Engineering Thermodynamics
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Lecture – 19
Laws of Thermodynamics: Devices. Cycles

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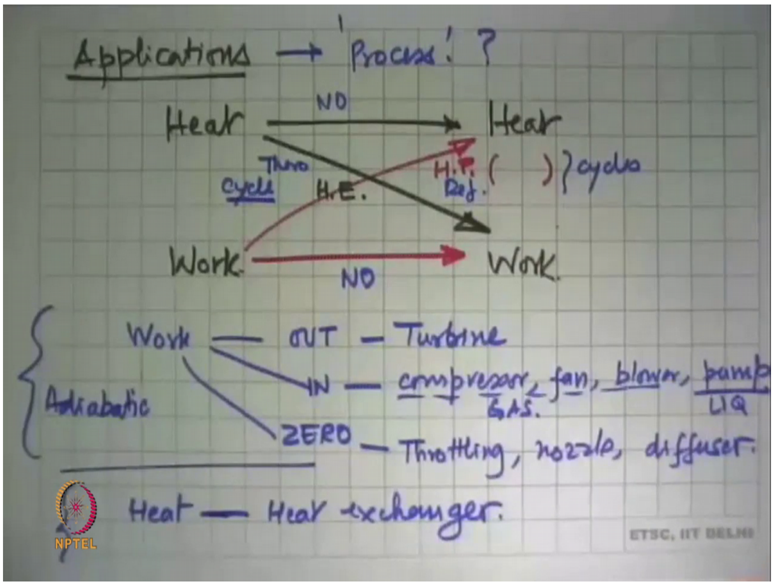

Now, what I want to do is look at all types of devices. So, now we will start getting into the application and say how can I apply these laws to different devices and so we say applications. And let us look at it in general that what we have talked about the thermodynamics is the inter relationship between heat and work. So, I am writing down here heat and work what we start with and heat and work that is our output.

And let us see now, what is the transformation of heat and work that is what a thermodynamics and that would laws available. So, (Refer Time: 01:06) as I can convert heat to heat, this is nothing but heat transfer. So, Fourier law of conduction, Planck's laws, these are what governed this. When you say that why to why to convert heat to work, what is that? And we just saw that this is your classical heat engine of thermodynamics and that is how the laws govern this conversion, which means that this is governed by the you know Carnot limit Carnot cycle.

Now, say work we have convert work to heat. Example of this is a bridge, you have worked (Refer Time: 01:56) friction on it f into d s at the break shoe, everything get converted into heat. There is no restriction, whatever work is there we can heat. But, we do have a possibility of making this into a heat form, this is limited by our second law statements.

And of course, all of them must obey the 1st law and the 2nd law. And the last one you have to convert work to work, you have to convert work to work this is like example is a gearbox or a fluid flowing over something and doing work. So, this is not a cycle; this is not the cycle, so, we make that clear now, which are the cyclic processes heat to work, but this is not a cycle, work to work is not a cycle. So, there are no limits on this and that is what happens in heat exchanger a radiator of an automobile, you have hot coolant coming in and gives all its energy to the surrounding air.

So, all the energy that the water gave out or the coolant gave out was taken by air. So, it is a what fraction went out, 100 percent went out. Work to work you have a gearbox you are putting work in you get work out of it, inlet was work, output was work and it is there is no friction or anything inside the gearbox. There is no reason, why it should not have 100 percent efficiency. Now, real in life there is friction maybe 98 percent and 99 percent efficiency.

So, I want to convert heat to work, now we have the issue that yes we have the laws of thermodynamics, which will tell us how best you can do this. And if you do it in a cycle, what are the limitations on this. I am here putting in work and pumping heat, then yes either heat pump or a refrigerator, they are both governed by cycles. And what we are learned here comes into play. So, the limits of cycle efficiency come only in these cases not in the other cases ok.

So, let us see how this thing works out. So, if it is not a cycle and application is only a process, there something happens. Then what does it tell us about the goodness of that process, how efficient or how good that process can be this is the question we are asking, and we will look at the series of process ok. So, what we have just looked at is one case where there was work. So, we have a work think where you can have work output device or you can have work input device or no work.

A thermodynamic process takes place no work and let us assume that in this device there is no heat transfer also, so, this is adiabatic. So, a device where you have work output, the most common one is a steam turbine steam turbine or a gas turbine or even a hydroelectric turbine. So, these are devices we have work output is there. Work input devices is the opposite of a turbine which is the compressor, but we can also include here a fan, a blower or a pump the difference is that; a pump handles a liquid these will handle a gas or a vapor. A turbine is a generic name if it handles a gas, it is called a gas turbine. If the substance flowing through it is steam, it is called a steam turbine. If a water flows through, it is called a hydro turbine, but they are all turbines.

And process where there is no work at all and these are processes like expansion or throttling or nozzle and a diffuser, so that many types of devices we can make besides if we have to say where there is heat transfer taking place, then basically we are looking at the heat exchange. So, work related devices is one category, heat related devices is another category. We are looking at it differently, because we saw in the Carnot cycle that you liked a two process where there is only heat and no work. And two processes where there is only work and no heat transfer, so that is how we are trying to look at these applications.

So, let us start with by looking at say the turbine. In the beginning, I had shown some pictures what the real thing looks like, these are very small machines these days some may very small turbines, micro turbines people talk of big turbines, which can go power of puts of 1000 megawatts. Those are the biggest turbines that you have look (Refer Time: 07:24) in the world.

