Engineering Thermodynamics
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Lecture - 38
Applications. Problem Solving: De-Superheater. Deaerator. Separation

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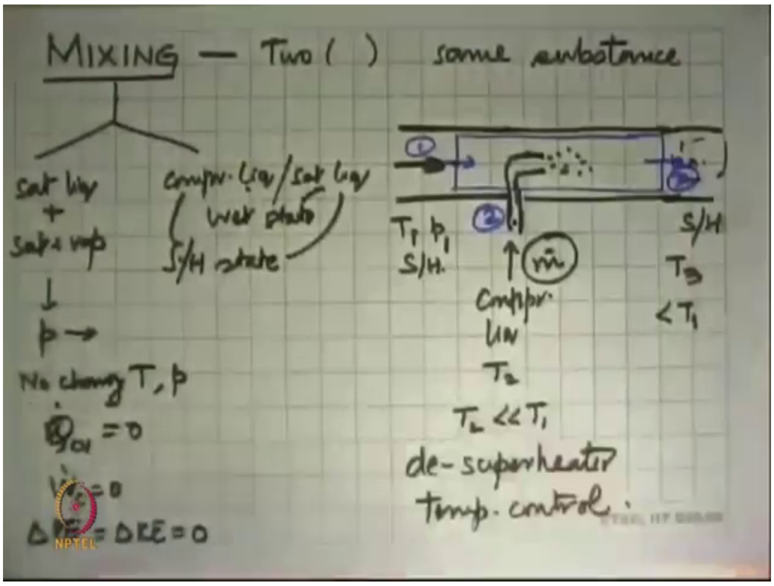

Now, we look at to the equal different, and the first thing here is mixing. And by mixing they are already saying that we are mixing two phases or two streams or two parts of the same substance. So, you take a hot water, cold water and mix it. And say well what do I want to know want to know, what is the final temperature for that. So, here we will see that there are some other possibilities also.

First there are two possibilities that we will look at. In one we take saturated state, saturated liquid and mix it with saturated vapor, and anything else other than this is what we will look at over here. So, what we are saying is that we could have either compressed liquid or saturated liquid or a wet state, and we mix either this and this or superheated state. So, we are mixing this with this or this with this or this with this.

The point is that in this case when we mix the two and we say that they are at the same pressure, the pressure is constant. Then by just putting them together physically there it is no change in temperature or in pressure. We assume that these are adiabatic processes W

2 dot c v equal to 0 W dot c v is also equal to 0 changes in potential and kinetic energy there also same. In this case, this will not be true, it will come to some other state.

So, let us say for practical example and then we will see on the property diagram what actually happens, and why we are even considering such a situation. So, one thing is that if you have say superheated steam or any other substance going through this like that superheated, if we want to control and maintain its pressure, the device to use the pressure regulator. So, it will throttle it, so you can only reduce the pressure and maintain it constant, you cannot increase it.

But what do I what if I want to reduce the temperature of this, then every we will tell you that you if you have steam at a certain temperature and pressure, and if it is superheated or saturated, and you want to reduce the temperature, there is either you expand it in the turbine or you expand it in the nozzle, both of which are not practical in most cases, then the only option left is that it should lose heat to something else or we should mix something cold with it.

So, what one does is if you have superheated steam here, and we want to reduce its temperature by a small amount, what one does is that through another pipe, we put in compressed liquid at a lower temperature. So, this is at T 1; this is at temperature T 2; T 2 is very much less than T 1. We inject very small amounts of this, it comes up those drops. And after a while it evaporates and mixes it and produces superheated vapor over here whose temperature T 3 is less than T 1. There is very little pressure change in, in this process to inject this you would have brought it in at a high pressure than p 1, but then it will immediately get throttle and then this liquid will come out.

