Indian Institute of Technology Kanpur

National Programme on Technology Enhanced Learning (NPTEL)

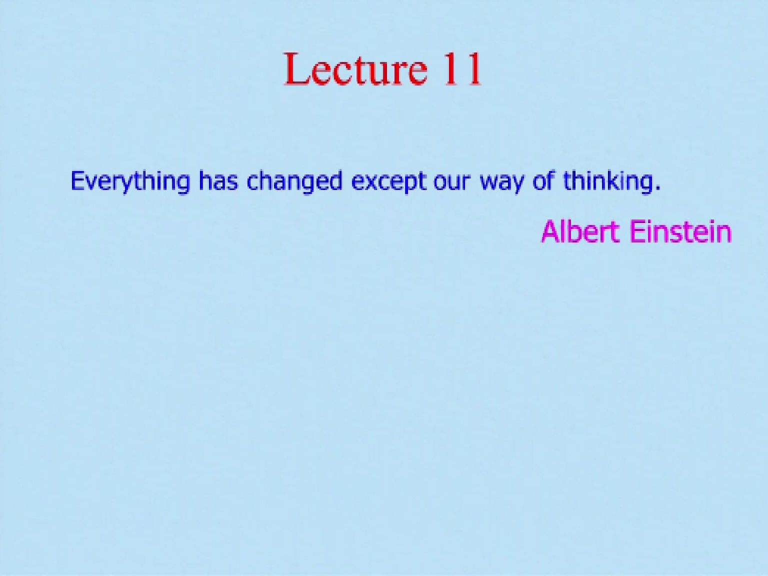
Course Title
Engineering Thermodynamics

Lecture – 11
Thermodynamic Properties of Fluids 4

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

Let us start this lecture with a thought process from Albert Einstein.

(Refer Slide Time: 00:20)



Lecture 11

Everything has changed except our way of thinking.

Albert Einstein

Everything has change except our way of thinking, it is very important to ponder about this statement because it is having fragrant meaning and before starting discussion on the today's lecture let us recapitulate what we learned in the last lecture I had initiated discussion on the phase change processes and of course before that we define a pure substance and we have considered the water as a pure substance one of the pure substance, and looked at the processes of vaporization, sublimation and other things using the you know experimental setup what it can be you know use.

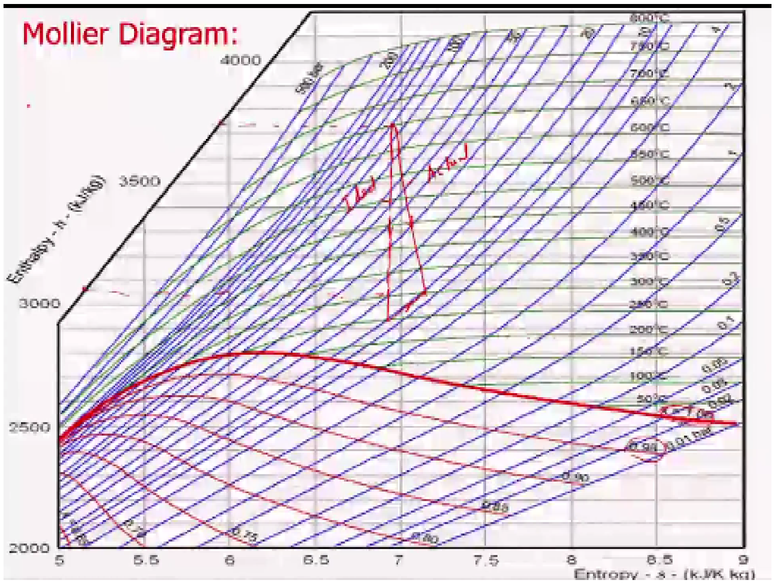
And also we depicted the processes in PV diagram and TV diagrams we have also seen the limitation of this desk of this diagram for describing the processes right then we also looked at another interesting you know diagram what we call it as this Kelly phase diagram where all three phases can be described that is basically P and D and when we combine all those you know diagrams we got a three-dimensional view of the faith change processes which depicts all the aspects like liquid, liquid vapor, solid and liquid solid and super heated vapor and other thing.

And we have also distinguished how this water phase diagram or water you know is different than that of the other substances particularly the water which is having peculiar features is that when it condenses into ice it is density decreases unlike other materials other pure substances where the density of the solid is higher than the liquid in case of liquid, water the density of ice is less than the water that is why it floats and that is the reason why you know we have evolved or the nature as evolved into so many spaces.

Otherwise ice could have submerged on the bottom of the sea or the river and which would not have not melted out to form the ice, so that ice age could have not overcome even though the solar energy and you know a son was giving enough it to the art, so beside this we have also looked up about the limitation of the what you call data being represented on a diagram and then we looked at the table steam table particularly we have not looked at refrigeration table but you can use the refrigeration table for solving problems.

And we have taken some examples also to how to solve this problem and I had also discussed the Mollier diagram in which was a very compact diagram for the steam which were using earlier days in the on the subfloor itself I mean subfloor means basically in the industries for example you are running a power plant steam power plant so you can use that and there the processes can be and we will spend little time again on this diagram and what is the importance of feed that is the Mollier diagram.

(Refer Slide Time: 04:44)



In this case if you look at the diagram is shown here and on this side if you look at enthalpy being plotted you know like on this so if you look at this line the is basically saturated line, right where saturated vapor line basically where x is equal to one if you look at this is X is equal to one this point, and the X is the quality of the steam and it goes on changing you know like decreases and all this line is constant you know quality line for example this is 0.095 this is your 0.9 and then 0.8 all those things and these line these blue lines if you look at for example this correspond to 500 bar and this is corresponding to 200 bar.

