

# Basics of Mechanical Engineering-3

Prof. J. Ramkumar

Prof. Amandeep Singh Oberoi

Department of Mechanical Engineering

Indian Institute of Technology, Kanpur

Week 06

## Lecture 25: Basics of Power Plants (Part 1 of 2)

Welcome to the lecture on power plants.

---

### Contents

- Thermal Power Plants
- Boilers - Water tube, Fire tube
- Requirements of a good boiler →
- Nuclear Power Plants
- Diesel Power Plants
- Gas Turbine Power Plants
- Boilers comparison: Water tube, Fire tub
- Steam Condensers



In this lecture, we will try to see the application part of what we have studied in thermodynamics. As you all know, friends, there are only two things. One is either you generate heat, or you use the heat to generate work. So these are the two things.

So evaporation becomes important. Condensation is the counterpart of it. So by using these phenomena and pressure-temperature, we are trying to convert thermodynamic laws into technology-based applications.

---

## Power Plant and Boilers



- Power plants are large-scale industrial facilities that convert primary energy sources such as **coal, oil, natural gas, nuclear energy, water flow, solar radiation or wind** into usable electrical energy.
- These plants play a crucial role in powering modern society by supplying electricity to residential, commercial, and industrial sectors through a national or regional power grid.
- Among the different types of power plants, **thermal power plants are the most widely used, especially in countries having abundant fossil fuel reserves.**



<https://studentenergy.org/conversion/power-plant/>

3

---

We will first go through power plants where the understanding of thermodynamics plays a very important role. So thermal, diesel, nuclear, and gas turbine. All four power plants we will try to have a superficial idea of. A thermal power plant starts with coal and generates electricity at the end. Diesel starts with diesel and generates. All your DG sets, diesel generators, are based on it. Then nuclear, where you use nuclear fusion concepts to generate energy and proceed.

Gas turbines replace coal with gas and then start generating electricity. So it can be a small system. It can be a large system. Gas turbines can be as small as those used in airplanes, small jet planes, or glider planes. Diesel works in the same way.

So today you can use diesel. It's not a power plant. It's a small engine that can be used in drones. These are very important applications where you see thermodynamics. Next is nuclear versus steam power plants.

What is the advantage? Why are people going for nuclear compared to steam? These are some fundamental concepts we will explore. Then we will examine different types of boilers, including water tube boilers and fire tube boilers. Boilers are basically used to increase temperature and convert the phase from liquid to gas.

Then, the requirements of a good boiler. We will try to see milling, pulverizing, ball, ball and race, and shaft milling. Why? Because when you are trying to use coal, you have to use the best of it. So what we do is, we have a larger coal piece.

We try to crush it into smaller pieces. So you have smaller coal particles. These coal particles, when you try to burn them, the complete area is burned, and it releases energy. So it is much more efficient. So people always try to convert the solid into pulverized particles.

Then we will try to see steam condenser, then ethical problems, nuclear power plant, then IC engine four-stroke and two-stroke, electric vehicles, hybrid vehicles, and finally IC versus electric versus hybrid vehicle. We will try to see in the next two lectures. Power Plant and Boilers. The moment we say a power plant, there is an integral component called a boiler in it. It is a complete system of its own.

Power plants are large-scale industrial facilities that convert primary sources of energy such as coal, oil, natural gas, nuclear energy, water flow, solar radiation, or wind into usable electric energy. These plants play a crucial role in powering modern society by supplying electricity to residential, commercial, and industrial areas through national or regional power grids. Among the different types of power plants, thermal power plants are the most widely used, especially in countries having abundant fossil fuel reserves. India also has more thermal power plants in number. So this is how a typical power plant looks. So you see there is a cooling tower.

---

## Power Plant and Boilers



- **Thermal power plants** typically operate on the Rankine cycle, a thermodynamic cycle in which water is heated to generate steam, which then expands through turbines to produce mechanical energy, subsequently converted into electricity via a generator.
- **So, they can also be termed as Steam Power Plant.**
- At the heart of thermal power plants lies the boiler, a closed, pressurized vessel that heats water using combustion of fuels such as coal, oil, or gas.
- Boilers are responsible for generating high-pressure, high-temperature steam necessary to drive the turbine.
- **Based on design and function, boilers can be broadly classified into fire-tube and water-tube type boilers.**

The thermal power plant typically operates on a Rankine cycle. Do you remember the Rankine cycle? PV diagram, TS diagram—we saw this and then we saw something like this. You remember this TS diagram, right?

This is liquid, this is liquid plus vapor, and this is vapor. This is a critical point. So it operates on the Rankine cycle, a thermodynamic cycle in which water is heated to generate steam. Follow this: the steam then expands through a turbine to produce mechanical energy. It is subsequently converted into electrical energy via a generator.

So water, heating, steam, steam passing through a turbine, turbine rotates, it will be one shaft, several turbine blades attached. When liquid gets converted into steam, there is a temperature increase, there is also a pressure increase. This pressure dies down when it tries to do its work, heating the turbine, it rotates. The temperature falls down, the pressure also falls down, and then we try to collect the output from the turbine blade through a shaft. This shaft is attached to a generator, and electricity is produced. Whatever is left out, the pressure is reduced, and the temperature will not be room temperature; it will be slightly higher than room temperature. We put a condenser or we again put a generator there, a heater there.

