Refrigeration and Air-Conditioning

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Lecture No. # 16

Vapour Absorption Refrigeration systems (contd.)

Welcome back, the last lecture we discussed vapour absorption refrigeration system based on water Lithium Bromide pair. In this lecture, I shall introduce systems based on ammonia-water pair okay.

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16. Absorption Refrigeration Systems based on ammonia-water pair

- The objectives of this lesson are to:

1. Discuss differences between water-LiBr and ammonia-water systems
2. Discuss properties of binary mixtures:
   composition
   vapour pressure
   enthalpies of liquid and vapour mixtures
3. Discuss basic steady-flow processes using binary mixtures

The specific objectives of this particular lesson are to discuss differences between water lithium bromide and ammonia water systems and discuss properties of binary mixtures with reference to composition vapour pressure enthalpies of liquid and vapour mixtures and finally discuss some basic steady-flow processes using binary mixtures.

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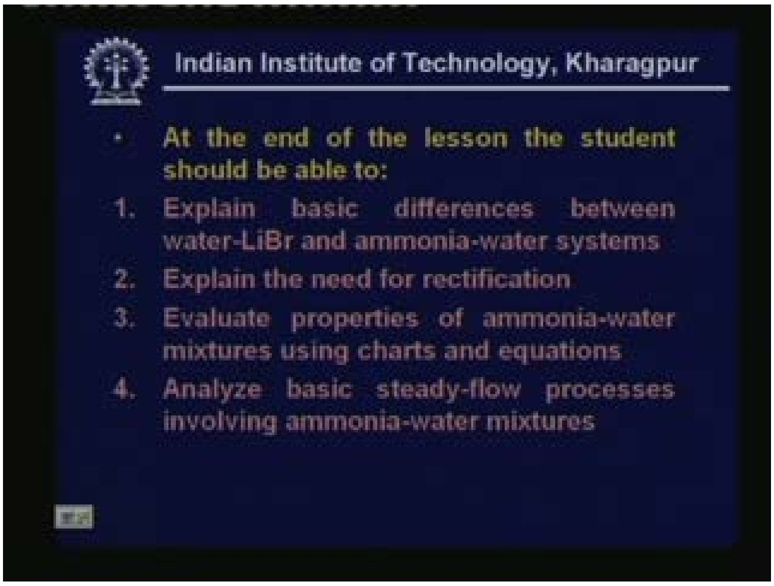

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- At the end of the lesson the student should be able to:

1. Explain basic differences between water-LiBr and ammonia-water systems
2. Explain the need for rectification
3. Evaluate properties of ammonia-water mixtures using charts and equations
4. Analyze basic steady-flow processes involving ammonia-water mixtures

At the end of this lesson you should be able to explain basic differences between water lithium bromide and ammonia-water systems, explain the need for rectification in ammonia water systems, evaluate properties of ammonia water mixtures using charts and equations and analyze basic steady-flow processes involving ammonia-water mixtures.

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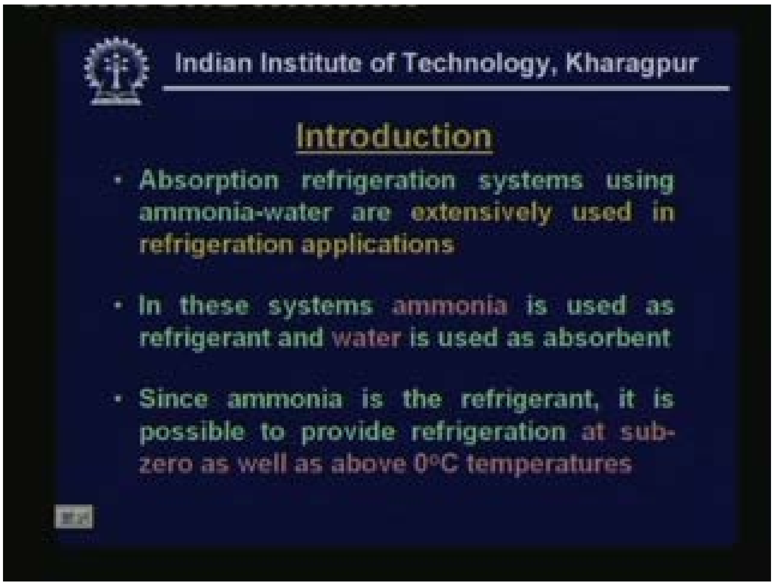

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Introduction

- Absorption refrigeration systems using ammonia-water are extensively used in refrigeration applications
- In these systems ammonia is used as refrigerant and water is used as absorbent
- Since ammonia is the refrigerant, it is possible to provide refrigeration at sub-zero as well as above 0°C temperatures

Let me give a brief introduction as a name implies absorption refrigeration systems using ammonia-water. Ammonia is a refrigerant and water is the absorbent and they are extensively used in the refrigeration applications. Since ammonia is the refrigerant, it is possible to provide refrigeration at sub-zero as well as above zero degree centigrade temperatures. That means actually ammonia-water systems are much more versatile than water Lithium bromide system because you do not have the problem of temperature restriction. Whereas in water lithium bromide system you cannot operate the system below zero degree centigrade. Whereas ammonia-water systems can be used for both sub-zero as well as above zero degree centigrade application. That means you can use them for air-conditioning as well as refrigeration application such as cold storage okay. So in the, this manner there more versatile.

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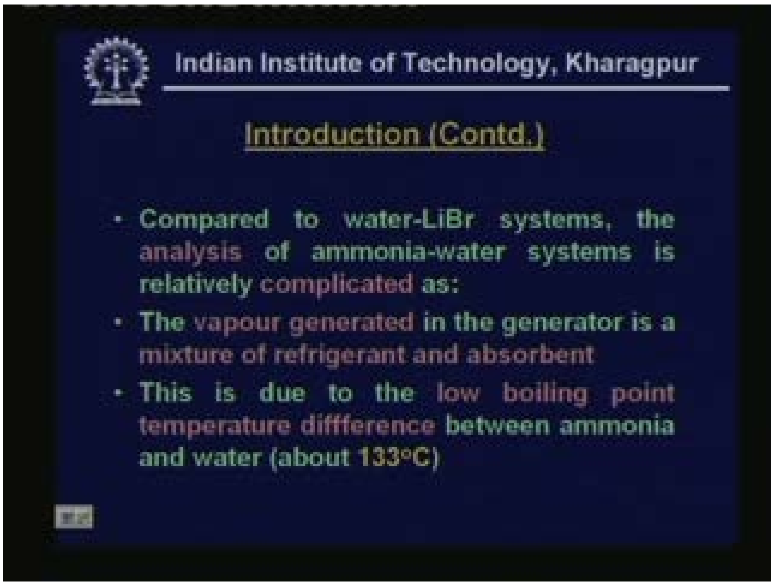

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Introduction (Contd.)

- Compared to water-LiBr systems, the analysis of ammonia-water systems is relatively complicated as:
- The vapour generated in the generator is a mixture of refrigerant and absorbent
- This is due to the low boiling point temperature diffference between ammonia and water (about 133°C)

However compared to water lithium bromide system the analysis of ammonia-water systems is relatively complicated. In fact in have mentioned this in the last class. The complication comes because the vapour generated in the generator is a mixture of refrigerant and absorbent. And what is the reason for this the reason for this is the low boiling point temperature difference between ammonia and water. This is about one thirty three degree centigrade in a water lithium bromide systems. The boiling point temperature difference between the absorbent and refrigerant is very high. As a result in the generator, as I mentioned in the last class you will not find any absorbent or the mode of absorbent is practically negligible. That means what you have in the generator exit is a pure water vapour okay.

So in the refrigerant circuit you have pure refrigerant circulating whereas in the ammonia-water systems because of the low boiling point temperature difference when you boil the solution you find that both ammonia vapours as well as water vapour both are generated in the generator. Okay. If you, if nothing is done then both refrigerant as well as the absorbent enters into the refrigerant circuit and this will create some problems which I will show now.

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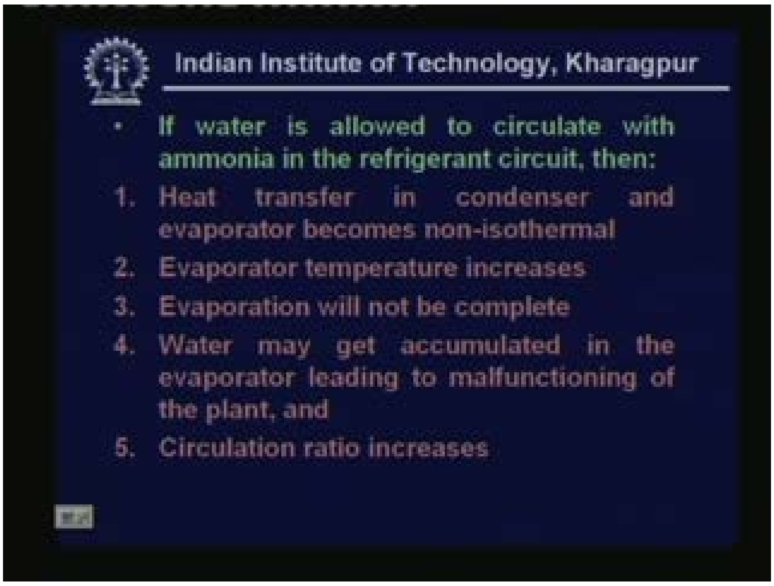

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- If water is allowed to circulate with ammonia in the refrigerant circuit, then:

1. Heat transfer in condenser and evaporator becomes non-isothermal
2. Evaporator temperature increases
3. Evaporation will not be complete
4. Water may get accumulated in the evaporator leading to malfunctioning of the plant, and
5. Circulation ratio increases

So if water is allowed to circulate with ammonia in the refrigerant circuit, what are the problems? The problems are, first problem is that the heat transfer in condenser and evaporator becomes non-isothermal. Then evaporator temperature increases evaporation will not be complete. Water may get accumulated in the evaporator leading to malfunctioning of the plant and finally the circulation ratio also increases all these effects are detrimental to system performance.

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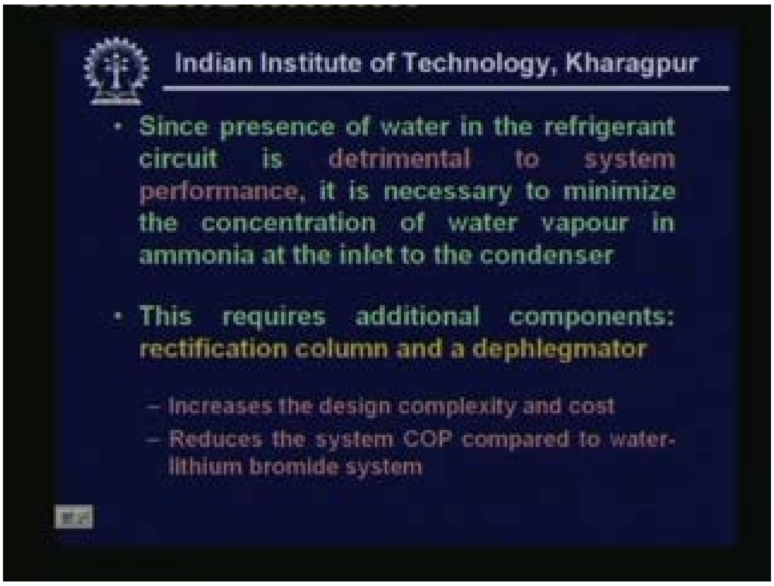

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- Since presence of water in the refrigerant circuit is detrimental to system performance, it is necessary to minimize the concentration of water vapour in ammonia at the inlet to the condenser
- This requires additional components: rectification column and a dephlegmator
  - Increases the design complexity and cost
  - Reduces the system COP compared to water-lithium bromide system

So what we have to do is, we have to minimize the concentration of water vapour in ammonia at the exit of the condenser or at the inlet to the, I am sorry at the exit of the generator or at the inlet to the condenser. We have to ensure that almost pure ammonia vapour goes to the condenser. So this requires additional components namely a rectification column and a dephlegmator. As a result of this you will find that the design of ammonia-water systems are more complicated and the cost also is higher because of the additional components. Not only that due to this additional components the system COP is also reduced when you compare it with water-lithium bromide system. So these are the main differences between water-lithium bromide systems and ammonia-water systems.

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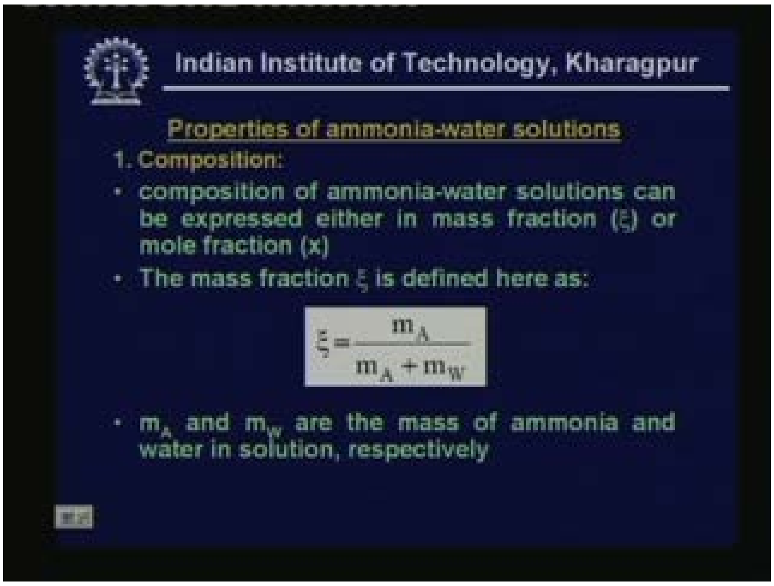

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Properties of ammonia-water solutions

1. Composition:

- composition of ammonia-water solutions can be expressed either in mass fraction (ξ) or mole fraction (x)
- The mass fraction ξ is defined here as:

$$\xi = \frac{m_A}{m_A + m_W}$$

- m_A and m_W are the mass of ammonia and water in solution, respectively

Now let us first begin the discussion with properties of ammonia-water solutions as we have done in the last class. Let us begin with composition. So similar to water-lithium bromide solution we can also define composition of ammonia-water solution in terms of either mass fraction or mole fraction. However there is one important difference in case of water-lithium bromide systems. The mass fraction, mole fraction composition everything is defined in terms of the mass or number of moles of lithium bromide. That means it is defined on the basis of the absorbent. Where as in the case of water ammonia-water systems the mass fraction mole fraction are defined on the basis of ammonia. That means they are on the basis of refrigerant okay.

So as a result of which the meaning of strong and weak solutions will be different for these two systems okay. I shall discuss in the subsequently but you have to keep in mind that when I say mass fraction in water-lithium bromide system. It means mass of the lithium bromide to the mass of the total solution. Whereas in ammonia water systems when you say mass fraction or mole fraction that means we are always referring to the mass of the ammonia or number of moles of ammonia in total, in the total mass of the solution or in the total number of the molecules in the solution okay.

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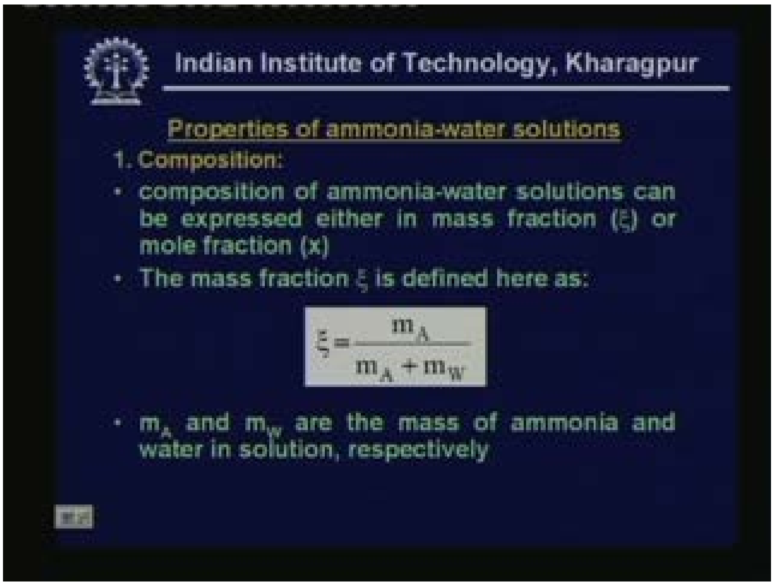

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So the mass fraction is defined as mass of ammonia mA divided by the total mass of the solution that is mA plus mW where mA and mW are masses of ammonia and water respectively.

