Concepts of Thermodynamics
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Lecture – 61
Example Problems: Otto Cycle and Diesel Cycle

We have discussed the Otto Cycle and the Diesel Cycle and we will move on to other air standard cycles as we promised in the previous lecture, but I thought that it will be nice, if we work out a couple of numerical problems on Otto cycle and diesel cycle. So, that is the agenda of today's lecture.

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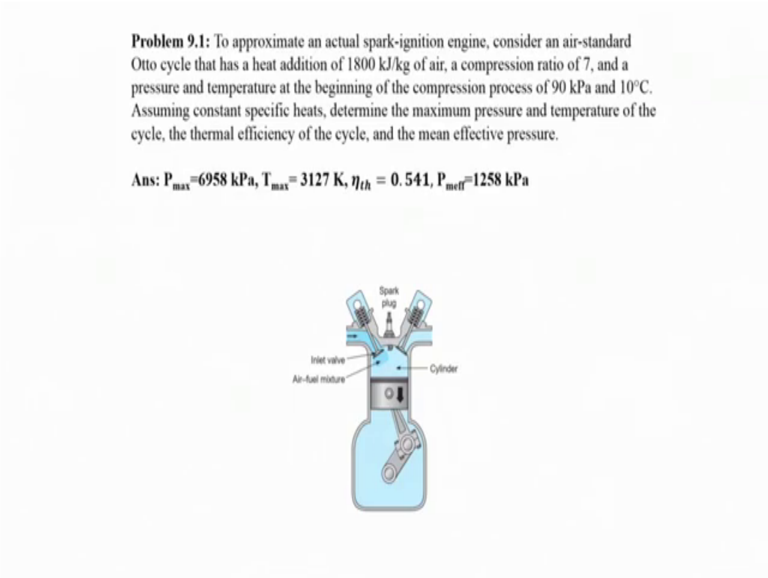

Problem 9.1: To approximate an actual spark-ignition engine, consider an air-standard Otto cycle that has a heat addition of 1800 kJ/kg of air, a compression ratio of 7, and a pressure and temperature at the beginning of the compression process of 90 kPa and 10°C. Assuming constant specific heats, determine the maximum pressure and temperature of the cycle, the thermal efficiency of the cycle, and the mean effective pressure.

Ans: P_{max}=6958 kPa, T_{max}= 3127 K, $\eta_{th} = 0.541$, P_{meff}=1258 kPa

So, the first problem; is problem 9.1, to approximate an actual spark-ignition engine, consider an air-standard Otto cycle that has heat addition of 1800 kilo Joule per kg of air and a compression ratio of 7, and pressure and temperature at the beginning of compression process of 90 kilo Pascal and 10 degree centigrade. Assuming constant specific heats, determine the maximum pressure and temperature of the cycle and the thermal efficiency of the cycle, and the mean effective pressure.

So, I will define what is mean effective pressure as we go forward, this is the new term that you have encountered and we have not defined it so far. So, as usual I will go to the board and draw a schematic with the given data, and then we will work out the problem step by step.

Normally, whenever we give such problems we expect that the students will work out the problems from the fundamentals; that means, we will identify the state points in the thermo dynamic cycle and then do the calculation, instead of using the final formula for efficiency that we have already derived in the previous lecture. In such a situation the subject really becomes concept based on, not a formula based where you have formula and you plug in the value to get the answer. So, we will follow the same speed here.

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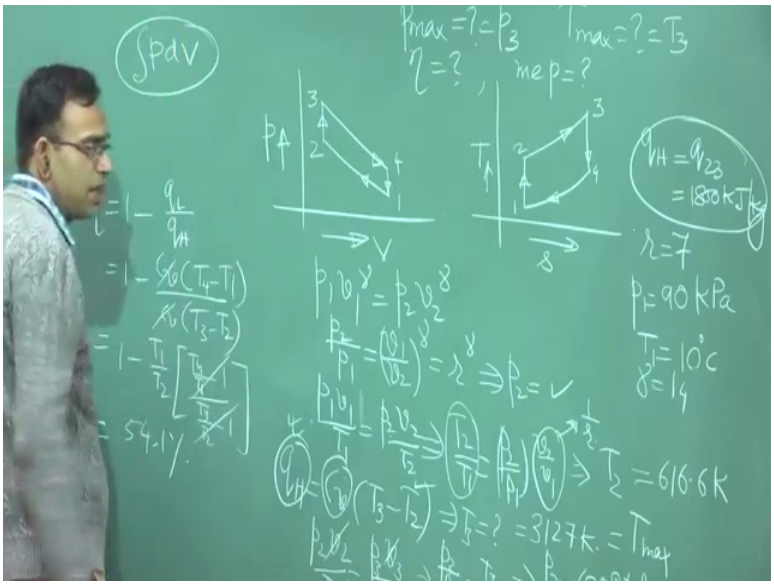

So, you have a Otto cycle I will draw the p V and T s diagram very quickly because this is what we have done in one of the previous lectures.

