Energy Resources and Technology
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Lecture - 8
Thermal Power Plants

We will start a different topic, but before we do so, let me tell you that the input output methodology that we have learnt in the last two classes that is not only applicable for a whole economy, but also applicable for individual industries. For example, if you take a large industry, for example TISCO, the Tata Iron and Steel Company, it has various sub units like the coke oven plant, the blast furnace plant. After the iron, raw iron comes out of the blast furnace that goes to some processing plant; all these individual plants are there and there is intersectoral transfer of material as well as energy between these sectors. For example, the coke oven plant produces coke; also produces coke oven gas as a fuel, so these two go to the other units of the company. So, you can see that the way we have understood intersectoral transfers in the context of a whole economy, country's economy, similarly the same methodology can be applied to individual sectors of a single industry and thereby, you can also find out quantitatively how good a unit is functioning.

This is one of the standard practices in some of the western companies, but it is not difficult to understand that in order to really account for this, one has to account for the monetary value of the things. For example, if say the coke oven plant is producing coke out of raw coal, that coke that goes into the other plant, the blast furnace plant, has to have, has to be attached with some kind of monetary value. Similarly, the coke oven gas that goes to say processing of the iron that means the iron has to be again melted and then processed into specific products and this is used as fuel; so, when it goes that has to be attached with some monetary value and then only you can do the proper accounting. So, that is often done in some of the industries, but that is one of the ways in which you can identify which unit is functioning all right, which unit is not functioning all right, where the, if you take stock of it year by year, you know, which units performance is increasing in the sense of improving the energy efficiency, clear. So, the point is that it can be also used in the context of individual industries and that is one of the ways of proper scientific energy management.

So, today we are discussing a different topic; that was last two days material. Today we will, in the main, discuss how electrical power is produced from say, heat source and heat source that will take, will be in the context of India is mainly coal. Though there are quite a few these days, electrical power plants, they run on gas, natural gas; I will come to that little later. So, the point is that if there is a heat source and you are trying to produce electricity, what is the most convenient and efficient way of producing electricity out of the heat source? The most convenient way is to first heat up water, so that becomes steam, run a turbine and after it goes out of the turbine, then you cool it back into liquid form and put it back into the boiler that is the essential thing. So, the essential things should be - one, there has to be a boiler.

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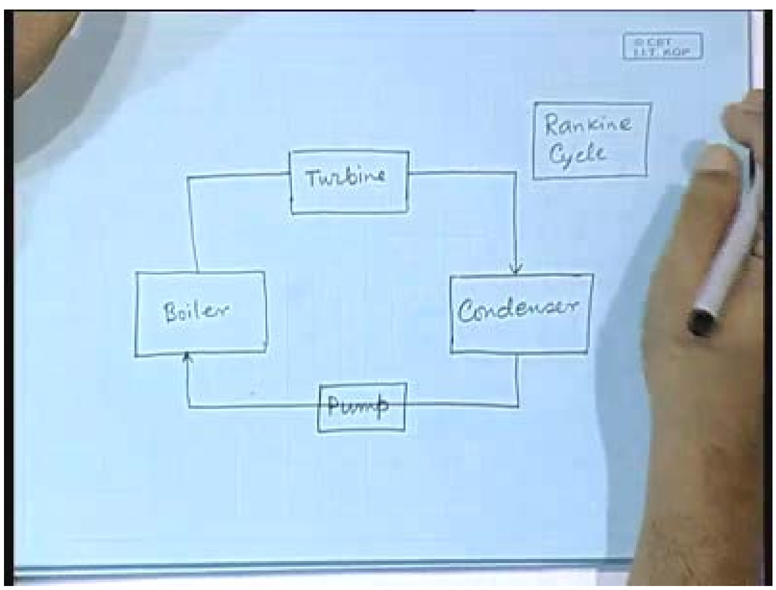

There has to be a turbine, then there has to be a condenser and you put it back to the boiler. So, this is the essential thing; sorry, there has to a pump, otherwise you will do not be able to put it. So, the boiler is at high pressure, high temperature; condenser is at low pressure low temperature. So, in order to put the water from the condenser into the boiler, you need to have a pump, because you are putting something from low pressure to high pressure. Now, when you do so, it is not difficult to see that there is a high pressure here, there is a low pressure here and turbine is extracting the energy by allowing it to expand from the high pressure to the low pressure and pump is something that is doing the opposite work.

Won't this have the same kind of work? That means this one fellow is getting the steam from the boiler to the condenser and it is extracting work out of it and this fellow is doing just the opposite thing. Won't the power that has come out of the turbine be required to run the pump, …… right? Here is the basic point of what is known as the Rankine cycle. No, these two powers are completely different. Why because, here it is steam and here it is water; headed with steam that means you simply cool it down to a steam form, but at low temperature, then it would require exactly the same amount of power. But here, it is water, water means highly condensed form. Naturally, this fellow has to handle far lower a volume and naturally the power in the pump is far lower than that extracted by the turbine. That is the essential point of the Rankine cycle. This is called the Rankine cycle. So, this is what goes on inside a thermal power plant.

So, before we discuss the physical layout of the things, have you, have you done any elementary course on thermodynamics? How many of you done? Probably only the final year people have done, right, out of you? Any course of thermodynamics? You have not done; so, I need to start from the basics, fine. Probably it is only here that you have learnt about entropy, right, fine. In general, when handling a fluid like this, fluid means here in this case, water. Remember, it could have been some other fluid also. The principle fluid that circulates all through in this case is water, but it could have been other fluids also. I will come to those cases a little later.

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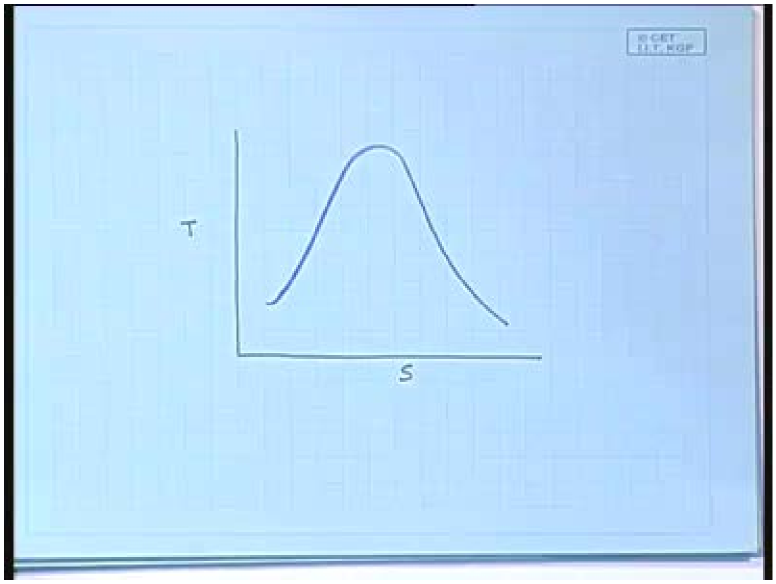

For a fluid, we normally draw what is known as the temperature entropy diagram or T-S diagram. I will not go into the details of it, because most of you will anyway attend courses on thermodynamics, but I will just give you the basic points, so that you can appreciate what is happening inside a thermal power plant. In it, we draw the characteristic of the fluid water, also steam. Now, it so happens that the dividing line between water and steam would be something like this.

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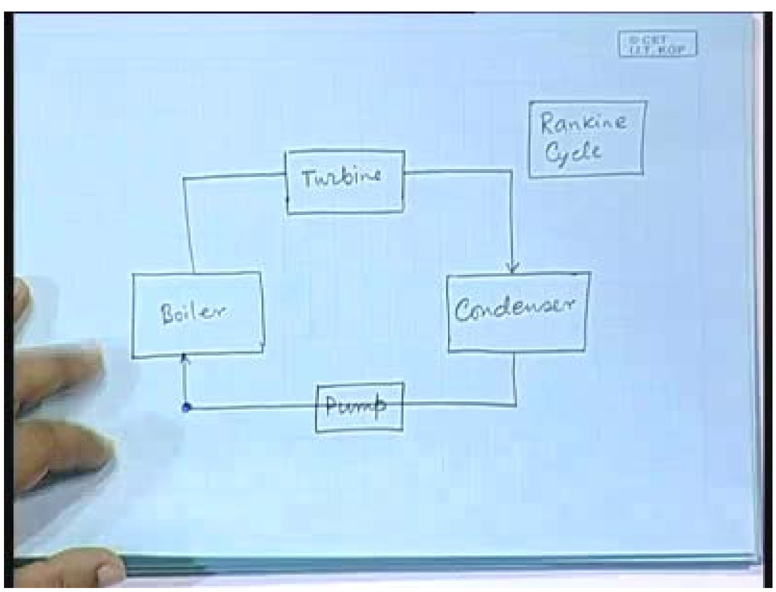

So, supposing we start somewhere here, which means we will be starting somewhere, I will do it in another colour, somewhere here.