And then we try to take an output, produce the next, the second stage output and finally we try to condense it. So this is what is told in this section. So they can also be termed as steam power plants. Thermal power plants can also be termed as steam power plants. At the heart of a thermal power plant lies the boiler, where there is a phase change.

A closed—see, you can always have an open-loop power plant, but an open-loop power plant means the water gets wasted. So it is always good to have a closed one so that you recycle the same water. While recycling, also, every time one cycle is done, you will lose 3 to 4% of the water. But still, they call it a closed loop, and it is okay. The pressurized vessel that heats the water uses combustion of fuel such as coal, gas, or oil.

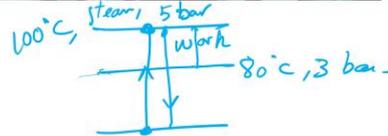
Wherever there is natural gas coming out, they directly attach this natural gas output to a boiler, or you can use oil or coal. When the power plant is very small inside a factory, they try to use oil. The boilers are responsible for generating high-pressure, high-temperature steam necessary to drive the turbine. The turbine is a huge, massive mass. It's like a blade, but a huge, massive mass.

If you have to rotate it, you should heat it with so much power. That is achieved by pressure and temperature. You cannot increase only temperature without pressure. So it is pressure and temperature. When that hits, it tries to rotate.

And the blade will also be at a tangent. So when it hits, it hits tangentially, so this rotates. So when one blade rotates, the second blade comes, and again the steam will be hitting there. This will try to generate a rotational motion. Based on design and function, boilers are classified as fire-tube boilers and water-tube boilers.

## Power Plant and Boilers

- Fire-tube boilers have hot gases flowing through tubes surrounded by water, suitable for low to medium pressure applications.
- Water-tube boilers have water flowing inside tubes with hot gases outside and are ideal for high-pressure, high-capacity operations, commonly used in large thermal power stations.
- Modern power plant boilers include additional components like economizers, superheaters, and air preheaters to enhance thermal efficiency and reduce fuel consumption.



The fire tube boilers have hot gas flowing through the tubes. In a fire tube boiler, the hot gas (working fluid) flows through tubes surrounded by water. They are suitable for low to medium pressure applications. So, you will have a tube. Inside the tube, there will be gas flowing.

This gas will be hot. Outside, you will have water. So, if you go back and see, we studied in the previous lectures—crisscrossing, coaxial flowing—all these things apply here. The water tube boiler has water flowing inside the tube. That is a big difference.

Fire tube is gas. In water tube, it is water. With hot gas outside, they are ideal for high pressure. This is for low pressure. This is for high pressure.

These are boilers. High-capacity operation commonly used for large thermal power stations. Modern power plant boilers include additional components like economizers, superheaters, and air preheaters to enhance thermal efficiency and reduce fuel consumption. What does it mean? After the work is done on a turbine blade, there will be a pressure reduction and temperature reduction.

Now, what we do is, for example, these are two levels. From here, you try to increase it to a higher level. For example, this is 100 degrees Celsius, and it is all steam. Maybe assume the pressure is 5 bar, just for discussion's sake. So now it is high there. When it does work in a turbine, it will try to do the work here and fall to maybe 80 degrees Celsius, and maybe it can be 4 bar or 3 bar. Normally, what happens? It increases from here. And then it falls from here to here.

Now, what we are trying to say is, As soon as it reaches an in-between value, Now we will tap out this. And again try to pump in a little bit of energy such that it can go high. And start moving the turbine blade.

So that is why we are trying to talk about the economizer, superheater, air preheater, and all those things. It is only to make sure that the energy efficiency of the power plant increases.

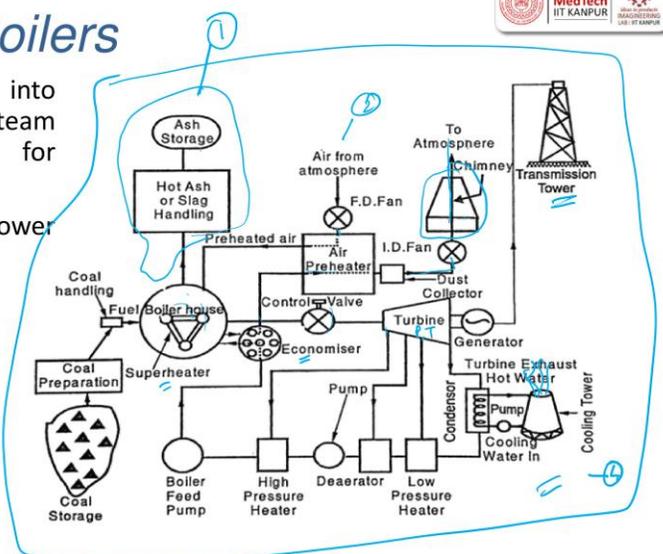
## Power Plant and Boilers

- Heat energy is converted into mechanical energy in the steam turbine, which is used for generating electric power.

- The layout of the steam power plant is shown in figure.

It consists of four main circuits:

- Coal and ash circuit
- Air and flue gas circuit
- Water and steam circuit and
- Cooling water circuit



The heat energy is converted. This is how a typical power plant looks. So you will see the coal is stored. Then the coal is prepared. So preparation can be pulverization or it can be sorting. Then the coal is pushed into here. The coal is fired here. Then the fired hot gas is pushed into a boiler. So in a boiler, there is always a phase change happening. Whenever there is boiling happening, there is also residue there. So hot ash or slag is produced here. So that will be removed by this process.

