

Indian Institute of Technology Kanpur

National Programme on Technology Enhanced Learning (NPTEL)

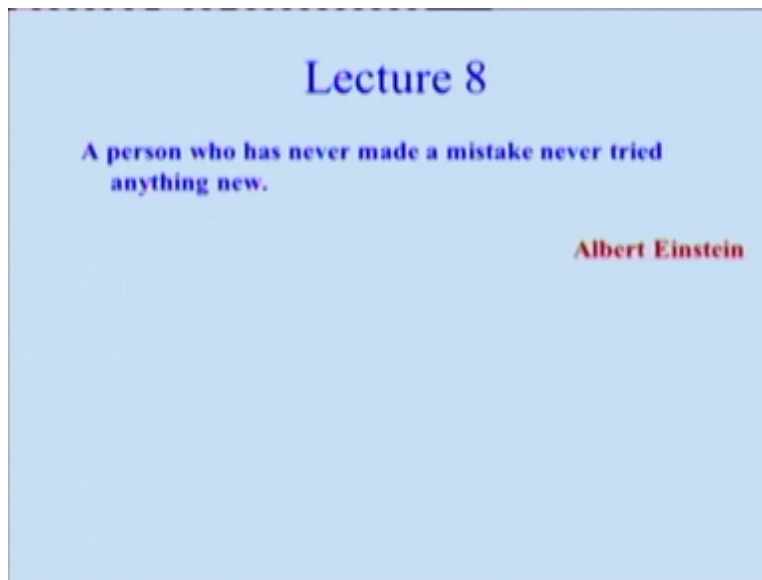
**Course Title
Engineering Thermodynamics**

**Lecture – 08
Thermodynamic Properties of Fluids 1**

**by
Prof. D. P. Mishra
Department of Aerospace Engineering**

Let us start this lecture again a quotation from Albert Einstein.

(Refer Slide Time: 00:24)



A person who was never made a mistake never tried anything new and that is a very important one and, so before starting our lecture today let us recall what we learnt in the last lecture and we discuss about basically the heat is one mode of energy interaction between system and surrounding and which is basically due to the temperature gradient. And then we also find out like how it is different from the work and what are the similarities between the work and heat and we learned that both the work and heat are basically path function it does not depend on the water column rather it is an in exact differential and it will be what you call a boundary work that means a boundary interaction between the system and surrounding.

It goes through the boundary and then we moved into the how many thermodynamic variables one can you know very independently for a system and we state the state postulate we say that number of thermodynamic properties that can be varied independently is equal to number of reversible work mode plus one and we have taken some examples, and then to demonstrate that how it can be and then we moved into the various ways of measuring temperature and also the importance of the temperature scale which will be independent of thermometric fluid. And now today we will be looking at basically the properties and related to the thermodynamics.

(Refer Slide Time: 02:32)

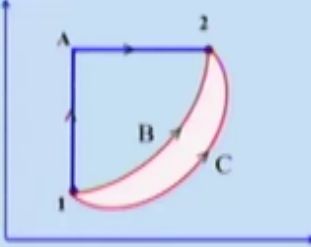
Thermodynamic Properties

The system interacts with its surrounding by work and heat modes. To evaluate degree of change, system's properties are to be known.

Change of state => Change in properties

Kinds of Thermodynamic Properties :

1. Measurable (P, V, T, etc)
2. Non-Measurable (U, H, S, etc)



Properties : Point Function = Unique value Independent of path

And how it is varied because the properties only will tell us about the systems interaction with the surrounding and how it is you know doing and the state of the interactions can be just by looking at the properties in a quantitative manner. So to evaluate the degree of change the system properties had to be known right, and basically because the change of state means change in properties I mean thermodynamic properties let us look at a system which was it at state 1 it is can move through the path B or it can move through the path C to the point 2 or it can move through the path A the properties will be basically not dependent on the path taken by the system. It will be depend will be related to the point like where it is state 1 or state 2 therefore it is a point function, so what are the kinds of thermodynamic properties will be handling in other words how we can classify it you can we can classify into two kinds one is measurable properties

like pressure, volume, temperature you know all these things we can measure but there will be some non measurable properties like internal energy enthalpy, entropy gives free energy helmets free energy and other things.

So these are non-measurable properties, so we need to also learn how we can you know have those non measurable properties by using the data of measurable property that means we need to create some you know ways and means of connecting both the measurable and non measurable properties that will be doing little later on but what here we will be doing this properties is basically for a pure substance.

(Refer Slide Time: 04:56)

What do you mean by Pure Substance?
It consists of matter with fixed chemical composition.
Examples: H_2O , N_2 , He, CO_2 , H_2 , O_2

Can air be considered as a pure substance ?
Air is a pure substance at ambient T & P.

Oil	Its Vapor	Its Vapor
Water	Water	Liquid Air

Can a mixture of water & oil be considered as a pure substance ?
Can a mixture of water & its vapor be considered as a pure substance ?
Can a mixture of liquid air & its vapor be considered as a pure substance at a specified pressure?

Right because substance can be various kinds but we will be looking at Pure substance question arises what do you mean by pure substance right, for example if I say a brass and if I take a copper right okay, so can I call it as a pure substance the brass is a pure substance or copper is a pure structure which one naturally copper but is it then since what we talked about here right, so what do you mean by a pure for example if I take nitrogen gas, right and I take air here having constituent of what oxygen nitrogen mainly right.

It can be other gases but we are neglecting other gases so can I call it as a pure substance you tight I cannot right, now air I cannot say as a pure substance am I right some of you people are agreeing to my statement that air cannot be a pure certain we will see as you go along whether you were right or wrong right for example I will take water and some oil that is a lot of

emulsions kind of thing I can take a biodiesel and diesel you know we can mix you know nowadays we are trying to mix that or alcohol with your diesel right.

