Engineering Thermodynamics
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Lecture - 40
Applications. Problem Solving: Realization of Carnot cycle. Practical cycles. Air-standard cycles

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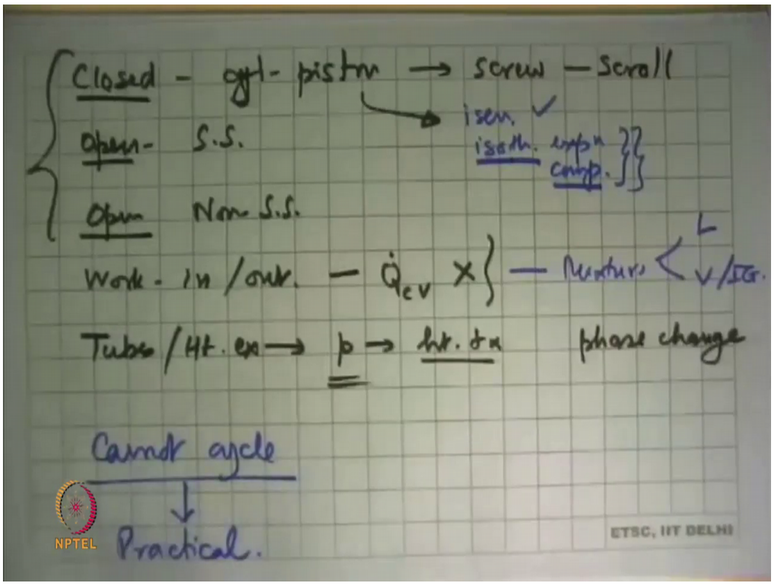

So, what we have done now is we have looked at all types of processes that are possible. We looked at a closed system, cylinder piston arrangement has done a arrangement simplest thing, but we also saw that it counter parts or screw compressors, scroll compressors, they all do basically in the same thing. The trap, the working fluid and change its volume, and but energy way.

Then we looked at open systems in steady state, and saw that these are the common engineering things from which we have to design everything else. Then we saw open systems in an non-steady state. And during the discussion we said that depending on the type of machine, we are looking at this machine has certain characteristics.

For example, we said that if it is work in or work out type of a machine, then Q dot is not possible, we cannot make up the bind, when you can cool it or heated at the same time get the working substance to extract. Same thing with the compressor that we said make me a compressor, where I will compress it in the same time heat it also such a machine cannot be made. So, we are now seeing certain restrictions on what happens.

When you looked at tubes and heat exchangers, we saw that what is possible in the real world is constant pressure, heat transfer. You say you make me a device which is isothermal heat transfer, the only thing we can do is to have phase change. But, if you do not have phase change, which is not possible with an ideal gas making an isothermal heat transfer device, practically is not possible. Theoretically yes, it is there, practically the engineering just does not work out, and you do not see those things in the market, nobody makes it. So, we have to make some compromise and say look if I have a heat transfer process, I will have to assume that it is constant pressure. If I have to lose some of the reversibility in the process, so be at that is my compromise. So, these are the type of things, we looked at.

And now let us ask the question that given the same thing happens in a cylinder piston arrangement. If we say that in the cylinder piston arrangement, if I have to have isentropic expansion, you said fine insulated, more friction unit, it will be expand to get isentropic expansion that is fine. But, if we say that I want isothermal expansion or isothermal heat compression we have a problem, isothermal expansion would be that when the gas expands, we know it is temperature will come down. If I have to make it isothermal that means, I have to supply heat. So, the compression process means, the piston has to move like heat has to be added, two things have to be done simultaneously.

In isothermal compression, you have to do the opposite. So, there are big problems that we cannot design isothermal compression or isothermal expansion in a cylinder piston arrangement. The next best thing that we can see is what we see in practical engine, I can make iso, the project we can gave isothermal with isochoric heat transfer, which is your petrol engine or isobaric heat transfer which is your diesel engine, but we are not able to produce isothermal heat transfer.

This has implication in both cases on the Carnot cycle. And how do we go from Carnot cycle to various practical cycles. The other thing we looked at, we cannot make a work producing or a work consuming device which has a mixture, it has to be either fully liquid or it has to be fully vapour or an ideal gas. We cannot pump in a wet state, we cannot expand a wet steam very much in your turbine up to 0.9 quality we can do it, 0.6 quality, 0.3 equality is not possible.

So, thermodynamics tells us you can do it, practical engineering tells us not possible, do not worry about it try something else. So, what we will do is before we look at the practical cycles, we will look go we now revisit the Carnot cycle, and say that what is it that in is possible in closest to the Carnot cycle, and what is not possible in the Carnot cycle. And, that will tell us what becomes a practical cycle, so that is what we are going to look at next.

