# Engineering Thermodynamics
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Lecture 11
# Thermodynamic properties of a pure substance from a property table

Okay. So, welcome back!

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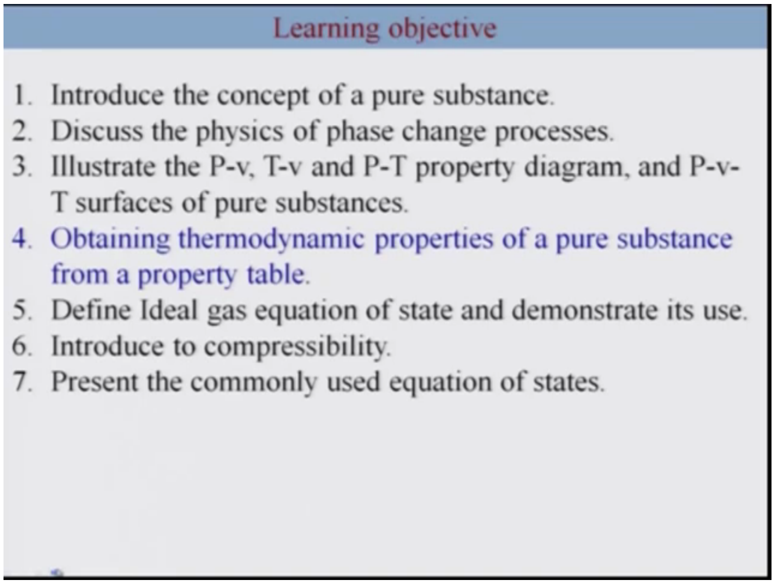

Learning objective

1. Introduce the concept of a pure substance.
2. Discuss the physics of phase change processes.
3. Illustrate the P-v, T-v and P-T property diagram, and P-v-T surfaces of pure substances.
4. Obtaining thermodynamic properties of a pure substance from a property table.
5. Define Ideal gas equation of state and demonstrate its use.
6. Introduce to compressibility.
7. Present the commonly used equation of states.

So let us look at now there property tables most of the substances which we interested in are difficult to provide in some kind of empirical relations between pressure, volume and temperature. Of a simple system such as water of course which is quite widely used and it is very complicated system it is easier for providing the information such such that a table can be used with all the properties okay.

For the other cases, for example you want to look at very high temperature pressure, many times is difficult to do experiments or may not be able to obtained the properties and then you make like to you some kind of empirical relations for doing that and that something call equation of state.

So, in the tables of the properties became popular which was introduced by Richard Moliere and hence is (())(1:15) quite prevalent in various different engineering applications . So, we will look at it we look at understand the table properties and how to make use of it the most common example would be water and refrigerant for of course obvious reasons for many system in steam engine and other applications okay .

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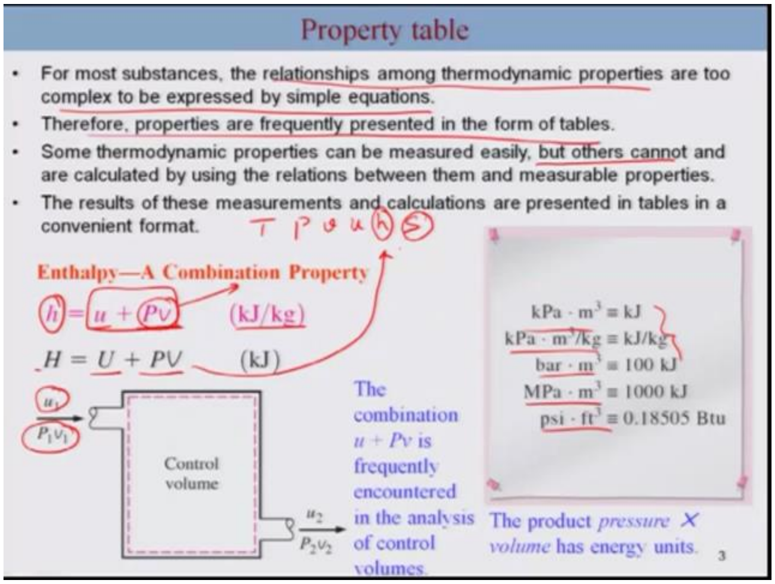

## Property table

- For most substances, the relationships among thermodynamic properties are too complex to be expressed by simple equations.
- 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.

T P v u h s

**Enthalpy—A Combination Property**

$$\boxed{h} = \boxed{u + \boxed{Pv}} \qquad (\text{kJ/kg})$$

$$H = U + PV \qquad (\text{kJ})$$

The combination $u + Pv$ is frequently encountered in the analysis of control volumes.

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

The product *pressure* × *volume* has energy units.

So, as I said the sometimes that relationship among different properties at two complex to express by simple equation and this is true for water and thus is easier that property should to represent in some kind of table. And then there are other properties which are difficult to measure such as entropy, for example but it has relation with other property which are measurable. So, you represent those properties in measurable properties form and then put it in table.

Now typical table which are provided in the appendix of the book are for water and refrigerant. You will see that you will have the properties, temperature, pressure a specific volume, internal energy and then 2 more additional properties would be introduced which is h and s okay. H is something which we going to talk now, but s is your entropy and this is related to your second law of thermodynamics and we are going to talk much later.

So, h is defined as u plus P v and the reason for that is, is commonly or frequently encountered in the analysis of control volume. So, you have your internal energy and as well as your P v energy.

And thus this becomes more useful that for the sake of convenience we put it together okay as you plus P v and defined the term called h.

And this particular P v we have already discuss in mechanical energy this is nothing but energy of and thus what the different units gives you, for per unit mass this would be the unit and for the case of total enthalpy it would be simple total internal energy plus P v term okay.

So, this is included in your tables for helping you to solve the problems much easier otherwise you have to always calculate the P v term also. So, this is something which we are going to make use of it in our calculations.

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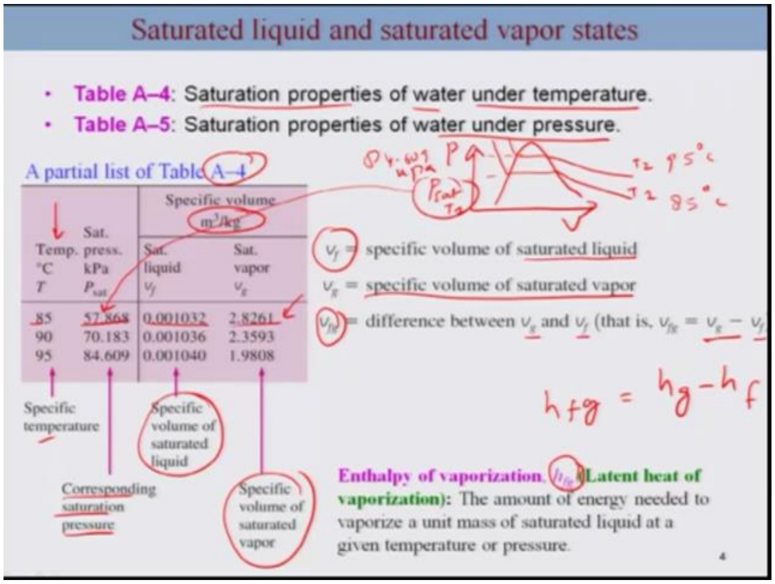

## Saturated liquid and saturated vapor states

- **Table A–4**: Saturation properties of water under temperature.
- **Table A–5**: Saturation properties of water under pressure.