Because of we can use that and can we call those as a pure substance or not that we will see first of all let us understand what do you mean by pure substance a pure substance we can call you can define it as a you know consists of a matter with a fixed chemical composition right it will be homogeneous in its composition then we call it as a pure substance right examples are water, nitrogen, helium, carbon dioxide you know hydrogen oxygen any gas because it will be homogeneous if I take a cylinder of hydrogen gas right.

So what will be its collar how will know it is a hydrogen or oxygen I had suggested you to look at the symbol right I think you must not have looked at it am I right please look at it suppose as an engineer somebody will say look this is oxygen cylinder and this is hydrogen you may say make a mistake so if you make a mistake catastrophic will occur am I right, so you need to know this you know color code and let us say it is a hydrogen if it is containing yes you know in a content in a cylinder then it will be all uniform, so therefore I can call it as a pure substance and as I ask earlier can air be a considered as a pure substance, of course it can be provided the air is at the ambient temperature and pressure.

If I take air cylinder or air in this room it will be uniform in chemical composition you cannot separate the oxygen from you know nitrogen unless you do some separation procedure you know like or is some kind of a membrane dealer to use to separate it or how I can separate oxygen from nitrogen one can think of membrane you know using is there any other way of doing it how you can think of liquefying it right.

If you liquefy it then one can think of is separating it out so, therefore it is at ambient temperature and pressure it will be uniform in chemical composition therefore we can call it as a what you call pure substance let us say if I say water and oil right it will be definitely what it will be can a mixture water and oil be considered pure substance similarly if I take water and it is vapor right can I call it as a pure substance and if I take liquid air and it is vapor can I call it as a pure substance right.

So which one is it three examples I have given right liquid air and it is vapor it cannot be really a pure substance yes or no because you know some of the compositions between the both the

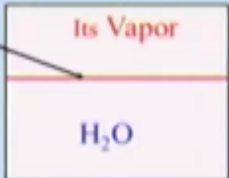
liquid air and its vapor need not to be same, so therefore it cannot be and similarly for water and its vapor can we call it as a pure substance or not we can definitely call because it is same water molecule will be there whether it is a liquid state or a vapor state, so therefore we can call it as a pure substance . And water and oil we cannot really call it as a pure substance because it is at different compositions.

(Refer Slide Time: 10:30)

What is a Phase ?
A distinct state in which matter remains homogeneous physically and chemically.
It can be identified as a distinct molecular arrangement that is homogeneous throughout its boundary.

1. Solid phase
2. Liquid Phase
3. Vapor Phase

Phase Boundary



The diagram consists of a rectangular box divided into two horizontal sections. The top section is labeled 'Its Vapor' and the bottom section is labeled 'H₂O'. A horizontal line separates the two sections, and an arrow points to this line from the label 'Phase Boundary' on the left.

TD properties of a substance change abruptly at phase boundary although certain intensive properties remains constant.

For Ex: Liquid H₂O and its vapor coexist at 100 °C & 101.325 kPa. Properties like v , u , h , s are quite different across its phase boundary.

So now whenever we are talking about like you know we will be talking about a phase so what do you mean by phase, phase is basically a distinct state in which matter remains homogeneous physically and chemical chemically if it is homogeneous what we call we call it as a pure substance right, but here not only the chemically homogeneous it should be physically as well the common example you know in summer season you will be getting some ice water right if it is ice is there then you know that is in solid phase and water will be in the liquid phase.

This can be identified as a distinct molecular arrangement that is homogeneous throughout its boundary as I told the ice will be solid, so it will be you know having a distinct boundary and that boundary which will separate from its liquid you know if we call it as a, what you call phase boundary. For example if it is I will take another example this is a water and it is vapor and this is your phase boundary where you know water can be converted into vapor and there is a you know what a label you can see.

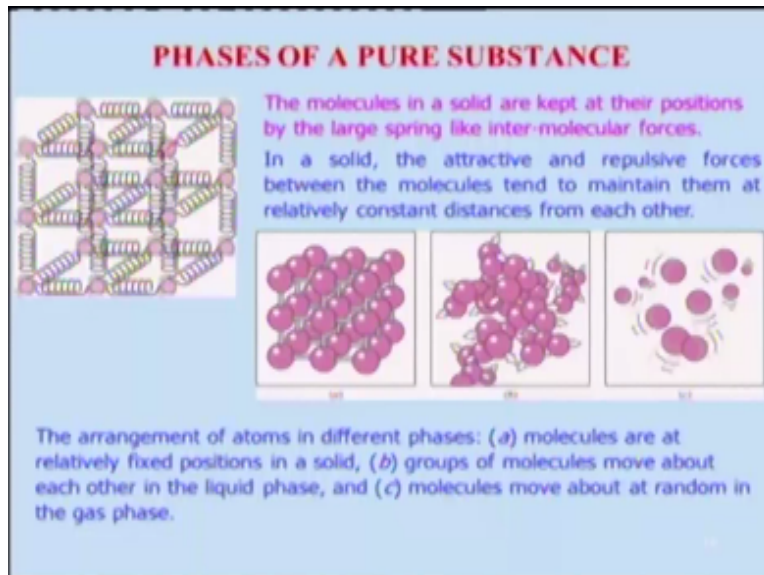
And that itself will be known as the phase boundary, so the phase can be broadly divided by three categories one is solid phase, liquid phase and vapor phase right and thermodynamic properties of a substance change abruptly at the phase boundary right yes or no although the certain properties like intensive properties for example pressure or temperature you know will be remaining constant.

So therefore that there will be change of certain properties of the substance across the boundaries for example if you look at water right and if you look at the specific volume of the water will it be same as that of the it is vapor it will be very different right in order of magnitude difference will be there, so but whereas the pressure here if I say it is ambient you take a pan and then hit the water, so if you look at ambient pressure is there and temperature will be what may be 100 degree Celsius right.