So, what will happening is that if you can control this flow rate here, then you can adjust the temperature over here. So, in any process and it is may be saying power plant when you say that the turbine inlet temperature has to be fixed at this value, we cannot just by heating this state produced by temperature, we produce a slightly higher temperature. And then by injecting small amounts of this we are able to maintain the temperature that we want. So, this type of a device is called a de-superheater. And this allows us in the practical world temperature control.

So, it is hardly any power station they would not have this type of an arrangement before the steam enters the turbine and starts the expansion process. So, here what we are doing is we now have to do the thermodynamic analysis of that. So, we make the system boundary here. We exclude all the metal and we say look there is only the substance that is coming in. So, we have 1 state here coming in, a second state here coming in state 2; and state coming out here, this is state 3.

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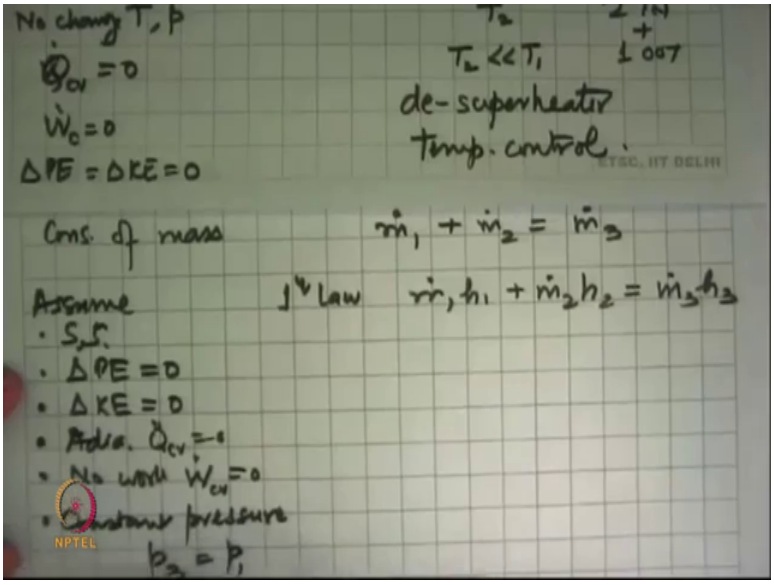

No change T, p

$\dot{Q}_{cv} = 0$

$\dot{W}_c = 0$

$\Delta PE = \Delta KE = 0$

T_2

$T_2 << T_1$

2 IN + 1 OUT

de-superheater

temp. control

Cons. of mass $\dot{m}_1 + \dot{m}_2 = \dot{m}_3$

Assume

- S.S.
- $\Delta PE = 0$
- $\Delta KE = 0$
- Adia. $\dot{Q}_{cv} = 0$
- No work $\dot{W}_{cv} = 0$
- Constant pressure $p_3 = p_1$

1st law $\dot{m}_1 h_1 + \dot{m}_2 h_2 = \dot{m}_3 h_3$

So, this is an example where in this control volume we have 2 inflows and 1 outflow. So, the analysis of this will proceed exactly the same way that we have looked at before. We know this is open system. So, we write the conservation of mass as before, but before that we make all the assumptions that we need to do. We say that first of course, it has in steady state. Then we say that changes in potential energy are very, very small. The devices there is compact changes in kinetic energy are also negligible. We do not accelerate the fluid very much here at all. And there is no heat transfer to it. This little whole device is insulated, which means that this is adiabatic Q dot C v equal to 0, and there is no work your pumping happening, so W dot C v equal to 0.

So, if you do all these assumptions, conservation of mass tells us that m dot 1 plus m dot 2 will be equal to m dot 3. So, mass flow rate has increased a little bit yes. And the conservation of energy, the first law tells us for a control volume that m dot 1 h 1 plus m dot 2 h 2 is equal to m dot 3 h 3. And so if we most states 1 and state 2 and we know the two mass flow rates, then there are two unknowns left outflow mass flow rate and plus outlet state. So, we can use this equation to get the outlet mass flow. And from this equation, we get h 3 which is specific enthalpy of the final state, and this process we assume is constant pressure, which means that p 3 is equal to p 1.