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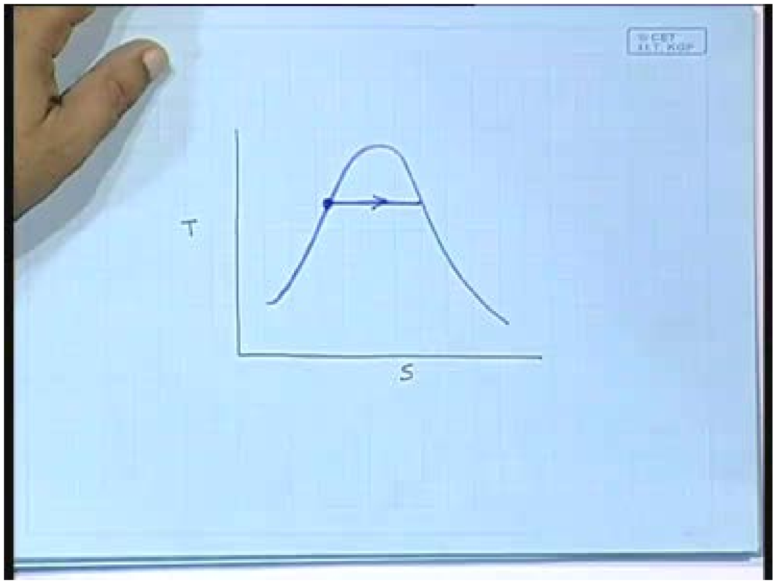

First, it will be heated up at constant temperature. Why because, when water is being heated up, when water is being heated up means it has reached the 100 degree centigrade temperature or whatever is the temp…, depending on the pressure inside the boiler, it will be a higher temperature all right, but whatever is the temperature, boiling temperature, it will be fixed there, so long as it boils, right. So, the temperature will remain constant, so long as it boils. So, in the boiler you will have a passage like this. Now, as it goes out of the boiler, it has become steam, all right. Steam is this part, this side; here it is water. So, as it goes out of the boiler, if it is just only heated up into steam, the moment you cool it down, it will again become water. So, you need to heat it up further. That means you have reached the temperature, boiling temperature. The steam that is coming out is at the boiling temperature. You need to heat up further; that is done by something called super heater, I will come to that.

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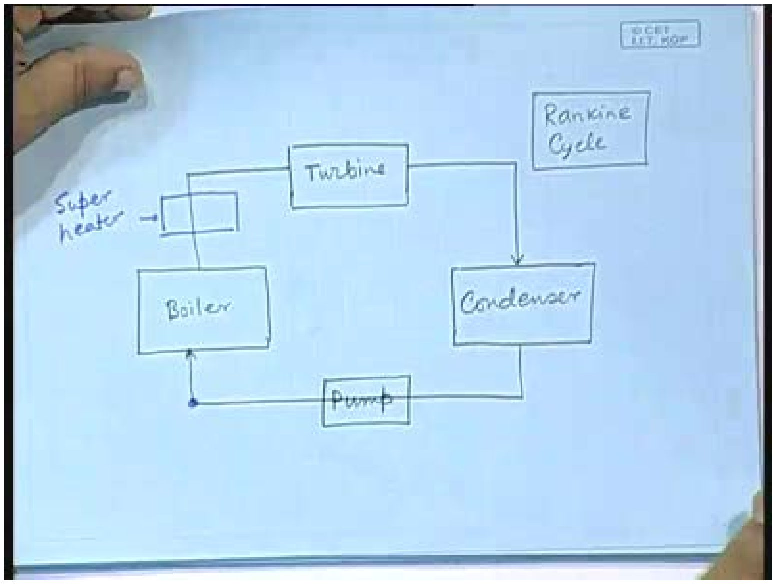

So, another thing is to be inserted here. This is super heater, without which the moment you extract some energy out of the turbine, it will again become water which you do not want. So, super heater means you again add heat to the steam that comes out of the boiler. So, when you do so, then you have, it rises both in temperature and in entropy. Whenever there is a heat transfer, there is a change in entropy; dQ by t is the change in entropy. So, when this was going the entropy was rising, because you had dQ.

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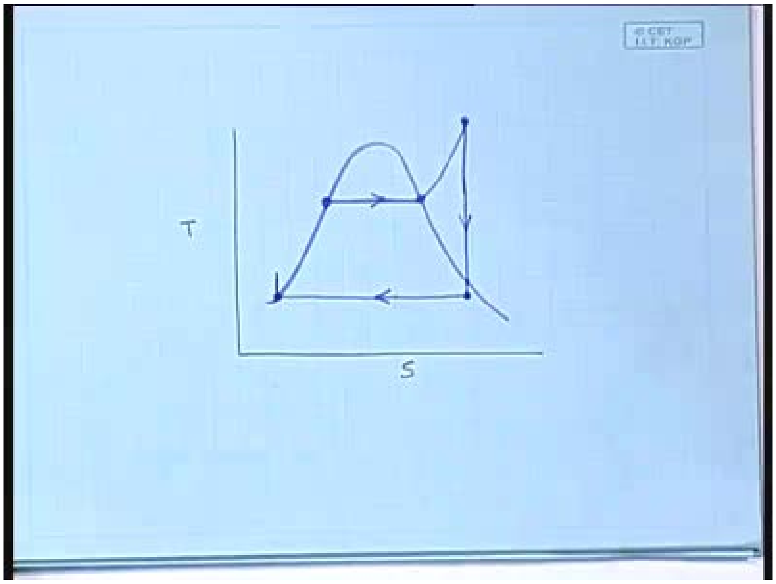

Now, after this, it goes like this, up to a point to which, up to a point to which, you can go inside the super heater. It is restricted by the maximum pressure that you can sustain physically. After that, what is there? There is a turbine. Turbine means something that extracts energy out of it. But, is there heat transfer? No; ideally the turbine does not lose any heat in practice. It might, by radiation or something like that, because it is a bit heated up, but normally you have a big, you know, insulation material around the turbine, so that it does not really allow much heat to escape. If the heat does not escape, dQ by t is zero; dQ is zero, which means it should be a process where temperature falls, but the entropy remains constant. So, it should be a process by which temperature falls, but entropy remains constant. So, it is allowed to fall to this point.

What is this point? When it starts to condense into water; beyond it, it is superheated steam. It is in fact allowed to, allowed to form some amount of water droplets inside, but not much. If you go deep inside, then what will happen? The steam will start to condense and it is still inside the turbine. As a result, water droplets will start forming and since it is a rotating machinery, the water droplets will impinge on the turbine blades and it will corrode the blades. So, you cannot allow that much, but you allow it to go slightly. So, this is the point where you extract the steam out of the turbine. Where does it go next? Goes to the condenser; what happens inside the condenser? Condenser means some device, something that condenses the steam into water, which means that it take, it takes the heat out. If you take the heat out, then what happens? dQ by t is there, so entropy falls, because the heat is taken out.

What happens to the temperature? It should be constant, because it is the same process. It is only the latent heat that is being taken out. So, the temperature will remain constant and it will go like this to a point here. So, this is, this is where you take out the heat in the condenser. As a result, what was earlier mainly steam with a few droplets forming, through this process more and more steam is condensed and when it comes here, it is basically water, all right. So, it comes here. What do you do next? It has to be pumped. Now, as I told you, the pump will require far less amount of power, because it is handling water.

Now, if that is so, then obliviously, again the pump is the same as turbine in the sense that that does not allow any heat transfer; it is not a heat transferring device. So, ideally the pump also should have the entropy constant, right; it should also have the entropy constant, so entropy constant. But, since you are pumping in, you are pushing something, there is work into it. There will be some rise in the temperature. All pumps have the temperature rising a bit, so it should be a bit raised. So, that is the pumping part. Now, we have come to a stage where it is water, but water at a lower temperature, very low temperature; the temperature at which it was condensed like 30 degrees, 40 degrees or something like that and then, it has to be put into the boiler.