This is the ISO bar line you know line you can say or the process will be isobaric 100 and 50, 200 bar and 10, 4, 2, 1 all those thing it goes on to the 0.01 bar kind of things beside this you know you please observe this diagram which is little complex in nature as compared to other diagrams and these lines which are green lines if look at this is your 50 degree Celsius this is 100 degrees Celsius 150-200 this line I mean you know this green lines it goes on temperature till three and 800 degrees Celsius.

So if you look at this very compact process for example like you can use this quickly you know calculate what would be change for a for example if I take a plot over here 100 let us say bar you know and I will say that my given point I am just taking for the simplicity like let us say this is the point which is given to me like that means this corresponds to this will be what like this is my 100 right and this will be maybe 100, 20, 40, 60, 80 and under this will be what will be pressure here at this point pressure will be 100 20 bar right okay, and what will be temperature for this point that will be your 650 degree Celsius right. And there is another point I am getting like let us say arbitrarily I will take corresponding to let us say you know something 300 degree Celsius right.

This is another point this is 300 degrees Celsius and pressure if you look at this line is corresponding to 100 bar right, now what are the process could have been taken place like this you know this is my process let us say I want to evaluate I can directly evaluate what will be my enthalpy I will do this line you know find out what will be change in enthalpy similarly I will find out what will be mine enthalpy as draw a parallel line to this you know parallel to the entropy you know like this thing that will give me directly enthalpy here it will give me enthalpy so I know the change in antelope process.

But however is this process is reversible or not suppose you say that this process which is not really reversible and if it is reversible right then the entropy could have been constant, so if I draw a vertical line here you know I can draw a vertical line here right and then you know I can say this is the pressure line okay the same pressure, so this is your basically the particle of course I could have drawn that solid line you know this one and this could have been a dashed line right.

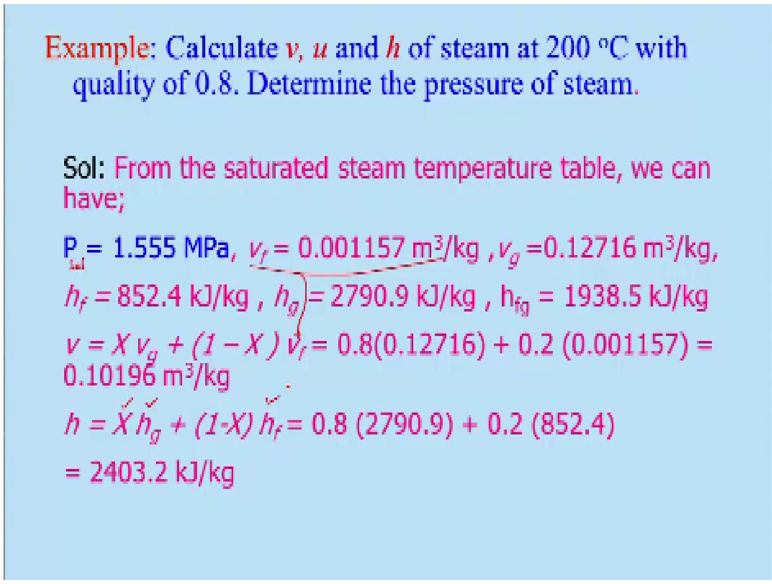
Then this is basically the isentropic process and this is the ideal process okay, and this is actual process so I can know that how it is happening because entropy here remaining constant right and it should be vertical and then I know how it is from this I can evaluate what it would be you know efficiency if I want to find out that is one way but another way suppose I do not know this passes in between these two state I can say look it is being what you call expanded here because from high pressure to low pressure and then again I can go by the constant pressure passes right.

As a constant pressure line and I can beach there, so it will not only give you the data because it will not only they give you the data but also it will tell you how the process can be just knowing the path this thing, so therefore it is it will give a visual you know understanding of what is happening and also it will give you data but problem is that how you will get a data here you know which is because if it could have been here you know it could have been easier for you to get the data but in between you will have to approximate it, so therefore there will be a an error which can be incurred because of as a result there will be an in accuracy in data.

And of course one can use these things and this is quite interesting and can be utilized for what you call quickly getting the data it may be inaccurate but however in the plant you know like you want to take a decision what is to be done you know like then naturally you will you know quickly get into this and you can visualize the things very easily even till today also it can be used but however people have now computerized instead of this thing they can go and put the data and quickly get so that is happening.

So this can be computerized and can be used, so now what we will do we will take another example just to find out.

(Refer Slide Time: 11:58)



Example: Calculate *v*, *u* and *h* of steam at 200 °C with quality of 0.8. Determine the pressure of steam.

Sol: From the saturated steam temperature table, we can have;

P_{sat} = 1.555 MPa, v_f = 0.001157 m^3/kg , v_g =0.12716 m^3/kg,

h_f = 852.4 kJ/kg , h_g = 2790.9 kJ/kg , h_{fg} = 1938.5 kJ/kg

$v = X v_g + (1 - X) v_f$ = 0.8(0.12716) + 0.2 (0.001157) = 0.10196 m^3/kg

$h = X h_g + (1\text{-}X) h_f$ = 0.8 (2790.9) + 0.2 (852.4)

= 2403.2 kJ/kg

How we can use a table to get the thermodynamic properties data for example like we need to calculate v that is a specific volume internal energy and enthalpy h of a steam at 200 degrees Celsius with a quality of 0.88 okay, so and determine the pressure of the steam now in this case you know like you know the temperature is given at 200 degrees Celsius of course the quality is given point A, so what table you will have to use if you look at even now you know exposed to three kind of date data table steam tables right one is the saturated temperature you know steam table saturated pressure steam table and superheated steam table.