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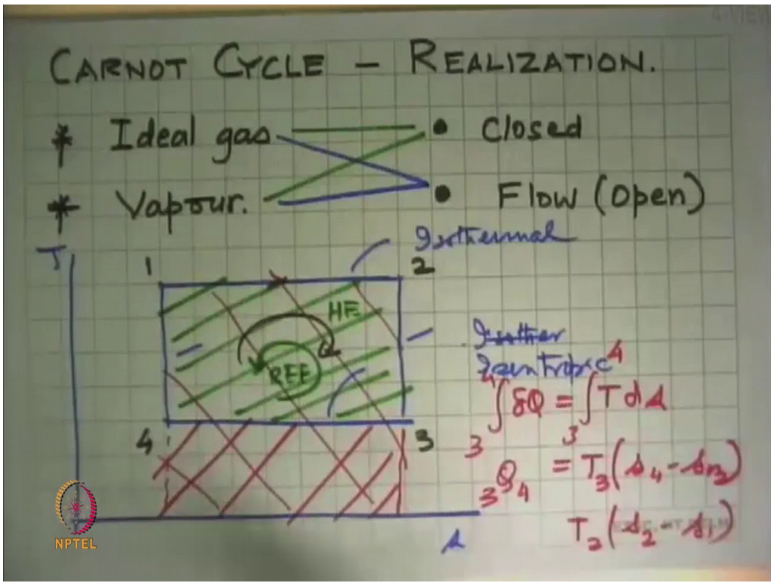

CARNOT CYCLE – REALIZATION.

- Ideal gas • Closed
- Vapour. • Flow (Open)

$\int_3^4 \delta Q = \int_3^4 T\,ds$

${}_3Q_4 = T_3(s_4 - s_3)$

$T_2(s_2 - s_1)$

Over there (Refer Time: 04:47) that we will get the practical realization of a Carnot cycle. And we have four possible combinations, the working substance as we have now learned from this course that I can either treat the working substances in ideal gas or we treat it as the vapour. So, a two distinct categories of (Refer Time: 05:07), we also learned that we can have a closed system or as flow system which is something going through a circuit.

And because of that I can make an ideal gas with in a closed system, which is a cylinder piston arrangement or I can make vapour with a closed system again a cylinder piston arrangement or box type of screw arrangement, so that is one type two types of cycles that one can makes. We can also make an ideal gas, and say that I put it through a flow system and make a Carnot cycle or I can take vapour, and put it through a flow system and make a thermal cycle.

So, it tells me that we can have four possible ways in which we can think of a Carnot cycle here. What happens in the previous first module? In the second module, we have learned that to make a Carnot cycle on the TS diagram, what we said was there has to be two isothermal processes sorry two isentropic, and two isothermal. And this started with the argument that I want everything to be reversible. And if everything is reversible in a cycle that means, the best cycle that we can make, and that is what we said in the Carnot cycle. And so there we argued out why we have to have these two, so that was the basis on which we conceived the Carnot cycle at these four processes as the best cycle possible.

So, now there are two things possible, either this cycle could go in this way that way that means, it start state 1, state 2, state 3, and state 4. And we see here that say take process 3 to 4, then delta Q is equal to T d s, and we integrate this from state 3 to 4, this will tell us that this is T 3 or T 4 into s 4 minus s 3. On this picture, this expression is this area.

And in this case, the cycle is going like this. So, this one s 4 is the less than s 3. So, here Q dot or Q C V whichever we want to see Q 3 4, this is heat rejection by the system. Then if you do the same thing for 1 to 2 process, we get the similar type of a thing which will give me T 2 s 2 minus s 1. And so this entire area, this is heat input to the centre. And what is left to us is that the difference of these two, which is a cyclic integral of heat, this has to be equal to cyclic integral of work, this is the work output of the cycle, which would be the area inside this rectangle.

So, graphically this is how we are able to consider, this way it is a heat engine is a cycle goes in the opposite direction, this is a refrigerator. And now, we will see how can I put this cycle in the real property diagram for an ideal gas and a vapour, and see what practical which will crop up.

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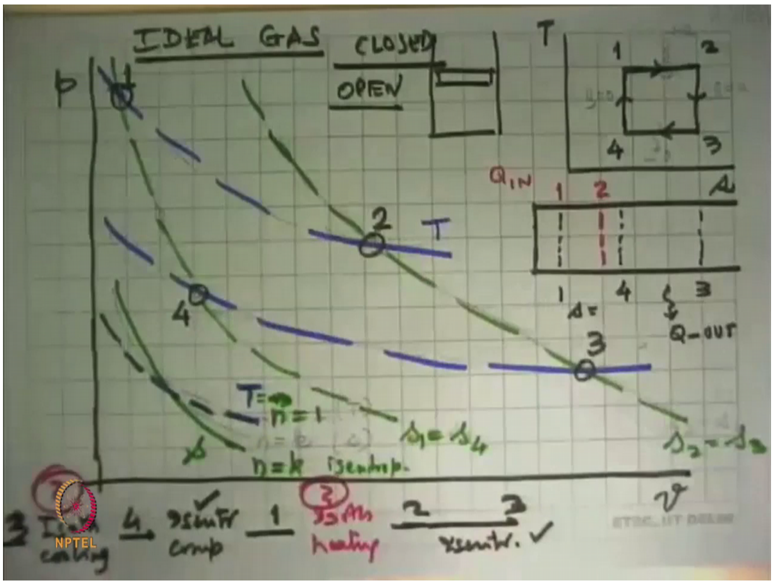