So, let us see what is given. So q H, the heat addition is from 2 to 3 right; so, q H is q 2 3 this is 1800 kilo Joule per kg. So, for making a cycle analysis we can assume that 1 kg of air is the working fluid. The compression ratio r is 7 and pressure and temperature at the beginning of the compression is 90 kPa and 10 degree centigrade so; that means, p 1 is 90 kPa and T 1 is 10 degree centigrade ok.

So, we have to find out, let us see what you have to find out. You have to find out what is p max, this is nothing but p 3; you have to find out T max which is nothing but T 3. You have to find out the efficiency and the mean effective pressure.

So, let us try to find out p max and T max in a step by step manner. See this kind of problem is very important because had this questions not been; had this parts not been given find out p max T max efficiency calculation people would have. I just spontaneously try to plug in the formula and get the answer, but p max T max you cannot really plug in any formula to get the answer, you have to identify the state point.

So, you know that p 1 v 1 to the power gamma is equal to p 2 v 2 to the power gamma right. So, p 2 by p 1 is equal to v 1 by v 2 to the power gamma so, this is R r the power gamma, gamma is 1 point 4. p 1 is known so this will give you what is p 2. Let me see whether I have the value with of p 2 or not I do not have the value of p 2, but I mean you can calculate this straight away.

Then you also have p 1 v 1 by T 1 is equal to p 2 v 2 by T 2 right; that means, you have T 2 by T 1 is equal to p 2 by p 1 into v 2 by v 1 this is 1 by R right and p 2 by p 1 you have already calculated. So, you will get what is T 2 by T 1 because you know what is T 1, in this formula you have to use Kelvin, that is 273.15 plus 10. So, that will give you what is T 2. T 2 is 616.6 Kelvin.

So, once you have T 2 then what you require? You require T 3 and p 3. So, how do you know T 3? So, for that you are given this heat addition process; so, q H is equal to C v into T 3 minus T 2. So, because q H is equal to C v into T 3 minus T 2, you have a value of q H known C v of air known, constant C v then you will get what is T 3. So, T 3 is 3127 Kelvin, Cv of air is 0.717 kilo Joule per kg Kelvin. So, that you can use to get what is T 3 this is T max.

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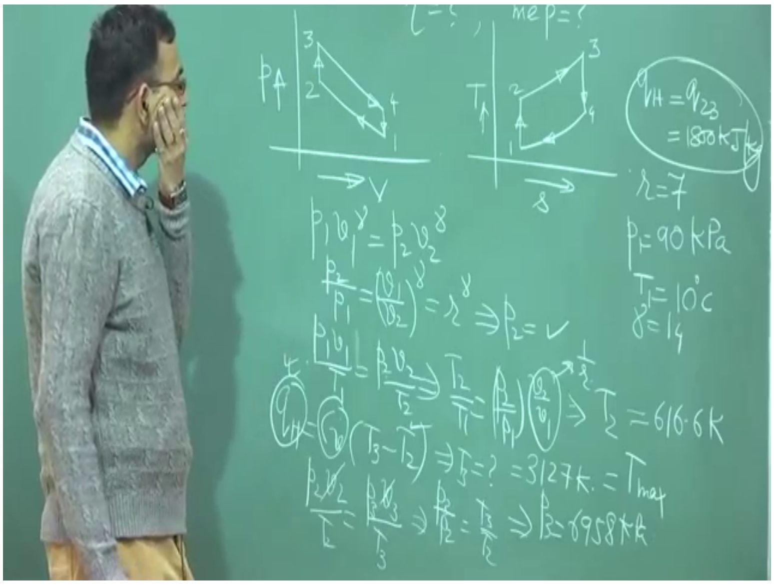

Then what is p max? So, to calculate that you can use p 2 v 2 by T 2 is equal to p 3 v 3 by T 3. v 2 and v 3 are the same so, p 3 by p 2 is equal to T 3 by T 2 so that will tell you what is p 3; so, p 3.

