Engineering Thermodynamics
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Lecture – 24
Properties of a Pure Substance: p-h diagram

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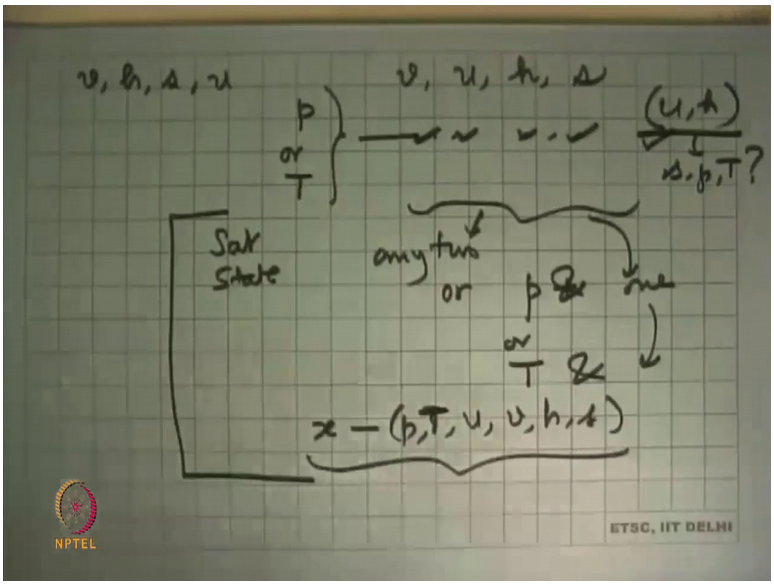

Now we go on to the other types of diagrams that we have to deal with. And what we have said now, is that to get two independent properties I can have either v h s or u, become any of these properties v, u, h, and s. Any two of these are always two independent properties, no problems p or T and any of these are always two independent properties, no problem. But in saturated state it has to be either any two of these or pressure, and any one of these or temperature and any one of these or any of these write x.

So, x with any of these properties p, T, u, v, h, s, this will constitute two independent properties. And when we do problems we get different combinations of properties coming in, we should not get some oxygen we just simply ask the question we have a saturated state; if yes, then we have to look at all of this; if no, any two of these properties are cooling down. If the state is completely different maybe a little more difficult to get properties if size were given u and h are given we automatically know that I have two independent properties. The only trick is how do I get s p and T and this is a little more tricky or put software package will get it is more to issue at on just put this numbers (Refer Time: 02:15) ok.

So, that is we need that will give us the complete details of states of all these vapour liquid and mixtures.

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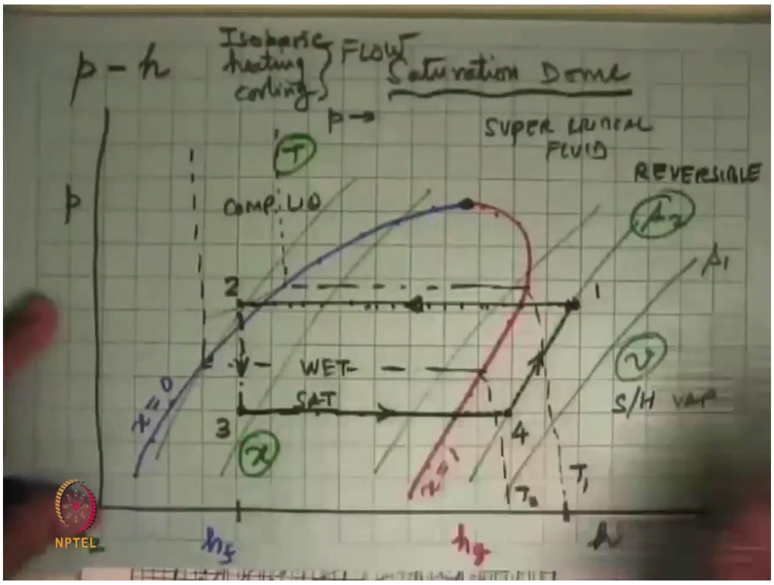

Now, we look at some other properties. Property diagrams beginning with the pressure and specific enthalpy diagram the p-h diagram. This diagram is very popular with users in refrigeration, air conditioning, and those type of cycles. And by looking that the diagram itself people use to solve problems in the good old days that 25 to 30 years back. Today of course, you can do all of that on a computer or even program it, but one needs to understand what is the diagram telling us, and how do I know the time doing the right thing, and in case I did a mistake how do I correct.

