Refrigeration and Air Conditioning

Prof. M. Ramgopal
Department of Mechanical Engineering
Indian Institute of Technology, Kharagpur

Lecture No. # 17

Vapour Absorption Refrigeration Systems (Contd.)

Welcome back, in the last lecture I introduced ammonia water systems and we discussed the properties of binary mixtures of ammonia water. This lecture is the continuation of the earlier lecture and in this lecture I will discuss in detail the working principle of ammonia water systems.

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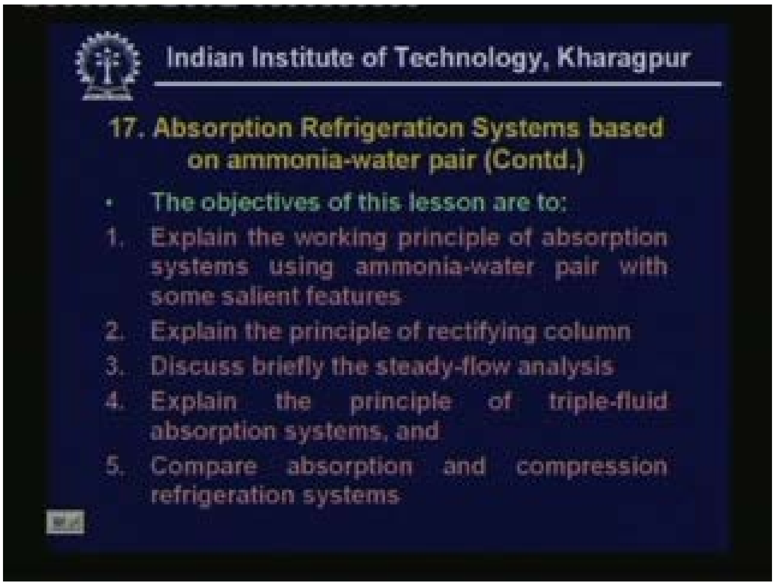

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17. Absorption Refrigeration Systems based on ammonia-water pair (Contd.)

- The objectives of this lesson are to:

1. Explain the working principle of absorption systems using ammonia-water pair with some salient features
2. Explain the principle of rectifying column
3. Discuss briefly the steady-flow analysis
4. Explain the principle of triple-fluid absorption systems, and
5. Compare absorption and compression refrigeration systems

So the specific objectives of this particular lesson are to explain the working principles of absorption systems using ammonia water pair with some of its salient features, explain the principle of rectifying column discuss briefly the steady flow analysis of the system, explain the principle of triple fluid absorption systems and finally compare absorption and compression refrigeration systems.

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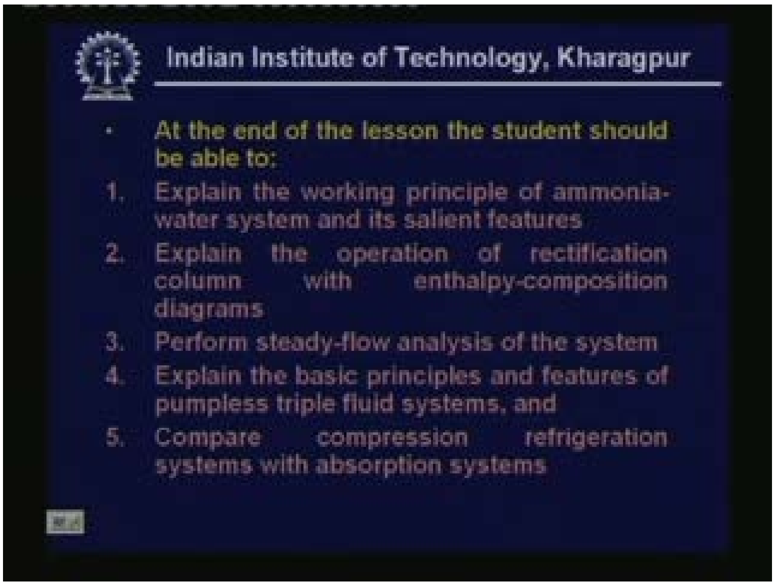

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- At the end of the lesson the student should be able to:

1. Explain the working principle of ammonia-water system and its salient features
2. Explain the operation of rectification column with enthalpy-composition diagrams
3. Perform steady-flow analysis of the system
4. Explain the basic principles and features of pumpless triple fluid systems, and
5. Compare compression refrigeration systems with absorption systems

At the end of this lesson you should be able to explain the working principle of ammonia water system and its salient features, explain the operation of rectification column with enthalpy composition diagrams perform steady flow analysis of the system, explain the basic principles and features of pumpless triple fluid systems and finally compare compression refrigeration systems with absorption systems.

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Introduction

- Absorption refrigeration system based on ammonia-water is one of the oldest refrigeration systems
- These systems can be used for both refrigeration and air conditioning applications
- They are available in very small (as pumpless systems) to large refrigeration capacities in applications ranging from domestic refrigerators to large cold storages

So let me give a brief introduction absorption refrigeration systems based on ammonia water where one of the oldest refrigeration systems which was developed at the end of nineteenth century. These systems can be used for both refrigeration and air conditioning application because ammonia is the refrigerant here. So it has very low freezing point and you do not have the problem of like in water where it cannot be used for sub zero temperatures. And these systems are available in very small refrigeration capacities to very large refrigeration capacities and mainly they are used in domestic refrigerators in pump less form and also in large cold storages.

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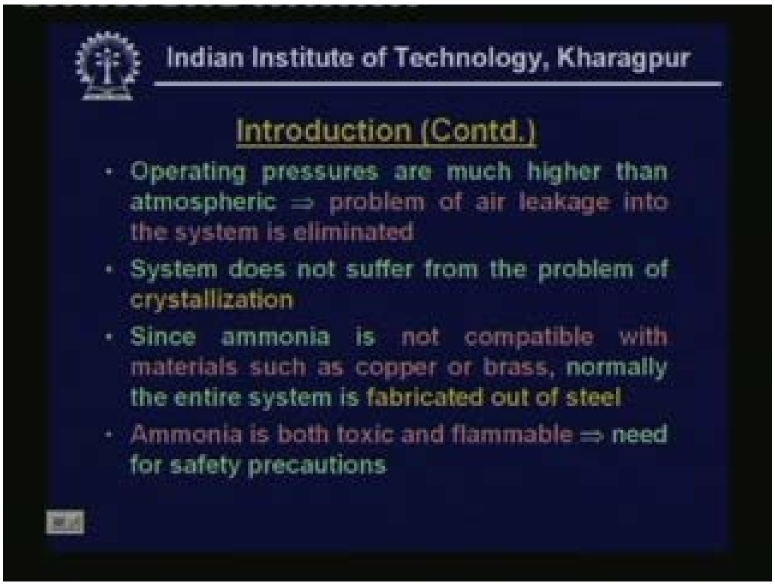

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Introduction (Contd.)