This is removed. This is a subsystem because when combustion happens, you have smoke coming out like this. You will have fly ash coming up. This fly ash will be accumulated and kept here. So here inside the boiler, you are trying to superheat the boiler.

Superheat means you are trying to spend more energy, converting steam, liquid vapor into pure vapor. So it is done there. So here, what we do is, in order to get this pure heat, we also try to preheat the air and send it to it. So what happens? Already, air with some temperature plus fresh air gets mixed.

So then the process efficiency improves. So you can see here, air is taken from the atmosphere. There is preheated air. This preheater can be tapped out from here. From the boiler, whatever remains after the turbine is done can be tapped out.

You preheat it and then send it back here. Okay. Now the boiler is produced. Then it is sent to a control valve. This control valve, in turn, hits against a turbine.

So this turbine rotates. This shaft rotates. The generator takes this and sends power to the transmission station. Right. After the turbine, there is a fall in the pressure and temperature of the gas.

So it falls down. So you have a low-pressure heater there. Then a deaerator is there. Then it is pumped to high pressure. It is sent back to the turbine.

So the temperature is there, and the air is removed. So you try to take it to high pressure and then heat it here. Then whatever comes here, the rest is left after you use it here. Then you can also tap it from here and bring it to the high-pressure heater. Then from here, it gets into a boiler feeder. So in the boiler feeder pump, the temperature is further reduced, and again it is pumped in.

So here you have an economizer. So this economizer, what it does is it tries to take the water, and then wherever there is a delta T in the water, it also gets mixed. So that this is

pushed into the control valve. So here, the water that is already there is at a higher temperature. So with less energy, it can gain high pressure and temperature.

So this is how a complete system works. So then you will also have a chimney there. So the chimney uses the fan. So you can see here a dust collector. So the chimney uses the ID fans that are there.

So then you have the two atmospheres. The air is sent through the ID fan into the atmosphere. So, this is passed through the chimney again. In the chimney, we try to trap many other unwanted elements from getting into the atmosphere. So, this is the complete cycle. So, if you see, this chimney is one, and you also see a cooling tower.

So, what happens when the temperatures are very high? It passes through the condenser, steam to liquid. So, here it is cooled because you extract heat. When you extract heat, you should also understand that. The extracted heat cannot be stored, so it has to be dissipated. So, there will be a condenser, then it will pass through a cooling tower. So, through this cooling tower, the hot air will go out, and the rest of the air, cooled, gets into the system.

So, then from cool air, it goes to low pressure, deaerator pump, high pressure, then into the turbine. So, the heat energy is converted into mechanical in the steam power plant, which is used for generating power. The layout of the steam power plant is shown here. You have four main circuits. The first circuit is the coal ash circuit, which we saw. This is circuit one.

Then you have the air flue gas circuit. So this is the second circuit. Then you have the water steam circuit, the central one. Then we have the cooling water circuit. There are four circuits.

Four circuits, each of them is an independent system by itself. They are very massive, and there are a lot of mechanical engineering parts involved here. Ultimately, there is only the working fluid: water. This water gets converted into steam. The steam can be dry.

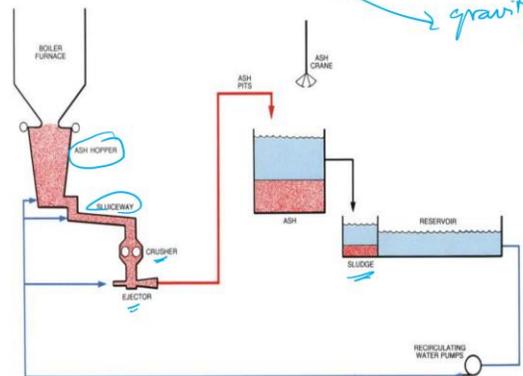
The steam can be mixed with water. When you have dry steam, the efficiency is very high. To generate it, you need to use heat. So, how does this heat come? By burning coal.

And I try to take the last bit of essence that is there in the steam or in the water with respect to temperature and pressure. So I try to have a cooling system. This is a closed-loop system. This is how a typical power plant works.

# Power Plant and Boilers

## 1 Coal and Ash Circuit

- Coal from the storage yard is transferred to the boiler furnace by means of coal handling equipment like belt conveyor, bucket elevator, etc.
- Ash resulting from the combustion of coal in the boiler furnace, is collected at the back of boiler and is removed to ash storage yard through the ash handling equipment.



So coal and ash circuit to look into it. The coal from the storage yard is transferred to the boiler by means of coal handling equipment, belt conveyors, bucket elevators, etc. So sometimes you will see the coal will be stored at a very far-off distance, and the power plant will be here. So in between this and this, they used to have belt conveyors. In these belt conveyors, it always uses gravity. So this gravity, what they do is from up to down it moves.

While moving, all the dust particles are removed. Then while running through a distance of maybe a kilometer or kilometer and a half, they can go straight line or they can go in serpentine. The unwanted coal ore, whatever is there, the stone and other things are also removed. And then finally, it is taken to a very weighted height. From there, it is poured.

So then, what happens? All the dust also goes away. So finally, what you have is, to a large extent, only coal. The ash resulting from the combustion. So what you do is you try to take the coal.

So this is the ash hopper. So then, you have a sluiceway. Then you have a crusher, a crusher to an ejector. Then it goes into an ash pit. Right.

So, from the ash pit, it goes to the ash, and then it goes into the reservoir. Sludge is also there. Sloughs and this is sludge. Slough way. This is slough way.

