Concepts of Thermodynamics
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Lecture – 11
Heat and Work: Representative Problems

We have earlier discussed about the concepts of Heat and Work and it is important that we go through the exercise of solving some problems related to the concepts of heat and work.

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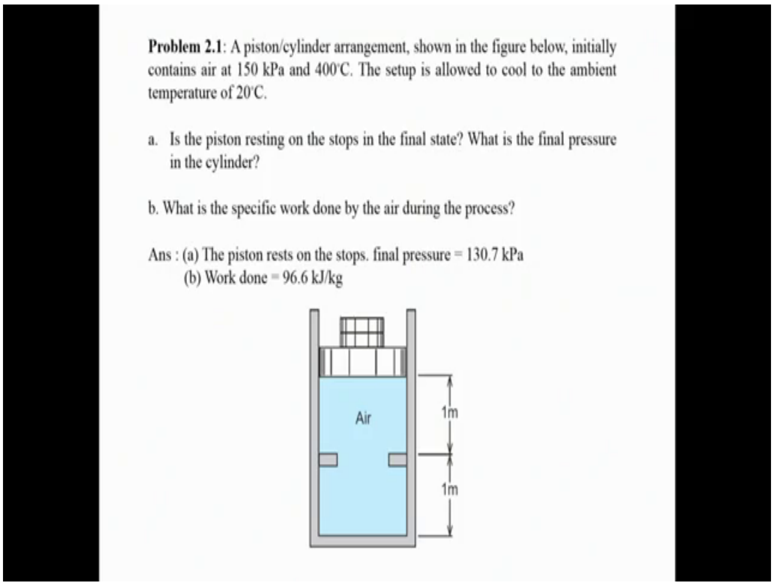

So, we start with a very simple problem which is a given here as we have done for our previous problems, we will do it in the same way we will go through the problem description first. And then we will go to the board draw the schematic of the problem note down the given data and try to solve the problem.

So, you have a piston cylinder arrangement. It initially contains air at 150 kilo Pascal and 400 degree centigrade. The setup is allowed to cool to ambient temperature of 20 degree centigrade; the question is the piston resting on the stops in the final state. So, you can see that physically what is going to happen is if heat is transferred from the system which is air in this case, the piston will start going down.

So, in the process it may heat the stops or not question is at 20 degree centigrade the final temperature will it heat the stops what is the final pressure and what is the specific work done; that means, work done per unit mass by air during the process. So, let me first draw a schematic of this problem and see what is the given data and then we will solve the problem accordingly.

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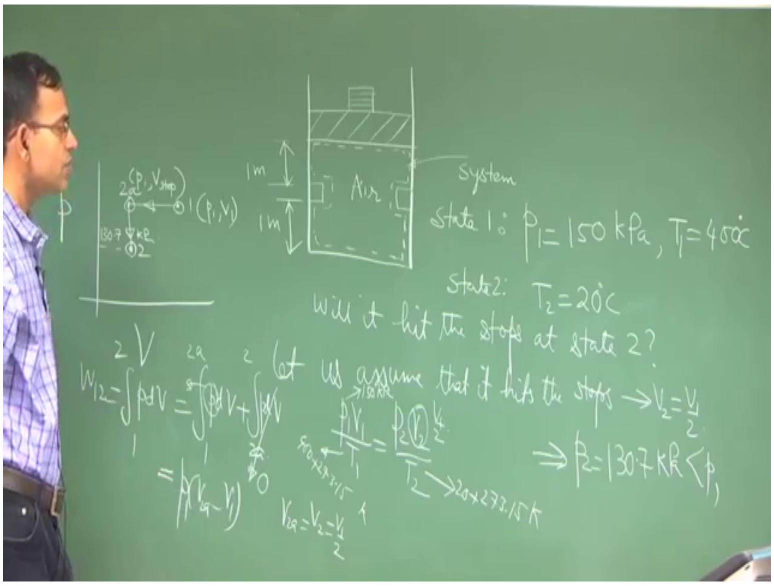

