control the quantity oil fuel supplied according to load. Centrifugal type governor is used to control the suction or bypass of the fuel.

23.7. SUPERCHARGING OF DIESEL ENGINES

It is a known fact that the power output of the engine increases with an increase in amount of air in the cylinder at the beginning of compression stroke because it allows to brun more quantity of fuel.

Supercharging is a term used to a process which helps to increase the suction pressure of the engine above atmospheric pressure and the equipment used for this purpose is known as supercharger.

Advantages of supercharging. The advantages of supercharged engines are listed below :

1. **Power increase.** By supercharging the engine, the engine output can be increased by 30 to 50% at the same speed of the engine.

2. **Fuel Economy.** The combustion in supercharged engine is better as it provides better mixing of the air and fuel than unsupercharged engine. Therefore, the specific fuel consumption of a supercharged engine in less than natural aspirated engine. The thermal efficiency of supercharged engine is also higher.

3. **Mechanical efficiency.** The mechanical efficiency of a supercharged engine is better than natural aspirated engine at the same speed. This is because, the power increase due to supercharging increases faster than the rate of increase in friction losses.

4. **Scavenging.** The scavenging action is better in two-stroke supercharged engines than naturally aspirated engines because the quantity of residual gases is reduced with the increase in supercharged pressure.

5. **Knocking.** Supercharging reduces the possibility of knocking in diesel engines because delay period is reduced with an increase in supercharged pressure. Actually, supercharging results in smoother running of the engine.

It has been found that four-stroke engines are more easily adaptable to supercharging than two-stroke engines.

Due to number of advantages of supercharging mentioned above, modern diesel engines used in diesel plant are generally supercharged. By supercharging, the size of the engine is reduced for given output and consequently the space requirements and civil engineering works also.

The Superchargers which are considered for diesel power plants are positive displacement type, centrifugal type and exhaust turbocharger. The selection depends upon its relative merits for a particular situation.

23.8. PERFORMANCE OF DIESEL POWER PLANT

Diesel plants also run at part load conditions like other plants. Therefore, it is necessary to study the effect of part load running on the characteristics of an engine like specific fuel consumption, brake thermal efficiency, and mechanical efficiency.

The effects of part loads on the engine characteristics are shown in Fig. 23.6.

The part load increases the specific fuel consumption, decreases the thermal and mechanical efficiency. But the effect is not as predominant as in thermal plants.

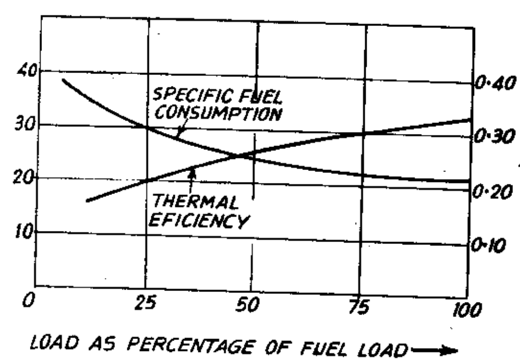


Fig. 23.6. Performance of diesel power plant.

23.9. PALNT LAYOUT

The layouts of diesel power plants for high capacity (50 MW and above), medium capacity (25 to 50 MW) and low capacity plants are shown in Fig. 23.7 (*a*), Fig. 23.7 (*b*) and Fig. 23.7 (*c*).

Generally in all three cases, the generating units are installed parallel. Sufficient space must be provided around the various units for dismantling and repairing purposes. The fuel oil tanks are generally located outside the main buildings to avoid the fire hazards.