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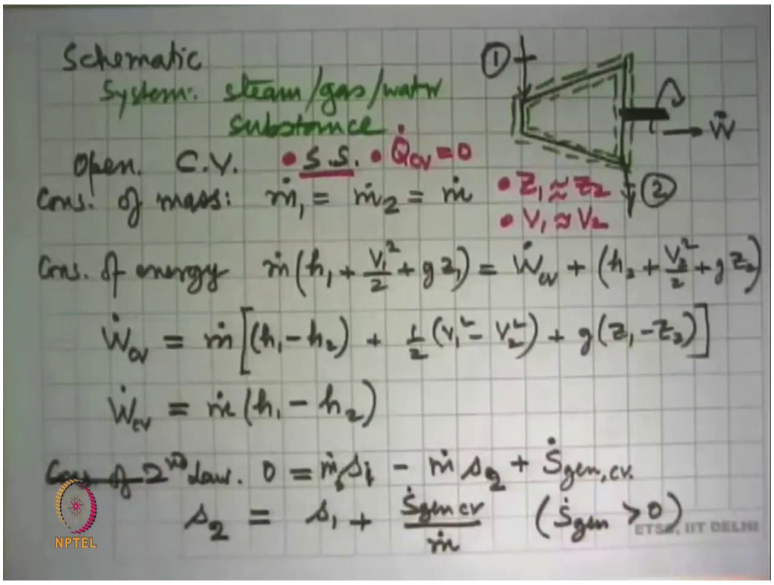

And the generic symbol for a turbine is this. And so we say that this is what we do first is make a schematic, the real turbine was very big and huge and complicated, we make a very simple one. This has got work output coming over there, output because this is continuously doing work, it is not intermittent like a cylinder piston element. There is flow into this which is at state-1, they flow out state-2 and the ideal case we say that there is no heat transfer across this.

And so we did not define the system boundary that it includes all the steam inside this system or if you want to be very clear. Even if you make this, you would still have to clarify that it excludes the wall excludes all the metallic parts inside this and the system is only the steam or the gas whatever was there in it or water the substance. And we want to analyze the performance of this.

So, we do the same thing what we done always, and in every problem we do the same thing. First look at this thing and say is it an open system or a close system. And say well there is steam going in and flowing out. So, there is mass inflow across the system boundary mass outflow across the system boundary, so, this is an open system. And approach and the equations that we shall use for this are the control volume approach.

And the first one is conservation of mass, and it tells us that in steady state we assume that only one inflow and outflow m dot 1 is equal to m dot 2 which we say is equal to m dot. So, we made one assumption and we should keep track of this, so, this is assumption number-1 steady state. The second thing we want is conservation of energy, we have already assumed that there is no heat transfer across this. So, this means that Q cv dot is equal to 0, steady state also we have assumed. There is only one inflow outflow, so that big equation that we had can now be simplified. And we have m dot into h 1 plus V 1 square upon 2 plus g Z 1 is equal to W dot cv plus h 2 plus V 2 square upon 2 plus g Z 2.

And by rearranging terms or objective is how can I estimate the work that the turbine gives out W dot cv, this becomes m dot and now inside brackets we can put all these terms matching there. So, this is h 1 minus h 2 plus half V 1 square minus V 2 square plus g times Z 1 minus Z 2.

And now we say that in real turbines this distance is of the order of a couple of meters, which for material like gas or a vapor is in significant. So, our next assumption comes out that Z 1 is almost equal Z 2 we can neglect this and the way practical turbines are made this velocity will be something, this velocity will be slightly more, but not very much more in that this total quantity will be much smaller. So, we can neglect that one also that is in this is almost equal to V 2.

But, if we are given the value of velocity at the outlet, we cannot make this assumptions and this term will stay. Right now we are saying that these two velocities are comparable, so we are mocking them up. And that these left with a very very simple elegant equation that the work output of this turbine is mass flow rate into enthalpy at the inlet minus enthalpy at the outlet. So, all that labor we did in going through that comes to the simple because of this assumption that we made. And the essence of research and design development is how can I keep making a machine by making less and it is assumptions are still making it more efficient.

So, right now we are beginning this, so this is what we have done. And then we say what does conservation of sorry the 2nd law of tell us. And it was that big equation we had written that rate of because of this, it is 0 on this side this is s m dot i s i, which is m dot into s i m dot into s e plus rate of generation of entropy in the control volume.

So, if you look at this equation and we say look I make one more assumption. And I know that this is always going to be a positive number. So, what it tells us is that if we rearrange the terms s e, which is s at the exit sorry this is I should put here 1 and this is two. s 2 is equal to s 1 plus s dot generation in control volume divided by m dot. And we have argued that s dot generation will always be greater than 0, because if there are irreversibility’s.

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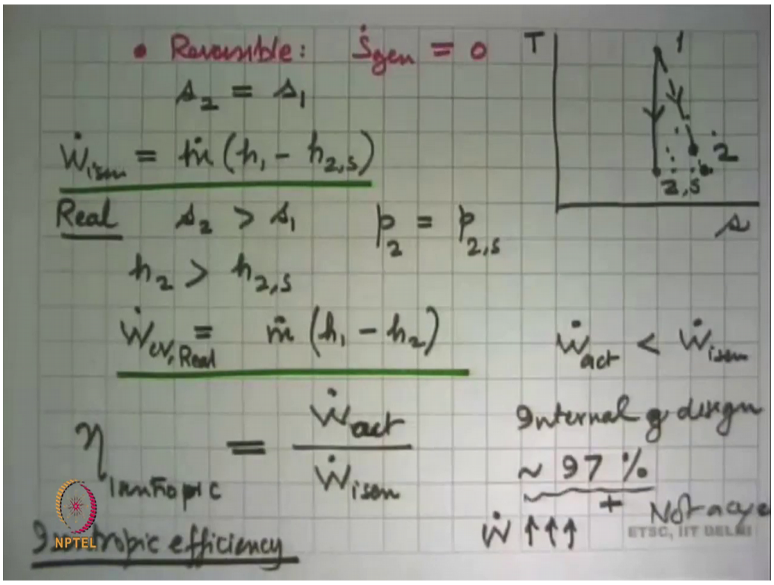

And now we argue and say let us look at first the case where the turbine is completely a reversible turbine, so that is the next assumption we make and later on we will reverse this. So, reversible turbine then s dot generation is 0 and we have got what the 2nd law tells us is that s 2 is equal to s 1 ok. So, if we now go back and say that let us try to plot it on a property diagram, this side is s, this side is T, then what it tells us is that s 2 is equal to s 1 that means, it will be a vertical line.

And the question is the process is like this or the process is going to be like this comes from here, turbine is got the network output. So, h 1 is less than h 2, so, we will say that state-1 was there, and the reversible turbine came down and come down to state-2. And what was important is that this was the case, we will call it 2 s to denote that this is the outlet state of the steam, if though turbine were isentropic.

So, what we can now write is that W dot cv or W isentropic, this is equal to m dot into h 1 minus h 2 s. And this is the maximum work that one can get from a turbine, what would happen in a real turbine. The thing is that this equation tells us that the real equation this is going to be the case. So, in a real machine s 2 will be greater than s 1, we do not know by how much. So, what it tells us is that in the real machine, the exit state will be to the right of this point, it could be here there or there or may be there somewhere or maybe there somewhere we do not know.