- Operating pressures are much higher than atmospheric ⇒ problem of air leakage into the system is eliminated
- System does not suffer from the problem of crystallization
- Since ammonia is not compatible with materials such as copper or brass, normally the entire system is fabricated out of steel
- Ammonia is both toxic and flammable ⇒ need for safety precautions

Now the operating pressures in ammonia water systems are much higher than atmospheric. So you do not have the problem of air leaking into the system this is one of the typical problems of water lithium bromide systems which operate under vacuum. So you always have air leaking into the system. This problem is not there with ammonia water systems and you also do not have the problem of crystallization which was again typical problem with water lithium bromide systems however ammonia is not compatible with material such as copper or brass. So normally the entire system is fabricated out of steel and ammonia is both toxic and flammable. So we need to take certain safety precautions while designing and operating these systems.

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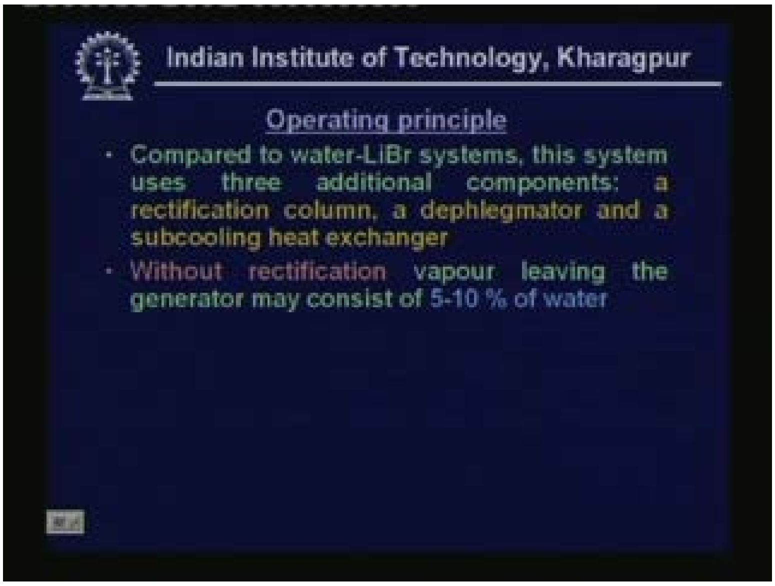

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Operating principle

- Compared to water-LiBr systems, this system uses three additional components: a rectification column, a dephlegmator and a subcooling heat exchanger
- Without rectification vapour leaving the generator may consist of 5-10 % of water

Now let me explain the operating principle major difference between this system and water lithium bromide system is that you use three additional components here. And these three additional components are rectification column a dephlegmator and a sub cooling heat exchanger without rectification vapour leaving the generator may consist of five to ten percent of water and the need for rectification was explained in the last class if you do not rectify the vapour. You have five to ten percent of water in the refrigeration circuit. This will create problems like non isothermal condensation and evaporation and it will also increase the evaporated temperature it increases circulation ratio. So ultimately the system performance suffers.

So in ammonia water systems they have to be design in such a way that most of the water is confined to the solution circuit only and in the refrigerant circuit you have almost pure ammonia. So this requires the use of rectification column okay. And the rectification column consists of the generator a rectifying column and dephlegmator. So this is something different from water lithium bromide systems okay. And what is the function of sub cooling heat exchanger?

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Operating principle

- Compared to water-LiBr systems, this system uses three additional components: a rectification column, a dephlegmator and a subcooling heat exchanger
- Without rectification vapour leaving the generator may consist of 5-10 % of water
- With rectification the concentration of water is reduced to less than 1 %
- The subcooling HX is used to increase the refrigeration effect and to ensure liquid entry into the refrigerant expansion valve

The sub cooling heat exchanger is used to increase the refrigeration effect and also to ensure that only liquid enters into the refrigerant expansion valve. Now let me explain the operating principle.

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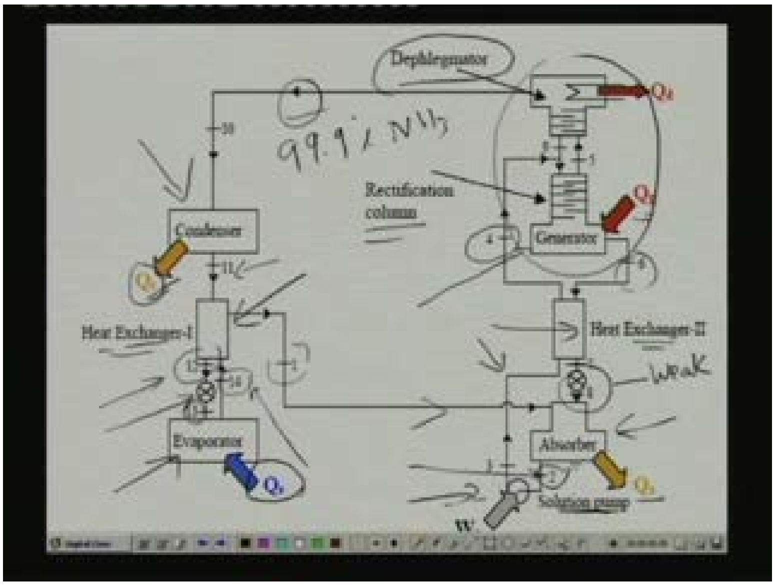

Okay, so as I mentioned you have the basic components here you have the evaporator condenser absorber solution pump and generator. In addition to these basic components you also have an additional heat exchanger. Here a sub cooling heat exchanger and you have what is known as the dephlegmator here. And you also have a rectifying column rest of the components are similar like your solution pump expansion valve liquid suction heat exchanger. All this components are similar to water lithium bromide systems. So working principle is like this, let us begin with point fourteen which is nothing but the exit of evaporator. So at this point you have low temperature low pressure refrigerant vapour. This low temperature low pressure refrigerant vapour enters into the heat exchanger one where it exchanges heat with the refrigerant liquid coming from the condenser in this process. The refrigerant vapour gets super heated and the liquid get sub cooled. So this is something similar to your liquid suction heat exchanger used in vapour compression refrigeration systems okay. So what comes out of the heat exchanger is a heat super heated vapour still at low pressure.