And first let us look at the know ideal gas, how to I derives these processes, and you take put that up on the pv diagram. I have shown a heat engine here, the opposite of that will be the refrigerator. So, to bring it on this diagram, let us first look at something you have learning now in the properties of a pure substance that on a pv diagram a line like this is n equal to k which is the isentropic process. And a line like that will be n equal to 1, which is the isothermal process, this is s constant that is T constant.

So, we can put these two, this is isothermal. And the other line this is isentropic, what it tells us that we can show this cycle, I need to make two isentropics and I need to make two isothermal lines. And that is what I have drawn in this line. So, we will say that the isentropic lines are here, this is one isentropic line, and this the other one. This is s 2 equal to s 3, this s 1 is equal to s 4.

Now, we draw the isothermals. So, this is one isotherm, and this is the second isotherm. And now we complete the mapping of the states in to this, this is state-1, this point where these two intersect that is state-2, this is state-3, this is state-4. So, now let us see what is it definitely get with then what they are looking at, you say let us say I have cylinder piston arrangement into which we move this piston up and down heat it, cool it that (Refer Time: 11:43).

So, volume tells you what that the position of the piston is in that sense. So, what it tells you is that, this is the maximum volume in the centre piston arrangement. So, state-3 will be somewhere there, we compress it, and come to some point to state-4, and this is an isothermal process. So, during the isothermal process, which is your 3 to 4, we have to have a piston moving and left p 2 junction. So, we have to have two things in the practical world that the piston is moving, and you have (Refer Time: 12:34) quickly taking of heat somewhere that is one thing. 4 to 1 the piston further moves up here comes to state-1, this is an isentropic process that means, there is no heating no cooling at adiabatic and reversible. So, ideally if there were no friction, it could go from here to here.

So, this is isentropic compression that fine with this. So, first part was your iso thermal cooling, why is the piston is moving followed by isentropic compression which practically, if we do the best we can possible, we can you know I can get very close to it that something we can get close to, this in a big problem. You cannot have that much heat transfer taking place from a cylinder in a very short period of time that bring us to state-4.

So, we started here we can call this as state-3, it came to 4 as an isothermal process. Now, 4 it comes to 1, there is that was the isotopic compression from state-1, we are getting this line which is an isotherm which is 1 to 2. And during this process, the piston moves from there and came out say somewhere here, this is state 2. And what did it do, it appose expanded, but 1 to 2 here was Q IN; so, here expanding the piston, the same time trying to heat it up.

Same problem as 3 to 4, where while compressing it, you are trying to cool it that little piston that we are say in a motorcycle or a car, it is just not possible to do that type of heating or cooling in a bunch of time, but isentropic compression is followed by isothermal heating. So, this is a big question mark cannot do isothermal heating, the next big question mark, we cannot do it. And then 2 to 3 this is isentropic expansion, and we can say well not isentropic, but I would not take off heat from it, I would not cool it, but yes I can lay very close to it, not n equal to k, but slightly less than k.

So, in realizing the Carnot cycle in a gas, in a cylinder piston arrangement, there are two things which are not there in the world of engineering, which is that you do a huge amount of cooling while the piston is moving or a huge amount of heating, when the piston is expanding. This is not possible. So, we have a problem in realizing the Carnot cycle with gas or even trying to get close to it in the real world, this is a problem we have here.

This processor and states will remain the same, if instead of a cylinder piston arrangement, this was a closed system, we wanted to realize the Carnot cycle in an open system. And what we will do then is if we have to compress it, we put it through a centrifugal compressor. And in this case, we have a centrifugal compressor which is being heated up. Again that is a device we saw in our earlier discussion, compressors we will treat as adiabatic, they can be made. But, to have a large amount of heat transfer during the compression process, we cannot make it.

Then we have an isentropic compression that is possible, the ideal compressor will be that we just compress it. So, most compressor you see whether it aircraft engine or you know gas turbine elsewhere this is possible, we can get very close to it. So, this is not a big problem, 1 to 2 is an expansion, so we have to use a turbine. And turbine in this case is a isothermal turbine like we when it is expanding, we are going to heat it also, this is not possible.

You cannot make a turbine and take heat it up, the practical turbine I said what we can make, you know isentropic turbine that the best we can do, this is again not possible. The last part in an isentropic turbine, we can do that and get close to it. So, even in an open system what we are seeing is we need two compressors, and two turbines, two adiabatic, two way heat transfer. The two heat transfer ones are not possible, so again the Carnot cycle has an ideal gas cycle, we cannot come close to it. This is the problem with the practical realization of the gas based Carnot cycle.

