Concepts of Thermodynamics
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Lecture –23
First Law for SSSF Process: Example Problem

In the previous lecture, we were discussing about the Steady State Steady Flow Process. Now, there are many engineering devices which are actually operating or functioning on the basis of this steady state steady flow principle and we will work out a few problems that will illustrate that.

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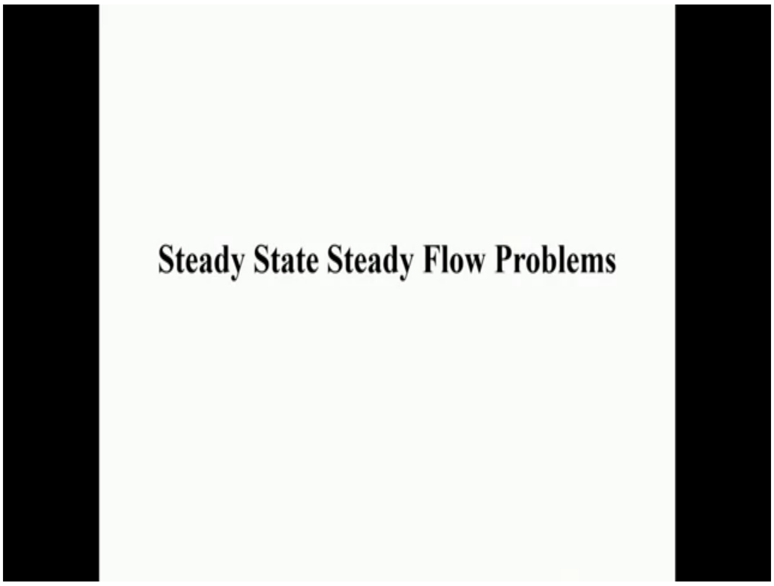

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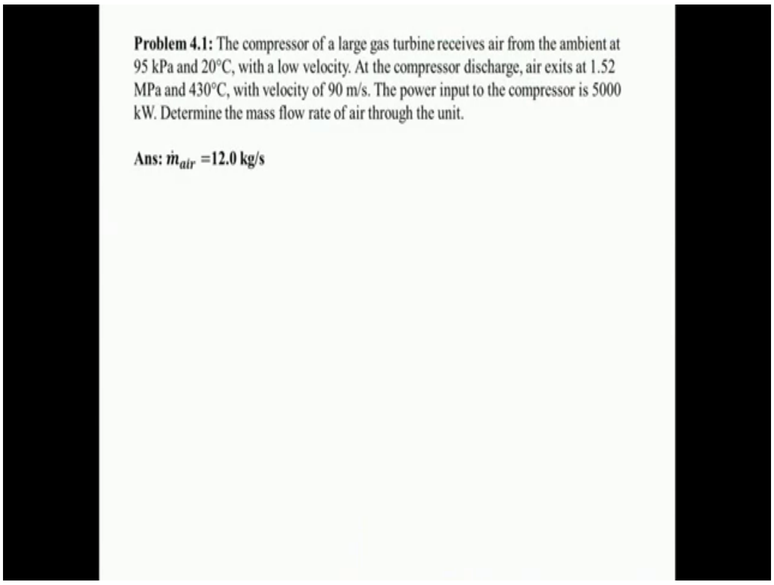

So, we will start with the first problem which deals with the compressor, I will tell you what is a compressor; compressor of a large gas turbine, I will also tell you what is a gas turbine or what is the turbine to be more specific, because you know you are may be as an engineering student, you are learning this terms for the first time. So, for solving a problem it is important of course, to solve the specific problem, but also it is important to have a broader idea of the engineering system which it is trying to address.

So, let us go through the problem. The compressor of a large gas turbine receives air from ambient at 95 kilo Pascal and 20 degree centigrade with a low velocity. At the compressor discharge air exits at 1.52 MPa and 430 degree centigrade with a velocity of 90 meter per second. Power input to the compressor is 5000 kilowatt; determine the mass flow rate of air through the unit.

