Basics of Mechanical Engineering-3

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Week 06

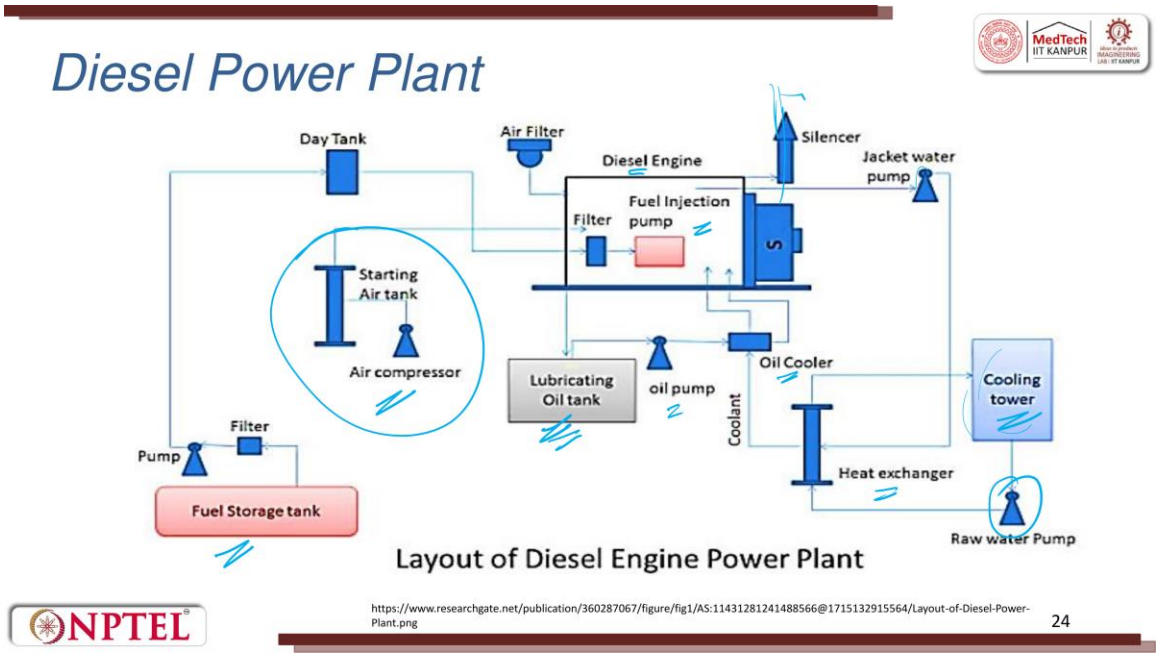
Lecture 26: Basics of Power Plants (Part 2 of 2)

Welcome to the lecture on Power Plants.

Power Plant and Boilers

Diesel Power Plant utilizes diesel engine to generate power.

1. Diesel power plant/generator has the range of 2 to 50 MW power generation capacity. They are used as central station for small or medium power supplies.
2. They can be used as stand-by plants to hydro-electric power plants and steam power plants for emergency services.
3. They can be used as peak load plants in combinations with thermal or hydro-plants.
4. They are quite suitable for mobile power generation and are widely used in transportation systems such as automobiles, railways, air planes and ships.
5. Now-a-days power cut has become a regular feature for industries. **The only solution to tide over this difficulty is to install Diesel Generating Sets.**



Now, let us move to Diesel Power Plants. DGs utilize diesel engines to generate power. Generally, they operate within a range of 2 to 5 megawatts in power generation capacity. They are used as central stations for small and medium power supplies. They can be used as standalone power plants or alongside hydroelectric and steam power plants for emergency services.

When a power failure happens, we always deploy a DG. A DG is a small setup called an engine, but when it is large, it becomes a power plant. They can be used as peak load plants in combination with thermal and hydroelectric plants. Most of the time, during evening hours, everyone uses AC. So now the peak power demand goes higher.

When peak power demand increases, the power supplied from the grid often becomes unstable. To stabilize the power supply, these DGs are used as peak power or peak load controllers. They are quite suitable for mobile power generation. For example, you can move them from place to place. In the cinematography industry, they use portable generators.