So it will boil it will do a vapor itself will come over so that our vapors will be produced, so that it will be changing right that means pressure and temperature remaining constant however the it is a specific volume will be changing, so to make it more concrete you know you can say that liquid water in vapor coexist at 100 degree Celsius 101.3 25 kilo Pascal's like properties like specific volume internal energy specific enthalpy entropy are quite different across the it is bound phase boundary.

That means there is a lot of difference of this properties if you look at the numbers you know both the liquid and vapor will be quite different which we will see as we look at in this you know either in that this lecture on the next lecture we will be looking at it.

(Refer Slide Time: 14:11)



So let us look at the phases of a pure substance if you look at this is a solid kind of thing and there is a which can be considered as this spring mod like these are the molecules which are sitting over here and it is as if connected with a solid with the spring connected with a spring and these molecules in a solid are kept at their position kind of by last spring like intermolecular forces you can this a model it is not that basically what will be existing between the molecules in a solid is a intermolecular forces.

And which will be quite large and there will be also the repulsive forces right, repulsive forces will be there only when these molecules will come very closer to each other that means you know the distance between the molecules will be tending towards 0 then you will get a repulsive as a result you know like they can move and these molecules are basically will be vibrating you know in this ways it will be vibrating and then these molecules are we repeated at this pattern what we call it is in lattice structures kind of things it will be repeated.

And there will be together kind of things right the intermolecular forces are quite high right if you consider that earlier days in our family system there is a lot of intermolecular force our inter man are the people things were there they can take more resistance right if we apply a force you

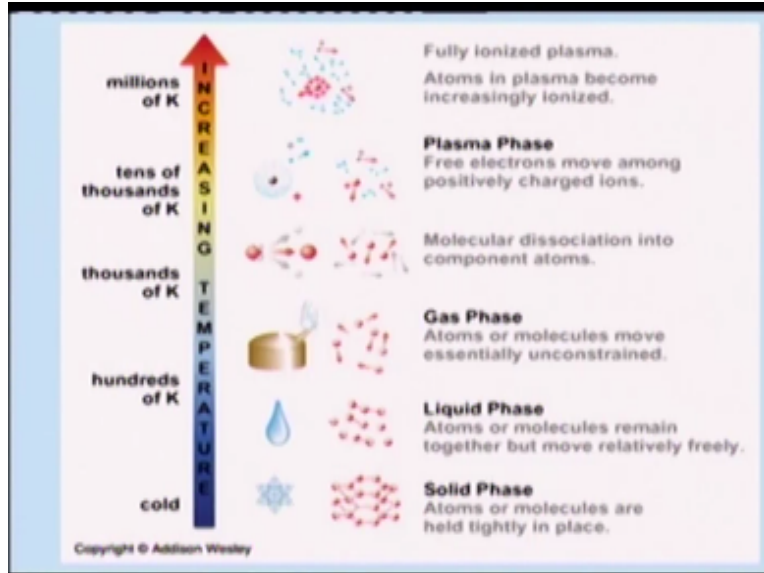
know or a kind of thing stress they can take and today it is not right if you consider. And this can vibrate as you told as I told that this will be molecularly vibrating over that and when you will be giving some kind of a heat or the temperature will go up what will happen this vibration energy will be increasing.

And when it is increases then what happened that velocity of the vertical molecules are the which will be vibrating along with mean position that will be increasing as a result it will go away from this from their lattice and then move with a certain patterns and then you will get what you call the liquid state and this look is state they will be together nests but they will be you know not in a fixed position like in your solid, so therefore it became a fluid or a liquid and then we would go give more energy then what will happen that became separated out and then the molecules will be far away.

And they move in a random manner in the gas phases and as a result you know like they will be interacting but they will be interacting very rarely and by the interaction will take place through the, what you call molecular collisions. If you look at in our country that our earlier days the people were having what we call lot of kind of forces they were together Ness was there and today after few years you know like or what you call after maybe few years back we are liquid now today we are gaseous state and moving randomly although.

The is molecule helping having a higher energy level right, so this molecule will have been higher energy level and therefore we get a lot of stress and strain in our life, so if you look at what I am trying to emphasize here that solid is similar to our earlier culture of family having a family or a car or a village is having a lot of you know family bond was a stronger today it is broken and therefore we become gaseous state and then we will be facing lot of problems, so one has to look at that.

(Refer Slide Time: 18:34)



So now if you look at these things in the low temperature you know like the solid phase will be there atoms and molecules are held tightly in place together and as it is you know temperature increases we you know molecules will be separated from their place which were there occupying in a very secure manner that and then the you know moved of course they will remain molecules will remain together but move relatively freely not either fixed position like solid.

But in the gas when the temperature goes up the atoms or molecules move essentially unconstrained without any constant they will be moving here and there and of course there is another state with the plasma states which are very, very high temperature.

If you look at this is that the you know low temperature less than 100 here you know this became above hundreds and other thing of course for water it is hundred but for other metal it will be different temperature to liquid temperature or and then we will go to thousands and ten thousands kind of things you know you will get a plasma state kind of things and then it will be fully ionized plasma is a very high temperature. So if you look at like this is the kind of phase change what it occurs?

(Refer Slide Time: 20:02)

All substances change their specific volume, v when subjected to a change in P & T .

Incompressible Fluid : Change in v is small. Ex: Solid, Liquid

How to characterize it quantitatively ?

Isothermal Compressibility (k):

$$k = -\frac{1}{V} \left(\frac{\partial V}{\partial P} \right)_T$$

k is quite small : Incompressible substance
 k is large : compressible substance

Coefficient of Volume Expansion (β):

If P remains const., T is changed.

$$\beta = \frac{1}{V} \left(\frac{\partial V}{\partial T} \right)_P$$

And we will be discussing more about that and let us look at the all substances change their specific volume when subjected to change in pressure and temperature and as I told that you know like it will be changing for example if I take a solid you know rod which is inelastic nature either I will give a force right or it is applied to a force or it is applied to a temperature there will be expansion right when it will remove that parts or the temperature then it will be contact.