A partial list of Table A–4

| Temp. °C $T$ | Sat. press. kPa $P_{sat}$ | Specific volume m³/kg<br>Sat. liquid $v_f$ | <br>Sat. vapor $v_g$ |
|---|---|---|---|
| 85 | 57.868 | 0.001032 | 2.8261 |
| 90 | 70.183 | 0.001036 | 2.3593 |
| 95 | 84.609 | 0.001040 | 1.9808 |

Specific temperature

Corresponding saturation pressure

Specific volume of saturated liquid

Specific volume of saturated vapor

$v_f$ = specific volume of saturated liquid

$v_g$ = specific volume of saturated vapor

$v_{fg}$ = difference between $v_g$ and $v_f$ (that is, $v_{fg} = v_g - v_f$)

$$h_{fg} = h_g - h_f$$

**Enthalpy of vaporization**, $h_{fg}$ **(Latent heat of vaporization)**: The amount of energy needed to vaporize a unit mass of saturated liquid at a given temperature or pressure.

So, let us look at it how this tables look alike, so we will start with table A 4 which is saturation properties of water under temperature. What does that mean? It means the first column of the table will be temperature and for each temperature you will have a saturation pressure values.

So, for 85 for example degree Celsius for water, you have 57.868 Pascals as saturation pressure okay. And the corresponding saturation liquid and saturated vapor volumes specific volumes are given in this okay. This is a unit meter cube per kg. So, this is your specific temperature this is your corresponding pressure, this is your specific volume or saturated liquid and specific volume of saturated vapor the other columns which have missed out for the sake of just to illustrate only this specific part now.

So, this is what we are going to use as a nomenclature, V f stands for specific volume for saturated liquid, f mainly for fluid. So, you can say saturated fluid but let us just state liquid here and g for gas but it is for saturated vapor, okay. And then we are going to make use of this V f g which is nothing but the difference between V g minus V f, because the volume of the gas or saturated vapor we much larger and this you will have V g minus V f.

Now in addition you will have another column in this A 4. So, which will also have this enthalpy of vaporization, okay h f g okay which is nothing but h g minus h f okay. So, we we are going to use that as well okay. Now this is for saturation properties of water under temperature and the other case is saturation properties water under pressure.

This is relevant for the case where you have pressure versus volume as your diagram and you have this phase diagram. And what you have done is you have kept your temperature constant as a decrease in the pressure. So, this is T some constant and this is another temperature T 2 right.

So, for a given temperature let this is your 85 and this is let say 95 degree Celsius okay. So, if somebody ask the question that well this is a the condition what is a saturation pressure, well essentially it means that this is your saturation pressure for the specific temperature T 1 and this value is nothing but this value, it is 57.86 and similarly for 95 P is your 84.609 kilopascal okay. So, this is how we are going too learned or bit on it.

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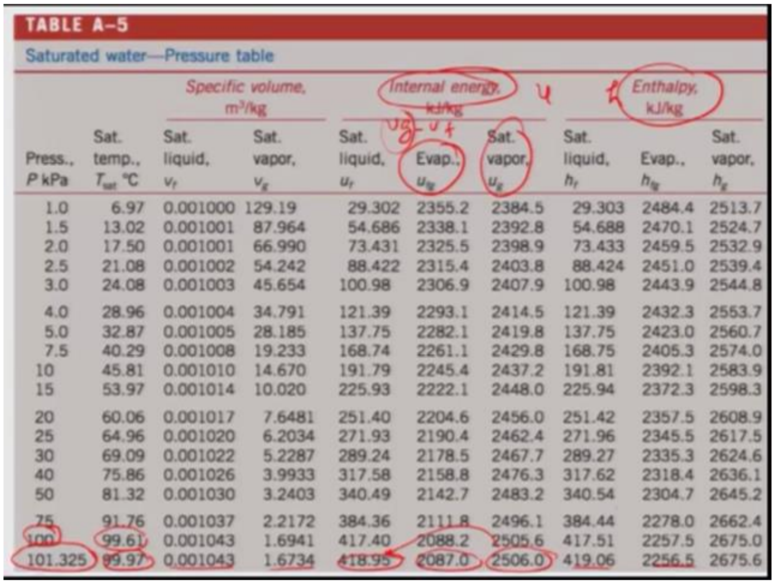

