Concepts of Thermodynamics
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Lecture – 05
Properties of Pure Substances: Example Problems

Today, we will look into various aspects of identifying state points, considering the property tables of pure substances. The best way in which this can be understood is through solution of problems, and we will consider a few problems which we will work out.

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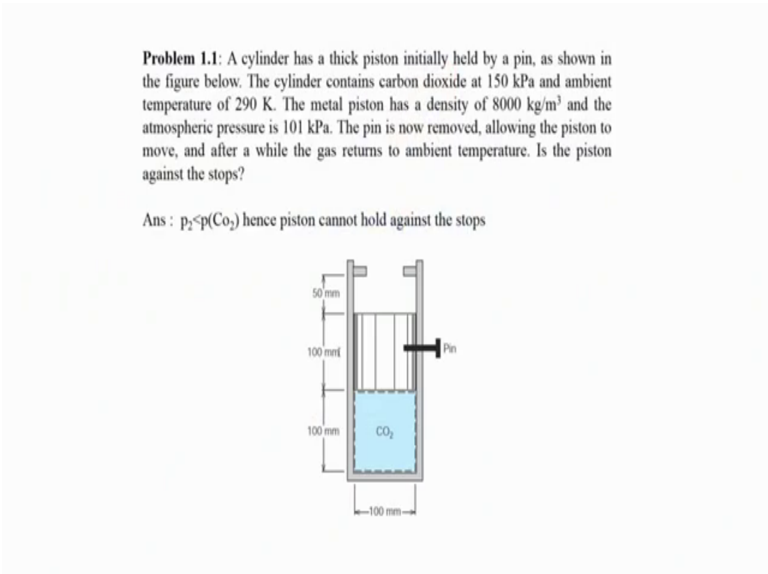

So, the first problem, which is problem 1.1 is written here, described here: the as per the custom I will go through the problem description, then draw a schematic of this problem, and then we will proceed towards solving the problem.

A cylinder has a thick piston initially held by a pin, as shown in the figure below. The cylinder contains carbon dioxide at 150 kilo Pascal and at and ambient temperature of 290 Kelvin. The metal pistons density is given and the atmospheric pressure is given. The pin is now removed, allowing the piston to move and after a while the gas returns to ambient temperature. So, you can see that there is a piston; there is a pressure imbalance across the two sides of the piston. This is the first important information from the problem. So, because there is a pressure imbalance the piston has a tendency to either move up or down it depends on you know which side pressure is more.

So, to erase the piston from moving further there is a pin which is holding the piston. If the pin is removed, the piston will freely move and it will come to a location where it is dictated by the equilibrium of forces from all sides which is called as mechanical equilibrium. Question is: that is the piston against the stops or not. So, to work out this problem, so let us draw a schematic of this in the board. So, I will draw a schematic of this problem in the board.

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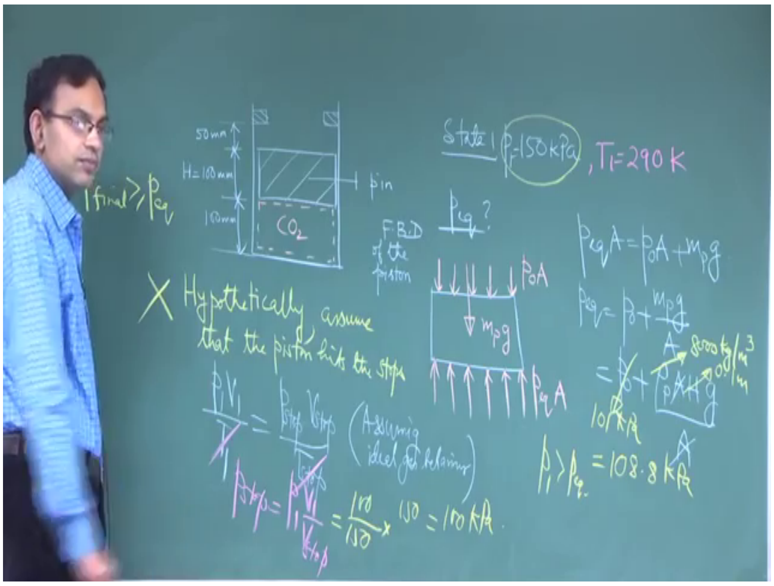

So, you have a pin, this is the height of the piston H is equal to 100 millimeter. Then you have again this as 100 millimeter and this as 50 millimeter. The system here is carbon dioxide which we show by this dotted line. So, whatever is given let us note it down it may help us.

