Engineering Thermodynamics
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Lecture – 34
Applications. Problem Solving: Heat Exchangers

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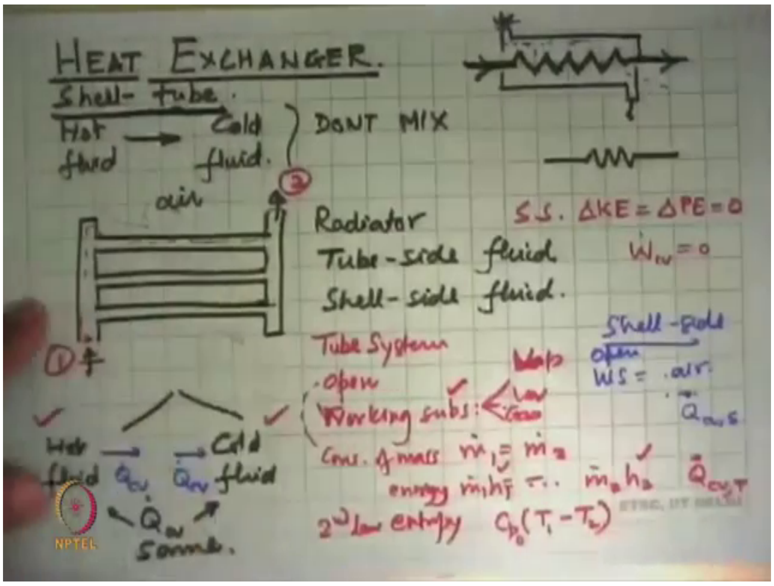

The term Heat Exchanger basically denotes a device in which we have two fluids that do not mix; one is hot, one is cold and the hot fluid transfers energy to cold fluid. So, this is a very quick broad definition what is a heat (Refer Time: 00:39). Largely you will see this devices being analyzed in a (Refer Time: 00:44) heat transfer which is when you do the detail engineering of what I did that if I want to have 1 kilowatt heat exchange between this fluid and that fluid how big a tube should I have, what should be its length, what should be the velocity all those considerations will come out of the heat transfer course knowledge.

The thermodynamics knowledge tells you that look this is how much is going to be your pressure and temperature no matter, what the mechanical design or the thermal design of a heat exchangers. The common symbol is shown here varied black and a zigzag lines these zigzag lines basically you know that the fluid is one fluid comes in here and goes out here and in going. So, it could be like this that it comes in here goes through many parallel tubes or maybe some are in series and then connect again and goes out.

So, that is a typical design of the radiator of an automobile. If you open up the hood of a car or look up any diesel generator set your radiator will look like this there is a bunch of tubes going vertically you see a lot of fine sheet metal pieces there that is the fins which came from the heat transfer considerations and that whole device is basically that the hot water is going inside this becoming cold and outside this we are blowing the cold fluid which is the case of a radiator is ambient air.

So, that air goes over it and as long as the temperature of the coolant inside is more than the air temperature it will give heat to the air cool down the cold fluid will go out there. So, that is a very common example of a heat exchanger. The difference is that we do not have this outside thing shown there. So, we can just show like this, but if the fluid. So, this fluid which goes in, it is called the tube side fluid; it could be either the cold fluid or the hot fluid that depends on the design and the fluid which flows over it is generally known as the shell side fluid.

The radiator does not (Refer Time: 02:51) and what the shell means is that you have enclosed the other fluid also in the device say a tank or big enclosure. So, the other fluid flows inside this and comes out the tube side fluid goes only inside through the tubes. So, when you make this entire thing this gets known as a shell and tube heat exchanger and this is a very very common device used in not just power plant, but refinery, power factory, any industry where some heating or cooling has to take place. So, this is a very common (Refer Time: 03:29).

So, this is what happens and the question now (Refer Time: 03:35) and for that we have split this problem two ways; one is the hot fluid and the other is the cold fluid. (Refer Time: 03:48) mix. So, what we will do is one case; if you apply the conservation law only to the hot fluid as the system then will apply the conservation law only to the cold fluid and the system.

So, when we say that I will look at for the tube side fluid we will say that it includes all the fluids that is contain in the tube from the inlet state 1 to the outlet state 2 and it said the space inside all of this this is my system. So, this is a tube system and you are only going to be looking at this fluid. Once we do that what we find that this is an open fluid coming in going through this and exiting the system. Our system boundary ends at the outlet of this tube; the system boundary begins at the inlet of this tube. So, this is an open system.