Now, the boiler temperature is not really 100, but beyond 100, because it is at high pressure. So, here it is a temperature which is low, here it is temperature that is high. If you simply put it inside the boiler, what happens is that the boiler that has thermal stress produced, because a part of it becomes cold, another part of it becomes hot; iron material that produces thermal stress, it cracks. So, obviously you cannot do that. You have to bring the temperature close to the boiler temperature, before putting it into the boiler. That is why something additional is put here.

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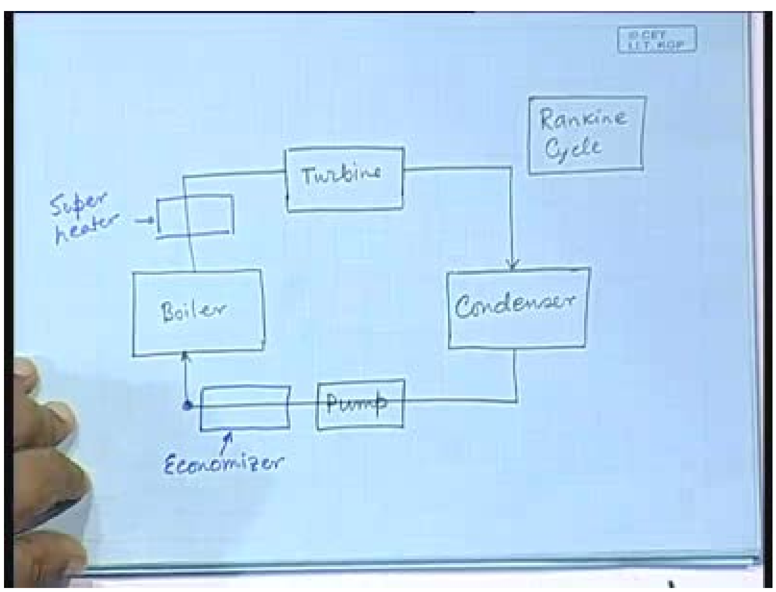

That is that is called economizer, whose job is to bring the temperature to a value close to the temperature inside the boiler. So, how you will represent it in the T-S diagram? It is a process in which you are adding heat, you are having the temperature rise, so both T and S should change.

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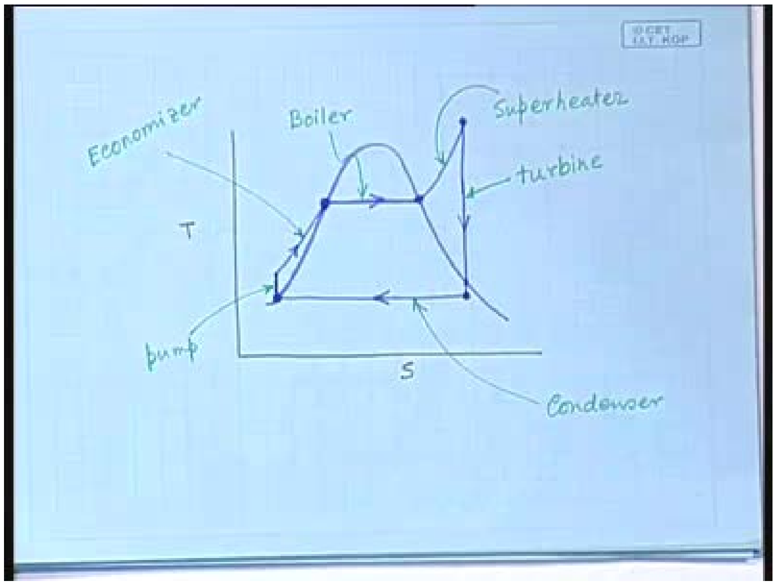

So, the starting point should be here and the ending point should be here. So, it should be a rise like this. So, have you been able to identify the parts? Let me write down separately, so that you do not forget. What is this part? Boiler; no, yes, boiler. What is this part? Super heater. What is this part? Turbine. What is this part? Condenser and what is this part? Pump and what is this part? Economizer. So, this is the essential structure of the cycle. It is cycle, because the same steam goes on circulating inside the system and you have it going like this; its temperature, entropy changing as shown in this diagram. This is the temperature entropy diagram or often called T-S diagram of the Rankine cycle. Clear, is there any question? No, okay.

So, now come to the, let us come to the point, how does this diagram get actually reflected in the physical structure of the power plant?

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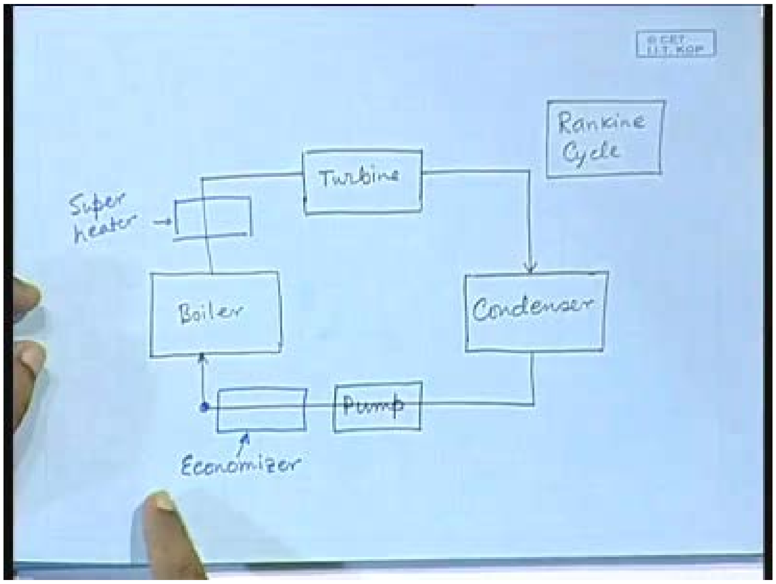

Here, we have done only a sort of block diagram. Here is a block, here is a block; obviously these are not squares, physically in a power plant. How does it really get done? The first thing that you have to understand is in most of the modern power plants, the boiler that means first you have to generate the heat. In generating the heat you have to burn the coal, but the coals burning will be complete if, now, coal is normally coming in big chunks. If you really put the chunk and burn it, obviously some part inside will be, will remain unburnt.

So, what can you do? You simply grind it, called pulverization process; you pulverize it into powder, then blow it with air. So, if you have pulverized it into a powder, if you blow with air, what happens? That goes along with the air and that comes into a chamber where there is a flame. So, the whole thing burns and you ensure essentially that complete burning occurs. So, inside the boiler the structure is that there are, it is a big, you know, column; boiler is not like your domestic chula, it is not quite like that. It is pulverized coal that is burnt and it is inside a big column something like 5 stories high.

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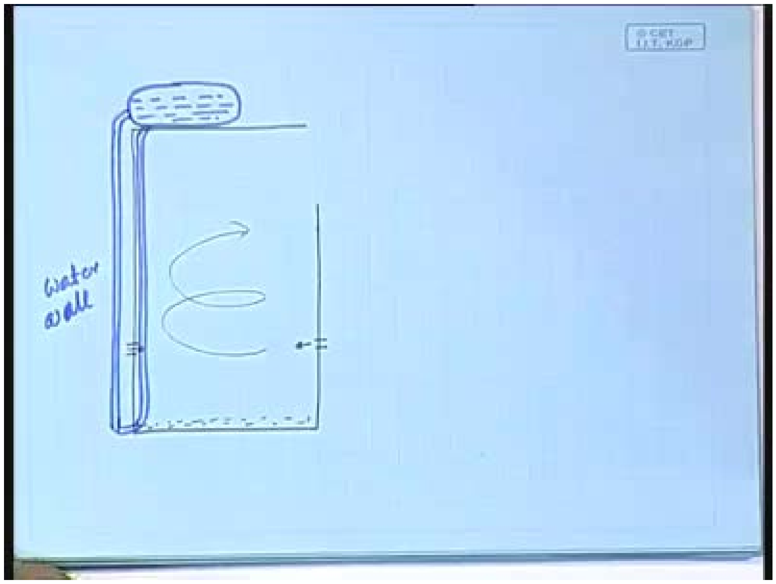

So, you have a column something like this, where there should be ports through which you insert the fuel air mixture and the whole structure is such that, if this is the column, now see from the top; this is the column, then here the ports are in the sides. All these ports do not really point to the center, rather a bit off center, so that inside a vortex is created. If there is a vortex created, what happens? There is a, you know, continuous churning of the materials, so that the ash takes some time inside, so that complete burning is ensured. If the ash very quickly settles, then there may be incomplete burning. So, you intentionally create a vortex inside. So, inside there will be some vortex like thing and the gases rise through this as burning takes place and that has to be taken out through some process. I will come to that later.