So, next is efficiency. So, we have the temptation of using the formula, I mean nowadays with multiple choice type of answers; so, if you know the formula you should not waste time and just you know plug in the formula to get the answer, but there is always a great joy of getting the result from fundamental calculations instead of going through the formula. So, the efficiency is at least 1 or 2 fundamental steps you can write 1 minus q L by q H.

So, 1 minus C v into T 4 minus T 1 by C v into T 3 minus T 2. So, 1 minus T 1 by T 2 into T 4 by T 1 minus 1 by T 3 by T 2 minus 1 and you can easily show that these two are the same, this we have earlier shown in our derivation. So, it is 1 minus T 1 by T 2, T 1 by T 2 you have already obtained as a part of this problem. So, you straight away use that so, what you will get is this answer, this is 54.1 percent. The final part of the problem that remains to be answered is what is the mean effective pressure? So, what is mean effective pressure? So, recall that the work done is integral of pdV in a quasi equilibrium process.

So, instead of this pdV, if this particular expression does not work still you have some work done, but the work done is not pdV; I will tell you that in the real internal combustion engine process because the process is not a quasi equilibrium process pdV is not valid, but still you get some work, that work is not just evaluate able through the pdV formula.

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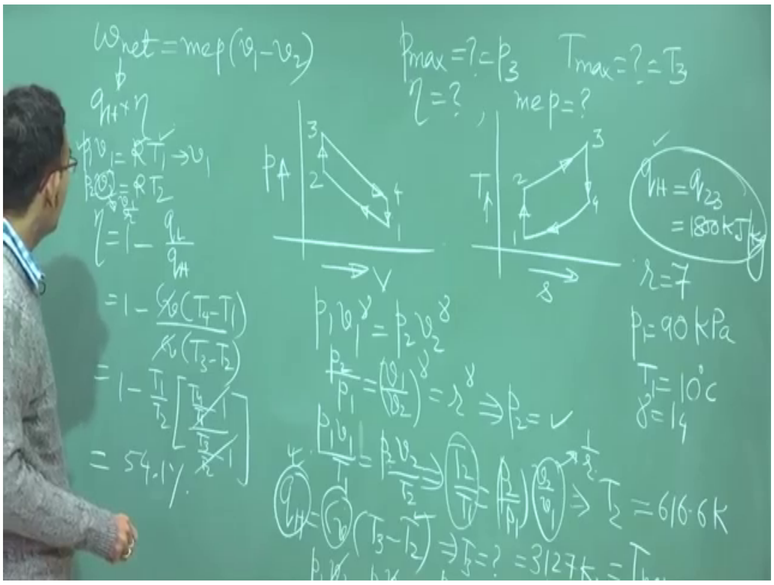

So, instead of this we could have a network and had this network been achieved by an average pressure undergoing a change in volume from v 1 to v 2 then that equivalent pressure is called as mean effective pressure.

So, this is mean effective pressure times v 1 minus v 2, that is the definition of mean effective pressure. So, it is an average, it is a hypothetical first of all its not a real pressure it is a hypothetical pressure; constant pressure which multiplied with the change in volume would have derived the same equivalent network as what is obtained from a thermodynamic cycle, that is the definition of mean effective pressure.

So, here how do you calculate w net, w net is q H times the efficiency q H is already given and for v 1 minus v 2 you have p 1 v 1 is equal to RT 1 and p 2 v 2 is equal to RT 2. You know p 1 RT 1 so, this will give you what is v 1 and v 2 is v 1 by r small r. So, you will get what is v 1 and v 2.

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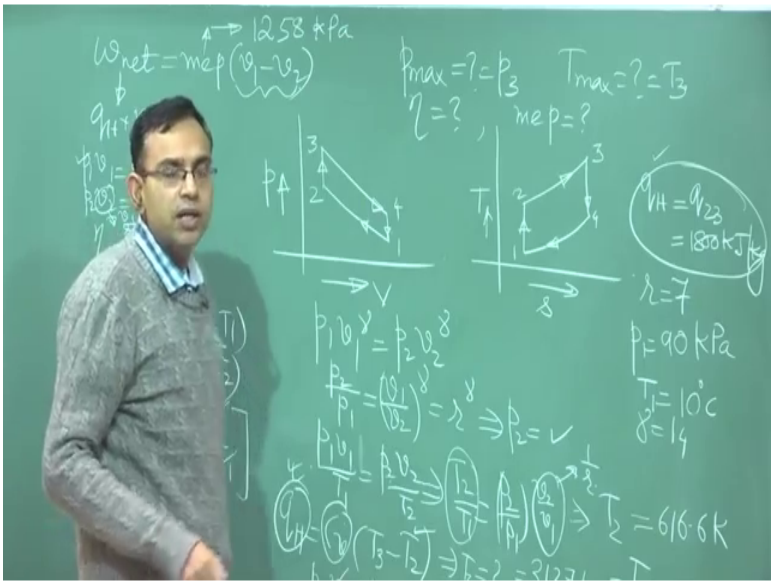