Ash resulting from the combustion of coal in the boiler furnace is collected. So when it burns, the coal is converted into ash. It's not 100%. The ash consists of small, lightweight particles. So that ash is collected in the boiler furnace, gathered at the back of the boiler, and removed to the ash storage yard through the ash handling equipment.

Today, this ash finds many applications in the construction industry. When building blocks are made, this ash is used, and now it is also mixed with bitumen and added to roads. So now the fly ash that comes out is being put to practical use.

---

## Power Plant and Boilers



### 2 Air and Flue Gas Circuit

- Air is taken from the atmosphere to the air preheater, whose function is to raise the air temperature by heat of flue gases passing to the chimney. The preheated air is supplied to the furnace of the boiler.
- The flue gases after combustion in the furnace, pass around the boiler tubes. They then pass through a dust collector, economizer and pre-heater before being exhausted to the atmosphere through the chimney.
- This way, the heat of the flue gases which would have been wasted otherwise is used effectively. Thus the overall efficiency of the plant is improved.



In the air and flue gas circuit, air is taken from the atmosphere to a preheater. It is heated, and its function is to raise the air temperature by heating the flue gases passing through to the chimney.

The preheated air is supplied to the furnace of the boiler because, at a higher temperature, it is easier for it to boil. The flue gases, after combustion in the furnace, pass through the boiler tubes, then through the dust collector, economizer, and preheater before being exhausted into the atmosphere through the chimney. So, you can see here the exhaust goes to the chimney; the last step is through the chimney. So, you can see the preheat. So, from the FD forced air, it comes here, preheats, then it goes into the control valve, right, then it enters the economizer.

So, the other way around, it also goes vice versa. This way, the heat of the flue gas—flue gas or burnt gas—which would have been wasted otherwise, is now used efficiently. Thus, the overall efficiency of the power plant is improved by preheating.

---

## Power Plant and Boilers



### 3 Feed Water and Steam Circuit

- **Steam Flow:** Steam from the boiler goes through the superheater to the turbine, where it does work, and then moves to the condenser to turn back into water.
- **Water Heating and Circulation:** The condensed water is heated using steam from the turbine (in LP and HP heaters), then further warmed in the economizer by flue gases before going back to the boiler.

### 4 Cooling Water Circuit

- **Water for Condensing:** A large amount of water is needed to cool and condense steam in the condenser, usually taken from a river or lake.
- **Reuse of Water:** If enough water isn't available, the hot water is cooled in cooling towers or ponds and reused in the system.



Feed water and steam circuit. Steam flows from the boiler through the superheater to the turbine, where it does work, and then moves to the condenser to turn back into water. Water heating and circulation. The condensed water is heated using steam from the turbine in LP and HP heaters—low-pressure and high-pressure heaters. So, the water is there. It is now heated using steam from the turbine. Then, it is further warmed in the economizer by flue gas before it enters the boiler.

Normally, in the boiler, we used to pour a room temperature one. So now, what has happened? You are trying to increase the temperature by passing through this economizer, preheater, and everything. And then you try to push it into the boiler. So now it is already in a hot condition.

It is not in steam, but in a somewhat higher condition, 50 to 60 degrees Celsius. So now the efficiency becomes better. Cooling water circuit: the water for condensing—a large amount of water is needed to cool and condense the steam in the condenser. Usually, it is taken from a river or a lake. That is why major power plants are constructed close to a

river. So the cooling tower water is taken from there. Reuse of water. If enough water isn't there, the hot water is cooled in a cooling tower or pond and reused in the system.

---

## Power Plant and Boilers

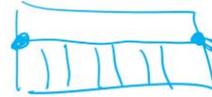
### Components of a Hydro-Electric Power Plant

#### 1 Water Reservoir:

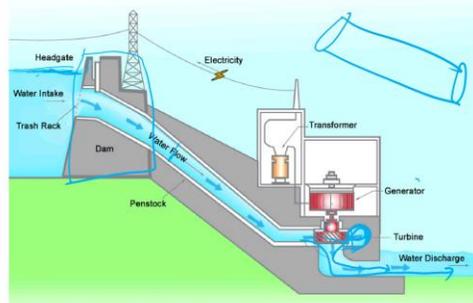
- For continuous availability of water being the basic necessity for a hydro-electric plant, water collected from catchment area during rainy season is stored in a reservoir.

#### 2 Spillway:

- Water in the dam after a certain level in the reservoir overflows through spillway without allowing the increase in water level in the reservoir during rainy season.



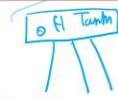
### Hydroelectric Power System



The other one is the hydroelectric power plant system. Here, the water is moved from a certain height, and the water with very high pressure comes and hits a turbine. This turbine rotates, as it is attached to a generator, and there it produces electricity.

This is another kind of power plant. This is called a hydroelectric power plant. A continuous availability of water, being the basic necessity of the hydroelectric plant, is collected from the catchment area during the rainy season and stored in a reservoir. So then it is allowed to pass through a penstock, right?

# Power Plant and Boilers



### 3 Dam:

- The function of a dam is to store and maintain water level, which ultimately increases the reservoir capacity.
- The dam also helps to increase the working head of the power plant.

### 4 Pressure Tunnel:

- It carries water from reservoir to surge tank.

### 5 Penstock:

- Water from surge tank is taken to the turbine by means of pen stocks, made up of reinforced concrete pipe or steel.



