Engineering Thermodynamics
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Lecture - 25
Properties of a Pure Substance: T-s diagram. h-s diagram

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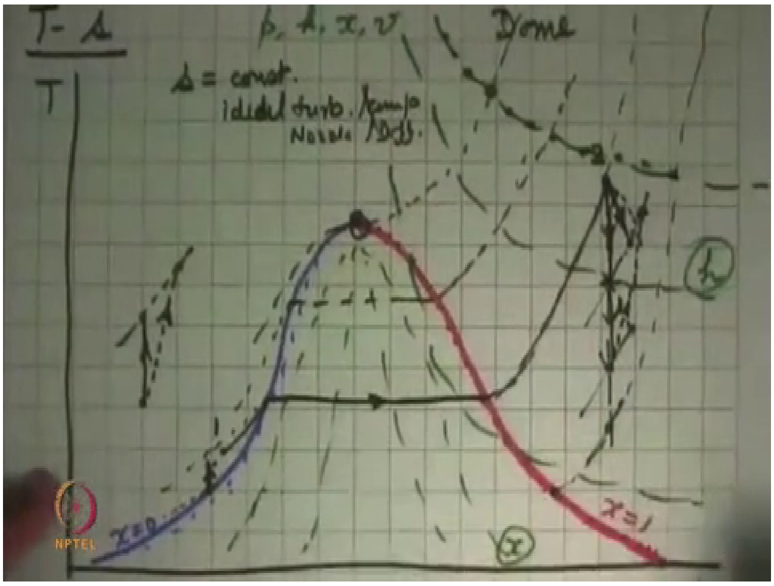

So that was the p-h diagram, we now go to the next type of a diagram which is again very popular in use is temperature entropy diagram. On the y axis is temperature, and on the x axis is specific entropy. And again making this plot we have to be we have to of the same caution that we had with the p-h plot. Once you have set specific entropy at a particular point to 0 specific entropy also gets set to 0.

So, specific entropy has the same issues that specific entropy of nitrogen has got some value specific entropy of water has some value the 2 was not on the same scale. Temperatures are on the same scale specific volume is on the same scale, but specific enthalpy and specific entropy are not on the same scale. We will have to have a common reference point for everything only then we can compare ok.

So, now, let us look at the T-s diagram, and we do the same thing we did for the P-s diagram. And what happens here is you should look at many of these substances; what we see here that the saturated liquid states all come on the line like that. This is all the saturated liquid states; saturated liquid line is plot for x equal to 0. And we continue the same plot we take all the properties of the dry saturated vapour and make a plot and it looks something like this. This is all x equal to 1 and we can join all of these this is the saturated liquid line and this side, we get the saturated vapour line and on the top is the critical point.

So, this is a dome again. And what happens here is we can now drop as per for constant pressure lines, we can ask for constant enthalpy lines, constant drainage selection lines, and constant specific volume lines ok. So, easiest one is x and this will follow exactly the same style as we had earlier right. And at any given temperature x equal to 0 is here, x equal to 1 is here it is increasing (Refer Time: 02:39) same with every pressure. So, constant drainage section lines will all look like that. So, these are constant drainage section and they are always inside the dome only.

Now we asked for constant pressure lines. That is what it what happens is; we do the same that tv type of a thing here it starts from here and very quickly it say comes to the saturated liquid state, then the pressure is constant, and then from there the constant pressure line deviates to go up. Then we come another point there and then again it starts to go up. At given high pressures they come there and finally at the critical pressure we get this critical isobar.

So, pressures below the critical pressure and temperature below the critical temperature we see the phase change techniques. So, constant pressure-heating, so on this state we will first take this co-saturated liquid state the specific entropy is increasing, then it will be followed by constant temperature elaboration, and then it will become a superheated vapour and then continue on this line.

So, that is what the constant pressure heating line looks like. Constant pressure cooling line will be exactly opposite of this which is now P-s diagram was a nice straight line pr term will become a little more convenient. Now we ask that this was state 1 this state 2. From state 2 we undergo an isentropic process; isentropic process means s is constant, and this will be achievable in an ideal situation in a turbine or a compressor, nozzle or a diffuser. These are all isentropic processes and these are all (Refer Time: 04:50) processes, that does not matter.

