Engineering Thermodynamics
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Lecture – 41
Applications. Problem Solving: Materials. Compressible flow

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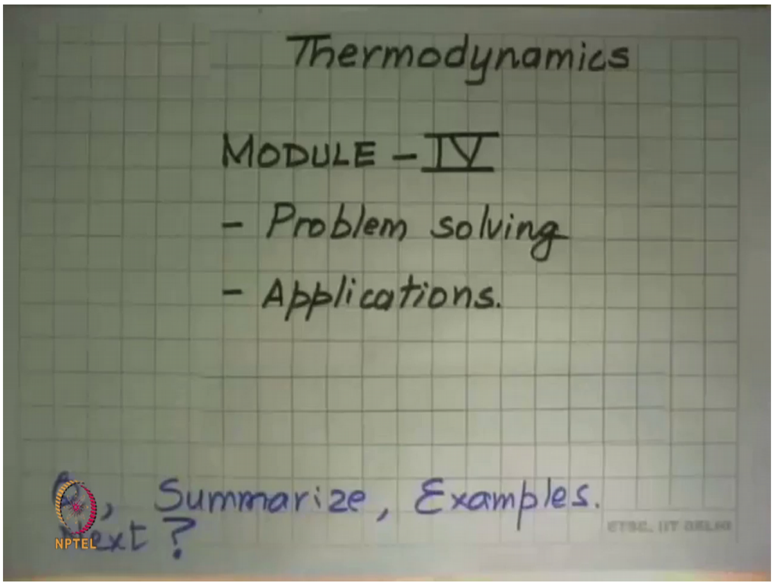

This is the last lecture of the 4th module, this is also the last module. So, what I have (Refer Time: 00:24) take the time today is it take first of all questions, and throughout the time you can keep on asking questions, and I will immediately take them up. I will also take time to summarize, what we have learned in the four modules. And take a couple of examples to show how we do problem solving. And we will end the hours by saying we have learned something what is more to learn in thermodynamics. So, we stop at we will we take little time to talk about that.

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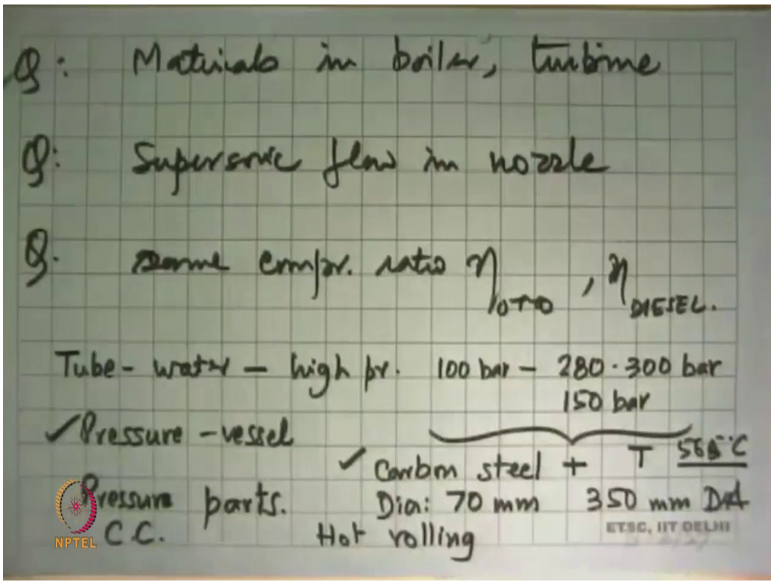

So, some our questions paper pending since yesterday. So, let us take (Refer Time: 01:09) first. They were the question about what are the materials used in boiler and turbine ok. So, if you look at all side boilers or oil sides boilers, the tubes carry the water. And these are subjected to high pressures, on the high pressure need, whatever the pressure we get in the thermodynamic analysis that is the pressure of the water inside the tubes.

And this could be anything like for small boiler, this mainly about 100 bar and for large power boilers, (Refer Time: 01:50) 280 bar, 300 bar is not conform. The thing is because you have such high pressures, we need to make a whatever the tube or the cylinder or the container, whose diameter is small because of stress analysis. If you recall your solid mechanics that larger the diameter, the stress will increase the proportion to the diameter, and the thickness of the wall that you require to make that device keeps increasing.

