Indian Institute of Technology Kanpur

National Programme on Technology Enhanced Learning (NPTEL)

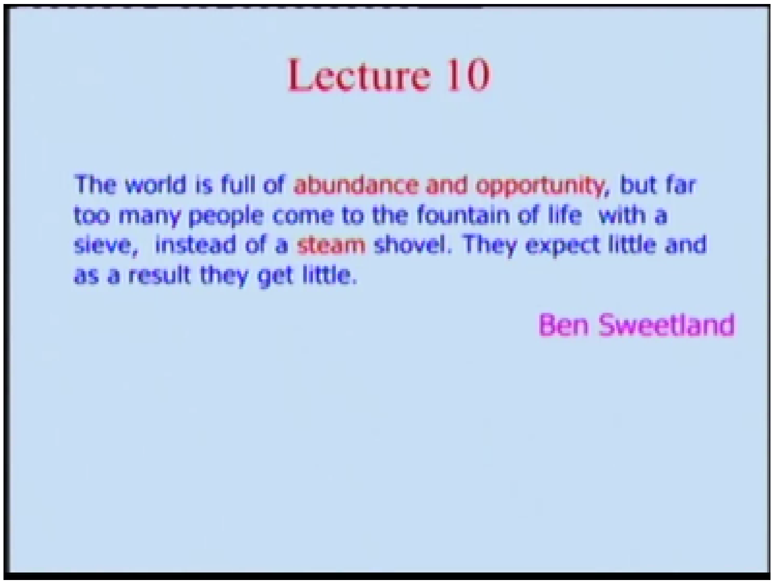
Course Title
Engineering Thermodynamics

Lecture – 10
Thermodynamic Properties of Fluids 3

By
Prof. D. P. Mishra
Department of Aerospace Engineering

So let us start this lecture with a quotation from Ben Sweetland.

(Refer Slide Time: 00:23)



Lecture 10

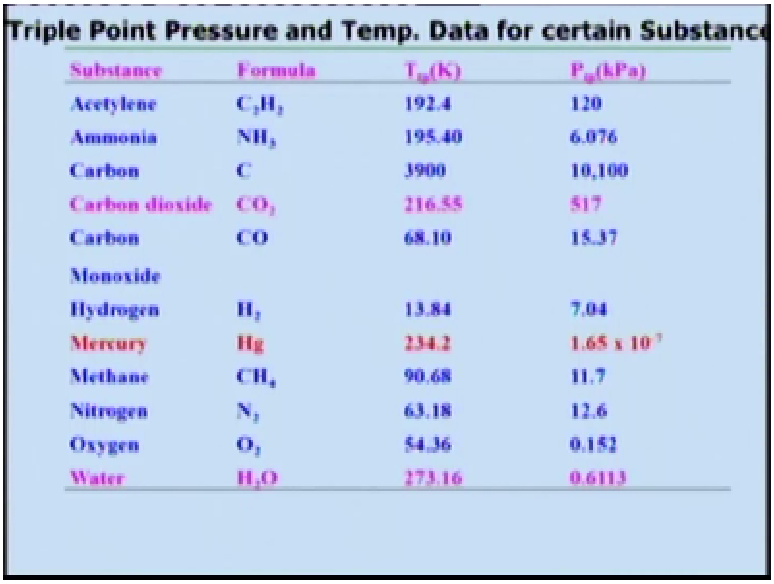
The world is full of abundance and opportunity, but far too many people come to the fountain of life with a sieve, instead of a steam shovel. They expect little and as a result they get little.

Ben Sweetland

Who says the world is full of abundance and opportunity, but far too many people come to the fountain of life with a sieve, instead of a steam shovel right. And they expect a little as a result they get little. Although Buddha has told expectation is cause of the misery, but however expectation is very essential for any progress. So let us now get into a discussion on our thermodynamics and in the last lecture we discuss about basically the phase change process in that we will also talked about not only the liquid and vapor phase, but we also discuss about solid and liquid phase, solid and vapor phase, and solid liquid vapor existing together right, that we call the triple point.

At the triple point you know all the properties thermodynamic properties will remain same or it cannot be changed. So that is why it is being used as a reference point for the temperature scale.

(Refer Slide Time: 01:50)



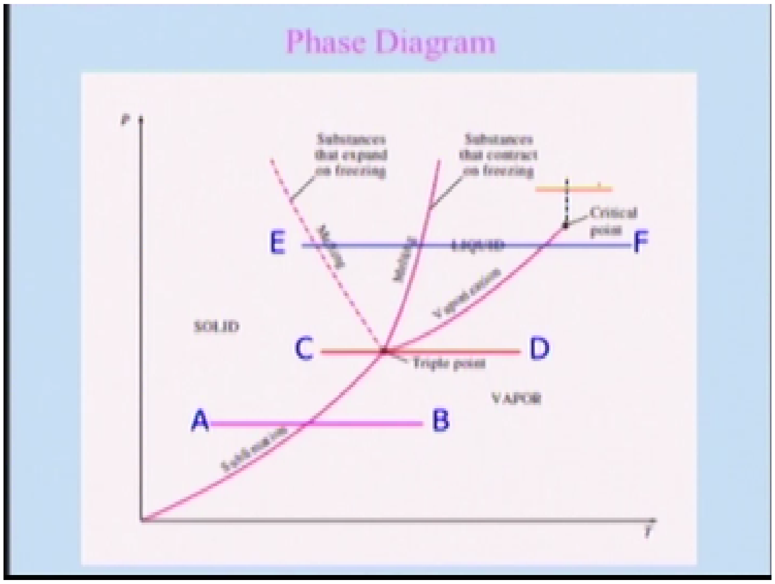
Triple Point Pressure and Temp. Data for certain Substanc

Substance	Formula	T_{tp}(K)	P_{tp}(kPa)
Acetylene	C_2H_2	192.4	120
Ammonia	NH_3	195.40	6.076
Carbon	C	3900	10,100
Carbon dioxide	CO_2	216.55	517
Carbon Monoxide	CO	68.10	15.37
Hydrogen	H_2	13.84	7.04
Mercury	Hg	234.2	1.65×10^{-7}
Methane	CH_4	90.68	11.7
Nitrogen	N_2	63.18	12.6
Oxygen	O_2	54.36	0.152
Water	H_2O	273.16	0.6113

So let us look at some data about what you call triple point data for certain P or substances in this table as you can see if you look at I am like it varies a lot like where the carbon, you know it is having a very high temperature 3900 and the pressure is 10,000, 100 kilo Pascal's. And interestingly if you look at the carbon dioxide it is having triple point of 216.55 Kelvin @ 517 kilo Pascal, 517 kilo Pascal means what something 5 atmospheric pressure roughly okay.