So, I will briefly described what is the appearance of this diagram, what are the different regions on this diagram, then I will show you some real p-h diagrams, then we will see p-h diagrams for many other substances. So on the y axis, on the p-h diagram we had p and on the x axis we had specific enthalpy h. And if we do the same thing what we did earlier that will be plot all the saturated liquid states, then we will get a bunch of states which are something benefits. So, this is all x equal to 0.

So, what you have done: is you have taken this pressure and asked what is at this point this is this pressure and at that pressure what is h f. So, we have plotted p versus h f that call we have the things. And now we do the same thing with p versus h g the saturated vapour state. And this graph will give us a bunch of states that have approximately this. And this is all x equal to 1, and what we have plotted this pressure versus the dry cells; specific enthalpy in the dry cell on its h g. And the critical point is write at the top of this, the critical pressure. And this graph will of course always end on the lowest point it will be the triple point. So, except what are for many most substances we do not get anywhere close to the point where we starts in a solid, except maybe carbon dioxide in the begin.

And so many diagrams where triple point nine and what happens at the bottom which not even shown, but it is there we do not need to be to concern about. So, you should draw these lines, we get this shape; one on that side and one that comes down the images. So, this has this particular shape (Refer Time: 05:14). Inside this region and we will now start giving it a name. So, this is what all diagrams will look like, this we will call as the dome or in many cases this is the saturation dome.

So, we will use this word very frequently that: the state lie inside the dome is the wet state it means that state is somewhere in this region inside here. So, that is inside this is all are wet saturated states, x equal to 0 is here, x equal to 1 is there and at constant pressure if you keep heating it you will go like that from x equal to 0 equals to x equal to 1.

Constant temperature lines will go something like this, then they will continue like this, and then starts went down there. So, this is T 1 and like that there will be a similar line T 2 and then the criticalize from there will be a line T 3. So, this is what one see. So, this is T 2; and like that there will be a family of these lines coming on this and along with that we can also plot constant entropy lines. So that was T, and constant entropy lines on this line diagram they end up going something like that: s 1, s 2, s 3 and so on. So, what does this diagram tell us? This side is the compressed liquid, this portion here of the subcooled liquid. This side here this super heated vapor and above this is super critical fluid or dense fluid by the way.

And the next thing about this is that processes like heating and cooling, especially in a flow process. Another example of that you say the air conditioner evaporator in which we are pumping in the substance it goes through all the tubes comes out. In the real case, there will be some pressure drop. So, the outlet pressure will be slightly less than the inlet pressure. For the time being let us not worry about it and say that there is no pressure drop. In the first that analysis in thermodynamics we assume that flow processes involved in heating and cooling, and no work transfer these are constant pressure processes or isobaric.

That is an important assumption we make in this course, that wherever we are going to look at a flow system and we look at either condensation or heating or cooling we say that within isobaric which is an approximation to the extent that we are neglecting pressure drop in the pipe; pressure drop is what one we are learnt in a fluid mechanics the same thing. In the good first assumption when you start doing real systems, then of course you will start worrying about pressure drops, but they can also be shown on this diagram.

So, let us even ask the question, what happens in the condenser of the air conditioner? Well we start with a superheated state somewhere there, which is what we got after the compressor. And then we put it into a set of tubes on which we blow ambient here, the temperature of the vapor inside is more than that ambient temperature, so it start rejecting heat. And it gradually keeps cooling down and it goes through all these states like this, at some point it becomes a saturated vapor. We continue cooling it and at some point we say: ok, enough cooling is done and this is our exit state.

So, this line this 1 to 2 is an ideal condensation process in the air conditioning. What the real process we will do? There will be some pressure drop along this line, so the final state will be at a pressure slightly below this pressure. So, we can say that it came somewhere there and so this line would be it is about (Refer Time: 09:56) from here.

That is how we show a state on v state diagrams and we show a line with an arrow would depict what is the process. A solid line means that this is the reversible process. If the process is irreversible this well have to be a dotted line. And the next thing about this diagram is that if we are able to get these two states plotted on this diagram, then we can say that what is the enthalpy change in this process. Well, I should do the first the mass conservation and first two analysis within a relation that heat transfer rate is the mass flow rate multiplied by the enthalpy difference between the inject and then it's states.