Now that changes will be quite small right if I consider the what you call a gas where I will apply the pressure and where I will apply the temperature of the heat then expansion will be very high therefore the change in specific volume in case of solid and liquid is quite small as compared to the gas and we call it as an incompressible fluid and where it is you know change is very large then we call it as a compressible fluid.

Now question arises how to characterize it quantitatively, right because we will say look it is a compressible substance or incompressible substance by just looking at the specific volume change with the change in the pressure or temperature kind of thing but how we will quantify it unless we know quantification some number we cannot really use it right, so for that we will have to define you know two terms one is we are saying that the temperature is remaining constant there are two variables which can make the same changes in the volume so therefore we will have to keep one of them constant we are saying that temperature is remaining constant and there will be change in volume with the application of the pressure I mean force here and then we change in volume per unit volume.

With the change in pressure when the temperature is remaining constant we call it isothermal compressibility and keep in mind that this is having a negative sign here, why that negative sign? Because whenever you are applying a force right and trying to compress it the volume will change volume will decrease will it increase or decrease, it will definitely decrease so $v_2 < v_1$ therefore negative signs comes over here.

But we will just look at the another way of quantifying it right, that is the coefficient of volume expansion where pressure will be remaining constant and temperature he change so if you look at the $\beta = 1/v (\partial v/\partial T)$ when pressure is constant.

(Refer Slide Time: 23:21)

Simple Compressible Substance (SCS)

Simple Substance: One relevant reversible work mode

SCS : Reversible PdV work

State Postulate: Independent TD Properties
= No of Independent Work Mode + 1

For SCS: Independent TD Properties = 2

Most convenient properties are (\hat{u}, \hat{v})

$Ex : P = P(\hat{u}, \hat{v}), T = T(\hat{u}, \hat{v}), \hat{s} = \hat{s}(\hat{u}, \hat{v}).$

These are fundamental relations (FR)

So if you look at this β is having a positive quantities and this is known as the coefficient of volume expansions and this will be you know quite small if it is having incompressible substance so also the isothermal compressibility if it is large we call it a compressible substance right and keep in mind that these properties are this you know quantities will be very useful for deriving these non measurable properties by using the measurable properties for example volume pressure temperature these are all measurable properties right.

We will be using these coefficients either the isothermal compressibility or the coefficient of volume expansion this will be using to connecting the non measurable properties with the major property and vice versa. So let us look at simple compressible substance which will be dealing with in this course and is one in which one relevant reversible work mode will be used and we

that is the simple compressible substance we call and as we know the state postulate says that independent thermodynamic properties that can be varied is equal to number of independent work reversible work mode plus one right.

So in the simple compressible substance reversible work mode work is basically one so therefore the total number of properties that can be varied independently is 2 in this case the simple compressible substance, so most convenient properties will be what you call internal energy and specific volume specific internal energy and specific volume so we can think of pressure is a function of internal energy and specific volume temperature similarly function of specific internal energy and specific volume so also the entropy and other things.

And which will be relating this to the what we call the other non measurable properties later on and these relationships we call it as a fundamental relations which will be looking at towards the end of this course.

(Refer Slide Time: 26:14)

By knowing FR, we can find out thermodynamic property of the system. FR will be discussed briefly latter on.

TD Properties: Mathematical relations
Tables
Charts or Diagram.

TD Properties can be determined experimentally at specific T and P.

By Interpolation method & Fundamental relations.

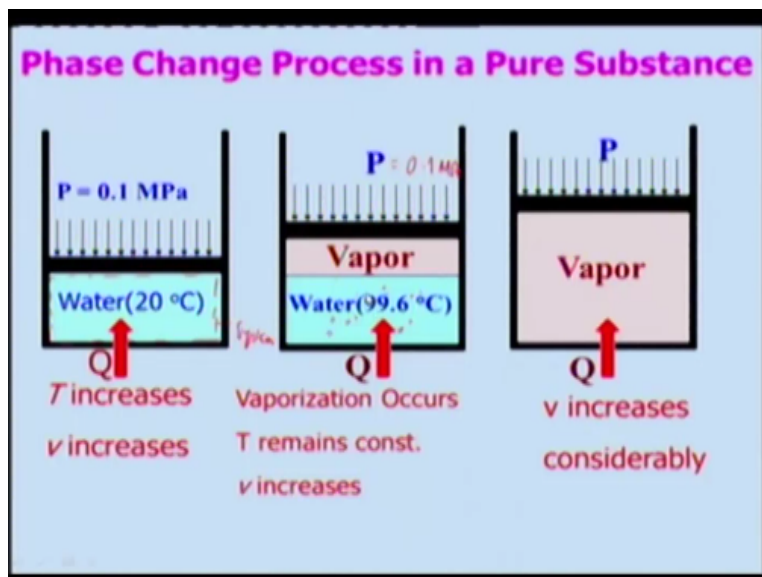
By method of statistical thermodynamics at higher T.

And by knowing these fundamental protocol properties are the fundamental relations we can find out thermodynamic property of the system and as I told that we will be discussing about these fundamental relations towards the end of this course and so but however here we need to look at this thermodynamic properties in the mathematical relations right either we can express in terms of mathematical relations or we can use the vertical tables data tables like your steam table refrigeration data tables and other things.

And we can also use some charts or diagrams right to describe the process and also use the properties so thermodynamic properties as I told earlier that can be determined experimentally at specific temperature and pressure by interpolation method and using these fundamental relations which I have not discussed we can relate these experimental properties with the non-experimental properties of course another way of doing is that by using the statistical thermodynamics at a higher temperature.