So, this is the air which is our system. So, for this system state 1 is given as p 1 is equal to 150 kilo Pascal and T 1 is 400 degree centigrade. State 2 is T 2 is equal to 20 degree centigrade and these volume this is so, this length is 1 meter and this length is 1 meter. So, let us try to address the first question that is whether the piston will heat the stops or not. Now, first of all what kind of substance is this air that we have to figure out. See in thermodynamics there are certain substances which are sort of face changing substances and you require to read the property table to evaluate their properties.

In certain cases, the substance can be idealized as an ideal gas and normally even if it is a real gas at very high temperature or very low pressure or a combination of these two you can treat the ideal gas; the real gas as an ideal gas. So, here at least at state 1 the temperature is quite high pressure is close to atmosphere 1 atmosphere is roughly 100 kilo Pascal. So, in that respect treating this as an ideal gas will not be a very bad assumption.

So, at state 2 the question is that will it heat the stops at state 2. So, let us assume that it heats the stops if it heats the stops then in that case V 2 is V 1 by 2, why? Initial height is 1 meter plus 1 meter when it comes down and heats the stops the height is 1 meter. So, area of cross section remaining the same V 2 becomes V 1 by 2.

So, then you can write for ideal gas, remember that when you are using this ideal gas equation this T 1 and T 2 are absolute temperature. So, this is 400 plus 273.15 Kelvin and this is 20 plus 273.15 Kelvin V 2 is V 1 by 2 p 1 is 150 kilo Pascal.

So, from here you can calculate what is p 2. So, if you calculate p 2 will come out to be 130.7 kilo Pascal. This is less than p 1. So, from here what can you conclude? See if this is moving this piston is moving in a quasi equilibrium process because the resistance pressure does not change the inside pressure will not change until and unless it encounters the stops, where it encounters the stops it wants to go down what the stops is preventing it from going further.

So, the very fact that the pressure has come down to 130.7 kilo Pascal and this is because of continuous heat rejection, it signifies the fact that you know it has already heat the stops because if it does not heat the stop or just it has just heat the stops the pressure will still remain 150 kilo Pascal because it has not remained as 150 kilo Pascal and it is less than this one; that means, it has heat the stops.

So, the question the answer to the first question is the piston against the stops resting on the stops in the final state? The answer is yes and this is the pressure at state 2. Then at now what is the specific work done by air during the process? So, for any problem where work done is involved it is very convenient if we can draw the p v diagram because p v diagram gives us a physical insight of how pressure is changing with volume and then integral of p d v will give the work done for the simple compressible pure substance.

So, to do that, what we will do is we will consider the state 1 this is p 1 comma V 1, From state 1 what is happening the piston is coming down. So, its volume is decreasing at constant pressure of 150 kilo Pascal till it encounters the stops so, volume is reducing.

So, it comes to a state 2 a where still the pressure is p 1 and volume is v stop then it cannot decrease its volume anymore, but because of continues heat rejection the pressure is decreasing. This p 2 is 130.7 kilo Pascal. So, what is the work done?

This much so, this is integral pdV from 1 to 2 a plus integral pdV from 2 a to 2 this part is 0, because it is a constant volume process. So, and during this part the pressure is constant at p 1. So, its p 1 into v 2 a minus V 1 and what is V 2 a this is same as V 2 which is V 1 by 2. So, you can substitute the values and get what is the work done.

So, you can find out the work done only per unit mass air and that is what is expected. The question is what is the specific work done by the air during the process. So, in this case if m is the mass of the air then this is m.