That is quite nice because you can just go down this chart look up this value of the specific enthalpy, go down this point look up this value of the specific enthalpy, we can get h 1 we can get h 2. And the difference of this is the enthalpy drop during the process, that multiplied by the mass flow rate in the heat transfer in this process in steady state more change in kinetic expressions assumptions. That is nice thing to know.

The next thing that happens in the refrigerator and we can now see get another process that happens there is throttling. In the previous model I had discussed that if potential energy changes are very small kinetic energy changes are small, this is adiabatic more work transfer steady state, then inlet and outlet enthalpy they are equal to one another in a throttling process. So, in this diagram h equal to constant will be a vertical line and that is what we do in a fridge or in an AC that after this thing the fluid is throttled and brought down to a low pressure. And this process will be shown by a broken line because throttling, no matter what is a hugely irreversible process always.

So, this brings us to another state, state 3 and it tells you that if we know the specific enthalpy at 2 and the final pressure of throttling then I know that h 3 is equal to h 2 because it is a isenthalpic process p 3 is given to me. I have two independent properties we can do rest of the calculation. In the exit state that the refrigerant enters the evaporator then the cooling take place and keeps getting heated up and it goes through a bunch of effect in the room, and the wet saturated refrigerant kept getting heated its dryness fraction kept increasing became x equal to 1 and then became a superheated (Refer Time: 12:39); that follows now.

And to complete this refrigeration cycle, this at this point it enters the compressor and if we assume that the compression process irreversible adiabatic. It means that it is an isentropic process then the process inside the compressor will go along an entropy line. This will again have to be a solid line and that is our compression process. And so very nicely we are able to visualize what this diagram looks like, and also we can even get quantifiable data earlier we had to look up the charts and do interpolations. These days we can even make this whole thing in a software and by touching the points on a screen we can just get all the data from there. Or it will be more exact, we go to the tables input all these properties and get much more accurate data that is the best thing.

So, that is the p-h diagram.

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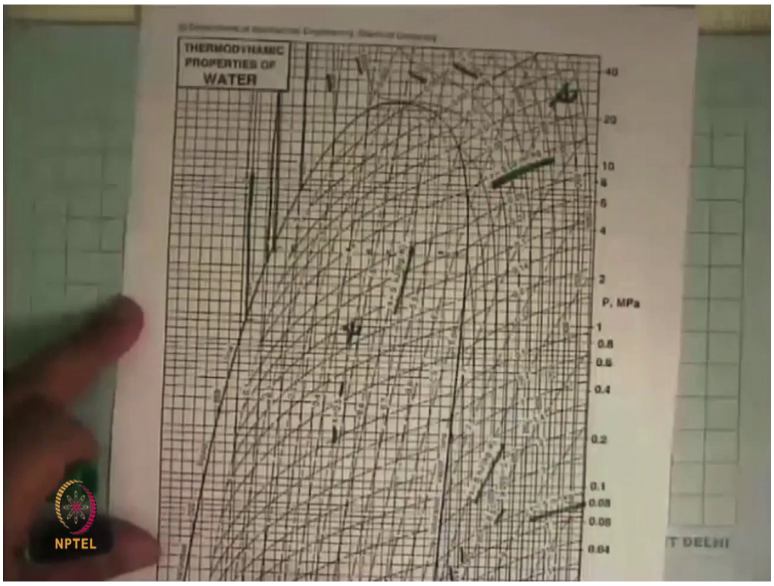

Now, I will show you a real p-h diagram. We take a first one that I have here with me is p-h for water, and its a lots of lines over there and but what we have to see mainly is that pressure is on this axis in a logarithmic scale in mega Pascal. On the x axis it is specific enthalpy in kilojoules per kg. And you can see this dark lines it says saturated liquid line here it goes up, and on this side is a saturated vapor line this goes up over there and at the top is the critical point for water.

And from this you can see there are many other lines on this. So, let us spend a few minutes while these are what they tell us. The first is the set of lines that you can see here which says 0.1, 0.2, 0.3, 0.4, and 0.9. And here it says x is equal to 0.5. So, these lines inside the dome are lines of constant (Refer Time: 14:40). There are another set of lines which are going here, slightly at larger angle than that, s is equal to cycle used per kg Kelvin. So, these are lines, we can see here everywhere this is s is equal to 8 kilo joules per kg, 9.5, 8.5 these are constant entropies in the s. Constant s lines constant X lines; X lines of course are inside the dome only they are not outside the dome.