The water in the dam, after reaching a certain level in the reservoir, overflows through a spillway without allowing the water level in the reservoir to increase during the rainy season.

Spillway: spillway means many a times you can see here this is the way the water flows but here they will used to have some small something like a small hole. So the excess water will be drained through it so that the tank level or the reservoir level is maintained. So that is done by the spillway. So when you try to store, the head is high. When the head is high, the pressure is high.

So you can see here the head gate. Then the water intake track rack. So this is the track rack. So it goes. This is completely a dam.

This is a dam. So there is water which flows through a penstock, which goes and hits a turbine blade. So now this turbine rotates. And after doing the job, it tries to enter. It tries to go in two or three ways.

One, it tries to come through this, and the water gets discharged. The other way is the water goes because it splashes, right? It tries to hit the wall, then it comes down and goes away. So this is a turbine, and here if you make it flat, it will create back pressure. So they make a small channel through which the water gets hit, circulates, and goes down.

So, dams: you see this is a dam, which we have. And you will have small spillways from here at that a certain height or from this itself side you can have something flowing. The function of a dam is to store and maintain water level because this water level will give you head, and this head will give you pressure in turn. So, if you see in many cities, you will have overhead tanks. These tanks will be constructed at very high elevated locations or they will support and construct right overhead tank, maybe 30 meters high, 40 meters high, 25 meters high. You go higher and higher and higher, more is the head, then the water here can move to the entire town or entire village without any motor. That's why you create this.

So the function of a dam is to store and create that head and maintain the water level, which ultimately increases the reservoir capacity. If you increase this water level more and more, then what will happen? You will have a pressure head that is larger and larger. The dam also helps to increase the working head of the power plant. The pressure tunnel carries water from the reservoir to the sludge tank.

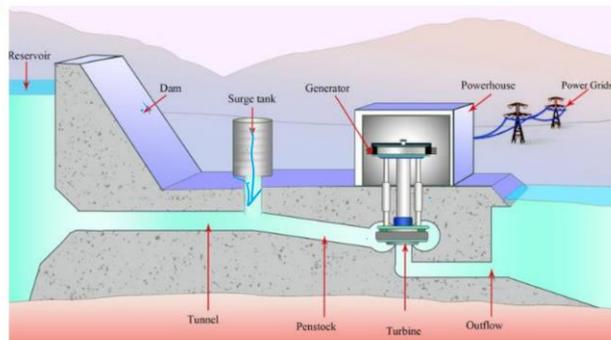
Penstock: the water from the sludge tank is taken to the turbine by means of a penstock made up of reinforced concrete pipe or steel. So, what they are trying to talk about is this. There can be a pipe or there can be a duct which is concrete-built.

## Power Plant and Boilers



### 6 Surge Tank:

- There is sudden increase of pressure in the penstock due to sudden backflow of water, as load on the turbine is reduced.
- **The sudden rise of pressure in the penstock is known as Water Hammer.**
- The surge tank is introduced between the dam and powerhouse for reducing the sudden rise of pressure in penstock.
- Otherwise penstock will be damaged by water hammer.



The surge tank: there is a sudden increase in the pressure in the penstock due to the sudden backflow of water as the load on the turbine is reduced. So, when there is a flow, there is a sudden increase in the pressure in the penstock.

Right. Due to sudden backflow. So, there is a backflow which happens in the penstock of the water as the load on the turbine is reduced. Right. So, the sudden increase of pressure in the penstock is known as water hammering.

So, we will try to avoid as much water hammering as possible. So, what we do in the surge tank is the water comes to the tunnel, water comes to the penstock, and when it is not having much water or when there is nothing, there is water which is released from here. The surge tank is introduced between the dam and the powerhouse to reduce the sudden rise in pressure in the penstock. So the such tank is either has a tank, it can pump in water, or this can ease out some water from here the water can go. Otherwise, the penstock will be damaged by water hammer.

This is the turbine blade I have been talking to you about for so long. You can see these are the blades, or here it is a bucket. These are angled in such a way that the water hits tangentially and starts rotating.

---

## Power Plant and Boilers



### 7 Water turbine:

- Water from the penstock flows into the turbine (like Pelton, Francis or Kaplan), where its potential energy is converted into mechanical energy to drive a generator, and the water is then released through a draft tube.

### 8 Draft tube:

- It is connected to the outlet of the turbine. It allows the turbine to be placed over tail race level

### 9 Tail race:

- Tail race is a water way to lead the water discharged from the turbine to the river.
- The water held in the tail race is called tail race water level.



The water turbine: water from the penstock flows into the turbine, where its potential energy is converted into mechanical energy to drive the generator, and the water is then released through the draft tube. The draft tube is connected to the outlet of the turbine.

It allows the turbine to be placed above the tailrace level. The tailrace is a waterway to lead the discharged water from the turbine to the river. The water held in the tailrace is called the tailrace water level. Okay. So if you go back, this level is also very important.

So that is what I said. So, the turbine, and then you have an outflow happening. So you will have this tailrace. Okay. The draft tube and tailrace will be there.