So the mobile power plant generation works. And it is widely used in transportation systems such as automobiles, railways, airplanes, and ships. Mobile towers are now also attached to the mobile power generation units. During Kumbh Mela, at several points, they had these mobile power generation units and mobile towers so that many people could use and access them. So diesel is used there.

Again, the power generation is very low, 2 to 50 megawatts. And when you talk about mobile towers, it will not even be that much. Nowadays, power cuts have become a regular feature for industries. The only solution to tide over this difficulty is to install a DG. This is what a typical diesel power plant looks like.

So you have fuel which is stored. The fuel is filtered and then pumped. It is taken to a day tank. From the day tank, it is again taken to a fuel injector pump, and from there it starts burning and generating heat. So this day tank, it goes here.

Then, you also have a starting air tank. The air compressor is there. It provides the air. This air is also sent to the filter. This is a diesel engine.

It is sent here. The tank supplies the fuel here. It is injected by a fuel injector. Then, there is piston movement. This piston movement rotates the engine.

The engine is attached to a generator, and then you take the output. Since there are moving parts, a lubricating oil tank is needed. That takes care of the friction involved. You will have a lubricating oil tank. The lubricating oil tank gets oil from an oil pump.

Then we have an oil cooler. So this is also used, as it comes from the heat exchanger. So the cooling tower is there. Then you have a raw water pump there. So this is how it keeps generating.

The jacket of water is being pumped, and it is coming here. You have a silencer on the top through which the exhaust goes up. So this is a typical setup. You will have a tank, a compressor, this is the engine, this is the lubrication, and a cooling tower if there is a requirement.

Diesel Power Plant

Diesel Engine:

- Diesel engines or compression ignition engines as they are called are generally classified as two stroke engine and four stroke engines.
- In diesel engine, air admitted into the cylinder is compressed, the compression ratio being 12 to 20.
- At the end of compression stroke, fuel is injected. It burns and the burning gases expand and do work on the position. The engine is directly coupled to the generator. The gases are then exhausted from the cylinder to atmosphere.

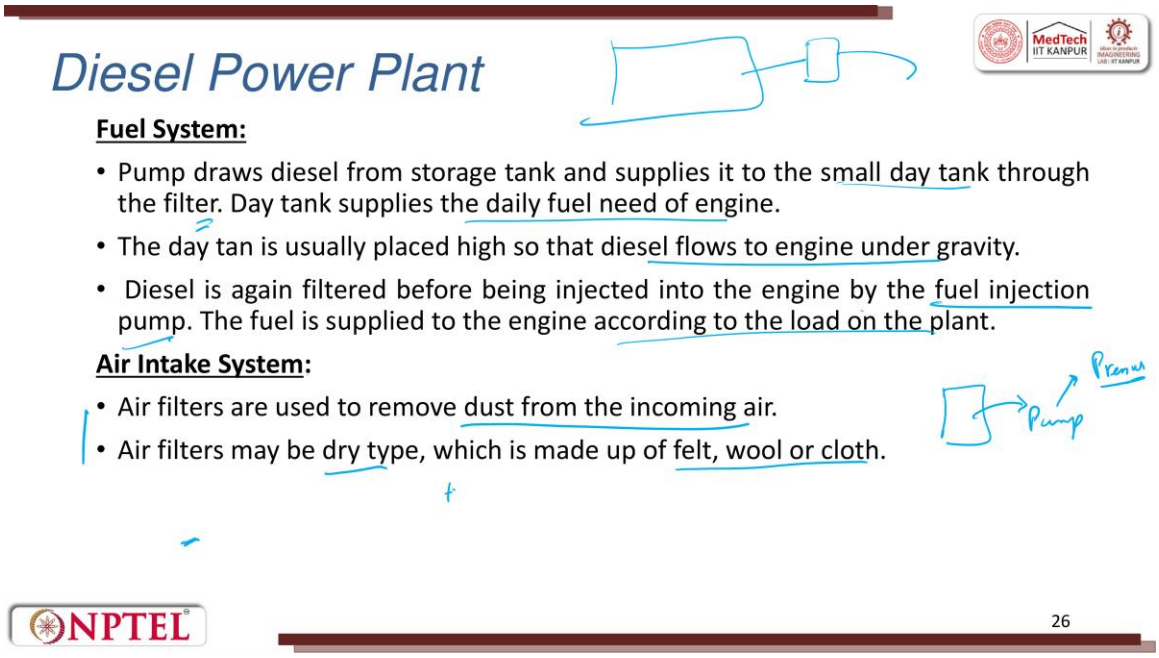
Engine Starting System:

- This includes air compressor and starting air tank.
- The function of this system is to start the engine from cold by supplying compressed air.