So, what it means is that if s is constant a turbine with a nozzle attains its which are on this line, anywhere. And then depending on if the pressure was there this will be the state, pressure was there this will be the state, pressure was there this will be the exit state.

And this diagram tells us that in any of these devices were non-ideal that is what we learnt in the laws then; there will be an increase in entropy which means that while the ideal turbine, these are come like this the real turbine or the real nozzle will go like that to that part. And that will not be a solid line, so this has to be a dotted line. So, from here to here the turbine ideal turbine will be like this, the real turbine will be like that. The compression pressure will be exactly opposite, ideal compression will be isentropic it will go up the real compression will of course have an increase in entropy, so the line will go that side.

So, that is how the T-s diagram helps us in visualizing all these work consuming devices. The same is proved even at this end that when you have compress little. So, they are pumping water from this pressure to this pressure this will be the ideal pumping, this will be the real pumping. So, the term is if you see in a minute that all these lines on this side they are very very close to one another. And what we draw here as pumping as this state is the ideal one this is the isobar and real pumping will be like this, this is a big exaggeration on what we can actually see on the diagram because that lines are very very close, but in the real world this is something we will have to take care, ok.

So, that is the lines of constant pressure that we looked at. Now we want lines of constant enthalpy and what happens is that lines these lines go like that. So, these are constant enthalpy lines. And what it tells you is that if you are going to do shortening from here that is an isenthalpic process, then the states that one would get will be along that side and not along this side. Shortening is a irreversible process entropy has to increase so the states should lie to the right and not to the left. You cannot sorted the substance to a higher it has always to be sorted to the lowest.

So, these are constant enthalpy lines. Specific volume lines are also somewhat similar on this, but over different slope. And so that tells us that everything that we wanted about the T-s diagram. And I have illustrated this to be a heating process which is like a cooling process, the turbine and the nozzle, and also the starting process on this line.

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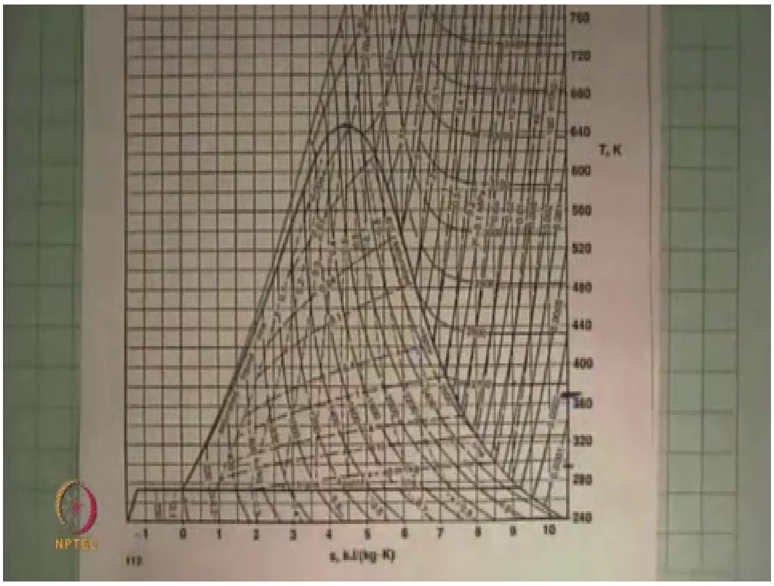

And now we will see the real T-s diagram, ok. You see a lot of lines over there, this is specific entropy it is 0 here, which is saturated liquid at triple point, this is a triple point line of water, and this is temperature in kelvin; so this is for water. And the shape of the dome is like what I have qualitatively shown and inside this dome we have the same thing x is equal to 0.1, 0.2, 0.3 constant drainage section lines are moving in line with. Then, you have p is equal to dome like a first term 0.2, 5, 10, 20, 100 mega Pascal. These lines are going up there like that.