So this super heated vapour now enters into the absorber in the absorber it comes in contact with the weak solution coming from the generator. So this is your weak solution okay weak solution here means weak in refrigerant. So this weak solution and ammonia vapour coming from the evaporator. They come in contact in the absorber and the refrigerant is absorbed in the absorber since this is an exothermic process heat is rejected in the absorber. And what you have at the outlet of the absorber is a strong solution at point two okay. So at point two you have solution that is rich in ammonia okay, this is still at low pressure. So this strong solution is pumped to the generator pressure using a solution pump okay. So in the solution pump it is pressurised and this high pressure solution which is still at low temperature enters into this heat exchanger two okay.

In the heat exchanger two this is nothing but your solution heat exchanger where it exchanges heat with the hot solution coming from the generator that means at point six okay. In this process this strong solution becomes preheated. So it comes out at a higher temperature. So temperature at point four is much higher than temperature at point three. So this preheated strong solution enters into this rectifying column. And in this rectifying column this strong solution falls through this rectification column and it ultimately comes to the generator where you supply the heat. And because the heat supply vapour is generated and this vapour gets rectified in the rectification column and dephlegmator and finally what you have at the exit of this dephlegmator is almost pure ammonia. That means almost about ninety nine point nine percent ammonia okay. So this ninety nine point nine percent ammonia vapour which is at high pressure and high temperature goes to the condenser. It condenses in the condenser by resetting heat of condensation Qc to external heat sink and it becomes a high pressure liquid point eleven and the high pressure liquid at point eleven. Now flows through the heat exchanger where it rejects heat to the vapour coming from the evaporators in this process it get sub cooled.

So at point twelve you have sub cooled refrigerant liquid still at high pressure. So this sub cooled liquid refrigerant at high pressure is expanded in this expansion valve. And the resulting mixture of liquid and vapour at point thirteen which is now at very low temperature and low pressure enters into the evaporator. It takes heat from the refrigerated phase provides refrigeration effect Qe and in this process it becomes a vapour and this vapour goes to goes back to the heat exchanger and that is how the refrigerant circuit is completed. Now coming back to the solution circuit in the generator refrigerant vapour is removed from the solution. So what you have at the exit of the generator is a weak solution point six.

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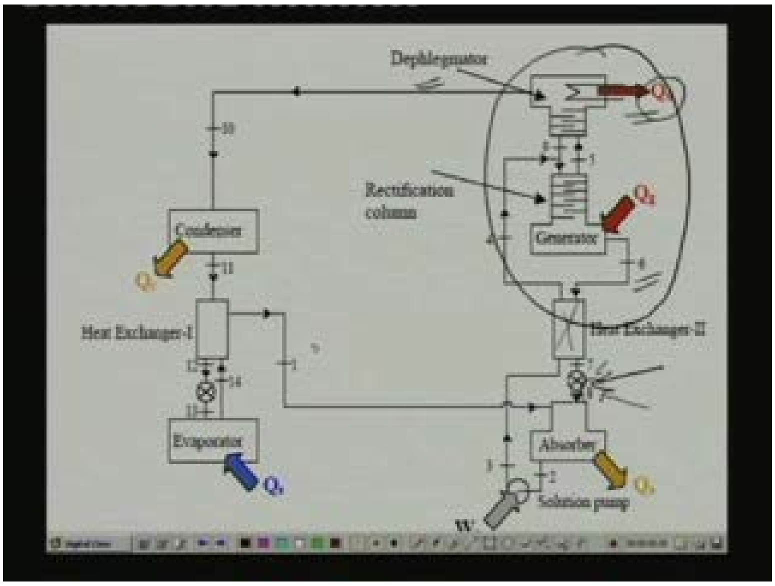

So the weak solution at point six which is quiet hot and which is at high pressure. Now flows through this solution heat exchanger where it gives off heat to the strong solution coming from the absorber. So in this process the temperature of the weak solution reduces from t six to t seven. Still, since this is still, at high pressure its pressure has to be reduced to that of absorber pressure that is takes place in this solution expansion valve. So at the exit of the solution expansion valve you have low pressure weak solution that is point eight this low pressure weak solution. Now comes in contact with the refrigerant vapour coming from the evaporator and absorption takes place and that is how the solution circuit is completed. So this is the working principle of ammonia water system. And this is actually you can call it as a single stage ammonia water system okay. This is the typical system used in most of the commercial in installations okay.

So the analysis and analysis of this system I will explain little later before coming to the steady flow analysis. Let me explain the working principle of the rectification column. This is a rectification or the rectifying column which consists of the three components. And let us first concentrate on this rectification column. Before explaining that, I forgot to mention one thing in the dephlegmator the refrigerant vapour rejects some of the heat to a heat sink. That means some heat rejection takes place in the dephlegmator that heat rejection is given by Qd. And during due to this heat reduction some of the solution condenses in the dephlegmator that is known as reflex okay. So I will explain this while explaining the rectifying column okay.

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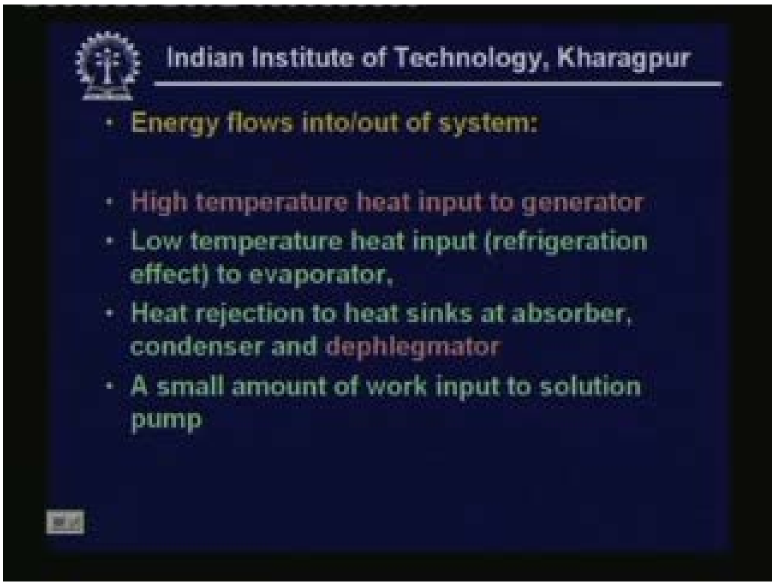

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- Energy flows into/out of system:

- High temperature heat input to generator
- Low temperature heat input (refrigeration effect) to evaporator,
- Heat rejection to heat sinks at absorber, condenser and dephlegmator
- A small amount of work input to solution pump

So now let me just summarise the energy flows into and out of the system. We have seen that high temperature heat input is given to the generator Qc and low temperature heat input is given to the system at the evaporator. This is nothing but your useful refrigeration effect Qe and then heat rejection takes place at absorber condenser and dephlegmator. Dephlegmator is a new component here and a small amount of work input is required to run the solution pump. So these are the typical energy flows into and out of the system.