So, but wherever that state is and say in general we just put it over there and say this is state-2. Then the process that happens in the turbine will be this line and that is an irreversible turbine. And the condition that we put in such a case is that I will expand it to the same pressure that p 2 is equal to the pressure that was there in the first case or you can even talk of. If it is temperature, then of course these two will come over there, the line will be the same in that case.

So, given this now what happens is from here we know that because of irreversibility's the work output is going to be less, because some of that energy is going to be lost in friction. So, it is there and so h 2 will be greater than h 2 s. And what when we put that back in the formula W dot cv is equal to this, now remember this formula is valid for any process reversible or irreversible.

So, W dot cv this for the irreversible thing say we call the real cycle, this is m dot h 1 minus h 2, whereas for the isentropic case we had this equation this was the isentropic case, this is the real case. And what is coming out of this is that the real machine the work output or we call it say actual thing is less than W dot isentropic. So, we now want a measure of how good the turbine is and we call that and efficiency of the turbine, where we compare its actual output to the ideal output that is possible from that condition. So, this is called the isentropic efficiency, this is equal to work output of the real turbine or the actual turbine divided by the power output of the isentropic turbine, so that is the concept of isentropic efficiency and the formula that you see here is valid only for the turbine, it will change slightly for other cases.

But, what has happened here is that it tells you how good are we and as things have changed the design, this entirely depends on the internal design of the turbine. The design of the flow passages, the design of the blades, the design of the surfaces, all those things come into play. And large turbines that operate these days like in power plants 500, 800, 1000 megawatt turbines, their isentropic efficiencies are typically of the order of 97 percent. And slightly going up, but very very slowly that means we are very close to what the ideal turbine will do, but slightly will of maybe 2 percent, 3 percent, 4 percent less. Smaller the machine, this efficiency keeps decreasing.

And if you get a very small turbine, your isentropic efficiency may be as low as 10 percent or 5 percent or 3 percent. And that is the reason, why historically the capacities of turbines the power output kept increasing, because that way your isentropic efficiency kept going up. And if you look at the history of power generation, sizes of turbines kept growing for a very long time until the 70's and then somehow because of the nature of the power industry, it has not grown too much.

But, 97 percent isentropic efficiency is typical of big turbines not small turbines ok. So, this is one thing which has come up is isentropic efficiency, and this is not governed by the Carnot cycle be very clear on that. This is not a cycle, but what we have done here in this efficiency and so cycle efficiencies are not applicable in this case. So, it tells you that your individual equipment is very very efficient. And the generator coupled to it takes mechanical power in, mechanical power out.

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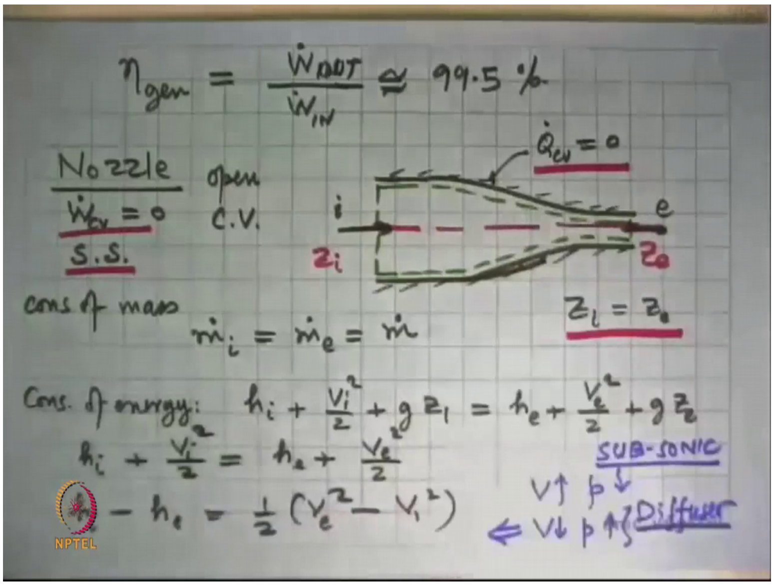

And so we can define generator efficiency and that is not an isentropic efficiency in this case, but it will be an ideal case that work input divided work output divided by work input. We are not comparing it with the ideal case, but big generators this efficiency is of the order of 99.5 99.7 percent. The remaining is losses lost is magnetic losses, heat losses I square are losses, but big generators are very very efficient.

So, this is one part of the story of what happens in a work producing device, how efficient can we get? Hydro turbines efficiency will be somewhat lower 90 percent, 95 percent, but still scope to improve it. So, before I go further, we have some questions, let us take those questions. Here how Bernoulli's equation relates to thermodynamics that is one question.

So, I just showed you by starting with the laws of thermodynamics, we made a series of assumptions and it is under those assumptions that we got Bernoulli's equation. Note it tells us if that if any of those assumptions were violated, Bernoulli's equation cannot be applied. And to say that fluid mechanics is disconnected from thermodynamics is not entirely true knowledge is not really that is connected, so, do not worry too much about it.

If there is flow taking place and you are heating it, Bernoulli's equation cannot be applied. If you are cooling it, Bernoulli's equation cannot be applied. If air is going through a pump and you say my state one is at the inlet of the pump and two is at the outlet of the pump, we cannot apply Bernoulli's equation.

If you take a streamline of a air going through the ceiling fan, you cannot apply Bernoulli's equation on that. So, the assumptions are very important telling us, where it can be applied, where it cannot be applied. But, it is the same Bernoulli's equation where in fluid mechanics, you derived from a different set of assumptions, but embedded in that are all these assumptions ok. So, in that case thermodynamics is much more over encompassing than what fluid mechanics was telling you.

The next question here is whether internal energy of system changes with change in pressure and volume ok. So, the change of internal energy with pressure and volume there is a change, when we look at properties of a substance and processes that happen there, we will hope numbers on that ok. Then there is a question here which says a standard enthalpies of water or any substance at specific temperatures, then is this enthalpy h equal to p equal to u v are use this standard enthalpy calculation, the answer is yes. So, if you look up any property tables, the h value given there is equal to u plus p v. So, if you are given u and p and v in that table, this plus u plus p v is the value of the h which is there in the h column, so, absolutely correct ok.