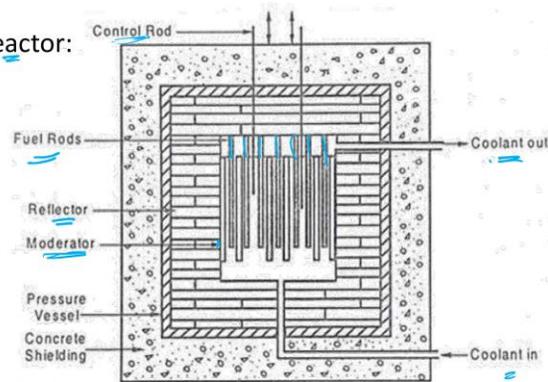
## Power Plant and Boilers



**A nuclear reactor** is an apparatus in which heat is produced by nuclear fission chain reaction.

The figure shows the various parts of reactor:

1. Nuclear Fuel
2. Moderator
3. Control Rods
4. Reflector
5. Reactors Vessel
6. Biological Shielding
7. Coolant.



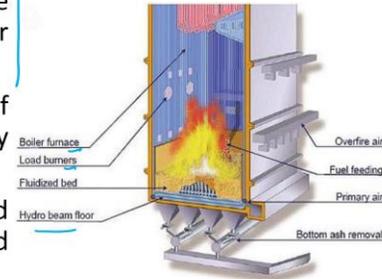
So now let us get into the nuclear power plant. Till now, what we saw was thermal steam, and then we moved into water. So in water, the pressures are high, but there is not much temperature. Now let us get into nuclear reactors. Nuclear reactors is an apparatus in which the heat is produced by nuclear fission chains. So here, the figure shows various parts of a nuclear reactor.

# Power Plant and Boilers



## Nuclear Fuel

- A nuclear reactor fuel should be fissionable material, defined as an element or isotope whose nuclei can be caused to undergo nuclear fission by nuclear bombardment and to produce a fission chain reaction.
- U235 is most unstable element and is capable of sustaining chain reaction, so generally used as primary fuel.
- U233 and Pu239 elements are artificially produced from Th232 and U238 respectively and are called secondary fuels.



So you have nuclear fuel. Then you have moderators. Moderators are here. These are moderators. Then you have control rods. These are control rods. These are control rods, right? 2, 1 which goes. Then you have a reflector.

These are reflectors. Then you have a reactor vessel where you will see the boiler and other components. Then there is biological shielding, and finally, you will have a coolant out and coolant in because the temperatures will rise very high. So, where are the fuel rods? These are the nuclear fuel or fuel rods.

You see rods which are there: 1, 2, 3, 4, 5, 6, 7. These are all the fuel rods. So, these are all the various parts of a nuclear reactor. So, nuclear fuel. Nuclear reactor fuel should be fissionable material, defined as an element or isotope whose nuclei can undergo nuclear fission through nuclear bombardment and produce a fission chain reaction.

So here, this is very important: fissionable material, fusion, fission, right? And then, whose nuclei can undergo nuclear fission through nuclear bombardment and produce a fission chain reaction. Because the reaction is a chain, you would need a moderator to control it. Uranium-235 is the most unstable element and is capable of sustaining a chain reaction. So, it is generally used as the primary fuel. So, U-235 is an unstable element.

U-233 and Pu-239 are elements artificially produced from thorium-232 and uranium-238, respectively, and are called secondary fuels. First is 235 primary material and the second

one is  $^{233}\text{Pu}$  and  $^{239}\text{Pu}$ , Right? They are produced artificially from thorium. Thorium and uranium-238 are called secondary fuels; primary fuel, secondary fuel. And the availability of this material is very rare. But if you have a small mass, it can continuously produce a reaction, and you can produce a lot of power.

But obtaining that small mass itself is difficult. And around the globe, people are struggling to extract uranium and bring it to a form such that it can be used.

---

## Power Plant and Boilers



### Moderator

- In the chain reaction the neutrons produced are fast moving neutrons.
- These fast moving neutrons are far less effective in causing the fission of  $\text{U}235$  and try to escape from the reactor. To improve the utilization of these neutrons their speed is reduced.
- It is done by colliding them with the nuclei of other material which is lighter, does not capture the neutrons but scatters them.
- Each such collision causes loss of energy and the speed of the fast moving neutrons is reduced. **Such material is called Moderator.**
- The slow neutrons (Thermal Neutrons) so produced are easily captured by the nuclear fuel and the chain reaction proceeds smoothly.
- Graphite, heavy water and beryllium are generally used as moderator.



Moderator. In the chain reaction, the neutrons produced are fast-moving neutrons. So, there is a reaction. So now, there is fusion. And there is a release, right? So when there is a release, the neutrons are produced. And these neutrons, which are produced, move at extremely high speeds. So now, what we are supposed to do is reduce the speed of the neutrons.

These fast-moving neutrons are far less effective in causing the fission of uranium-235 and try to escape from the reactor. To improve the utilization of these neutrons, their speed must be reduced. This is done by colliding them with the nuclei of another material, which is lighter, does not capture the neutron, but scatters them. So, assume there is a shield; you throw a ball with very high energy. The ball hits the shield or the wall, and then what happens?

It dissipates; it tries to take a different angle. So now the nucleus hits, and then it shatters. When it shatters, it reduces energy and changes direction. So, that is what happens here, right? These fast-moving neutrons are far less effective in causing the fission of uranium-235.

They move very fast. So now you have to stop these particles. So, that is what we are trying to do. Each such collision causes a loss of energy, and the speed of fast-moving neutrons is reduced. Such materials are called moderators.

You have a controller separated so that these are moderators. The slow neutrons, or thermal neutrons, so produced are easily captured by the nuclear fuel, and the chain reaction proceeds smoothly. The violent neutron movement is reduced. The speed is reduced by the moderator. Graphite, heavy water, and beryllium are generally used as moderators.