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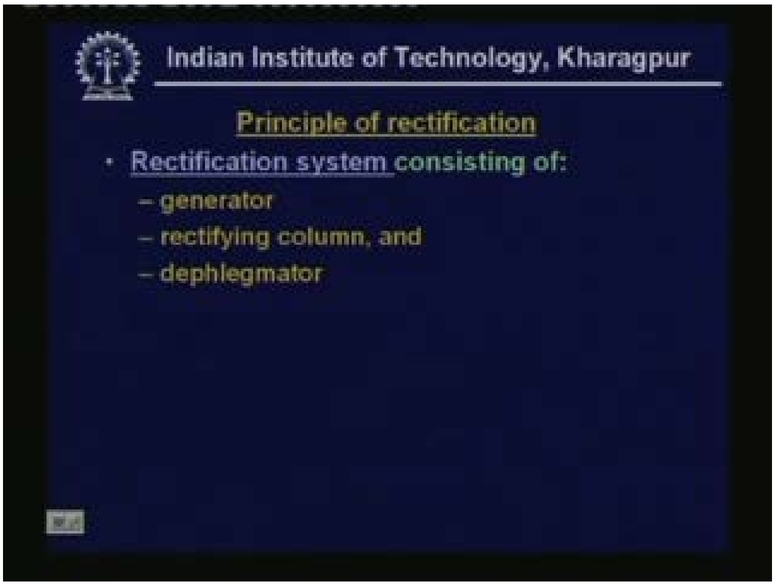

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Principle of rectification

- Rectification system consisting of:
  - generator
  - rectifying column, and
  - dephlegmator

Now let me explain the principle of rectification. So the as I explained already the rectification system consist of consisting of generator a rectifying column and a dephlegmator. So let me show the schematic of it..

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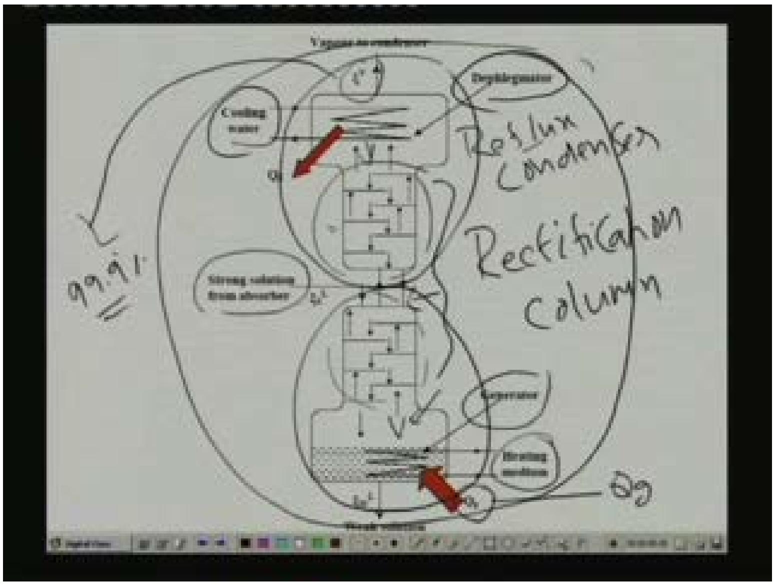

So you can see that the whole thing is your rectification system it consists of three components generator. And this is your rectification column rectification column and a dephlegmator is at the top of the rectifying column. And heat is supplied to the generator high temperature heat Qg is supplied to the generator via heating medium. So because of this vapour is generated uh okay. So vapour regenerated vapour moves up this vapour comes in contact with the strong solution coming from the absorber okay. So there is a direct contact between the strong solution and the vapour in this lower portion of the rectification column as a result we will see that this vapour becomes rich in ammonia. That means by the time this vapour comes from this point the lower portion to this point it becomes stronger in ammonia. And further enrichment takes place in this column where the vapour comes in contact with reflux that is coming from the, what is known as reflux condenser. Sometimes the dephlegmator is also known as reflux condenser reflux condenser. So in the reflux condenser what happens is some heat is taken out of the hot vapour by using a cooling water. And during this process some of the vapour condenses that condensed vapour is called as reflux. And due to gravity this falls down and as it falls down it comes in contact with the vapour that is moving up.

That means the descending liquid comes in contact with the ascending vapour and during this process further enrichment of the vapour takes place and ultimately what you have at the exit of the rectification system is almost a pure ammonia. That means as I already mentioned you have about ninety nine point nine percent ammonia in the vapour okay. so almost pure ammonia okay. So in order to achieve this you have to design the rectifying column properly. Now let us concentrate on each component that means the lower portion of the rectifying column. And let us see how what is the working principle of this and how do you show this on enthalpy composition diagram. Similarly we will look at the upper portion and explain the working principle and show this on enthalpy composition diagram.

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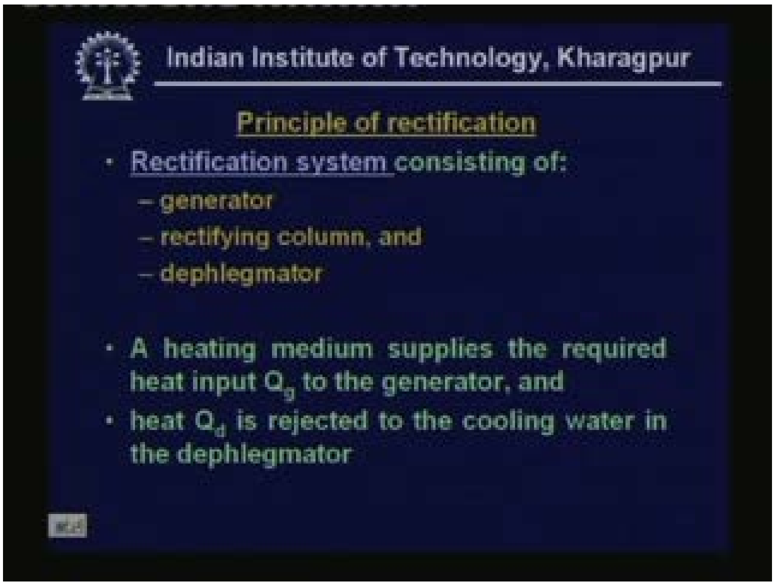

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Principle of rectification

- Rectification system consisting of:
  - generator
  - rectifying column, and
  - dephlegmator

- A heating medium supplies the required heat input Q_g to the generator, and
- heat Q_d is rejected to the cooling water in the dephlegmator

Okay, as I said you have seen that rectification system consists of the three components. And heating medium supplies the required heat input as a, as I have already mentioned to the generator and heat Qd is rejected to the cooling water in the dephlegmator okay.