**TABLE A–5**

Saturated water—Pressure table

| | | Specific volume, m³/kg | | Internal energy, kJ/kg | | | Enthalpy, kJ/kg | | |
|---|---|---|---|---|---|---|---|---|---|
| Press., $P$ kPa | Sat. temp., $T_{sat}$ °C | Sat. liquid, $v_f$ | Sat. vapor, $v_g$ | Sat. liquid, $u_f$ | Evap., $u_{fg}$ | Sat. vapor, $u_g$ | Sat. liquid, $h_f$ | Evap., $h_{fg}$ | Sat. vapor, $h_g$ |
| 1.0 | 6.97 | 0.001000 | 129.19 | 29.302 | 2355.2 | 2384.5 | 29.303 | 2484.4 | 2513.7 |
| 1.5 | 13.02 | 0.001001 | 87.964 | 54.686 | 2338.1 | 2392.8 | 54.688 | 2470.1 | 2524.7 |
| 2.0 | 17.50 | 0.001001 | 66.990 | 73.431 | 2325.5 | 2398.9 | 73.433 | 2459.5 | 2532.9 |
| 2.5 | 21.08 | 0.001002 | 54.242 | 88.422 | 2315.4 | 2403.8 | 88.424 | 2451.0 | 2539.4 |
| 3.0 | 24.08 | 0.001003 | 45.654 | 100.98 | 2306.9 | 2407.9 | 100.98 | 2443.9 | 2544.8 |
| 4.0 | 28.96 | 0.001004 | 34.791 | 121.39 | 2293.1 | 2414.5 | 121.39 | 2432.3 | 2553.7 |
| 5.0 | 32.87 | 0.001005 | 28.185 | 137.75 | 2282.1 | 2419.8 | 137.75 | 2423.0 | 2560.7 |
| 7.5 | 40.29 | 0.001008 | 19.233 | 168.74 | 2261.1 | 2429.8 | 168.75 | 2405.3 | 2574.0 |
| 10 | 45.81 | 0.001010 | 14.670 | 191.79 | 2245.4 | 2437.2 | 191.81 | 2392.1 | 2583.9 |
| 15 | 53.97 | 0.001014 | 10.020 | 225.93 | 2222.1 | 2448.0 | 225.94 | 2372.3 | 2598.3 |
| 20 | 60.06 | 0.001017 | 7.6481 | 251.40 | 2204.6 | 2456.0 | 251.42 | 2357.5 | 2608.9 |
| 25 | 64.96 | 0.001020 | 6.2034 | 271.93 | 2190.4 | 2462.4 | 271.96 | 2345.5 | 2617.5 |
| 30 | 69.09 | 0.001022 | 5.2287 | 289.24 | 2178.5 | 2467.7 | 289.27 | 2335.3 | 2624.6 |
| 40 | 75.86 | 0.001026 | 3.9933 | 317.58 | 2158.8 | 2476.3 | 317.62 | 2318.4 | 2636.1 |
| 50 | 81.32 | 0.001030 | 3.2403 | 340.49 | 2142.7 | 2483.2 | 340.54 | 2304.7 | 2645.2 |
| 75 | 91.76 | 0.001037 | 2.2172 | 384.36 | 2111.8 | 2496.1 | 384.44 | 2278.0 | 2662.4 |
| 100 | 99.61 | 0.001043 | 1.6941 | 417.40 | 2088.2 | 2505.6 | 417.51 | 2257.5 | 2675.0 |
| 101.325 | 99.97 | 0.001043 | 1.6734 | 418.95 | 2087.0 | 2506.0 | 419.06 | 2256.5 | 2675.6 |

This is a case for saturated water pressure tables. So, the pressure is given and the forgiven pressure you have saturated temperature, for example your for 100 kilopascal pressure you have 99.61 degree Celsius and for 1 atmosphere which is this you have 99.97 degree Celsius which we approximate to 100 okay. Then you have this saturated liquid volume vapor volume, then you have internal energy also, okay and this is enthalpy.

So, this u, this is h okay. So, this is your fluid or this is your evaporation which is nothing but u g minus u f and this is your saturated vapor okay. So, and this this means that there internal energy of g is going to be much higher, than the liquid which you can also see here this is much higher than the liquid. And similarly for enthalpy, now it also includes P v term okay. So, this is for convenience you can also calculate separately but this given to you which means essentially lot of properties are available for you to make use in the analysis, okay.

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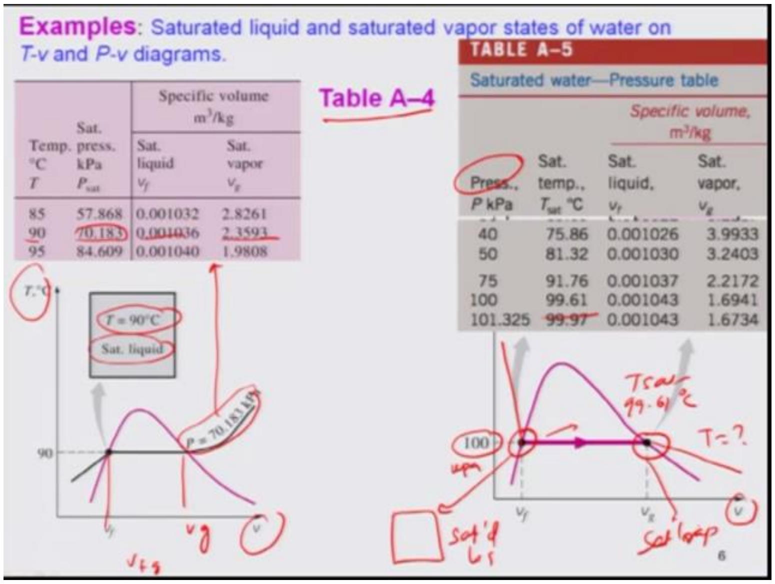

**Examples**: Saturated liquid and saturated vapor states of water on $T$-$v$ and $P$-$v$ diagrams.

Table A–4

| Temp. °C $T$ | Sat. press. kPa $P_{sat}$ | Specific volume m³/kg<br>Sat. liquid $v_f$ | <br>Sat. vapor $v_g$ |
|---|---|---|---|
| 85 | 57.868 | 0.001032 | 2.8261 |
| 90 | 70.183 | 0.001036 | 2.3593 |
| 95 | 84.609 | 0.001040 | 1.9808 |

TABLE A–5

Saturated water—Pressure table

| Press., $P$ kPa | Sat. temp., $T_{sat}$ °C | Specific volume, m³/kg<br>Sat. liquid, $v_f$ | <br>Sat. vapor, $v_g$ |
|---|---|---|---|
| 40 | 75.86 | 0.001026 | 3.9933 |
| 50 | 81.32 | 0.001030 | 3.2403 |
| 75 | 91.76 | 0.001037 | 2.2172 |
| 100 | 99.61 | 0.001043 | 1.6941 |
| 101.325 | ~~99.97~~ | 0.001043 | 1.6734 |

So, we will try to do some examples. So, let us take a case just for the sake of illustration here. So, you have saturated liquid and saturated vapor sates and this is the case of temperature volume is plotted. What you have been asked is you have a system which is at 90 degree Celsius and this is the saturation liquid corresponding pressure would be 70.83 if this is being asked you can find out directly from the table A 4. So, this the corresponding pressure, you can also find the V f and V g you can also find V f g also from the, the tables okay .

This is an example of a pressure versus volume and for 100 kilopascal you can find out what particular condition it is, so this is going to be like this. So, what is your temperature for such a system, okay. You can look at A 5 because A 5 gives you this pressure and the temperature. So, for the case of this principle this is your 100 kilopascal and the corresponding temperature here would be your 99.61 degree Celsius okay.

So, that would be your T sat here okay. And this corresponding state would be your saturated (sat) liquid and this would be a saturated vapor here, okay.