So, I will try to explain this problem in the board as we have done for the other problems in the same course. So, first of all what is a turbine? Forget about gas turbine or steam turbine; so, keep in mind that, there are devices which take the help of thermal energy and convert the thermal energy into useful work or power; turbine is one such device.

So, turbine takes a fluid at high thermal energy. So, high thermal energy means it can come from a combustor or a boiler this kind of you know, it depends on the whether the turbine is handling a gas or a steam or what type of system. So, essentially fundamentally there is a heating device which increases the thermal energy of the fluid and then that fluid enters the turbine, because you cannot get power out of 0 cost.

So, the cost is heating the fluid; so, that is why you require fuels. So, when you heat the fluid, it is thermal energy get elevated that is reflected in the form of enthalpy if it is flowing. So, that energy is now converted into kinetic energy. So, maybe there is a nozzle which is essentially of fluid flow device with decreasing area of cross section; so, if the cross section area from large to small it is decreasing to maintain the same flow the kinetic energy is increasing, because the velocity is increasing. So, with that high kinetic energy so, entire enthalpy of the fluid is converted into kinetic energy with that high kinetic energy, the fluid is falling on a wheel.

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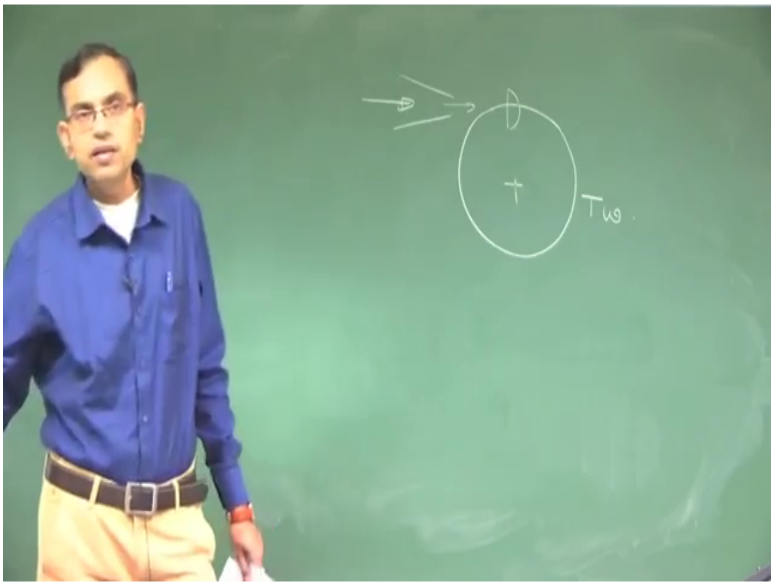

So, let us say there is a wheel like this and there is a nozzle, here the fluid enters with a high enthalpy and from here it comes out with high kinetic energy and here there is something which is a blade of the turbine. So, when this fluid strikes the blade, there is a linear momentum change and there is a moment of the linear momentum with respect to the axis of this wheel that is called as angular momentum.

So, the moment of linear momentum does change and therefore the angular momentum does change. When there is the rate of change of angular momentum, then there is a torque and this wheel with this impact on the blade starts rotating. So, when it starts rotating, there is an angular velocity so, there is a power produced which is the product of the torque and a angular velocity. And essentially, the hallmark of the power produced is that the shaft on which this turbine wheel is mounted, this is the turbine wheel that shaft starts rotating and so, that is the mechanical part of the energy generation.

Now, this shaft is coupled with the shaft of the alternator which is the electrical part of the power generation and that is how, the mechanical energy is converted into electrical energy and that energy is you know transmitted and distributed to across the grids. So, this is one of the very basic mechanisms of thermal power generation and turbine essentially happens to be one such a component where this energy conversion takes place.