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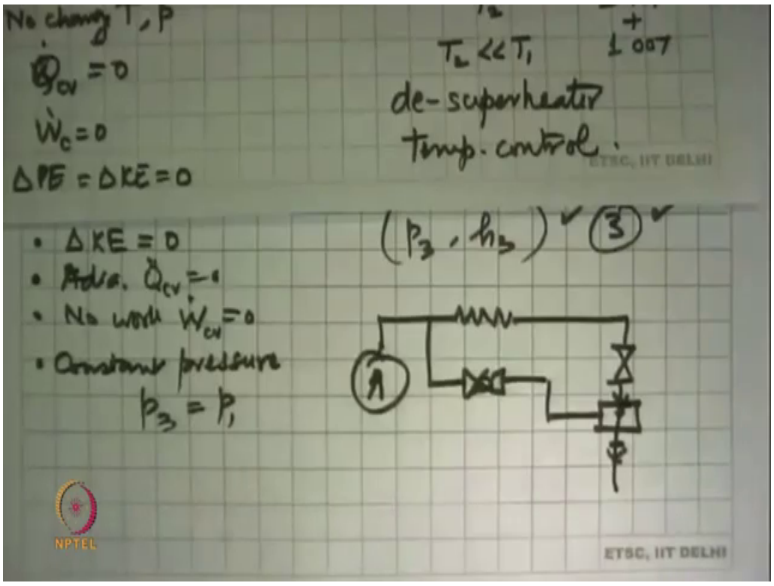

And that tells us that state 3 we know p 3, and from this equation we calculated h 3, these are two independent properties. State 3 is completely defined, we can get temperature also and all the other things are. So, this is an example where we are mixing two things, a similar thing is also done in refrigeration systems and air conditioning systems, where if you want to control the temperature or says the, say this is the compressor, and after condensing, we have expanded it, and we want to control this temperature now.

There is very little we can do by controlling throttling in this little very small amount of length one can do. The rest we can then do is by taking something from here putting a flow control valve over there and injecting small amounts of this into a device at this point, which controls the state over here. So, you can control this and adjust the temperature at the outlet over here. So, these are practical things, where in reality you do not have a system that will always do what the thermodynamics are tells you is done at one state, but in their systems here to operate at lower capacity or we need to shut it down, we need to start it up and all of that we need to do in a very safe and the secure way.

And so many of these devices have to be added on to make the system practical. It makes the system complicated, but that does not matter ultimately when you want to analyze it.

This is the way in which we can go about, and see then what is it that I am being into worry here.

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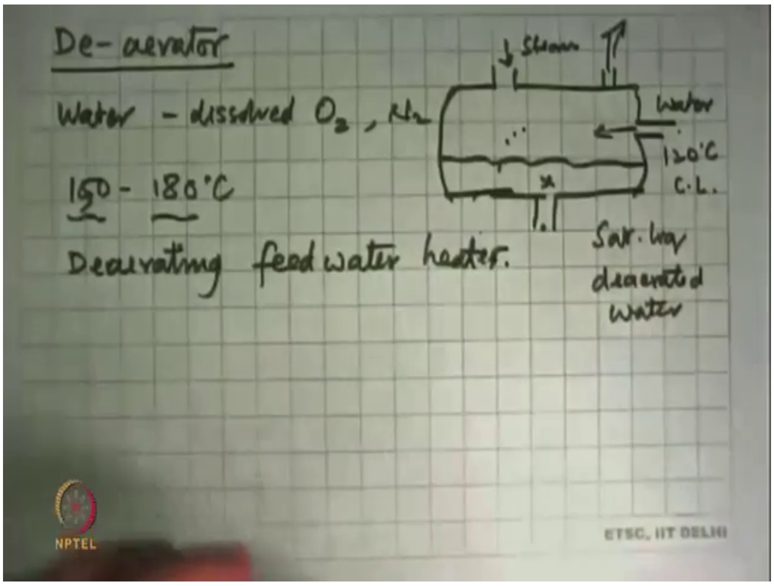

De-aerator

Water - dissolved O_2, N_2

150 - 180°C

Deaerating feed water heater.