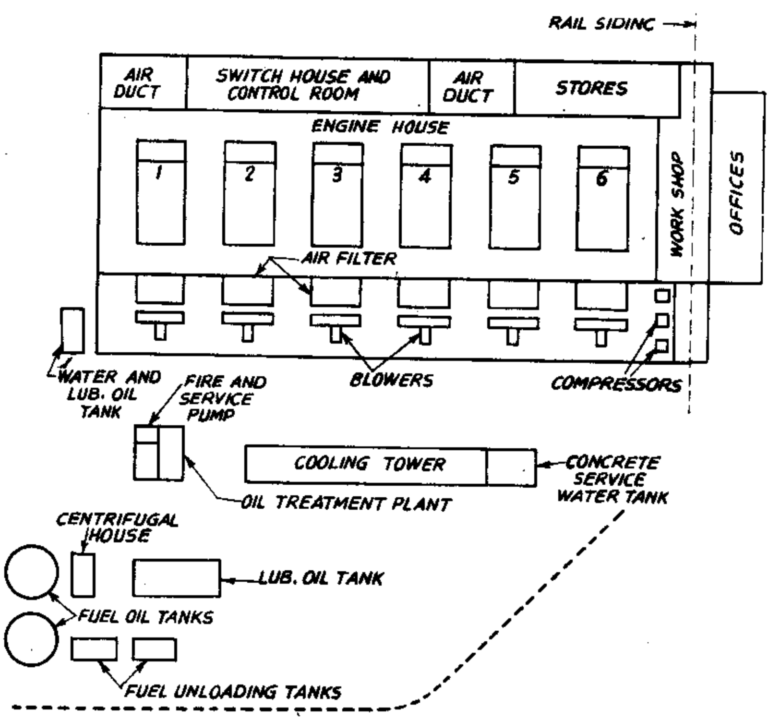


Fig. 23.7 (*a*). Layout of high capacity diesel power plant.

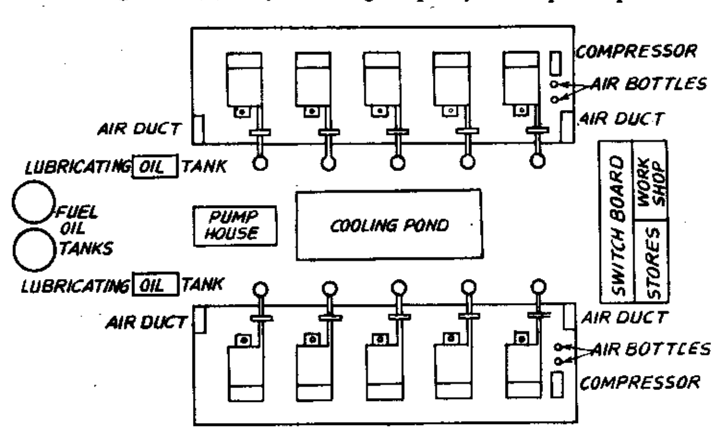


Fig. 23.6 (*b*). Layout of medium capacity diesel power plant.

The construction of buildings and engine layout are similar in many respects to the steam power plants, although on a much smaller scale. A steel frame with brick panels and asbestos sheet roof is quite satisfactory. Good natural lighting can be provided by including large vertical or horizontal windows in the side walls and rows of skylights in the engine house roof.

A workshop must be situated at one end of engine house with rail or roadway running across it, so that the crane can be used to unload direct from the wagons.

The ventilation problem of engine house is not easy job particularly in hot climate. Generally, forced circulation with evaporative cooling is used for cooling the engine room. The air ducts are placed in the

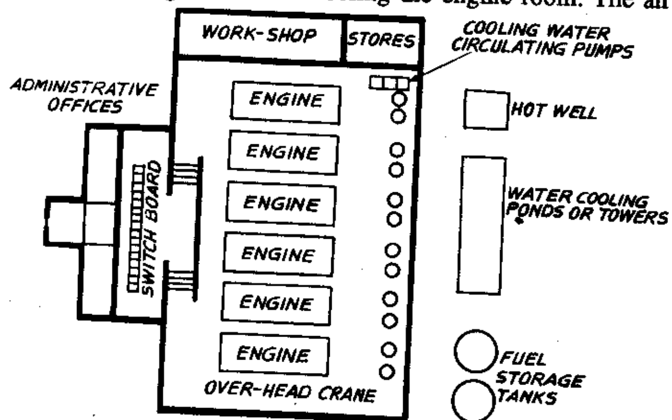


Fig. 23.7 (*c*). Layout of low capacity diesel power plant.

basement wall at the alternator side and supply air to the alternator pits and to the operating floor for cooling the buildings.

23.10. ADVANTAGES AND DISADVANTAGES OF DIESEL PLANTS OVER THERMAL PLANTS

1. The diesel power plants are more efficient than steam power plants in the range of 150 MW capacity. They maintain high operating efficiency in the load range of 50% to 100% of full load.

2. Diesel plants are cheaper in first cost than steam plants ; plant units upto about 7 kW. Above this capacity, the diesel cost rises rapidly while that of steam plants continues to fall.