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- Generator + lower part of rectification column:
- Heat and mass transfer take place between the ascending vapour and descending liquid

So at one place you supply high temperature heat at another place you rejects some of the heat. Now let us look at the generator plus lower part of the rectification column okay. First let me show the working principle okay.

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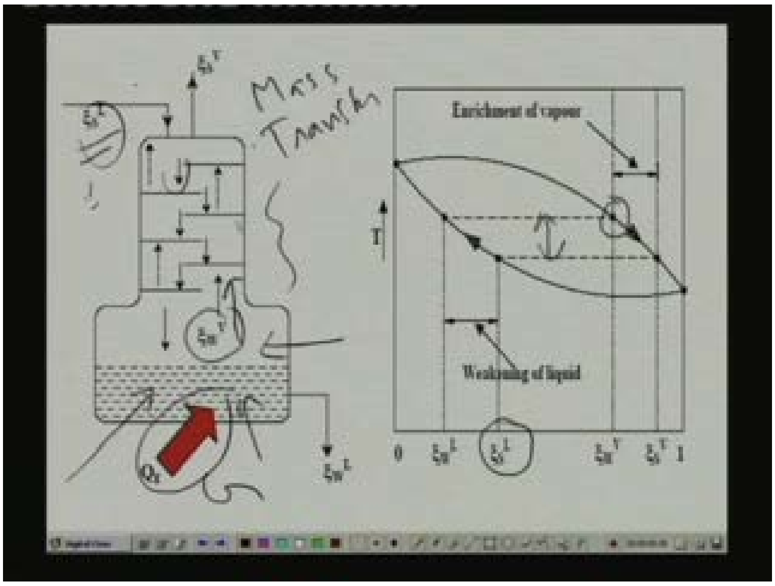

So you can see here the generator here this is the generator G and this is the lower portion of the rectification column okay. So you have in the generator you have weak you have a solution of ammonia and water okay. And from the top strong solution of ammonia is coming from the top okay. So this is what is coming from your absorber okay. And heat is supplied to this solution bath at the bottom portion you are supplying the heat to the solution here as a result vapour is generated. So this is the vapour moving up and vapour has a initial concentration of zeta WV okay. So this vapour moves up and as it moves up it comes in contact with the liquid that is coming down okay. The liquid is coming down and remember that, this liquid is much cooler and it is coming from the solution heat exchanger. So it is temperature is always lower than the vapour temperature the hot vapour comes in contact with the strong solution in this column okay. What happens then see you can see this in the enthalpy composition diagram.

This is the state of the vapour at this point okay, state of the vapour at this point okay. That means at the lower portion of the rectification column this vapour comes in contact with the solution that is entering into the rectification column. And what is the state of the solution that is entering into the rectification column that is this okay. So that you can see that there is a temperature difference between the vapour and the solution and the vapour is much hotter than the solution. As a result heat transfer takes place from the vapour to the solution and in this process the temperature of the vapour reduces and the temperature of the solution increases simultaneous to heat transfer you also have mass transfer okay. How mass transfer takes place when heat is supplied to the solution that is coming into the system some ammonia vapour is generated okay. That means ammonia generated from the solution and this ammonia vapour will be mixed with the vapour that is moving up see you can see that as the okay.

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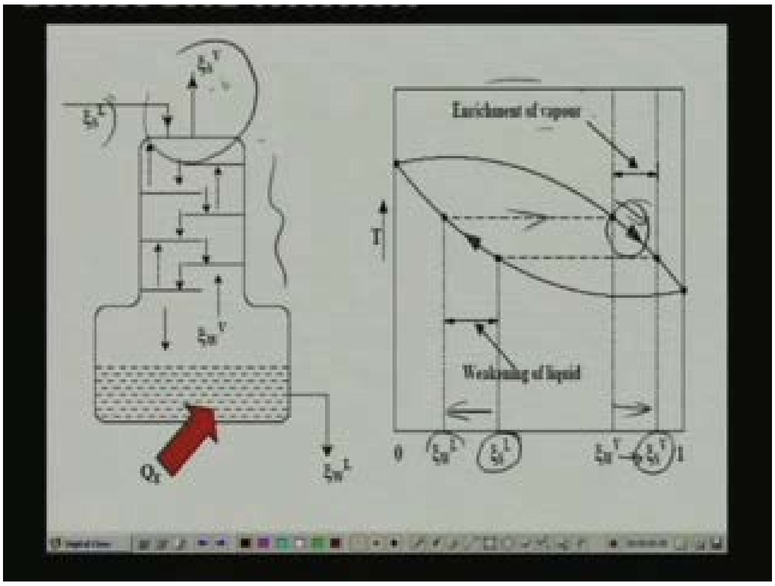

So as the vapour is moving up its state is shown by this arrow here. That means it becomes progressively rich in ammonia so okay. So you can see the concentration varies from this point to this point. That means it gets enriched in ammonia and at the same time its temperature drops because of the heat transfer simultaneously what happens is since you are at stripping this solution of ammonia obviously it is concentration has to drop. So you can see that it is concentration is decreasing in this direction okay. That means the vapour concentration increases in this direction and the solution concentration decreases in this direction okay. So the net effect is that the vapour becomes rich in ammonia and the solution becomes weak in ammonia okay. So that is what shown in this process okay. The, all the temperature increases and if this rectification is perfect you will find that at the, at this point the strong solution that is entering into the system will be at equilibrium with the vapour that is leaving the system that is what we shown here okay. So the, this solution this vapour is at equilibrium this liquid is in equilibrium with vapour that is leaving the system okay. Of course in actual case this is not possible because for perfect rectification and perfect equilibrium you require an infinite column.

So in an actual system you will find that there is equilibrium is not there okay. One advantage of this particular system is that you can see that some of the heat is transferred from the hot vapour that is coming from the generator okay. And this heat is given to the solution that is going to the generator. That means solution that is going to the generator is getting preheated by extracting heat from the vapour okay. This is beneficial because obviously this will reduce the required heat input in the generator okay. Otherwise if let us say that if this is not there then it has the entire heat has to be supplied by the external medium in the generator itself okay.

And this is wasteful because ultimately the vapour has to go to the condenser and it the heat will be rejected in the condenser to a low temperature heat sink okay. So instead of throwing it to the low temperature heat sink you are extracting some of the heat from the vapour before it goes to the condenser okay. So this is good as for as the system COP is concerned okay. So ultimately what has happened in this particular lower portion of the rectification column and the generator is that there is an exchange of heat and mass between the vapour and the liquid okay. During this process vapour becomes hot and it becomes weak in ammonia and vapour I mean sorry, the liquid becomes hot and weak in ammonia and the vapour becomes cool and rich in ammonia okay.