Another example of mixing one here, and this is a very common thing, which is gives me all steam systems, which is called a de-aerator. This is exactly the opposite of what you get de-aerator drinks. In an aerator drink, we take water and compress into carbon dioxide into it and that is what you get is stored upon. In the de-aerator, our objective is exactly the opposite, like water and water that we drink or comes out of the tap or whatever we have has dissolved air in it. Dissolved air means O 2 and N 2 are dissolved in it and that is the reason why fish can survive in water is just that little oxygen over there.

In steam systems if we just take that water produce steam like, we do saying that domestic users, then what happens is this when you heat water, some of this oxygen comes out without the saturation pressure of oxygen or dissolving in water decreases with temperature. The result is some of the oxygen comes out into the gas phase, and then this reactor with the steam or components let me called corrosion. And this is something we definitely do not want in a machine like a power plant or even a steam system of a submarine, which is powered by a steam turbine, because we want that to last for, for 20, 30, 40 years.

So, we need to remove this. And what we do is we just heat the water to a temperature of like 150 to 180 degree Celsius, and allow some of the oxygen to come out. So, this reduces the concentration of oxygen in water, and then we get de-aerated water and that is then put through the boilers and the turbines. So, what we have done is take in we put water into a tank into which we also introduces steam. And this all mixes and collect inside the tank or you know adjacent position below this. So, water is coming there and this could we say water at about hundred 1300, 40 degree or 120 degree Celsius compressed liquid, here we put steam this could be slightly superheated steam.

And we adjust the flow rate of steam and water (Refer Time: 11:49) that what you get here is saturated liquid at 150, 180 degree Celsius. The oxygen comes out here and we have a small opening here so which water and some of the steam will continuously keep coming out. So, that way what you are left here is de-aerated water. So, you have mixed compressed liquid mixes superheated steam or dry saturated steam to produce a saturated liquid, the equations everything will be identical to what I have just done and the analysis of this can be in pressure.

In vapor power cycles, this also called a de-aerator, and it is combined with the temperature rise water came at 120 and goes out at say 150, this is a de-aerating feed water heater. And higher the temperatures that one implies in on the steam less these are ability to tolerate dissolved oxygen in the water. So, as you go from 550 degree Celsius to 600 to 700, we have to remove much more oxygen out of this water than what we have in say conventional power plants, so that is one of the engineering challenges that if you want to increase the thermodynamic efficiency that going to higher temperatures, your oxygen dissolved in the water has to be brought down.

These are different set of things that one needs to put in this. They brought two examples of such mixing that I have given the one thing that you will look at there see what happens on the property diagrams.

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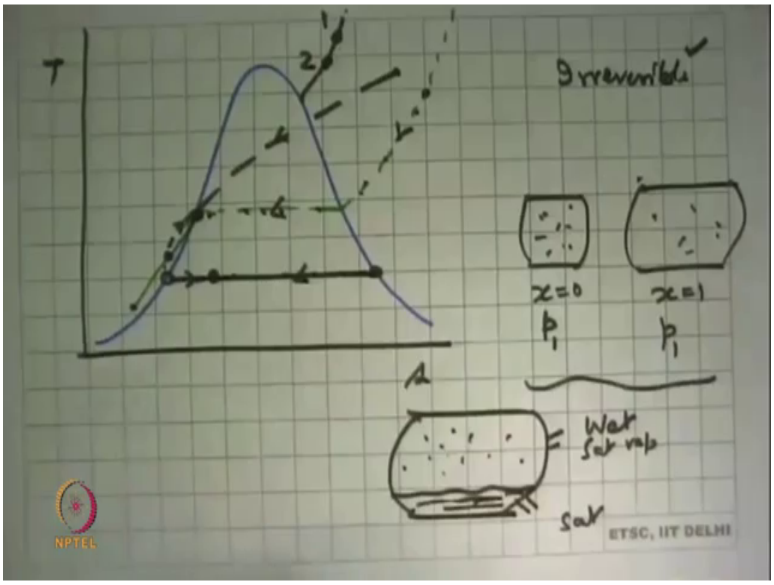