Because all these properties what we will be using basically at the low temperature because low temperature we can measure but in the high temperature it is very difficult to measure let us say it is a you know something ten thousand to two thousand degree Celsius you are talking about you cannot really measure it you know, so therefore we need to use the statistical thermodynamics which we would not be discussing but however it can be done right.

(Refer Slide Time: 28:06)



So now we will be looking at the phase change processes in a pure substance will be considering the water as a you know substance to be discussed the phase change processes and that can be valid also for other pure substances, we will consider a case of water at 20 degree Celsius in a piston and cylinder arrangement what is shown here and water will be at 20 degree Celsius here and the pressure which is applied this 0.1 mega Pascal.

So if I will go on adding to the heat and if I take this as my system boundary right, so what will happen what will happen to this water what properties will be changing, so if you look at this at 20 degree Celsius and what will happen to the temperature of the water definitely it will increase you know you are giving heat and what happens to the pressure, will it increase, will it decrease or what will happen, it will be remaining what same.

Because you are applying the same 0.1 mega Pascal it would not be changing that means here it will be constant pressure process one can think of right and then what happened to the specific volume, what will happen, volume will increase right but the increase you know will be not much as we have seen that it will be water at this point will be incompressible because very you know what are we considered as incompressible substance right and this state at 20 degree Celsius we call it sub cooled state also.

So now what will happen if we will go on this temperature, temperature will be going up like 20 degree 25 degree like go on and then there will be a temperature it will come that is known as like let us say it will reach the water temperature 99.6 degree Celsius what will happen at that point with the pressure equal to the point what you call 1 mega Pascal, what will happen?

It will start boiling right once you start boiling what happens to the temperature it will be remaining constant temperature on change then the water bubbles which will be you know going up and it will go up because it is right and then collected and then there will be the vaporization will start occurring right and once this vaporization occurs what it will be it will be a mixture of water and its vapor right.

And what happens to pressure, pressure remain constant temperature is also remaining constant but the specific volume increases at a very high rate why? Because the specific volume of the vapor is one order magnitude higher than that of the water right so here therefore the volume will

be increasing rapidly kind of things and keep in mind that this all these things happening in a very, very quasi-static process or quasi equilibrium process right.

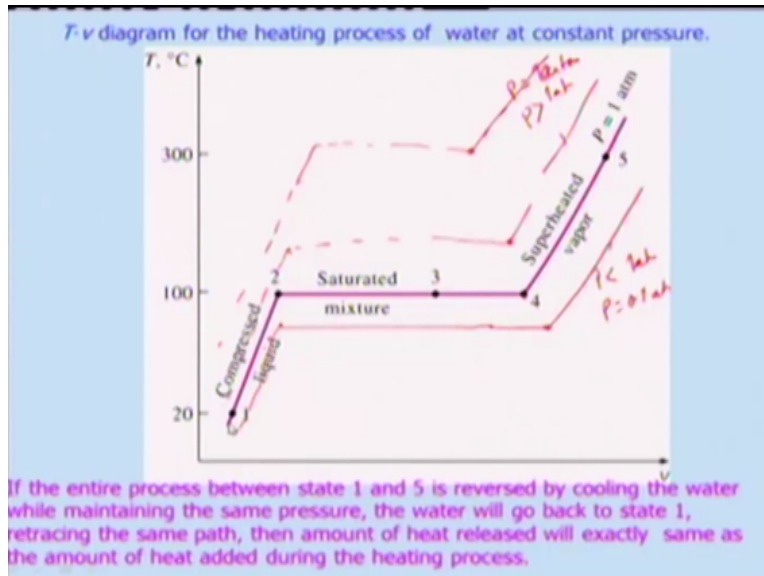
If I look at if I will take this heat out from this here what will happen some of the vapor will condense back to the where? To the water and similarly heat I will take out it will be known as the what you call it will be temperature also will be reducing from the system whenever i am taking the heat from the system the surrounding let us say it is at 50degree Celsius here and then you know it will reduce to that it can press back.

So if you look at this temperature increase here from let us say 20 degree Celsius to the higher temperature with the addition of heat to the system from the Torah's from its surrounding we will call it as a say sensible change in sensible enthalpy change okay because you can sense it here the temperature is remaining constant although you are giving heat you will give go on giving heat but still the temperature is remaining constant.

Because that heat what you give we call it Latent heat and how long this will go on that means the temp even though you are giving heat to the system but there is no change in temperature although the specific volume will be goon increasing right how long it will go on this process how long, till the last drop of water is converted into its vapor right and in this case if you go on giving heat, what will happen?

The specific volume definitely will increase right and what happens to temperature, what happens to temperature, temperature also will go on increasing right so and this suppose in this case I will take you know it is last this thing some heat then what will happen this will be condensed back to the liquid and it will get into this two phase situation because this we call it as a wet mixture because mixture of vapor and liquid in this case and then it can come to the liquid.

(Refer Slide Time: 34:47)



So this passes we can press in a what you call T-V diagram this is the temperature right this is the volume if you look at we started here with 20 degree Celsius right and this we call it as a compressed liquid or sub cooled liquid then the temperature is remaining constant and this point we call it as a saturated liquid point right this point we call it as a saturated liquid point and in this case there will be mixture of both the liquid and it is vapor and keep in mind the temperature is remaining constant and this we call it as a saturated vapor line vapor point.

And as you goes you know go beyond this and add it there will be increase in the not only the specific volume also the temperature up right this we call it as a superheated vapor right and if I will conduct this experiment for different pressure let us say if it is a lower pressure what will happen, if it is a lower pressure so it will be go on this you know kind of things point and again it will go like that way if it is higher pressure, what will happen?