So, the hot the tube side fluid is an open system once we do that we now know is what is the working substance that we have is it water or is it a coolant or is it some oil whatever that may be. And, then so, that tells us where to get the properties from. Once we know that, this is an open system we know that we have to write conservation of mass and then the conservation of energy the first law and the conservation of the entropy equations the second law and say this is what I need to solve.

Then we make a set of assumptions which will be true for the both this case. You will say that is flow this is the flow type of a system with it open we will assume there is steady state if nothing is mentioned we will assume that and we will say that kinetic energy and potential energy changes of the fluid on the tube side is 0.

So, I will put that there is only one inlet and one outlet in the system. So, this equation we will become m dot 1 is equal to m dot 2 and this equation we will come and say that the fluid going here there is no work transfer on it. So, W dot cv is equal to 0. And so we get the first law equation as m dot 1 h 1 to related to m dot 2 h 2 and Q dot cv and in this case we can say this is two dot c v tube side fluid. So, this is everything is for the tube side.

So, this is one equation here which tells us what the relation between mass flow rate inlet outlet enthalpies and the heat transfer rate. Then depending on the substance that we had if it was a vapour or a liquid is dealing in one way if it is a gas, it is something else even liquid if we know throughout that the system there is a liquid let us say water is going to it then in both cases we will write the difference of enthalpy as C p or C p 0 minus T T 1 minus T 2 or T 2 minus T 1 whichever way that is, but only need the constant pressure specific heat of the only. If there is a phase change we cannot do this then we have to go back to h 1 h 2 and get h 1 h 2 data from the pressure and temperature at the inlet and the outlet.

So, in the example of a evaporator or of a air conditioner you would have say sub cooled you have a mixture of vapour and liquid going in. So, it is wet. So, you need that dryness fraction at this point along with temperature to get specific enthalpy and this side could be superheated vapour in which case unit pressure and temperature here you go to the property charge for the working substance that we have put up here and get the data from there C p T 1 minus T 2 will be a wrong. So, this is what we will do for the tube side.

And, we could the same thing for the other side which going to say the shell side. Exactly the same thing you can say that the fluid and the system boundary is from here and include everything and ends over here. So, everything contained on the shell side of this excluding of the metal this is our system and the working system substance in this case. So, this is also an open system where the substance coming in and going out the system boundary ends over there and there working substance could be whatever if they say a radiator or the evaporator the working substance will be air or it could be water if it is a water you know device.

And, then we follow exactly the same process that we did here get the property and in this case we will get Q dot cv for the shell side and those things that joins and completes the problem is that these two terms have to be equal that is heat given out by the hot fluid Q dot cv heat transferred to the cold fluid and these were equal. So, something that we know from experience that m dot C p T 1 minus T 2 for one substance will be equal to m dots C p T 2 minus T 2 for the other substance that comes up from this dimension.

We can then go about doing all the other analysis. The only thing to remember that for liquids and gases C p T 1 minus T 2 is fine. If there is the phase change we have to worry about that is properties from the tables. So, elaborating the case where a sub cooled or a wet came superheated states is same thing is that saturated state becomes a liquid state and there are devices, where you could take superheated vapour and cool it to work up sub cooled liquid.

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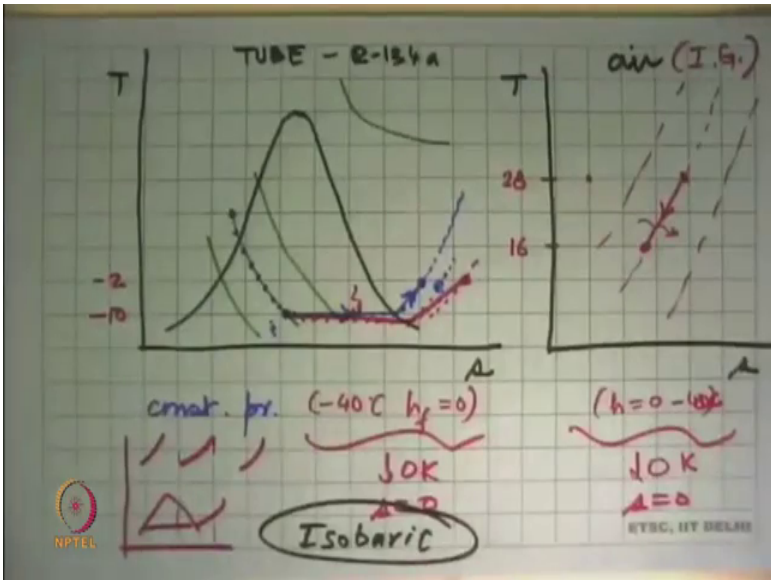

The next thing we will do is show these processes on one of the property diagrams and I am going to show it on the T-s diagram. So, let us take the evaporator of a air conditioner. We know that there is a wet state. So, the dome has to be shown on the T-s diagram if it were on the air side we do not need to show it. So, we would say this is the tube side which is the refrigerate whatever that may be say R 134 A and we will make a T-s diagrams simultaneously for the outside fluid which is the air.