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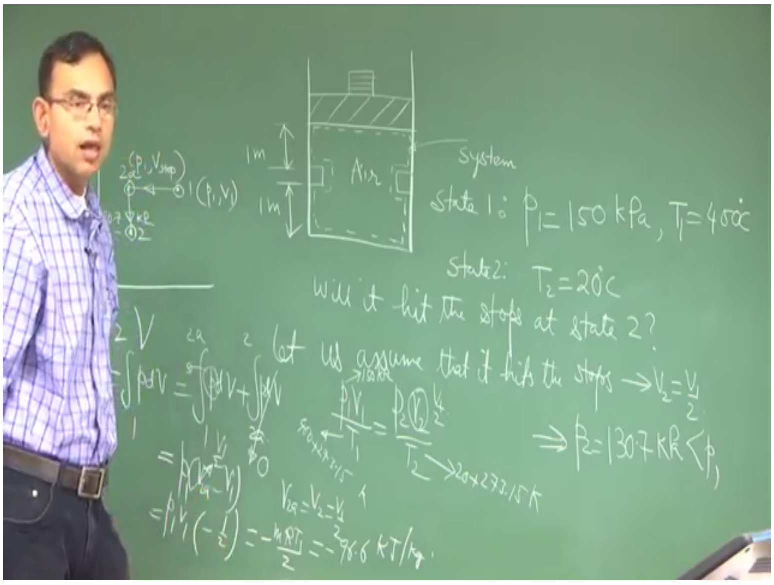

So, v 2 a is first of all v 1 by 2 then you can write p 1 V 1 into half minus 1 that is minus half and p 1 V 1 is m RT 1 minus m R T 1 by 2 this T 1 is again absolute temperature. What is this R? This is specific gas constant not universal gas constant; this is universal constant divided by the molecular weight.

So, this is per unit mass for example, for air it is 0.287 kilo joule per kg Kelvin right. So, if you do that this comes out to be the answer to this is 9 minus 96.6 per kg if you take m as 1 kg. So, in this case the answer is minus; the reason is that there is work associated which is work input so, that the system is getting compressed.

If work leaves the system, what is the sign convention? If work leaves the system it is positive, if work gets into the system which allows the system to gets compressed then that work is negative work. And that is why it is minus in this case ok. So, let us workout another problem so, problem 2.2.

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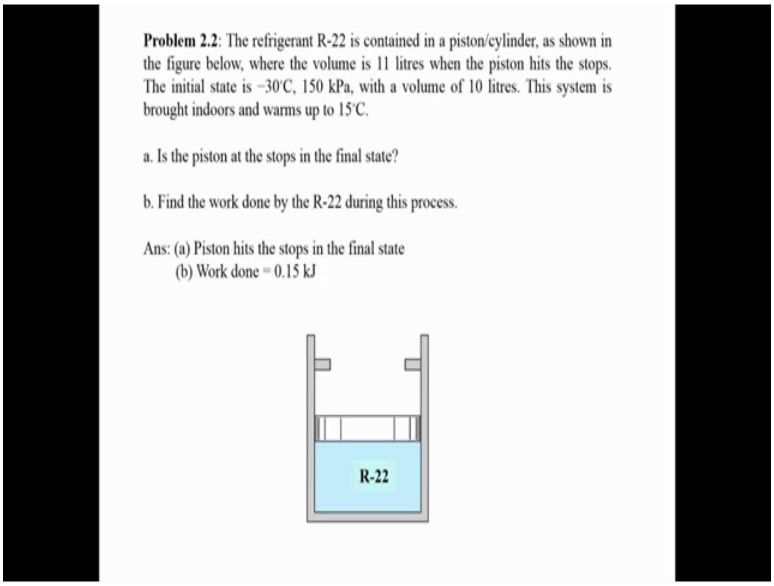

There is a refrigerant R 22 these kind of name are with certain numbers and in some cases with certain letters this combination is normally for refrigerants. So, there is a refrigerant which is contained in a piston cylinder as shown in the figure where, the volume is 11 litre when the piston heats the stops. So, if it heats the stops the volume is 11 litre the initial state is minus 30 degree centigrade and 150 kilo Pascal with the volume of 10 litre. The system is brought to indorse and wants up to 15 degree centigrade.