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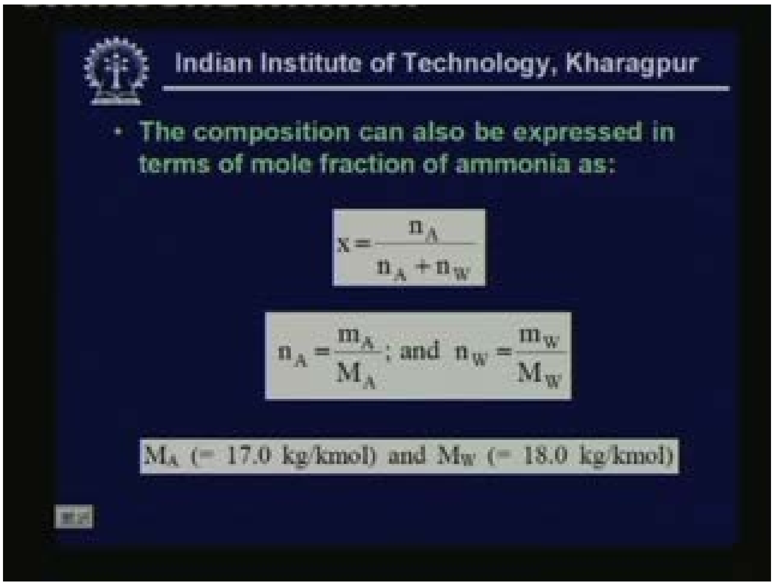

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- The composition can also be expressed in terms of mole fraction of ammonia as:

$$x = \frac{n_A}{n_A + n_W}$$

$$n_A = \frac{m_A}{M_A}; \text{ and } n_W = \frac{m_W}{M_W}$$

M_A (= 17.0 kg/kmol) and M_W (= 18.0 kg/kmol)

Similarly just like the earlier this things, the composition can also be expressed in mole fraction. So if I am writing this in mole fraction this is liquid mole fraction. X is defined as a number of moles of ammonia in liquid phase divided by the total number of moles in liquid phase okay. And this can be easily obtained from the mass of the substance and its molecular weight. For example nA that is the number of moles of ammonia is equal to mass of ammonia divided by the molecular weight of ammonia.

Similarly the number of moles of water is equal to mass of water divided by the molecular weight of the water. And for calculation purposes you can take the molecular weight of ammonia is seventeen kilogram per kilo mole and molecular weight of water is eighteen kilogram per kilo mole.

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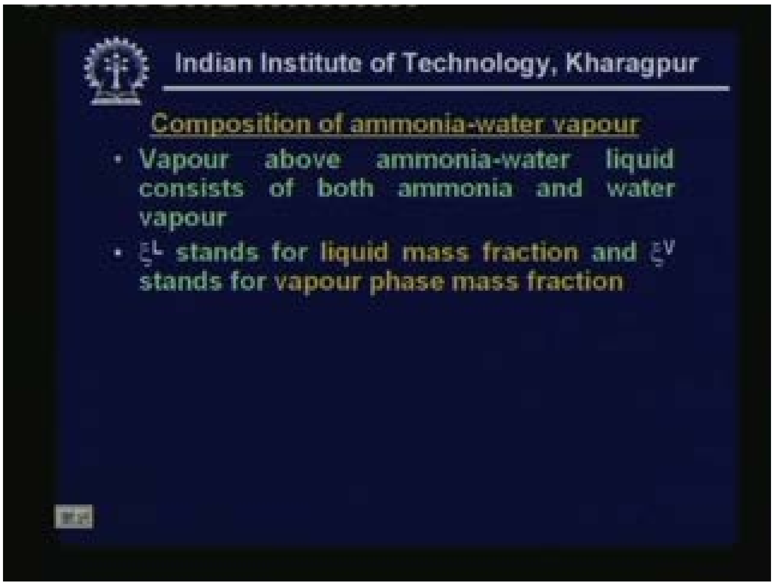

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Composition of ammonia-water vapour

- Vapour above ammonia-water liquid consists of both ammonia and water vapour
- ξ^L stands for liquid mass fraction and ξ^V stands for vapour phase mass fraction

However there is one important difference between lithium bromide water lithium bromide systems and ammonia-water systems. Because the vapours above ammonia-water the above solution consist of both ammonia vapour as well as water vapour okay. That means we have to talk about composition in the liquid phase as well as composition in vapour phase. Because you have mixture in both liquid as well as in vapour phases okay. So to distinguish between the concentration in liquid and vapour phases we define superscript l for liquid phase composition and superscript V for vapour phase composition. So when I say XL that means mole fraction in liquid phase. Similarly X superscript V means mole fraction in vapour phase okay. This is the normal I will be using throughout the lecture all right.

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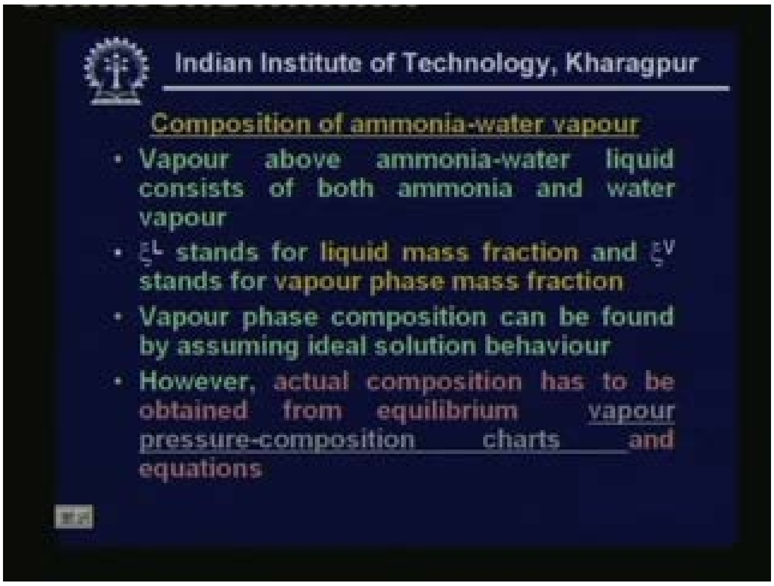

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Composition of ammonia-water vapour

- Vapour above ammonia-water liquid consists of both ammonia and water vapour
- ξ^L stands for liquid mass fraction and ξ^V stands for vapour phase mass fraction
- Vapour phase composition can be found by assuming ideal solution behaviour
- However, actual composition has to be obtained from equilibrium vapour pressure-composition charts and equations

So similarly zeta L stands for liquid phase mass fraction and zeta V stands for vapour phase. Mass fraction vapour phase composition can be found by assuming ideal solution behaviour. If you are assuming that it's behaving as the ideal solution then you can apply ideal gas equations like etcetera. And you can find out the vapour phase composition but the actual mixture deviates from ideal behaviour. So the actual compositions have to be obtained from equilibrium vapour pressure-composition charts or equations okay. So let me just show a typical vapour-pressure composition chart.

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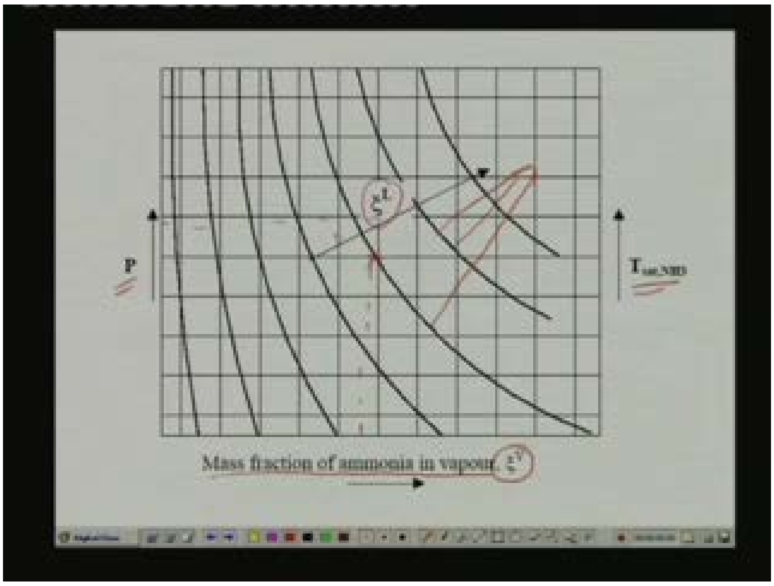

Okay, so what I am showing here is a typical vapour-liquid equilibrium chart were you have mass fraction of ammonia in vapour phase as x-axis and y-axis is pressure or saturated temperature of ammonia okay. So this is an equilibrium chart that means the vapour is in equilibrium with the solution okay. And also shown here are different concentration lines for liquid okay. These are the liquid constant liquid concentration lines all these okay. So if you know the concentration of the liquid. For example let us say that this concentration of the liquid and this is the pressure. Then you can easily read, what is the concentration? Concentration of ammonia in vapour phase okay. Similarly you can find out from the pressure in solution also okay. Such kinds of charts are available in literature using which you can find out the exact composition in vapour phase from the knowledge of liquid phase composition and the pressure.

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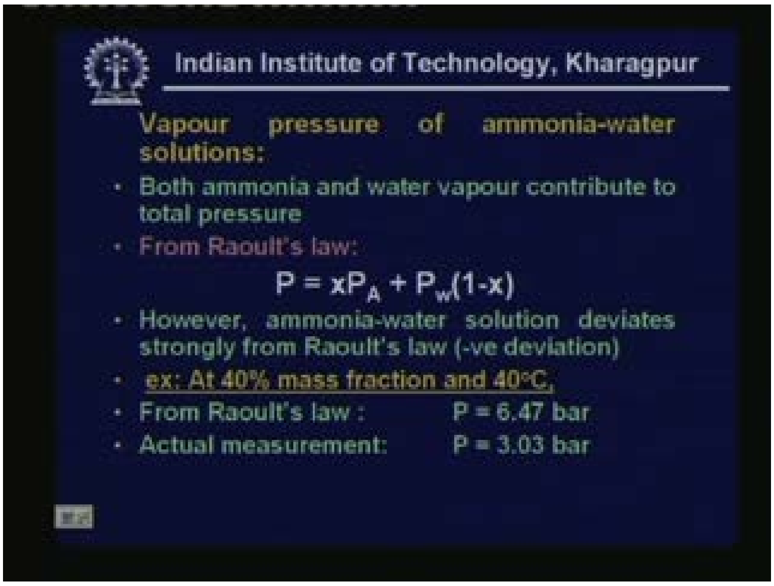

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Vapour pressure of ammonia-water solutions:

- Both ammonia and water vapour contribute to total pressure
- From Raoult's law:

$$P = xP_A + P_w(1-x)$$

- However, ammonia-water solution deviates strongly from Raoult's law (-ve deviation)
- ex: At 40% mass fraction and 40°C,
- From Raoult's law : $P = 6.47$ bar
- Actual measurement: $P = 3.03$ bar

Now let us look at vapour pressure of ammonia-water solutions. So both ammonia and water vapour contribute to total pressure. So we have to write from Raoult's law. The total pressure, if you are assuming that the mixture behaves as an ideal mixture then you can use a Raoult's law and from Raoult's law. You know that the total pressure P is equal to x into PA plus PW into one minus x where x is a liquid phase mole fraction of ammonia and PA and PW are the saturated pressures of ammonia and water at that particular temperature. But we know that the ammonia-water mixture deviates strongly from Raoult's law in a negative manner. So you cannot really use the above expression when the concentration is high okay. So let me give an example, at forty percent mass fraction and forty degree centigrade if you are using Raoult's law you will find that the total pressure is six point four seven bars okay. So this is what is obtained from Raoult's law. But you will find that from actual measurements the total pressure is three point zero three bar okay. So deviation is really strong which gives an activity co-efficient of less than point five okay.

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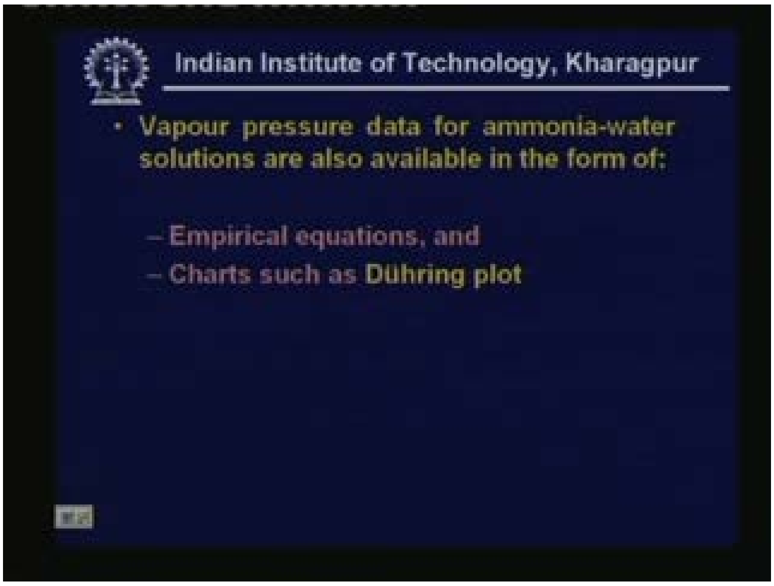

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- Vapour pressure data for ammonia-water solutions are also available in the form of:
  - Empirical equations, and
  - Charts such as Dühring plot

So vapour pressure data for ammonia-water solutions are also available in the form of Empirical equations and charts such as Duhring plot and all and I have discussed these Duhring plot et cetera in the last lecture. And construction wise the plots will be exactly similar. That means Duhring plot for ammonia-water system will be almost similar to Duhring plots of water- lithium bromide systems okay.

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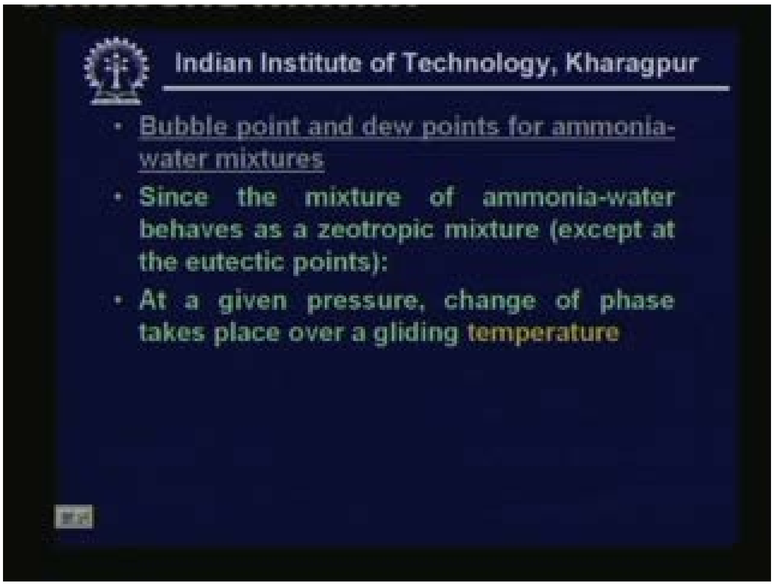

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- Bubble point and dew points for ammonia-water mixtures
- Since the mixture of ammonia-water behaves as a zeotropic mixture (except at the eutectic points):
- At a given pressure, change of phase takes place over a gliding temperature

Now let us introduce an important concept of what is known as bubble point and dew point for ammonia-water mixture. In fact this discussion holds good for any binary mixture which a zeotropic mixture okay. So since the mixture of ammonia-water behaves as a zeotropic mixture except at the eutectic points at a eutectic point it will be behaves as a mixture but otherwise it behaves as a zeotropic mixture. So what is the meaning of the zeotropic mixture behaviour. It means that at a given pressure change of phase takes place over a gliding temperature had it been a mixture or had it been a pure fluid. Then you know the change of phase takes place at a constant temperature. But if it, if the mixture behaves zeotropic mixture you will find the change of phase. For example boiling or condensation you will find that at a given pressure boiling and are condensation take place over a gliding temperature not at a constant temperature. This is the nature of zeotropic mixtures okay. If it, as I have already repeated, if it is pure fluid or a mixture the phase change takes place at a constant temperature when the pressure is kept constant okay.