And I will draw the case of say the de-aerator that is the saturation dome. And what we have is compressed liquid coming from here heated up to this point. And if nothing would have been done, this is constant pressure heating. So, this line will go up there, and then it will go there, and then this will go there. And there mixing this which say superheated steam at the same pressure or at a higher pressure over there.

So, we brought this in contact with this mixed it up and we got saturated liquid at this state. So, what is the process that this followed well, we cannot in any way get back the original states without putting in extra work or heat or both. So, these are completely hugely irreversible process. And this one comes down to here. And they come up in the state. If it was this state, it would have again come there, but you might if you want to show it this way that dotted lines coming in there that is ok.

But even if we should just join it here and show it by a dotted line, because it has irreversible process that is also, so that that is what we are doing here. In the case of the de super heater what we did we had a state over there, they are superheated state here. And we mixed water with it which was I would say this state to produce a state, which is at the same temperature sorry the lower temperature, but the same pressure. So, they came from 1 to 2, but mixing thing.

So, if you move from here to here, and there to there, but in this case we have moved from there and there moved to this place. One thing that we had listed there what, what happened if you mixed to saturated states. F or example, we have dry saturated liquid in a vessel here, so this is a vessel in which there is only x equal to 0 at this condition, say pressure p 1 or temperature t 1. Then you have another vessel at this state, then x is equal to 1 at the same pressure dry saturated vapor.

And now we mix the two, it is adiabatic, there is no work transfer involved in this. We said this have a valve in between that into a opened up, it got mixed and the final state of the mixture was wet. So, this could have come somewhere over here, here, there, wherever (Refer Time: 16:35). So, the question is, is this also reversible or irreversible? And one can argue that look if I have a vessel that you took all this mixture, and you have put it in another vessel and allowing it to just stand there, we know that by gravity the liquid water will come down here, the vapor will stay up there.

And if it is just take this thing out we got saturated liquid, we take this out they got a saturated vapor and so we got backward initial states. In some sense this mixing of saturated states is a reversible process ok. It does not produce a new state in the sense that pressure and temperature are different, but we just produce a mixture, where the proportion of saturated liquid and saturated vapor, they are different. So, that was about the mixing of saturated states.

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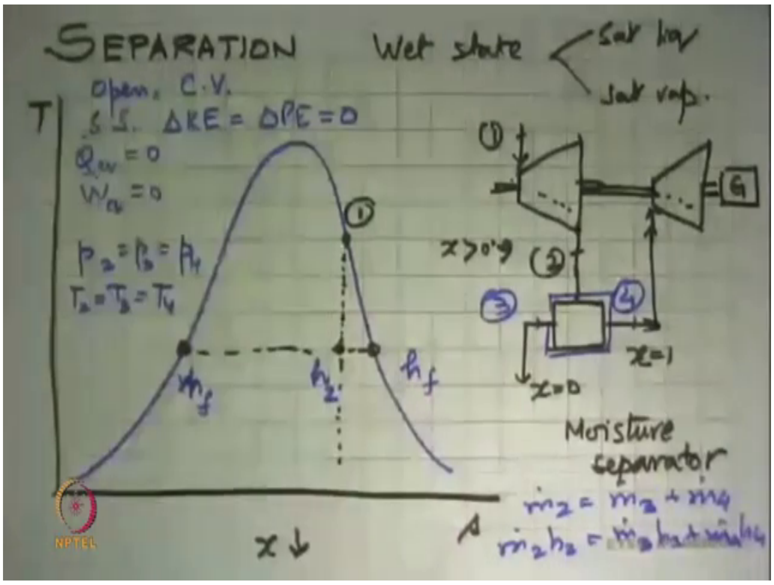