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- Generator + lower part of rectification column:
- Heat and mass transfer take place between the ascending vapour and descending liquid
- Ascending vapour is enriched in ammonia and descending liquid becomes weak in ammonia
- In an ideal case vapour leaving will be in equilibrium with liquid entering
- Solution entering the generator is preheated ⇒ beneficial as required heat input is reduced

So that what I have summarised here heat and mass transfer take place between the ascending vapour and descending liquid. And ascending vapour is enriched in ammonia and descending liquid becomes weak in ammonia and in an ideal case vapour leaving will be in equilibrium with liquid entering solution entering the generator is preheated. So this is beneficial as required heat input is reduced.

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- Dephlegmator (or reflux condenser):

Now let me explain the dephlegmator or reflux condenser.

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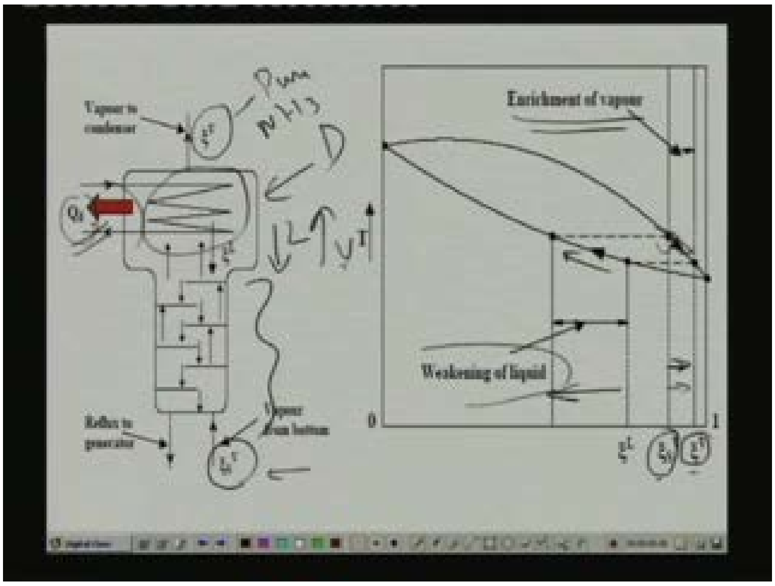

Okay, this shows the upper portion of the rectification column plus the dephlegmator as you know that this is the dephlegmator D okay, what is happening in this one you the vapour that is entering into the dephlegmator is nothing but the vapour that is leaving the lower portion of the rectification column okay. So that enters into the dephlegmator and let us say that it moves up and at the upper portion it rejects some heat to the low temperature heat sink okay. So this is the heat rejected in the heat dephlegmator QD so as a result some liquid condenses okay. And this condensed liquid which is called as reflux moves down okay. So the liquid is moving down and vapour is vapour is going up okay. And this vapour temperature is much cooler than the liquid temperature.

So again there will be exchange of heat and mass between the vapour and the liquid okay. So the net result is that at the end of this column you have a very pure ammonia okay, which goes to the condenser and the refrigerant circuit again this is shown in the temperature composition diagram you can see that zeta SV this is the condition of the vapour that is entering into this column. And as it comes in contact with the reflux you can see that its temperature drops and at the same time it is getting rich in ammonia okay. So you can see finally it leaves at this concentration which is much higher than this concentration okay. So enrichment of vapour is taking place in this column at the same time the liquid again becomes weaker because some ammonia is generated since you are taking ammonia out of the solution obviously its concentration reduces okay. So liquid follows this path and vapour goes in this direction okay. And since there is heat transfer during this process liquid temperature increases in this manner and vapour temperature reduces in his manner okay. So heat has to be rejected to the low temperature heat sink QD.

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- Dephlegmator (or reflux condenser):
- At the top of the dephlegmator, heat is removed from the vapour so that a part of the vapour condenses (reflux)
- This reflux that is cooler, exchanges heat with the hotter vapour ascending in the column
- During this process water vapour is transferred from the vapour to the liquid and ammonia is transferred from liquid to the vapour
- Vapour leaves the rectification column in almost pure ammonia form with a concentration of greater than 99 %.

So again this is the summary of what I have explained at the top of the dephlegmator heat is removed from the vapour. So that a part of the vapour condenses which is known as reflux this reflux that is cooler exchanges heat with the hotter vapour ascending in the column.

During this process water vapour is transferred from the vapour to the liquid and ammonia is transferred from liquid to the vapour and vapour leaves the rectification column in almost pure ammonia form with a concentration of greater than ninety nine percent.

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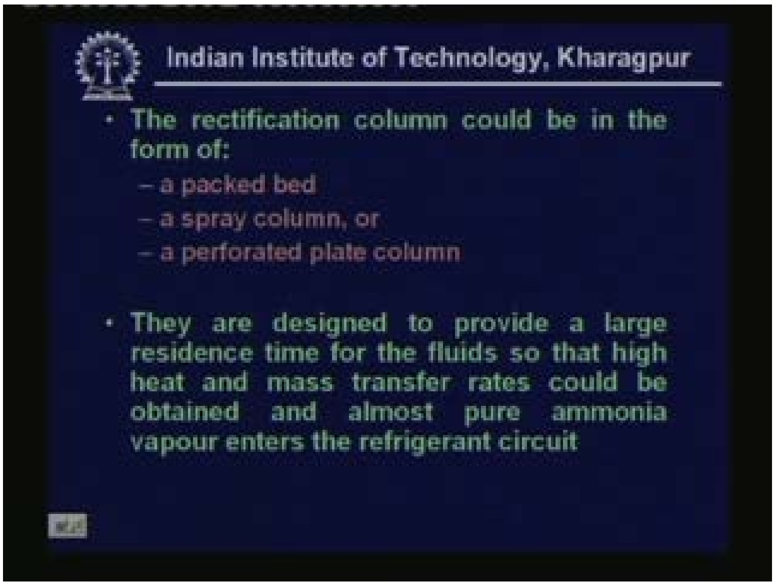

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- The rectification column could be in the form of:
  - a packed bed
  - a spray column, or
  - a perforated plate column
- They are designed to provide a large residence time for the fluids so that high heat and mass transfer rates could be obtained and almost pure ammonia vapour enters the refrigerant circuit

Now how what do we uh so far we have explained the working principles of rectification column but how do it look like or how do you design it. So the rectification column could be in the form of a packed bed or a spray column or a perforated plate column why do we need a packed bed or a spray column or a perforated plate column. Because we need to have what is known as a large residence time. So that the fluids can spend more time together. So that there will be high heat and mass transfer rates. So that ultimately you get almost pure ammonia vapour at the exit of this rectification system okay. So you have to have higher heat and mass transfer rates.