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- Bubble point and dew points for ammonia-water mixtures
- Since the mixture of ammonia-water behaves as a zeotropic mixture (except at the eutectic points):
- At a given pressure, change of phase takes place over a gliding temperature
- In the two-phase region, the composition of liquid will be different from the composition of vapour

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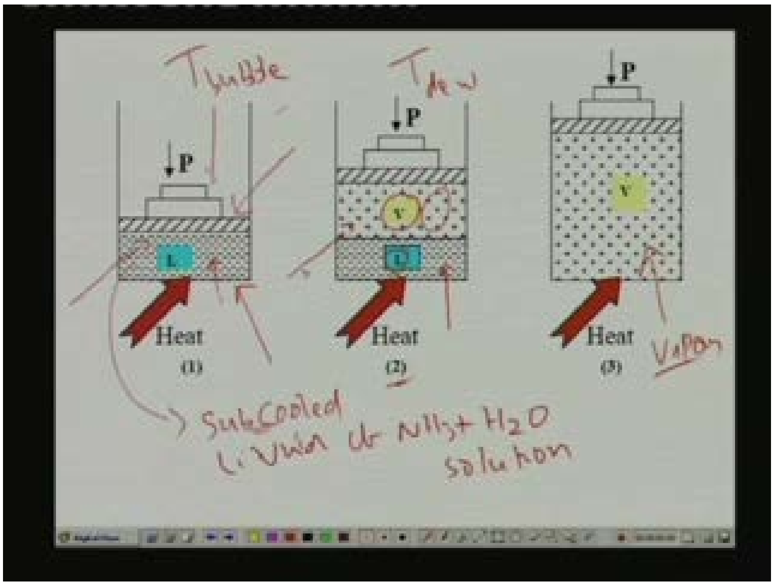

So in the two-phase region the composition of liquid will be different from the composition of vapour. So let me explain this. Let us do a small experiment. Let us assume that we have a cylinder okay. And this cylinder has the free floating piston and this is loaded by fixed weight okay.

These are the weights and initially this piston cylinder arrangement consist of sub cooled sub cooled liquid of ammonia-water solution okay. So initially we have sub cooled liquid of ammonia water solution and we are exiting a constant pressure. Because it is a free floating piston and the weights are kept constant. So the pressure exerted on the system remains constant throughout the process. Now let us say the, we start heating the system or we start heating the solution by supplying heat to the solution okay. Then what happens you will find that since the initial condition is sub cooled liquid to start with nothing happens okay. But as the temperature increases slowly you find at the certain point the first vapour bubble forms okay.

So if the cylinder is a transparent cylinder you will observe that the first vapour bubble forms at a particular temperature let me call it as T bubble okay. So T bubble is the temperature at which the first vapour bubble forms at a constant pressure okay. So if you heat the solution further. Let us say that state two. So continuously supply heat you will find that temperature increases and along with the temperature more and more vapour formation takes place. That means more and more liquid is converted into vapour. So you can see that there is lot of vapour here okay. So this process continues as long as liquid is present okay. If at a particular point you will find that the last liquid droplet also evaporates. That means at a particular temperature let me call it as T dew point okay. The last liquid droplet evaporates further heating will simply result in super heating of the vapour okay. So here you have vapour here. You have, as I said sub cooled liquid and here you have it two-phase mixture consisting of vapour and liquid okay. Now let us say that you are plotting this process.

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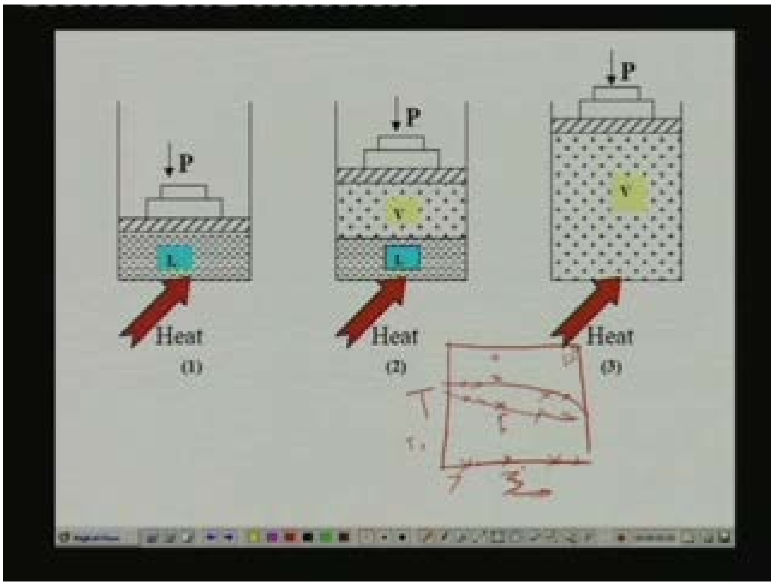

Let me say that you have, we have taken a graph paper and i on the x-axis. I have composition and on the y-axis i am plotting temperature. Let us say that p is constant here. Let us say that this is the initial concentration okay. And you are plotting this process on this chart then you find that as you start heating it. Let us say that this is the initial, some initial temperature okay. As you start heating it at some particular point the first vapour bubble forms okay. And at some other temperature the last liquid bubble liquid droplet evaporates. So you get two points here further heating will result in continuous increase of temperature okay.

Now let us say that I repeat this experiment with another concentration okay. You find that exactly same process appears but these two temperatures will be different. So instead of having temperatures like this, you will have another two temperatures okay. If you are starting this process, at this initial concentration, then again you will find that you will have some other temperatures okay. So if you carry out this experiment for different concentrations you will find different temperatures okay. And if you join all these temperatures you get what is known as a dew point and bubble point lines for this pressure okay. So let me show this dew point and bubble point lines.

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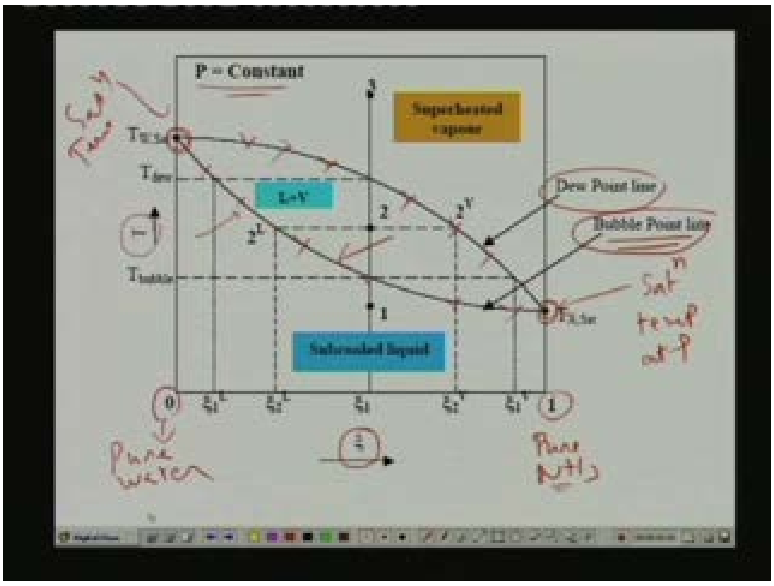

Okay, so what I am showing here is a plot obtained by taking concentration or mass fraction on x-axis and the temperature on the y-axis. As I said we are keeping the pressure constant and this data is obtain by varying the concentration from zero to one. So what do you mean by zero zero means it is pure water okay, one means it is pure ammonia okay. So if you are carrying out the experiment taking pure water in the piston cylinder arrangement you will find that you have only one point at which phase change takes place. Because obviously pure water is a pure fluid. So phase change takes place at a constant temperature. Let us say that you have marked that point on this temperature axis like this okay. Similarly you have if you are conducting the experiment with pure ammonia. Again you will, that the phase change takes place at a constant temperature which is nothing but the boiling point or saturation temperature corresponding to this pressure okay at p.

Similarly this is the saturation temperature for water okay at this pressure. And the intermediate points as I was mentioning are the bubble points for different concentrations but at the same pressure. Similarly the points on this line are the dew points at different concentration and at the same pressure okay. And this line what is called as the bubble point line is nothing but the, of all the bubble points okay. That means we have joined all the bubble points starting with the saturated points of water and saturated points of ammonia then you get a curve of this shape okay. This is your bubble point line. Similarly if you joint all the dew points you get a line called as dew point line okay.

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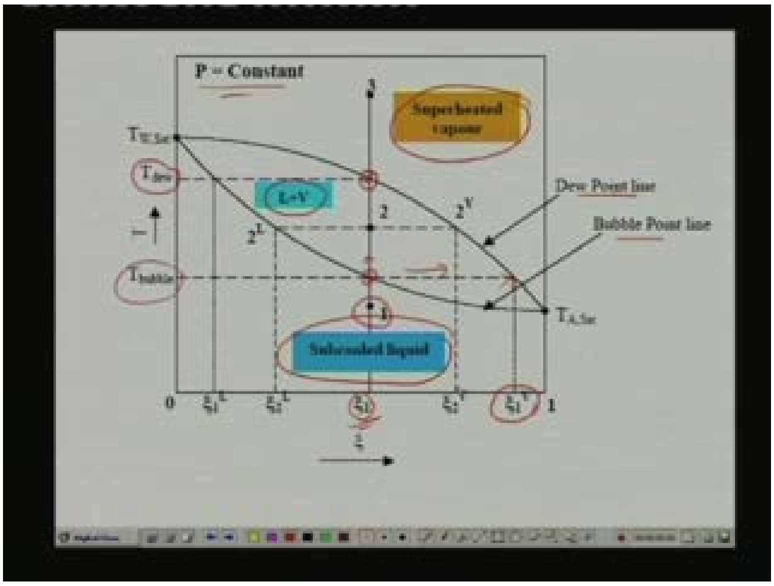

So ultimately you get a shape of this form okay. So you get a dew point line and a bubble point line and what do you have here below the bubble point line you have a sub cooled liquid and above the dew point line you have a superheated vapour region okay. And in between the dew point and bubble point line you have the two-phase liquid plus vapour region okay. So this is a typical dew point bubble point line, lines for a constant pressure okay. That means at a single pressure and the process of the heating is shown here. As I explained to you we started with sub cooled liquid so point one lies in the sub cooled region. So we started heating it that means temperature started increasing and this is the point at which the first vapour bubble appeared.

So that is why this is the temperature bubble point temperature at this concentration zeta one and at this pressure P okay. So if you heat it further you are in, you have entered into the two-phase region okay. So that means you have both liquid as well as vapour. If you continuously heat it you arrived at a point at which the last liquid droplet evaporates. As I have already mentioned okay. And this temperature where the last liquid droplet evaporates. As I told you it is nothing but the dew point okay. So you can read the dew point and bubble point from this chart what is interesting is the two-phase region. See if you we started with initial composition of zeta one okay. I am showing the sub cooled region the concentration is zeta one okay.

So what is the concentration of the first vapour bubble that is formed? Here you can find that one by drawing a horizontal line like this okay. And where this line intersects? The dew point line that will give you the concentration of the first vapour bubble that is formed because what happened let us say that you have taken a solution which consists of ammonia and water ammonia has much lower boiling point compared to water. So when you are heating that solution and when you are keeping the pressure constant and if you have heated it sufficiently you will find that ammonia liquid starts evaporating fast.

Why does it evaporate fast? Because it has a lower boiling point okay. And later water starts evaporating. So the first vapour bubble that has formed will be rich in ammonia and weak in water vapour okay. So as you continue, continuously heat it you will find that progressively the vapour that is forming will be rich in water will be stronger in water also okay. So initial vapour to be formed will be, will always be rich in the low boiling point substance okay. In this particular case it happens to be the ammonia okay. So that is what I am showing here.

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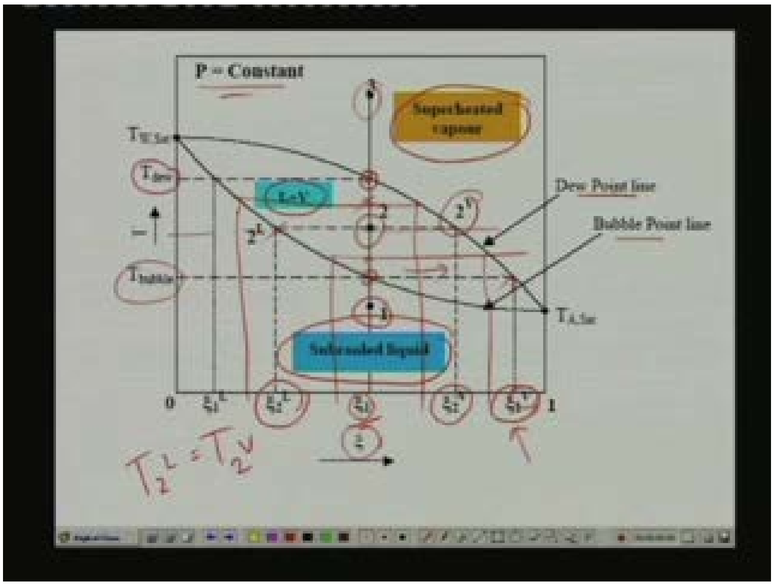

The first vapour bubble is quiet rich in ammonia vapour ammonia. So this thing so the concentration is given by zeta one v. v stands for vapour as I was explained and if you look at the point two where you have liquid as well as vapour. So what is the liquid phase concentration and what is the vapour phase concentration? Since both liquid and vapour are at thermal equilibrium both will have same temperature okay. So T two L for example will be equal to T to V okay. And what you have here you have the mixture of saturated liquid and saturated vapour okay. The concentration can easily be obtained if you are drawing this temperature line. And where this line intersects the bubble point line that will you the concentration of liquid okay.

And where this line constant temperature line intersects dew point line that will give you the vapour phase concentration okay. So using this you can find out easily what is the concentration at different phases. So it is interesting to see that the concentration will be different in the two phase region okay. And once you come back to the super heated region again you will find that because of the conservation of the mass the concentration again remains same okay. So this is how once you have the charts you can find out at any at any point. For example at some other point what is the concentration of the liquid what is the concentration of the vapour okay. At some other point what is the concentration will you get this is the concentration of vapour okay.

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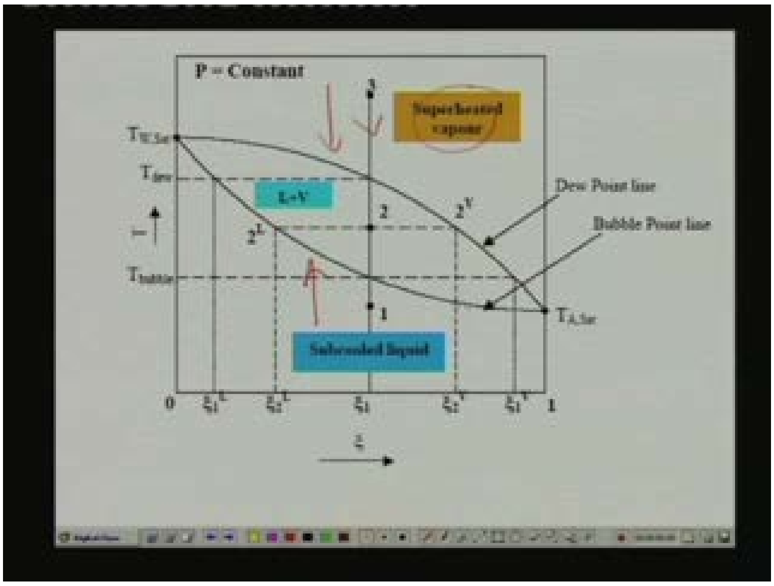

Of course this experiment can also be carried out in a reverse manner. That means initially you can take super heated vapour and start cooling the vapour okay. So you can proceed either in this manner or in this manner okay. Ultimately you will get the same curve.

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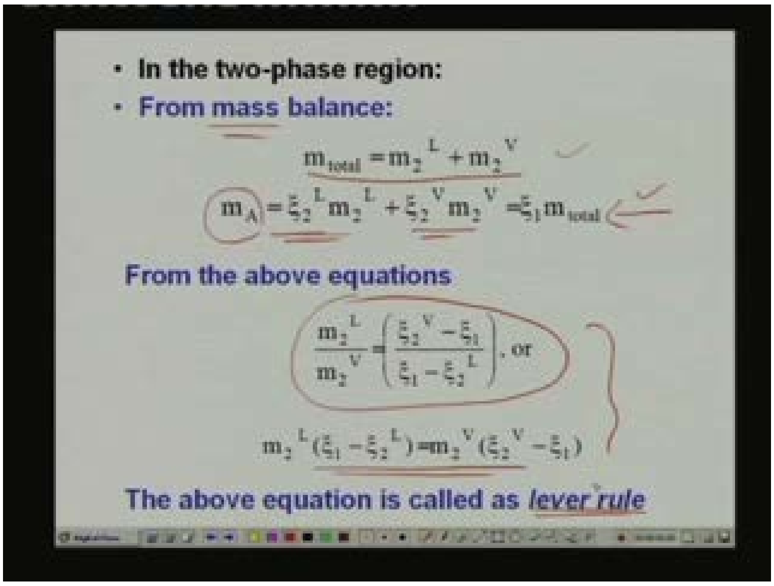

- **In the two-phase region:**
- **From mass balance:**

$$m_{total} = m_2^L + m_2^V$$

$$m_A = \xi_2^L m_2^L + \xi_2^V m_2^V = \xi_1 m_{total}$$

From the above equations

$$\frac{m_2^L}{m_2^V} = \left(\frac{\xi_2^V - \xi_1}{\xi_1 - \xi_2^L}\right), \text{ or}$$

$$m_2^L(\xi_1 - \xi_2^L) = m_2^V(\xi_2^V - \xi_1)$$

The above equation is called as *lever rule*

And for the two-phase region, just now I have explained you can write the mass balanced. So the total mass is always conserved. Total mass is nothing but m two L plus m two V and you can also write a conservation equation for the ammonia mass okay. This is nothing but the total mass of ammonia in the mixture that a, is nothing but ammonia in liquid phase plus ammonia in vapour phase okay. So you can write these two equations from the mass balance okay. And from these two equations you can easily show that you can eliminate m one and you can easily show that m two liquid by m two vapour is nothing but zeta two V minus zeta one divided by zeta one minus zeta two L okay. Or you can also write this in the uh this form okay. This particular rule is called as a mixing rule or it sometimes it is also called as lever rule. What do you mean by lever rule?