Why entropy is 0 for reversible process well, it is not entropy is not 0, entropy change is 0 for reversible process, your entropy generation is associated with irreversibility's in the process. Friction, unrestrained, expansion, heat transfer, so if none of those are happening in the ideal case, the entropy at the inlet outlet or the beginning and end of the process will not change. So, entropy change during that process is 0 ok.

The next question here is how v 1, v 2 are equal in a turbine ok. I accept that this is an assumption that the velocity at the inlet and outlet are same, they need not be the same. If some turbines they are similar, but not very much different. But, in some turbines the outlet velocity could be much larger than the inlet velocity if that is the case, then this term will have to be kept there and then the efficiency definition will also have be put it back way. So, then it cannot be neglected. So, I am making a very restrictive case, just to show you what is isentropic efficiency, but you are right in some cases that will not (Refer Time: 25:01).

And here is the question let a person is receiving heat energy from the sun according to 1st law as the internal energy may increase or he can able to perform extra work, but neither of these things happen instead he loses energy y (Refer Time: 25:18). Now, what you have stated is that a person sitting there, he was losing heat to the surroundings and the same time getting input from the sun as radiation.

If you look at the entire analysis, if you are it is actually the case that if you when you feel warmer and warmer, it means that your body temperature is going up. So, internal energy is increasing, because you got heat coming in from the sun that were not there you will think much more colder especially in cold climates, so that is not entirely true. But, the 1st law tells you that generation of heat in the body, then plus heat transfer across this system plus your breathing inflow, outflow all of that is connected by the 1st law. The question here is why volume is constant in reversible adiabatic process, so, a volume is not constant in the reversible adiabatic process, entropy is constant that is all. So, volume will change, so do not be worried about that volume will change ok.

So, we look at one application. Now, we have to look at another case, we will look at what is called a nozzle. A nozzle is a device where basically you are accelerating a fluid. So, we say that one typical nozzle would look something like this and the fluid comes out at high velocity. So, you have got a system that we will call this as this is the system boundary and here you have inflow there, outflow there, so, this is one this is i, this is e. These nozzles are not very long, so, heat transferred to the surroundings here is going to be very small.

Moreover, if they are insulated, then we do not have to worry about that fact that is these were insulated or if they are too small to allow any mini equal heat transfer be take place, you would be quite justified in saying that Q dot cv is equal to 0 or we are looking at a adiabatic movement. The way I have drawn it, there is no work producing device no shaft work or anything else happening, so, naturally W dot cv for this is 0.

And like before, let us assume that the system is in steady state. So, under all these conditions, the conservation of mass we say that this is an open system, there is mass going in and out of the system boundary, we apply the control volume approach. And so for that conservation of mass equation now becomes there will be one inlet one outlet m dot i is equal to m dot e is equal to m dot.

And then conservation of energy we can simplify those things Q dot cv is 0 W dot cv is 0 steady state, so the d by d t term is also 0. So, we are only left with a two flow terms mass flow rate on both side is the same. So, h i plus V i square by 2 plus g Z i is equal to h e plus V e square by 2 plus g Z e and being a small device. And if it is kept horizontally, one can say that the gravitational elevation difference is negligible. So, what we are left is just this term now h i plus V i square upon 2 is equal to h e plus v e square upon 2 or h i minus h e is equal to half V e square minus V 1 square (Refer Time: 29:38) the working equation that we want for a nozzle. Of course, the assumptions this is 0, steady state, no heat transfer, no change in elevation.

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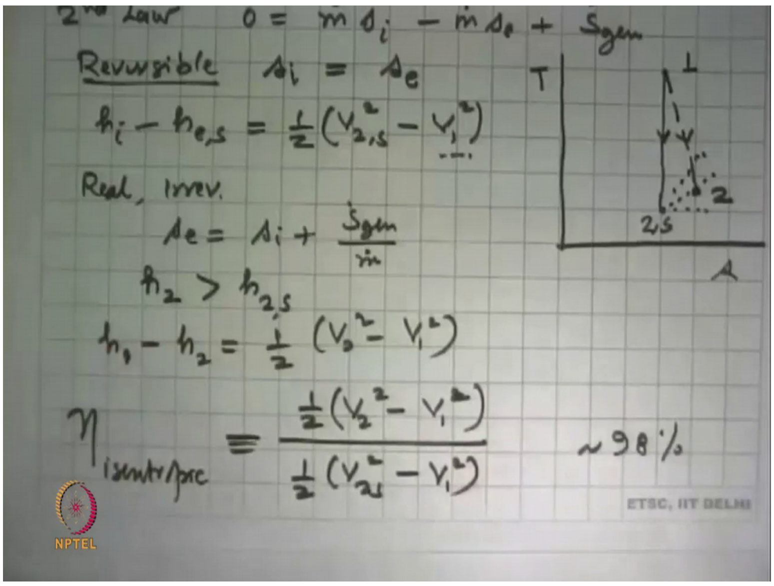

And now the 2nd law; again this becomes 0 is equal to m dot s i minus m dot s e plus rate of generation of entropy in the control valve. And we again like before do an ideal case first say that the nozzle is reversible that means, there is no generation of entropy, so s i is equal to s e. And say if that is the case and on the T s diagram, this is T, this is s this will again be a vertical line, but what is happening here? There is no work output, but the substance got accelerated, otherwise this equation will not be satisfied.

So, a state-1 is there and this comes down vertically down to state-2. And this is 2 s the isotropic state that is the process. No work, no heat, so the only thing that can happen is what the 1st law tells us is this one that the enthalpy change results in a large velocity change. So, we have h i minus h e isentropic or you can say two isentropic, this is half say I will put V 2 isentropic case square minus V 1 square.

And if the inlet velocity were constant, then we say that this difference will be largest, when this is smallest, so the isentropic case will give you the largest acceleration of the fluid. If it were a real nozzle with irreversibility's, then this equation tells us that s e is equal to s i plus rate of generation of entropy upon m dot that means, that real state will lies somewhere there. And say it lies over there this is state-2 and this becomes our process in the actual case. And the only way this can happen is because of friction inside the nozzle. So, fluid is rubbing over each other or the fluid is rubbing past the surface, and that is what is called the irreversibility.