So, you can substitute that here; from that you will get an expression or a value of mean effective pressure which is 1258 kilo Pascal. So, this is a very important practical engineering parameter because this gives you an idea. So, if you know this value somehow you can magically multiply this with the change in volume to get the work output of the cycle. Not only that, it gives you an area an idea of the average pressure that is prevailing during the cyclic process; we will work out another problem, this problem we have worked out for the Otto cycle, we will work out another problem for the diesel cycle.

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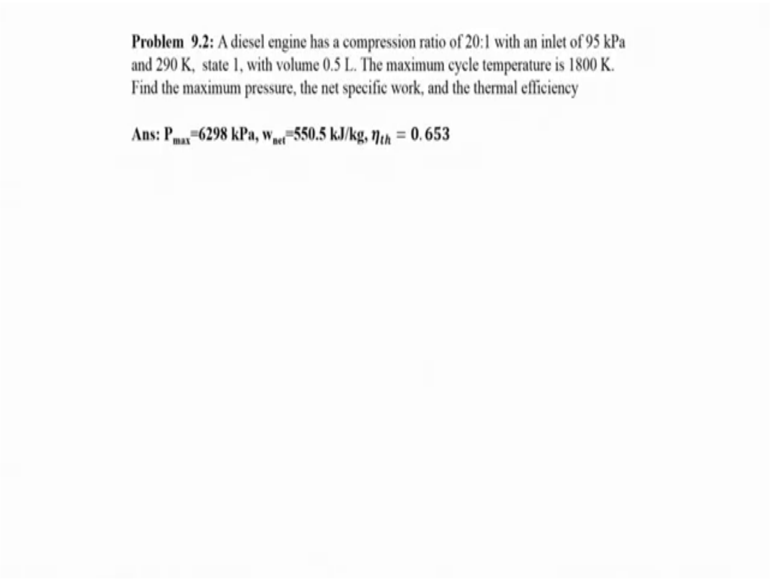

Problem 9.2: A diesel engine has a compression ratio of 20:1 with an inlet of 95 kPa and 290 K, state 1, with volume 0.5 L. The maximum cycle temperature is 1800 K. Find the maximum pressure, the net specific work, and the thermal efficiency

Ans: P_{max}=6298 kPa, w_{net}=550.5 kJ/kg, $\eta_{th} = 0.653$

So, a diesel engine has a compression ratio of 20 is to 1 with an inlet of 95 kilo Pascal and 290 Kelvin, state 1, with a volume of 0.5 litre. The maximum cycle temperature is 1800 Kelvin. What is the maximum pressure, net specific work' specific work means work per unit mass, and the thermal efficiency. So, we will solve this problem by going to the board as we have done for the previous examples.

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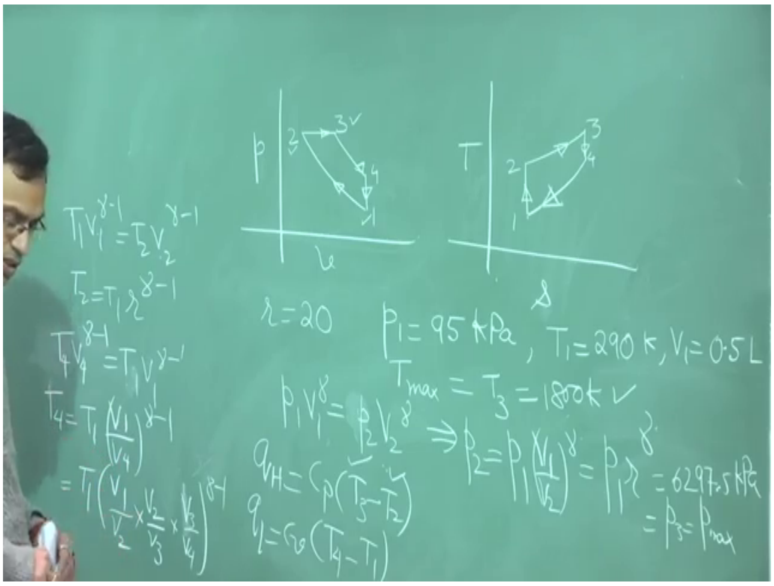