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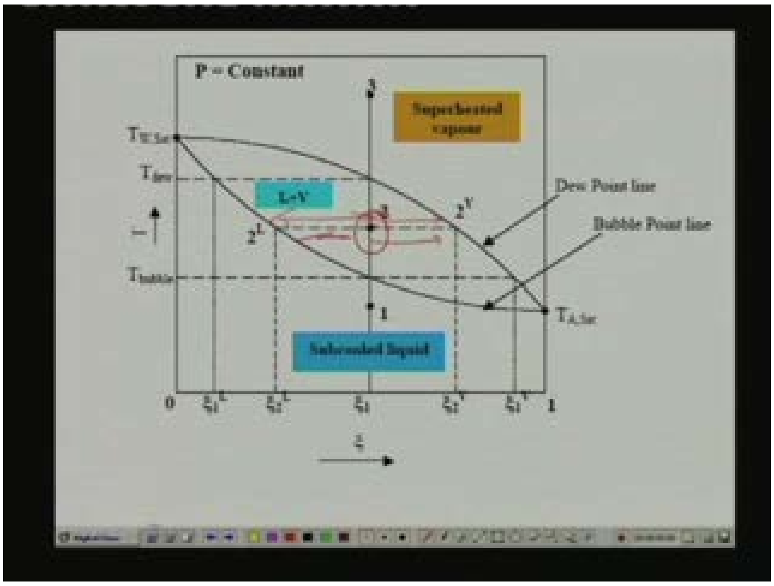

Lever rule means this point actually acts as a fulcrum okay. So the, we want to find out what is the mass of this thing okay. The total mass into this distance will always be equal to mass of vapour into this distance okay. So when as this distance increases you will find that this point move closer to this dew point line. That means vapour concentration increases. Similarly when this point moves this side we will find that liquid concentration increases okay. So that is what is shown in this equation.

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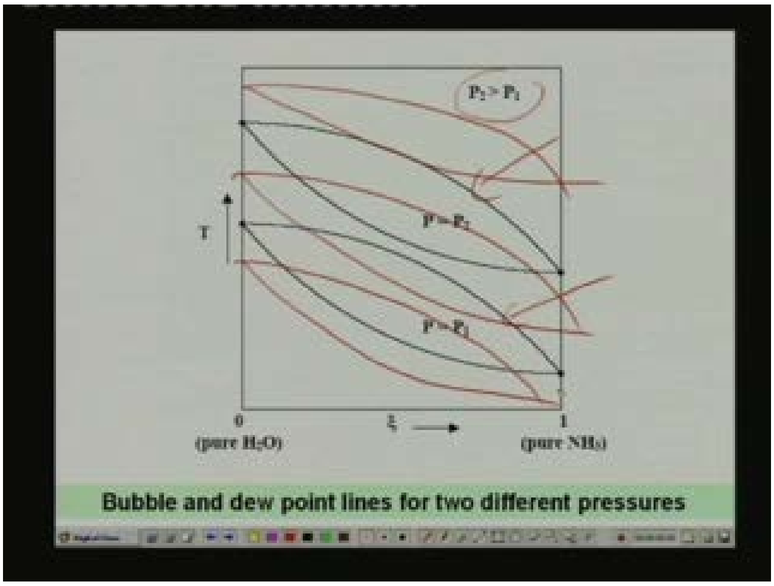

Bubble and dew point lines for two different pressures

Of course you by few of huh carrying out this experiment at two different pressures let us say then you will get two different lines okay. This is for one pressure P two and this is for another pressure P one and P two is greater than P one. So the same thing can be repeated at different pressures. So at different pressures you'll get different lines like this okay, right.
So this is the typical bubble and dew point chart for a binary mixture okay.

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Enthalpy of ammonia-water mixtures

Liquid phase:

- Since strong ammonia-water solution deviates from ideal solution behaviour:
  - the mixing is an exothermic process
  - The specific enthalpy of solution is given by: $h = \xi h_A + (1-\xi) h_W + \Delta h_{mix}$

    specific enthalpy at any concentration and temperature can be calculated provided the heat of mixing is known from measurements

So now, let us look at enthalpy of ammonia-water mixtures. First let us look at liquid phase enthalpy. Since strong ammonia-water solution deviates from ideal solution behaviour the liquid phase enthalpy has to be obtained by this equation. That is h is zeta h A plus one minus zeta hW plus delta h mix delta h mix is negative. Because the mixing process is an exothermic process just like water-lithium bromide system. And the specific enthalpy a, at any concentration and temperature can be calculated from the above expression provided. We know the heat of mixing heat of mixing is normally obtained from measurements.

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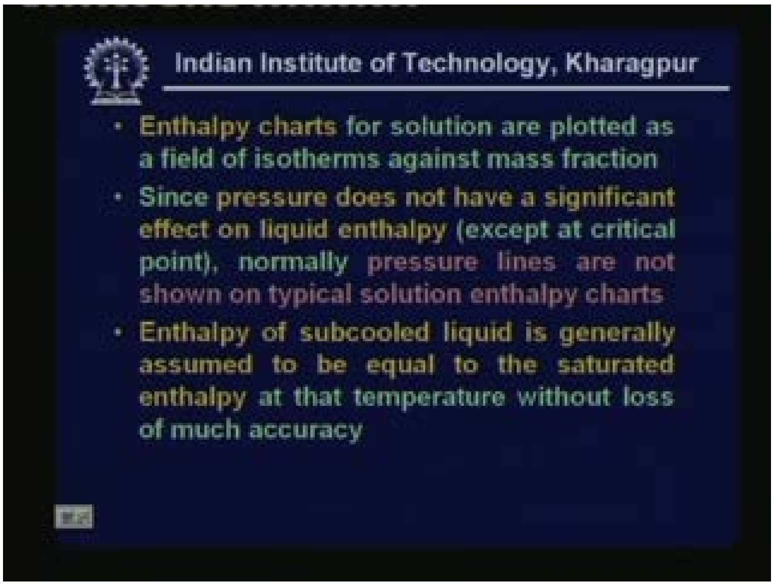

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- Enthalpy charts for solution are plotted as a field of isotherms against mass fraction
- Since pressure does not have a significant effect on liquid enthalpy (except at critical point), normally pressure lines are not shown on typical solution enthalpy charts
- Enthalpy of subcooled liquid is generally assumed to be equal to the saturated enthalpy at that temperature without loss of much accuracy

Now enthalpy charts for solution are plotted as a field of isotherms against its mass fraction. In fact I will show you the typical enthalpy chart for ammonia-water mixture in the next class. So normally there are plotted against mass fraction for different isotherms and since pressure does not have a significant effect on liquid enthalpy except at critical point normally the pressure lines are not shown on typical solution enthalpy charts okay. That means in the for the liquid enthalpy only the temperatures and concentrations are given okay. Pressures are not normally shown and it is also generally assumed that enthalpy of sub cooled liquid is equal to the saturated enthalpy at that temperature okay. If you are assuming this, it will considerably simplify the calculation procedure and it does not give really a big error okay, it is a standard procedure.

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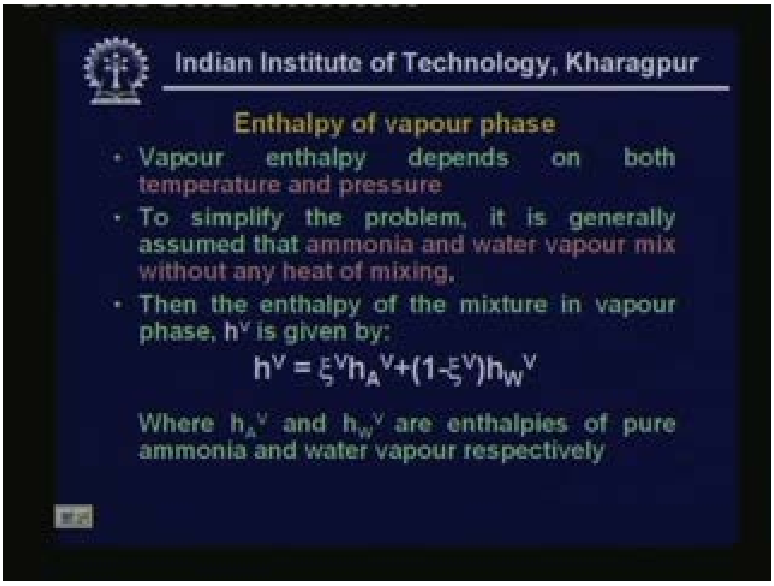

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Enthalpy of vapour phase

- Vapour enthalpy depends on both temperature and pressure
- To simplify the problem, it is generally assumed that ammonia and water vapour mix without any heat of mixing.
- Then the enthalpy of the mixture in vapour phase, h^V is given by:

$$h^V = \xi^V h_A^V + (1-\xi^V) h_W^V$$

Where h_A^V and h_W^V are enthalpies of pure ammonia and water vapour respectively

Now enthalpy of liquid phase is relatively easy so how do we calculate the enthalpy of vapour phase. The complication comes because in the vapour phase we both ammonia as well as water vapour okay. So and the vapour enthalpy as you know depends up on temperature and pressure okay. So to simplify the problem again what we what is generally done is, it is assume that ammonia and water vapour mix without any heat of mixing okay. That means there is no change of phase or any chemical reaction when vapours of ammonia and water mix okay.

And such case the enthalpy of mixture phase is given by this simple equation hV is equal to zeta V hA V plus one minus zeta V hW V where zeta V as you know is a vapour phase mass fraction and hA V and hW V are vapour phase enthalpies of pure ammonia pure water vapour. Now the problem comes because hA and hW for vapour phase are functions of both pressure and temperature okay.

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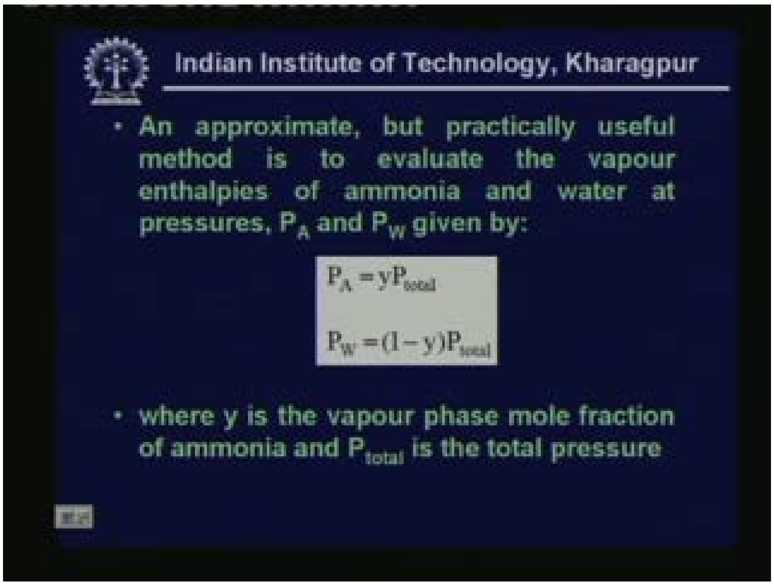

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- An approximate, but practically useful method is to evaluate the vapour enthalpies of ammonia and water at pressures, P_A and P_W given by:

$$P_A = yP_{total}$$

$$P_W = (1-y)P_{total}$$

- where y is the vapour phase mole fraction of ammonia and P_{total} is the total pressure

So an approximate, but practically useful method is to evaluate the vapour enthalpies of ammonia and water at pressures PA and PW given by PA is equal to y into P total and PW is equal to one minus y into P total. Remember this is an approximate method but is gives reasonably accurate results. And what is y here? y is the vapour phase mole fraction of ammonia and P total is the total pressure. If ammonia and water vapour behave as ideal gas you will find that y into P total is nothing but the partial pressure of ammonia in the mixture. Similarly one minus y into P total is the partial pressure of water vapour in the mixture. But you will find that most of the times the mixture deviates from ideal gas mixtures. So y into P total and one minus y into P total do not give partial pressures okay.

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Enthalpy-composition diagram

- Charts of enthalpy-temperature-mass fraction are available which give liquid as well as vapour enthalpy of mixtures
- Enthalpy-composition diagram at a single pressure:
- At a single pressure, the isotherms in two-phase region are obtained by joining saturated liquid and vapour states

Now let us look at enthalpy composition diagram charts of enthalpy-temperature -mass fraction are available which give both liquid as well as vapour enthalpy of mixtures. As I said, I will show this in the next class right. Now what I will show is enthalpy-composition diagram at a single pressure because in order to understand it's easier to start with the single pressure. At a single pressure the isotherms in two-phase region are obtained by joining saturated liquid and vapour states. So let me show the enthalpy saturated diagram enthalpy-composition diagram at single pressure.

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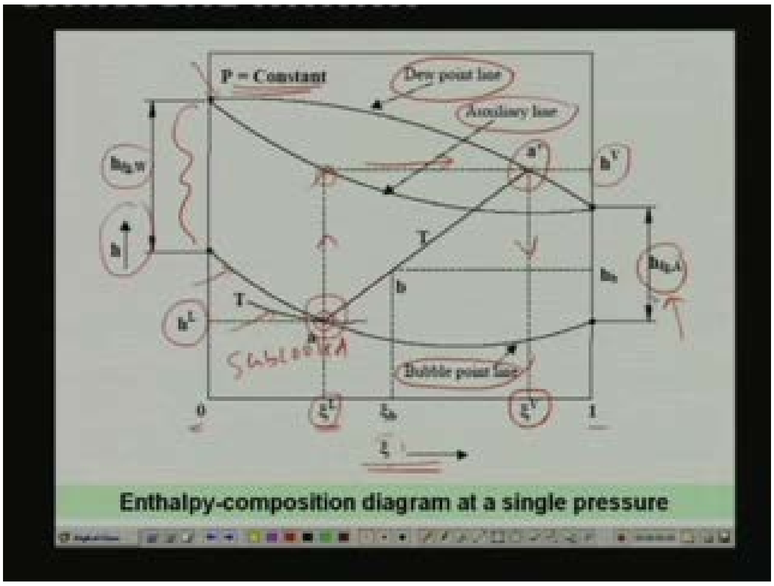

Enthalpy-composition diagram at a single pressure

Okay, so what we have here is the composition of ammonia in y-axis and enthalpy, I am sorry, in x-axis and enthalpy in y-axis okay. So again you have the bubble point line and the dew point line. In addition to that in order to find the enthalpy of vapour and composition of vapour and auxiliary line is shown okay. So this line is an auxiliary line okay, and remember that this for a single pressure that means at a constant pressure. And the isotherms are shown in the sub cool liquid region this is the sub cool that this is the sub cooled liquid for this pressure okay.

So the isotherms are shown in the sub cooled region and this is the one typical isotherm T okay. So this isotherm intersects this bubble point line at this point okay. So let us assume that initially we have a saturated liquid at this point so it has a mass liquid phase mass fraction zeta L okay. I would like to find out what is the mass fraction of the vapour that is in equilibrium with this solution. So in order to find and what is its enthalpy. So in order to find that what normally is done is you draw a vertical line starting from this point and find the point that is the intersection point between the auxiliary line and this vertical line. That means this point okay. So draw a vertical line and get this intersection point from this intersection point. Draw a horizontal line where this horizontal line intersects the dew point line that will give you the vapour phase mass fraction okay. So once you get this point the vapour phase mass fraction is obtained by going down vertically. And this is the vapour phase mass fraction and this is the enthalpy of the vapour phase saturated vapour okay. Similarly this is the enthalpy of the saturated liquid what it means is at this particular condition saturated vapour of this mass fraction. And this enthalpy is in equilibrium with saturated liquid of this mass fraction and this enthalpy okay.

So that is how you have to find out the saturated vapour enthalpies and mass fractions. And you can see that here I am varying the concentration from zero to one. That means from pure water to pure ammonia. So obviously this difference which is nothing but the enthalpy difference between saturated liquid and saturated vapour is nothing but your latent heat of vaporization for pure water at this pressure. Similarly at the other end the difference, this difference or this distance gives you the latent heat of vaporisation for ammonia at this particular pressure okay, and the line joining this point.