And now it will be opposite of those things by looking at idea of separation. And separation basically means that we have a wet state, and I want to separate out the saturated liquid and saturated vapor. For example, where we really want to do this and do this most certainly is a nuclear power plant. There is what happens in a nuclear power plant is that we have say the show it on the property diagram there that is the dome. And in nuclear power plants the steam produced by the nuclear reactor is at a state like this. So, dry saturated state. This is the state at which we introduce it into the turbine.

So, as a this is the turbine, there is a shaft which is producing power, we got state 1 over there, and over the steam to expand in this, and we take it out wet stream 2. Now what happens here then because it is dry saturated, the states in which the turbine will expand, they all be along a line, which is like this. And what it does is that as you keep going down, the dryness fraction keeps getting worse from 0.99, 9.8, 9, 0.8, 0.7, 0.6 something like that which means that the amount of liquid flowing in a turbine is decreasing. And this is largely dispersed at very small drops, and they can go and pick the blades, they do not follow the same expansion got that vapors follow, so that design and engineering of this type of a machine becomes practically impossible.

So, what one does is that we said that I will I can make a machine and I will have a exit dryness fraction more than say 0.9. So, I can design a turbine and its vapor up to this point. So, at 0.9 we take it out. And then once we do it we separated, so that this here the liquid goes into this state, the vapor goes into this state, the mass fractions are less now. If it was 1 k g per second going in, now we have here say depending on the dryness fraction, it will be 0.9 k g per second here, 0.1 k g per second here. So, this we have put into a device. And this is either separating by gravity or by inertia, that you just rotate this whole thing, the droplets will by centrifugal action go outwards and the vapor will stay inside.

So, in this we get the liquid coming out here x equal to 0, and out here you get x equal to 1 dry saturated vapor, but not the full mass flow rate. We then take this and introduce it into yet another turbine and expand it further. If you want you can connect these two shaft together and ultimately this is connected to a generator. So, that is device is called a separator or a moisture separator either a liquid, vapors.

And how do we look at the thermodynamics of this, well this is a system that we can say that this is the system boundary and this is of course an open system. So, we apply the control volume approach. This is state 2 coming in, state 3 going out here, state 4 going out over there. We assume steady state, no change in kinetic temperature energy, it is a small device no heat transfer. So, Q dot c v equal to 0. We did not put any work unit, W dot c v equal to 0.

And so the conservation of mass tells us that m dot 2 is equal to m dot 3 plus m dot 4. And conservation of energy tells us that m dot 2 h 2 is equal to m dot 3 h 3 plus m dot 4 h 4. So, we can then solve it out, and when you can know what is the mass fraction coming out at this end, but all of this is happening at constant pressure that means p 2 equal to p 3 equal to p 4. And same with temperature T 2 equal to T 3 equal to T 4. Only thing that we did that here it was the specific enthalpy became h f, this is h g and this was h 2, which is in between these two values, so that is the idea of a separator.

And what we have done here is just put it to a passive device without putting any work or heat or any (Refer Time: 22:19). And by inertia or the gravity we separated in liquid out from the vapor, and we get dry vapor coming out here, which you can then start to leave it again over there. So, that is the idea of separation. And like we just saw mixing here, we did not put any work or any heat. So, if you just reverse all of them, we get back the state. So, this becomes a reversible process. And on this picture, we can say that this state went over there, this state went over there and that is how we then have two streams from which you do two different things of. So, that is the process of separation.