So, in this case now h 2 will be more than h 2 s. And so the real case this will become h 1 minus h 2 is equal to half V 2 square minus V 1 square. So, the velocity increase will be less than the velocity increase in the isentropic case. And so for a nozzle we define isentropic efficiency has the maximum velocity change that we can produce which is the isentropic case, and the actual velocity change that we could get that is the case. And again there is no restriction on whether this will be 80 percent, 90 percent theoretically except for that friction, it can be quite high. So, 90 percent, 95 percent, 98 percent type of efficiencies are typical that is the second application that we looked at this was a nozzle.

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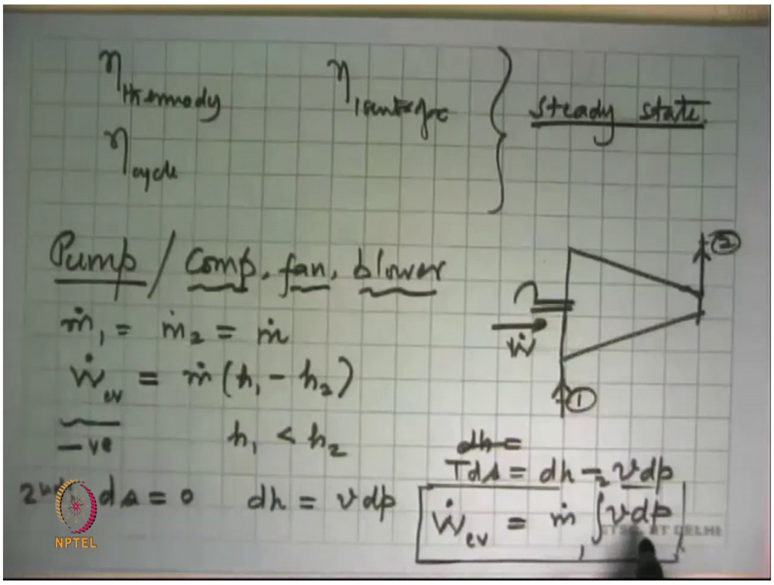

And why we are talking off all these efficiencies, there is one thing to remember that whether it was the cycle efficiency, which is what did we call the thermodynamic efficiency or the cycle efficiency or these efficiencies which are isentropic efficiencies all of them can be talked off only. And if and only the system is in steady state, otherwise efficiencies are not defined very important, because, in the practical in on in paper and problem solving we can always happily talk about it.

But, if you should look around and say look how can I get the efficiency of internal combustion engine in the laboratory, well you started the engine and you want to get steady state that means no parameter should change with time. So, to ensure that the cooling water temperature does not change with time, the ambient air temperature does not change with time, I mean pressure does not change with time and we know that over a few hours none of these conditions will be true. So, to actually do a test of a performance of an internal combustion engine, it is extremely difficult you need a very very well designed well controlled environment, which costs 100 crore rupees. And it takes a lot of money to actually do one test, and that is the only test which actually makes sense.

The same thing is the case of a operating power plant, where whole the day that ambient temperature keeps going up and down and how will you get steady state, when the temperature of air going in keeps changing all the time. It is very very difficult to make measurements, you have to make special test chambers in which we can do that and those are well documented in various processes and standards with which you can measure the efficiency of these devices, so that was the isentropic processes.

We will now come to another process and which is slightly different from what we have looked at we look at pump. But, in general we will first look at work input devices like a compressor or a fan or a blower, they slightly they mean slightly different things to from each other. In that a compressor is something that has a very large, pressure increase from inlet to outlet. There are fans and blowers the pressure increase is not much, but the volumetric flow rates are very large compare to what compressors, so that is the only difference between these two.

And before we go that, let us go back to the nozzle. And say look now if I run this nozzle in the opposite direction, what will happen? And you say look there were no irreversibility's if I just reverse everything, then I should get exactly the opposite portion that I started with. So, what it will do is the flow comes in and goes through this process the velocity will decrease and what I have not mentioned really that velocity increases in the direction of flow, the pressure decreases. And if you make the whole thing opposite then in the opposite direction flow going this way, velocity will decrease, pressure will increase, and this device is known as a diffuser.

There is a small catch, we will not worry about at this point too much is that these definitions and these behaviors are true. If the flow inside, this is subsonic that means, the velocities are much smaller than the local speed of sound, but does not worry about it for this time ok. So, diffuser the analysis will go exactly the same way, and the isentropic efficiency of the diffuser can also be defined in this way.

So, now let us look at this compressor or a blower and what you are seeing here is the schematic diagram of that is exactly the opposite of the turbine. Flow goes in and we make it into a larger area, because as it goes it gets compressed, it becomes more dense. So, the area of the machine also decreases and comes out at that side. But, in order to make that happen, there is work input into this. If instead of a gas or a vapour, this was handling a liquid going in through this that will be called a pump. So, the analysis will go exactly the same way we did for the turbine and we can actually borrow all those things from there that if this was 1 and this is state 2 m dot 1 is equal to m dot 2 is equal to m dot.

And the 2nd law, the 1st law tells us that W dot cv, this will equal to m dot h 1 minus h 2 just check that the thing is that the work going in. So, this side is going to be negative, which means that h 1 is less than h 2. So, now how do we calculate this part and for that we look at the definition of d h; d h we say this T d s is equal to d h minus v d p.

And the 2nd law is coming in now, this was the conservation of mass, conservation of momentum. In the 2nd law we say that d s equal to 0 isentropic machine in which case d h is equal to v d p. So, we have to integrate it and we get the work, then we will say that work done in this case this is m dot integral 1 to 2 v d p and that is the most general form of this equation. And valid for any compressor fan blower or a pump, and it is integral v d p. But, if you look at the closed system, we were integrating p d v, and that is the difference between what a closed system does, and an open system does.