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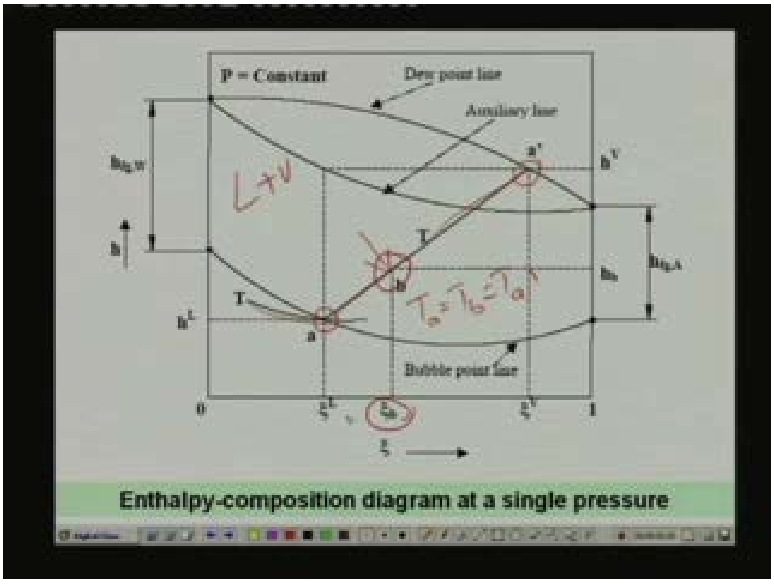

Enthalpy-composition diagram at a single pressure

Okay, so for this pressure the line joining the saturated liquid point with saturated vapour point. That means this line is the isotherm okay. That means the isotherm T is like this okay, right and point b. What is point b point b is in the two-phase region. So be this is the two-phase region. So if you look at point b point b is in two-phase region and at this point the temperatures are all equal. That means Ta is equal to Tb is equal to Ta dash okay. And at this two-phase, this thing, this is the enthalpy of the two-phase mixture. I am sorry, this is the mass fraction the two-phase mixture. This is the enthalpy of the two-phase mixture okay. So this is a very useful chart.

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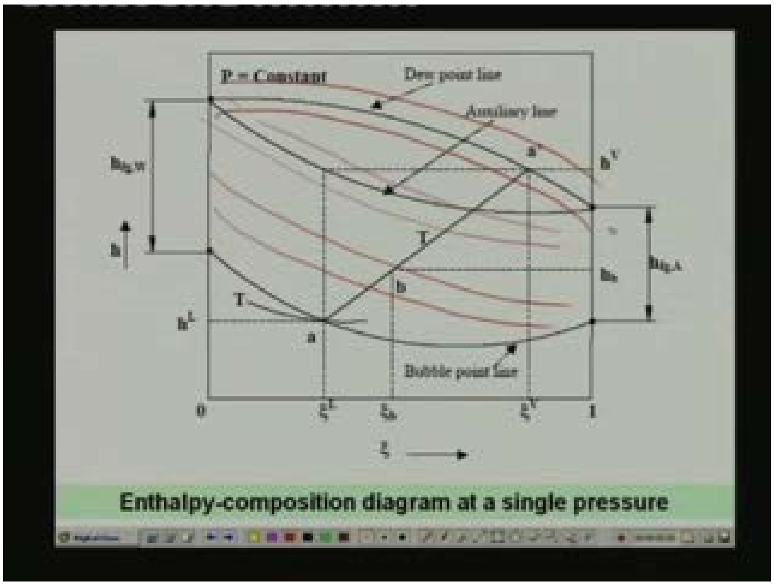

Enthalpy-composition diagram at a single pressure

And if it is, if you plot this for different pressures as you will see later you have different lines okay, different bubble point lines. Similarly different dew point lines and different auxiliary lines okay. So you will find a whole lot of lines and typical entire total enthalpy composition diagram for a binary mixture.

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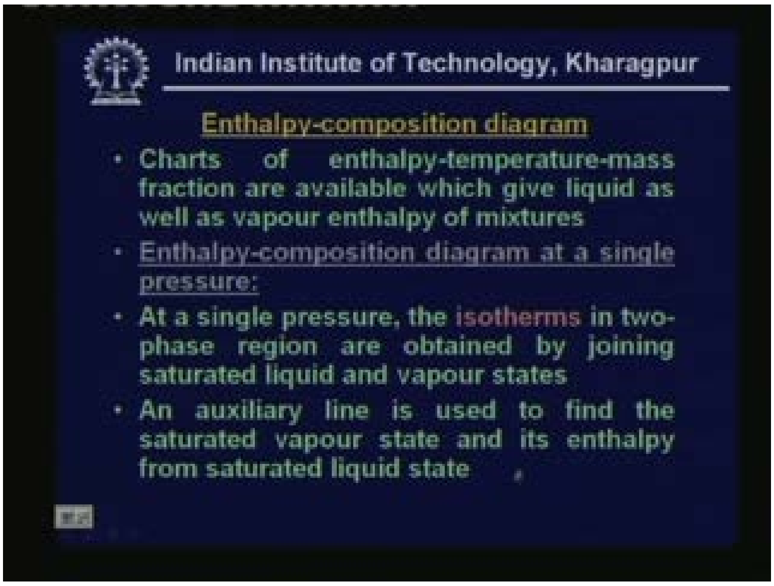

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Enthalpy-composition diagram

- Charts of enthalpy-temperature-mass fraction are available which give liquid as well as vapour enthalpy of mixtures
- Enthalpy-composition diagram at a single pressure:
- At a single pressure, the isotherms in two-phase region are obtained by joining saturated liquid and vapour states
- An auxiliary line is used to find the saturated vapour state and its enthalpy from saturated liquid state

And as I said an auxiliary line is used to find the saturated vapour state and its enthalpy saturated liquid state.

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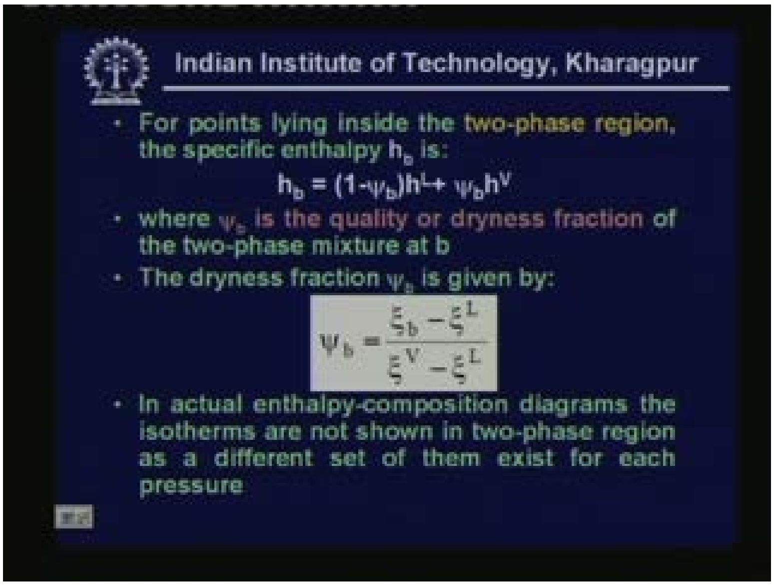

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- For points lying inside the two-phase region, the specific enthalpy h_b is:

$$h_b = (1-\psi_b)h^L + \psi_b h^V$$

- where ψ_b is the quality or dryness fraction of the two-phase mixture at b
- The dryness fraction ψ_b is given by:

$$\boxed{\psi_b = \frac{\xi_b - \xi^L}{\xi^V - \xi^L}}$$

- In actual enthalpy-composition diagrams the isotherms are not shown in two-phase region as a different set of them exist for each pressure

So points lying inside the two-phase region. The specific enthalpy hb has to be obtained from this equation just like a two-phase mixture of any fluid hb is equal to one minus phi b into hL plus phi b into Hv. Where phi b is the quality or dryness fraction and hL and hV are the saturated liquid enthalpy and saturated vapour enthalpy okay. And the dryness fraction is given by again what is the mass fraction at the, at that point minus saturated liquid mass fraction divided by the saturated vapour fraction minus saturated liquid fraction okay. And actual enthalpy concentration diagrams the isotherms are not shown in two-phase region. Because for each set of pressures you have a set of isotherms in the two-phase region okay. So it becomes very confusing so normally in enthalpy composition diagrams isotherms are not shown in the two-phase region. If that is the case how do we find the temperature in the two-phase region?

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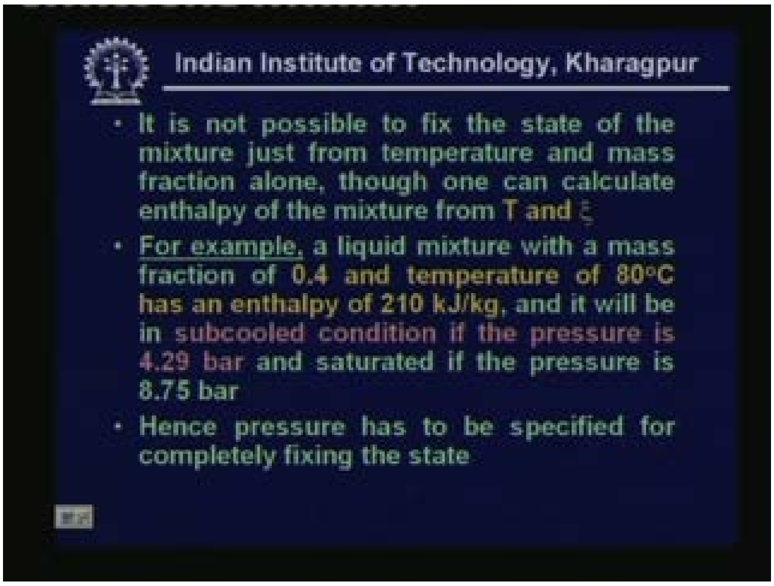

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- It is not possible to fix the state of the mixture just from temperature and mass fraction alone, though one can calculate enthalpy of the mixture from T and ξ
- For example, a liquid mixture with a mass fraction of 0.4 and temperature of 80°C has an enthalpy of 210 kJ/kg, and it will be in subcooled condition if the pressure is 4.29 bar and saturated if the pressure is 8.75 bar
- Hence pressure has to be specified for completely fixing the state

Okay, that I will discuss later and also it is not possible s to fix the state of the mixture just from temperature and mass fraction alone. Because one can calculate enthalpy of the mixture from temperature and concentration. But you cannot say whether it is in superheated region or sub cooled region or saturated region or two-phase region just by knowing temperature and huh composition okay. For example a liquid mixture with a mass fraction of point four and temperature of eighty degrees will have an enthalpy of two ten kilo joule per kilogram okay. This you can obtain from your enthalpy composition diagram. But it will be in sub cool condition if the pressure is four point two nine bar and saturated condition if the pressure is eight point seven five bar okay. So depending upon the pressure for the same composition and temperature solution can be in any state okay. So to remove the ambiguity you have to specify the pressure. So that you can completely fix the state.

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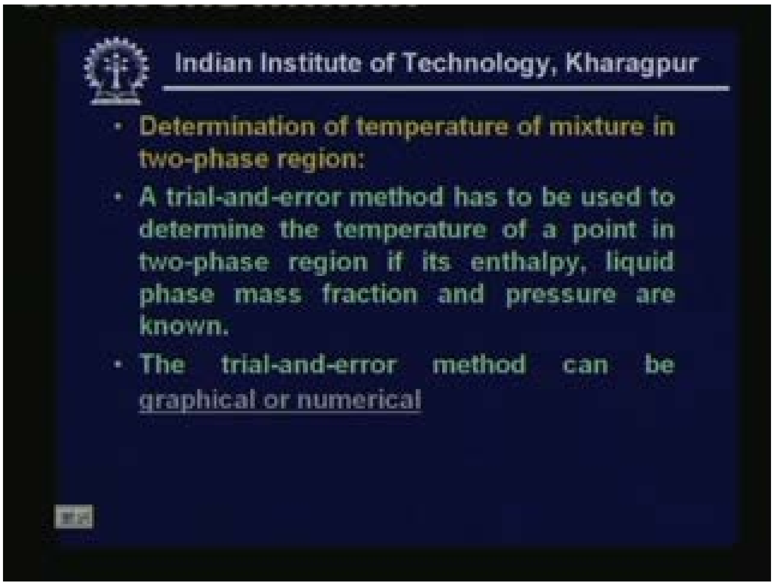

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- Determination of temperature of mixture in two-phase region:
- A trial-and-error method has to be used to determine the temperature of a point in two-phase region if its enthalpy, liquid phase mass fraction and pressure are known.
- The trial-and-error method can be graphical or numerical

Okay, determination of temperature of mixture in two-phase region, I was mentioning that you have to do, how do we decide this? Normally a trial -and-error method has to be used to determine the temperature and you have two n methods one is graphical and the other one is numerical. So let me quickly explain this.

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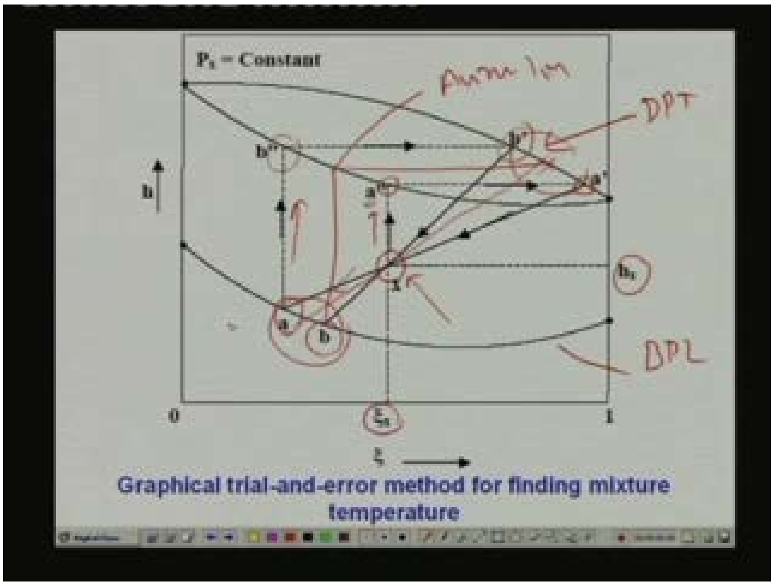

Graphical trial-and-error method for finding mixture temperature

Okay, in the graphical method let us the point X is the point in two-phase and I would like to find out what is the temperature of the mixture at this point. Initially what we do is we know that for this point. I know that this is the mass fraction and this is the enthalpy. So I know the mass fraction and enthalpy of the two-phase mixture. But I do not know its temperature okay. So to start with, what you do is you draw a vertical line in this manner and the point where it intersects this auxiliary line remember that this is the auxiliary line. This is your dew point line and this is your bubble point line okay. So where this vertical line intersects auxiliary line that is point a double dash you draw another horizontal line okay. This horizontal line intersects a dew point at a dash okay.

Now what you do draw a straight line passing through a dash and x okay. That is this line okay. So this line intersects bubble point line at point a right. So now what we have to do is you draw another vertical line from point a and where it intersects. Again the auxiliary line point is b double dash and from here you draw a horizontal line and this horizontal line intersects the dew point temperature at point b dash okay. So again draw one straight line passing through b dash and x and this intersects the bubble point line at x okay. So to repeat the process what we have to do we have to draw again a vertical line from this intersection point to draw another horizontal line. Get this point from this point again you draw line passing through x. So you get one more set of points. So this process has to be continued till the points here and points here converge. Normally the convergence takes place within three four iterations okay. So this is the graphical trial-and -error method for finding the temperatures. So how do you find the temperature?

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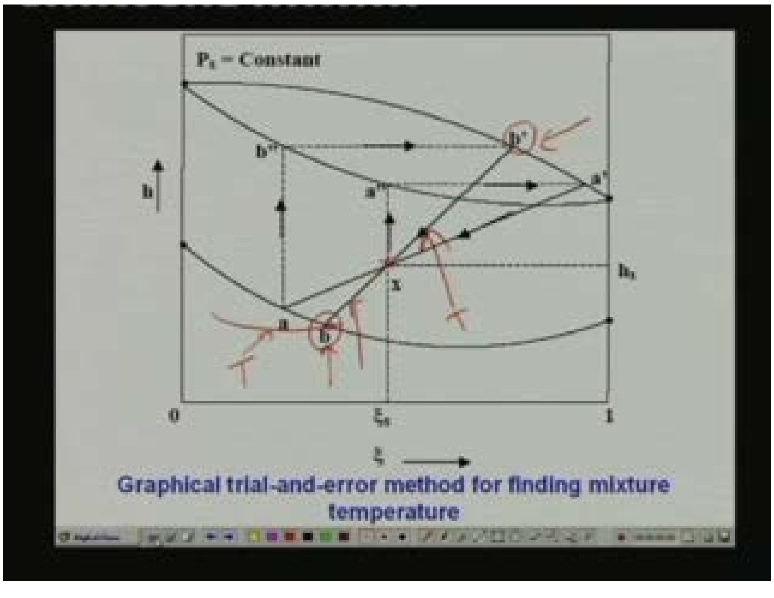

Graphical trial-and-error method for finding mixture temperature

From this method once you know the finally you know that this is, let us say that this is the line huh-uh the converse line. That mean, this is the line which gives the isotherm because you, that at this point is an equilibrium mixture consisting of saturated vapour and saturated liquid okay. That means this one has got to be the equilibrium line and the temperature in the sub cooled region which meets this point has to be the temperature of the two-phase mixture also okay. So you have to read this temperature so this temperature is same as this temperature okay. So this is the procedure.