So, when you have this, obviously some part of the coal that are in particle form will settle at the bottom here, right and some part will go along with the flue gas; we will come to that. Now, the top of this, let us draw it like this here, there would be a boiler drum. I am drawing schematically; there will be a drum, the drum actually stores the water and from which it is circulated. Now, this circulation you need to do it in a form that ensures highest amount of heat transfer from the burning gas to the fluid. How can that be done? Notice that there is a wall here and all the time, the burning gas is in contact with the wall. Naturally, lot of heat will be transferred to the wall and that will be lost; that will be lost.

So, what is done instead is in an actual physical thermal power plant, you have the water coming out through outside the boiler like this. There are pipes that bring all the way down and then, it is inserted from here and there are pipes all along the wall. I am drawing one of the, one such pipe, but there should be innumerable such pipes all along the wall. So, if water is inside, what will happen? The water by natural circulation will come down, because this is a, this is not where it is receiving heat, but it is here that it is receiving the heat. So, as a result, this part it will be heated up and the conversion into steam will be taking place here. It will be receiving, it will be receiving the radiation as well as the conducted heat and finally what will emerge here is steam mainly.

So, there will be a circulation of water like this and I have shown only one such thing. There is such tubes coming out all the, all the places and all the, whole of the boiler; inside the wall there would be such tubes, so that the flame here does not see the wall at all, it sees only those tubes. This concept is called water walls. So, these are the water walls. So, this is the water wall. Is the concept understood? So, this would be there in all the parts, all the sides, I am showing only one; but, you should understand that such water walls are everywhere. Then through this process the elementary boiling process takes place, this part.

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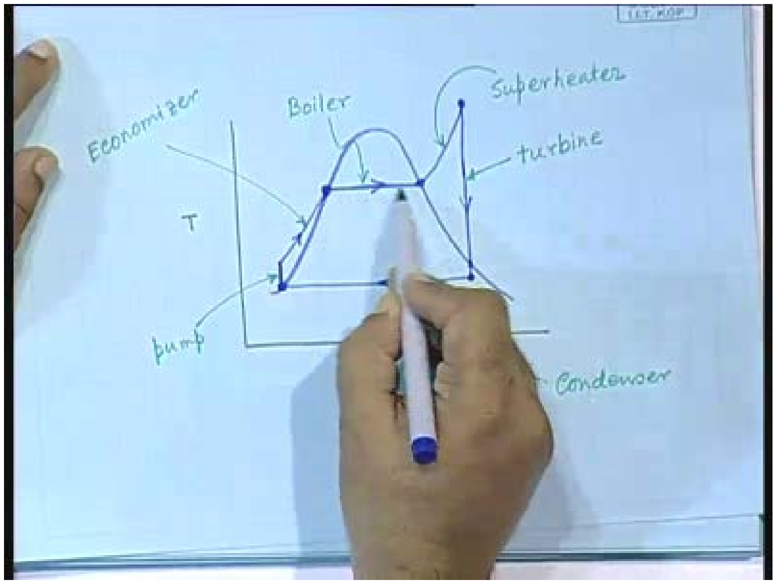

So, what happens is above this water steam gets accumulated and that needs to be taken out.

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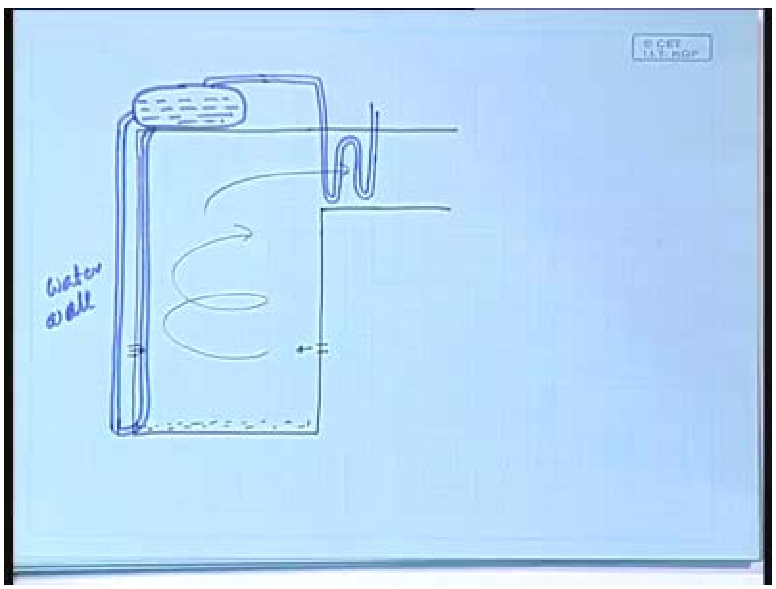

So, this steam needs to be taken out and that steam is in which state? This state, right. It is in the temperature inside the boiler drum. That was when the steam was in contact with the water. It is to be heated up now. Now, the flue gas that is rising, the flue gas that is rising is at a temperature, still quite a high temperature. So, as it goes, the steam goes, the flue gas goes, this steam is circulated something like this. So, there would be those, you know, super heater heat transfer elements essentially made of copper, because of the high heat transfer constant of this material, copper. So, what goes out of this is superheated steam, right. So, what goes out of this is superheated steam.

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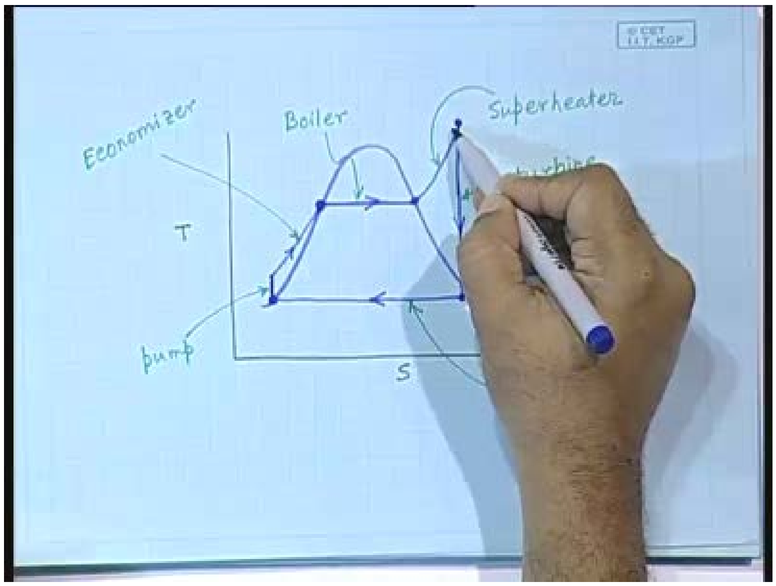

Where does it go next? It goes into the turbine. Now, naturally that has to be brought into the turbine. How do I show? Let me show it here and I will bring it down here.

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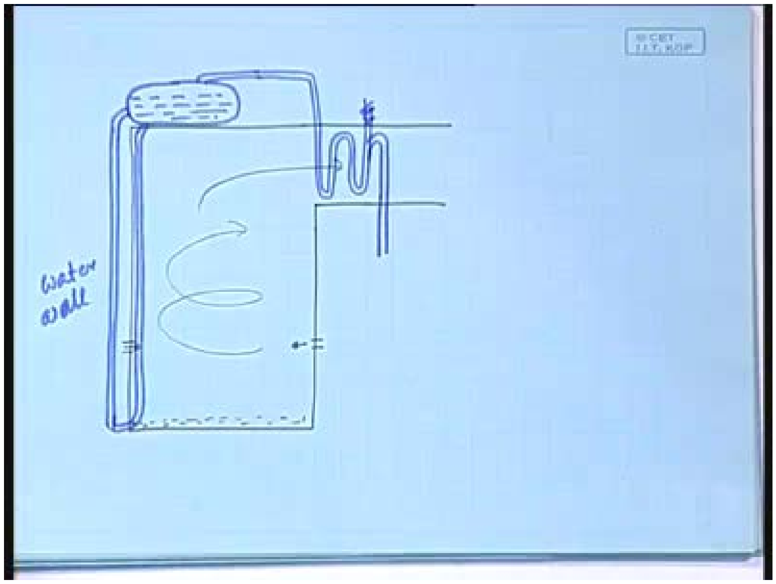

So, instead of, instead of going all the …., just imagine that it is again coming down. It is easier to show that way; yes, I will take it out. Now, here the turbine; turbine is something that allows the gas to expand and in that process it extracts the energy out of it, a rotating element. It has blades, the gas impinges on the blades, makes it rotate and it is, it is released, led to expand in nozzle. So, the nozzle essentially converts the pressure, energy in the pressure, to kinetic energy. That kinetic energy makes it impinge on to the, on to the blades and makes the blades rotate, as simple as that. So, you have the turbine that essentially looks, I will separately draw the structure of the turbine, once. It should be something like this.