3. It has no standby losses.

4. It can burn fairly wide range of fuels.

5. It can be quickly started up and brought into service (within one minute).

6. Manufacturing periods are short, therefore, a diesel station may be rapidly extended to keep pace with load growth by just adding the generating units of suitable sizes.

7. Where skilled labour is scarce, the full automation of diesel station can be provided for starting, synchronising and shutting down diesel sets with reasonably low capital costs.

8. Maintenance can be simplified by the provision of easily replaceable assemblies of parts, thus enabling reconditioning to be undertaken away from generating plants.

9. It is possible to instal compact, light weight, high speed diesel sets of smaller capacity for sites that are remote, cramped or difficult to access. This was the main reason in adopting many small diesel plants in the Namrup area of Assam.

10. The cooling water required for the same capacity is considerably less than the thermal plant. The site of the thermal plant is dictated by the availability of cooling water in many cases whereas diesel plant can be located without giving much importance to the availability of cooling water. The water ratio for thermal to diesel is approximately 50 : 1.

11. The diesel plants can be located very near to the load centres, many times in the heart of the town. The diesel plants are admirably suited to load centre location. The combination of fuel economy, remote operational control, flexibility as to installed capacity and high degree of freedom from hazard allow placement of diesel generation sets almost anywhere that it would be useful and economical.

12. The space required for diesel plant is considerably less than thermal plant and, therefore, cost of foundation and buildings is less.

13. The storage required for the fuel is considerably less than the thermal and it can be handled more easily.

14. There is no problem of ash handling as there is practically no refuse.

15. The plant layout is very simple compared with thermal plant. They are easy to operate and control.

16. The lubrication system is not only more economical but permits the use of specially compounded cylinder lubricants that provide dramatic improvement in wear rates. The cylinder liner life of 50,000 to 100,000 hours is common even burning the poorest grade of residual oils. The lubrication cost of diesel plant is 0.5 mills per kW-hr, even burning residual fuel oils which is 2 to 5 times compared with steam plant.

17. They can be employed in all climatic zones.

18. They are very adaptable and can be easily extended to the given power requirements.

19. Machine sets are readily available as standard sets in the range of 500 kW to 40 MW.

20. Operational reliability with high availability is ensured.

21. Due to its relatively low cost, it is possible to instal a spare unit which can be kept as permanent standby.

Diesel plants are universally adopted as emergency power generating plants. The purpose is to supply power to the installation in the event of failure of the public supply network. Examples are, hospital requirements, tele-communication, water supply and in various industrial processes.

Disadvantages. 1. The unit capacity of diesel engine is considerably low than the thermal unit. The cost of unit increases with an increase in unit capacity for diesel plant whereas the cost of the unit goes on decreasing in case of thermal plant with an increase in unit capacity.

2. The repair and maintenance costs are generally much higher than for steam plants. These costs are more or less fixed in case of steam plants and more or less are proportional to output in the case of diesel plants.

3. Life of 25 to 30 years is normal for thermal plant whereas the life of diesel plant is hardly 2 to 5 years or less.

4. The diesel plants are not economical where fuel has to be imported.

5. The noise is a serious problem in diesel plant.

6. Selected types of fuels are required in diesel engines whereas there is more mobility in case of thermal plant.

7. The lubrication cost is high.

8. The diesel plants are not guaranteed for continuous operation under overloads whereas steam plants can work under 25% overload continuously.

However, the direct numerical comparison is meaningless unless accompanied by a detailed analysis of each plant in respect to the construction difficulties encountered during erection, special foundation needs equipment, transportation costs, availability of materials and labour and other differences caused by location and general financial conditions.

With all these factors mentioned above, plus the variability of oil fuel prices, it is clear that there is no simple answer to the question as to where lies the border line of competition between diesel and steam plants. Broadly speaking, the diesel is more economical upto a total installed capacity of about 50 MW and steam is more economical for capacities in excess of about 50 MW.

Oil-fired steam plants compete with diesel at the lower part of this range, while coal-fired steam plants would start to compete at a higher level of installed capacity.

In general, high load factors and large differences in the pricess of diesel and boiler fuel will tend to lower the value of installed capacity at which the steam plant can compete and *vice versa.* Thus in countries having cheap solid fuel sources and imported diesel fuels are costly, a steam plant could be justified even in smaller sizes.