Am I right or wrong it is it I discussed in the last lecture saturated steam table and saturated pressure table steam table right and one can also you know we are having superheated steam table where you will be getting that this what you call two variables had to be given pressure and temperature right and so how will determine this right, so what will they this all you is basically a saturated steam table steam temperature table and from that we can have the data what you call pressure because this pressure is basically what is this pressure this pressure is nothing but your saturated pressure at saturated temperature of 200 degree Celsius right.

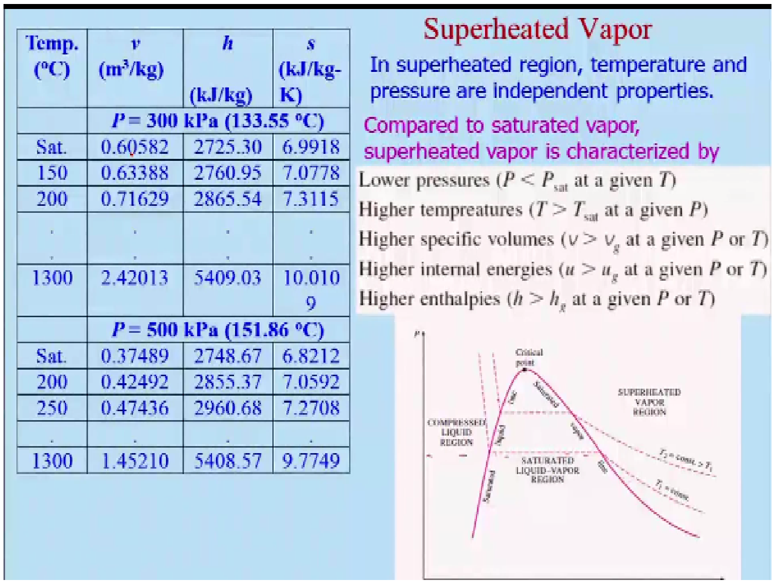
And correspondingly you will get V F which is the liquid you know a specific volume which is very, very small as compared to the vapor specific volume and you will get hf that is what you call liquid enthalpy or saturated liquid enthalpy and the saturated vapor enthalpy is 279 0.9 kilo Joule per kg which is much higher as compared to the liquid.

And of course a Hg – Hf will give me Hf G that is the latent heat of vaporization right and as X is given to you so you can very easily find out what will be the specific volume by you know with the quality 0.8 from this that vf and VG so we know that the formula is $V = x V_g + 1 - x V_f$ you just put these values here right that means if you look at these values you can use from here you know him substitute in this place and VZ you can substitute in this place and you will get these values very easily right.

And enthalpy also you can evaluate similar manner right I know the quality, if you look at this quality is given and this is given and hf is given you just substitute and get but now question arises how will get internal energy, of course there might be some steam tables which might have given the internal energy but however in your exam and in the textbook what we are following the inter what you call internal energy u is not given in the table.

So how will have to evaluate you have to basically evaluate using from this data that is enthalpy I know and from that I can get the internal energy is equal to h – Pv and P corresponding to the saturated pressure whatever is they and you multiplied by the V and you will get that right so by this we can use the what you call the steam table to evaluate properties and in the steam table like you know you can use the saturated steam temperature table or saturated steam pressure table or you can use the superheated steam tables right.

(Refer Slide Time: 17:04)



Temp. (°C)	v (m³/kg)	h (kJ/kg)	s (kJ/kg-K)
	P = 300 kPa (133.55 °C)		
Sat.	0.60582	2725.30	6.9918
150	0.63388	2760.95	7.0778
200	0.71629	2865.54	7.3115
. .	. .	. .	. .
1300	2.42013	5409.03	10.0109
	P = 500 kPa (151.86 °C)		
Sat.	0.37489	2748.67	6.8212
200	0.42492	2855.37	7.0592
250	0.47436	2960.68	7.2708
.	.	.	.
1300	1.45210	5408.57	9.7749

Superheated Vapor

In superheated region, temperature and pressure are independent properties.

Compared to saturated vapor, superheated vapor is characterized by

Lower pressures ($P < P_{sat}$ at a given T)

Higher tempreatures ($T > T_{sat}$ at a given P)

Higher specific volumes ($v > v_g$ at a given P or T)

Higher internal energies ($u > u_g$ at a given P or T)

Higher enthalpies ($h > h_g$ at a given P or T)

So what we will do now we will have to look at the superheated vapor and superheated vapor basically will be in the vapor region in this case temperature and pressure are independent properties unlike the saturated vapor or the saturated liquid in the if it is the weight mixture if we given one what you call either the temperature or the pressure then you know you will be good enough or you are in a position to find out the properties for example if it is you know temperature is even here.

So you know this property is what it would be and if it is other temperature is given so you can find out and if you are given the pressure saturate pressure you can but in this case vapor region what I love to will have to basically know the two properties both the temperature and pressure has to be given right then only you can evaluate the properties, for example this is the superheated vapor table.

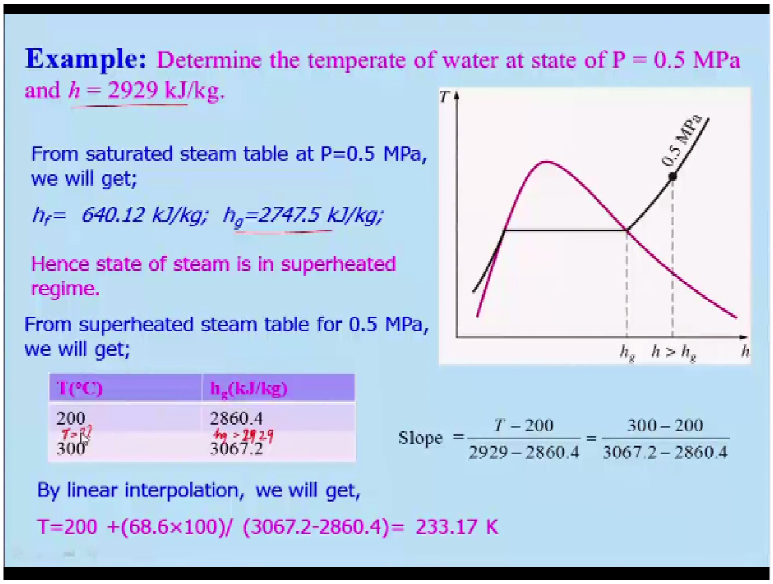
Where the pressure is given right and that is that is the 300 kpa of course corresponding to this pressure the saturated temperature will be 130 3.55 degree Celsius and then like you are given the data at different temperature for a particular 300kph kilo Pascal that 1550 DCL has 200 250 go on I mean this is the sort table what I have shown and here what you will see you will see that V that is the specific volume is given in this way.