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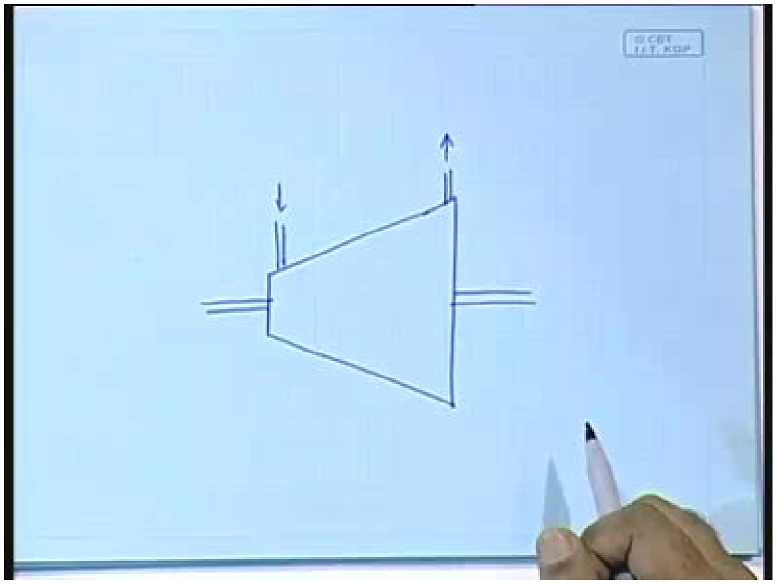

So, in one part it comes in and in another part it goes out and here would be the shaft. Why do I draw it in …. out of shape? Because here, it is still at high pressure and as it expands you have to allow the space for it to expand. So, it has a larger area, volume in the other side. But, you will notice that it expands from a very, very high pressure to a very, very low pressure. As a result, if you have to expand that, then this factor has to be very large and cannot really be accommodated in one turbine. So, in a normal power plant, if you go, you will find three turbines - a high pressure turbine, an intermediate pressure turbine and a low pressure turbine.

In relatively smaller power plants that are there in some of the industries, industries have sometimes captive power plants, you will find a high pressure and a low pressure.

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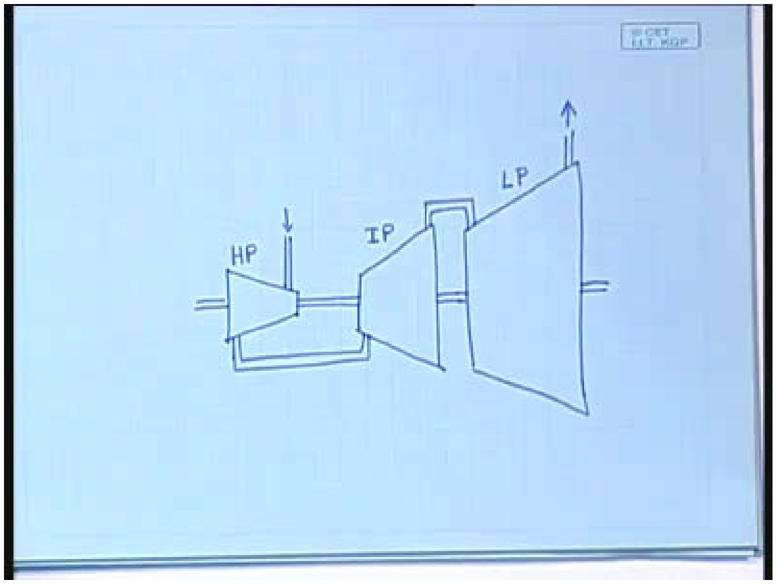

So, essentially this structure would be something like this that there will be one high pressure turbine. It is connected to the same shaft as an intermediate pressure turbine; again connected to the same shaft to a much low pressure turbine. So, it should come here; from here it should go into the intermediate pressure turbine, from here it should go into the low pressure turbine and finally from here it should go out. That is the normal structure of a, of the set of turbines in a power plant. So, this is called the HP turbine, high pressure turbine. This will be called the intermediate pressure turbine, IP and this is the LP turbine, right, clear.

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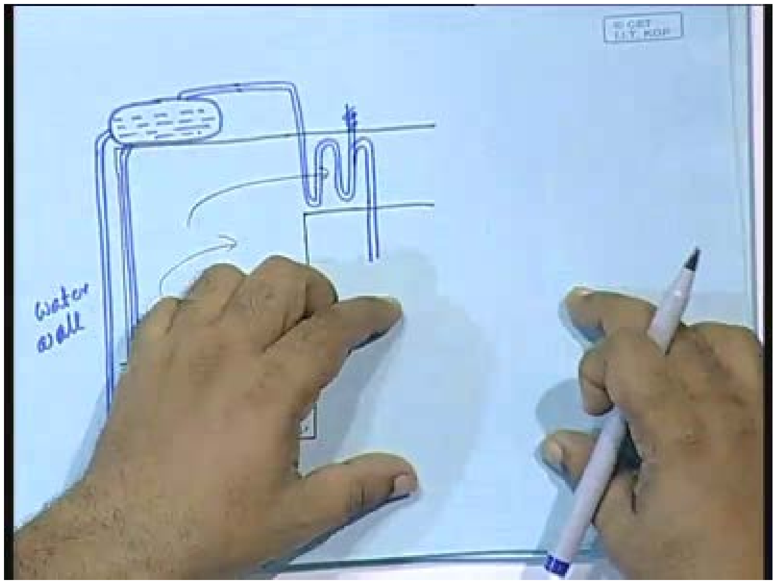

So, this structure that you see, imagine the whole block, that should be stationed somewhere here, so that the steam comes here. I will draw a little later, with good reason though and what goes out finally should go where? It should go into the, into a, notice where does it go next?

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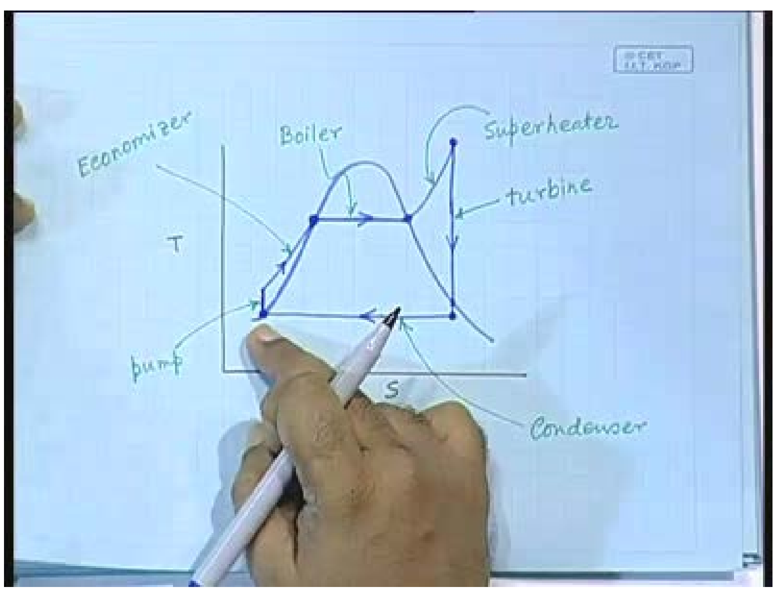

A condenser; it goes into a condenser. So, after this I have not drawn into the actual diagram, which I will come to later.