And mercury of course it is a very what we call high temperature, but the pressure is very, very low $.6x10^{-7}$ of course we always deal with water as the steam that is 273.16 at 0.6113 kilo Pascal very low pressure you know is not it, is it very low pressure or not because 100 kilo Pascal is your atmosphere so this is a very low pressure. And as I told that this temperature is being used as a reference that what will be the plot for the phase diagram that means what are the variable we can think of using the pressure and temperature.

(Refer Slide Time: 03:24)



Phase Diagram

As you know in this plot and what we call it as a phase diagram. And if you look at in this region it is the solid and this region is the vapor right. Now if you are at here and if you go on you know giving some heat at this pressure then you will be directly getting into vapor without passing through the liquid phase and that process is known as the sublimations. Bt however, you increase the, what you call pressure further in case of water we have seen it is very low pressure 0.6113 kilo Pascal's.

So you will find a point that is basically a what you call triple point where solid, liquid, and vapor exist together you know, so that is the triple point. And if you consider another point right here let us say you are at here and then you go on adding the heat to that, you know solid let us say water if you consider and there are two kinds of things what we can think of one is substance that contract on freezing right okay.

And a substance that expand on freezing right, so we have already discussed that is the water which expand on freezing that is the reason why the ice is floating on the water am I right? So am I right or wrong? So therefore the substance, you know one is like that and the rest of the most of the substances that contract on the freezing. So if you are at the solid then it will be converted into the liquid and then it will be converted into vapor that means at this pressure it can go through all the process.

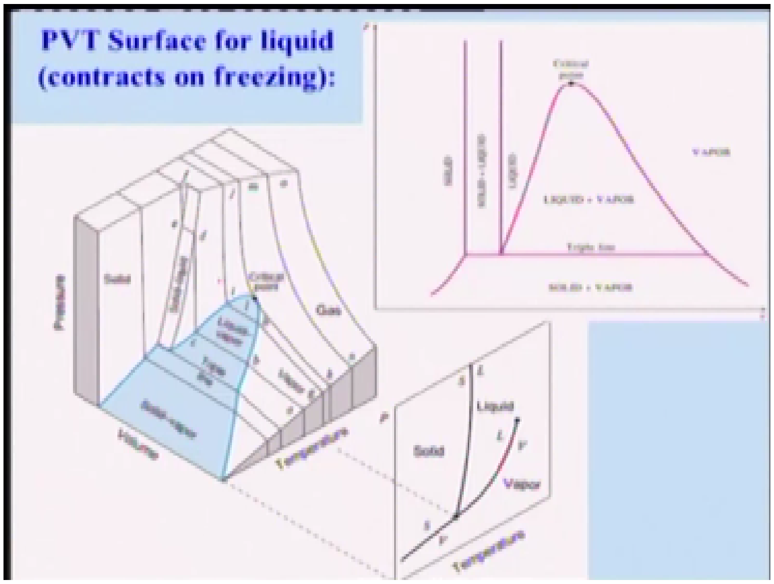
Now if you look at this phase diagram is a very compact one, but it would not give you lot of other things what are those it is not depicting or describing can anybody tell me? So if you look at this line let us say sublimation line right it is going directly to the solid and vapor, but there is a kind of situation where both the solid and the vapor will be existing right yes or no? So that you cannot really described in this, similarly for the what you call liquid to the vapor right there will be a weight mixtures we cannot describe like in this diagram.

And this diagram, you know is very important particularly for metallurgy and other things and so also far like your steam or any other pure substances what we will be dealing with keep in mind this what you call triple point the, how it exist one side is solid here, and other side is vapor and this side is your liquid right that we call it as a triple point is not it. And below this triple point there will be sublimation only the solid and vapor will be existing.

But is it true for all the time or is it true for all the substances or will it be different can I not have some solid, and maybe two solid, and one liquid I can call it as a triple point is it possible. or I can have two liquid point and one gas point or the vapor point can I call it as a triple point, I can call if it is joining together you know like, but is it possible for any substance or we will go by this you know triple point means three phases will be, you know around existing independently you know like and kind of things.

What do you feel? I am not getting any answer. So let us look at that and what is happening, but before that let us look at another point what it is critical point, you know critical point if we just go where the liquid and vapor will be coexisting as I told in the last lecture that at this point the specific volume of the gas will be same as that of the specific volume of the liquid. But as you go on little bit above it, you know let us say you are here it is a liquid and then it will be converted into vapor and then if you look at across that it changes right.

(Refer Slide Time: 09:19)



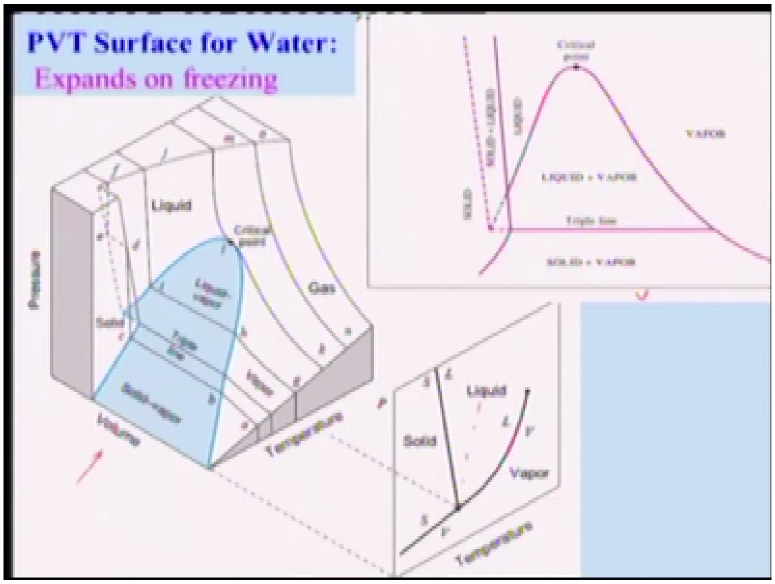
PVT Surface for liquid (contracts on freezing):

So let us now look at like something a substance like which will be contracting on freezing that is the, what you call water. So if I, till now we have looked at what you call till now we have looked at two dimensional kind of diagrams, but now I have put it all the three dimensional that is pressure, volume, and temperature right. So if you look at this point these are the points what you call solid and vapor region and this region is the solid right, and this is the line which you call it as a triple line this is the solid liquid, and this side is solid, and this side your vapor and liquid and this side is your vapor.