Now, notice one thing that this is 20 mega Pascal, 50 mega Pascal, 100 mega Pascal. So, tell me within this small range here had a huge increase in pressure, this side we are going lower and lower in pressure 0.1 mega Pascal 0.001 mega Pascal, so they are going like now 1 kilo Pascal. So, these are very low pressures. And then if you see this part practically they have not drawn anything over here and we know that all these states on this side and this is now this extreme line on the right on the left is 100 mega Pascal very very high pressure and this is the saturated liquid line.

So, pumping water from 1 bar to 10 bar will not even shown up on this line and they have very very small line somewhere seen in between this 0. And that is because the dependence of entropy on pressure is very very weak, and so we cannot see those lines here. And so, although on my diagram on freehand we can show all these complete processes isentropic and isentropic if we were to use the diagram; and we cannot even show this visualize this procedure over here, but reality there will be there. And these are the constant enthalpy lines h equal to 3.00.

You can see that these lines are going like this and what ones sees interesting thing is that as this h line comes in it is somewhat like a constant vertical straight line here then it goes through a turn, and then these lines are pretty much outgoing to a distance look at this point and the minute will see why this h lines have become horizontal which means that h is now 3500 at h at this particular temperature. So, it becomes any pressure that does not matter specific enthalpy is the same, that is it is independent of the pressure. And that is what we will see that this is what ideal gas behaviour it behaves like ok.

So, this is the thermodynamic properties of water and again now let see what use I can put this to. And when pose a question that in a refrigerator we use 134 a or r 22 or any voltage dyer there was ammonia why cannot I make a refrigeration cycle or a air conditioning system with water as the working substance. We have steep power cycles all of them use water, there is no exception in that; why not to use a water in a refrigerator.

And so, let us begin to look at this what will happen. First thing we cannot go below 0 degree Celsius it will freeze. So, we have got to a make a compromise and say that I will give a safety multi say I will not go below say 6 degrees or 5 degrees Celsius; and that means that we will be something like you say this was 280, this part is 278 plus 6 right say about 290; so somewhere over there is the lowest temperature we can get. And then we want to eject heat to the environment, so we want to heat it to temperature above 55 degree Celsius say given the ambient. So, some of 80-85 degree Celsius, so that makes it to 73 plus 85 that gives about 360 or something like that. So, that will be here say approximately.

So, we have to make a cycle which will operate between these points 360 and this thing, and so it has to have a one throttling process. So, this will be a condensation process which will happen at the higher temperature. So, it will make condensation like this, liquid then a throttling which is h constant line comes here then here and then goes back over there and then compress constant entropy and pressure. The trouble is that you should look at 360 and you start looking at the numbers that come up you will see here that the specific volume a one started of which is 100 metre cube per kg. So, this is very

very big specific volume, this is vapour at low pressure and to occupy the very large volume. So, to get the same mass fluid we need very very big pipes, many metres and diameter before you can even make this thing even work.

And to get any reasonable amount of cooling effect this whole system will become very huge very bulky and so you will have to make a compromise and set. Look only if I can make a compromise and use all of this in a very compact way then I will use water as a refrigerant, but otherwise water as a refrigerant is in fact is not possible for freezing at all. I can only emulate at best for air conditioning.

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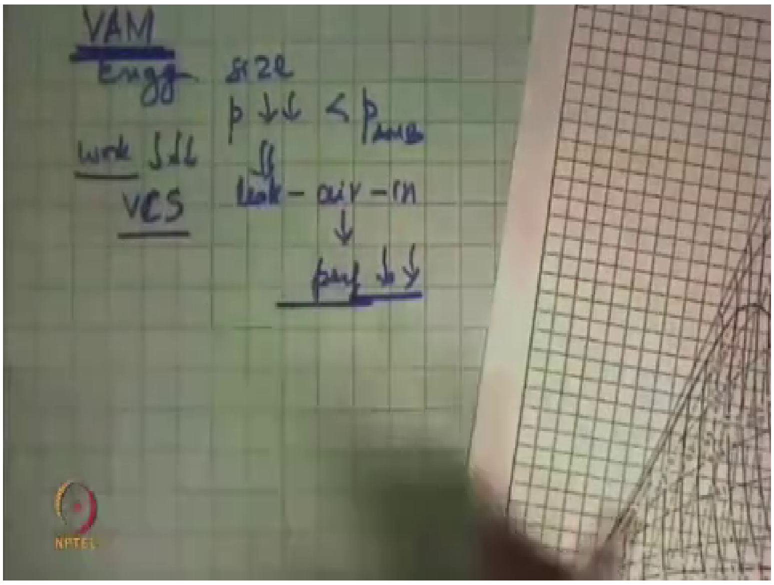