What you can observe from this data what you can observe from this specific volume data that means it is increasing with the temperature but a particular pressure right and similarly the enthalpy it is also increasing and entropy it is also increasing with the increase in temperature and you can get various table on that you know like at different pressure and so that from this you can find out but if you compare this superheated vapor table with the saturated vapor table it you can observe this one that always at a given temperature right the pressure will be less than the saturated pressure right, for example like if you look at this diagram right if it is let us say I am operating at this what you call some pressure here right.

Let us say this is the pressure I am looking at temperature so vapor means always it will be here you know which will be what you call the lower than that this temperature if you look at this temperature, similarly if you look at higher temperature that means T always will be for a given pressure the t always will be you know at a more than the CCS rated and the specific volume we have already seen that means the at a given pressure it will be more than you know then the saturated value.

Because this is the saturated values and this will be higher than that a specific so also the enthalpy so also the internal energy will be higher than the saturated vapor you know values.

(Refer Slide Time: 21:05)



Example: Determine the temperate of water at state of P = 0.5 MPa and $h = 2929$ kJ/kg.

From saturated steam table at P=0.5 MPa, we will get;

$h_f = 640.12$ kJ/kg; $h_g = 2747.5$ kJ/kg;

Hence state of steam is in superheated regime.

From superheated steam table for 0.5 MPa, we will get;

T(°C)	h_g(kJ/kg)
200	2860.4
T > [illegible]	$h_g > 2929$
300	3067.2

$$\text{Slope} = \frac{T-200}{2929-2860.4} = \frac{300-200}{3067.2-2860.4}$$

By linear interpolation, we will get,

T=200 +(68.6×100)/ (3067.2-2860.4)= 233.17 K

So we will take an example like how we can use that so for example like determine the temperature of water at state of pressure equal to 0.5 mega Pascal’s and enthalpy was 2929kilo joule per kg how I will know whether you know it is corresponding whether I will have to use the superheated pressure table or I will have to use sorry whether I will have to use the saturated pressure table or superheated table corresponding to this pressure.

How I will know the pressure is given if pressure is given of course the enthalpy is given here I have taken a very simple example to illustrate how to go about because that confusion may arise in your mind which one I will have to choose because there are various tables you know what we have looked at till now three tables one is superheated steam table other is saturated temperature papal steam table and saturated pressure steam table.

Of course in this case the pressure is given so there and temperature is not given so you need not to use the saturated Tim saturated temperature steam table right so you love to use saturated pressure steam table am I right or wrong so now whether you will be using the superheated or not how will arrive at what for that what we will have to do you will have to first take the saturated steam table corresponding to the pressure of the what you call 0.5 mega Pascal we get this value HF is 640.12 kilo Joule per kg and HG is 2747.5 kilo joule per kg right.

Now from this can you guess whether this data whatever is given this example is in the saturated raising or it is in the superheated definitely it is superheated because the H is given here and which is 2929 kilo Joule per kg which is greater than the HG right, so therefore it will be superheated steam table you know or the steel or this condition is occurring at the superheated regime.

So therefore you have to use the superheated steam table just to illustrate this point I will just say that you are at here right at this point and because H this his greater than the edge, so hence the steam is in the superheated region and from superheated steam table corresponding to 0. 5 mega Pascal will get these values like that means at 200 degrees Celsius 2860.4 kilo joule per kg and 300 degree Celsius.

The values of HG is 3067.2 that means my you know condition that is H 2929 kilo Joule per Kg will be in between you know this to raisin that means if I say this is my temperature this I need to find out hg here right at this point I need to find out and this is given to me right what is that, that is 2929 right so from these what I will have to do, this is this is basically not known.

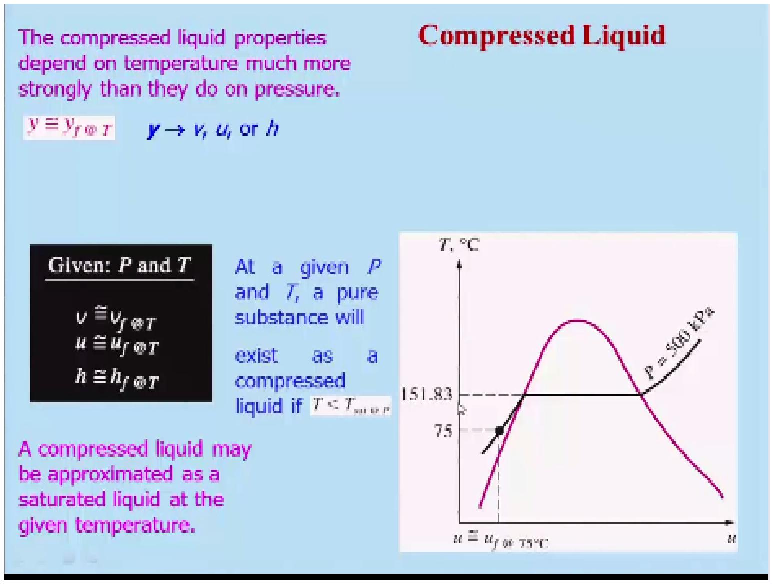
So you will have to find it out, how I will do that will have to use what linear interpolation right and if I do a linear interpolation I will get t = 200 + 68.6 x 100 / 3067.2 - 2860.4 if you look at what we will do we have earlier seen that how to get that if you look at the slow here the t minus

200 is divided by the 2929 - 28 60.4 = 300 - 200 / 3067.2 which is a corresponding 300 Kelvin and 2860.4 kilo Joule per kg which is corresponding to the 200.