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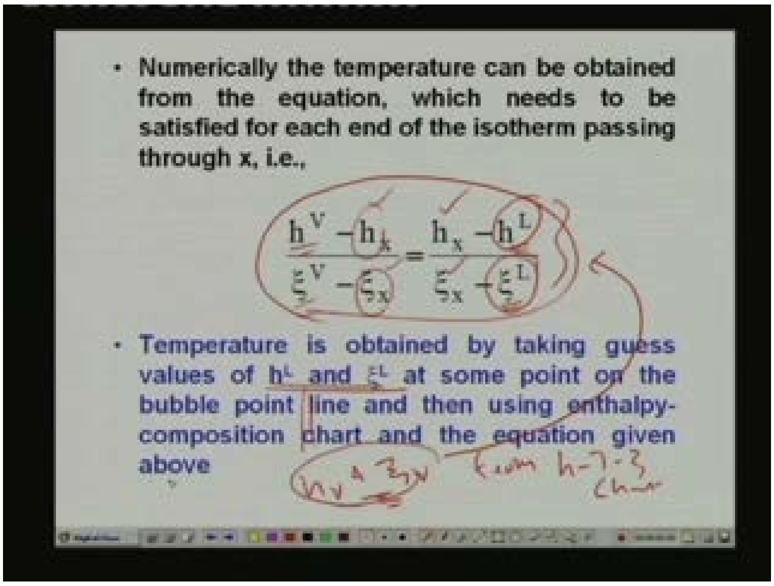

- Numerically the temperature can be obtained from the equation, which needs to be satisfied for each end of the isotherm passing through x, i.e.,

$$\frac{h^V - h_x}{\xi^V - \xi_x} = \frac{h_x - h^L}{\xi_x - \xi^L}$$

- Temperature is obtained by taking guess values of h^L and ξ^L at some point on the bubble point line and then using enthalpy-composition chart and the equation given above

And numerically the temperature can be obtained from the equation which needs to be satisfied for each end of the isotherm passing through X okay. That means the isotherms passing through the two-phase mixture has to satisfy this equation oaky, where hV and hL as you know are saturated vapour and liquid enthalpies. Similarly zeta V and zeta L are saturated vapour and liquid compositions and hX and zeta X are the mixture properties and we know this mixture properties okay. So these things are known to us. So what we do is, initially you assume a guess values of hL and zeta L then from the guess value find out hV and zeta V from your h-T composition chart okay. Then you substitute these values in this expression. And substituting this you find this value and his value okay. And again use these two values to find again a new value of hV and zeta V. So this procedure has to be carried continued till you again get converse values.

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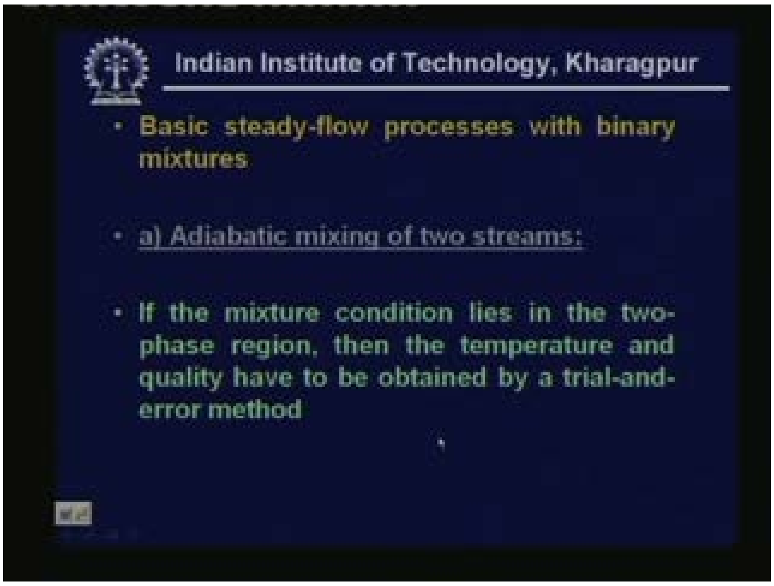

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- Basic steady-flow processes with binary mixtures
- a) Adiabatic mixing of two streams:
- If the mixture condition lies in the two-phase region, then the temperature and quality have to be obtained by a trial-and-error method

Now let us quickly look at some basic steady-flow processes with binary mixtures. First very simple process that is the adiabatic mixing of two streams. So let me show this process.

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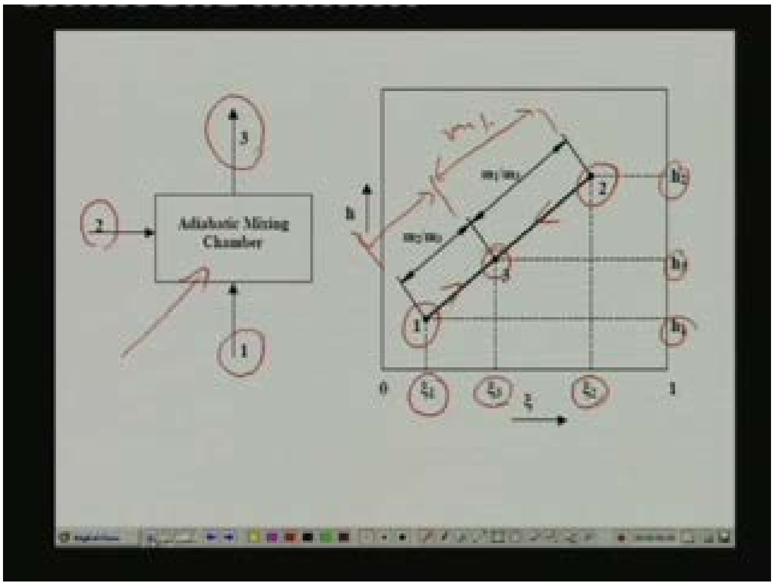

So what we have here is an adiabatic mixing chamber. That means, that is neither heat transferred to or from the mixing chamber and in this mixing chamber two streams. One stream at condition one and other stream at condition two there we have getting mixed in this adiabatic chamber. And finally what you are getting out is the single stream at state three okay. The same thing is shown on enthalpy and composition plot. So this is the state one this is the stream one and this is stream two. These two streams are mixed and let us say this is the condition of the exit stream okay. So you can point the composition this is the composition of the stream one composition of stream two and this is the composition of stream three. Similarly this is the enthalpy of stream one enthalpy of stream two and enthalpy of stream three okay. And you will find that I can be easily shown. I will show you in a minute that this distance is nothing but m two by m three and this distance is nothing but m one by m three okay. How to do that okay, so let me show this again on.

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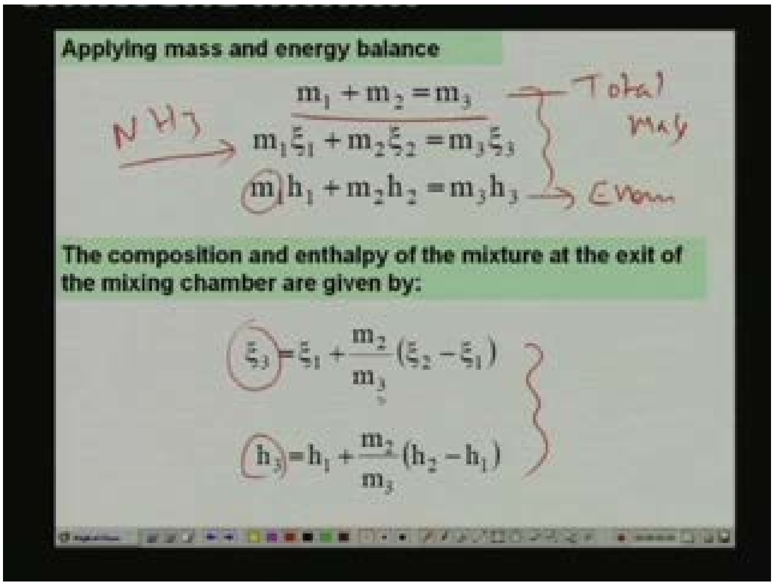

Applying mass and energy balance

$$\underline{m_1 + m_2 = m_3} \rightarrow \text{Total mass}$$

$$\text{NH3} \rightarrow m_1\xi_1 + m_2\xi_2 = m_3\xi_3$$

$$\boxed{m_1} h_1 + m_2 h_2 = m_3 h_3 \rightarrow \text{Energy}$$

The composition and enthalpy of the mixture at the exit of the mixing chamber are given by:

$$\boxed{\xi_3} = \xi_1 + \frac{m_2}{m_3}(\xi_2 - \xi_1)$$

$$\boxed{h_3} = h_1 + \frac{m_2}{m_3}(h_2 - h_1)$$

So of then I will show these equations if we are applying mass and energy balance. Then you know that some mass balance m one plus m two should be equal to m three this is the total mass balance oaky. You can also write a mass balance for ammonia right. So m one zeta one plus m two zeta two is m three zeta three and this is the energy balance for the adiabatic mixing chamber okay. So no heat transfer or work transfer. So the composition enthalpy of the mixture at the exit of the mixing chamber for using these equation and eliminate m one you can easily show that the mixture condition. The composition is given by this and the enthalpies is given by this simple equation okay.

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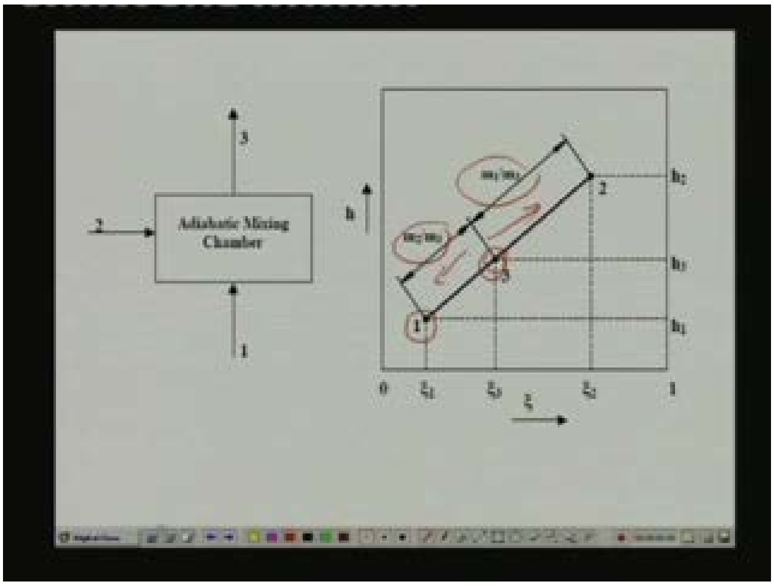

So the from that you can easily show that this mixture condition these distances are m two by m three and m one by m three. For example as m two increases you will find that this point as m two by m three increases this point will shift to this side. That means the exit conditions will be moving closer to two similarly when m one increases this point will shift to in this direction and the mixture condition will be one. If m one and m two is zero then you will find that this condition coincides with one or two.

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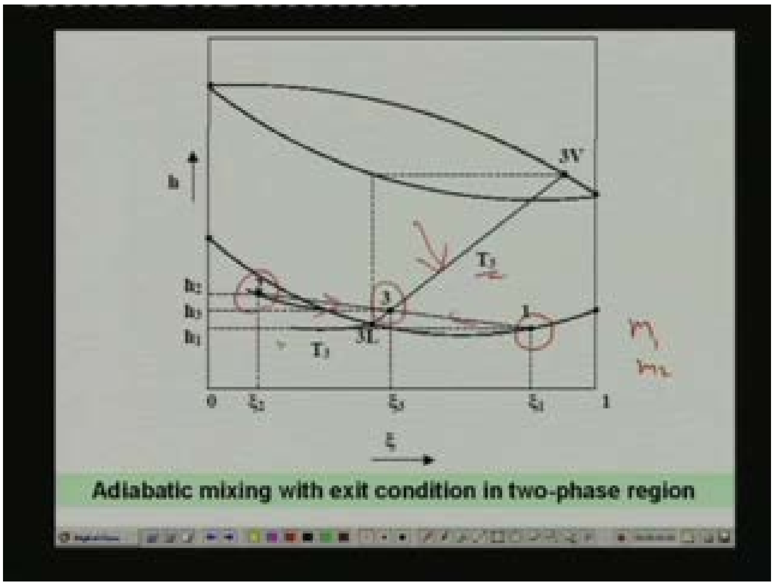

Adiabatic mixing with exit condition in two-phase region

Now if the streams are such that the mixing condition in that in the two-phase region then what you will do. For example let us say that we have mixed two streams where stream one stream one is saturated liquid and stream two is a sub cooled liquid okay. So these two streams are mixed and you will find that the resultant mixture that means the outlet mixture lies in the two-phase region. Because as you know that the outlet condition must lie on a straight line joining point one and two okay. So this is the mixing process. So the outlet condition must lie on point three. So when you are pointing it out on this knowing m one m two and if you are finding that this point lies in the two-phase region okay. Then we do not know this temperature okay. And two-phase region is again it will have vapour and liquid phase mass fractions. Again this temperature as well as vapour and liquid phase mass fraction have what we obtained from trial a-and error method as I have explained earlier okay.

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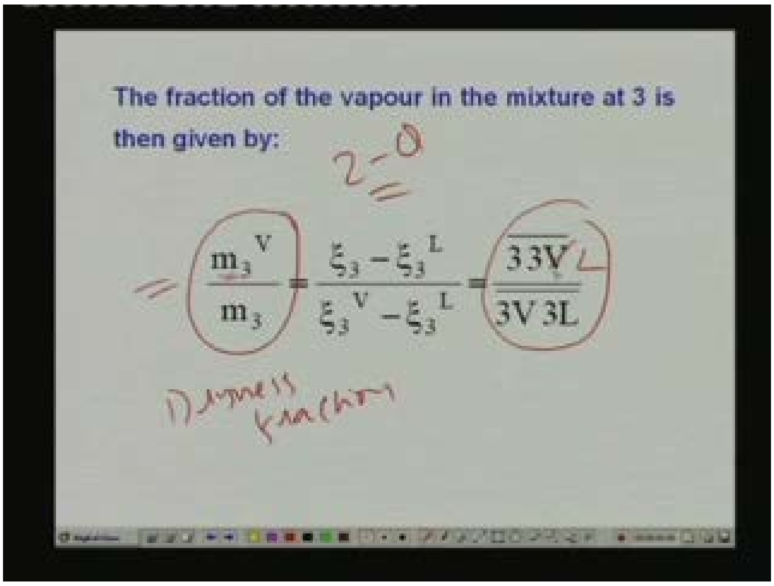

The fraction of the vapour in the mixture at 3 is then given by:

2-0

$$= \frac{m_3^V}{m_3} = \frac{\xi_3 - \xi_3^L}{\xi_3^V - \xi_3^L} = \frac{\overline{33V}}{\overline{3V\,3L}}$$

L

Dryness fraction

And it can be easily shown that the fraction of vapour in the mixture at three in two-phase region okay, in two-phase region is given by this expression. That means this is the mass of vapour to the total mass this is nothing but you dryness fraction and this should be L okay, three three L zeta three minus zeta three L by zeta three V minus zeta three L okay. This is nothing but your dryness fraction okay. So if you know these points then you can easily find out the dryness fraction and geometrically you can find out once you get these lengths.