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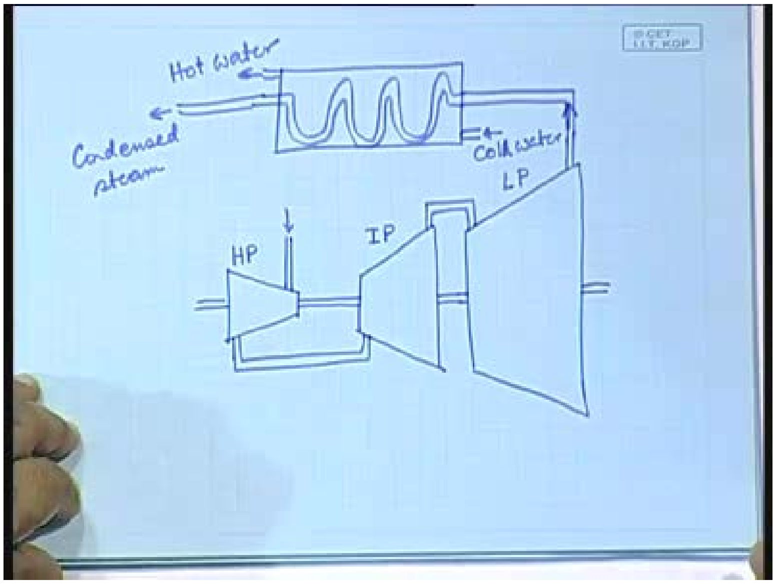

After this, it goes into, let me draw it here, so that you get a clear idea, it goes into a condenser and condenser is system where this is, this goes into a, I am schematically drawing that; there are heat transfer elements and the cold water is coming from here and the hot water is going out of here, hot water and what goes out here is condensed steam, after we condense mainly water and in actual power plants, you will find that this is done in the following way. The water from some nearby rivers, stream, pond, whatever it is, lake, is pumped in and it is fed into here and naturally it collects the heat from the steam. In that process, it gets heated up. This steam that is circulating inside gets cooled down to water that goes out.

This hot water, what do you do with it? Earlier, people used to simply release that into the lakes, stream, river, whatever it is; but, that obviously causes a very large damage to the natural environment, because the water gets heated up, no fish can survive, so all that problems are there. So, these days what is done is this. Hot water is cooled down naturally before releasing into the, whatever, natural environment. So, for that you have those cooling towers where there are big chambers in which the water is sprayed from the top, air is blown so that the air takes the heat out of that water and the air gets heated with the bit of steam input into the air, but the water is again cooled down before being released into the atmosphere and that is what you see probably, when you go from here to Calcutta, you see the Kolaghat thermal power plant and you will find there are big chambers something like this and you will find steam rising.

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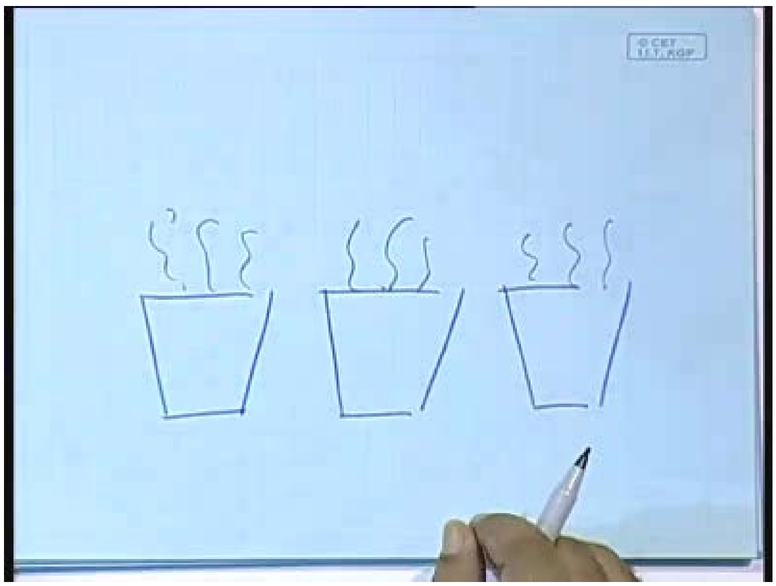

Have you seen that? Next time when you go, do look at the plant and see steam rising, right. This is not really the steam that is being, that is taking part in the power plant; it is not the steam that is actually circulating here. This is the steam that is essentially, the water sprayed, the cooling water sprayed. It takes the heat, …. air takes the heat and lets the water pass relatively colder, when it is again released into the atmosphere and remember, this takes in a lot of heat. How much? How much will that be? Let us have an estimate.

A power plant like the Kolaghat thermal power plant has 4 units say, each with 200 mega Watts. The ideal thermodynamic efficiency is 1 minus T 2 by T 1, we have done that already.

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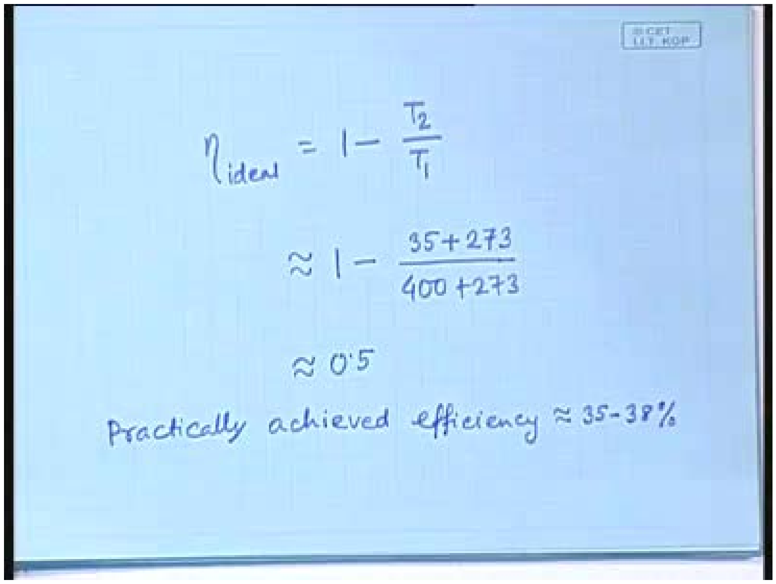

So, the ideal thermodynamic efficiency is 1 minus T 2 by T 1. What is T 2? It is the temperature inside the condenser, sink temperature; would be something like say 30 degrees 35 degree centigrade, so 30 degree 35 degree plus 273. So let us say, let us put some numbers. This is say, 35 plus what is T 1? T 1 is the, is the source temperature; that is not the flame temperature though that is the temperature to which you have been able to heat up the steam in the super heater. So, let that be say, some, some value. Now, the question is what is the value? Can you calculate? Does anybody have a calculator? Just calculate how much is the ideal efficiency? Nobody has a calculator? Do calculate and tell me what is the value?

0.5 approximately; so, approximately, all right. You will notice that the lower this temperature is and the higher this temperature is, the ideal thermal efficiency goes up. But, the actual efficiency of a normal power plant would be something like 35 to 38%. So, the rest 62%, what happens to that? If a power plant produces 800 mega Watts or let, let it be 1000 mega Watts, so how much heat is put into the atmosphere? Can you calculate? Efficiency, let it be 38%. A 1000 mega Watt is actually converted into electricity. How much heat is released into the atmosphere? Presently you calculate in mega Watts, but obviously that will have to be converted into its equivalent thermal units.

Yes, close to 1500 mega Watts; a huge quantity of heat, huge quantity of heat that must be released into the atmosphere.

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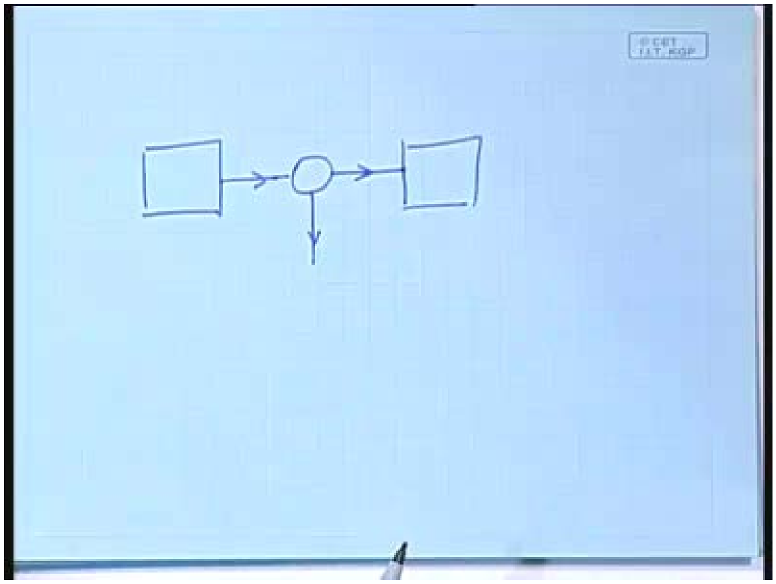

There is no other way, because the whole process is that you have a source, you have a sink and you have a converter that takes a part out. Without this passage you can do nothing that was one of the essential postulates of the second law and the amount that goes here for a power plant like that would be something like 1500 mega Watts, huge amount. So, that amount of heat has to be released into the atmosphere; you cannot help it. So, obviously that is a great deal of thermal pollution and we need to understand how this thermal pollution can be minimized. That is one of the things that we will discuss.