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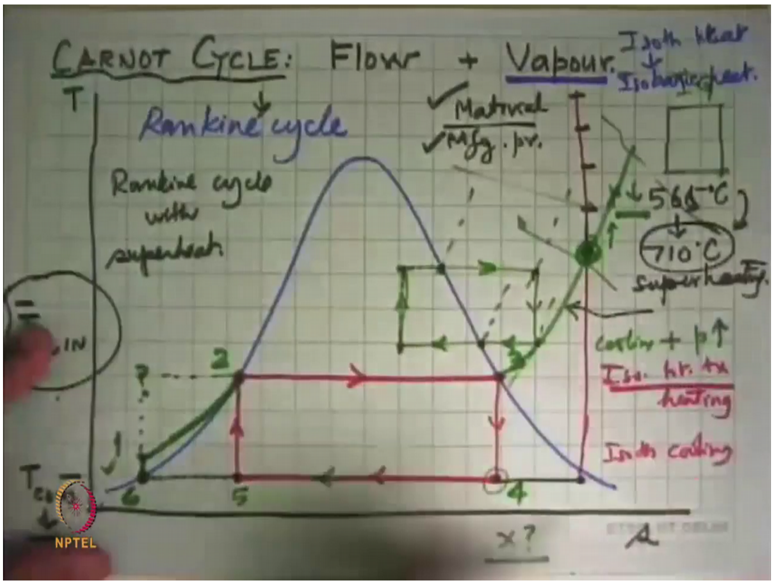

Now, let us look at happens to Carnot cycle in the flow system. So, here we have the T s diagram, and what we have here is the saturation dome we have to work with, we are dealing with a vapour. So, we have to show this term, and now what happens? Now say any rectangles that I can put on, this is a Carnot cycle, said ok.

So, we put a rectangle over there at the Carnot cycle, we are far away from the dome. So, this is an ideal gas, and we just argue that whether it was flow system or a closed system, we cannot make this or we cannot come close to it also. Now, let us see what happens here. Somebody says even I make a Carnot cycle like that. And what do we see happening? This is the turbine process, superheated steam going in, superheated state coming out it does not matter what the work is something else with steam it is ok, if it is some organic chemical that also.

The next problem happens here, what we are seeing here is that this is a constant pressure line here, and this is the constant pressure line here, and then you go up pressure increases. So, this process from here to here cooling is taking place that means you are rejecting heat. So, this is cooling plus at the same time pressure is increasing, you can increase pressure without doing work, so that becomes a complicated process, we do not try to do it.

Next part is here from here to here, you have condensation taking place that is not a problem. We can make a heat exchanger to remove this. The next process is this vertical line, this is your what input process, and here we have the wet state. Wet state there, and wet state all the way through them. And we have said that if you have to make a compressor or a pump or anything, it has to either handle only a liquid or it has to handle only a vapour. This is handling completely of wet mixture in the real world, we cannot make such a thing. So, this is not work.

This is isobaric evaporation from here to here, no problem we can make it. But, from here to here, when we are adding heat, this is a pressure here, this is the isobar here, this direction the pressure decreases, which means that you have to make a device a heat exchanger. When there is heat transfer taking place with the substance, at the same time the pressure is decreasing again not possible. So, we cannot get these two things and we cannot get this thing, so that is the reason this cycle will become impractical.

So, let us see, now what are the other options we have, and what the closest that we can get. First let us try to avoid heat transfer processes, when there is the pressure change. So, I will not make a device in which I will have heat transfer big pressure change, I will make a device where heat transfer takes place at constant pressure, constant temperature that fortunately for us works out. And we can say that I will have this is my input device, phase change is taking place x equal to 0, because x equal to 1, constant pressure, heat transfer, entirely doable. Fortunately, the constant saturate state, it is also constant temperature heat transfer. So, we got two advantages in the same shot that we got isothermal heat transfer something that the Carnot cycle not, we got it.

The next thing, we have to have an isentropic process from this point. So, this process will come down there, here we have a little problem. When as you come down, the dryness fraction keep getting less. So, we are getting into wet zone, when the dryness fraction is like 0.9, 0.95, it is not too much of a problem machines have still been made, they are reasonably reliable. So, it is unless it goes down to very low dryness fractions, then this is not possible.

Then we go on to now have a heat rejection. So, we take this process, and we said this is the temperature at which we are rejecting heat, condensation is taking place, temperature is constant, pressure is constant. So, what we got here is isothermal cooling or heat rejection, this was isothermal heating, possibly entirely possible to do it.