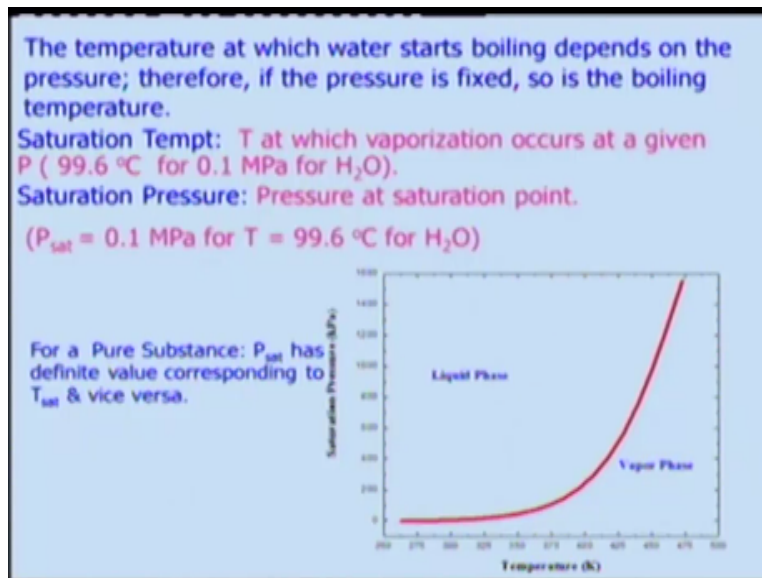
It will go on this ways so what is happening to this saturated vapor point it is changing and in this case the higher pressure this is $p > 1$ atmosphere pressure and here is $p < 1$ atmospheric pressure I can say p here is 0.1 ATM and this is $p = 1, 8$ or 10 ATM okay 10 atmospheric pressure and if will go on like that what will happen if I go on increasing pressure what will happen.

Let us say I will take a little higher pressure here what will happen what you are observing so that means these portion the saturated mixtures are portion is decreasing like these points are contracting are becoming lower and this of course it is occurring at higher specific volume and

these points are occurring at the lower specific volume, so there will be a situation where the liquid will directly convert it into what, its vapor right.

So let us look it further so I must emphasize this thing that as I told earlier that if the entire process between state 1 and 5 is reversed by cooling the water while maintaining the same pressure water will go back to the state 1 right, tracing the same path. Then amount of heat release will be exactly same as the amount of heat added during the heating process right that is a very important point you should keep in mind.

(Refer Slide Time: 38:33)



And the temperature at which the water starts boiling depends on the pressure we have already seen that therefore if the pressure is fixed so is the boiling temperature and the temperature saturation temperature for 0.1 mega Pascal is basically 99.6°C/water and saturation pressure will be what you call 0.1 mega Pascal you know for 99.6°C water it is just I'm saying saturation temperature such an inspiration because it is corresponding to that. And for a pure substance you can think of the saturation pressure you know goes on increasing with the increase in temperature right.

So what is his implication can I really learn something from this, can you or in other words can you tell me based on the simple principle can we devise something which can be useful for us.

See you might be seen your mother uses the pressure cooker for cooking food am I right or wrong yes or no, you might be knowing however not why it is, so pressure cooker you must have seen right yes or no how many of you have not seen pressure cooker. No, not a single you have not seen pressure cooker in your home I am really amazed by this so what will be the pressure in the pressure cooker an area okay.

Let me ask you a question suppose you boil the dal in a pan which is subjected to atmospheric pressure how much time it will take, it will be taking something let us say around 20 minutes okay, but if I use the same amount of dal and same amount of water in a pressure cooker how much time it will take will it be higher or lower, it will be lower let us say five minutes that means what why it is taking, if you look at this curve right that means you know let us say it is at a lower temperature like kind of things or lower pressure something 100 kind of right ambient temperature if you look at right.

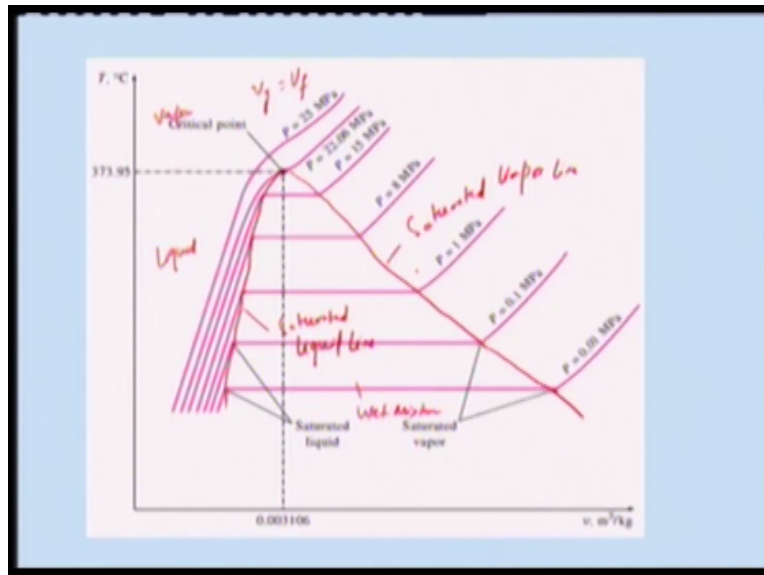
Let us say this is right ambient temperature we have seen ambient pressure we know that you know water will boil at ninety 99.6°C right, so at a higher pressure what will happen to the saturation temperature it will be higher right, yes or no. So that if you are boiling at a higher temperature using a pressure cooker in which the pressure inside the pressure cooker will be higher than the atmospheric pressure then you can cook it easily or quickly right generally you know two atmospheric pressure is being kept in a pressure cooker domestic pressure cooker, right.

But if you look at the nutrient values of those food will be much lower than the, what lower than their what you can cook in the atmosphere pressure but you want to have a fast. For example, let me ask you a question it is very interesting you know, suppose you cook in a pressure cooker and you cook in a solar cooker and you cook in a your general with a simple pan same thing by the same person which will be tastier, three cases I have told so which one will be tastier and why, you are not saying me anything at least I was thinking you will tell me, no idea.