And that is the central idea of what is called a vapour absorption chiller or a vapour absorption gene. That water is the working substance you operate at very very low pressures along the cycle and you have to keep worrying that air does not leak into it. And that is where the engineering becomes complex.

Now firstly was size, second thing all this property diagram tells us that pressures of water will be very low much less than the ambient pressure which means that I can always expect leakages, and leak will be air into the system. And once air leaks into the system, but partial pressure of air goes up the performance of the system drastically goes down and we have a peak drop.

But that is where the engineering challenge lies. This is a very attractive way of doing air conditioning, because the work or the electricity that it consumes its very very small compared to vapour compression systems which is what is known as h and s system. But that is the implication of property of a pure substance on what we can do and what we cannot and why (Refer Time: 14:55) ok.

So, that for the other diagram that I has and the question here is. So, let us see here is a question which is what we examples where there will be chemical composition is different at different phases, ok. I will come back to it a little later, and come back to it tomorrow after we discussed ideal gasses, ok.

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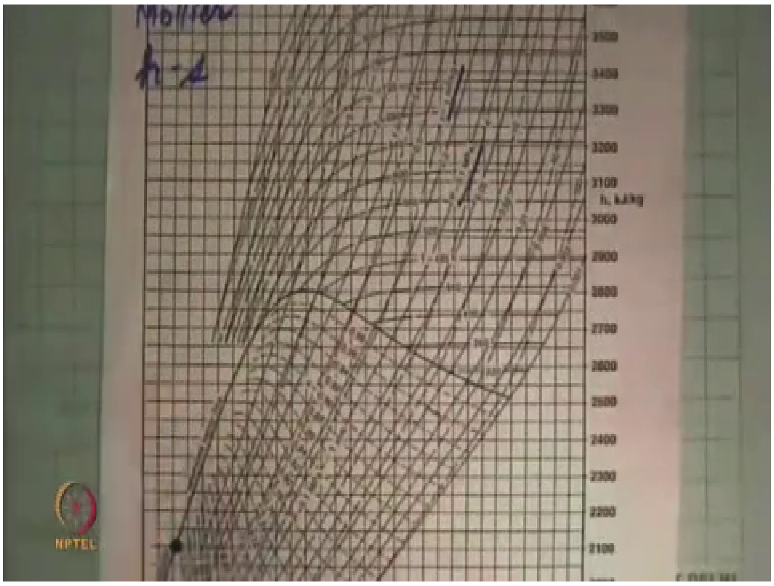

There is one more diagram that has input out and this is historically a very popular diagram. And lot of the initial engineering in the early 1900 was done with this plot and that of course that plot was made by hand there were no computers or anything. So, all this property data were taken and using free hand and using various things people made nice beautiful curves and made this picture. And that was the main stay of engineering into the late 17s.

That is when slowly computers started coming this is called list of diagram as h on one side s on one side. So, this is the h s diagram and popularly this was known as the Mollier diagram or the Mollier chart. And the whole generation of engineers did design of thermal power systems and other steam based systems with this diagram. They plotted the points on this found out what it worked and that is how they went about doing it. Do you remember we are talking of liquid oxygen of this, this is also the time in the 60s and 50s in last century that there were no computers and the whole design of doing manual moon and launch vehicles was all done by such diagrams right; there are quite possible tools.