And then we say now to complete my Carnot cycle, the last process to put is this one. And here we run into a problem that well what you have here is the wet state, and you are trying to compress it to make it a liquid, I cannot make this machine. So, this cycle can very close that we almost got this, these two we are able to get, this we cannot get. And so this cycle is very close to being realized, but not realizable. So, what do we do next then, what we have is a modification of this Carnot cycle, and we say that look I want to make it practical. So, instead of condensing it here, we will take it all the way there and condense it over here. So, this to this is condensation.

Now, we have liquid we can make upon and compress it. And at this state, we can then begin the heat input process, and it will go from here to there. So, now 1, 2, 3 is our heat transfer process, it is happening at constant pressure, so possible. This expansion is happening here, and we are still saying that if I can get down to 0.9, I am ok, otherwise, I have to do something else here also.

We will see in a minute what else we can do this side, from here to here we bring it down all the way. So, this is a safe state 4 say 1, 2, 3, this is state 4, this was state 5, this is state 6. 6 to 1 from realizable, 1, 2, 3 it is also process, 2 to 3 is isothermal heat transfer, 1 to 2 is not isothermal heat transfer, so which means that I have sacrificed something over here. 4 to 5 is isothermal heat transfer that is fine, 3 to 4 isentropic expansion except for the dryness fraction problem in the that is there, this is ok. And this is becomes the first practical cycle that one could make, and this is called the Rankine cycle.

And in some sense, this is what the first steam engine was all about. You have a boiler into which we pumped water at ambient conditions, so that was like 1. The boiler heated it to produce steam, which was some where there, this steam was taken out of the boiler and put in the cylinder piston arrangement and expand it, so that expansion would not exactly like this, but very close to this.

And then after expansion that was an open system that steam was thrown into the atmosphere. And then we took keep getting fresh water put it in there, and do this process expand it through it out. So, 4, 5, 6 the heat rejection process was not there in the original steam engine or any steam engine that came afterwards, but this form the basis of trying to make the flow type of a power cycle with is the standard thing now in all types of power generating systems.

So, before we go there, let us look at this process 1, 2, 3. And see what does it tell us about the thermodynamics of it in the context of a qualitative way of looking at how good is my Rankine cycle compared to the Carnot cycle, where the Carnot cycle ideally if we have made it up to this point, they would say the make a cycle which is like this. Then you would have got the Carnot efficiency or this cycle would be the same Carnot efficiency, but what we have done now instead of this cycle which was the Carnot cycle we have gone this, our efficiency has come down. And let us see how and why and back how much?

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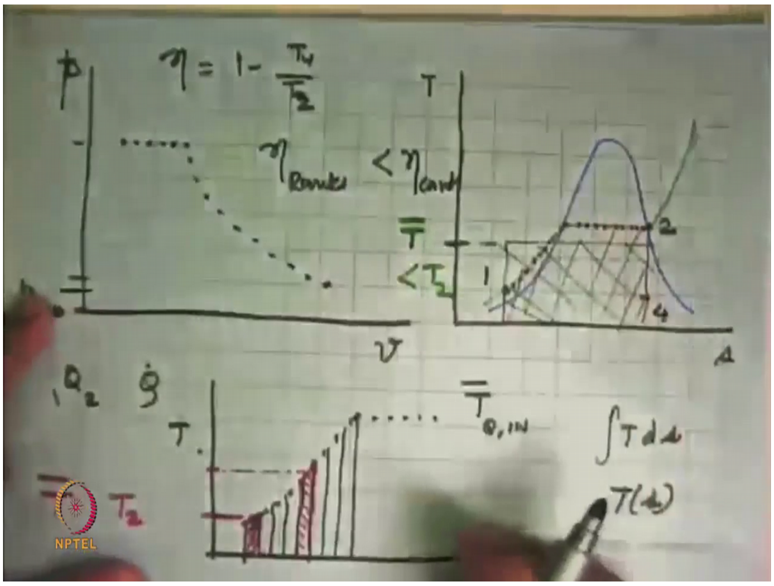

So, for that we will look at the process is separately ok. So, this is the process that I have drawn here, this is a constant pressure line there, and constant pressure line there, and the constant pressure line that moving at there, and because we know that these are all compressed liquid states, and this they just have basically liquid state.

So, we ask the question, what is the all the heat which were added from 1 to 2, whether it is a closed system or open system does not matter. They just says that say this Q 1 2 or flow system would be Q naught. We added heats at some heat at some temperature, then little more at this temperature, then little more at this temperature, little more at this temperature.

So, if I have to make it on a T s diagram, and we put all these states together, then we do what we did for the part integral T d s as the heat added in that cist process. But, now what is happening is we have a process where entropy is increasing, and temperature is also increasing. So, if we know explicitly T, as the function of s, we can integrate this.

The next best option is what we do now with computers, it know a numerical integration, and say we will look, I will say that we will divide into very small steps where there are small changes of entropy, and this is the heat added in this part of the process. So, this much heat was added, and I said well at what temperature did we add this heat, we will say that we will take the midpoint of this, and say that this is the temperature at which this much heat was added.