So you cannot simply have a hollow tube in which liquid and vapour comes in contact. Because the in such case there will not be enough time for heat and mass transfer to take place okay. So you want to design it properly you have to have something like a packed bed or a perforated column or a spray column okay. So that liquid comes in intimate contact with the vapour and heat and mass transfer can take place okay. Now let us briefly look at the steady flow analysis of the system.

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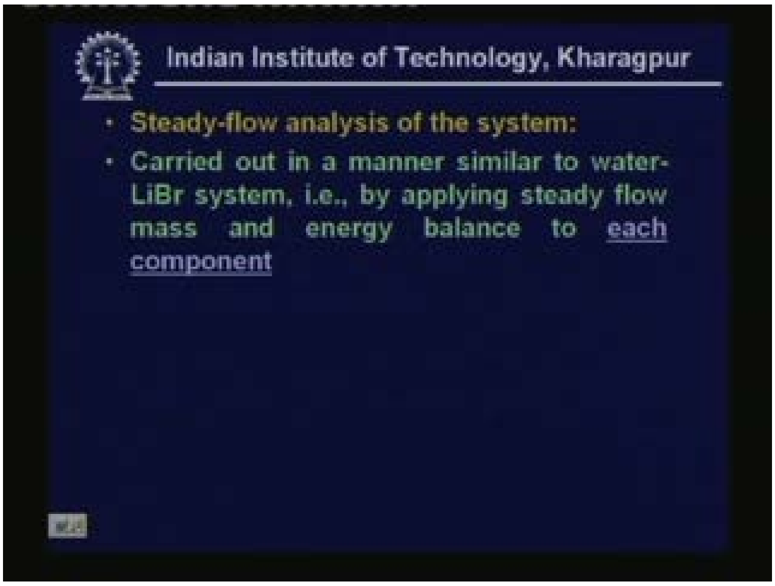

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- Steady-flow analysis of the system:
- Carried out in a manner similar to water-LiBr system, i.e., by applying steady flow mass and energy balance to each component

This is carried out in the manner similar to water lithium bromide system that is by applying remember that for water lithium bromide system we have carried out the steady flow analysis by applying heat and mass balance across each component okay. For example if you have to do this for ammonia water systems.

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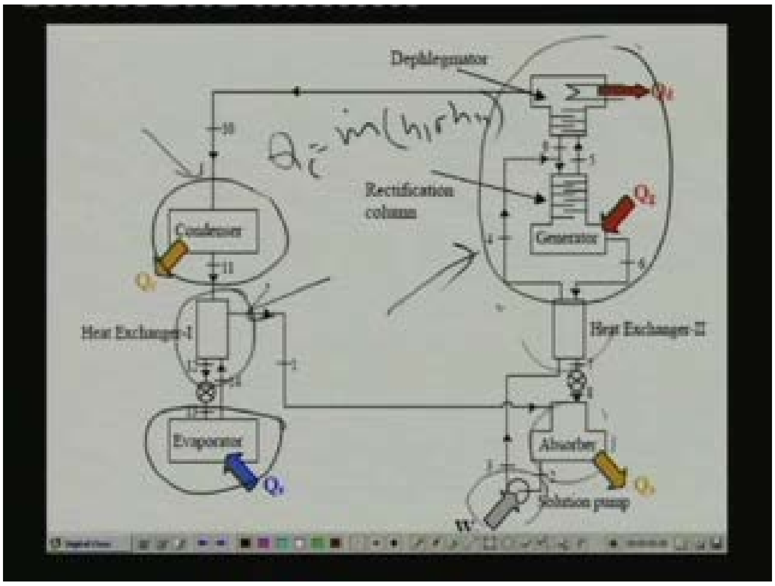

What you have to do is you have to take individual component apply heat and mass balance. For example if you take the condenser remember that if you apply mass energy balance to this you will find that QC is equal to mass flow rate of refrigerant into h ten minus h eleven okay. Similarly you can do an energy balance to the for the evaporator you can also do an energy balance for the heat exchanger okay, energy coming in is energy going since it is steady flow process. Similarly you can do steady flow energy balance for the other components like solution pump solution heat exchanger absorber and all that only difference between this system and ammonia water system is at this point okay. Of course this point also the solution heat the sub cooling heat exchange also different but this analysis is very simple okay. What is the major difference is in this portion okay. So I will show you how uh steady flow analysis has to be carried out for this portion. So that you can evaluate the performance of this particular system.

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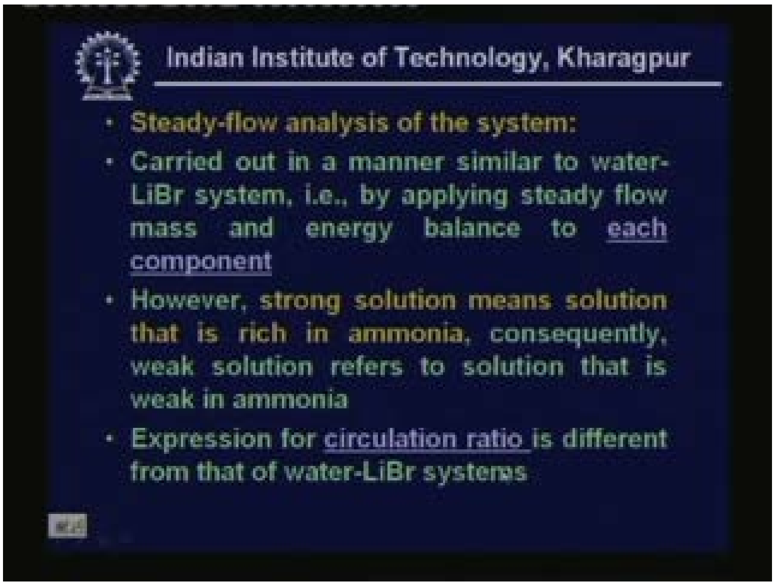

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- Steady-flow analysis of the system:
- Carried out in a manner similar to water-LiBr system, i.e., by applying steady flow mass and energy balance to each component
- However, strong solution means solution that is rich in ammonia, consequently, weak solution refers to solution that is weak in ammonia
- Expression for circulation ratio is different from that of water-LiBr systems

So and there is one difference here in water lithium bromide systems when we say strong solution. That means the solution that is strong in the lithium bromide okay. The, and weak solutions means solution weak in lithium bromide where as in ammonia water system the meaning of strong and weak solutions are different when I say strong solution in ammonia water systems. That means the solution that is strong in ammonia okay. That means that is rich in ammonia strong solution and rich solution are same okay. Similarly weak solution means the solution that is weak in ammonia okay. So if you are applying this nomenclature strong solution means the solution that is leaving the absorber in this case whereas in water lithium bromide case strong solution means the solution that is entering into the absorber. So you have to keep this difference in mind since we are defining strong and weak solutions in this manner the definition of circulation ratio will be different and also the expression for circulation ratio will be different okay. So what is the expression for circulation ratio?