So from these I can get this relationship I can evaluate that happens to be 2303.17 Kelvin keep in mind that here we are doing an approximation there will be some error because you cannot really relate this thing linearly right however if the data points is not you know interval is not much then that error which will be incurred by this simplification or approximation would not really matter much.

So therefore one can use it, so what we will be looking at we have looked at till now saturated you know saturated condition such as a steam table and we have looked at superheated steam table and also there is a some table for the compressed liquid right and compressed liquid table will be available but in some places it would not be.

(Refer Slide Time: 27:31)



Compressed Liquid

The compressed liquid properties depend on temperature much more strongly than they do on pressure.

$y \cong y_{f\,@\,T}$ $y \rightarrow v, u, \text{ or } h$

Given: P and T

$v \cong v_{f\,@\,T}$
$u \cong u_{f\,@\,T}$
$h \cong h_{f\,@\,T}$

At a given P and T, a pure substance will exist as a compressed liquid if $T < T_{sat\,@\,P}$

A compressed liquid may be approximated as a saturated liquid at the given temperature.

So now if it would not be available how to use compressed liquid do you know, what do you mean by compressed liquid, is basically sub cooled liquid where the pressure will be higher you know than the saturated pressure corresponding, now compressed liquid depend on the temperature much more strongly than they do on the pressure right, what people are found if the pressure will increase 100 times you know the change in properties will be something around one percentage kind of thing.

So then people say that you will not bother about it right but however it is more dependent on the temperature. So a compressed liquid may be approximated as a saturated liquid at a given temperature a because if I know the temperature I can go directly to the saturated steam table and corresponding to that temperature what is given I can use the properties for my calculation. For example like if you look at this at a given pressure and temperature what you lot do alert to go to the temperature and go to the saturated temperature steam table

For example if we are considering water or you are considering other things like carbon dioxide or some other gases or some other few material then you can go for that. So what you can use that V specific volume has to be evaluated at what at saturated temperature condition right similarly for the internal energy and enthalpy but if you look at and entropy you can evaluate but among all these properties you will find that enthalpy variation you know due to this you know you are neglecting the pressure then will be little bit higher.

So therefore one can think of how to do that so at a given pressure and temperature your pure substance will exist as a compressed liquid if T is less than the saturated what we call a temperature for a particular pressure and if you know you can generalize it this property is Y. Y can be a specific volume or is can be internal energy specific internal energy or specific enthalpy and it has to be evaluated at saturated temperature from the saturated temperature table.

And if you want to improve this you know what you call you want to improve the value of the enthalpy which might have been you know this thing then you can use the enthalpy kind of things so just to illustrate this point what you call like that that how you can evaluate for example if it is 500 kilo Pascal and you look at saturated temperature will be what to come 150 1.83 degree Celsius.

But however if the temperature is given 725 you know 500 KP and seven this will be definitely compressed liquid and you will have to evaluate properties not correspond to500 KPA rather corresponding to the 75^0 Celsius and then you can get these values you know enthalpy entropy and other properties corresponding to 75 degrees Celsius. And if you want to have what you call accurate relay data for the enthalpy one can evaluate you know a one can improve this evaluation by considering that article enthalpy at the saturated temperature conditions.

Plus V F at the saturated temperature into P – P such a piece a g-rated saturated pressure at the saturated temperature what is given. So that you know these are what you call this portion is additional things you can help in improving the quality. If you look at you know you can evaluate these properties you will find this is you know adding a smaller error to the enthalpy if you only you know evaluate at the saturated temperature without considering this term.

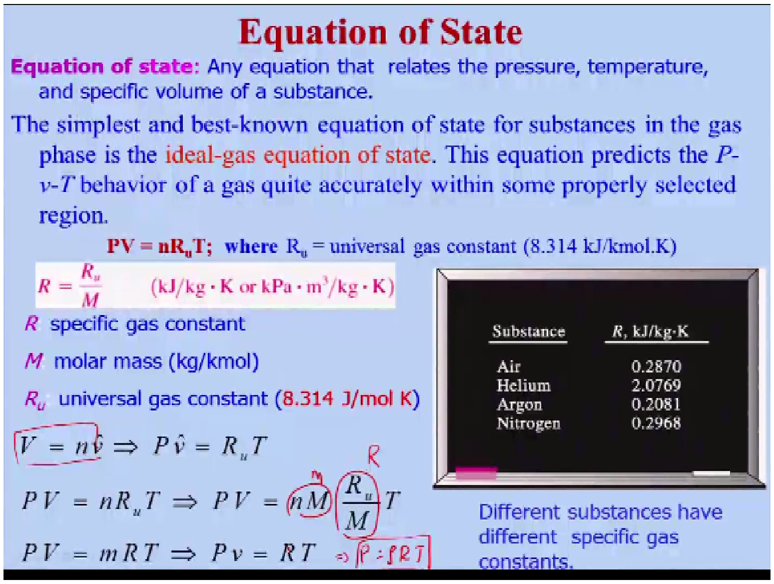
That means the contribution of this term is very small but however you know it is important when you go for particularly for a higher pressure you know conditions and the temperature saturate temperature condition is lower. So you can look at this so if you look at in the if we compare this you know these things that we will get that at a given pressure the what you call the temperature is less than the saturated temperature.