Next is the control rod. Control rods regulate the nuclear reaction by absorbing excess neutrons, allowing operators to control the rate of fission and the power output of the reactor. So, if the speed is high, you are trying to reduce the speed. Now there are more neutrons; what are you trying to do? You are going to stop it, arrest it.

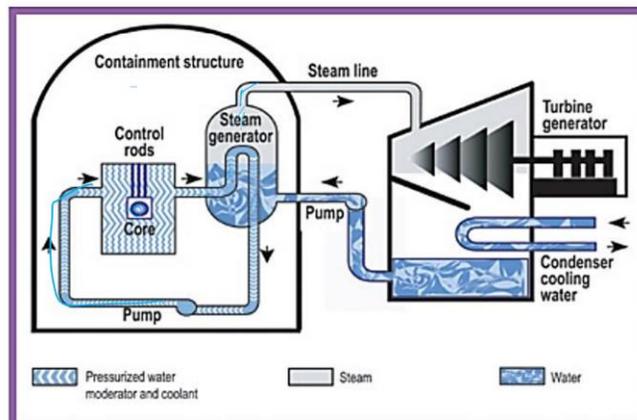
So, the control rods regulate the nuclear reaction by absorbing excess neutrons. And they allow the operator to control the rate of fission and the power output of the reactor.

---

## Nuclear Power Plant



Main components of a nuclear power plant



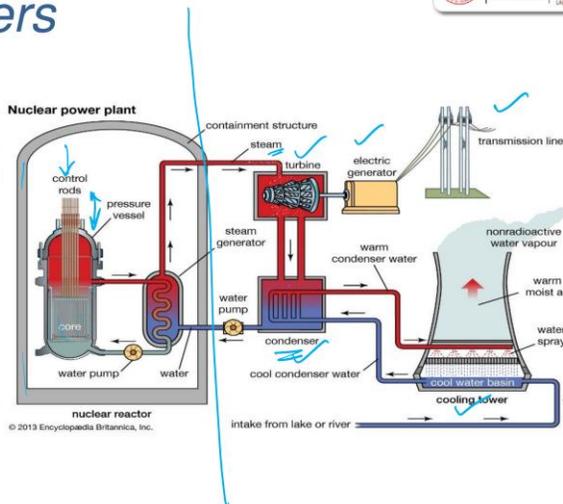
So, if you see here, this is how a typical schematic diagram of a nuclear power plant looks. So there are two entities, right? This part is one entity, and the other part is here. The first part has a strong concrete-walled shield constructed around the reactor. That is point number one.

## Power Plant and Boilers



### Control Rods

- Control rods regulate the nuclear reaction by absorbing excess neutrons, allowing operators to control the rate of fission and the power output of the reactor.
- Inserting or withdrawing control rods from the reactor core is the primary method for maintaining a safe and sustained chain reaction, preventing unsafely increases the reactor temperature.



In the reactor, you have the core and then the control rods, which are on top. You can go back and see these are the hydro beam floor. Then you have a fluidized bed, a burner, and then a boiler furnace.

So you will have this. From here, you can see the other things. Here, in the nuclear reactor, you have a core where the material is placed, and then you have the cooling moderator and controller, which are there. The reaction happens and produces a lot of heat. This heat, whatever is there, is managed by the water present.

You can see water that comes from the condenser or the cooling tower; the water comes through the water pump. It is pumped into the center evaporator. Then, the water from here is pushed into the reactor. So it gets heated. The steam is sent through a high-pressure pipe.

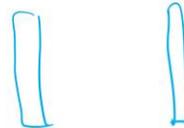
This high-pressure pipe comes in contact with the turbine. The work is done here. The generator is done, and it goes away. So, whatever heat is left out comes down and gets condensed. So, from steam to water, the water gets into the circuit, OK.

So, this is a nuclear power plant. It is very similar. The cooling tower is a common entity; the generator, turbine blade, and condenser are common entities. We do not have an economizer, right? So, this is a very, very simple setup, a highly energy-efficient setup.

The control rods regulate the nuclear reaction by absorbing excess neutrons, allowing operators to control the rate of fission and the power output of the reactor. Inserting or withdrawing control rods—these rods move up and down—from the reactor core is the primary method of maintaining a safe and sustained chain reaction, preventing an unsafe increase in the reactor temperature. More and more neutrons mean the temperature goes higher and higher, with no stop to it. So, the better way is, the moment the temperature goes high, you push the control rods down.

---

## Power Plant and Boilers



### **Reflector**

- Some neutrons produced during fission are absorbed by fuel, moderator, coolant, or structural materials, while others may escape the core; to minimize this loss, a reflector is used around the reactor.
- Reflectors made of materials like graphite or beryllium bounce escaping neutrons back into the core, enhancing neutron economy and sustaining the fission chain reaction.

### **Reactor Vessel**

- It is a strong walled container housing the core of the power reactor. It contains moderator, reflector, thermal shielding and control rods.

Then, you have reflectors. Reflectors mean these are on the walls. Some neutrons produced by fission are absorbed by fuel, moderator, coolant, or structural material, while others may escape the core. To minimize the loss, a reflector is used around the reactor. So, all these fellows do—the fission is absorbed by fuel, moderator, coolant, structural

material; everybody absorbs, but there are still residues, while others may escape the core. To minimize this loss, reflectors are used.