Diesel engines, or compression ignition engines as they are called, are generally classified as 2-stroke or 4-stroke engines.

The diesel engine air admitted into the cylinder is compressed to a ratio somewhere between 12 to 20. At the end of the compression stroke, the fuel is injected, it burns, and the burning gases expand to do work on the piston. The engine is directly coupled to a generator, and the gas is exhausted from the cylinder to the atmosphere.

This is what the silencer set is for, through which the air gets exhausted. Engine starting system. This includes an air compressor and a starting air tank. The function of this system is to start the engine from cold or by supplying compressed air. So, this part.



Then, the fuel system: the pump draws diesel from the tank and supplies it to a small day tank through the filter. So, a large tank sends fuel to a smaller tank, and then here.

So, the pump draws diesel from the storage tank and supplies it to a small day tank. From the day tank, it is then sent to the filter. The day tank supplies the daily fuel needs for the engine. Because you might have a larger tank, right? And then a smaller tank.

The day tank is usually placed high so that the diesel flows to the engine under gravity. The diesel is filtered again before being injected into the engine by the fuel injector pump. So, what happens is you will have a fluid. This fluid will be pumped to increase the pressure, right? So, to increase the pressure, that is done by the fuel injector pump, right.

So, a larger tank, a smaller tank, and then you have an engine on one side. So, there has to be pressurized diesel that is to be injected. So, you will have a fuel injection pump. The fuel is supplied to the engine according to the load of the fuel. The air intake system, because here it is a mixture of air and diesel.

So, the air intake system: the air filter is used to remove dust and other unwanted particles. The air filter is dry, as it is made of felt, wool, and cloth. So, it is dry. So, you can remove the filter and clean it as well.

Diesel Power Plant

Exhaust system:

- In the exhaust system, silencer (muffler) is provide to reduce the noise.

Engine cooling system:

- The temperature of burning gases in the engine cylinder is the order of 1500 to 2000°C to keep the temperature at the reasonable level, water is circulated inside the engine in water jackets which are passage around the cylinder, piston, combustion chamber etc. hot water leaving the jacket is sent to heat exchanger.
- Raw water is made to flow through the heat exchanger, where it takes up the heat of jacket water. It is then cooled in the cooling tower and recirculates again.

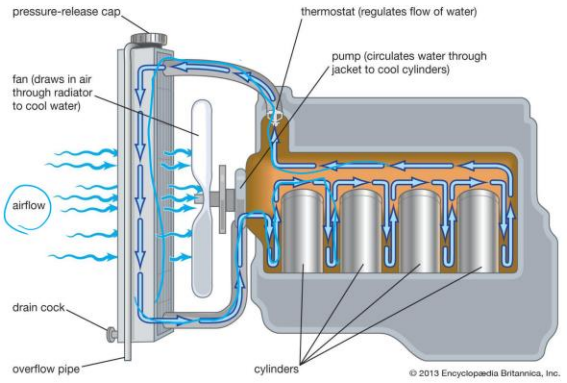
Exhaust system: in the exhaust system, the silencer muffler is provided to reduce noise. Engine cooling system: the temperature of the burning gas in the engine cylinder is of the order of 1500 to 2000 degrees Celsius. To keep the temperature at a reasonable level, water is circulated inside the engine in the water jacket, which is passed around the cylinder, piston, combustion chamber, etc. The hot water leaving the jacket is sent to the heat exchanger. You can reuse the water. So, because you have an engine, there is water that goes around.

So the water will try to remove heat; water is a working fluid, and it will try to remove the heat and come out. So now, whatever comes out is still very hot. So then, that will be passed to a heat exchanger where it is exposed to cold air, and the temperature comes down, making it a closed-loop system. Raw water is made to flow through the heat exchanger, where it takes up the heat from the jacketed water. It is then cooled in the cooling tower and recirculated. If you see here, there is a cooling tower also.