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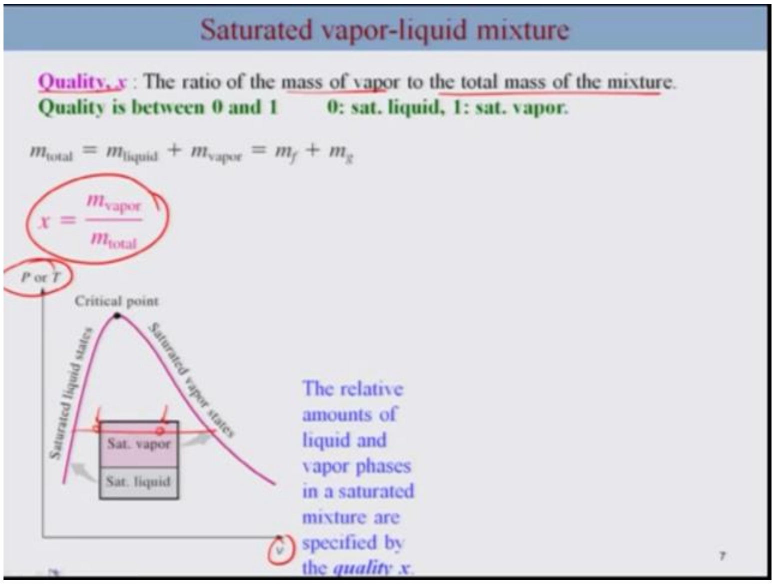

## Saturated vapor-liquid mixture

**Quality, $x$** : The ratio of the mass of vapor to the total mass of the mixture.

**Quality is between 0 and 1 0: sat. liquid, 1: sat. vapor.**

$$m_{\text{total}} = m_{\text{liquid}} + m_{\text{vapor}} = m_f + m_g$$

$$x = \frac{m_{\text{vapor}}}{m_{\text{total}}}$$

The relative amounts of liquid and vapor phases in a saturated mixture are specified by the *quality x*.

Alright, so let us try to further analyze this we are to going to introduced quality x and this particular quality x is the ratio of mass of vapor to the mass of for other mixtures okay. Which essentially means m is equal to m vapor divided by m total and this tells you that how much amount of vapor is present in the mixture.

So, again you have a P or T as the function of V. So, whether if for given conditions your system lies here or system lies here depends on what is the quality of few systems. Now so will try to do some analysis or some exercise.

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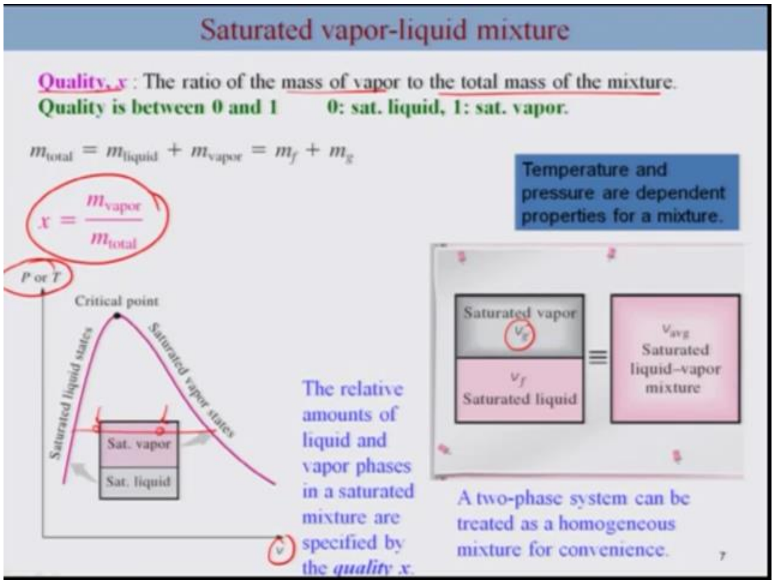

Saturated vapor-liquid mixture

**Quality, x** : The ratio of the mass of vapor to the total mass of the mixture.

**Quality is between 0 and 1    0: sat. liquid, 1: sat. vapor.**

$m_{\text{total}} = m_{\text{liquid}} + m_{\text{vapor}} = m_f + m_g$

$x = \frac{m_{\text{vapor}}}{m_{\text{total}}}$

Temperature and pressure are dependent properties for a mixture.

The relative amounts of liquid and vapor phases in a saturated mixture are specified by the *quality x*.

A two-phase system can be treated as a homogeneous mixture for convenience.

Here what we going to consider is that when you have a saturated system, for example in the case of system containing V g a volume specific volume of vapor and V g specific volume of liquid can be approximated as the V average of the system.

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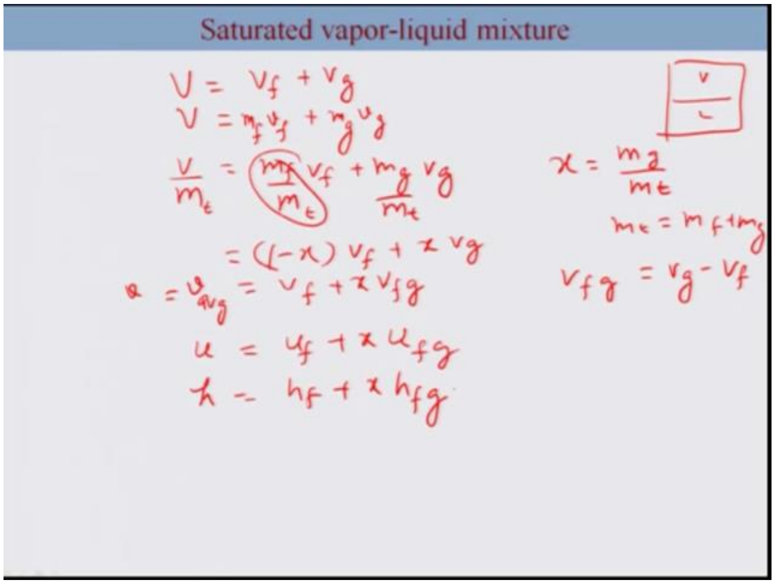

Saturated vapor-liquid mixture

$V = V_f + V_g$

$V = m_f v_f + m_g v_g$

$\frac{V}{m_t} = \frac{m_f}{m_t} v_f + \frac{m_g}{m_t} v_g$

$= (1-x) v_f + x v_g$

$= v_{avg} = v_f + x v_{fg}$

$u = u_f + x u_{fg}$

$h = h_f + x h_{fg}$

$x = \frac{m_g}{m_t}$

$m_t = m_f + m_g$

$v_{fg} = v_g - v_f$

So, let us look at some mathematics here. So, here the total volume of the system which contains let say vapor and liquid can be considered as V f plus V g okay. Now V f is the total volume of the fluid okay which is nothing but the mass of the fluid or the liquid multiplied by the specific volume of the liquid. So, this would be your m of f and v of f plus m of g and v of g and this is your total volume.