And of course this is the critical point where both the vapor and the liquid you know will be existing and if you look at like this is the substance as I told earlier that it will contract on freezing unlike the water. The water will be expanding on freezing that is why density became lower and the water will be floating on the sorry, ice will be floating on the water right. So if you consider I mean from this figure if I take this pressure and temperature you will get a line here and that is basically liquid and vapor, and this is your solid and vapor, and this is your solid and vapor line.

And of course if you do that P&V might if you look at from this side it will be you know plotted like this and this is liquid and vapor as I told this will be triple line, this is the liquid region there will be solid and liquid region and there will be solid region. And this will be what you call valid for most of the substances except water right.

(Refer Slide Time: 12:04)



PVT Surface for Water:

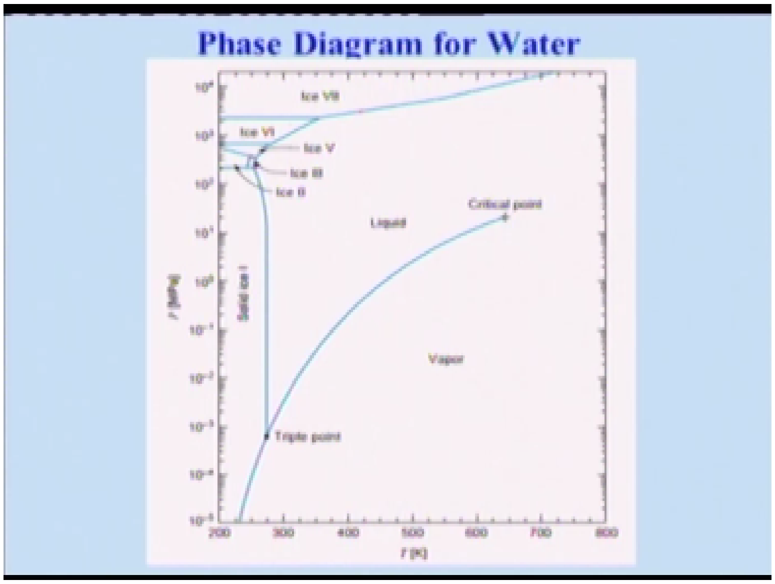
Expands on freezing

Now we will consider another situation that where, you know liquid will expanse unfreezing that is water and it will be having what we call the similar features like it will be having solid in these regions right, and there is a liquid vapor region, and this is a solid vapor region, and of course this is the vapor region, and this is your critical point. If I just plot it here the pressure and temperature it will be having similar like you know liquid and vapor these in line and this is solid and vapor region line.

But here this has been changed as compared to the previous one that is a solid vapor line it has been slope has been change earlier it was, you know like this earlier and it has been changed. So if you look at this line if I plot this, you know from this side that is from this side if I plot I mean if I look at from this side you know pressure and the volume I will get this is basically volume. So I will get the liquid vapor region here, and this is the vapor region. However and this region you know it is a different you cannot have it will go directly you know kind of things from the liquid vapor, and you will get solid here of course in this region it will be solid and liquid and that is the liquid region.

Therefore become is expand on the point that is the reason why at what you call below this point you know it will be go directly to the solid.

(Refer Slide Time: 13:58)



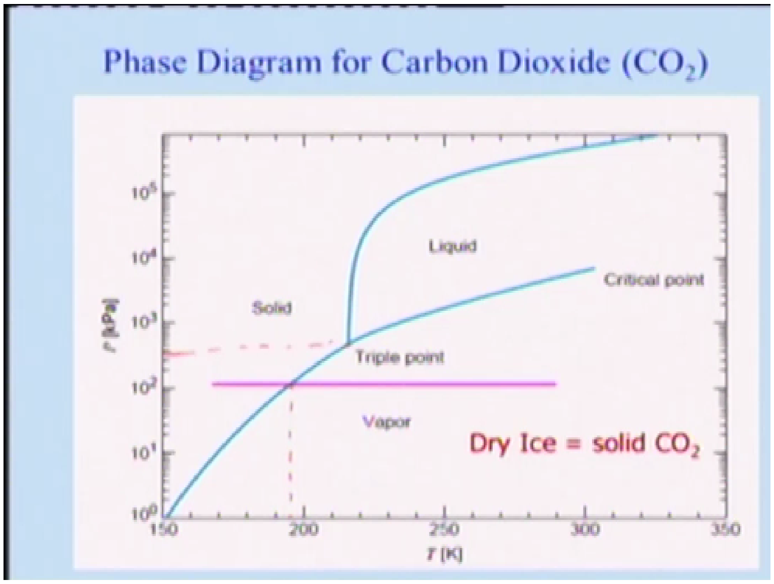
Phase Diagram for Water

And as I told that, you know like let us look at this phase diagram of water which is quite interesting and because the ice will be at total maybe something around seven in a solid ice will have seven phases right. Similarly if you look at your carbon, you know carbon will be two phases right like your diamond and then what you call carbon right and sorry there is a three phases the carbon, graphite, and diamond three phases.

Similarly you can think of liquid helium, you know like it will be having two phases so here the solid eyes is one here and then if you look at this is also a triple point right I can think of about a triple point here. And in this case if I consider this as a two point one side is solid, another side is solid, another side is liquid, but if I consider here this point as a triple point requirement 3 point as joining right, you know three pages are existing together right.

So one side is solid, other it is solid, other is solid. So it is really possible and similarly one can think of also any other points here this will be two solid and then liquid. So I thought that I will, you know show you this diagram which will be quite interesting that ice is having seven solid phases, you know. So these phase transformation what will be knowing from the one phase two solid to another we can call it basically solid, electrophic transformation kind of things.

