Concepts of Thermodynamics

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Lecture - 09
Properties of Pure Substances Spring – Piston Problem

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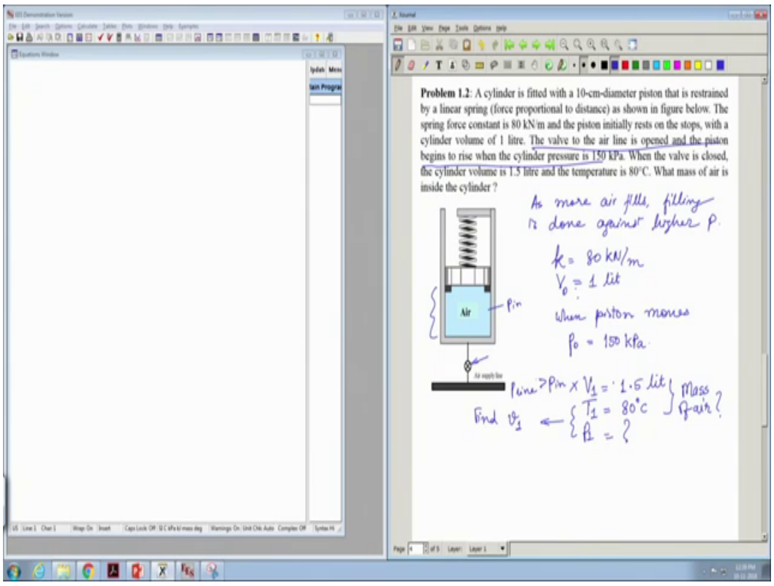

Hello and welcome to this lecture. We will consider slightly more complicated problem that of a piston loaded by a spring, a linear spring and the piston is charged by means of an air supply line. So, air supply line; obviously, has a higher pressure and then you open the valve, the valve is opened when the valve is opened air at higher pressure rushes into the piston.

So, this P line and this P inner. So, line is greater than P inner and then it starts to move the piston, but because it spring loaded the moment you start moving the piston it encounters a larger force and this, the P inner because also the volume is increasing. So, there will be a complicated relationship between the actual pressure, but as more and more air flows in it has to flow in against a higher P inner. So, it does has to do it against the higher pressure and then the valve is closed, then what happens that is the question.

So, the spring constant is given as 80 kilo Newton per meter and the initial volume is given as 1 liter, let us call this as V 0 you have 1 liter. Now it is given that after opening the valve the piston rises only when the cylinder pressure is 150 kPa. So, when piston moves there has to be first enough pressure developed inside this particular chamber and that pressure I will call it as P 0 in that is equal to 150 kilo Pascal. After the closure of the valve the volume V 1 is given as 1.5 liter, it is given that the T is 80 degree Celsius what is the mass of air inside the cylinder.

So, when the pressure is acting on the piston the piston rises up, the final volume is given the final pressure is not given and the final temperature is given ok, but we do not know what the mass is that is why we do not know what the specific volume is. So, total volume is not an indication of the specific volume, I do not know what the mass is I cannot find out the specific and total volume is neither a intensive property which I can use as an independent parameter, I cannot use total volume I need the specific volume.

So, that is why I need the mass of air, but I do not have the mass of air so, but may be you see the problem when you think yes it is given that it expands to this volume. So, may be with that and the fact that the spring constant is given I can find the pressure. And if the temperature and pressure are known maybe I can find the specific volume and with the specific volume and total volume I can then find out the mass ok. This is how we should proceed, logically you have been only given the total volume that is why you cannot proceed you need to find out the specific volume and do it.Bbut how can we relate the final pressure and initial pressure with the spring constant.

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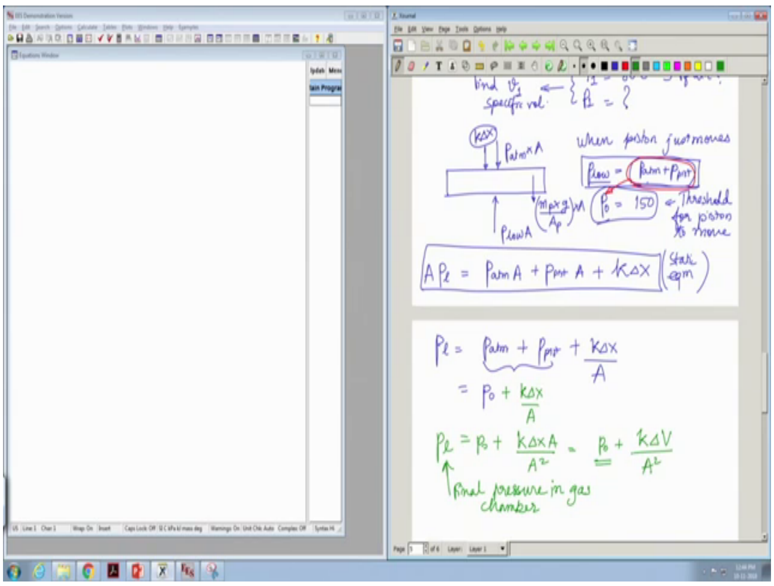