Then you can see these are the lines which are going constant specific volume lines. So, these are those lines: 5 meter cube per kg 0.03 meter cube per kg and so on. And these (Refer Time: 15:25) lines on those coming from the top these are constant temperature lines. And what I was just drawing are these lines over here which says that 550. So, this is the line that is coming at 550, this is the line at, this is the line coming at 500, this is the line going at 450.

And they all most vertical lines in the compress liquid part become horizontal inside it, so they are not been shown but we know that it is the same thing. And then from there it further goes down and comes 500, 450, 400, 350 Kelvin.

So, on that p-h diagram, this is what we were looking at: they have constant temperature lines, they have constant entropy lines, and we also saw inside the dome constant drainage fraction lines. And of course we have also the diagram drawn here, but also constant specific line in this.

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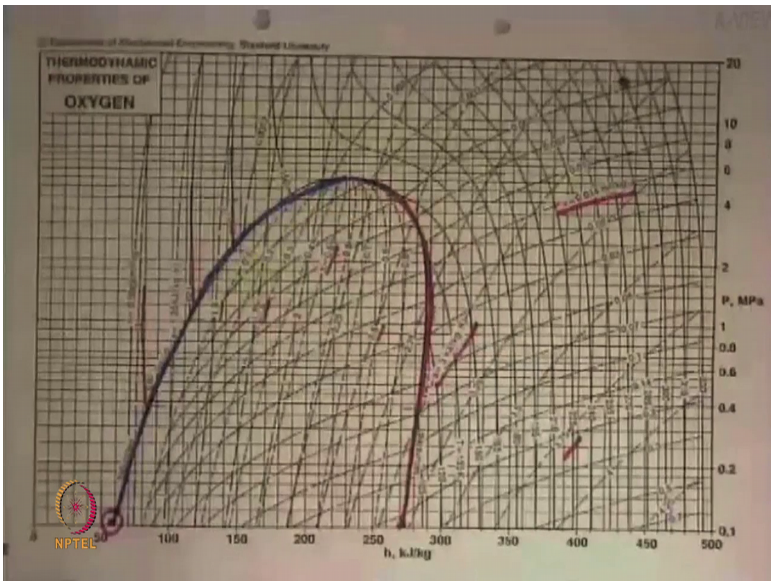

So, that is for water, and another substance that I will put up here is oxygen; simply because now that scale of temperatures is completely different on this, but you can look at the shape of this is the exactly the same ok. So here we are, pressure in mega Pascal's, 0.1 mega Pascal, 1 mega Pascal, 10 mega Pascal; specific enthalpy h. And same thing we see here: saturated liquid line over there, saturated vapor line over there; just like what we are seen. Qualitatively there, but this your saturated vapor line and on the other side we end up getting the saturated liquid line.

Inside the dome we have the similar thing 0.1, 0.2 like this, this is constant drainage fraction over there then 1.5 1.75 these are all constant specific entropy lines; outside these are constant specific volume lines over there. This is s equal to 3 kilojoules per kg k. And then we have constant temperature lines which is like what we are drawn there one. This is a constant temperature line another constant temperature line.

The temperatures here are very low: 150 Kelvin, 135 Kelvin, 120 Kelvin, 105 Kelvin we are looking at very low temperatures. But look at this thing here: ambient pressure is 0.1 mega Pascal and so its come over here. So, at 0.1 mega Pascal what we see is oxygen and in this condition is in a wet state, which means that at this thing if we cool it down and this temperature here is 105 Kelvin, this is even below that turns out to be about 77 Kelvin. So 77 Kelvin, 100 Kelvin at these pressures oxygen behaves like a has a liquid and a vapor state, and you can start getting wet states in this.

And the reason for saying this is that in the cryogenic engines, picture of which I showed you yesterday the oxygen is liquid oxygen which is filled at this state. So, we know we need to know what is the specific volume there, how sensitive is it to temperature, what is the specific entropy, what is the pressure and temperature to which I need to cool it. And then we know how much is the volume that we need to have in a solid tropic motor to put that much (liquid oxygen.