For a compressed liquid and similarly for either a given pressure or a temperature specific volume is less than the specific volume at saturated conditions right and in the similar way the enthalpy is less than the saturated enthalpy at a given pressure and temperature and this is just oppose it of that of the superheated vapor what we had seen earlier. So now we have learned how to handle the compressed liquid if the compressed liquid data is table is not available.

If it is table is available you can go directly and use okay there is no problem but he was not available you need not to or it you know get or it you need not to get worried about it rather you can what you call use the saturated table corresponding to the temperature not to the pressure. So you know till now we have used the table or the data thermodynamic properties in the tabular form but however you know it is not very elegant.

It is a cumbersome to evaluate and other things if you look at if we can get equation in by which we can evaluate the data it will be very important and you know and also the accuracy will be very higher provided if that equation itself is accurate to predict the data, and in modern times you can also use that for your modeling you know if it is the equation is there it will be easier. People have attempted to find out the relationship between the pressures.

(Refer Slide Time: 35:07)



Equation of State

Equation of state: Any equation that relates the pressure, temperature, and specific volume of a substance.

The simplest and best-known equation of state for substances in the gas phase is the ideal-gas equation of state. This equation predicts the P-v-T behavior of a gas quite accurately within some properly selected region.

PV = nR$_u$T; where R$_u$ = universal gas constant (8.314 kJ/kmol.K)

$$R = \frac{R_u}{M} \qquad (\text{kJ/kg} \cdot \text{K or kPa} \cdot \text{m}^3/\text{kg} \cdot \text{K})$$

R specific gas constant

M molar mass (kg/kmol)

R_u universal gas constant (8.314 J/mol K)

$$\boxed{V = n\hat{v}} \Rightarrow P\hat{v} = R_u T$$

$$PV = nR_uT \Rightarrow PV = \overset{m}{(nM)}\overset{R}{\left(\frac{R_u}{M}\right)}T$$

$$PV = mRT \Rightarrow Pv = RT \Rightarrow \boxed{P = \rho RT}$$

Substance	R, kJ/kg·K
Air	0.2870
Helium	2.0769
Argon	0.2081
Nitrogen	0.2968

Different substances have different specific gas constants.

Temperature and the volume and that we call is basically equation of state and most of you are aware and you have used left and right that is the equation of state for an ideal gas. Right and that equation predicts basically the pressure volume temperature behavior of a gas quite accurately within certain properly selected you know region. That means equation of state what we have used our ideal gas law what we call is being utilized only for ideal gas.

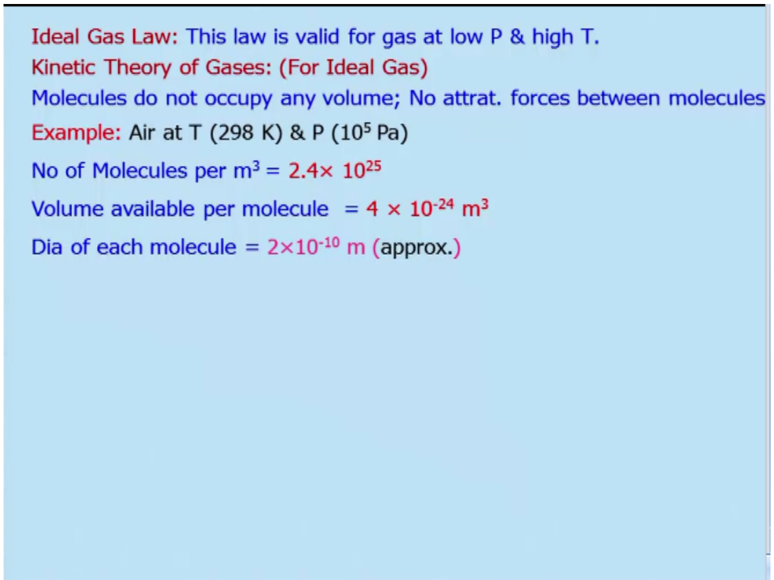
You know and that is equal to PV= N are UT and where RU is the universal gas constant and which is equal to 8.314kilo joule per kilo mole in that you are all familiar with from Vega and if you know I can use also specific gas constant that is R and can be related to universal gas constant RU and molecular weight a specific gas constant is basically =RU / molecular weight and the its unit will be kilo joule per kg and Kelvin kind of things and a different substance of different specific gas constants.

If you look at like air you know is having point 287kilo joule per kg Kelvin and whereas the helium is a very high value that is 2.0769 and of course the nitrogen is very closer to the air and of course argon is little away from the air that is 0.20 81. And this you know like equation can be written in various form because we know that volume is basically if we look at is equal to number of moles into specific volume.

And if I can put these values here okay in the equation of state PV =NRT then I can get P new =RUT. So this is basically one another form of equation of state and from this equation PV is =NRI 2if I can do i can multiply the molecular weight there and also divided by molecular weight and this is nothing but your what you call our right and this is nothing but R and M. So I you get PV is equal to MRT and if you look at the i can say volume per unit mass this is nothing but specific volume and this is PV = RT i can write it down this as also P= ORT right this is one of our new is nothing but the density right.

So various forms one can use of ideal gas law which most of you will be familiar with and we will have to see what are the limitation of this gasps this gas law.

(Refer Slide Time: 39:05)



Ideal Gas Law: This law is valid for gas at low P & high T.

Kinetic Theory of Gases: (For Ideal Gas)

Molecules do not occupy any volume; No attrat. forces between molecules

Example: Air at T (298 K) & P (10^5 Pa)

No of Molecules per m^3 = 2.4×10^{25}

Volume available per molecule = 4×10^{-24} m^3

Dia of each molecule = 2×10^{-10} m (approx.)