Let me tell you that all this thing will be cooked at a low you know like in the solar cooker temperature at which the food will be cooked is much lower in the simple pan with using LPG stove or any other store right will beat higher temperature and the pressure cooker will be at highest temperature among all these three okay, so where the food will be tastier solar cooker right, you got the point why it is, because the temperature gradient is very low.

So also in our life that when we are subjected to the less gradient we perform better okay, so that is the important point we should keep in mind and that is the application of thermodynamics. Similarly the saturation you can think of several of examples you know one can think of cooling and getting eyes right, and from the water by lowering the pressure I can get ice just by lowering the pressure it will go to the vacuum the water become you know converted into ice and several other things.

(Refer Slide Time: 44:35)



So as I was telling that these are the points these are the points is a saturated liquid point and similarly these points are the saturated vapor points at different pressures as if you look at these zones are goes on decreasing and there is a point where the liquid if you look at these are the basically liquid right, it will be converted into gas and that point that is corresponding to the 22.06 mega Pascal's and the temperature of 373.95°C right, where the liquid will instantly converted into vapor that means the specific volume of the liquid and it is vapor is same are you getting my point that means at this point the critical point here the $V_G=V_F$.

V_F means is a liquid specific volume of the liquid is same and this critical point is very important right, because that will tell me whether it is a liquid or the vapor and that is the you know kind of things and if you look at this is liquid and above this point we call it as a vapor and above this point all this vapor you know it will be we call it superheated what you call vapor

kind of things. And if you do that then you will not having this weight mixture this is known as weight mixture.

Weight mixture means is the mixture of liquid and it is vapor and that will be corroded and we will be discussing that maybe whenever we are talking about power plant, steam power plant and boiler you know like we will be encountering this mixtures it will corrode it another problems. Nowadays people are thinking of using or rather they are using not thinking they are using supercritical boilers, because they will be operating at a very, very high pressure so that liquid it will instantly get into the vapor and you will not avoid the mixture of weight or wet mixture, mixture of the vapor and liquid.

So if I join this line you know points right, this is known as, this line known as what saturated liquid line this line is known as saturated liquid line. And similarly if I join these points over here in these points this is known as saturated vapor line and keep in mind this slope is steep and this is little flat and that indicates that in between these two lines the mixture that means weight mixture will be there, mixture of vapor and water will be there and question arises what would be the part you know like percentage of water, what will be percentage of vapor.

In this case the percentage of you know vapor will be 0 here the percentage the vapor will be in this point will be 100% right, so we will be defining a quantities for that and also look at how to find out these properties because we will be interested in evaluating the properties you know in these mixtures also like internal energy, enthalpy, entropy all those properties we need to evaluate. So what will be available here the properties will be available here and properties will be available there but we need to know this and then find it out that is the challenge will have to look at how we will do that.

(Refer Slide Time: 48:52)

Critical Point Pressure and Temp. Data for Certain Substances

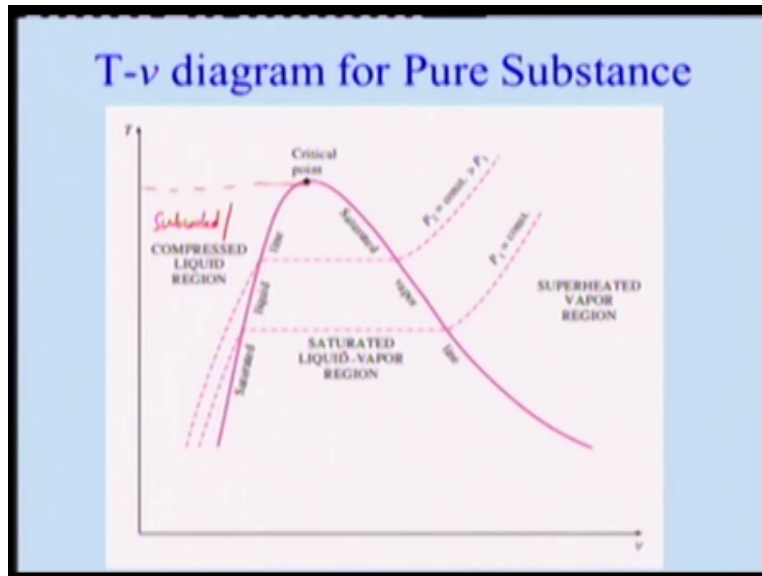
Substance	Critical Temperature (K)	Critical Pressure (MPa)	Critical Volume (m ³ /kg)
Water (H ₂ O)	647.39	22.07	0.003155
Carbon dioxide (CO ₂)	304.20	7.37	0.002143
Oxygen	154.80	5.08	0.002438
Hydrogen	33.30	1.3	0.032192
Helium	5.3	0.23	0.0578

Most metals have a much higher critical temperature than water.

So just to say that what are the critical point pressure and temperature data, let us look at some of the data is here like water I have already told you the critical temperature is 647.39 at critical pressure of 22.07 mega Pascal's and this is the critical volume and various other substances I have put it, I have place it in this table that is carbon dioxide, oxygen, hydrogen and helium interestingly if we will find the critical temperature for helium is very, very low 5.3 Calvin you know.

And so also the pressure is something 0.23 mega Pascal's of course the if we look at the others are in between but most of the metals have higher critical temperature than water because you know like it is having a what to call this thing so they are having higher metal critical temperatures at which it will be vaporizing.