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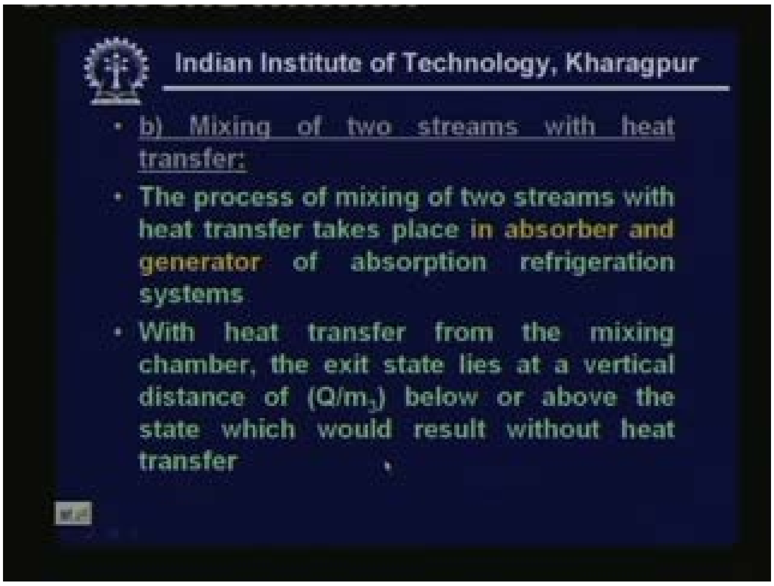

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- b) Mixing of two streams with heat transfer:
- The process of mixing of two streams with heat transfer takes place in absorber and generator of absorption refrigeration systems
- With heat transfer from the mixing chamber, the exit state lies at a vertical distance of (Q/m_3) below or above the state which would result without heat transfer

Now let us look at another process where mixing of two streams takes place with heat transfer okay. This, the typical process that takes place either in the absorber or generator of absorption refrigeration systems okay. So let me show that process.

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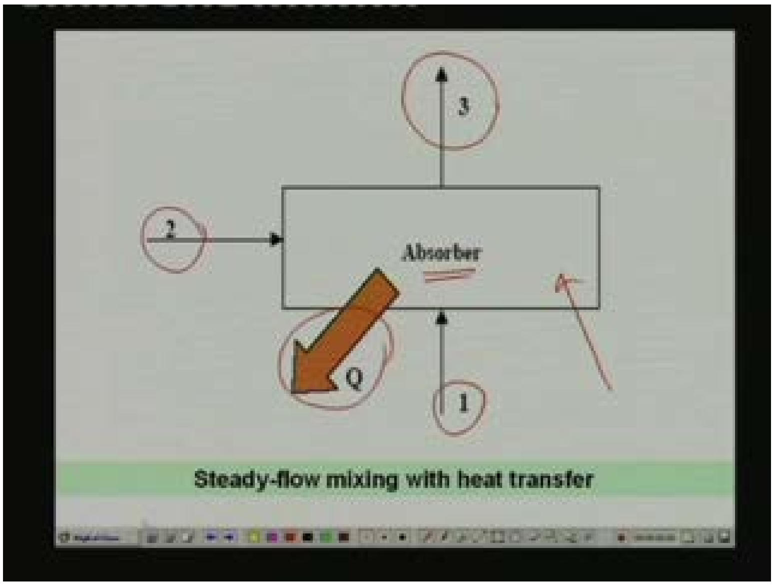

Steady-flow mixing with heat transfer

Okay, so this is similar to the earlier one only difference is here you have heat transfer okay. So again stream one is mixing with stream two and the resultant mixer is stream three and during this process some heat has been transferred okay. If it is an absorber you know that it is an exothermic process. So heat is transferred out of the system if it is generator you have to supply heat to the system okay. Let us say that this is the process for this process what are the steady-flow equations.

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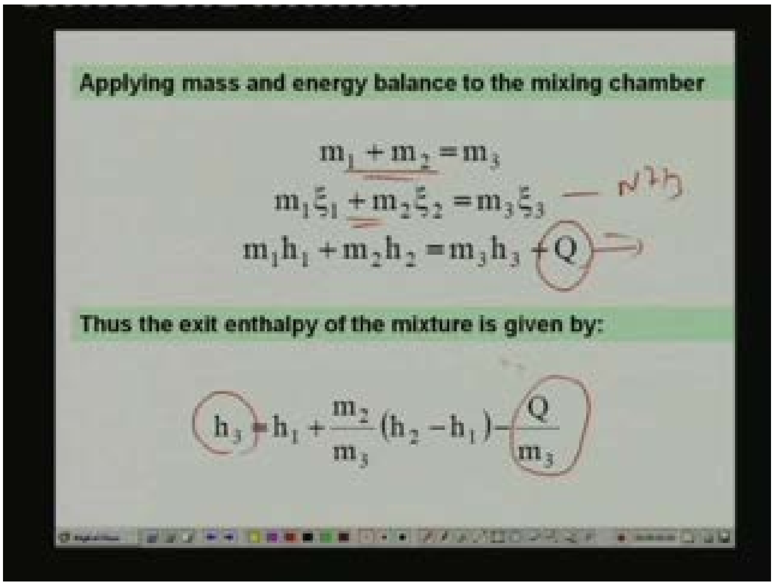

Applying mass and energy balance to the mixing chamber

$$m_1 + m_2 = m_3$$

$$m_1\xi_1 + m_2\xi_2 = m_3\xi_3 \quad — NH_3$$

$$m_1h_1 + m_2h_2 = m_3h_3 + \boxed{Q} \Rightarrow$$

Thus the exit enthalpy of the mixture is given by:

$$\boxed{h_3} = h_1 + \frac{m_2}{m_3}(h_2 - h_1) - \boxed{\frac{Q}{m_3}}$$

Steady flow equation just like earlier this thing mass balance is this total mass balance. This is the mass balance for ammonia okay. And this is the energy valance okay. So the only different between adiabatic mixing and mixing with heat transfer is in this term when this Q becomes zero you will find exactly this equation exactly same as adiabatic mixing process when Q is non-zero you get this equation. So from this equation it can be very easily shown that the exit enthalpy h three is nothing but h one plus m two minus h three into h two minus h one minus Q by m three. So this is the difference okay.

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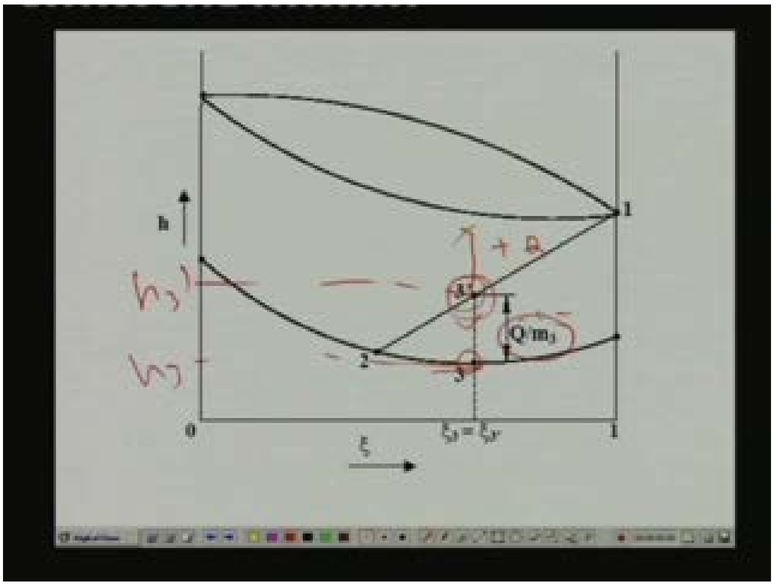

So the same thing can be easily shown and your concentration enthalpy diagram like this without any mixing this will be the process okay. I am sorry without any heat transfer this is the process with heat transfer you will find that the exit condition lies at a vertical distance below this point if heat transfer is from the system okay. And this distance is nothing but the heat transfer rate divided by the mass flow rate of the solution at condition three okay. So if you know these two things first find out this point assuming that it is adiabatic mixing. Then this point is simply assumed simply obtained by drawing a vertical line and going down by this much distance okay. That means this is without any heat transfer h three dash is the specific enthalpy and h three is an enthalpy with a heat transfer from the system okay. If the heat transfer is to the system obviously this point will move up okay, this is for the positive Q whereas this is for the negative Q.

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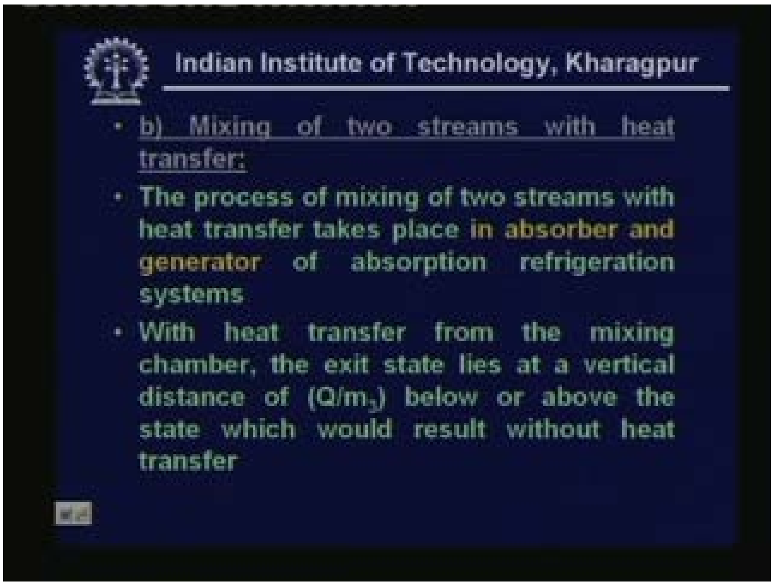

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- b) Mixing of two streams with heat transfer:
- The process of mixing of two streams with heat transfer takes place in absorber and generator of absorption refrigeration systems
- With heat transfer from the mixing chamber, the exit state lies at a vertical distance of (Q/m_3) below or above the state which would result without heat transfer

Okay, so with heat transfer from the mixing chamber the exit state lies at a vertical distance of Q by m three below or above the state which would result without heat transfer. That is what I have explained just now.

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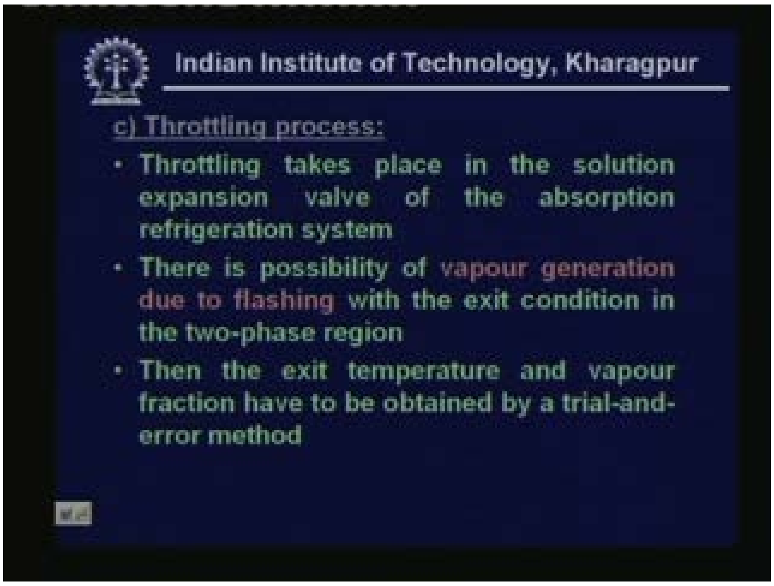

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c) Throttling process:

- Throttling takes place in the solution expansion valve of the absorption refrigeration system
- There is possibility of vapour generation due to flashing with the exit condition in the two-phase region
- Then the exit temperature and vapour fraction have to be obtained by a trial-and-error method

Now let us look at another simple process that is the throttling process as you know throttling takes place in the solution expansion valve of the absorption refrigeration system okay. So throttling is an isenthalpic expansion process. And during this process there is a possibility of vapour generation due to flashing okay. This we have seen earlier. If this is the case then you will find at the exit condition lies in the two-phase region. If the exit condition lies in the two-phase region again you have to use a trial-and-error method to find the exit temperature and vapour fraction okay. So let me quickly show the throttling process.

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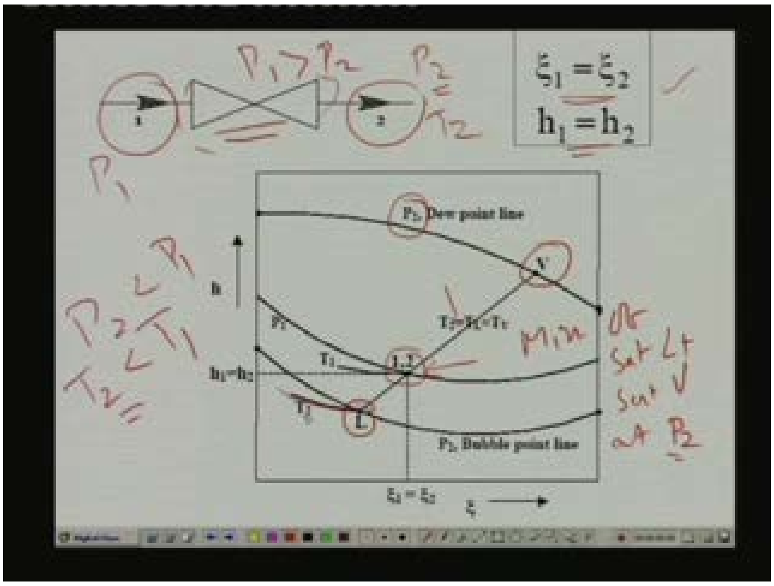

$$\xi_1 = \xi_2$$
$$h_1 = h_2$$

Okay, so as you know this is the throttle one. So a solution at condition one passes through the throttle valve and it emerges out at point two and if the pressure p one is at condition one. And if the p two at the exit you know that p one is greater than p two okay. And this is typically an isenthalpic process so there is neither heat transfer nor work transfer during this process. So if you are applying mass and energy balance you will simply find that the composition remains constant and the enthalpy also remains constant. So if you are trying to show this throttling process on enthalpy composition diagram you will find that both inlet and exit points are on the, at the same point okay. That mean they are identical okay. Why they are identical because enthalpy is also same as this equation shows and concentration also same right.

So they will be identical but we know that at this point the pressure is different and if there is any vapour generation the temperature also will be different. That means pressure is will be lower than outlet pressure will be lower than inlet pressure. Similarly outlet temperature will be lower than inlet temperature okay. So how do you find this outlet and inlet pressures. We know that this exit condition for example point two is just a mixture of saturated liquid plus saturated vapour at outlet pressure p two okay. That means suppose this is the saturated liquid condition and this is saturated vapour condition at the outlet pressure p two. And if you know these by trial-and-error method then you can find out the temperature okay. Because this temperature is nothing but the temperature of this isotherm okay. So this how you have to find the exit condition of the throttling process.

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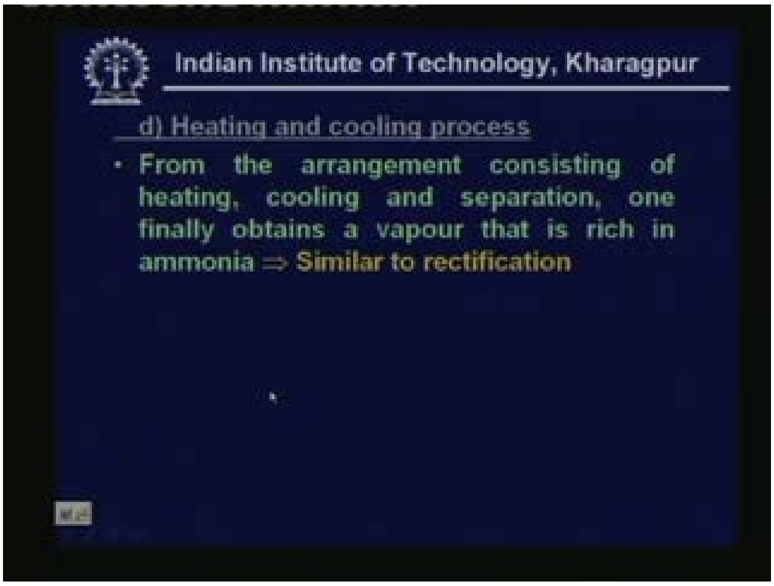

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d) Heating and cooling process

- From the arrangement consisting of heating, cooling and separation, one finally obtains a vapour that is rich in ammonia ⇒ Similar to rectification

Now let us look at another simple but important process that is called heating and cooling process. So let me first explain the arrangement.

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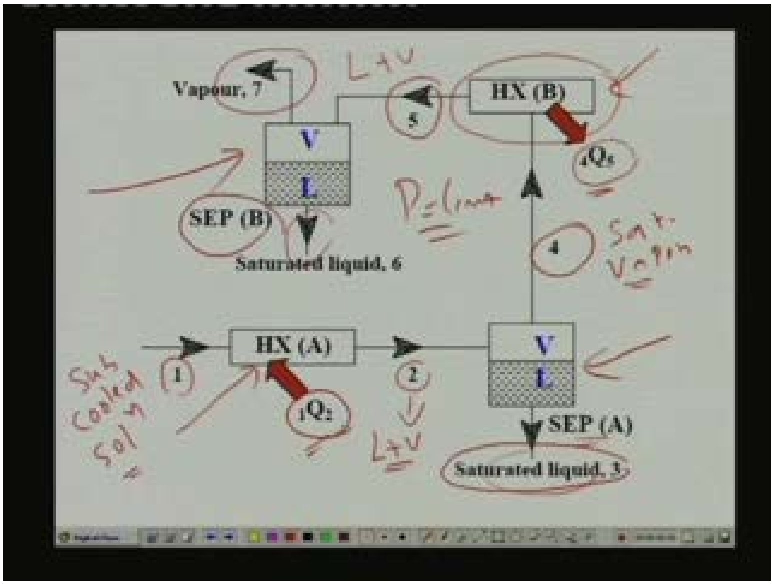

Okay, what we have here is an arrangement which consist of two heat exchangers heat exchanger A and heat exchanger B and also two separators separator A and separator B okay. So initially I have taken a sub cooled solution okay this is the sub cooled solution remember and here pressure is constant ever where. So I have taken in a sub cooled solution at state one and I have heated that sub cooled solution in a heat exchanger A by supplying heat one Q two okay.