So, these devices which are at high pressures, if it just a vessel or a tank that is called a pressure vessel and all these parts in a boiler or in the power plant or any other cycle, you just subjected to high pressure, these are called pressure parts. The common materials that are used, these are lots of a carbon steels of different types, and it is not just the fact that they are of which type of a material, but also that so when we make these affects their quality also affects their life.

So, most of these things, they are firstly made out of small diameters. So, diameters are relatively small of the some the tubes in the water is boiled and evaporated. Those tubes could be something like may be 50 to 70 mm diameter. And the pipes that carry the steam from the boiler to the turbine, these could be like 350 to 400 millimeters in diameter.

And to get the best mechanical properties of the vessel, these are made by hot rolling that means, you make a tube you just heated up, and then you first excluded. And then you expand it, turn it, bend it everything while it is hot, the what you have learned in metal forming. And that is how we get (Refer Time: 04:08). So, we cannot trump a very long tubes to the site, so this tubes are made in lines which are transportable which is the length of a railway sprayed metal.

So, all these tubes go to side an excite them, we took the cook together, and welded by hand. After welding is done, their radiograph; see if there is any defect, and after that they are filled finally filled with water, which is pressurized more than the design pressure what thermodynamics hold us make sure that there is no rule, so that is what is done most of the tubes, and pressure pipes, these are of carbon steel.

And how we selected this is that we needed to go to the temperatures that are cycles are telling us like 560, 600 degree Celsius that type of temperatures. And our objective is that they should have strength, and intensity at that elevated temperature continuously year after year, already 2015, 13 years that is the whole thing, so that is what done in boiler tubes. The turbine story is quiet different ok. When I talk about boiler here, this boiler include the (Refer Time: 05:22) power plant, it also includes a combined cycle power plant. We have (Refer Time: 05:27) combined cycle power plant.

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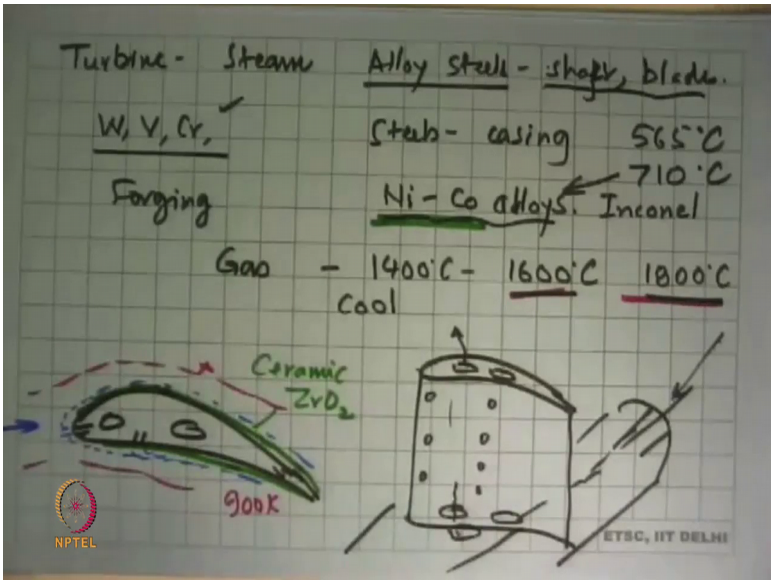

We come to turbine now; first we have the steam turbine. And these are alloy steels, alloy steel for the shaft, and the rotating parts the shaft, blades, and rotating parts. And types of steels for casing the stationary parts, these the real high tech part or these rotating part, because they are not just at high temperature, but they are also rotating, they are transmitting torque. And it has lot of blades on it, they would have also be (Refer Time: 06:16). So, these are alloy steels.

Typically, they will be tungsten, vanadium, chromium alloys, and almost all of these are made by forging. Then they are machine, and finally assembled to make a complete rotor. The casings are produced by casting, and after that they are machine the blade they have put in it on the turbine tungsten. So, this is the material for steam turbines.

Gas turbines the temperature at which they operate are much higher, so this temperature we are saying is limited to 565 degree Celsius the highest anywhere. And I mention here, there are efforts to design it or a temperature of 710 degree Celsius. So, what happens here is steels are of no use, they do not maintain the strength at this elevated temperatures. And so let materials that are used here are various type of nickel based alloys nickel and cobalt alloys.