This we will do now with the next one also, so this one then with this one. So, then we will say now what happened in this part, so this much heat got added and the average temperature at which this heat got added was this much. So, like that we can integrate it, and then compute from here, that this much heat work added at this temperature, this much at this temperature, this much at this temperature. So, we can get some sort of an average temperature at which we added this heat. And this temperature was constant there say we call it T 2.

And then (Refer Time: 28:46) what the total heat that we added in this process which is this much. If I have to say what is the average temperature at which we added this heat that, I can approximate this area by a rectangle which is like this, which has the same area as the area under that curve. So, this area, and that area are equal that means the same amount of heat are added.

But, now what we have learned is that this is the average temperature at which heat transfer takes place in the process one here, and here and that is to be expected at because, now we are adding heat to a lower temperature. So, T bar, this T average temperature is now less than T 2. And so the Carnot cycle efficiency which was entirely dependent earlier on T 2, and the state here which was T 4, there the efficiency was 1 minus T 4 upon T 2, now sorry yeah 1 minus T 4 upon T 2. Here T 2 has now come down, and it has become less. And so the efficiency of this cycle is going to be less than the Carnot cycle efficiency.

So, in that sense Rankine cycle efficiency is less than Carnot cycle efficiency, we make that sacrifice. But, in the process we have made a cycle which is very close to practically making it, on top of that there will be irreversibility is of friction, some expansion, heat loss all of that. So, efficiency will be further less than the ideal Rankine cycle the real cycles which will be less. But, we moved out from seeing that the Carnot cycle was practically impossible to make, when we say that at least in one case, they are able to make a modification here and realize something close to a Carnot cycle. In the case of gas cycles, we would replace isothermal heat transfer processes, while the isochoric or isobaric heat transfer processor and we will see how we do that little later but this is what we did.

The next thing what one does is how can I reduce this problem that the dryness fraction here is very low, I want to have combine which is very close to over there. And the answer for that is that we will show it on this diagram. I want to take 0.4 from here to here very close to 1 that means, this is the state at which the steams expansion in the turbine comes to an end. So, the turbine processes have to lie on a vertical line which go up here.

So, what it tells is that I have one restriction that the states, I did the term steam comes into the turbine has to lie on this line. And I have a second restriction that the state at which the heating will end will be on this isobar; so, isobar which was here 1, 2, 3, we continuing that isobar. And say when look this is the isobar at which heat transfer takes place, intersection on these two in the state at which the steam should leave the boiler and enter the turbine, so that is what we did.

You should do that this line comes up over here, the average temperature at which now heat is added has increased a little bit, because we added this heat at a higher temperature. So, cycle efficiency has gone up, and we got this problem also solved the dryness fraction of steam in that exhaust at the turbine has improved. And we say look these are my cycle, it meets all our practical requirements.

And the first power plants were made with this cycle. And that is how the idea of this heating, which is super heating this, has come down. So, almost all cycles whether it is nuclear or whether it is ocean thermal or solar thermal, all of them will be something or some variant of this basic Rankine cycle. So, this is Rankine cycle with super heated ok. So, this becomes a practical of cycle, and all engineering happens like this.

And the reason for bringing this up is very simple. If I want to increase the efficiency of the cycle, I have an option of reducing this temperature or increasing the average temperature at which heat input takes place, this is isothermal heat transfer. So, this is dependent by the condenser which is directly related with ambient. We cannot play too much with the ambient, there of the too much heat into the surroundings the now water body, ocean or a river or a canal back us to take away the heat only atmosphere has to take that.

Idea is how can I increase the temperature at which we added heat, the average temperature at (Refer Time: 34:21). So, everything we want to do is to take this point as high as possible. And this very simple fact becomes the basis of doing all R and D related to not just steam power plants, but also gas turbines, aviation turbines everything. So, what we see happening in the real world are greater and greater efficiencies, happened because of this very fundamental motivation that comes from very simple thermodynamics that we are numbered that is the how reaching implication of (Refer Time: 34:52).

So, this temperature kept going up, and that is what happened historically. 1920 the first power plants were made with very low pressures. The first steam engine was something like 3 bar 4 bar pressure very low, then this temperature started increasing they kept going up. And the way we could do it was happening because of two things. When they were increase this pressure, the device will break, fail, explode and so that needed new materials and better manufacturing process.

Remember beginning of the industrial revolution started with casting, and reverting you can very quickly that is what how pressure (Refer Time: 35:36) what we made. Later on we started getting steel, then we started getting bending. And has those things started happened, then came forging not rolling. And with each one of them came alloys, because alloy steels. And with each one of those things, this temperature kept going up. And that is what is happening, now also that we are trying to increase the current limit of say then 565 degrees Celsius, their effort to increase this to 710 degrees Celsius.