(Refer Slide Time: 15:55)

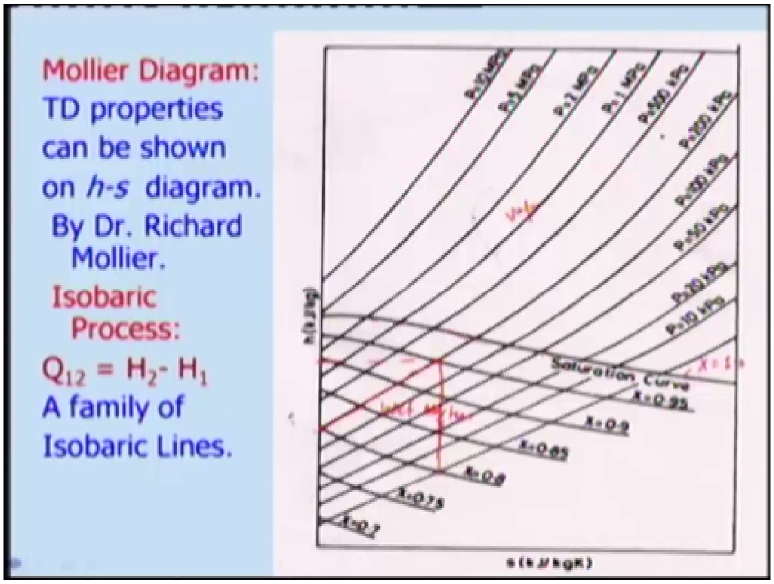

Phase Diagram for Carbon Dioxide (CO_2)

So let us look at the phase diagram of a carbon dioxide right. It is similar in nature, but if you look at this is having a little difference here like it is you know moving this way generally the diagram will be like that but if going this way but the important point is here that if you look at this triple point right where all these three phases existing it is if you look at this pressure right this pressure is above the atmospheric pressure am I right? But whereas the water it was below right because the atmosphere pressure is something around here hundred kilo Pascal's kind of things.

Now if you just add that atmospheric pressure if you are in what you call solid right and if you know you it can be converted directly into the what you call the its eyes because it will be in the eyes form right so if I consider this as atmosphere pressure the gas you know it can be converted directly into the solid form and at a temperature if you look at it is something less than 200 Kelvin right if you look at this temperature at which the phase change will be occurring is basically less than 200 that means.

If I extract the heat from the carbon dioxide at atmospheric pressure right and he would reaches something less than 200 Kelvin then it can convert it directly in twice we call it as a solid carbon dioxide or dry eyes right, so that is why Emily that is being used using this carbon dioxide and can one can think of so and all these properties what we have seen in basically what you call the temperature pressure you know kind of things and then specific volume.

(Refer Slide Time: 18:33)



Mollier Diagram:
TD properties
can be shown
on *h-s* diagram.
By Dr. Richard
Mollier.
Isobaric
Process:
$Q_{12} = H_2 - H_1$
A family of
Isobaric Lines.

But however a thermodynamic properties we need to talk in terms of entropy and enthalpy because for our analysis we need and that properties can be shown on the HS diagram the H is the enthalpy and s is the entropy and this diagram was made by Dr. Richard Mollier therefore this diagram is known as the Mollier diagram right and so this diagram will be looking like that H is plotted here with the earth entropy if you look at this is your saturation line this line corresponding to saturation line here and this is your vapor line vapor gas or the vapor here.

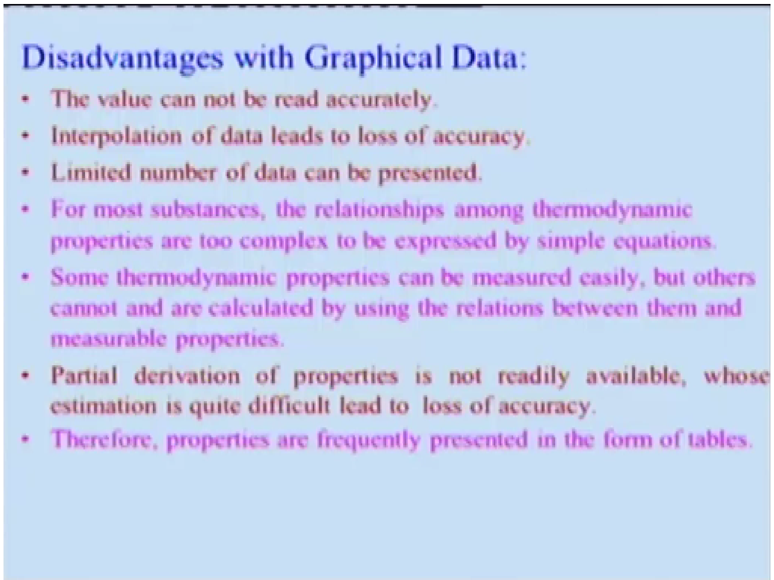
And in this case this is the weight mixture of different you know quality like point 7.75. 8 it goes on and this became a saturated line x is equal to 1 and if you look at this is all corresponding to different pressure like you can say think of like10 kpa here and 20 kPa it goes on increasing till 10 mega Pascals earlier days we used to you know this diagram to evaluate the properties for example if I take the pressure a particular pressure line you know let us say 200 kPa right and if I know let us say some weight fraction.

For example if I take a 12 200 kPa if I my weight fraction is here right and this is the isobaric process right I will go from quality of point 0.95 to let us say I will go to the 0.8 I am moving here to let us say 0.858 right so what is happening I can get directly enthalpy in this point so this enthalpy this enthalpy change will give me basically how much heat he being added you know or it is being protocol there will be change in enthalpy that enthalpy I can get directly from this chart and what are the problems I will face with this for example if you find out that your x the quality is not 0.95 it may be 0.96.

Right then you will have to interpolate and do that and then there will be lot of error involved in that so that will be but you can get quickly the data from this plot and evaluate it and you can also feel what is happening at a constant pressure thing you can think of it is not only the constant pressure one can think of one can find out what will be the isentropic process from here for example I can move from this point and say the vertically I can go down and say that what will be my these things and what will be the pressure I can get all the data from here.