Now you can divide this by your mass. So, this is going to be m and this m f by m total, okay. This is total mass v f plus m g by m total v g. Now we have already defined that x is nothing but m g by m t. So, this is going to be 1 minus x, because we know that m t is nothing but m f plus m g okay. So, in that case the ratio this will be 1 minus x V f plus x V g or in other word you can write this a V f plus x V f g okay, where V f g is V g minus V f okay.

So, this is going to be the v average of the system okay. Now you can also write the other properties, you can also write your internal energy of the system as u f plus x u f g. Similarly you can write h as h g plus x h f g.

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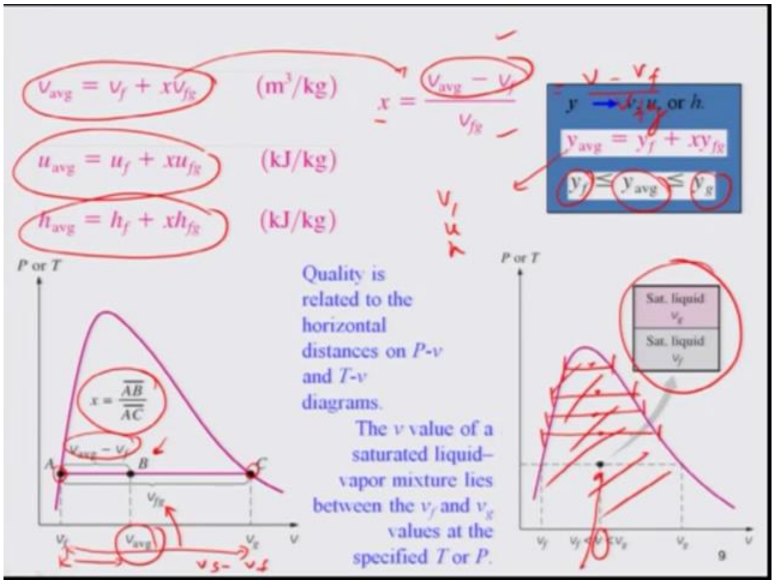

$v_{avg} = v_f + xv_{fg}$ (m³/kg)

$x = \frac{v_{avg} - v_f}{v_{fg}}$

$u_{avg} = u_f + xu_{fg}$ (kJ/kg)

$h_{avg} = h_f + xh_{fg}$ (kJ/kg)

$y \rightarrow v, u,$ or $h$.

$y_{avg} = y_f + xy_{fg}$

$y_f \leq y_{avg} \leq y_g$

Quality is related to the horizontal distances on P-v and T-v diagrams.

The v value of a saturated liquid–vapor mixture lies between the $v_f$ and $v_g$ values at the specified T or P.

So, this is something already summarized here or in this particular slide this is already summarized here okay. So, x from here you can find out x as simply the V of the system, specific volume of the system minus the specific volume of the liquid and V f g okay.

So, this in case you are not aware of the values but if the graph is given if there P v diagrams are given to you, you can make use of the geometry to find out the quality. For example this here is an illustration, so A is of course we know is a saturated liquid line. So, is on top of this line A and C is on top of the saturated vapor, B is your system okay. And systems the volume is V average and this distance is nothing but V average minus V f which is nothing but this one okay.

And this one the total difference here from here to here is V f g because this is Vg minus V f. Thus you have geometrically you have the numerator and as well as denominator and thus x can be simply the distance A B divided by A C on this P v diagram. The other thing which we will should remember is that the average of any thermodynamic property for this saturated system lies within their saturated region.

Which essentially means that y average which we are generalizing which is nothing but y f plus x y f g, where y can be V u h. The y average should be greater than and equal to y f and less than equal to y g. which essentially means that the specific volume of such a system we here should lie somewhere in this region okay for any point. So, for example here we were saying specific that this one should be here but you can have somewhere here okay.

You can have a system where you can keep this specific volume constant as well. So, this should lie between the, this two points okay for each particular variable which you have keeping constant here, within this domain okay.

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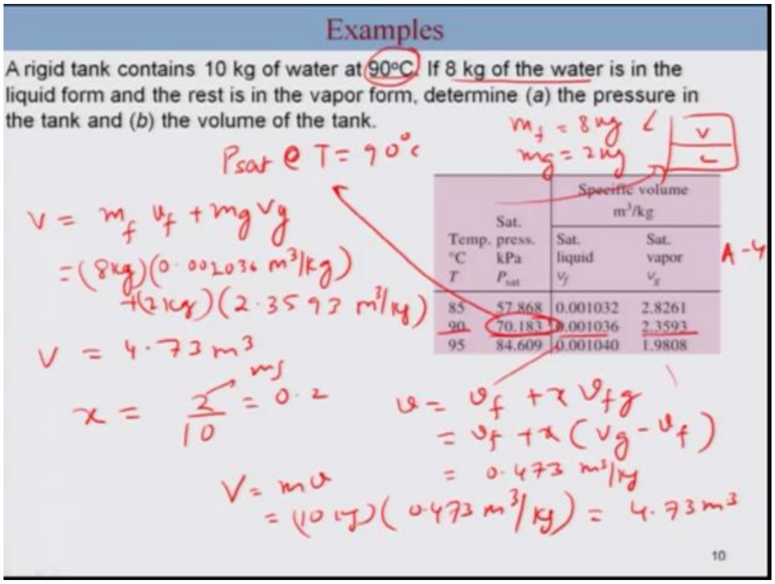

## Examples

A rigid tank contains 10 kg of water at 90°C. If 8 kg of the water is in the liquid form and the rest is in the vapor form, determine (*a*) the pressure in the tank and (*b*) the volume of the tank.

$m_f = 8\,kg$ ℓ

$m_g = 2\,kg$

$P_{sat}$ @ $T = 90°c$

| Temp. °C $T$ | Sat. press. kPa $P_{sat}$ | Specific volume m³/kg | |
|---|---|---|---|
| | | Sat. liquid $v_f$ | Sat. vapor $v_g$ |
| 85 | 57.868 | 0.001032 | 2.8261 |
| 90 | 70.183 | 0.001036 | 2.3593 |
| 95 | 84.609 | 0.001040 | 1.9808 |

A-4

$$V = m_f v_f + m_g v_g$$
$$= (8kg)(0.002036\ m^3/kg) + (2kg)(2.3593\ m^3/kg)$$
$$V = 4.73\ m^3$$

$$x = \frac{2}{10} = 0.2$$

$$v = v_f + x v_{fg}$$
$$= v_f + x(v_g - v_f)$$
$$= 0.473\ m^3/kg$$

$$V = mv$$
$$= (10\ kg)(0.473\ m^3/kg) = 4.73\ m^3$$

So, let us take an example and apply this concept. So, this is a rigid tank which is contains 10 kg of water at 90 degree Celsius okay. If 8 kg of water is in the liquid form and the rest is in the vapor form determine the pressure in the tank and the second part is the volume of the tank.