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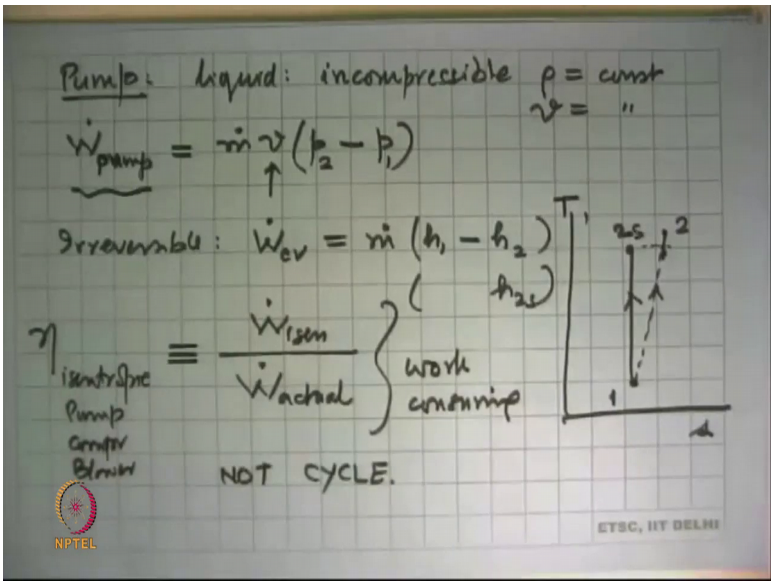

So, now we take one special case, which is we will come to the case of a pump. So, if you are now looking at a pump, we are handling a liquid and liquids we say are incompressible not entirely incompressible, but incompressible compared to gases, so that tells us that rho is constant which also means that specific volume remains constant during the process, so that means, the case this equation now becomes W dot cv or W dot, now we can say the pump. This is equal to m dot the V comes out of the integration and integrate d p 1 to 2 it is a property, so this becomes p 2 minus p 1 ok, so that is the relation we have. And that is how we can calculate the work on a pump with this being constant.

But, if we go back in general to this equation that will say that if it was a real case, which was a irreversible pump, reversible any machine compressor or a fan or anything, then W dot cv will be more, because m dot now h 1 is the same, and h 2 will be there. The earlier case it was h 2 s this is h 2 versus h 2 s and on a property diagram. This is T, this is s, this was take one the isentropic case, went up like that be 2. And if it is not isentropic, we can go the same way that we looked at earlier. And say that s e will increase, so state-2 this is 2 s, the state-2 will lie somewhere over there that is the real case that is the ideal case. In both cases it is adiabatic, but entropy increase is because of irreversibility's inside the machine.

So, the isentropic efficiency of this device is defined as W dot isentropic, which will be the minimum work that we would have to put versus the actual work that we do. And these can vary a lot small devices will have 30 percent, 40 percent efficiencies, your agricultural pumps that operate all over the nation, typical isentropic efficiency of those pumps is 40 percent. Very large industrial pumps well designed efficiencies can as high as 90 percent.

So, you have a big scope that since agricultural pumps consume a lot of most of the a big chunk of the electricity in the country, if we can improve their isentropic efficiency from 40 to even 50 percent, but if not 60, 70 percent, then there will be a huge saving in the nation's electricity consumption. So, this is isentropic efficiency for a pump or a compressor or a blower or a fan. So, this is for a work consuming device, the turbine was a work generating device. And what we are saying again in all these three cases nozzle pumps and turbines that these are not cycles and so we are not constrained by the Carnot efficiency on this machine.

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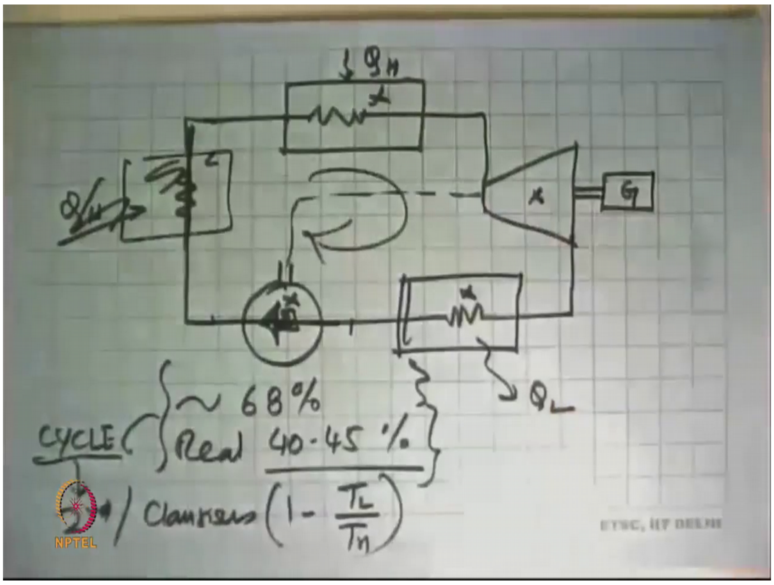

So, if this were the case, we will not go back and look at the entire cycle. And say I have a Carnot cycle in which you have a device where you got Q H, then it went through a device which produced work say there is a turbine attached to a generator, then we rejected the heat to the atmosphere or to the surrounding ocean the lowest temperature that we could get which was Q L. And then we again went in and got energy from the boiler by burning fuel, we put in hot gases and this was Q H sorry in between there is a pump. And then (Refer Time: 45:29) it here oh sorry, I have already put the Q H is already there, so, this is a straight Q H is here already.

And this pump get some of its energy from here and what we are seen here is that this machine can have in isentropic efficiency of 98, 97, 98 percent. This pump can be 90 percent efficient. Here all the energy given by the hot gases goes to the (Refer Time: 45:56) substance that is 100 percent efficient all the energy given by the substance here with surrounding that is 100 percent.

So, if all these individual devices are 100 percent how come the cycle efficiency, we get in ideal case is 68 percent and the real case 40-45 percent, and that is because this efficiency this is the cycle efficiency which is constrained by the 2nd law and the Clausius statement. If the upper limit of 1 minus T L upon T H, whereas this limit does not apply to this device or this device or this device or this device, so while effort is to make these devices more and more efficient, the idea whether you cannot you can go very much lower. This lower temperature sink, I do not have too much of a choice your only hope is to increase the temperature, where it go up and that what is happens in gas tributes. So, it will take a minutes to I showed you aircraft engines, I showed you some pictures of that.