Like what will be quality if I go down and if I know that you know like how much I will be then I can get what will be the pressure what will be enthalpy all those properties I can get from this diagram that is a Mollier diagram earlier days these diagrams were being used very much but nowadays it is being less used because it is a little bit inaccurate to this thing and this but however this diagram will be helpful to visualize what is happening instead of doing some mundane calculation so keep in mind that critical point is not shown in this case but however if you look at a bigger kind of things one can think of using that.

(Refer Slide Time: 22:57)



Disadvantages with Graphical Data:

- The value can not be read accurately.
- Interpolation of data leads to loss of accuracy.
- Limited number of data can be presented.
- For most substances, the relationships among thermodynamic properties are too complex to be expressed by simple equations.
- Some thermodynamic properties can be measured easily, but others cannot and are calculated by using the relations between them and measurable properties.
- Partial derivation of properties is not readily available, whose estimation is quite difficult lead to loss of accuracy.
- Therefore, properties are frequently presented in the form of tables.

So what are the disadvantages with the graphical data because what we are looking at not only the processes from this we can find out graphical the data and which will be useful for our calculation the value as I told the value from this you know diagrams or the or the Mollier chart of any other the kind of diagrams will be not very accurate but as it is difficult to read properly you know so therefore that is one disadvantages the interpolation of data as I told you that suppose we want to evaluate the quality at 0.96.

However in the diagram it is given as 0.95 so therefore it want to then it will be inaccurate you will be have to approximate in a paper so that will be lead to the loss of accuracy of the data and limited number of that can be represent can be presented in a diagram you cannot put all the things because it will be very clumsy and clutter so therefore that is the limitation and for most substances the relations among thermodynamic properties are too complex to be expressed by the simple equation.

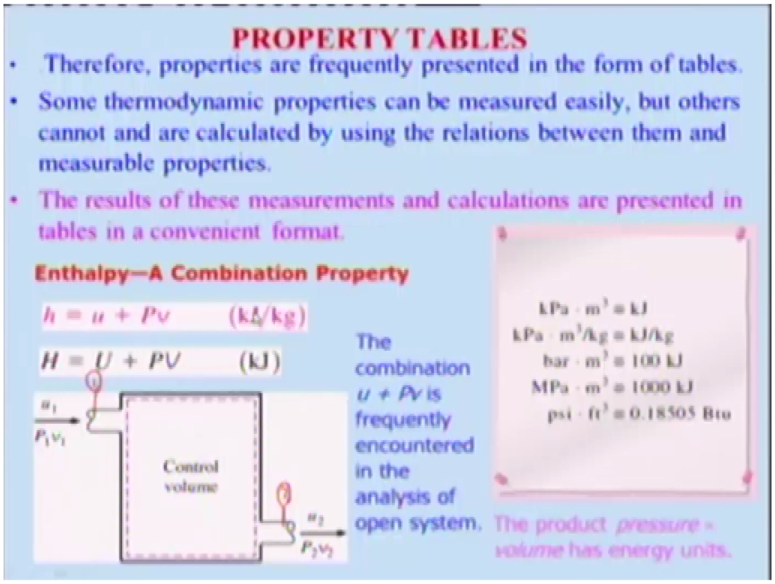
You can say that why not to express in equation that is really little difficult to do that but however as we are progressing maybe we can find out a data or a relationship which can take care of that so that is an open challenge to have a you know at least semi empirical relationship which can be utilize but till now people are not successful in giving expression which will be accurate enough to be used for the calculation.

So some thermodynamic properties can be measured easily as I told like pressure volume temperature this can be measured easily but however there are several which cannot be measured for example like your entropy gifts free energy almost free energy and enthalpy internal energy so those can be really calculated by using the properties which can be measurable or measure properties can be utilized but we need to have a relation between this thing and which will be discussing little later on by that one can do that.

And the partial derivative property is not readily available so whose estimation is quite difficult to lead to the loss of accuracy because these graphical data one can think of you know like using you know for particular pressure a particular certain measurable properties right so then if it is not available then you will be you know will be trouble and also the there will be loss of accuracy therefore that is the reason why the properties are frequently presented in the form of tables right.

Because of this disadvantages we need to keep the data on a tabular form and which will be discussing particular the steam table and refrigeration tables and I will be discussing more the steam table in your tutorial classes depreciation table will be discussed. So let us look at this property data in a tabular form.

(Refer Slide Time: 26:44)



PROPERTY TABLES

- Therefore, properties are frequently presented in the form of tables.
- Some thermodynamic properties can be measured easily, but others cannot and are calculated by using the relations between them and measurable properties.
- The results of these measurements and calculations are presented in tables in a convenient format.

Enthalpy—A Combination Property

$h = u + Pv$ (kJ/kg)

$H = U + PV$ (kJ)

The combination $u + Pv$ is frequently encountered in the analysis of open system.

$\mathrm{kPa \cdot m^3 = kJ}$
$\mathrm{kPa \cdot m^3/kg = kJ/kg}$
$\mathrm{bar \cdot m^3 = 100\ kJ}$
$\mathrm{MPa \cdot m^3 = 1000\ kJ}$
$\mathrm{psi \cdot ft^3 = 0.18505\ Btu}$

The product *pressure × volume* has energy units.