Now what is given to you is 90 degree Celsius, it is also given that 8 kg of water is in the liquid form. So, you know your mass of fluid, you know your mass of gas in this vapor liquid system.You know the temperature as well is already stated that this is a saturated system because the vapor and liquid masses are given. So, we know this is a within the saturated region okay.

So, what is a pressure, pressure would be simply saturation pressure at T equal to 90 degree Celsius, because this system is saturated because of the vapor liquid are at equilibrium and is given. So, this something which you can clearly use some table and the table you are you going to use is this which is A 4 table. The temperature is given to you 90 degree and the corresponding pressure is this. So, this becomes your saturation pressure. So, this is the answer for the first question okay.

So, this is your pressure, now what about the volume of the tank. So, you can solve this problem in two ways, so let us first look at what is volume V have to write in this because we have been given already mass of the fluid and gas. So, we can simply write total volume is m f v f plus m g v g. Now we know already v f and v g from the table. So, we can simply plug in all this values, so 8kg and then you have this 0.001036 plus 2kg into 2.3593 meter cube per kg okay. Hence your value is 4.73 meter cube.

So, this is one way of solving such a problem. You can also try a different form where you start with the quality okay because mass is given already the x is equal to 2 by 10, okay, which is 0.2 okay, because this is your m g, okay. So, x is given to you. So you can make use of x and you know that v is nothing but v f, so look at it I am using specific volume here plus x v f g, okay.

Because v f is given here v f is given okay. So, v f plus x (v g minus v f) so, we plugged in this values which form there and this value would be 0.473 meter cube per kg okay. Then the volume is nothing but m times specific volume. So, we know m total, which is given as 10kg multiplied by 0.473 and this is going to be the same answer. So, there both ways will work a sometimes one form is much easier than other one.

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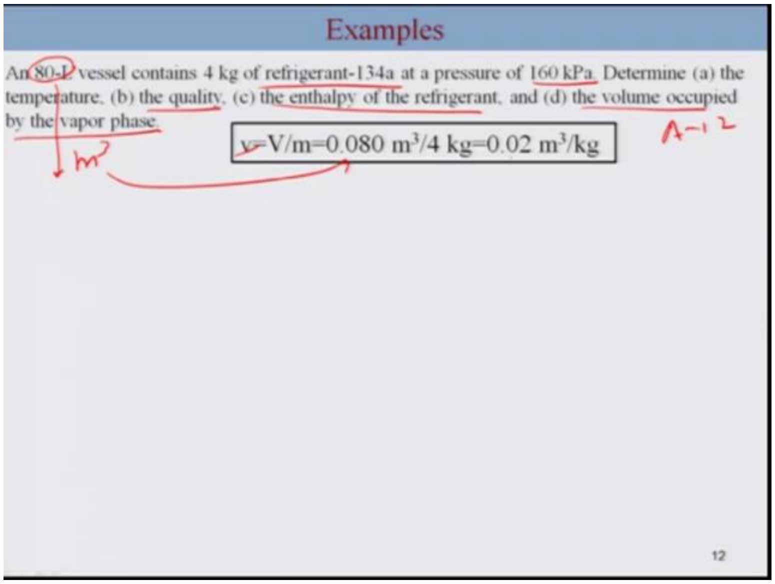

## Examples

An 80-L vessel contains 4 kg of refrigerant-134a at a pressure of 160 kPa. Determine (a) the temperature, (b) the quality, (c) the enthalpy of the refrigerant, and (d) the volume occupied by the vapor phase.

$\boxed{v=V/m=0.080\ m^3/4\ kg=0.02\ m^3/kg}$

So, let us take another example this is completely different fluid it is a refrigerant. So, these refrigerant tables are given in A 12. So, what you have is a 80 litter vessel can which contains 4 kg of refrigerant at a pressure 160 kilopascal determined the temperature, the quality, the enthalpy of the refrigerant and the volume occupied by the vapor phase. So you can find the specific volume which is V by m. So, you can convert this thing into meter cube which would be this.

So, this be the volume divided by 4 kg this becomes a specific volume right. Now the question is, is this specific volume within their saturated region or the compressed liquid or is it in superheated vapor. That is a first thing which we have to find out. So, that means you need to look at the table okay.

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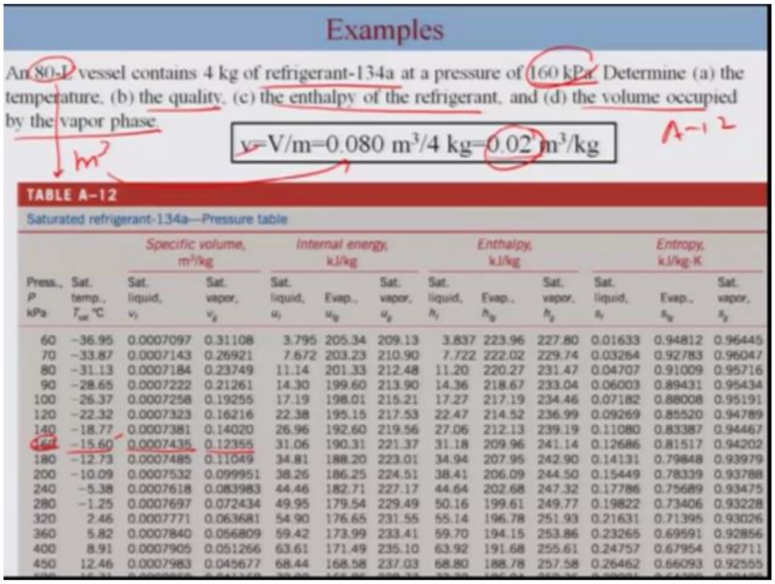

## Examples

An 80-L vessel contains 4 kg of refrigerant-134a at a pressure of 160 kPa. Determine (a) the temperature, (b) the quality, (c) the enthalpy of the refrigerant, and (d) the volume occupied by the vapor phase.