Now, when you have a turbine, the pressure of the fluid gets reduced, because the fluid essentially gets expanded in turbine to maintain a mechanical as well as the thermodynamic cycle, the pressure of the fluid which has come down has to be elevated again to the pressure at which this energy transfer takes place. And that device where the pressure of the fluid is elevated, it is called as either compressor or a pump depending on whether it is handling a gas or it is handling a liquid.

So, in this case for a gas turbine, the problem is the compressor of a large gas turbine. So, this is handling the gas at low pressure and converting the gas to a high pressure gas and that is possible by employing this device which is called as the compressor. So, I think this little bit of background is needed for all the problems that I will be solving, I will try to give this little bit of engineering background, what it is? See solving a problem is about putting numbers and getting an answer, but what is the brought practical perspective which this problem solving is allowing you to develop, that needs to be discussed and that is how we will approach.

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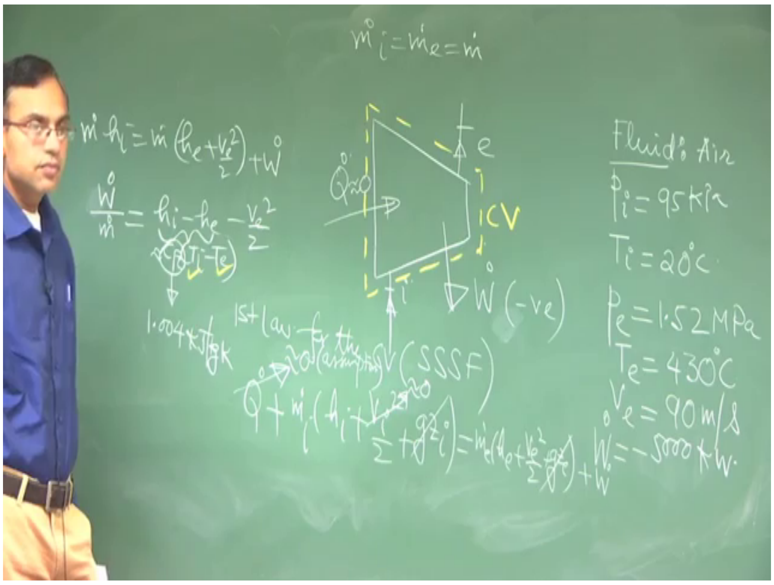

So now, in the thermodynamics perceptive, the act of you know drawing a compressor is something like this; so, let us say that you have the inlet and you have the exit just like this. So, because you know, it is compression, generally symbolically, it is drawn in this way, that you have a large area and it is you know it is sort of taper into a smaller area, this is how a compressor is normally so designed; I mean, drawn in the schematic way. If it was a turbine where the fluid expands, this could have been i and this could have been e.

So, it is the inlet is from a small and outlet is from big, it is not it has nothing to do with whether it is actually entering a channel or pipe with high area or small area, it is a conceptual diagram representing the device, that is all.

So now, when you have this in the compressor, remember that nothing is available at free cost right. So, you are pressurizing the gas from low pressure to high pressure, you have to pay the penalty of that. So, what penalty you pay? You put some work, right you put some work so that this pressurization of the fluid is possible; so, there is some work input.

So, conceptually we will write this W dot, but this is negative here; actually it is work input and you can also have a Q dot for all practical purpose. In this device, the work done is more much more significant than heat transfer so, this will be approximately equal to 0; so, this is the schematic representation of the device.

So, the fluid is air, P i is 95 kilopascal, Ti is 20 degree centigrade, I am just looking into the problem statement and writing the relevant properties. Pe is 1.52 MPa, Te is 430 degree centigrade, Ve is 90 metre per second and the power input to the compressor is 5000 kilowatt. So, W dot is minus 5000 kilowatt, input so minus very important.

So; now, what is the mass flow rate of air? So, compressor see these are the practical understanding that you have to develop when we say, compressor in a power plant just at that time it should strike you, that it is a it is modelled as a steady state steady flow device, there may be minor deviation from steady state steady flow concept, but it is model like that. So, practical it is very close to steady state steady flow process.