Make such large components on a big scale is something about technology development is all about, so that is being researched now will be sometime, before we get that the high temperature parts of the turbine will be made out of with these examples could be say what a family of materials called Inconel, define weights of Inconel that there is there. And once the temperature in the turbine after the expansion has reduced, then we make parts of the alloy steels.

Gas turbines have an entirely different story, because the temperature here as I mentioned are much higher than this 1400 degrees Celsius, 1600 degree Celsius stationary gas turbines are already used. And there are gas turbines with like 17- 1800 degrees Celsius. These temperatures are above the melting point of either nickel cobalt alloys or any steel alloy. So, it is not just enough to make the material and the blade, but you also have to actively have a method of cooling it, otherwise this are it will just melt away.

So, what is done is that as the flow takes place over these turbine blades, this is a typical sketch of a turbine blade. What is done in this blade is that be the hollow, at the base also they are hallow, and they set on the rotor, so this is the shaft. This shaft is also hollow, and some of the air from the compressor say about 700 Kelvin, 800 Kelvin, 900 Kelvin temperature instead of going to the combustor by passes that is pump through the passage in the shaft comes in connects with openings inside the blade, comes into the blade, moves through hollow passages inside the blades, comes out either from the top or there are small holes on the surface of the blade from which this air comes out, and what is done is that this air goes over this, and right next to the surface forms small blanket of cool air.

So, if you have to take a top view of this, one can say that this is the blade, these are the passages, and say here and here we were throwing out air over this. So, this air came out, and it went over there, this air came out, the flow over the turbine blade is like this. So, this cold air is going over there, and outside this, it has been hot gases that are flowing over here.

So, the temperature here is what I have mentioned at 1600, 1800 degree Celsius, this air that is coming out is above 900 Kelvin or something of that order. And so the surface of the plane, hence some air is also put out to the back part here, so this is sort of an open here. So, you have a blanket of cold air, surrounding this blade, so that material temperature in this does not go anything like 1000 degree Celsius or even less than that. To further reduce heat transfer to the blades one more thing is done, so this blade are all made of nickel cobalt alloys ok, so that one.

The second thing, they have a small thin coating on the top few 100 micro meters thick, and this coating is made of certain ceramic typically zirconium oxide. Ceramics have very very poor thermal conductivity, so the reduced the amount of heat that will go into the blade, so that we like to have that. The trouble is first ceramics are very very brittle, and in the machine like this if it comes of that is a problem. The second thing is if the blade is made of nickel and cobalt, and this is zirconium dioxide, there is no way that we can stick make Z r O 2, zinc of zirconium to stick to a nickel cobalt alloy.

So, the process of making zirconium substrate on a nickel cobalt alloy, this is extremely complicated. And we build layers and layers of different elements which stick to each other, and the last element in that is zirconium oxide. So, this is a very very so this whole thing casting of this blade, it is a very (Refer Time: 12:08) technology, then to get better mechanical strength. You do not like to have grains in the material, like you have learnt in your say casting or manufacturing process.

So, they try to make this, and pull it in such a way that the whole blade does not have grains, but in a single crystal that has very very good mechanical property, then there are cooling passages, and then there are ceramic coating on top of that. So, gas turbine blades, air craft bridge and blade, especially in the first two three stages, where the temperatures are very high, this is what is being used.

And the result that people are doing is that can we make the entire blade out of ceramic, and that is a huge challenge. But, ceramics cannot be processed by any of the conventional manufacturing techniques that are thought in the typical manufacturing process, so that is about blades used in turbines, so that is the that was one question.