$v = V/m = 0.080\ m^3/4\ kg = 0.02\ m^3/kg$

**TABLE A-12**

Saturated refrigerant-134a—Pressure table

| | | Specific volume, $m^3$/kg | | Internal energy, kJ/kg | | | Enthalpy, kJ/kg | | | Entropy, kJ/kg·K | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Press., $P$ kPa | Sat. temp., $T_{sat}$ °C | Sat. liquid, $v_f$ | Sat. vapor, $v_g$ | Sat. liquid, $u_f$ | Evap., $u_{fg}$ | Sat. vapor, $u_g$ | Sat. liquid, $h_f$ | Evap., $h_{fg}$ | Sat. vapor, $h_g$ | Sat. liquid, $s_f$ | Evap., $s_{fg}$ | Sat. vapor, $s_g$ |
| 60 | −36.95 | 0.0007097 | 0.31108 | 3.795 | 205.34 | 209.13 | 3.837 | 223.96 | 227.80 | 0.01633 | 0.94812 | 0.96445 |
| 70 | −33.87 | 0.0007143 | 0.26921 | 7.672 | 203.23 | 210.90 | 7.722 | 222.02 | 229.74 | 0.03264 | 0.92783 | 0.96047 |
| 80 | −31.13 | 0.0007184 | 0.23749 | 11.14 | 201.33 | 212.48 | 11.20 | 220.27 | 231.47 | 0.04707 | 0.91009 | 0.95716 |
| 90 | −28.65 | 0.0007222 | 0.21261 | 14.30 | 199.60 | 213.90 | 14.36 | 218.67 | 233.04 | 0.06003 | 0.89431 | 0.95434 |
| 100 | −26.37 | 0.0007258 | 0.19255 | 17.19 | 198.01 | 215.21 | 17.27 | 217.19 | 234.46 | 0.07182 | 0.88008 | 0.95191 |
| 120 | −22.32 | 0.0007323 | 0.16216 | 22.38 | 195.15 | 217.53 | 22.47 | 214.52 | 236.99 | 0.09269 | 0.85520 | 0.94789 |
| 140 | −18.77 | 0.0007381 | 0.14020 | 26.96 | 192.60 | 219.56 | 27.06 | 212.13 | 239.19 | 0.11080 | 0.83387 | 0.94467 |
| 160 | −15.60 | 0.0007435 | 0.12355 | 31.06 | 190.31 | 221.37 | 31.18 | 209.96 | 241.14 | 0.12686 | 0.81517 | 0.94202 |
| 180 | −12.73 | 0.0007485 | 0.11049 | 34.81 | 188.20 | 223.01 | 34.94 | 207.95 | 242.90 | 0.14131 | 0.79848 | 0.93979 |
| 200 | −10.09 | 0.0007532 | 0.099951 | 38.26 | 186.25 | 224.51 | 38.41 | 206.09 | 244.50 | 0.15449 | 0.78339 | 0.93788 |
| 240 | −5.38 | 0.0007618 | 0.083983 | 44.46 | 182.71 | 227.17 | 44.64 | 202.68 | 247.32 | 0.17786 | 0.75689 | 0.93475 |
| 280 | −1.25 | 0.0007697 | 0.072434 | 49.95 | 179.54 | 229.49 | 50.16 | 199.61 | 249.77 | 0.19822 | 0.73406 | 0.93228 |
| 320 | 2.46 | 0.0007771 | 0.063681 | 54.90 | 176.65 | 231.55 | 55.14 | 196.78 | 251.93 | 0.21631 | 0.71395 | 0.93026 |
| 360 | 5.82 | 0.0007840 | 0.056809 | 59.42 | 173.99 | 233.41 | 59.70 | 194.15 | 253.86 | 0.23265 | 0.69591 | 0.92856 |
| 400 | 8.91 | 0.0007905 | 0.051266 | 63.61 | 171.49 | 235.10 | 63.92 | 191.68 | 255.61 | 0.24757 | 0.67954 | 0.92711 |
| 450 | 12.46 | 0.0007983 | 0.045677 | 68.44 | 168.58 | 237.03 | 68.80 | 188.78 | 257.58 | 0.26462 | 0.66093 | 0.92555 |

So, let us look at this table, this is 0.02 and the corresponding pressure is given here, 160 is somewhere here. So, this is your 160 the saturated temperature which is the first part is already given. So, we can simply use this and these are the values for saturated liquid and saturated vapor.

Now clearly all value at 0.2 is greater than saturated (vap) saturated liquid but less than saturated vapor. Hence it has to be within the saturated liquid region. So, this is a saturated vapor liquid system okay.

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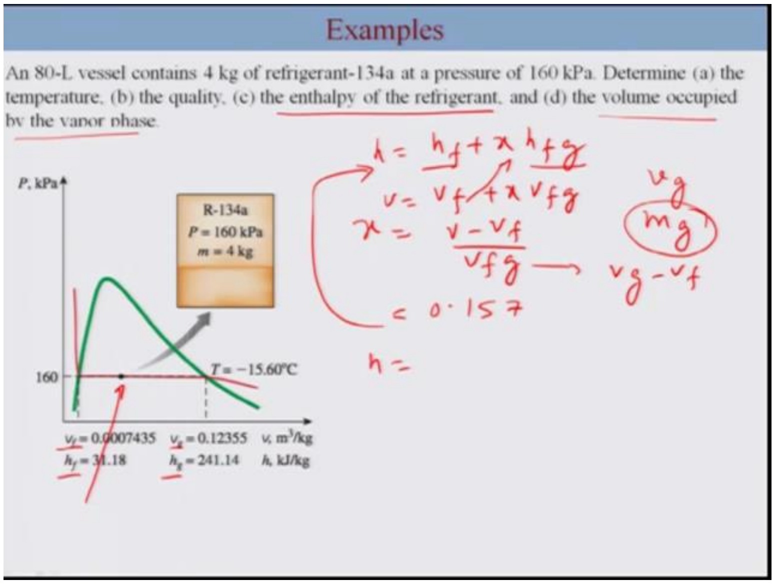

## Examples

An 80-L vessel contains 4 kg of refrigerant-134a at a pressure of 160 kPa. Determine (a) the temperature, (b) the quality, (c) the enthalpy of the refrigerant, and (d) the volume occupied by the vapor phase.

$h = h_f + x\, h_{fg}$

$v = v_f + x\, v_{fg}$

$x = \dfrac{v - v_f}{v_{fg}} \longrightarrow v_g - v_f$

$= 0.157$

$h =$

$v_g$

$m_g$

So, hence your system is somewhere here, so you can you can plug, you can find out from the table these values and then you can calculate the enthalpy of the refrigerant. Enthalpy of the refrigerant would be your h, h f plus x h f g which essentially means you need to find out what is x.

Similarly the second part is something which is a volume occupied by the vapor phase. So, you need to find out the volume of your vapor which essentially is given to you, but then you need to multiply it by mass of your vapor and then you have to find out. This you can find out from again the quality.

So, the first thing is to find out the quality. So, what is the quality, quality we have already defined v as v f earlier x v f g okay, or in other word x is v minus v f by v f g. And v f g is v g minus v f okay. So, you have the valued of f and v g you can find out quality it terms out to be 0.157 okay. Now you can plug this 0.157 here, so and you know these values of h f and h f g from the table. So, the h if you plug in because you have this h f g is also given.