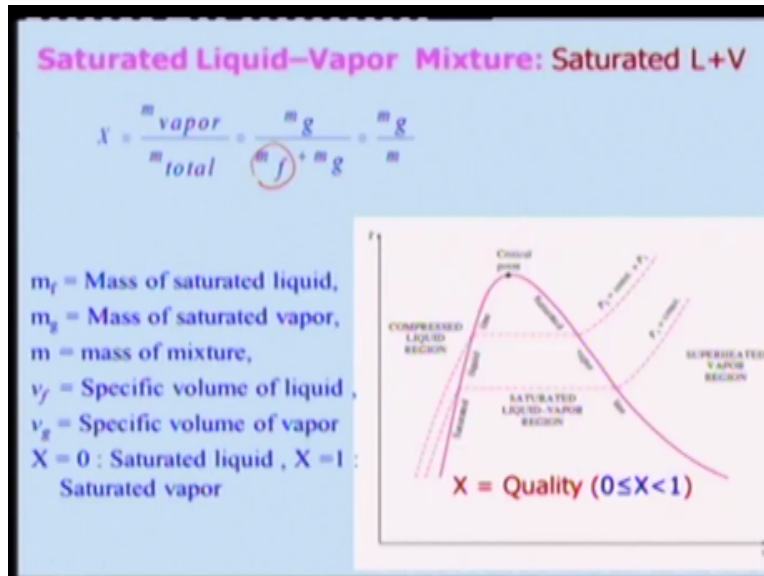
(Refer Slide Time: 50:10)



So just to have a feel for this what I have saying that this will be what you call just to summarize this and we will say that this is your saturated liquid line and this is your saturated vapor line and this is your constant pressure line p is constant and this is your constant another constant pressure line that p_2 is greater than p_1 and this as I told that this will be basically compress liquid region we call and people also call it as a sub cooled liquid region, sub cooled you know or compressed liquid region we call and this is your superheated vapor region right.

And we do always try to use in your power plant superheated vapors you know kind of things we need to avoid this mixture saturated liquid and vapor mixtures. So this is the in a TV diagram where the properties you know like where this can be processes can be described.

(Refer Slide Time: 51:28)

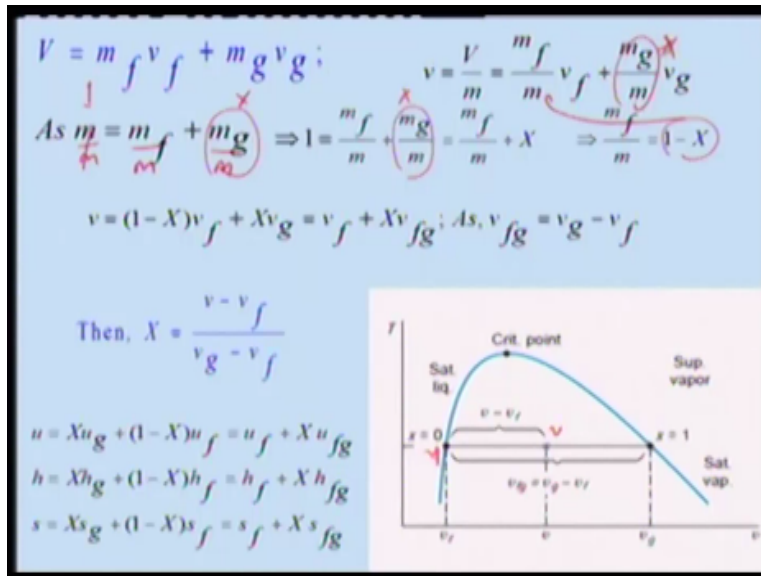


And let us look at the saturated liquid and vapor mixtures kind of things like because as I told will be interested to look at the how to handle this here saturated liquid and vapor mixtures. So we will define a quantity right which is X, I call that is nothing but mass of the vapor divided by mass of you know total mass, mass means total mass means mass of the liquid right, this is the mass of liquid and this is the mass of gas or the vapor right.

So this we call it as a quality what it indicates, it indicates that how much of mass of vapor is there with respect to the total mass of the mixture. And we will be using this same symbol F for the liquid okay, because historically this is being used and it is a meaning is basically liquid because in German if this word has come from progress so kind of things.

And this X you know quality if you look at this is we call it the steam quality you know steam quality so which will be as I told that X will be becoming 0 here right, and this will be one here equality will be 0 here and 1 here, in between it will be between 0 and 1 it can be 0.1, it can be 0.2, it can be 0.5, 0.1 means the you know if there is a 1kg of mass this will be 0.1 kg will be the gas or the vapor in that.

(Refer Slide Time: 53:28)



So let us look at the V total volume becoming basically mass of the fluid into specific volume plus mass of the gas into specific volume of the gas and we know this mass total mass will be mass of liquid plus mass of gas. And if I divide this by the mass what will happen and this is if you look at what is this by definition this is nothing but your mg by m, m is the mass of the mixture right, and mg is a paper what is this, this is nothing but your X right quality stream quality or the right.

So then I can write down this will be nothing but your this is become 1 and as I told this is nothing but your X so this is mf by m plus X right, so I can write down that mf/m is nothing but 1-X and if I will put this thing here you know this term over here and this X this is nothing but your X this is nothing but your X so I can find out the specific volume is nothing but 1- X VF plus X VG right, and we can also write down VA plus X VF g v FG is nothing but VG-VF right.

So therefore the X one can define V- VF / VG - VF so if you look at as I told earlier that X is basically 0 here and X is 1 so therefore at any point I can find out that x is equal to b-vm VF right, so this is the basically VER and this is your VF at this point and this is your VG divided by VFZ the difference will give me the X. So as I know this quality right X then I can knowing this thing i can find out all other properties like internal energy, enthalpy, entropy because if I know this VUG at this point I sorry at this point UF and you f at this point I can find out in between similarly enthalpy, entropy and other things.

So we will be using this quality in our calculation later on and by knowing this quality we can find out properties of the weight mixtures right. So I will stop over here and we will discuss further in the next lecture.

Acknowledgement

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

©copyright reserved