On this diagram the saturation dome is like this, but the saturation point is over here. Saturated and liquid line is over here, this is the saturated vapour line, these are lines of constant drainage selection 0.76, 0.78, 0.86, 0.98 we will get very good discrimination of drainage structure here. These are lines of constant temperature, these are lines of constant specific volume, and these are lines of constant pressure.

So, one can draw all the process that where is the inlet state to a turbine, where the outlet state, then where the heat taking place, where is the condensation and you can make the complete cycle of this, and then do all the calculations for sizing of (Refer Time: 17:30). Now this it is good to have know that this is there and by showing a cycle of this you get a very first time feel of what this cycle is all about. What are the possibilities where we can improve where what are the things that we cannot do on this diagram that also you can see in this ok.

Now let us go back to our say this time the T-s diagram.

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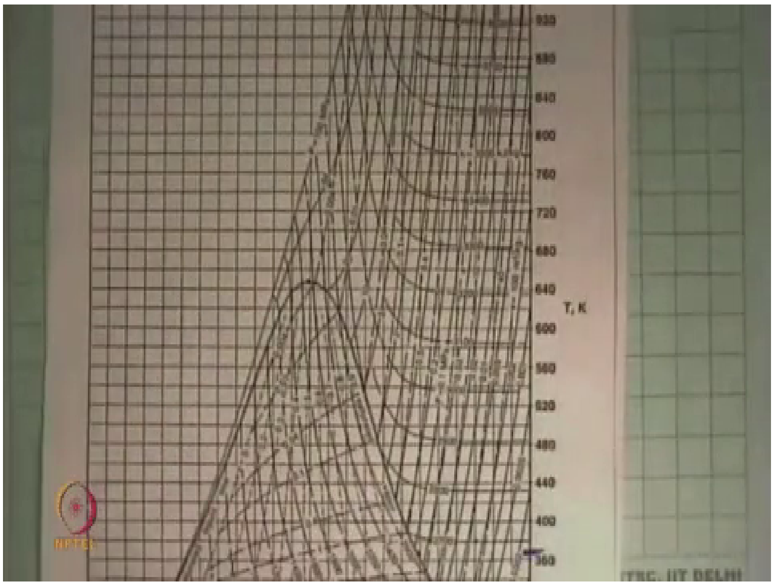

And as I have mentioned that as we go further and further away constant the h lines are becoming horizontal; that means constant temperature lines and constant specific enthalpy lines are becoming one and the same. So, h is now is linearly taken as T in some sense.

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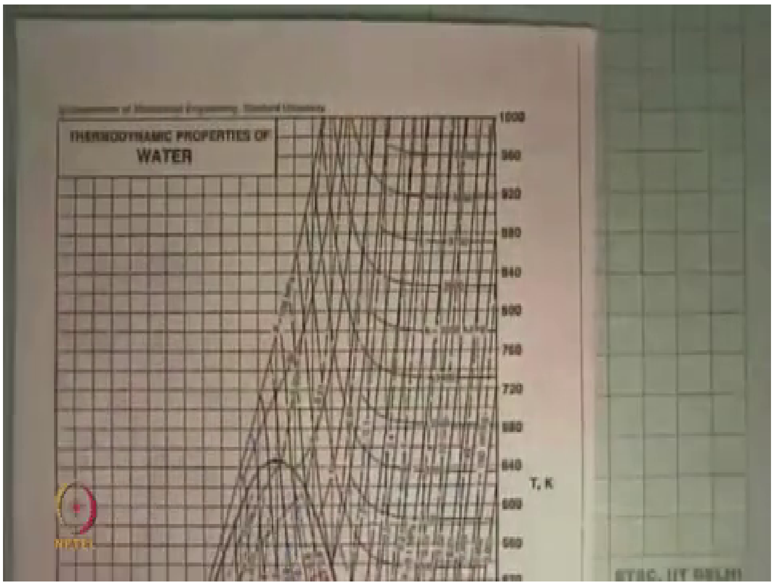

It is because in another way that you should look at this part of this chart. The lines have somewhat become straight, and they are somewhat parallel to one another ok. What that tells us is that that was not the case when we were looking at the lines in this region, here they are all sorts of funny shapes of the lines nothing seems to be parallel nothing seems to be straight, and that is the reason why in this whole region you have very strong non-linearity of behaviour of the properties. And that is why we needed to make a very complicated surface like the PvT surface that I showed last time it fits 60-70 constant equations in that, and then we are able to compute all the properties.