So, in this case what is happening is the, at the end of the condenser we got slightly sub cooled liquid and this was throttled. Now, throttling is a highly irreversible process some group or states happen in between, but the end we know that this is enthalpy does not change. So, it will follow a constant enthalpy line a constant enthalpy line on a T-s diagram look like this. So, the inlet state to the expansion valve was there and the outlet state was there in between we do not know what happened the one way to show it to that we put dotted or dashed line along this line and say took it is irreversible that number one; that is why I am not going is for midnight.

And, second I am superposing it on the constant enthalpy line, just to tell you like this is a constant enthalpy process, but otherwise any other line being got it irreversible is fine though the intermediate states are actually known. So, this is the inlet state to be evaporator from there, it goes out there and then what has happened here is that this phase change is constant pressure. We cannot have phase change with increasing pressure or decreasing pressure and in all heat transfer devices this fluid that goes to the tube we are not doing any pumping on it. So, the best in the easiest assumption is that the process throughout on either shell side or throughout on the tube side is a constant pressure process.

So, in this case it will follow the constant pressure line which is there. So, it will follow this and say end up over there. So, the process that happens in that evaporator is like this and we assume that the process internally is reversible, that is why we are drawing this (Refer Time: 12:28) line. So, this was the inlet state, this is the exit state and that is the process from the evaporator.

Now, what will happen in the air side? Now, air side we know that the air was warmer than this fluid at all states. So, if this was say minus 10 degree Celsius, this was say minus 2 degree Celsius and the air which came in was say 28 degree celsius and less the device at say 16 degree Celsius. So, that much temperature and difference was there between the hot and the cold fluid at all times and we know that as the air goes through it its temperature decreases. So, it started off having our temperature over there and pressure is again a constant. So, we have to take a constant pressure line on this in this case the constant pressure lines they look like that on a T-s diagram.

But, dome has not to be shown because this is not a vapour state we have implicitly saying I am assuming that air is an ideal gas and for ideal gas the dome is not to be shown, but we show the constant pressure lines and say now, where is the inlet state? Let us say this was my pressure, this is an inlet state, this was the outlet state and we say that this was reversible heat transfer. So, the air process was like this, the refrigerant process was like this. This gave away Q dot cv and this took it all of that Q dot cv.

Now, I make two separate T-s diagrams to we have to illustrate what is happening in both cases, instead of can I join these two diagrams to make one picture? The answer is yes, it is possible. The only issue is that temperature in both cases is the same scale. It is an absolute scale of temperature. So, zero for this in the same and the zero for this. The trouble is what the entropy side for R 134 A. There could be some temperature say minus 40 degree C where h f or h f are taken to be 0. But, for air we would have taken some other temperature.

If we reference both of these it was same value say that look for air also I will say that h is equal to 0 at minus 40 degree C or I take both of them to 0 Kelvin and say s is equal to 0, then the two scales become exactly the same and you can join all of them together and see what the composite diagram is look like. That could be the correct thing to do if we do not put the scales on the s and T and magic the diagrams will be there like to see most books like there say that one process is like this in the dome and the other process is like this. But, strictly speaking the entropy is here do not match. This could be here, this could be here, this could be here, does not matter ok.

So, the main assumption that has come out of this is that in addition to what the assumption that they do heat transfer processes either through heating all through cooling we take this to be isobaric processes. Like the additional thing that has come out and the reason is that these are substances going through a device they are neither doing work on them they are neither doing great expansion on it and so, the pressure in the first nourishes in assume to be constant.

In the real world, if we have a system like this like a radiator or the evaporator or the condenser and the fluid flows to these tubes there will be a frictional pressure drop. The outlet pressure will be slightly less than doing that pressure the real engineering will have the factor that P. The data on how much pressure fluid mechanics or heat transferred and that can when we put back into thermodynamics and say that in this process, if there valve a pressure drop taking place what will be the state? It will be that I need keeps going there is a slight pressure drop all the time. It comes over there then it would have gone along this, but there is a pressure drop.

So, the lower pressure isobar is there. So, from here it will go and finally, end up by this process. So, the real substance we will go like that and the pressure here will be less than the pressure here is less than this pressure but, in the analysis that we do. If that is not given we assume it to the constant pressure heat transfer process and the analysis one ok. So, that is the idea of a heat exchange.