So heat is supplied and this comes out at point two okay. And this heat supplied is as such that point two lies in the two-phase region. That means at point two you have both liquid and vapour okay. Then what is done is this liquid and vapour two-phase mixture is fed to this separator A in the separator the saturated liquid at state three is as separated from saturated vapour at state four. So this is the saturated vapour okay. That means separator. What is the function of the separator function of the separator is simply to separate the liquid from the vapour okay. At the same pressure and there is no heat transfer or anything in the separator that is assumption.

So here we are separating out the saturated liquid and vapour then here you have saturated vapour. Then what we are doing is we are I am cooling this saturated vapour in this heat exchanger B by extracting this much amount of heat okay. So the first the solution is heated in heat exchanger A and liquid and vapour are separated in separator A and then the saturated vapour is cooled in heat exchanger B by ejecting heat to outside okay. And it is cooled in such a way that this condition again lies in the liquid and vapour phases okay. So these heat transfer rates should be in such that the exit of heat exchangers you have two-phase region okay.

So again I am using a separator B where I am separating out liquid from the vapour. So finally I am taking the vapour from the arrangement at this point saturated liquid at this point and saturated liquid at this point. So this is the arrangement okay. Suppose I am plotting this process on enthalpy composition diagram how does it look okay.

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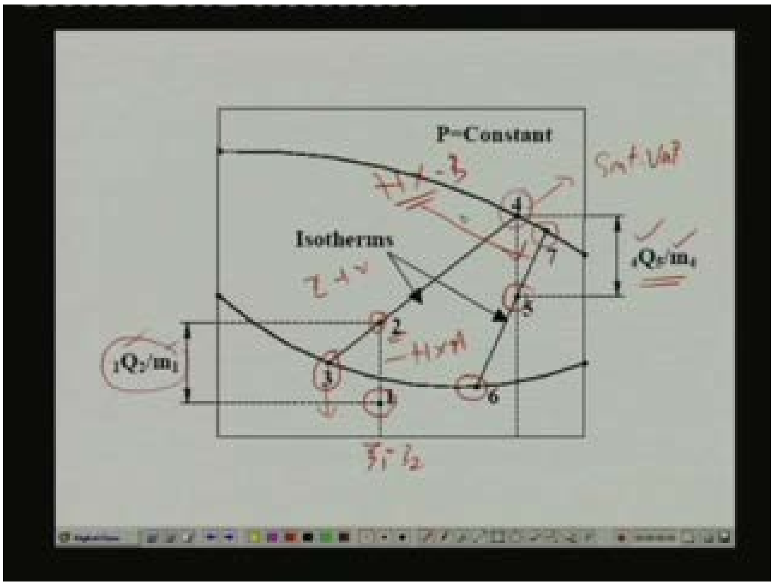

So we have started with sub cooled liquid at state one and we have heated this in heat exchanger A. So this is your heat exchanger A okay. So since this is the single stream you know that the exit condition will lie simply at a vertical distance of one Q two by m one above this point okay. So I can easily out this enthalpy and during this process your concentration remains same okay. So zeta one is equal to zeta two during this process, wait but the point two lies in the saturated lies in the two-phase region okay this is liquid plus vapour region. So that means at this point you have saturated liquid at point three and saturated vapour at point four. Now if you look at the earlier diagram what we have done is at this point we have taken out the saturated liquid and saturated vapour from the separator A okay.

So this is the process occurring in separator A and from that point onwards what is done is this saturated vapour okay, at condition four is cooled in the heat exchanger B okay. This is the process in heat exchanger B since this is cooled sensibly I mean this is cooled by etcetera. Dissecting heat to the surroundings you find that the exit condition lies at a vertical distance of four Q five by m four below this point okay. So you can easily find out this one if you know this and if you know this okay. Similar to this i you know this you can find out this point. So we have got the point five at this point at this point again this is in two-phase region. So again you have a mixture of saturated liquid at point six and saturated uh vapour at point s even okay, at this point the vapour is taken out okay.

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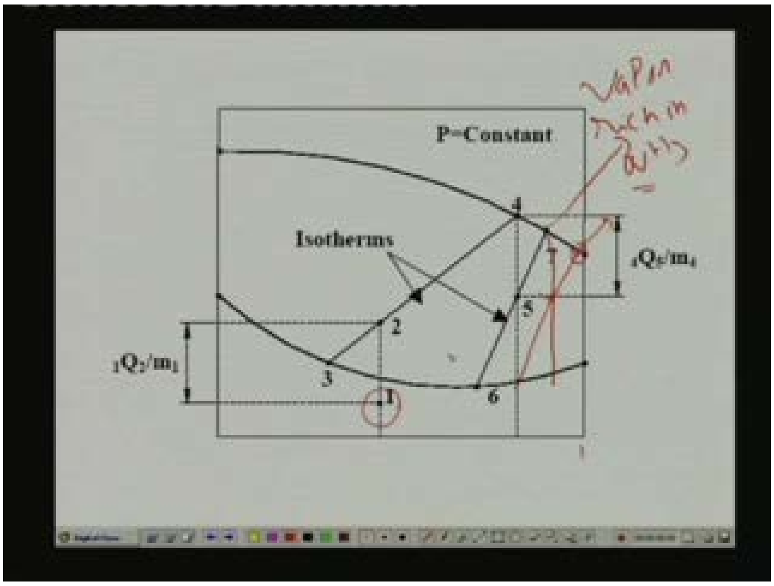

So what is that we have done during this process what we have done during this process is we have sub cooled liquid okay. We have taken sub cooled liquid at this point and we are getting vapour okay, that is rich in ammonia okay. Suppose this process is continued further okay. You will find that as you are, I have you have taken again this vapour and this vapour is again cooled okay, and you separated out again the liquid and vapour. So you can see that this point. That means the outlet point progressively moves closer to the pure ammonia state. That means you are getting vapour that is rich in ammonia at the exit of this arrangement okay. That means the whole system is working like a rectification column. So that means I have used a combination of two heat exchangers and two separators. And I have started the process with a sub cooled liquid. First I have, I heated the liquid then I separated the saturated liquid and vapours. Then I cooled the saturated vapour and again I separated the liquid and vapour fractions. And finally I have a rich ammonia vapour okay, rich vapour a strong, I am sorry vapour that is rich in ammonia okay. So this is actually the purpose of any rectification system where you feed the liquid. And you will get pure components right.

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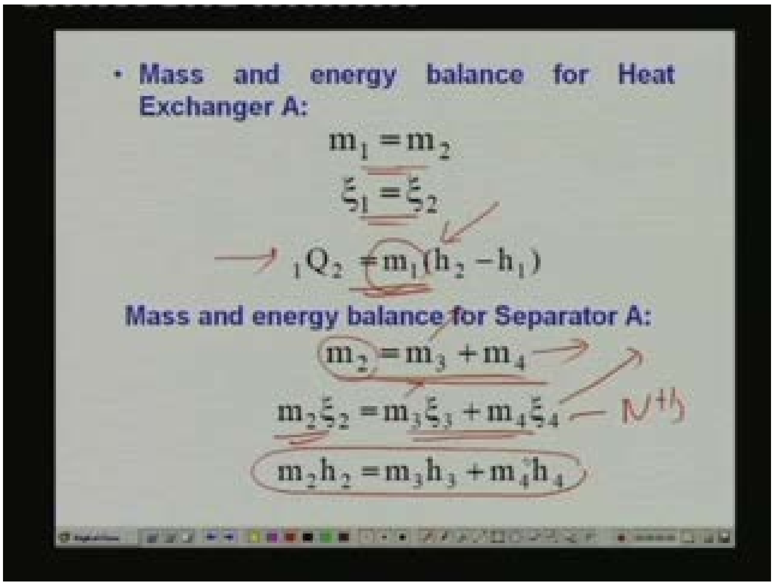

- **Mass and energy balance for Heat Exchanger A:**

$$m_1 = m_2$$

$$\xi_1 = \xi_2$$

$$\rightarrow {}_1Q_2 = m_1(h_2 - h_1)$$

Mass and energy balance for Separator A:

$$m_2 = m_3 + m_4$$

$$m_2\xi_2 = m_3\xi_3 + m_4\xi_4 \text{ — } NH_3$$

$$m_2h_2 = m_3h_3 + m_4h_4$$

Now if you apply the, a simple mass and energy balance for these components. For example for the heat exchanger as I explained total mass is conserved concentration remains same. So this is the energy balance okay. This is the heat supplied heat supplied is utilized for increasing the enthalpy okay. And this is the mass flow rate okay. And similarly mass and energy balance for the separator in the separator this, the total mass balance. That means water mass is coming in is mass going out in liquid form and in vapour form. Similarly you can write mass balance for ammonia okay. So this is the amount of ammonia entering into the separator A and this is amount of ammonia leaving the separator A okay. In liquid form again in vapour form and this is the energy balance for the separator. Now heat transfer or work transfer so this seems simple energy balance for the separator okay.

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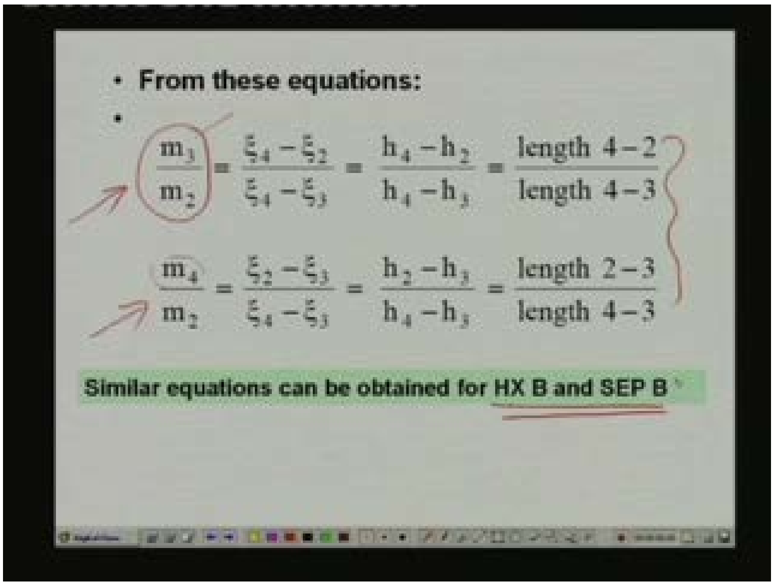

- **From these equations:**
-
$$\frac{m_3}{m_2} = \frac{\xi_4 - \xi_2}{\xi_4 - \xi_3} = \frac{h_4 - h_2}{h_4 - h_3} = \frac{\text{length } 4-2}{\text{length } 4-3}$$

$$\frac{m_4}{m_2} = \frac{\xi_2 - \xi_3}{\xi_4 - \xi_3} = \frac{h_2 - h_3}{h_4 - h_3} = \frac{\text{length } 2-3}{\text{length } 4-3}$$

Similar equations can be obtained for HX B and SEP B

So similarly a set of equations uh can be written for heat exchanger B and separator B also okay for these two also we can write similar set of equations. From this equations you can show that m three by m two is nothing but zeta four minus zeta two divided by zeta four minus zeta three okay. Length four this is nothing but your mass fraction liquid phase mass fraction. Similarly this is the vapour phase I mean liquid, this is the ratio of mass of saturated liquid to the total mass in separator A and similarly this is the ratio of saturated vapour to the total mass in separator B okay. And ultimately they are they can be expressed in terms of the different lines okay which are shown in the earlier diagrams. So if you can draw the diagram you can easily find out how much liquid you have how much vapour you have and as I said you can write similar equations for heat exchanger B and separator B..

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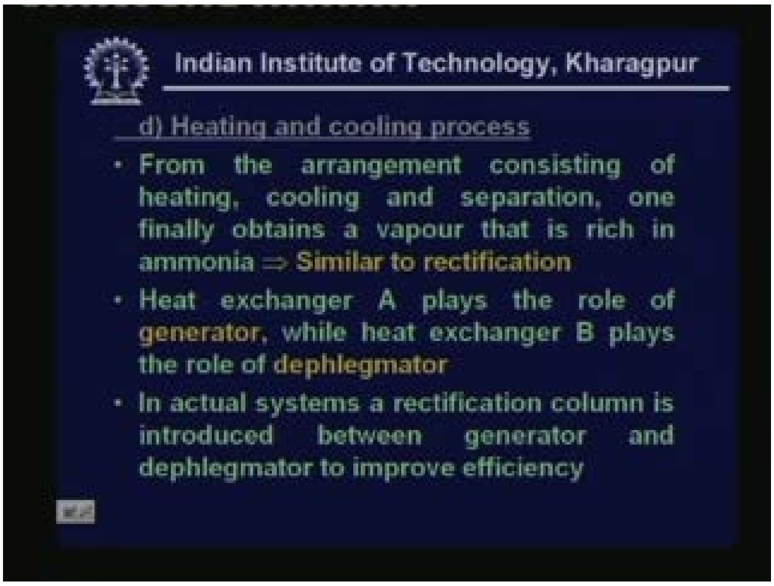

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d) Heating and cooling process

- From the arrangement consisting of heating, cooling and separation, one finally obtains a vapour that is rich in ammonia ⇒ Similar to rectification
- Heat exchanger A plays the role of generator, while heat exchanger B plays the role of dephlegmator
- In actual systems a rectification column is introduced between generator and dephlegmator to improve efficiency

Okay, so as I said from the arrangement consisting of heating cooling and separation one finally obtains vapour that is rich in ammonia okay. So this process is similar to rectification. So in this okay, if a heat exchanger A plays the role of generator while heat exchanger B plays the role of a component called dephlegmator okay. However in actual systems just a generator and dephlegmator are not sufficient. So we also use a rectification column which is introduce in between generator and dephlegmator this is required to improve the process of rectification okay. So an actual absorption refrigeration system based on ammonia-water will have the generator a rectification column and a dephlegmator okay. And the principle what I have explained just now okay. So I will explain the basic system consisting of all these components and the working principles in the next class. So let me quickly summarise what we have learnt in this lesson.

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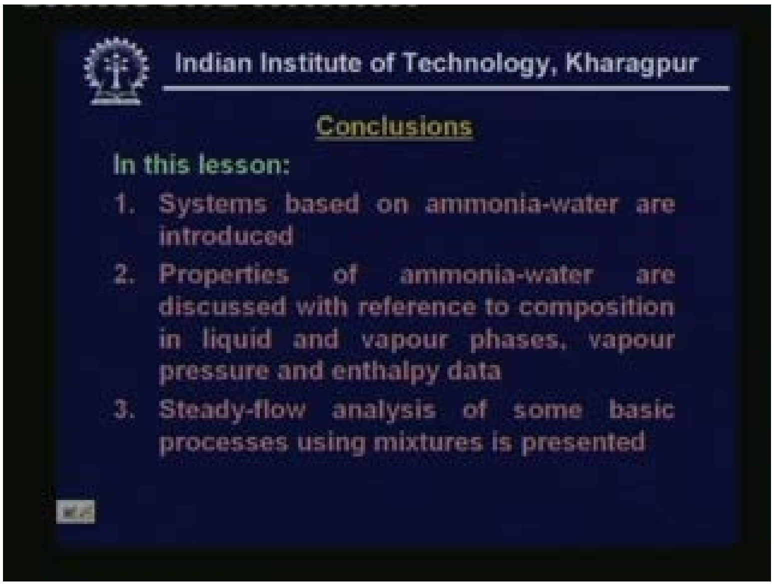

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Conclusions

In this lesson:

1. Systems based on ammonia-water are introduced
2. Properties of ammonia-water are discussed with reference to composition in liquid and vapour phases, vapour pressure and enthalpy data
3. Steady-flow analysis of some basic processes using mixtures is presented

So in this lesson a systems based on ammonia-water are introduced and properties of ammonia -water discussed with reference to composition in liquid and vapour phases vapour pressures and enthalpy data and some simple processes using mixtures analysed assuming steady-flow process okay. In the next class I shall discuss the actual systems okay.

Thank you.