Quick deliveries, simplicity of operation and ability to start quickly are in the favour of diesel plants.

Fig. 23.8 shows the diesel plants available today for installation as stationary plants. High speed engines are generally used as emergency plants due to their wear. Supercharged diesel plants are generally used as they substantially increase the utilization of the engine.

23.11. PRESENT TRENDS IN DIESEL RESEARCH

The present research work in the diesel engines development is directed towards higher operation speeds, lower specific fuel consumption (kg/kW-hr), lower specific weight (kg/kW) and higher unit size.

An air-fuel ratio of 25 : 1 is required for the combustion of diesel fuels. The power developed in the engine is proportional to the weight of fuel burnt in unit time. Therefore, the power developed by the engine can be increased by increasing the weight of air present in the cylinder at each cycle or by increasing the number of cycles per unit time (r.p.m.) or using both.

So long the necessary weight of air can be provided in an engine cylinder of given size, theoretically there is no limit to the weight of fuel burnt in unit time and hence to the power which can be developed.

The increased weight of fuel burnt creates lot of mechanical and thermal problems. The solution of these problems can be expected to be major lines of continuing research work.

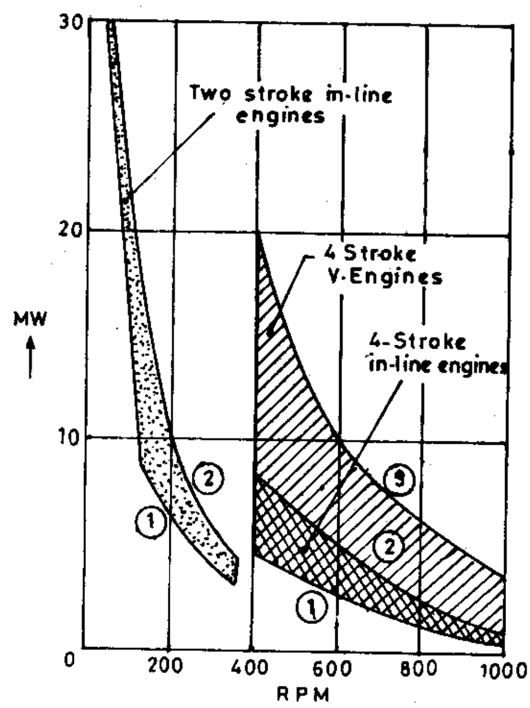
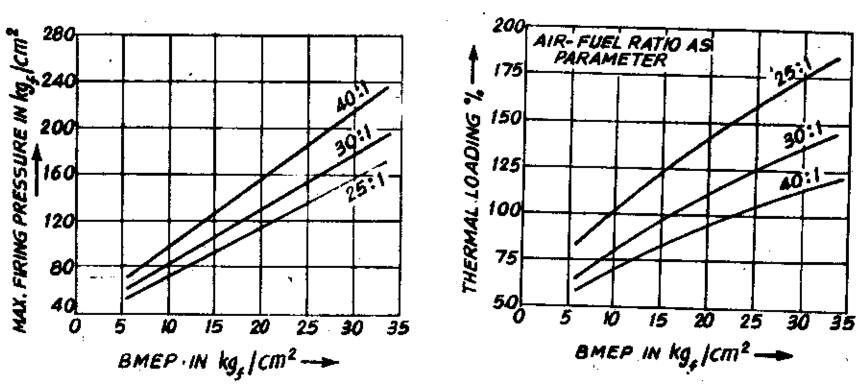


Fig. 23.8. 1/2/3-limit curves for 6/12/18 cylinders.

The effect of increasing brake-mean effective pressure at constant air-fuel ratio (this can be done by supercharging) on *mechanical and thermal* loading are shown in Fig. 23.9 (*a*) and Fig. 23.9 (*b*).

Fig. 23.9 (*b*) shows that the thermal loadings increase significantly with an increase in brake mean



(*a*) (*b*)

Fig. 23.9.

*Mechanical loading is defined as the maximum pressure occurring in the engine.

Thermal loading is defined as the percentage of heat flow in the naturally aspirated engine operating with an air-fuel ratio of 25 : 1.

effective pressure at constant air-fuel ratio. Thermal loading is an indication of temperature gradient in engine components and also an indication of the magnitude of thermally induced stresses. The present research is directed to separate these stresses from mechanical stresses so that each can be accommodated by appropriate means. The thermal loading can be reduced for any given brake mean effective pressure by increasing the air-fuel ratio.