So state 1: 150 kilo Pascal, this is p 1, ok. Now what will be the equilibrium pressure at which the piston will float if the pin is removed; let us calculate that. So, what is p equilibrium? P equilibrium means, if the piston is in equilibrium under all forces then what would be the corresponding pressure inside. So for that, we draw the free body diagram of the piston: free body diagram of the piston.

So, this is atmospheric pressure right, A is the area of the piston. Then, you have mass of the piston into g which is the weight of the piston. And then from this side you have p equilibrium into A right. So, if the piston is moving in a quasi equilibrium process or quasi static process these forces are always in equilibrium. So, if the volume is changing this is changing, but locally it is always in equilibrium; that means, resultant of these forces is 0.

So, we can write p equilibrium into A is equal to p 0 into A plus m g. So, p equilibrium is equal to p 0 plus m g by A ok. The mass of the piston you can calculate: the density into volume. So, rho piston into A into H, this is the mass, so A is not required. Density of the piston what is given? So, let us mark out these values. Density of the piston is 8000 kg per meter cube. H is 100 millimeter; that means 0.1 meter, g is 9.1 81. And what is p 0? p 0 is this one; p 0 is given as 101 kilo Pascal.

So, if you substitute the values in most of the problems that I will be solving in the class, I have made some pre-calculations. And I will not waste time by you know clicking the calculator to work this out. I will give you the value if it is available because, in thermodynamics depending on this value the solution of the problem will be there. That is why thermodynamics is so interesting. So, depending on the specific value the physics of the answer will be has to be set. It does not have a specific rule that whatever is the value the answer to the state point is unique; the answer to what is the state depends on what is the value which is coming. So, this value is very important not that we can say that whatever is the value based on which a general answer will come.

So, this value is 108.8 kilo Pascal. So, if this pressure is more than. So, what is p 1? p 1 is 150 kilo Pascal. That means, at state 1 this force in the upper direction is greater than the force in the lower direction. That means, had the pin not been there the piston will have a tendency to go up. Piston wants to go up and the pin actually restraints it from doing that, ok.

Now, what happens when the pin is removed? When the pin is removed this piston will have a tendency to go up. Question is how far will it go up, right? So, it says that the piston, the pin is now removed allowing the piston to move an after a while that the gas returns to ambient temperature. So question is: does the piston hit the stops. So, hypothetically assume that the piston hits the stops, ok. If that be the case then the final volume will be whatever is the volume plus this much up to the stops. So, we can write p 1 V 1 by T 1 is equal to p stop in to V stop by T stop.

What is the assumption? Assumption is that we can treat carbon dioxide at such low pressures as ideal gas. Remember a real gas can be approximated as an ideal gas at reasonably low pressure or high temperature: so assuming ideal gas behavior. What is given is that at step point two which is assumed to be the stop here, the gas returns to the ambient temperature. It started with the ambient temperature at what is that T 1 is 290 Kelvin, and it is returning also to the ambient temperature. So, if it is returning to the ambient temperature and starting with the ambient temperature then T 1 is T stop, right.

Remember, that T 1 is equal to T stop that does not mean that the process from one to stop is isothermal process. It says that the piston goes to whatever it may be stop or before the below the stop and then the system is allowed to come to ambient temperature by maybe transferring heat. So, T 1 is equal to T stop, but in between all the state points were not same as T 1. So, an isothermal process means that all the intermediate state points will be at the same temperature, not just that the final and initial temperature at the same.

So, this is a classical example where final and initial temperature at the same, but it is not an isothermal process. In between the temperature was not guaranteed to be same as T 1. So now, you can calculate from here p stop is equal to p 1 into V 1 by V stop.

So what is V 1 by V stop? V 1 by V stop is 100 by 100 plus 50; so this is 100 by 150. Into what is p 1? Is 150; so this is 100 kilo Pascal, ok. Now look into this equilibrium pressure, when the when the piston is moving its pressure can it fall below equilibrium pressure: the answer is no. It is It will move in a quasi equilibrium process so, its pressure will be equilibrium pressure. If it hit the stops, the pressure inside will be up. Why because it wants to go further but the stops is preventing that.