So, from minus 30 degree centigrade heat is transferred. So, that it comes to 15 degree centigrade. So, when heat is transferred it will expand and the question is will it heat the stops or not and what is the work done by the R 22 during the process. So, just like the previous problem, let us draw this in the form of a PV diagram.

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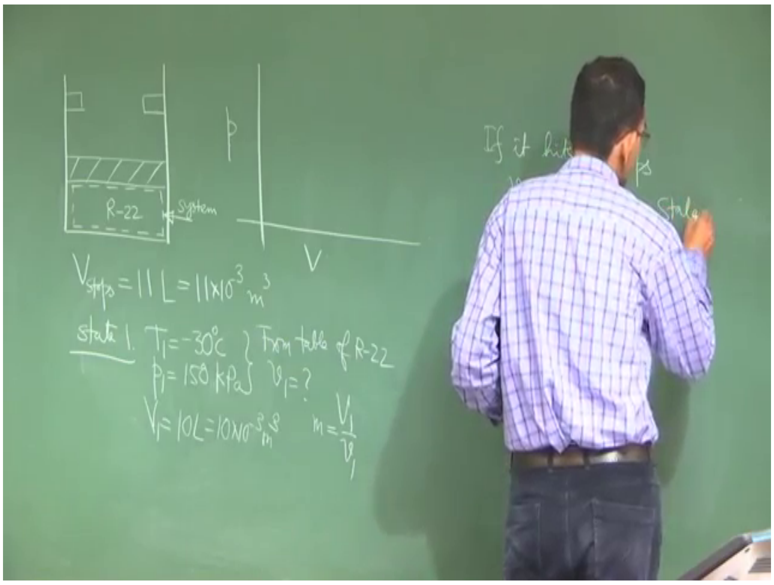

Before that let us make a schematic of the problem. So, V stops is equal to 11 litre 11 litre is 11 into 10 to the power minus 3 meter cube. Then state 1 T 1 is minus 30 degree centigrade and p 1 is 150 kilo Pascal and V 1 is 10 litre. So, for such a substance from this information what you can what additional thing that you can calculate is what is the mass of R 22.

So, you have the system here. So, in this system at state 1 so, you have two independent properties. So, not ideal gas by using the property see this is where I want to emphasize that from school level when you come to the college level this is where in most of the cases you have a confusion. In school, level almost all properties related to thermodynamics are corresponding to ideal gases. So, very frequently you are using ideal gas relationships.

So, for this you are tempted to write say p 1 V 1 is equal to a mod T 1 something like that. So, the question is that when you have this p 1 V 1 is equal to a mod T 1, can you use that formula here? The answer is no. This is very typical phase changing substance and in that scenario you cannot really you approximate it as an ideal gas that will be a very wrong approximation in reality no substances an ideal gas, but for certain substances approximation as an ideal gas is not a bad approximation.

In this case the approximation is a bad approximation. So, from table of R 22, you can find out what is v 1 from T 1 and p 1 and then the mass which does not change from state

1 to state 2 is simply V 1 by small v 1 this is volume per you total volume this is volume per unit mass. So, that is the mass of the system.

So, now let us look into the thermodynamic process what is asked. So, heat is transferred and the system is heated.