Right because this gas law is valid for the low pressure and high temperature gases question arises why it is so and when we can call it as basically the pressure should low for example if I consider one atmospheric is a low pressure or hundred atmospheric pressure is a low for air or it will be 200 adverse pressure and temperature whether the ambient temperature is high or I can say look 500 degree Celsius is high or i can say that look thousand degrees Celsius.

I that those things we need to know and how we will evaluate that we will talk about and where this ideal gas law will be valid. Because unless we know where it will valid we do not know where to use so from the kinetic theory of gases for an ideal gas we know that molecules do not occupy any volume that is the premises based on which this ideal gas law is derived but however the molecule will be having you know what you call certain volume

If the pressure is very high then what will happen the molecules actually the, occupy other volume occupied by these molecules will be you know compared not comparable at least a larger portion of the volume where the gas is contained. So then this ideal gas law may not be valid and also it is being device you know the ideal gas law will be valid only when there is no attractive forces between molecules but however the molecules will be having attractive forces.

Right and when it will be valid when the molecules is very far away from each other then the attractive forces will not be there and this can be possible only when the either the temperature will be very high or the pressure will be low so right. So therefore that is the things what it will be having example like as I told like let us consider you know air at 298Kelvin and pressure is around up you know what you call 100kilo Pascal kind of things atmospheric pressure you can say roughly.

And so number of molecules per meter cube will be something 2.4 into 10^{25} if you look at the volume available per molecule will be what 1/ 2.4^{1025} will give me 4 into 10 power to minus 24 meter cube that means each molecule will be occupying this amount of what you call volume which is quite small as come if we look at it so if you consider the diameter of each molecule approximately 2 into 10 power t minus 10meter.

And if you consider this to be spherical and then you can find out volume right then it will be something volume of each molecule will be 4 into10 power t minus 27 right if you divide this term what you call this volume available per molecule divided by the volume of each molecule then you will find volume occupied by the each molecule will be 1000 of the free available volume right and which you can say that it is negligibly small because it is something.

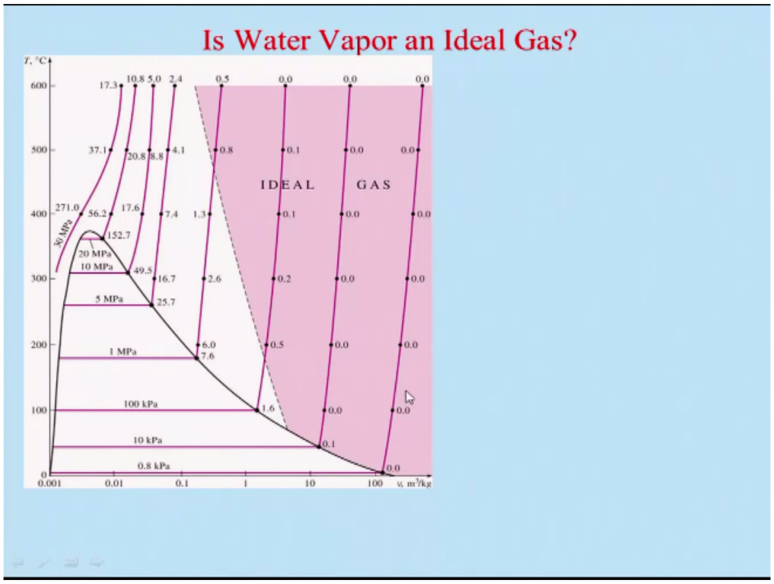
You know 1,000 timeless than that you know it is a one can say that and hence molecule do not occupy any volume approximately you know you can say that way because the very tiny numbers right and the distance between two molecules will be something10 power minus 8 meter of course that is at atmospheric pressure and the distance between two molecule will be something50 times of the diameter of the molecule right.

So you can say 50 times apart and then the intermolecular forces you know would not be really listing between button or it is a very small force will be existing between two molecule which is negligibly small so therefore we can happily say that ideal gas law can be valid at ambient pressure and temperature if you consider the air we have taken the example of a not only the air but nitrogen oxygen hydrogen helium air you know and even the heavier gases like co2can be treated as ideal gas.

In the range of certain pressure and temperature certainly in the ambient pressure and temperature but we need to look at what is that practical temperature where we can have you know use this ideal gas law and keeping the error incurred because of use of this ideal glass law where you know we have assumed that molecule do not occupy any volume and there is you know no attractive forces between the molecules. So question then arises we will be dealing with water vapor you know particularly when we are dealing with the steam power plant

Right all will be also looking at a refrigeration air condenses demark we will be considering the way vapor you know and it is liquid mixtures and we may be considering also particularly when were you know looking at some kind of as team what you call hydraulic turbine even some vaporization will be occurring you know even in hydrogen due to the low-pressure then also and the two-phase fluid will be you know using even in our atmosphere for example like a day before yesterday there was a sow right and then the air will be moist and the air will be containing not only the oxygen nitrogen also the water vapor so how to evaluate those properties you know so whether question arises water vapor can be treated as an ideal gas or not so let us consider this right.