So, let us look at the equilibrium of the piston. So, because of the spring apart from the atmospheric pressure look this cylinder is open to the atmosphere ok, because it is open to the atmosphere we can then write down the following facts, it is P atmosphere and k delta x apart from the mass of the piston.

So, when piston just moves we chose it as a reference point for the spring. So, we say P lower is equal to P atmosphere plus P piston, see mass of piston time g by A of pistol is the pressure due to this so; obviously, P low into area is the force P atmosphere into area is the force and; obviously, this into area is the force and k delta x is the force.

So, from equilibrium because the areas are equal we know that P lower is equal to P atmosphere plus P piston is the equilibrium and the moment just when the piston starts to rise.

So, P 0 is equal to 150 corresponds to the point where there is no pressure acting on this. So, there is no displacement. So, at this threshold the piston starts to move; at this threshold the piston starts to move. Now once it starts to move its k delta x will start accumulating therefore, we have P lower is equal to P 0 or rather let us write it down in this manner P lower is equal to P lower into area is the force is equal to P atmosphere multiplied by the area plus P piston multiplied by the area plus k delta X this is what you have static equilibrium. Actually during this process we assume that in the process is going on in a quasi equilibrium manner and thus we can write this down, we can write down the static equation, because the process is in static equilibrium there is no acceleration of the piston oops.

So, let us rearrange this let us rearrange this. So, P lower is equal to P atmosphere plus P piston plus k delta x by A, now we have already seen that P atmosphere plus piston was the threshold when it just starts to move ok. So, that is equal to P lower. So, that P lower for this particular state was equal to P naught. So, P naught this two term become P naught because P atmosphere plus P piston when it just starts to move this P naught and we said that as a reference state for the spring.

So, this becomes P naught plus k delta x by A is nothing, but P naught plus k delta x into A by A square is nothing, but P naught plus k delta V by A square. So, the final pressure or the pressure inside the chamber which is equal to the P lower is equal to the P naught when the piston just starts to move plus whatever change in volume you may accrue times k by A square. So, let us start crunching in the values.

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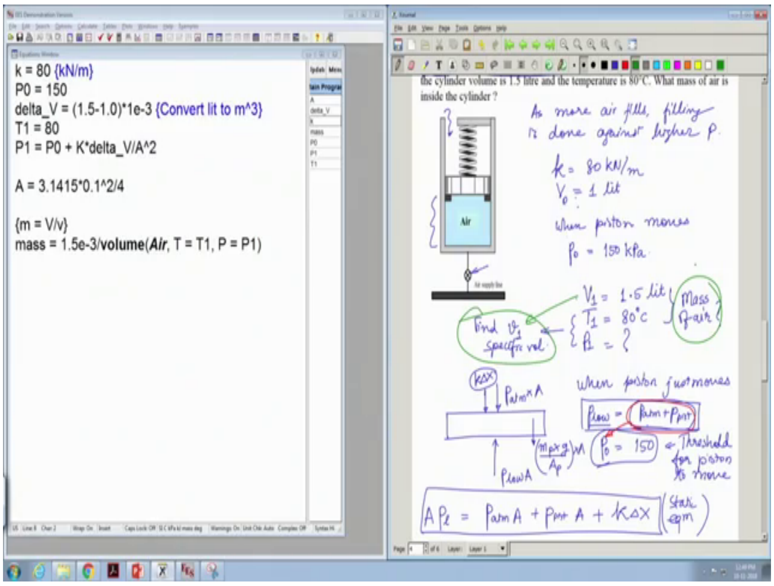

So, k is 80. So, this is in kilo Newton per meter we need the kilo I mean we do not get into to the kilo we do not multiply by 1000 because, we will use the kilo Newton to convert it directly into kilo Pascal. Otherwise, we have to multiply by 1e minus 3 to make a Pascal into a kilo Pascal we do not bother about that we will see how it checks out. So, P 0 is 150 and what else is given delta V is given as 1.5 liter minus 1 liter, see final volume is 1.5 liter initial volume is 1 liter multiplied by the area of the piston sorry.