But what this thing tells us is that, life has become much more easier you do not need such a complex formulation any more there you can do something much simpler one. Do not worry about this formula. So that is what is happening, and same thing happens on the T-v diagram also.

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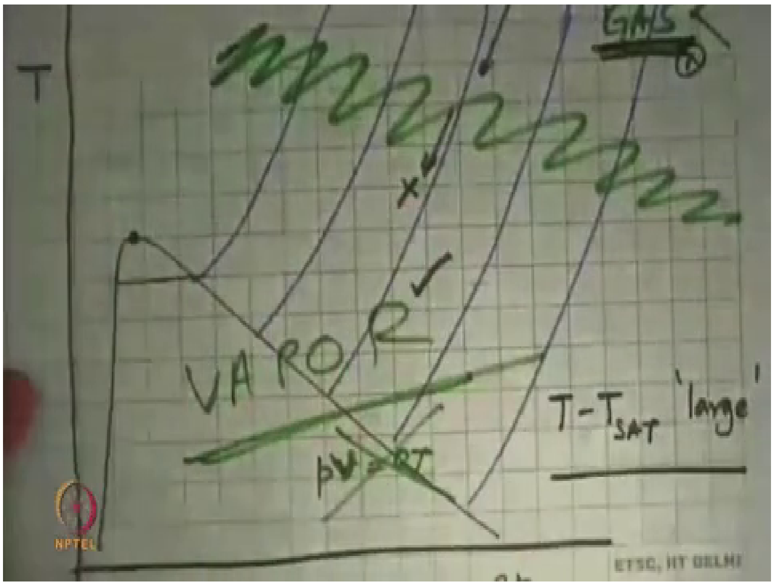

So, here is what is going on. If we make the T-v diagram this curve was like that and you had the critical point at the top, as we go far away all these constant pressure lines that we were looking at they become nice straight and almost like parallel to one another. Similar thing was happening on the T-s diagram. So, what it tells us is that somewhere there and we can say that roughly, here there is a region as I know hard and fast from that this is like this is in in that, path that is why I am drawing this a little bit zig zag. That here somewhere we can start here looking at the substance as a gas, and in this whole region we have to think of it as a vapour. And these are the two very distinct assumes; and within this gas region now seen ideal gas and real gas.

But the fact is that in this condition where there is a vapour like behaviour we should not even think of p v equal to RT, completely wrong. And that is why all property diagrams end at some point and they do not give that chart properties beyond that, because then it is assumed that after these range of pressures and temperatures the substance behaves like an ideal gas if they start during ideal gas equations of state you then forget about this part.

And as I have mentioned yesterday, we have several applications where you have the application entirely in this region. So, we do not even come into this part, and then we are application which are entirely in this region may be sometimes touching this region, but largely in this. So, those have to be treated as vapours and those other cycles have to be treated as gas, and was few examples where you had some behaviour here and some behaviour over there, you then have to do a mix and match, and very carefully see how properties are added up if it was a total change between this state and say this state ok.

So, what we will now do is separate it we have defined say we have for the first idea what is something going to be like a gas. And now we continue with this discussion and say when on this diagram can I say that the substance has begun to behave like a gas. And that tells us that basically we are looking at temperatures in this range where T minus T saturation or the degree of superheat is large. We have not yet defined what is large, but we say that look they are far away from this; that means, you have to detail into a lot more than this saturation temperature here let us start thinking of this as a gas (Refer Time: 22:28); first of our assumption and if that condition is not there it cannot be gas.

So now we will do is, first look at what is the criteria that we have besides in some more quantitative way whether the substance can be considered to be the gas or it can be considered to be a non-gas. Now I will tell you for that goes like this: you look the critical point. And we say that relative to critical point there is a straight line, and then we will define the series as a group of states which we can say are put for ideal gas range ok. So, the first thing we do is.