Diesel Power Plant

Engine lubrication system:

- It includes lubricating oil tank, oil pump and cooler.
- Lubrication is essential to reduce friction and wear of engine parts such as cylinder walls and piston.
- Lubricating oil which gets heated due to friction of moving parts is cooled before recirculation.
- The cooling water used in the engine is used for cooling the lubricant also.



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Engine lubrication: as there are a lot of moving parts, there will be friction. The friction has to be reduced. So lubrication has to happen. The lubrication, whatever you do, can happen by gravity or through a small force.

But it is good to have a lubricating pump so that the lubrication also moves back and forth in a pressurized manner. It includes a lubricating oil tank, an oil pump, and a cooler. And why a cooler? Because the lubrication, which tries to lubricate, operates at a working temperature of 1500 to 2000 degrees Celsius. So the lubrication also becomes very hot. So that has to be cooled.

Lubrication is essential to reduce the friction and wear of engine parts such as the cylinder wall and piston. The lubricating oil gets heated due to friction, and moving parts are cooled before recirculation. The cooling water used in the engine is also used for cooling the lubricant. So, you can see here, here is a fan which is almost like a radiator a fan is there. So, then you see the airflow which is happening.

So, here the lubricant is flowing. So, you see the lubricant from here, it flows, and then it moves through the cold air, and then it comes, and then it goes down, and then here it starts taking heat.

Diesel Power Plant

Advantages :

- Easy to set up: It has a simple design, so it can be installed and started quickly.
- Quick start: It starts fast and handles load changes easily.
- Can be built anywhere: It can be located close to where power is needed.
- Easy to operate: Needs fewer workers, and fuel handling is simple with no ash to remove.
- Good efficiency: Works well even at low loads and is more efficient than steam power plants.

Disadvantages :

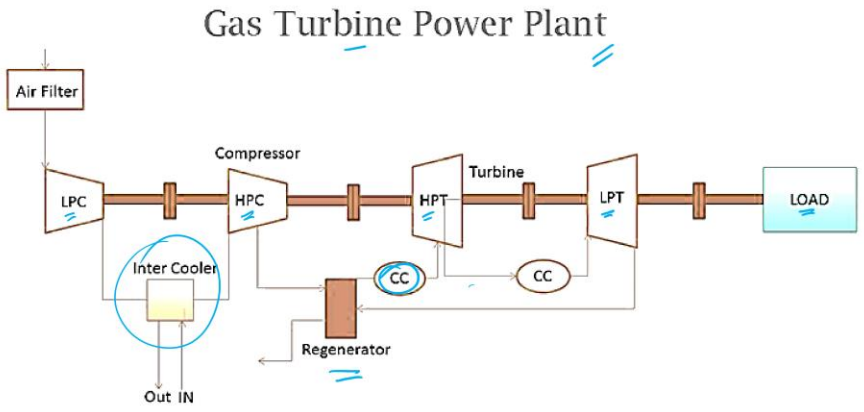
- Limited Power and Cost
- High Maintenance Needs

So, the advantage of a diesel pump is that it is easy to set up and quick to start. Thermal power plants, nuclear power plants, and hydro power plants, if switched off, take a long time to start. And hydro, if the water is drained, it cannot.

So, that is a big problem. So, the easiest to establish, quick to start, can be built anywhere, easy to operate, and very efficient is diesel. But the only thing is it cannot handle very heavy power. What is the disadvantage? The cost and the limited power.

The cost is because of diesel. If you want to run a diesel generator, it consumes huge amounts of diesel, right? So, that is expensive. Then, it is also because there are a lot of moving parts here and there, so maintenance is also regularly needed.

Gas Turbine Power Plant



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The next one is the Gas Turbine Power Plant. In a gas turbine power plant, we try to use gas. So here, the air is filtered and passed through an LPC, a low-pressure compressor, then it goes to a high-pressure compressor. Then it goes to a high-power turbine, then to a low-power turbine, and then you have a load, right? So here, the air filter tries to send air to the low-pressure compressor. It is compressed to a higher pressure, and then that, in turn, is pushed into a turbine. So, the work is done.

Then, once the work is done, there is a loss due to the reduction. So, that goes to the low-pressure turbine. There also, we operate, and the turbine rotates, so the load is taken. So, from here, what we do is we try to have this as a low compressor and a high compressor. So, this is intercooled by a cooler, a fluid.