So, this multiplied by 1 e minus 3 if converted liter to meter cube through this step final temperature is given as 80 degree Celsius and thus we need to know what P 1 is. So, we have already seen through our calculation through the logic the P 1 which is the P in the final state is equal to P naught as K delta V by A square.

So, we need to know what A is. So, A equal to, what is the area? We know that the diameter of the piston is 10 centimeter and thus the area is equal to 3.1415 multiplied by 0.1 square by 4 this is the area of the piston. Now delta V by A square is in standard SI units k is in kilo Newton per meter.

So, whatever this quantity will be is in kilo Pascal, P naught we have already done down in kilo in kilo Pascal and does this is consistent. So, we do not need any conversation going on. So, this is kilo Pascal already.

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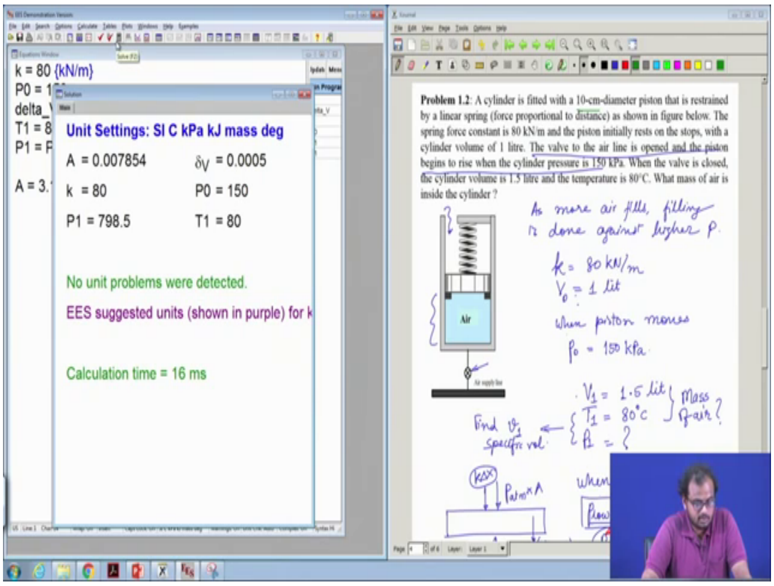

So, thus let us see what the final pressure is. So, the final pressure is 798.5 kilo Pascal. So, because of this what is the total mass so, the specific volume. So, let us write down directly. So, the mass is equal to the final volume which is 1.5 liter divided by volume of air at T equal to T1 P equal to P 1 and thus we obtain the masses 0.01182.

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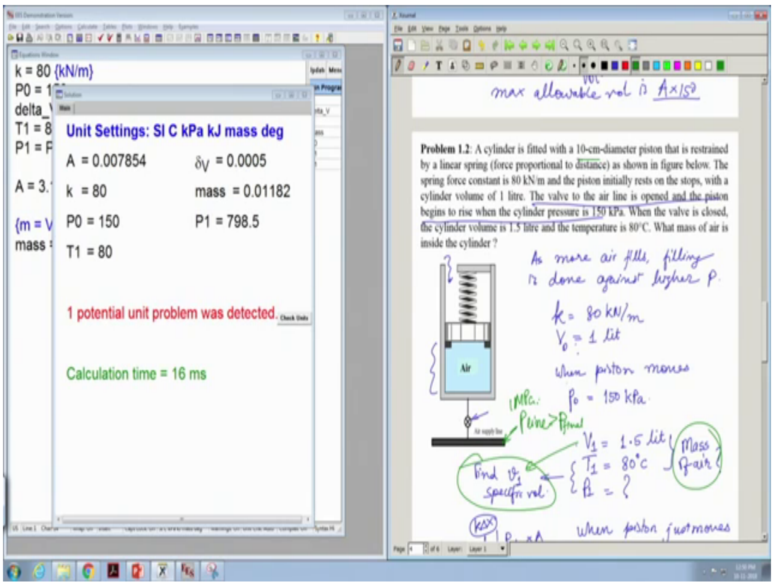

Now, we recall that air under normal operating conditions when it does not liquefy and so on does behave as a pure substance and thus even to find out the properties of air we can make do with just two independent properties. So, this is what the idea is, this was the volume. So, this we have just use the fact that mass is equal to volume by specific volume this is the formula that we have used the area is known.

So, the crux of the problem was to find out how to find out the final pressure and crux was also in the fact that we cannot find the final mass directly with just the total volume; total volume is not a intensive property and thus we cannot use in our calculation. We needed to find the pressure and the temperature; these are our independent quantities with which we were able to find out the specific volume.