The reflectors, made of materials like graphite or beryllium, bounce escaped neutrons back into the core, enhancing neutron economy and sustaining the fission chain reaction. The last one is the reactor vessel. It is a strong-walled container housing the core of the power reactor. It contains moderator, reflector, thermal shield, and control rods.

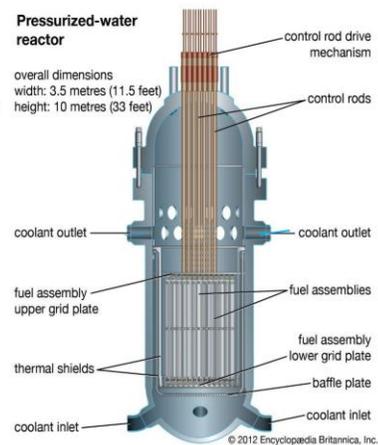
---

## Power Plant and Boilers



### Coolant

- Coolant circulates through the reactor core to absorb the heat generated by nuclear fission and either transfers this heat to another medium or, if water is used, directly produces steam to drive turbines.
- An ideal coolant should be thermally stable, have a high boiling point and low melting point, resist corrosion and possess a high heat transfer coefficient to ensure efficient and safe heat removal.



Coolants we use are circulated through the reactor core to absorb the heat generated by nuclear fission and either transfer the heat to another medium or, if water is used, directly produce steam to drive the turbine blade. So this is a coolant. So you can see here control rods more precisely, and then you have coolant outlets. This is a coolant outlet. Okay.

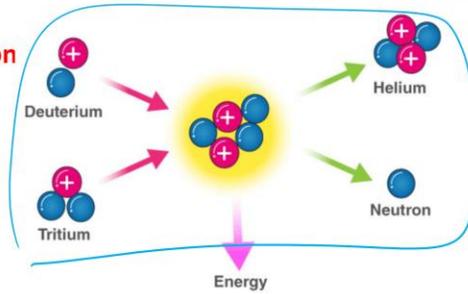
And this is where you have put the entire assembly, and you will have the thermal shield and everything here. An ideal coolant should be thermally stable. Water should be stable. It should have a higher boiling point and a lower melting point. You don't have it, so you mix something and try to get it.

So, heavy water is used. It should resist corrosion and possess a high heat transfer coefficient to ensure efficient and safe heat removal. So, the ideal coolant has to have a high boiling point, low melting point, low corrosion, and a high heat transfer coefficient.

# Nuclear Fusion

## Nuclear plants work on principle of Fusion or Fission

- **Fusion is the joining of atoms.**
- In fusion, two light atomic nuclei (like hydrogen) combine to form a heavier nucleus (like helium).
- It releases a lot of energy. When the atoms fuse, a small amount of mass turns into a large amount of energy (based on  $E=mc^2$ ).
- It occurs at very high temperature and pressure. Fusion needs extremely high heat (millions of degrees) and pressure to force atoms close enough to fuse.
- **It powers the sun and stars. The energy we get from the sun is produced by fusion reactions in its core.**
- **Clean and powerful energy source.** Fusion produces more energy than fission and creates no harmful radioactive waste or gases.



Nuclear fusion. The nuclear power plant works on the principle of fusion or fission. Fusion means the joining of atoms. In fusion, two light atomic nuclei like hydrogen, combine to form a heavier nucleus, like helium. It releases a lot of energy during this process. When the atom fuses, a small amount of mass turns into a large amount of energy, which is nothing but  $E$  equals  $mc^2$ . When the atom fuses, a small amount of mass turns into a large amount of energy.

It occurs at very high temperatures and pressures. This is fission. Fusion needs extremely high heat and pressure to force atoms close enough to fuse. It powers the sun and the stars. The energy we get from the sun is produced by fusion reactions in its core. It is called a clean and powerful energy source. Fusion produces more energy than fission and creates no harmful radioactive waste or gases. This is fusion.

---

## Fission



- Unlike fusion, which involves nuclei of similar electric charge and therefore requires high kinetic energies, fission can be caused by the neutron, which, being electrically neutral, can strike and fission the positively charged nucleus at high, moderate, or low speeds without being repulsed.
- Fission can be caused by other particles, but neutrons are the only practical ones that result in a sustained reaction because two or three neutrons are usually released for each one absorbed in fission.
- These keep the reaction going. There are only a few fissionable isotopes. U235, Pu239 and U233 are fissionable by neutrons of all energies.
- The immediate (prompt) products of a fission reaction, such as Xe<sup>o</sup> and Sry4 above, are called fission fragments.
- They, and their decay products, are called fission products.



Fission: Unlike fusion, which involves nuclei of similar electric charge and therefore requires high kinetic energies. Fission can be caused by neutrons, which, being electrically neutral, can strike and fission the positively charged nucleus at higher, moderate, or lower speeds without being repulsed.

Fission can be caused by other particles, but neutrons are the only practical ones that result in a sustained reaction because two or three neutrons are usually released for each one absorbed in fission. These keep the reaction going. There are only a few fissionable isotopes: U235, Pu239, and U233 are fissionable by neutrons of all energies. The immediate products of fission reactions, such as zelium and SRY4 above, are called fission fragments. Their decay products are called fission products.

This is a typical nuclear power plant where you can clearly see there is a core with control rods. Then there is water from a pump which is pushed into the reactor, and then there is hot water that comes out. This hot water that comes out is used; steam is generated, and that steam is pushed into turbine blades to get the work done.

And thank you very much.