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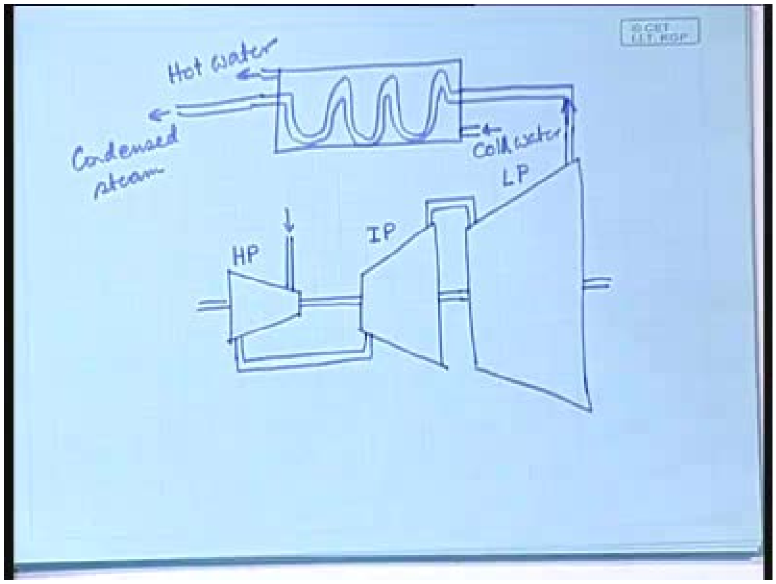

So, when you draw in a small diagram like this, it essentially hides the fact that this fellow is taking away something like1500 mega Watts, a huge quantity. The hot water is taking up that amount of heat. So, that amount of heat has to be dissipated in the most benign way that the environment can take and the easiest way is that where you simply spray the water, let water, let air be blown, so that a part of the heat is taken away by air and put in elsewhere. You cannot really allow that 1500 mega Watts of hot water to go into the, directly into the environment.

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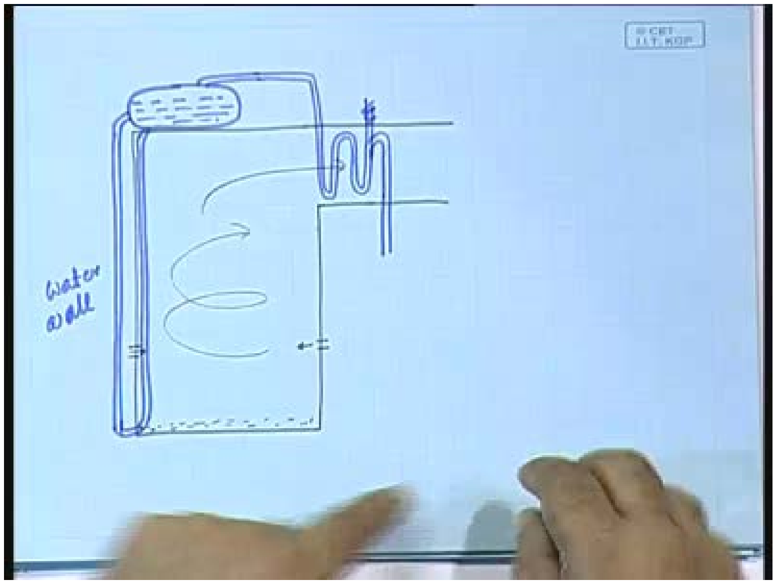

So, you have this structure, after which, so imagine that this structure is, here I will draw later, exactly why that I will come to later; again this structure is fed back to here. Is it really fed back from the condenser? Yes; there has to be economizer in between, so there has to be economizer.

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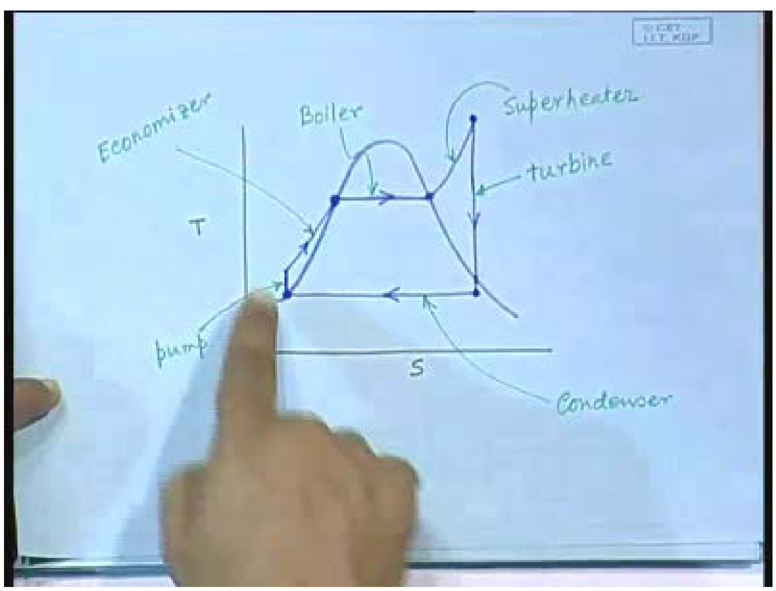

Where is that economizer?

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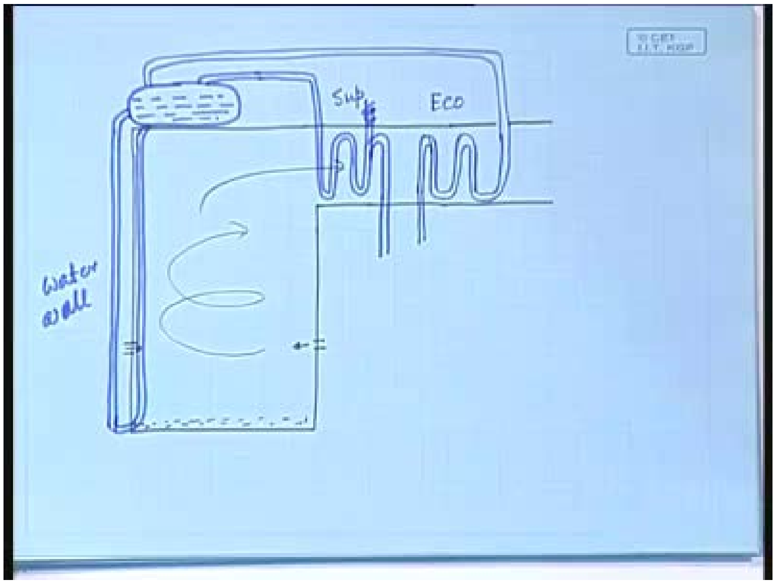

It is actually another set of, another set of heat transfer elements that go like this and finally it is feedback to the …. So, it comes from, so what are the parts? This is super heater - this part, this is economizer, this is the boiler, this is the boiler drum. Is it understood? So, here I will later draw the actual structure of the turbine assembly.

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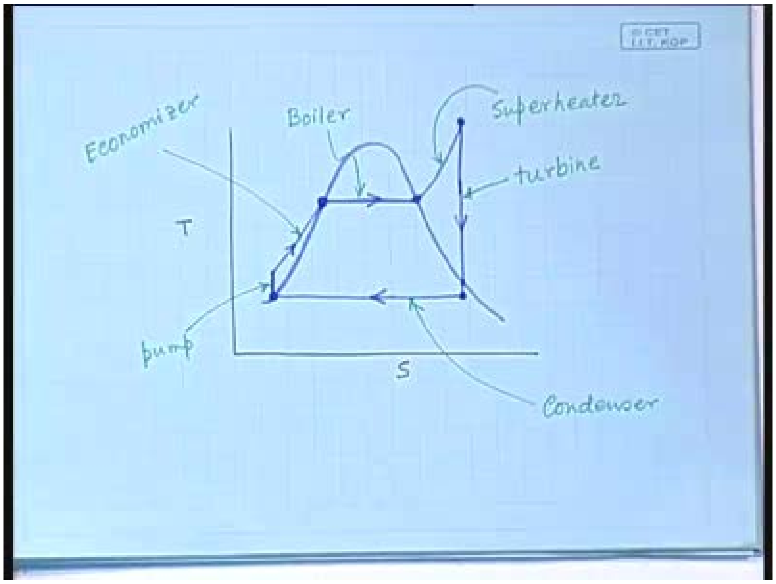

Now, the question is for an energy engineer, it is necessary to ponder how we can improve the efficiency of such a thing and actually, the amount of power that is extracted out of the system is area under this closed loop. So, essentially the problem boils down to how can we increase the area of this? You might suggest that if you bring down this level, obviously the area goes up. So, what is the problem of bringing down this level? No, it is not super heater; it is the condenser part, so bringing down this level means allowing this steam to expand further inside the turbine. What is the problem? The problem is that water droplets start to form and that will impinge on to the high speed blades and it will corrode, cavities will form. So, that cannot be allowed much. There is a physical limit to what you can do.