So, as usual we will draw the p v diagram and the T s diagram. Let us again note down what is written, r is equal to 20. You can see the value of r; so look in to the r of the previous problem.

So, previous problem was the Otto cycle problem r was 7, this is a diesel cycle problem where r is 20 and you can so, these are all practical data do not think that these are hypothetical data to solve some numbers. So, these will give you a quick practical idea that why it is not so legitimate to compare the Otto cycle and the diesel cycle with the same r, like the r ranges are grossly different.

So, R is equal to 20, p 1 is equal to 95 kilo Pascal, T 1 is equal to 290 Kelvin, V 1 is 0.5 litre, T max is equal to T 3 which is equal to 1800 Kelvin. So, what is the maximum pressure how will you find out? So, maximum pressure is p 2 right, p 2 and p 3 are same right. So, you can write so first of all p 1 V 1 to the power gamma is equal to p 2 V 2 to the power gamma right.

So, p 2 is simply p 1 in to v 1 by v 2 to the power gamma, so, p 1 into r to the power gamma. So, with all these values known you will get p 2 is 6297.5 kilo Pascal, this is same as p 3 which is p max. What else is required? The net specific work and thermal efficiency; so, for the net work you can calculate either area under the p v diagram, but easier way to do is just calculate q H minus q L because q H and q L you can calculate from the temperatures of the state points without going through the integral pdV root.

So, q H what is that? Cp into T 3 minus T 2 right so, you require T 2 and T 3. So, you have T 1 v 1 to the power gamma minus 1 is equal to T 2 v 2 to the power gamma minus 1. So, T 2 is equal to T 1 into V 1 by v 2 to the power gamma minus 1 that is r to the power gamma minus 1.

So, this will give you what is T 2 and then T 3 you can calculate p 2 v 2 by T 2 is p 3, T 3 is already given right so very nice. So, at we can calculate v 3 from here, but v 3 may not be needed v 3 may not be needed; let us see, what is needed only we will calculate that.

So, T 3 is; so, let us follow step by step whatever is needed we will calculate that. So, T 3 is 1500 Kelvin and T 2 is given here so, we can get q H. What is q L? q L is Cv into T 4 minus T 1. So, T 4 you can calculate this by noting so you already note T 1, T 2 and T 3 right you will not you do not know T 4, but what you know that T 4 v 4 to the power you require v 4 because you require v 3 that is why.

So, T 4 v 4 to the power gamma minus 1 is equal to T 3 sorry, T 1 v 1 to the power gamma minus 1. So, this v 4 is same as sorry so, then you can write v 4 by v 1 or T 4 is equal to T 1 into v 1 by v 4 to the power gamma minus 1. So, this you can write v 1 by v 2 into v 2 by v 3 into v 3 by v 4, or you can simply calculate v 4 and substitute it here instead of going through this route. So, what you can do is to calculate v 3 v 4 you have to know what is v 3.

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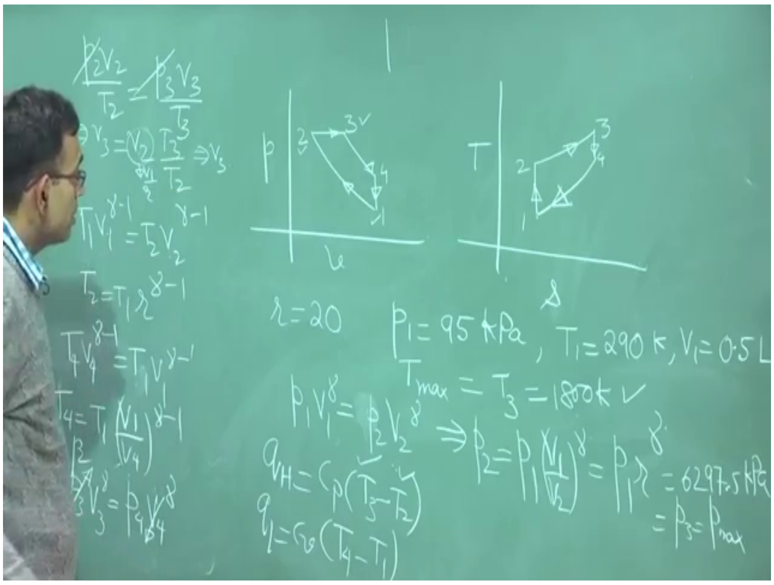