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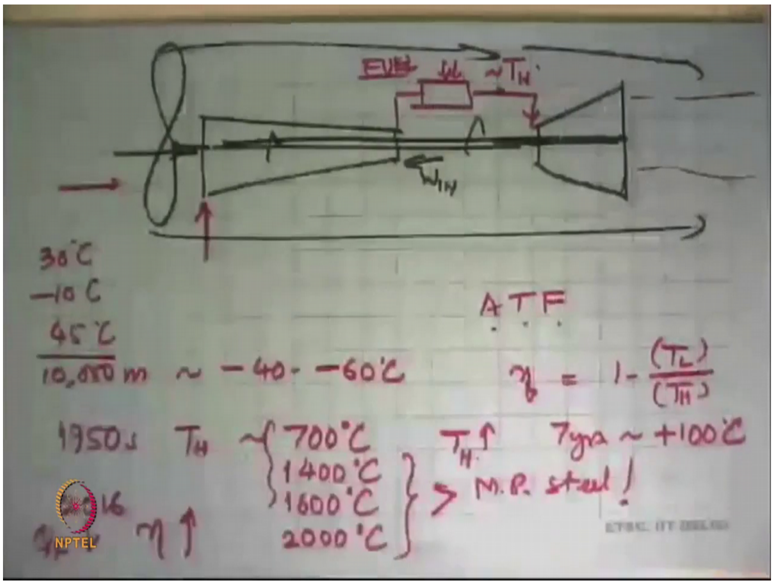

So, what the front part of the engine does is that it takes in air there is a shaft, which is coupled to a turbine this produces work. So, this work part of it is consumed to run this compressor that the work input in the compressor. And some of that work it gives out to the fan, which blows more air and generate the thrust, you will not bother about it for the time being.

But, what it does in aircraft engine is to take in air which we have seen say over there compresses it, then it goes to a device which is called the combustor, where we put in fuel this fuel is a very light grade of kerosene oil, which is called ATF, this is Aviation Turbine Fuel. And this burns in it and this is where you get very hot gases. So, this is in some sense your T H, this hot gases go (Refer Time: 48:19) in expand and they go out. And we try to cool it as much as possible, but in the aviation turbine you cannot cool it too much, on land things also we cannot go beyond 500, 550 degree Celsius, but we have other options on land, which we do not have in an aircraft.

So, this is T H and you are dumping heat out into this taking in colder from there. So, what has happened is in on the ground this is taking ambient air, wherever you it that airport was which temperature, it was taking a 30 degree Celsius may be a minus 10 degree Celsius or may be even 45 degree Celsius depends on the airport is and on the temperature there is. And then it produces a high temperature over there. Then it is cooling at 10,000 meters altitude temperatures are of the order of minus 40 to minus 60 degree Celsius, but the air it is taking in literally cold air. Of course, the ambient pressure is also much less, but then this is the temperature that is critical T H.

So, your when you are looking at efficiency 1 minus T L upon T H, some sort of a T L and some sort of a T H comes into play over here. And by these temperatures we cannot change too much we have no control on them, this temperature has a big history in the 1950's when the first aircraft engines were made, T H was of the order of 700 degrees Celsius. Today, you have land based engines, where temperature is of the order of 1600 degree Celsius, aviation engines where this could be typically 1400 degree Celsius and some specialized machines where it has even gone up to 2000 degree Celsius.

And remember these are temperatures, which are more than the melting point of steel, and we happily sit in the aero plane and fly not worry too much that you are hot gases inside over there, which can melt steel that it is a very reliable machine that we made, but the thing was that starting from the 50's. And now we come to the 2010 to 2016 time this has consistently is increased and that is because there is a lot of research and development done by engine designers, it takes couple of 100 and or may be even more millions of dollars.

A team of 100 highly qualified specialist including lot of doctorates, lot of people with experience, a lot of money and about 7-years typically to increase T H by 100 degree Celsius, this has been happening continuously even until today. And is going to happen for the next may be 15, 20, 30 years and because of that the efficiency of the turbine keeps going up.

And that the cycle efficiency that we are talking of and the efficiency goes down for the same amount of work, the amount of fuel that you have to burn Q fuel this goes down that means, your fuel cost goes down and so having a new aircraft with the efficient engine means that your fuel level is less than operating an aircraft which is 20 years old, whose peak inlet temperature is much less than the latest turbines.

And so it makes perfect sense for an airline to get rid of 20 year old aero planes heat by new aero planes, so that your fuel bill is less, because fuel cost is a large chunk of the air ticket that even I pay. And that what you see some airlines make profits and if you look at them why they are largely, because they are using very modern, latest engines nothing more than 3 years old. Whereas, an airline which is using fleets whose age is average age is 15, 20, 25 years, this purposely going to make loses, because it is fuel bill is very high always, so that is but all of the story started off from this, where the motivation was to increase the Carnot cycle the efficiency for which we kept increasing T H knowing that I do not have too much control over here ok, so that was story about the gas turbines.

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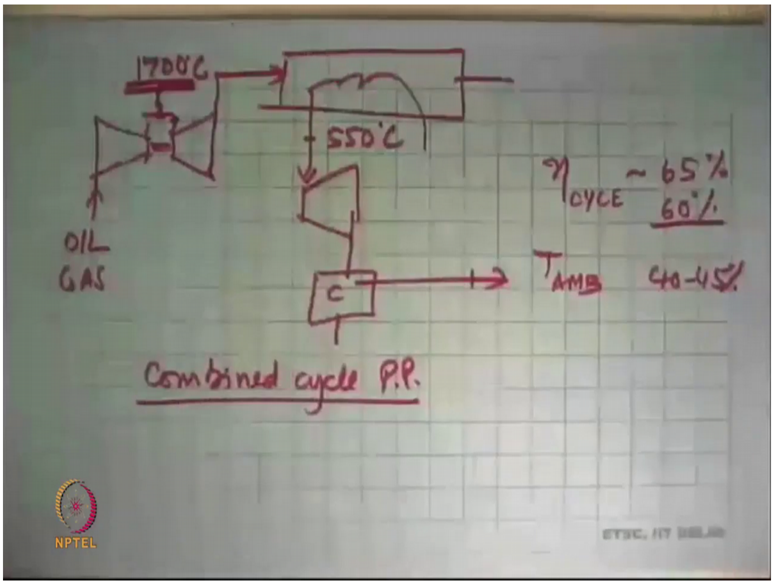

On land what we can do is we take this whole thing, put a gas turbine in there. And do the same thing what the aviation engine does take in air burn fuel in it and produce hot gasses, but then with this hot gases, we produce steam with which we run a steam turbine. And then we have a condenser in which we dump heat to the atmosphere. So, this peak temperature here is say 550 degree Celsius, the peak temperature here was 1700 degree Celsius.