And after finding out the specific volume we use the fact that specific the total volume divided by specific volume gives you the total mass and this is how you find out total mass of the system. And the static equilibrium idea was used where we say that the piston is in quasi equilibrium because of that quasi equilibrium we can apply a static equation, a static balance and then we saw that the pressure at which the thing is lifted is P chamber to find A is equal to P naught plus k delta x by Ath.

So, when delta x is 0 when there is no movement of the piston then P in the chamber becomes equal to P naught this is the pressure at which just the piston starts to move as seen from the problem. So, this is equal to 150 kPa from the problem and because of this air supply line we were able to achieve a much higher pressure.

So, much higher pressure was approximately 800 kilo Pascal, we went from 150 kilo Pascal to 800 kilo Pascal. We do not know what the pressure in the line is, but we have to assume that it is larger than 800 kilo Pascal P line is not given in the problem.

So, we know from our idea that if final pressure is 798.5 kPa the line pressure has to be at least larger than 798.5 kPa. So, maybe it is something like 1 mega Pascal or something who knows does not matter. So, initial whatever pressure it was suppose the pressure was initially let us try to, I mean let us go beyond this and try to see what actually can happen.

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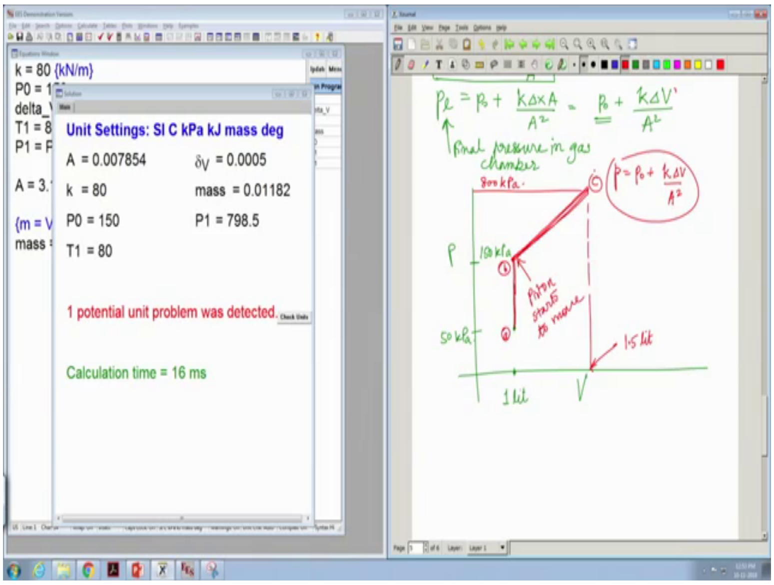

Let us draw pressure versus volume. So, like this. So, initially ok so, this is air so, we cannot draw the saturated domes. So, this is air pressure versus volume, we are maybe this is 150 kPa.

Now, suppose we start somewhere over here and then you open the supply line valve you open the supply line valve and you are at some lower pressure may be 50 kilo Pascal. So, up until the point so what is this volume going to be. So, this is total volume this volume is the initial volume, the initial volume is 1 liter because ok. So, this is 1 liter.

So, then you start letting air come in the volume does not change, but the pressure changes the volume does not change because in order to have a change in volume you need the piston to actually move, but the piston is held by a spring and the piston will not allow the spring will not allow the piston to move until you reach a pressure of 150 kPa.

So, this is how the process will proceed, the pressure increases a point till it reaches 150, the volume is still 1 liter. So, this is a this is b. Now once it hits 1 liter how does the pressure increase? The pressure increases linearly in volume. So, it increases linearly in volume, up until the point this is 1.5 liter and this corresponds to approximately 800 kPa.

So, this is how the process goes we have released the valve, the pressure reaches 150 kPa only after which the piston starts to move. So, here piston starts to move only when the piston starts to move you have an increase in volume and in increase in volume leads to a linear raise in pressure through this static equation we have already seen from studies equation this is how it varies and thus it will leads to an increase in pressure.

So, this is how the process line looks we will not do it in EES still we will show. So, this is how we were able to find the mass the logic was very clear. So, when you practice problems of this kind please try to rationalize the problem before jumping into the problem it helps in having a very nice flow to the program as well. If you do not rationalize things the program will not have a few it is you who are doing the work and not the computer, the computer is there to give you whatever you are asking it to give the computer does not solve anything directly.

For example, is I cannot just give the schematic and ask the computer solve this is not an AI, it is a human intelligence thing we have to tell these are the equations this properties have to have to be obtained using these independent parameters and then give me this quantity, thus this is how you should proceed you should take it in this sense.

So, next time I will meet you with more problems and we will discuss something else I will see you next time bye bye.