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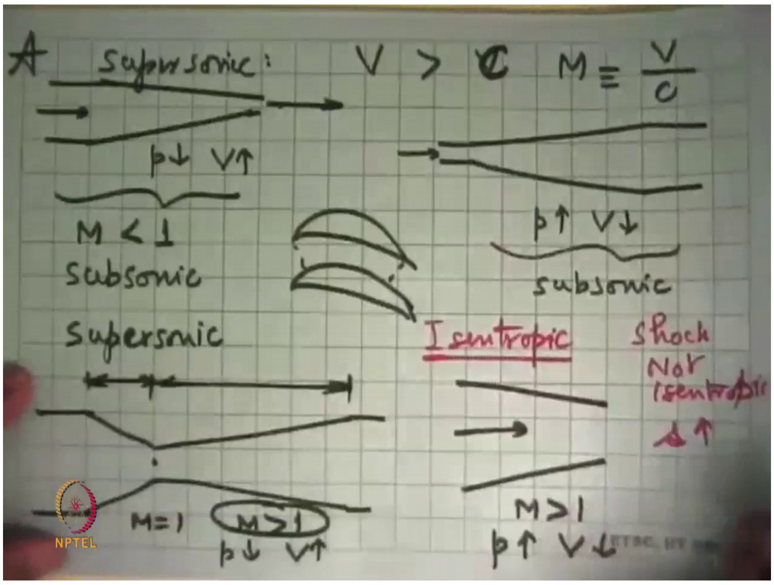

The next question was what about supersonic flow in a nozzle right, so this is what it is? When we say supersonic flow, what we mean is that the local velocity is greater than the local speed of sound or C. I am using the word local, because if you have say a nozzle as the flow goes through it, its temperature is changing. So, when the temperature at different locations is different, so local speed of sound is also there.

So, the Mach number this is we have defined it, as the velocity of the fluid divided by the local speed of sound. And the reason why this thing comes up in the context of nozzle when I am taking it here, say is that you have a nozzle which I have drawn like this yesterday, the flow goes in there, it comes out at a higher velocity. So, pressure decreases, velocity increases, and that behaves like a nozzle.

But, what will happen if that some point, so we are assuming first thing in this that everywhere Mach number is less than 1 that means, this is the flow is subsonic, this behaviour is correct. And the same is case with what we do (Refer Time: 14:39) yesterday. If you have a in passage in which area increases, and need not be a passage like this. I have showed you yesterday that if we make a turbine blade like this two consecutive blade, they produce you can make the shape in such a way that the areas could be equal or areas in the direction of flow could be decreasing or the area in the direction of flow could be increasing, either is possible.

So, here also when we said that the flow goes in pressure increases and velocity comes down, we have also assumed here that this is a subsonic flow. The opposite happens if the flow is supersonic, so this begins to behave like a diffuser, and this starts behaving like a nozzle. So, what happens is really if that if you have a converging nozzle passage, say it is like this, and at this point we have Mach number equal to 1. Then if you further decrease the area, it will not behave like a nozzle, but it will behave like a diffuser, and so pressure will start increasing.

So, now you ask that when I want to accelerate the flowing to a even lower pressure, then what I could get here, I cannot get this. Then what you do, then you put a diverging section, and this part behaves like a subsonic nozzle, and this part is designed to behave like a supersonic nozzle. So, what happens is that in this part we say Mach number is always greater than 1, we are accelerating it more and more.

So, Mach 1, and a area is here pressure will continue to decrease, and velocity will increase, but this is a pre-condition for this behaviour to take place. So, to accelerate fluids to velocities much greater than the Mach number local Mach number possibility the combination of these two is required. The opposite happens here that if we want to decelerate the fluid a supersonic fluid, then this were will not do the job passage like this, if Mach number is greater than 1, this will start acting like a diffuser, velocity will keep going down in the direction of flow, and pressure will increase.

The thermodynamics is the same. And we have not gone into the details thermodynamics of it, but the thing is to think to remember is that as there is no discontinuity in the properties, conservation of mass, and energy, the way we have learned will apply all these flows in the ideal case, as we have discussed these are all isentropic slopes.

And we have seen yesterday, how we could isentropic, it is a hugely irreversible process s will increase, and so the isentropic flow condition can be done before the shock after the shock, but not across the shock. We will not go into full details of what shock is if the whole different topic by it such that there is there is a need in your requirement, we will have a separate module on this types of shocks.

But, so our perspective what we have learned in thermodynamics, this is fine that we could get a we could say that there is a nozzle and expanding it to a pressure, where mach number actually becomes more than 1, but thermodynamics does not tell us what the shape of the (Refer Time: 18:25), you have to get from compressible (Refer Time: 18:27) thermodynamics.