Your overall cycle which is still a thermodynamic cycle, now operates between T ambient and this T H. The result is that this cycle the cycle efficiency this is much more than coal fired power plant and (Refer Time: 53:45) people are talking of 65 percent, 60 percent, they already sort of achieved. And this is much more than 40-45 percent that we get in a coal burning power plant it gives the steam rejects the heat to the atmosphere. This type of a plant is called a combined cycle power plant, why it is not very popular is because these machines are very very precise machines, you cannot burn coal in them, you must have fuel which is clean oil or a gas.

And our country does not have enough of either of them 80 percent of our oil and gas is imported. So, if you can get much more of that gas in, then yes go for lots of combined cycle power plants, otherwise we have no choice stay with coal burning power plants, but this is a very attractive propagation ok.

So, we have just ten minutes left we take some questions and then I will wrap up, I will read to the question. Here why gravity is 0 in a nozzle ok. So, this is the nozzle picture that I have made. And what is happening is that with knowledge you look at the physical size, there would be about like this much 300, 500 mm in size or even if there is an engine or in a steam turbine, there will be might even smaller than that. And the whole change of this happens over a very short distance. So, in simplest phase of a coaxial nozzle and if it is horizontal, they are all at the same level anyway. So, there is not the Z of the central line here and Z of this point here Z i, and Z e over here they are almost the same. So, you do not have to worry too much about that.

In the case, where this was say vertical, then the length of this would matter. And this length will be of the order of about a half a meter less than half a meter maximum square meter. And even if you have 1 meter, then this term g Z 1 minus Z 2 will still if you do a calculation, be very very small compared to either this term or compared to this term, and so also we are justified in neglecting the gravity change in this type of case ok.

So, but if this was the fluid here was water, then it is a different story altogether as long as the nozzle was horizontal you are ok, but if this nozzle were inclined like this or vertical, then gravity is a very very important thing. And in many cases where there is water or any liquid as the working substance Z 1 equal to Z 2 can be neglected only if it is horizontal in any other configuration we cannot neglect it ok, so that is the configuration. (Refer Time: 56:29) and say what have been done in these last 6 hours in module II.

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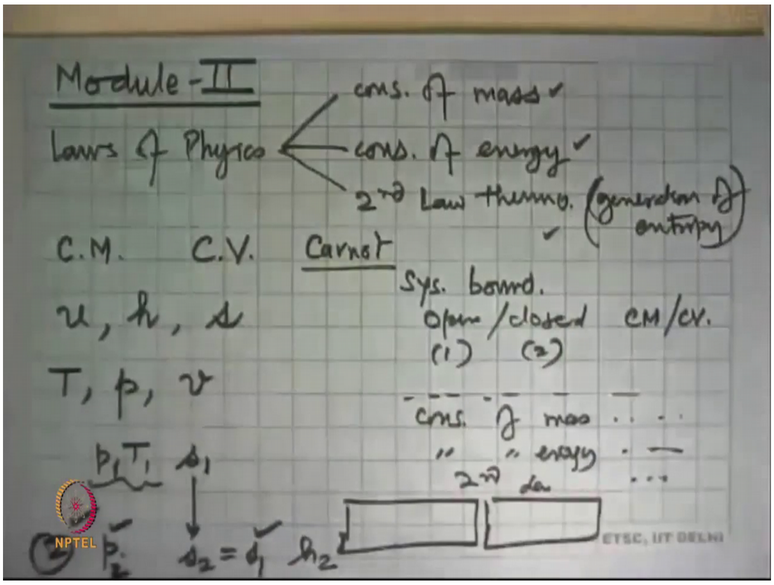

What we have got now is that the laws of physics have to be obeyed. And this we said were three conservation of mass, conservation of energy and the 2nd law of thermodynamics. I am not saying conservation of entropy because entropy is (Refer Time: 57:11). So, you can put it as may be generation of entropy or production of entropy. We developed a set of equations for a control mass and a control volume which we can apply to many applications. In the process of doing all of that, we discovered a property called specific internal energy, specific enthalpy and specific entropy. We already had with us ideas about temperature, pressure and specific volume.

So, we have reached the point where we can take an application like we just did, define a control volume and do a systematic process that first we define the system boundary, then see whether it is open or closed, defined the states, see whether you can applied control mass or control volume approach and you set up the problem. Then you continue further and say what does the conservation of mass tell me and we simplify that conservation of energy, simplify that and 2nd law and simplify that. This brings us to a point where we have certain mathematical relations involving these properties. And the way the problems have been setup in the assignment is that we should be able to say that if I had to solve this equation, I have enough information to do so, not as numbers, but in the form of actual data.

For example, we looked at the turbine and we say I know the inlet condition has to be given. So, may be p 1, T 1 was given, but then at the outlet condition only p was given. So, what happened which are well defined to the isotropic machine this is s 1 and at the outlet s 2 will be equal to s 1. And it tells us that if p 2 and s are given the state two is completely specified and we can get h 2 which we need for our calculation. So, this clarity of logic we have to build because in the next step what we will do is put numbers into those things and we will start getting numbers for work heat and all of those things.

So, we have now learn what is conservation of mass, conservation of energy, the 2nd law and what these terms represent. And what is the methodology by which we came to this point, so that is an important things that we have now that these tools are applicable for everything, every process, every cycle, no matter where, no matter what the substance in it, no matter what the size. This every subsystem, every device, every equipment has to follow these laws of thermodynamics and that is why we have treated them separately from applications and certainly we not got our application comes we will simplify it and see a special case or the special case is only limited by the assumptions that we put in coming from the full equations for their conservations, so that is what we have got.

And what we now we also saw that in order to talk about all these things, we heavily relied upon all the concepts that we learned in the first module. We have assumed that we know what is system; what is system boundary, what the reversible process, what is adiabatic process? All of that came naturally to us. So, we will take these arguments further and another thing that we can list as an important thing that came out was the idea of a Carnot cycle, the idea of an ideal cycle or an ideal process beyond which we cannot make anything in the real world. So, it tells us ideally idealistically the best thing that you can do what is it that you can do and that is what we aim for in developing devices and systems and process.

So, we will conclude here and in the next module, module-III we will look at how do I get these properties for different types of substances, how the substances behave and then we will put all of these together and actually solve the problems. So, with that we will now stop.

Thank you.