Then we have this connect of CC which comes from the high pressure turbine and the low pressure turbine. They get connected and there is a CC. That is sent to the regenerator. These are gas turbines which are used in as I told you in planes.

Gas Turbine Power Plant

L.P Air Compressor:

- In an L.P. Air Compressor, atmospheric air is filtered and compressed in stages—first in a low-pressure compressor powered by the turbine (which uses about 66% of its power), and then further compressed in a high-pressure stage with an intercooler between them to reduce power consumption and improve efficiency.

Intercooler:

- An intercooler is used between compression stages to lower the air temperature, reducing the work required for compression and increasing overall efficiency, as compression energy is proportional to the inlet air temperature.

H.P. Compressor:

- In the H.P. Compressor, air from the intercooler is further compressed to a higher pressure and then sent to the regenerator for heat exchange.

The LP air compressor in a LP low pressure air compressor the atmospheric air is filtered and compressed in stages. First in low pressure compressor powered by a turbine and then further compressed by a high pressure stage with an intercooler between them to reduce the power consumption and the improved efficiency. Single stage compression is going to be very costly. Second thing, it is going to increase the temperature and pressure phenomenally high. So it has to be cooled. So that is why we try to send this low pressure compressed power by the turbine and then further compressed air in a high pressure stage with an intercooler between them to reduce the power consumption, Right? And then and improve the efficiency.

What is a intercooler? An intercooler is used between compressing stage to lower the air temperature, reduce the work required for compression and increase the overall efficiency as the compression energy is proportional to the inlet air temperature. So intercooler is in between two compressor, low pressure and high pressure, between the compression stage to lower the air temperature reduce the work required for compression and increase the overall efficiency. That is what is done by the intercooler. Reduce the air temperature. The HP in the high pressure compressor, the air from the intercooler is further compressed to a higher pressure and then sent to the regenerator as a heat exchanger for heat exchange.

Gas Turbine Power Plant

Regenerator:

- A regenerator is used to save energy by capturing heat from the hot turbine exhaust and using it to preheat the air going into the combustion chamber, which reduces fuel consumption.

Combustion Chamber:

- In the combustion chamber, hot air from the regenerator mixes with injected fuel and burns, producing high-pressure, high-temperature gases that are sent to the turbine for power generation.

Gas Turbines:

- In gas turbines, hot gases from combustion are expanded through high and low pressure turbines; some of the energy runs the compressor, while the rest (about 34%) is used to produce electricity.

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The regenerator is used to save energy by capturing heat from the hot turbine exhaust. And reduce it to preheat the air going into the combustion chamber which reduces the fuel consumption. So you see here, the combustion chamber. CC is nothing but the combustion chamber. The regenerator is used to save energy.

By capturing heat from the hot turbine—where is the hot turbine? There is a hot turbine, the high-pressure turbine. From the hot turbine exhaust, it preheats the air going into the combustion chamber, reducing fuel consumption. CC or combustion chamber: in the combustion chamber, the hot air from the regenerator mixes with the injected fuel and burns producing high pressure, high temperature gases, that is used to run the turbine blade. So now you can see here, from the low pressure, it is combustion chamber, it is sent to high pressure turbine.

Whatever comes out of the high-pressure turbine is sent to the regenerator. The regenerator removes the heat and sends it to the high-pressure compressor. It captures heat from the hot turbine exhaust and uses it to preheat the air going into the combustion chamber, reducing fuel consumption. So the CC, what it does is? Produces high temperature, high pressure gas, that is sent to the turbine for the power generation. The gas turbine: hot gas from combustion is expanded through high- and low-pressure turbines. Some of the energy runs the compressor, while the rest—about 34%—is used to produce electricity. This is what a gas turbine plant looks like.

Gas Turbine Power Plant

Advantages of Gas turbine power plant

- Compact and Lightweight: Gas turbine plants are smaller and lighter than steam power plants of the same capacity.
- Quick Start-Up: They can start quickly and reach full load in a short time.
- Lower Initial Cost: The initial setup cost is lower compared to equivalent steam plants.

Disadvantage Gas turbine power plant

- Low Net Output: A large portion of the turbine's power (about 66%) is used to run the compressor, reducing the net output.
- High Material Requirements: It needs special high-temperature metals due to very high operating temperatures and speeds.