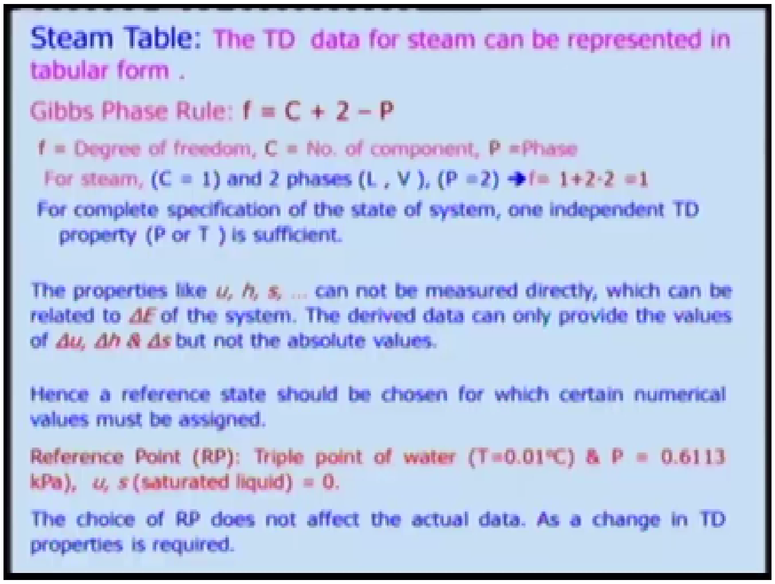
And as I told that properties are frequently being you know kept or presented in the form of tables so that it can be easily utilized and as I told earlier that these properties measurable properties can be utilized for finding the vertical non measurable properties of course using the thermodynamic relations and result of these measurements and calculated values of this all the properties can be presented in a tabular form in a convenient you know format which has format is also very important and how you are presenting the data and how it can be expressed expand extracted.

Let me tell you that I have already talked about enthalpy but the implication of enthalpy is that it is the combination property which we use in our flow systems as I discussed earlier that we are using the control mass system and you know control volume system or the clothes mass you know like a kind of things we call it an open system where the flow will be taking place in that case you know we use basically the internal energy let us say at station 1if I say this is station 1 and this is station 2.

So it will be having certain you know flow work that is P_1 V_1 and otherwise the flow would not move and it makes it the flow to move you can think of as if a piston is there and it is you know pushing the fluid to get into this and also it is going out we will be discussing that little later on so also it is with leaving the fluid is leaving this control volume with the internal energy u_2 and the flow work of P_2 V_2 so that together you know combination of this u + PV being utilized in the open system.

And we call that as a enthalpy right and that if you look at is say PV is basically the unit is you will and if you look at this is basically you can think of pressure is KPA and unit of the volume is meter cube that became kilo joule and if it is the specific volume you use if we use the specific volume right and that is meter cube per kg which is multiplied with the pressure kpa you will get the kilo joule per kg and you can think of using in you know FPS unit we call it be to be form its thermal unit and that is psi pounds per square inch into the feed cube that is multiplied so we will be using not only as I told that the enthalpy but rather the specific enthalpy which is basically per unit mass.

(Refer Slide Time: 30:16)



Steam Table: The TD data for steam can be represented in tabular form .

Gibbs Phase Rule: $f = C + 2 - P$

f = Degree of freedom, C = No. of component, P =Phase

For steam, (C = 1) and 2 phases (L , V), (P =2) ➔ $f = 1+2-2 = 1$

For complete specification of the state of system, one independent TD property (P or T) is sufficient.

The properties like *u, h, s*, ... can not be measured directly, which can be related to ΔE of the system. The derived data can only provide the values of Δu, Δh & Δs but not the absolute values.

Hence a reference state should be chosen for which certain numerical values must be assigned.

Reference Point (RP): Triple point of water (T=0.01°C) & P = 0.6113 kPa), *u, s* (saturated liquid) = 0.

The choice of RP does not affect the actual data. As a change in TD properties is required.

So the steam table which will be using very frequently forgetting the data for solving the problems kind of thing so it can be present in tabular form in the following manner but however before we could look at it we need to understand how many you know variables we can put and how what will be the format of the steam table for that we will have to use the gifts phase rule that is f is equal to C + 2 - P and F is the degree of freedom and see the number of components what you need to represent and P is the phase.

So if you look at for steam the component wise it will be water right component do is will be water so therefore C will be one but there might be several other things like let us say if you look at your petroleum right products it will be having several compositions right so therefore their composition will be need not to be one it will be several of them right at different kind of things it will be there so and we let us consider that we are interested in what you call two phases liquid and vapor that means the phase will be too right.

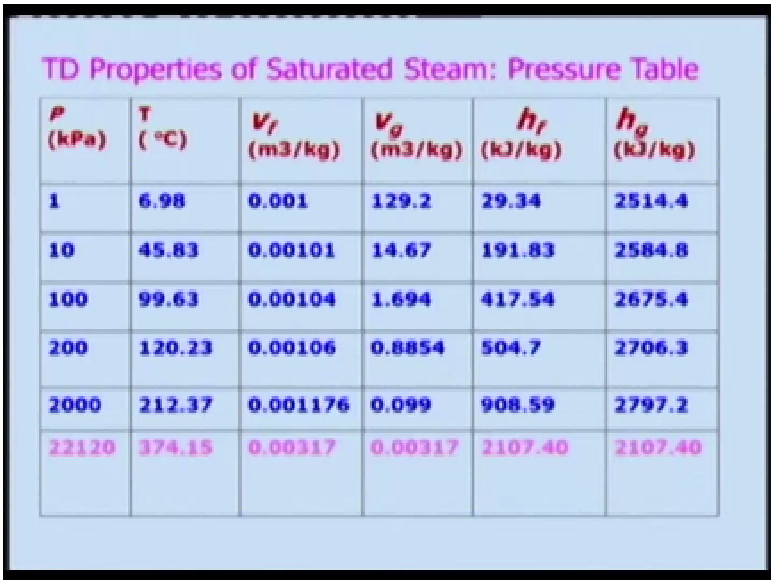
And then what will be the degree of freedom degree freedom will be one what is the meaning of that that means for the complete specification of a state of a system right when we are talking about two phases and you know. What you call the single component substance then one independent thermodynamic properties either pressure or temperature is sufficient to describe the system right, so therefore that is the reason why we will be using and knowing this thing we can find out the properties like internal energy like your enthalpy and your entropy and so on lieges free energy, elmas free energy right.

But however these properties cannot be really measure directly I have told several times and which can be related to the energy change of energy of system and this derived data can provide the values to the change in internal energy, change in enthalpy, change in entropy but not the absolute values right, absolute values you cannot really assign to this quantity. And hence we need to have a reference state and generally this reference state should be chosen such that you know this numerical values must not chosen and such that this certain numerical values must be assigned that means you need to assign certain you know values to the reference the way we have done for your what you call temperature kind of thing.

So a reference point for you know is taken considered as a triple point of water for these substances I mean if you look at the steam and further and that is corresponding to temperature of 0.01˚C and pressure of 0.61 13kilo Pascal's at these conditions you know like entropy and the internal energy enthalpy in a kind of thing can be considered as 0 and then we will go to change that positions and then get the values.