So, the pressure the final pressure has to be greater than equal to the equilibrium pressure. It is equal to the equilibrium pressure, if it is not hitting the stops, but if it is hitting the stops the pressure will be greater than the equilibrium pressure. So, this conceptual understanding you have to develop that, in the thermodynamics that we are studying in this course if the piston is moving it is moving in a quasi equilibrium process. If it is moving in a quasi equilibrium process; that means, the pressure here is always the equilibrium pressure. The resistance pressure is not changing, so the equilibrium pressure is also not changing. When it hits here, the pressure inside will be low.

So, none of this is happening; that means, actually this hypothesis is wrong. That means, the piston does not hit the stops ok. So, that is the answer to this problem. The problem what is asked is that is the piston against the stops? The answer is no, the piston is not against the stops. We will work out another problem.

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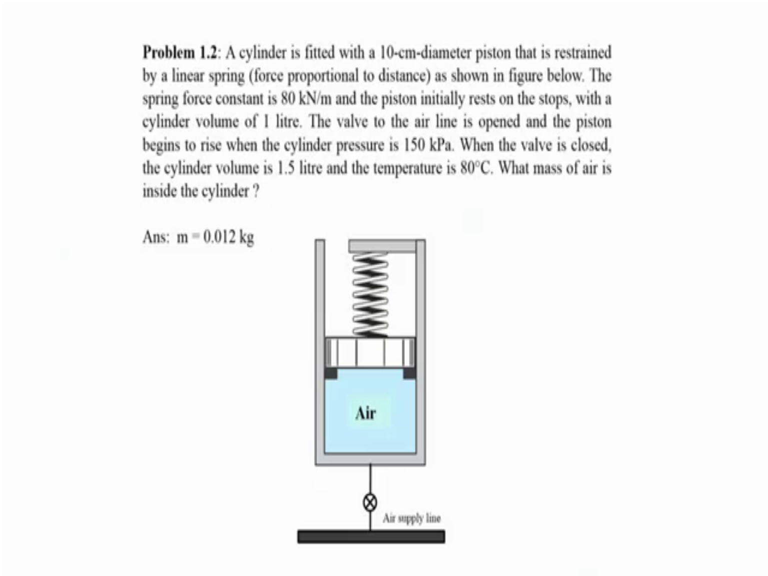

So, we will look into the next problem, problem 1.2. So, the diagram of the problem is given here and again I will read out the problem. A cylinder is fitted with a 10 centimeter diameter piston that is restrained by a linear spring; linear spring means the spring force is proportional to the displacement as shown in the figure below. The spring force constant is 80 kilo Newton per meter and the piston initially rests on the stops, with a cylinder volume of 1 litre.

Now, there is a air supply line. When the air supply line is opened the piston begins to rise, because the additional air will pressurize the air from the below and the piston which was earlier resting on the stops will experience more pressure from bottom than the top, and then it will go up. In this process the cylinder pressure rises to 150 kilo Pascal, when the valve is closed the cylinder volume is 1.5 litre and the temperature is 80 degree centigrade. Question is: what is the mass of air inside the cylinder. So, just like the previous problem here also we will draw a schematic.

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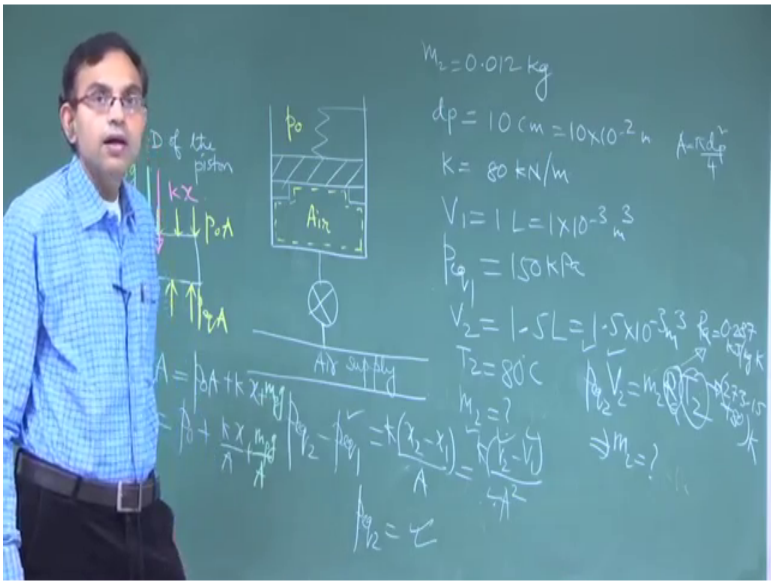