Fig. 23.9 (*a*) shows that the mechanical loading also increases significantly with an increase in brake mean effective pressure at constant air-fuel ratio. The mechanical loading further increases with an increase in further air-fuel ratio. Therefore, the basic design problems associated with the use of higher thermal loading and with mechanical loading must be resolved satisfactorily.

If a costant bore to stroke ratio is assumed, it follows that the value of BMEP that can be tolerated will decrease with an increase in cylinder bore. Therefore, the cylinders of larger bores result in bulkier, heavier and costlier engines for a given output. There is also an upper limit to the number of cylinders to an engine, it follows that the engines of large capacity must have large bore cylinders. This is one of the reasons for rise in first cost of the diesel plant above 2.5 MW capacity.

Rotational Speeds. The electric generators require specific speeds for directly driven alternators. The widely used frequencies for industrial and domestic purposes are 50 Hz and 60 Hz and corresponding synchronous speeds related to the number of pairs of poles on the alternator rotor are listed in the following table :

Number of pairs of poles	*R.P.M. required*	
	for 50 Hz	*for 60 Hz*
1	3000	3600
2	1500	1800
3	1000	1200
4	750	900
5	600	720
6	500	600
7	428	514
8	375	450
9	333	400
10	300	360

The lower cost requirements always favour the alternators with the minimum number of poles and it is clear from the table that the maximum speed to be achieved is 3000 r.p.m. or 3600 r.p.m. Therefore, increase in rotational speed is another way of packing more power into an engine.

The dynamic forces on the engine increase proportional to the product of piston stroke and N. Therefore, the permissible operating speed decreases with an increase in engine size due to the limit set by the physical properties of the material available. Presently 500 R.P.M. is regarded as an acceptable speed for base load generation. The acceptable speeds are increased from 500 to 750 and are expected to increase to 1000 R.P.M. in future as the research is directed to find out the materials to bear such heavy stresses. The operating speed increases with an increase in number of cylinders.

Fuel. The research is also directed towards using heavy low grade fuels in the diesel engines to reduce the operating cost to minimum. The diesel oil fuels are produced to closely controlled specifications. There is another wide range of fuels known as heavy fuels which are commonly used in boilers and in other industries. Heavy fuels are produced to wider specifications and they are identified by their viscosity at a specified temperature. Presently engines are designed to use variety of them successfully in medium speed engines.

Fig. 23.10 shows the cost of fuel oils of various viscosities with that of class '*A*' diesel fuel. It is obvious from the graph that there is significant financial saving by using fuel oils having viscosities upto 1000 seconds Redwood but further savings by using still high viscosity oils are relatively small.

Now-a-days, it is possible to run the engines of 1000 kW at 600 r.p.m. on fuel oils of viscosities upto 3,800 Redwood seconds and 100 kW engine at 1,000 r.p.m. on fuel oils of viscosities upto 1,500 Redwood seconds.

Keen interest is taken in the use of gaseous fuels in diesel engines which uses a small quantity of liquid fuel as a means to ignite the air-gas mixture in the cylinder. Such types of engines are known as dual fuel engines. Dual fuel engines may become an attractive method of electric generation due to the wider availability of natural gas at lower prices.

The overall effect of these trends of rising the mean effective pressure, rotational speed and adoption of the diesels to burn cheap heavy oil fuels is to raise the frontier of competition between the steam plants and diesel plants into a higher level of installed capacity.

If the research trends mentioned earlier are continued, the present unit capacity of diesel may be doubled within a short span of time. The changeover point from diesel to steam plant, until recently, was about 20 to 50 MW and with the present research programme, it is expected that it may soon reach about 40 to 100 MW. Among all the factors, the increase in rotational speed has marked effect on the development of this plant because it results in a greater degree of compactness, with consequent cheapening of engine, alternator and building requirements.