So choice of this reference point does not affect the actual data right, you can have a different but this is the internationally accepted triple point as a reference point as a change in thermal properties you know is basically required so therefore we have a reference point and then from that we will evaluate because what will be getting is a Δu so therefore you should have a known the reference point and then you will calculate what it would be.

(Refer Slide Time: 34:58)



TD Properties of Saturated Steam: Pressure Table

P (kPa)	T (°C)	V_f (m3/kg)	V_g (m3/kg)	h_f (kJ/kg)	h_g (kJ/kg)
1	6.98	0.001	129.2	29.34	2514.4
10	45.83	0.00101	14.67	191.83	2584.8
100	99.63	0.00104	1.694	417.54	2675.4
200	120.23	0.00106	0.8854	504.7	2706.3
2000	212.37	0.001176	0.099	908.59	2797.2
22120	374.15	0.00317	0.00317	2107.40	2107.40

So let us look at the typical thermodynamic properties of the saturated steam and we call it as a basically pressure because the pressure is a variable if you look at I have given 1 kilo Pascal here and 10 and then 100, 200, 2000 of course this is the very large 22,000 10020 kilo Pascal's kind of things. So of course if you look at this is not given this interval larger interval you know it is not given in a very uniform way.

But if you look at actual table like it is given as a closer interval right, so that you can get the data. And what you can note here let us say one kilo Pascal if I take you know temperature is very, very low like 6.98˚C if I take is you know this temperature is basically corresponding to the saturated temperature if I take something 10 kpa this is 45.8˚C and this VF is what is happening here it is goes on what, goes on increasing am I right, very slightly because is a compressible liquid you know so therefore that is not much change. But however if you look at this VZ that is specific volume of the vapor you know it is goes on decreasing at a very rapid rate as compared to the liquid because this is compressible in nature.

And if you look at the enthalpy this is the enthalpy of the liquid at that pressure of one and enthalpy of gas is 2514.54 kJ/kg and this enthalpy is goes on what you call increasing and this is basically if you look at that is it is also goes on increasing kind of things. And if you look at the change in enthalpy is you know latent heat of vaporization is goes on decreasing here right, if you look at here it will be very high and a low.

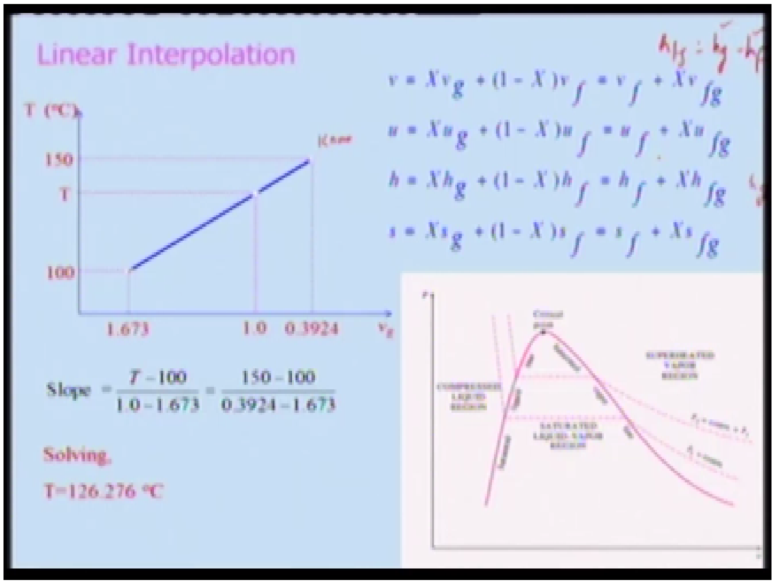
And keep in mind that these corresponding to the pressure of 22,000 under 20 kilo Pascal that is mega Pascal 22.1 is corresponding to the what you call critical point where this specific volume of the vapor as a specific volume of the liquid is same as that of the specific volume of the vapor the same that is a critical point. So let us look at the another table what we will be using we call it as a temperature table for saturated steam here in this case what is given is the temperature and corresponding saturated pressure you know and the first one what I have given here is 0.01˚C and pressure is 0.6113.

And these are the specific volume of the liquid and specific volume of the gas and enthalpy of the liquid enthalpy of the gas, so this basically the your triple point temperature you know case. And of course as you goes on increasing the temperature your saturated pressure goes on increasing and it reaches a pressure where you are having a what you call the this pressure is corresponding to if you look at this temperature 3374.15˚C is corresponding to what this 1 is your critical point.

Because the specific volume of liquid is same as that of the specific volume of the gas and this is corresponding to where the enthalpy of the what you call the liquid and the vapor is also the same that means latent heat of vaporization at the critical point is 0. So now what happened suppose you know we are having a table here, of course it would not be as I told it will be not that you know into interval that big interval large interval so it will be nearby but let us say we are having 10˚C and there is another temperature 20˚C but you want to evaluate at the let us say 15˚C at you a temperature what will be the properties so how will go by that what we will be doing this is not really linear but we take a linear interpolation.

If it could have been the real relationship so if you look at this table this data you know like all these are not linearly fitting otherwise you can have expression and then do that very beautiful you need not to have a worried about the steam table or the refrigerant table and put the data in a tabular form if it is linear. So keep in mind that the relationship between this datas cannot be expressed as a linear form.