There are many other uses of oxygen. For example, a medical oxygen cylinder that comes filled at 150 bar; 150 bar is 15 mega Pascal which is somewhere here. And if we say what is ambient temperature that is about 300 Kelvin, so it is 300 Kelvin line is here. So, medical oxygen cylinder is at this state. Highly super heated vapor, but substantially higher pressure; now we need to think is this compression going to deviate the behaviour from what we have seen ok.

So, this is for oxygen and now we will see for a few more substances and see one important aspect same thing what we have seen so far.

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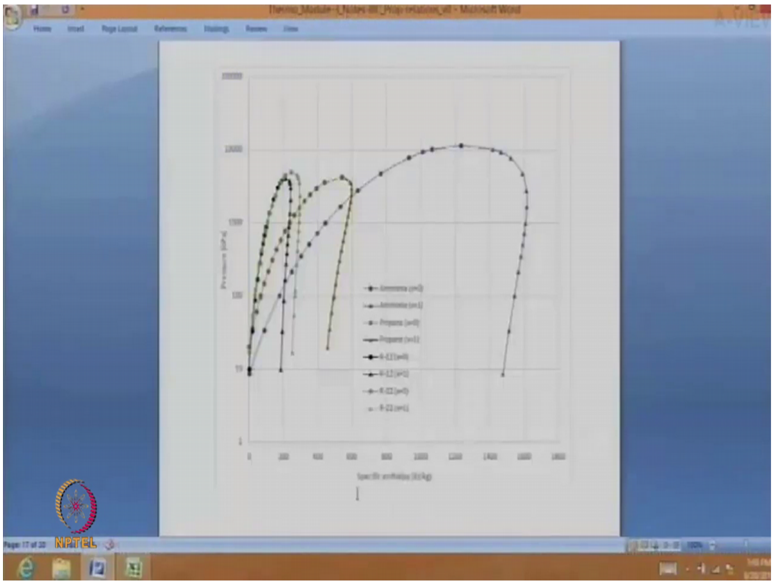

Specific enthalpy on the x, axis pressure on the y axis the logarithmic scale; but what I have done here and this is data taken from the tables and I just made the plot my selves is this side this is the chart for water. On the left side a saturated liquid state for water, on the right side sorry this is not water this is ammonia. This is for ammonia and on the right side is dry saturated vapor state of ammonia.

And then we have put other things here. So, this side is you have propane and then we have r 12 and r 22 over there. So, what we are seeing here is they all have the same shape, but in making this drawing we have to be very careful, because in all these cases specific enthalpy which is here set to 0 is decided quite generally as per the wishes of the person making the property tables. These materials the specific enthalpy h f at 200 Kelvin has been set to 0. And so we could make all these property plots of different substances on this.

Water tables that you see there the specific enthalpy of liquid saturated liquid water at triple point is set to 0. So, I cannot just make that plot and plot h of that on this there will be they will look fine ok, but actually they are quite different there. They whole thing will have to be shifted quite away up. The other thing that this sort of a picture tells us is that what are the substances that have somewhat similar properties. And this issue came up 20 years back, when r 12 as a refrigerant was banned because of ozone layer depletion and immediate question people started asking that what is the material that I can put my in my refrigerator and air conditioners.

So, people started looking at these properties. And said look let us sees what all materials we have we have propane, we have butane, we have r 22, or 23, 14, so many hydrofluorocarbons. And we start looking at all the properties and we find the two materials which are very similar in properties we can substitute them with one another provided all the other things do not come in the way.

For example there is no corrosion or reaction with the oils or its nontoxic it becomes toxic, then we will not use it. But if those things are also ok, then what it means is that even in the existing refrigerator or the existing air conditioner throughout r 12 and put it your new refrigerant and your fridge and AC is good enough to keep working on. And that is what initially was done. But as time goes on we came from r 12 to 22; now 22 has to be banned and removed, so we are now looking at even more refrigerants which we can change. And that is how you see in the market today 134 air in refrigerators; fine just from now even that will be probably faced out and you will have something more coming in.

And this is the basic starting point from which we do the design and engineering of all those devices. So, that is why I have put this diagram. And the idea is that beyond just looking at it and getting properties it tells us lot more about how these substances behave and which can be used in new of the other ones.