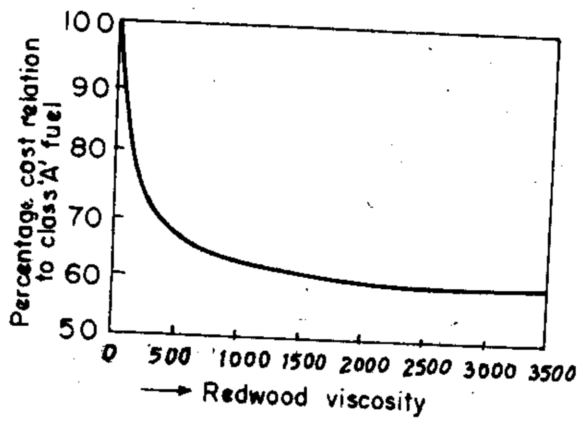


Fig. 23.9.

With its rising competitiveness with steam plant, the diesel plants have to play two important roles as mentioned below :

1. It may serve as a means of generation in islands and remote centres of population in countries.
2. It may serve for generating power in the developing countries (tens of MWs rather than hundreds) where heavy capitals are not available and low cost fuels are available in abundance.

These are the major features of diesel plants that are ideally suited to developing countries.

EXERCISES

23.1. What are the different fields where use of diesel power plant is essential ?

23.2. Draw a neat line diagram of a diesel power plant showing all the systems.

23.3. What are the different types of engines used in diesel power plant ? When two-stroke engines are more suitable and economical than four-stroke engines ?

23.4. Draw a neat diagram of a fuel storage and fuel supply system used for a diesel power plant. What are the advantages of underground fuel storage ?

23.5. What are the different methods of fuel injection used in diesel plants ? Which method is commonly used in big diesel plant and why ?

23.6. Draw a neat diagram of a cooling system used for diesel power plant showing all the essential components. What are the advantages of double circuit over single circuit system ? What precautions should be taken to ensure that cooling is satisfactory ?

23.7. Why the cooling and cleaning of lubricating oil is necessary ? Draw a neat diagram of lubrication system used for medium capacity diesel power plant.

23.8. Why the starting of diesel plant is more difficult ? What different methods are used for starting diesel engine ? Which method is common and why ?

23.9. Why the supercharging is necessary in diesel plant ? What are the methods used for supercharging the diesel engine ? What are advantages of supercharging as fuel consumption and overall efficiency of the plant are concerned ?

23.10. Draw a plant layout for 5 MW diesel power stations showing all the required equipments. Show the arrangement of the cooling system and engine layout.

23.11. What are the outstanding features of diesel plants over the thermal plants ? Why diesel plants are not used for high capacity ? What are its drawbacks when used for high capacity compared to steam plants ?

23.12. What is the present trend in diesel research ?

23.13. Explain the method of determining the annual fuel consumption and cooling water requirement of a diesel plant. State methods of cooling the circulating water of a diesel plant.

23.14. What are the various factors to be considered while selecting the site for diesel engine power plant ? Calculate yearly fuel cost of 50 MW capacity plant based on oil price of 40 rupees per barrel of 120 kg capacity.

23.15. A mine is situated at an elevation of 4270 metres above sea level and requires 1000 kW. Two diesel plants each of 600 kW at sea level are available. Would these engines be sufficient to meet the power requirement without any modifications ? If not, what should be the approximate capacity in m^3 of air per minute of a supercharger for each engine and the power absorbed by this supercharger. Use the following data : Barometric pressure falls by 8.3 cm of Hg for every 1000 metres A : F ratio = 26, temperature at sea level and mine elevation is same $v_s = 0.77\ m^3/kg$ at N.T.P. volumetric efficiency of supercharger = 65%, 75% of the work given to the supercharger is used for compressing the air.

23.16. A cooling tower needed with a diesel plant will require to cool 900 litres of water at 67°C entering temperature. The DBT and WBT of atmospheric air are 28°C and 22.5°C respectively. A forced draft tower with 70% cooling efficiency is used for cooling. Calculate make-up water flow and estimate the fan power. Assume air goes out of tower at 60°C and 90% relative humidity. No carry-over loss.

23.17. Cooling water for 500 kW diesel plant is pumped to a cooling tower at 60°C. It is desired to cool the water to a maximum temperature of 40°C under atmospheric conditions of 33°C DBT and 28°C WBT. Find the required capacity and efficiency of a cooling tower.

23.18. A diesel plant has a cooling system employing a cooling tower that loses to the atmosphere approximately 5% of the water circulation. When two 500 kW engines are operated at full load on an average per day, the tower cools the water from 55°C to 35°C. What should be the capacity of water softing plant in litres per minute for the make up ?

□□□