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What are the advantages? It is compact and lightweight, slightly bigger than a diesel engine. Gas turbine plants are smaller and lighter than steam power plants of the same capacity.

Quick start is possible. They can start quickly and reach full load very fast. Lower initial cost compared to a thermal power plant. What are the disadvantages? Low net output.

A large portion of the turbine power is used to run the compressor, reducing the net output. So where are the compressors? The compressors are the low-pressure compressor and high-pressure compressor. They take 66% of the energy. High-quality materials are required; it needs special high-temperature metals due to very high operating temperatures and speeds.

Nuclear Vs Steam Power Plant

The cost of electricity generation is nearly equal in both these power plants.

The other advantages and disadvantages are as follows:

(i) The number of workman required for the operation of nuclear power plant is much less than a steam power plant. This reduces the cost of operation.

(ii) The capital cost of nuclear power plant falls sharply if the size of plant is increased. The capital cost as structural materials, piping, storage mechanism etc. much less in nuclear power plant than similar expenditure of steam power plant. However, the expenditure of nuclear reactor and building complex is much higher.

(iii) The cost of power generation by nuclear power plant becomes competitive with cost of steam power plant above the unit size of about 500 MW.

Now, we will try to see the comparison between nuclear and steam power plants. The cost of electricity generation is nearly equal in both plants. The advantages and disadvantages are as follows. The number of workers required to operate a nuclear power plant is much lower than that of a steam power plant. The capital cost for a nuclear power plant falls sharply if the size of the plant increases.

This is because the major cost goes into structural materials, piping, storage, etc. The cost of power generation by a nuclear power plant becomes competitive with that of a steam power plant above a unit size of 500 megawatts. So, if you try to put the size with respect to cost or if you put size with respect to cost, maybe it will go like this. So, this also will come like this something like that, right?

Boilers

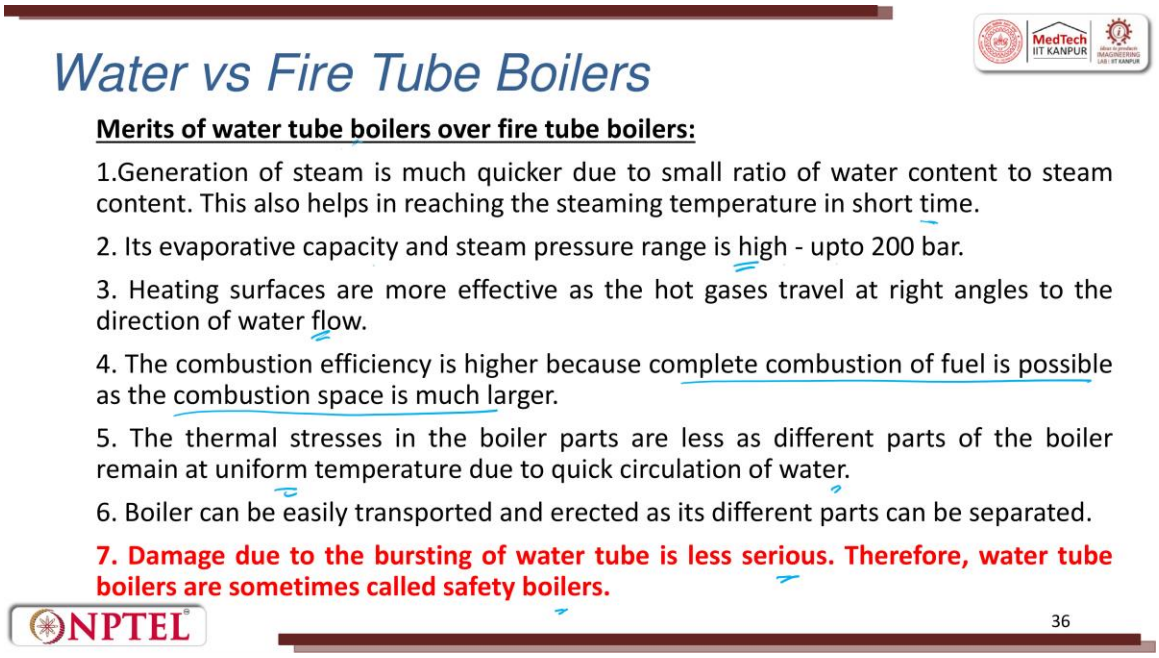
The Thermal or Steam power plants work on principle of steam generation, which is done in boilers, classified according to flow of water and hot gases as:

1. Water tube.
2. Fire tube.

- In water tube boilers, water circulates through the tubes and hot products of combustion flow over these tubes.
- In fire tube boiler the hot products of combustion pass through the tubes, which are surrounded, by water.
- Fire tube boilers have low initial cost, and are more compacts. But they are more likely to explosion, water volume is large and due to poor circulation they cannot meet quickly the change in steam demand.
- For the same output the outer shell of fire tube boilers is much larger than the shell of water-tube boiler.

Boilers: we have seen there are two types of boilers. One is called as water tube boiler, the other one is called as fire tube boiler. The water tube boiler: the water is circulated through the tube and the hot products of combustion flow over these tubes. In a fire-tube boiler, the hot products of combustion pass through the tubes, which are surrounded by water. So the fire tube boilers have low initial costs and are more compact, fire tube boiler, where you use gas to flow through. But they are more likely to explode. Water volume is larger and due to poor circulation, they cannot meet quickly the change in steam demands.

That's the problem with the fire. Initial cost is low, but it can explode. For the same output, the outer shell of the fire tube boiler is much larger than the shell of the water tube boiler.



Water versus Fire Tube Boiler. The merit of water tube boilers over the fire tube boilers, the generation of steam is much quicker due to the small ratio of water content to steam.

This will help in reaching the steaming temperature in short time. So this is water temperature. Its evaporative capacity and steam pressure range is higher. The heating surface are more efficient as the hot gases travel at right angle to the direction of water flow. The combustion efficiency is higher because the complete combustion of fuel is possible as the combustion space is much larger.

Water Watt The thermal stresses in the boiler parts are less as different parts of the boiler remain uniform temperature due to quick water circulation that is for the water tube boiler. Finally, the damage due to busting of water tube is less serious. Therefore, water tube boilers are safer than fire tube boilers. So, the evaporative capacity and the steam pressure range are high, up to 200 bar.

Water vs Fire Tube Boilers

Demerits of water tube boilers over fire tube boilers:

1. It is less suitable for impure and sedimentary water, as a small deposit of scale may cause the overheating and bursting of tube. Therefore, use of pure feed water is essential.
2. They require careful attention.

The maintenance costs are higher.

3. Failure in feed water supply even for short period is liable to make the boiler over-heated.

As for the demerits, it is less suitable for impure and sedimentary water. They require careful attention. The maintenance costs are higher. Failure in the feed water boiler, even for a short period, is liable to make the boiler overheat.

Requirements of a Good Boiler

1. The boiler should be capable to generate steam at the required pressure and quantity as quickly as possible with minimum fuel consumption.
2. The initial cost, installation cost and the maintenance cost should be as low as possible.
3. The boiler should be light in weight, and should occupy small floor area.
4. The boiler must be able to meet the fluctuating demands without pressure fluctuations.
5. All the parts of the boiler should be easily approachable for cleaning and inspection.
6. The boiler should have a minimum of joints to avoid leaks which may occur due to expansion and contraction.
7. The boiler should be erected at site within a reasonable time and with minimum labour.

What are the requirements for a good boiler? Because everything revolves around a boiler here. The boiler should have the capacity to generate heat at the required pressure and quantity as quickly as possible. This is very important. The initial cost should be low. Installation cost should be low.

The boiler should be lightweight and occupy less floor space. The boiler should be able to meet fluctuating demand without pressure fluctuation. When the water content increases or decreases, fluctuating demand should not cause power fluctuation. All parts of the boiler should be easily accessible and repairable. The boiler should have minimal joints to avoid leaks. The boiler should be erected on-site within a reasonable time. So the installation cost is very low. The installation time should also be very low for a boiler.