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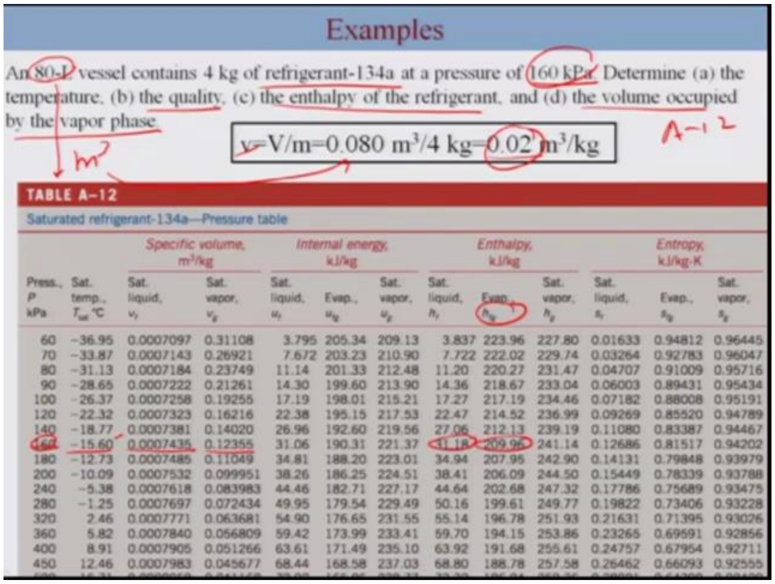

## Examples

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$\boxed{v = V/m = 0.080\ m^3/4\ kg = 0.02\ m^3/kg}$

$m^3$

A-12

**TABLE A-12**

Saturated refrigerant-134a—Pressure table

| | | Specific volume, m³/kg | | Internal energy, kJ/kg | | | Enthalpy, kJ/kg | | | Entropy, kJ/kg·K | | |
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| 450 | 12.46 | 0.0007983 | 0.045677 | 68.44 | 168.58 | 237.03 | 68.80 | 188.78 | 257.58 | 0.26462 | 0.66093 | 0.92555 |

So, let me go back this h f g is also given to you. So, this h f g is this and h f is this. So, make use of these two values.

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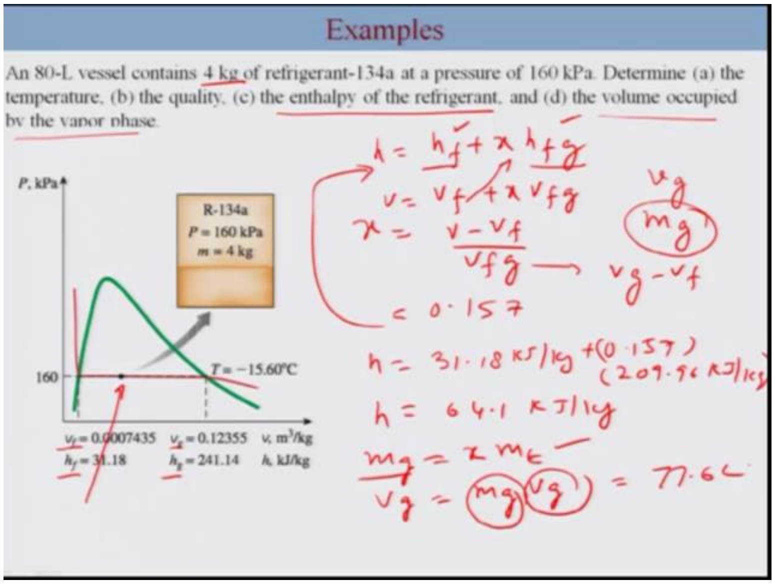

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$v = v_f + x v_{fg}$

$x = \frac{v - v_f}{v_{fg}}$ $\rightarrow v_g - v_f$

$= 0.157$

$v_g$

$m_g$

$h = 31.18\ kJ/kg + (0.157)(209.96\ kJ/kg)$

$h = 64.1\ kJ/kg$

$m_g = x m_t$

$V_g = m_g v_g = 77.6L$

So you can replace this here and then you have the value 31.18 kilojoules per kg plus 0.157 multiplied by 209.96 kilojoules per kg and this is going to be 64.1 kilojoules per kg, okay. So, once you have this h, so this is a enthalpy of refrigerant. So, you can also find out m f g, now which is much easier because you have the value of x and you know already note to total mass which is 4 kg.

So, this is you can calculate, you can also calculate volume of gas by multiplying m g by V g. So, because already I have got m g information you have m g you already know V g from the table okay. And this turns out to be 77.6 litters okay. So, you can do the rest of analysis yourself but this is the procedure of solving such a problem okay.

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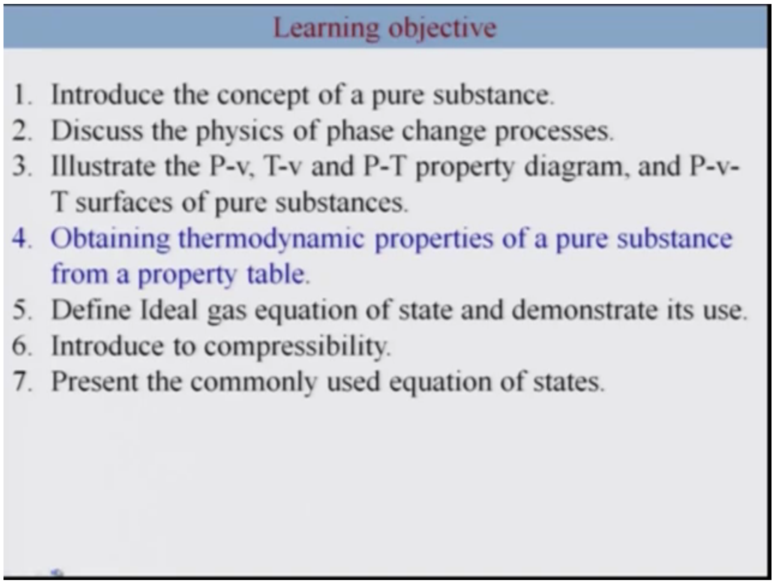

Learning objective

1. Introduce the concept of a pure substance.
2. Discuss the physics of phase change processes.
3. Illustrate the P-v, T-v and P-T property diagram, and P-v-T surfaces of pure substances.
4. Obtaining thermodynamic properties of a pure substance from a property table.
5. Define Ideal gas equation of state and demonstrate its use.
6. Introduce to compressibility.
7. Present the commonly used equation of states.

So, I guess this was interesting that you made use of the tables to solve some process related problems and we will continue this discussion in the next lecture okay. So, see you in the next lecture.