Then you take another 5, 6, 8 years to happen, but the big challenge here to here is the material, and how do we make it. The thermal dynamics tells us that look, this is what you need to do with the material to you how do a manufacture it, what is it cost, this is where a lot of research also is going to happening, but all of that research is coming from this motivation, which is coming from this motivation ok. So that was an important thing that how do we quantify the average temperature at which heat transfer takes place in a cycle, so that was the Carnot cycle coming in there.

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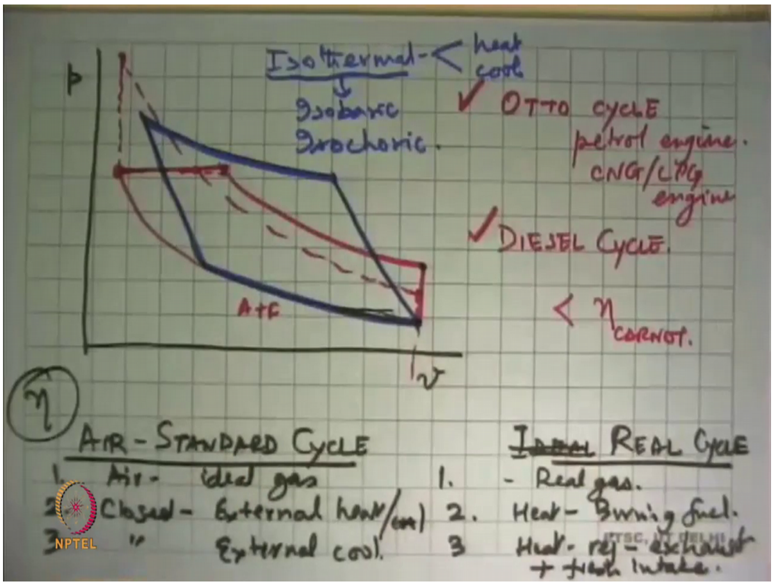

We take a few methods to look at the gas cycle, and then well have questions coming in. What happens in the gas cycle, if we modify that diagram and said look isothermal heat transfer is not possible. So, what we do and we have to do it on a pv diagram, we saw that pv diagram that was coming up, it was like this, then like this, then like this, and then like that not practical.

So, we said isentropic process, I can very closely get, but then do not bother too much about anything else. So, what we did is we took this isentropic process, and took it all the way here. And then we said I can do two things, I can do constant volume heat addition or I can do constant pressure heat addition. If you do constant volume heat addition, we then expect I have this expansion isentropic.

And then I said constant volume heat rejection, and this becomes the Otto cycle or this is the thick thermodynamic cycle for the petrol engine or what they call as the gas engine the CNG engine or the LPG engines or when we went into this route, then we got the diesel cycle say clearly both are quite different from the Carnot cycle that we would have like to have, but this is what is practically possible.

And what we have done here is that in this cycle, we put in a mixture of air plus fuel ignited it suddenly, pressure went up that got approximated as a heat transfer. And here we open the exhaust wall and let everything come out and expand to ambient temperature, and only got that at the cooling equivalent of a cooling uses.

In the diesel engine, during this process we injected fuel increase the temperature, and then stop the fuel injection at that point, when the piston is moved a little bit and allow it to expand so called isentropic process, and then we got this thing. So, both cycles became practical, but both cycles have an efficiency less than the Carnot efficiency, but both are practical.

So, we stop by making one more thing that what we have drawn here is something, what we will call as an air standard cycle, and verses ideal gas cycle sorry the real cycle. And I will list the differences between these two, there was a standard cycle the one whose performance we can analyse, we know all the equations and processes for that. Real cycle is complicated, and subject out like higher courses and practical engineering, but this is the beginning point by which we start getting qualitative idea about what happens.

So, what happens here is that first the working substance here, the air which is assumed to be an ideal gas. Here the working substance is air plus a mixture of a combustion gases, and that would actually behave like a ideal gas. The second thing is the heat addition that we show on these diagrams in an air standard cycle; it is a closed system, where externally it is heated and cool. In the real cycle, the heating process is replaced by the burning of fuel, and burning fuel in the working substance itself. So, the working substance does not even remember like the same here.

And heat rejection, so heat heating is like that and heat rejection is also closed, heat rejection is replaced by an exhaust and fresh intake. So, in this cycle ideal, we would say that the same mass of air which is undergoing these processes. In the real cycle, we say that after this process is over we throw everything out, and let fresh air in and we come to this state, so that is the approximation we do.

So, the three major differences between the air standard cycle and the real cycle; the reason we make this differences in that air standard cycle can be analysed from everything we have learned so far. And from there, we can calculate at least efficiency heat transfer, work transfer for each process that can come, we know the parameters of the cycle maximum pressures, maximum temperatures all of that can be calculated.