You would suggest that okay, instead let us increase this temperature.

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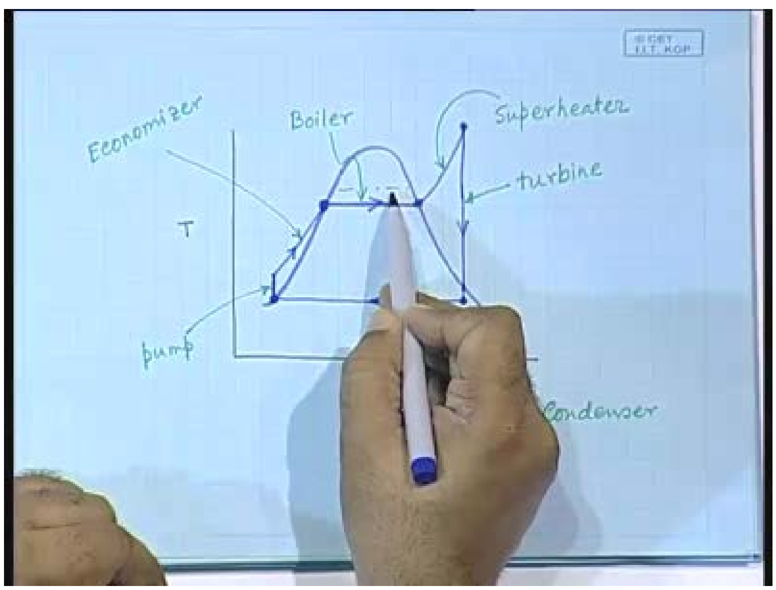

Let us increase this temperature or you might suggest that why do not we go up and allow, allow it to, in the boiler let it be slightly higher position. What does it physically mean?

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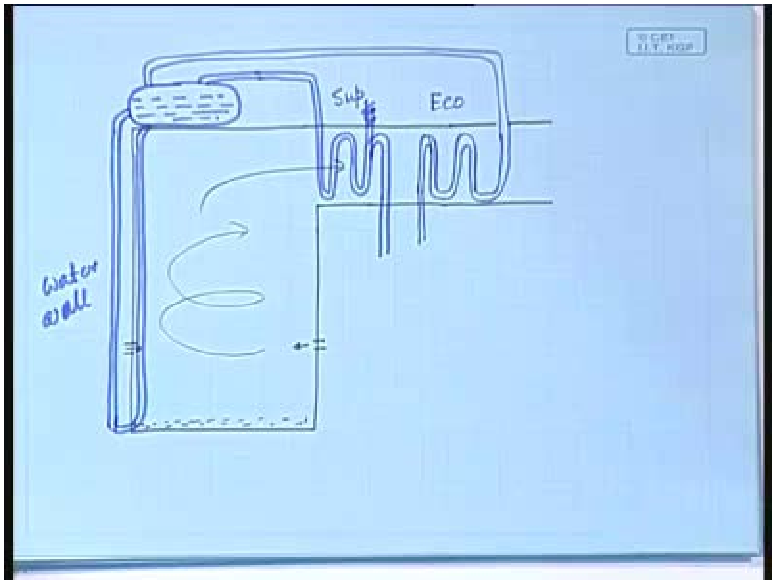

High pressure inside the boiler; if you have high pressure inside the boiler, then only there will be high temperature inside the boiler and high pressure inside the boiler means, boiler is a physical thing with some material that makes its body and there is obviously a limit to the pressure that it can stand, because it is a large chamber. Had it been a small chamber, it is possible to increase the pressure further, but if it is a large body, then obviously there might be failure and failure might be catastrophic and that is why there is a limit to the pressure to which you can take it. So, you cannot really raise it like this. There is a physical limit. Let us show that the physical limit can be overcome if you can get away with the boiler drum; is a big body that is why the physical limit is there.

Instead, nowadays there are new power plants coming up that simply from the economizer, there is no boiler drum, it goes on circulating directly that means there are only pipes; that is all. It is called a once through system, where the economizer output is simply pumped like this, so that it is pumped in circulation. If you have boiler drum, you can have natural circulation. But, if it is only pipes you have to pump it, but nevertheless, people do pump and you have the circulation directly. Since there is no boiler drum you can raise the pressure. So, it is possible to raise the pressure here, only if you use a once through type of system. So, you cannot raise the pressure here.

Is it possible to go up here further to include some more area? That will increase the energy in the pump and pump is, pumping energy is something that you supply; does not really help. So, where else can we do something in order to increase the area inside the curve?

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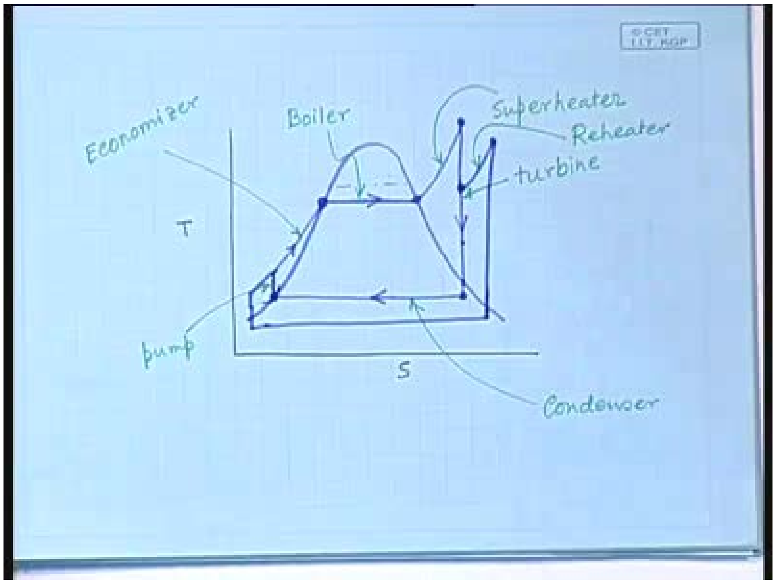

What is done is that at some point like this, after the high pressure stage of the turbine that means it is expanding in three stages, right - high pressure, intermediate pressure, low pressure - after the high pressure, it is extracted and it is allowed to expand again, so that it comes to another point like this and then you notice that this curve is going like this and therefore, you can go further down here and then you allow it to expand. All these area comes in. This particular thing here is called a reheater, is called a reheater. So, what is actually done, after the high pressure stage it does not go directly to the intermediate …. stage. It is taken out and put into the, into this segment, so that it extracts further amount of heat and finally you put it into the intermediate stage.

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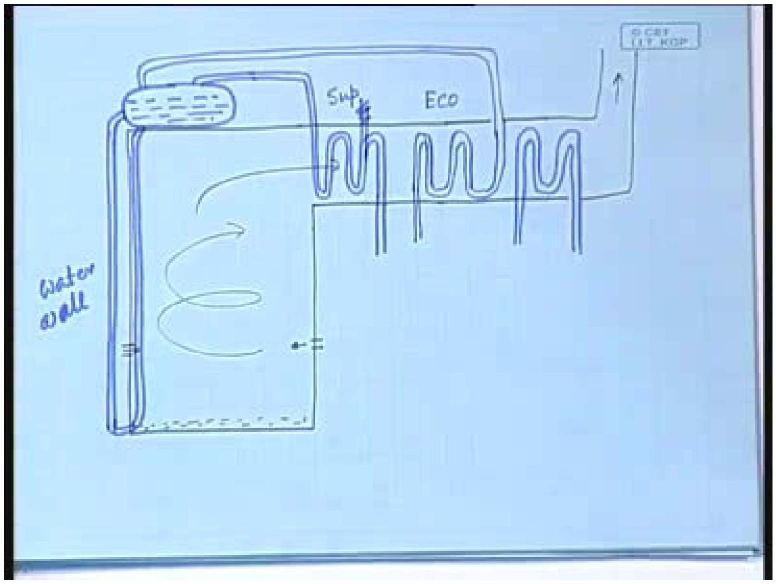

So, you have another stage here like this, after which the flue gas goes out into the chimney. I will detail that in the next class.

Thank you very much.