So, you can write p 2 v 2 by T 2 is equal to p 3 V 3 by T 3 ok. So, what is given? You have p 2 and p 3 you know all this in fact, that they are the same so; v 3 is v 2 into T 3 by T 2. So, V 2 you know because V 2 is V 1 divided by r. So, you know what is v 3 from here and how do you get V 4? So, 3 to 4 is p V to the power gamma equal to constant. So, p 3 V 3 to the power gamma is equal to p 4 v 4 to the power gamma right. And how do you know, what is p 4 you can relate p 4 with p 1 right. So, you can write 1 to 4 is constant volume so yes p.

Student: 4 is p.

P 3 is p 2.

Student: (Refer Time: 26:06).

v 4 is v 1, but for calculating for calculating oh. So, here we just require just a V 4 is yes sorry; here this is not correct; so, let us do little bit refreshed. So, you know; so, we so, we require T 4 and T 1, so let us do with this.

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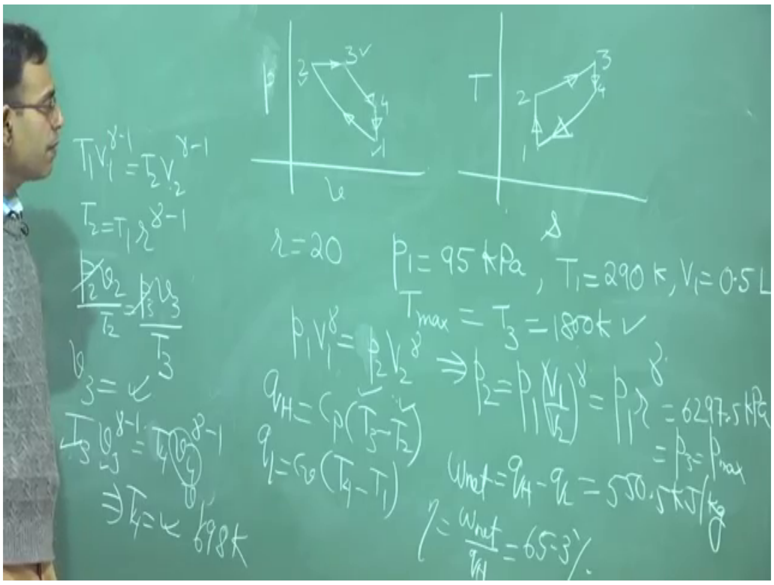

So, you have T 4 so from; so, up to state 3 we know everything right, up to state 3 we know everything you will also know v 3 because; so, let us complete that, let us up to state 3 you know T 3, you know p 3 which is same as p 2 and p 2 v 2 by T 2 is equal to p 3 v 3 by T 3.

So, you know so, mistakenly I wrote this T v to the power gamma equal to constant, that is not this one, but this one 3 to 4. So, I am just recalculating that part. So, p 2 and p 3 are the same; so, from here you will get what is v 3? So, once you know v 3 you know state point 3 completely p 3 v 3 T 3, only remaining state point is state point 4.

And so, T v to the power gamma minus 1 equal to constant so, T 3 v 3 to the power gamma minus 1 is equal to T 4 v 4 to the power gamma minus 1 right. So, if you know what is v 3, if you know what is T 3 and v 4 is same as v 1. So, this equation will give you what is T 4 right, then you know all the relevant temperatures. So, I am very sorry, I mean instead of 3 to 4 I mistakenly wrote 4 to 1 as T v to the power gamma as constant.

So, this is T 4 let me see if I have the value yes, it is sis ninety 8 Kelvin. So, the efficiency; so, the net work w net this is nothing but q H minus q L. So, this answer is 550.5 kilo Joule per kg and the efficiency is w net by q H this is 65.3 percent.

So, we have worked out couple of problems today on Otto cycle and diesel cycle, we will continue with another air standard cycle in the next lecture that is called as Brayton cycle or joule cycle.

Thank you very much.