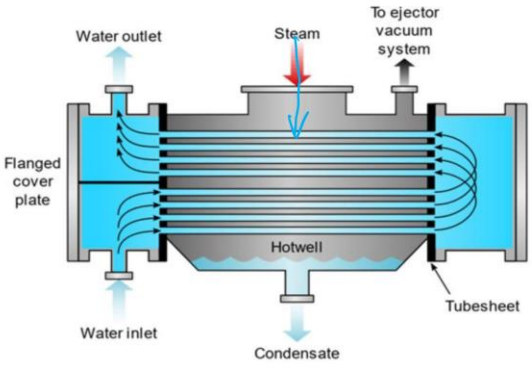
Steam Condensors

A steam condenser is a heat exchanger that converts low-pressure exhaust steam from a turbine back into liquid form by removing heat. This process is crucial for maintaining efficient turbine operation and recovering water for reuse.

Types of Condensers:

Jet Condensers (Mixing Type): In jet condensers, the cooling water directly mixes with the steam.

Surface Condensers (Non-Mixing Type): Surface condensers keep the cooling water and steam separate, with heat transfer occurring through tubes.



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Steam Condensors

Working Principle:

- The steam enters the condenser and comes into contact with tubes carrying cold cooling water.
- As heat transfers from the steam to the cooling water, the steam condenses into liquid water (condensate). This condensate is collected and pumped back to the boiler for reuse.
- Meanwhile, an air extraction pump creates a vacuum inside the condenser, lowering the pressure below atmospheric levels, which helps improve turbine efficiency by increasing the pressure drop across the turbine and facilitates easy circulation of cooling water and condensate flow.
- The vacuum also removes non-condensable gases that might reduce heat transfer efficiency.

Steam Condenser: a steam condenser is a heat exchanger that converts low pressure exhaust steam from a turbine back into liquid form by removing heat. So, a condenser, if there is a phase change happening, is a heat exchanger that converts low-pressure exhaust steam from the turbine back

into liquid form by removing heat. This process is crucial for maintaining the efficiency of turbine operation. This is very important. There are two types of condensers. One is called a jet condenser.

The other one is called a surface condenser. Jet condensers are also called mixing type. In a jet condenser, the cooling water directly mixes with the steam. The steam comes from here. The cooling water directly mixes into the steam.

In a surface condenser, the surface condenser keeps the cooling water and steam separate, with heat transfer occurring through tubes. So there are two types of condensers: jet, where water and steam are mixed, and surface, where they remain separate. The next one is surface, where you have two independent systems, and heat transfer occurs to cool the steam. The principle is that the steam enters the condenser and comes in contact with tubes carrying cold water. As heat transfers from the steam to the cold water, the steam condenses into liquid water. The condensate is collected and pumped back into the boiler for reuse. Meanwhile, the air extraction pump creates a vacuum inside the condenser.

This lowers the pressure below atmospheric level, which helps improve turbine efficiency by increasing the pressure drop across the turbine and facilitating easy circulation of cooling water and condensate flow. So this point is very important. This is how a steam condenser works.

Steam Condensors

Advantages and Disadvantages of a Surface Condenser

The various **advantages** of a surface condenser are as follows:

1. The condensate can be used as boiler feed water.
2. Cooling water of even poor quality can be used because the cooling water does not come in direct contact with steam.
3. High vacuum (about 73.5 cm of Hg) can be obtained in the surface condenser. This increases the thermal efficiency of the plant.

The various **disadvantages** of the surface condensers are as follows:

1. The capital cost is more.
2. The maintenance cost and running cost of this condenser is high.
3. It is bulky and requires more space.

The advantages of a Surface Condenser, or steam surface, are very important. What are the advantages and disadvantages of a surface condenser? The condenser can be used as boiler feed water. Cooling water of even poor quality can be used. A high vacuum can be obtained in the surface condenser, which increases thermal efficiency. Disadvantages: it is costly, requires maintenance, and is bulky.

To Recapitulate

- What do Power Plants do?
- Name and define various types of Power Plants.
- What are different components of a Thermal Power Plant?
- What is working principle of a DG set? What are its Pros and Cons?
- State working of Gas Turbine Power plant alongwith its components.
- What type of boilers are used for steam generation?
- State requirements of a good boiler.
- What is working principle of a Nuclear Power Plant?

To recap what we have seen in this lecture, we have seen what a power plant is, the different types of power plants, and the different components of a thermal power plant, such as DG and gas turbine. We have also seen what types of boilers are used for steam generation, then the requirements of a good boiler, and finally, we saw the working principle of a nuclear power plant.

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These are the references used, and thank you very much.