So the system is air, and then what is asked is to calculate; that what is the mass of air inside when the valve is closed. So, let us try to note the property data diameter of the piston 10 centimeter, this is 10 into 10 to the power minus 2 meter. The spring constant is 80 kilo Newton per meters. V 1 is 1 litre that is 1 into 10 to the power minus 3 meter cube. Then p equilibrium 1, the pressure at which the equilibrium pressure at which the piston starts rising is 150 kilo Pascal. V 2 is 1.5 litre is 1.5 into 10 to the power minus 3 meter cube. And T 2 is 80 degree centigrade. Question is: what is m 2 ok.

So, can you tell: what is the difference between the previous problem and this problem? The difference is that because the spring force varies as the piston is moving the equilibrium pressure also varies as the piston is moving. In the previous problem there was no spring, so equilibrium pressure remain constant; now here the equilibrium pressure will vary. So, we draw the free body diagram of the piston.

So, we will identify the forces. So, first is let us identify the forces due to pressure. So, you have p 0 into A which is the atmospheric pressure the pressure is p 0; here it is p equilibrium into A. And then, the spring force it is very important to figure out what is the direction of the spring force. So, when the air is being supplied the pressure here is increasing. So, if the pressure here is increasing the piston will have a tendency to go up. So, the spring will give a restoring force downwards. So, you have a k x like this. So, p equilibrium into A is equal to p 0 into A plus k x. So, p equilibrium is equal to p 0 plus k x by A, right.

So, p equilibrium 2 state 2 minus p equilibrium state 1 is equal to k into x 2 minus x 1 by A, right. And x 2 minus x 1 is V 2 minus V 1 by A, so this becomes V 2 minus V 1 by A square. So, what is A? A is pi d square by 4, it is a circular piston. So, k is given, A is given, V 2 is given, V 1 is given, all this data are given; so if you calculate this and p equilibrium 1 is also given. So, this equation will give you what is p equilibrium 2. So, p equilibrium 2 is equal to; I mean some value I do not have the value with me exactly, but you can substitute all these; so p equilibrium 2 value is known.

Student: Sir, why did not you consider the weight of the piston?

So, the weight of the piston here is not given; so the important question is why don't we calculate, why don't we consider the weight of the piston we can way considered the weight of the piston and still that will not be important. So, we can add the weight of the piston; you will see that it gets cancelled out. So, actually you can consider mpg along with this, so plus mpg. So, we will see that I mean whatever is the weight of the piston it will not matter if you find the difference in pressure. Ideally, you are correct you should consider the weight of the piston; I mean somehow I omitted that in the free body diagram, but you it is very easy and straight forward to include the weight of the piston.

So, if you include the weight of the piston, you have an additional term, but this p 0 plus mg by A this gets cancelled out, so you will get p equilibrium 2. Once you get p equilibrium 2 it is very easy because m 2. So, p equilibrium 2 into V 2 is equal to m 2 R T 2. What is this R? Again coming from school students confuse, this is not the universal constant. This is the universal constant divided by molecular weight ok. So, this is the specific gas constant.

So, this for air what is the substance here? The air right this is air. So, R for air is 0.287 kilo Joule per kg Kelvin. This you divide the universal constant divided by the molecular weight ok. So, once you do that, this is R air, this is T 2. Remember that when you write this equation this temperature has to be in Kelvin. So, this is 273.15 plus 80 Kelvin; V 2 is known, p equilibrium 2 is known, so from here you will get what is m 2. The answer to this problem is m 2 is 0.012 kg ok.

I hope I could illustrate two very typical problems in which one case there is a piston cylinder without spring, another case piston cylinder with spring, and how to calculate the equilibrium pressures under that condition. Let us stop here for this lecture, we will continue with other problems on properties of pure substances in the next lecture.

Thank you.