(Refer Slide Time: 40:55)



Linear Interpolation

$h_{fg} = h_g - h_f$

$v = Xv_g + (1 - X)v_f = v_f + Xv_{fg}$

$u = Xu_g + (1 - X)u_f = u_f + Xu_{fg}$

$h = Xh_g + (1 - X)h_f = h_f + Xh_{fg}$

$s = Xs_g + (1 - X)s_f = s_f + Xs_{fg}$

$$\text{Slope} = \frac{T-100}{1.0-1.673} = \frac{150-100}{0.3924-1.673}$$

Solving,

T=126.276 °C

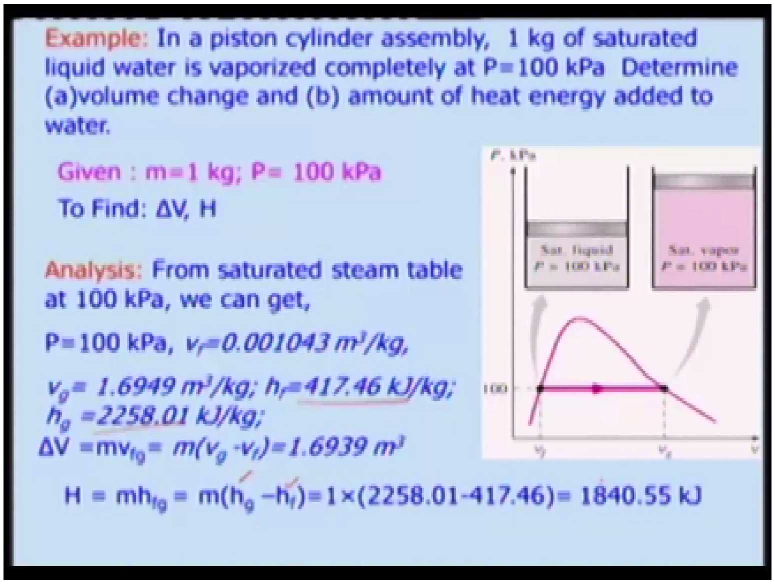
But however we will be using a linear interpolation between the two data points just for the approximation sake, and this is an approximate because we do not have any better way as the interval will be small that is good enough to take a linear interpolation. For example, like if I take this there is a temperature here corresponded 150˚C and I can have a properties from the table I can get 0.3924 what you call m^3/kg right and I if this is known so if you look at this is known right, this point is known and you will be knowing either temperature so that you can find out the specific volume and you if you know this temperature you can find out the specific volume at this point.

But you need to find out you know what will be the specific volume here that means for that I need to find out I should know the temperature then I can find out specific volume right, for that what we will do we will have to use this slope because this is a linear this slope is same as that so I can say T-100 is divided by the 1 right, because that is at 1 and this as 0.393=150 like if I know this is 150 and corresponding to this specific volume right, 150-100 and because this is, this position is known right, values then I can evaluate find out what will be temperature take.

In this case of course I know that at this specific volume what will be temperature there might be a situation you know the temperature and then you can find out what will be specific volume right, vice versa you can do. So of course if you look at like if you want to handle the saturated mixtures kind of things then you can find out the quality and from knowing these qualities you can find out the specific volume right, and if I know this what you call from the table if I know this internal energy or the enthalpy at the saturated liquid point.

And if I know this HFG or if I know this HG right if I know this HG, HG is basically saturated vapor enthalpy and then from that I can find out HFG, HFG is nothing but your HG-HF so if I know this if I know this one then I can find out that by knowing this quality I can find out enthalpy for any quality. Similarly I can find out entropy and other properties like an internal energy and other things.

(Refer Slide Time: 44:17)



Example: In a piston cylinder assembly, 1 kg of saturated liquid water is vaporized completely at P=100 kPa Determine (a)volume change and (b) amount of heat energy added to water.

Given : m=1 kg; P= 100 kPa

To Find: ΔV, H

Analysis: From saturated steam table at 100 kPa, we can get,

P=100 kPa, v_f=0.001043 m³/kg,

v_g= 1.6949 m³/kg; h_f=417.46 kJ/kg;
h_g =2258.01 kJ/kg;
$\Delta V = mv_{fg} = m(v_g - v_f) = 1.6939\ m^3$

$H = mh_{fg} = m(h_g - h_f) = 1 \times (2258.01 - 417.46) = 1840.55\ kJ$

So let us take an example like and to illustrate how to use the steam table like in a piston cylinder assembly 1kg of saturated liquid water is vaporized completely at 100 kilo Pascal and we need to determine the volume change an amount of heat energy added to the water so that is the you know this thing what we need to do. So if you look at the mass is 1 kg and pressure is 100 kPa and we need to find out change in volume and enthalpy so how to go about this.

Let us say change in volume I will do basically change in volume will be change in specific volume into mass that will give me the what you call the change in volume. so what in this problem what we know we know basically at 100 kPa this point is known this is basically saturated, saturated what this is saturated liquid point from the table of if I look at 100 kPa right, I will be knowing what will be VF.

And similarly I can find out what will be because saturated vapor right, I am saying that this in this problem what liquid water is vaporize complete that means this point, so if I know this VG from the table I can very easily find out the change in what you call the volume. So if you look at from saturated steam table at 100 kPa we can get this values VF is very, very small keep in mind that this is 0.001 you know you can say 043 m^3/kg is a very, very small and VG is of course very high that is 1.6949 m^3/kg we can find out also HF which is 417.46 kJ/kg and HG is very high that is 2258.01 kJ/kg.

And if I know these values right I know these values at 100 kPa so from the steam table then we can find out very easily that is ΔV is nothing but M into VFZ is equal to M into VZ-VF right and you just multiplied the difference because it happens to be 1 kg I have taken example which is a simpler one so that the change in volume is 1.69 or 1 points you know 7 meter cube you can think of right.

So similar way we can find out the enthalpy change during space change process is basically phase change so it will be same as that h or ΔH=MxHFG=M HG-HF and HG and HF is known see this is known because this is nothing but your these values and HF is known this values 417 it might substitute these values you will get this amount of kilo Joule. So we will stop over here and we will be taking some few examples in the next lecture how to use the tables and what are the problems associated with it and later on we will be moving into the also how to talk about the gases or the relationship thank you.

<u>Acknowledgement</u>
Ministry of Human Resource & Development

Prof. Satyaki Roy
Co-ordinator, NPTEL IIT Kanpur

NPTEL Team
Sanjay Pal

Ashish Singh
Badal Pradhan
Tapobrata Das
Ram Chandra
Dilip Tripathi
Manoj Shrivastava
Padam Shukla
Sanjay Mishra
Shubham Rawat
Shikha Gupta
K. K. Mishra
Aradhana Singh
Sweta
Ashutosh Gairola
Dilip Katiyar
Sharwan
Hari Ram
Bhadra Rao
Puneet Kumar Bajpai
Lalty Dutta
Ajay Kanaujia
Shivendra Kumar Tiwari

an IIT Kanpur Production