(Refer Slide Time: 46:12)

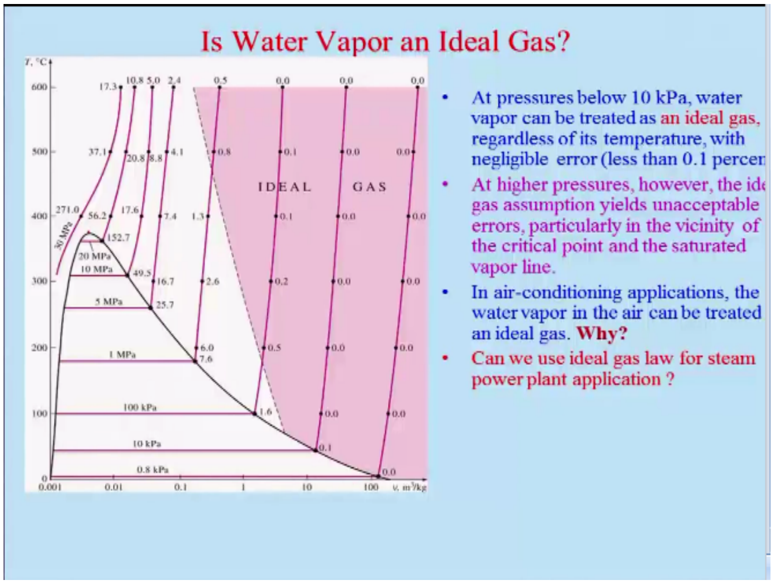

Is Water Vapor an Ideal Gas?

if you look at were using again this T and V diagram here and these are the weight mixtures we can consider here where you know ideal gas we can assume here in this regime because the temperature is high and the pressure is you know what you call may be little low also we can look at it and at even pressure below the 10 kpa water vapor can be treated as an ideal gas regardless of which temperature with negligible error like point one percent Emily you can say look I am not bothered about point one percent because in engineering sense three to four percent error is not really much right .

So at high pressure however ideal gas assumption eels unacceptable error particularly in the vicinity of critical point if you look at these values you know whatever it is given here you know these values are basically indicates error if you look at critical point will be somewhere here the error is very high if you look at you know something here it is 271 percentage error and this is 56 point and this is if you look at150 200 point seven and it is quite you cannot really you know consider this region like unacceptable particularly efficient critical points and so also in this region you know is a very high regions.

Where the vapor will be existing however the error will be enormous so in air conditioning applications as I told the water vapor in the air can be treated as an ideal gas or not whether one can assume we can definitely because you know the vapor whatever it is therein the air will be very less and it is at ambient temperature kind of things and also the ambient pressure so therefore we can have we can use the ideal gas law and can you use the ideal gas law.

(Refer Slide Time: 48:18)

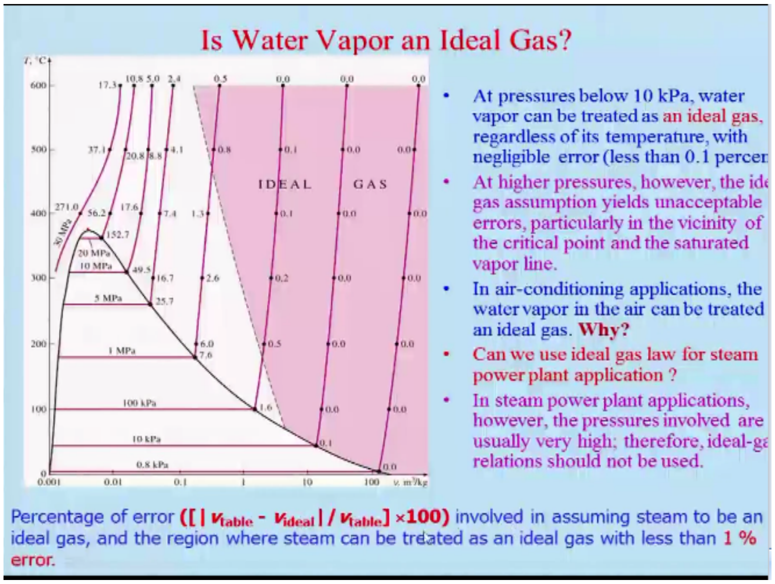


Is Water Vapor an Ideal Gas?

- At pressures below 10 kPa, water vapor can be treated as an ideal gas, regardless of its temperature, with negligible error (less than 0.1 percen
- At higher pressures, however, the id gas assumption yields unacceptable errors, particularly in the vicinity of the critical point and the saturated vapor line.
- In air-conditioning applications, the water vapor in the air can be treated an ideal gas. **Why?**
- Can we use ideal gas law for steam power plant application ?

For steam power plant application because the steam power plant applications you know or in steam power plant the pressure will be very high right so therefore you know one has to be careful you know to use ideal gas law because the ideal gas law will incur a lot of error and the ones must not use the ideal gas law rather to get into the steam table to evaluate the properties..

(Refer Slide Time: 49:02)



Is Water Vapor an Ideal Gas?

- At pressures below 10 kPa, water vapor can be treated as an ideal gas, regardless of its temperature, with negligible error (less than 0.1 percen
- At higher pressures, however, the id gas assumption yields unacceptable errors, particularly in the vicinity of the critical point and the saturated vapor line.
- In air-conditioning applications, the water vapor in the air can be treated an ideal gas. **Why?**
- Can we use ideal gas law for steam power plant application ?
- In steam power plant applications, however, the pressures involved are usually very high; therefore, ideal-ga relations should not be used.

Percentage of error **($[|v_{table} - v_{ideal}| / v_{table}] \times 100$)** involved in assuming steam to be an ideal gas, and the region where steam can be treated as an ideal gas with less than 1 % error.

And as I told you this percentage error you know this V table you can use and this is from the ideal and table into multiplied you know it will give this thing and of course this ideal is basically assuming ideal gas there that will where steam can be treated I will go when it is less than one percent error for example in this region one cause you know the kind of a one percent error kind of thing but however in this region right if you look at.

One should not if you are having steamed here one should not use this vision because errors much higher so we will I mean we have seen in this lecture how to handle the superheated steam table and how to use the you know data when the compressed liquid table is not available by using the saturated steam table and then we have looked at ideal gas law and it is you know applicability where we can use where we cannot and why it is so that we have seen and in the next lecture we will be looking at basically the better equation of states apart from the ideal gas law and we will proceed on that thank you.

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