In the real cycle, we will have to go to much more sophisticated programs, they are now they are all designers of engines and all they will do this part, but that is and that is how they actually make the machine. But, from beginning purpose, we take the air standard cycle assumptions and analyse the cycles. So, with that we will stop here. And tomorrow, we will take example and we will solve some problems ok.

The second question there is a question here, what types of modification is done for Carnot cycle. And that is you need to answer, because I just showed that for gas cycles, this is the Carnot cycle. Now, we summarize that again that we replaced the isothermal heating and cooling, we replace the isothermal part by either isobaric or by an isochoric process constant pressure heat transfer or constant volume heat transfer that what we have done.

In the vapour cycles, the modification that we did is that instead of getting wet states here, we condensed it all the way to a compressed to a saturated liquid, and then compressed it. And then we started adding heat, so the heat transfer is not isothermal heat transfer. So, what here also we did the same thing, we replaced isothermal heat transfer iso heating isothermal heating got replaced by isobaric heating, this got replaced.

But, isothermal cooling is still there, because we are condensing it at constant temperature. So, in vapour cycles we replaced isothermal heating, by isobaric heating, and in ideal gas cycles we replace isothermal heating and cooling by isobaric heating or isochoric cooling. So, they replaced both processes here by something else in the vapour cycles, we only replace the isothermal heat transfer process by isobaric heat transfer process that is the difference we have, so that is the question.

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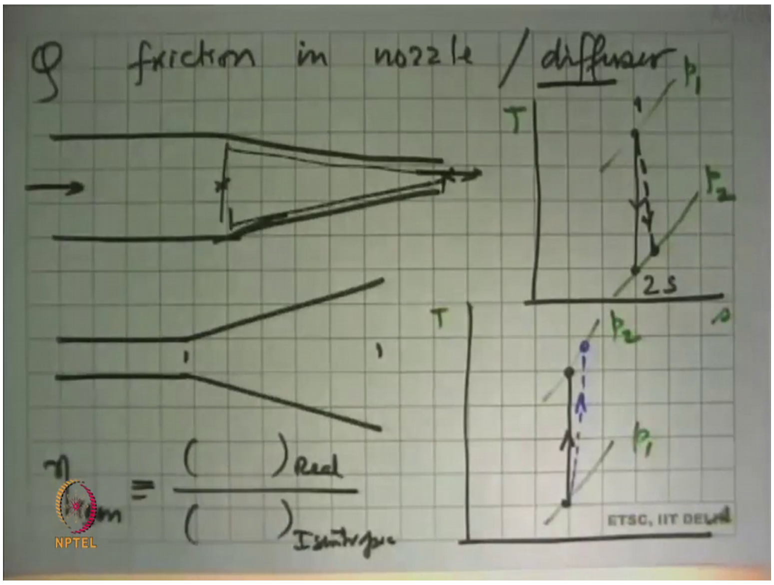

Then what is the effect of friction in a nozzle and a diffusion, so that is the question now; effects of friction in nozzle or diffuser ok. So, what here is what happens? Say we have a nozzle, and the flow is flowing like that, this is our control volume. Now, what friction does is dissipates energy, which gets converted into internal energy raises the temperature of the fluid, and the velocity that we get is less than what you would have gone.

So, in the nozzle say this one inlet state-1, the isentropic nozzle where there was no friction would have come here 2, and said 2 s isentropic. So, what happening is this is the constant isobar there, and this is the isobar. So, this is a line of p 1, this is the line which tells you where is p 2. So, this was isentropic nozzle. The real nozzle because of internal irreversibility’s, it is entropy has to increase. But, you see expanded from the same inlet pressure, the same outlet pressure with increasing entropy that means, the state has to rise somewhere there. Entropy has increased, pressure is still the constant. And now the real nozzle because of friction does this thing ok, the diffuser does the opposite.

So, it has increased the area, and increase the pressure (Refer Time: 46:47). So, if the initial state was there, it went to that state. So, this is T s, these are the two isobars p 1, p 2. And now you there is friction inside this, what it will do is it go there somewhere, and the temperature below also increase, so that is what the diffuse ability it so that is what the difference between the nuzzle and the diffuser.

And the way we characterize this is that isentropic efficiency as we defined earlier, if you recall the third module, this was defined in the case of a nozzle as velocity change in the real case divided by velocity change in the isentropic case. In the diffuser the question recovery will be the opposite of that, so that is for nozzles and diffusers. What we have done today is completed our discussion on various types of devices with which we make systems, and that gives us all the tools for doing any practical engineering.

And at I will give examples tomorrow was how the engineering of a system begins with what we have learned. The second thing, we did today is we looked at the Carnot cycle, and said what is the best; I can do to make it realizable. And what we saw that the Carnot cycle itself, as it is cannot be made because of practical restrictions. We modified some of work lacks some of those requirements, sacrifice the efficiency a little bits and got the cycles that we can measure. So, tomorrow we will look up some design problems of how we make a system, and we solve some problems in tomorrow's class ok.

Thank you.