So, first law for a so for a steady state steady flow process you have to define a control volume so, this is your control volume. So, without drawing a control volume, your problem solving is meaningless, you have to define a control volume and based on the control volume, you have to write the expression.

So, first law for the control volume, for a steady state steady flow process Q dot, I have written the first law of thermodynamics expression as we have derived in the previous lecture. So, first of all see nothing is told about the compressor whether it is adiabatic or not, but from practical considerations, because this device is primarily related to work transfer.

And the work transfer is huge and the rate at which the process takes place is so fast that there is insufficient opportunity for heat transfer to take place. So, keeping all these into account it is therefore, practical to assume that, this is 0 this is an assumption; this is the first assumption.

So for all problems please note down the assumptions; I am not writing separately in the board, but I am formally telling you, the first assumption specific to this problem is there is no heat transfer, second assumption is there is negligible change in potential energy and third assumption is that the inlet kinetic energy is negligible as compared to the exit kinetic energy and that is quite logical because after pressurising the flow, the flow velocity it gains a value which is this one 90 metre per second.

So, earlier before pressurizing the fluid was not at that high kinetic energy and also because there is one inlet and one exit; so, mass balance wise, m dot i is equal to m do t equal to m dot. So, we are left with m dot into h i is equal to m dot into h e plus v e square by 2 plus w dot.

So, you have a w dot by m dot is equal to hi minus he minus v e square by 2 right. Now, I mean there are many assumption that go with the practical problem solving.

So, the next level of assumption comes can we treat air as an ideal gas. Well, in many cases the temperature difference is so huge, the pressure difference is so huge, that the ideal gas assumption even if it is taken, constant Cp Cv cannot be taken. Air as an ideal gas, normally at moderate pressures and at reasonable high temperature is not a bad assumptions. So, here the pressures are moderate, temperature while inlet is not that high, but exit is high, but it is not that high, that Cp Cv will vary with temperature and Cp Cv if it varies with temperature, then it is called a calorically imperfect gas.

So, here just for simplicity we will consider it to be calorically perfect gas; so, this will be Cp into Ti minus Te. Constant Cp we often write Cp 0 to indicate that, we are assuming this fluid to be not only an ideal gas, but a special case of ideal gas which is called as calorically perfect gas where Cp and Cv are constants ok.

So, what is the value of Cp of air? Cp of air, if you take that constant, it is 1.004 ok, Ti and Te are given ok. So, what is Ti? Ti is 20 degree centigrade and Te is 430 degree centigrade, w dot is also given. What is Ve square by 2? So, this is where believe me or not, 90 percent of the students make mistake and this is actually in terms of concept of very minor mistake, but in terms of getting the final answer, it is a very severe mistake. See all these units, we are putting in terms of kilo joule, kilowatt like this.

So, w dot 5 minus 5000 kilowatt, Cp this is kilo joule and this is Kelvin. So, then it becomes kilo joule per kg this becomes and with m dot multiplied it becomes kilo joule per kg into kg per second. So, kilo joule per second, it will become kilowatt; so, this is kilowatt, this is kilowatt. So, these also has to be in kilo joule per kg whatever. So, if you directly substitute it as 90 meter per second, then it will be in joule not in kilo joule.

So, in this expression I am writing it separately, see my job as a teacher is not just to give you know concepts which are very nice and abstract, but also to help you to you know workout problems in accurate manner.