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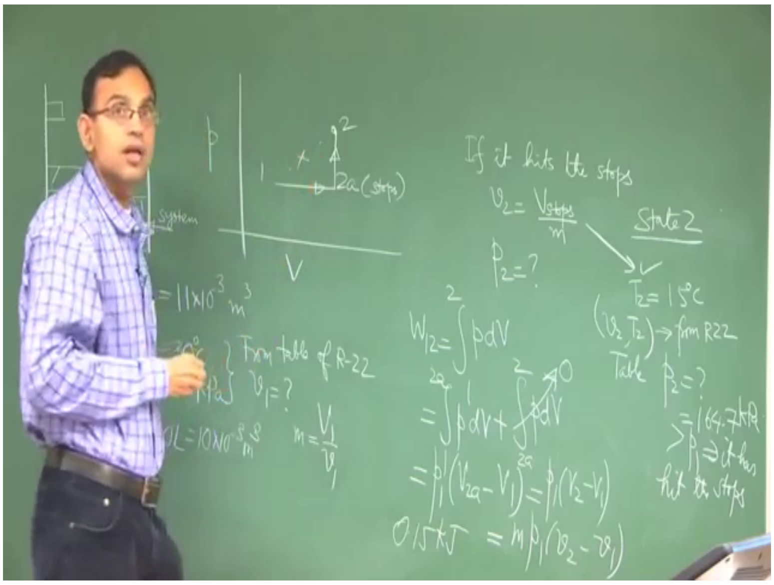

So, if it heats the stops we do not know whether it has heat the stops, if it heats the stops then what is the specific volume at state 2 specific volume at state 2 is V stops y m that m you get from here. So, now, from V stops by m that is I do not have the data, but you can calculate what is the pressure at state 2 how do you calculate what is the pressure at state 2 there is some additional data which is given.

So, state 2 remember always try to follow these problems in this way. So, to identify a state point for a simple compressible pure substance you require two independent intensive properties. So, one property is this one the other property is T 2 is equal to 15 degree centigrade ok. So, this is still a hypothetical state because this state is true if it heats the stops if this state.

So, we have to verify whether it heats the stops or not this is the very important part of the problem and this is where thermodynamics is so challenging. If the verification does not show that it heats the stops, then this state remains hypothetical. If the verification shows that the it heats the stops then this state is real. So, whether the state is real or hypothetical that needs to be worked out from the problem data itself.

So, unlike many other subjects where changing the data does not change the method of solving the problem in thermodynamics changing the data itself may change the method of solving the problem and that makes this very unique subject where just by a structured way of solving problems you cannot really make a grasp of the problems.

So, you have T 2 as fifteen degree centigrade v 2 as this combination v 2 T 2 these combination from R 22 table will give you what from R 22 table this will give you what is p 2. So, once you have got what is p 2 then what you do with this let us say that we have got p 2 as 164.7 kilo Pascal this is what actually you will get if you look into the table.

So, I have jotted down this data because the problem solving further depends on this data how it further depends on this data this is greater than p 1 right had this been less than p 1 ? Less than p 1 is not what is expected because heat is transferred to it and it is moving. So, how its pressure can fall down below p 1, but incidentally its pressure could have remains same as p 1 that is possible, he had its pressure remains same as p 1 then; that means, it might not have heat the stops you are not sure or in the limiting case it may just have reach the stops. However, when it is greater than p 1; that means, it has heat the stops and then the pressure is going up right so; that means, it has heat the stops.

So, once it has heat the stops then what will happen its volume cannot change anymore, but its pressure will build up because heat is transferred to it from the room the room is hot room heat is transferred to it wants to go up, but stops or preventing it from going further up. So, its pressure will build up inside. So, the p v diagram is look something like this 1 2 2 a is this is basically stop and then from here to state 2 the pressure will rise.

So, you have to find out what is the work done in this process. So, what is the work done just like the previous problem. So, this part is 0 and this is 1 into V 2 a minus V 1 and V 2 a is same as V 2 and by expressing these in terms of the specific volume you can write in terms of specific volume and this comes out to be 0.15 kilo joule the final pressure does not matter right.

So, if you cannot draw this PV diagram correctly I have seen some students making mistakes here they will just have point 1 and point 2 and they will write the work done as half of p 1 plus p 2 into V 2 minus V 1 because they will draw the PV diagram incorrectly as this. So, the PV diagram is not like this it is this step plus this step one constant pressure another constant volume.

Thank you so much we will continue with more problems in the next lecture.