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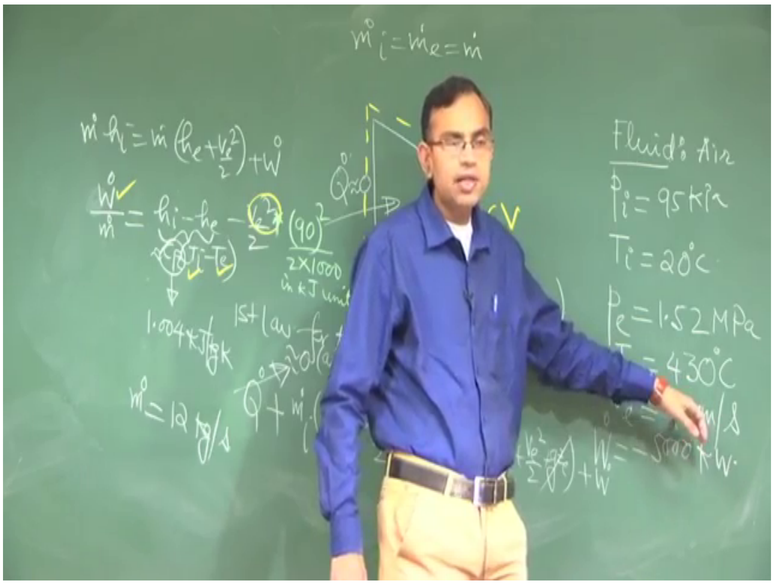

And here, this if it in kilo joule units, if you write this is 90 square by 2 into1000; so, this is joule divide by 1000. So, this is in kilo joule unit ok.

So, if you do all this, then m dot. So, you substitute all this then m dot will become 12 kg per second. So, we have taken a good amount of time today to solve a problem and I will not solve any more problem in this lecture. the whole understanding is that I must give you a gestation period, this is a kind of a very routing problem in thermodynamics whoever is solving a steady state steady flow problem, but for you the solving the problem is not trivial, you have to understand first given the device what is it is, you know what does it do in engineering, can it be approximated as a steady state steady flow device, if it is approximated as a steady state steady flow device, what are the subsequent assumptions? Here, what are the assumption that we are made? See nowhere in the problem it is given that assume the compressor to adiabatic, but from here we have learn that assuming the compressor as adiabatic is not a very impractical preposition. So, when you say adiabatic see, always if we say something is less; it has to be less in comparison to something which is more. So, what are more here? More here are the changes in thermal energy and the work transfer.

So, as compared to the changes in thermal energy and the work transfer, the heat transfer is small. So, it should not be technically taken as adiabatic; it is negligible heat transfer as compared to work transfer and the change in thermal energy, that should be the spirit and this spirit is maintained for analysing the compressor.

Then we are neglecting Vi as compared to Ve, there are many situations where for the compressor, we neglect the change in kinetic energy all together. Sometimes we say, they loosely for solving a problem neglecting kinetic energy; we are not neglecting kinetic energy, we are simply neglecting changes in kinetic energy for those problems.

In this particular problem, we are not neglecting the change in kinetic energy, because we can be more precise because this information is already available, had this information not been available, typically in thermal devices data for temperature, pressure all these are recorded, but sometime velocity data is not recorded, but change in kinetic energy if it is negligible as compared to change in thermal energy, then that contribution sometimes is neglected. And potential energy change also is neglected. So, it is not kinetic energy, potential energy as such which are neglected, but changes in kinetic energy and potential energy these are neglected.

So, with those assumptions and the final assumption that air is an ideal gas with constant Cp Cv, we are able to solve this problem. So finally, let us summarize, if somebody ask you given this solution of the problem, what are the all the assumptions. So, let me point these out one by one; first assumption that all properties are uniform across the inflow and out flow.

So, at the inflow so this is not a straight line right, there is a pipe which is supplying to it, there is a pipe through which it is leaving. So, properties across the section of the pipe are uniform for i and separately uniform for e, then it is steady flow and steady state; so, steady state steady flow all together.

Then negligible heat transfer as compared to other modes of transfer of energy, negligible kinetic energy at the inlet as compared to the kinetic energy at the exit, negligible changes in potential energy and air can be treated as an ideal gas with constant Cp.

See, so many assumptions we often forget and try to put a formula to solve a problem, but so many assumptions are there to analyse this very critical device which is the compressor, which is very important for many power plant and refrigeration applications.

Thank you very much for trying to patiently understand the details of solving this problem, we will continue with more problem solution in the next lectures to follow.

Thank you.