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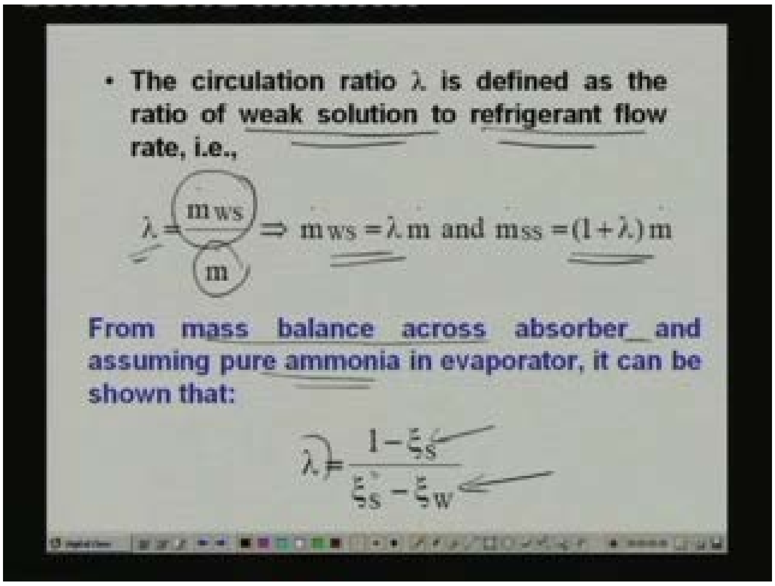

- The circulation ratio λ is defined as the ratio of weak solution to refrigerant flow rate, i.e.,

$$\lambda = \frac{\dot{m}_{WS}}{\dot{m}} \Rightarrow \dot{m}_{WS} = \lambda \dot{m} \text{ and } \dot{m}_{SS} = (1+\lambda)\dot{m}$$

From mass balance across absorber and assuming pure ammonia in evaporator, it can be shown that:

$$\lambda = \frac{1-\xi_S}{\xi_S - \xi_W}$$

Okay, so circulation ratio here is defined as the ratio of weak solution to refrigerant flow rate okay. So weak solution is m dot WS refrigerant flow rate is simply m dot okay. So circulation ratio lambda is equal to m dot WS by m dot this implies that weak solution flow rate m dot WS is equal to lambda into m dot and strong solution flow rate is nothing but one plus lambda into m dot this you can easily get by applying mass balance across the absorber okay. And from mass balance across the absorber you can also show that if you are assuming pure ammonia is circulating in the refrigerant circuit you can write the expression for circulation ratio in terms of strong solution concentration zeta S and weak solution concentration zeta W okay. So this expression is different for water lithium bromide system and for ammonia water system. So this is one difference you must keep in mind while performing calculations okay.

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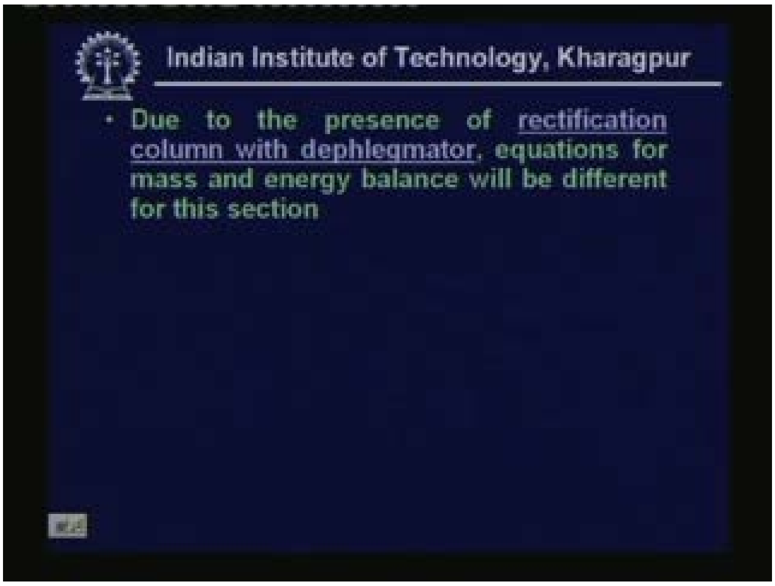

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- Due to the presence of rectification column with dephlegmator, equations for mass and energy balance will be different for this section

So due to the presence of rectification column with dephlegmator equations for mass and energy balance will be different for this system okay, how they are different. Let us see.

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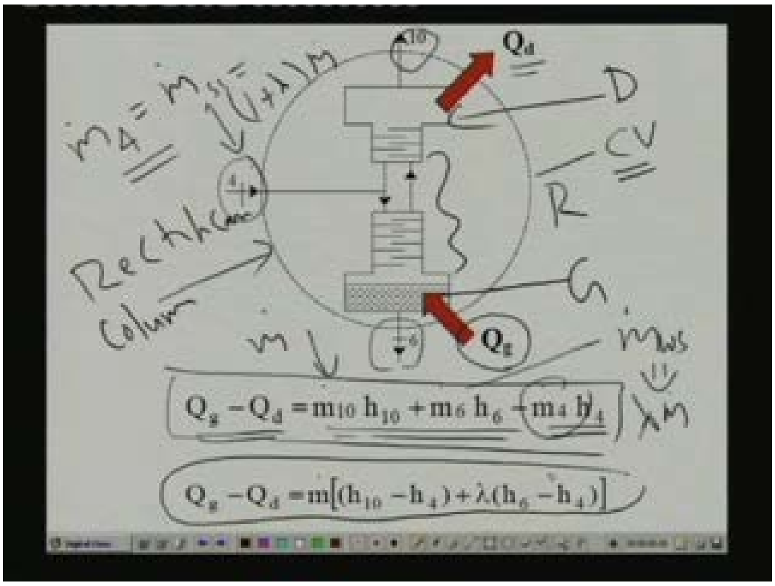

$$Q_g - Q_d = m_{10} h_{10} + m_6 h_6 - m_4 h_4$$

$$Q_g - Q_d = m[(h_{10} - h_4) + \lambda(h_6 - h_4)]$$

So what we do here is we take a control volume this is the control volume across the entire rectifying rectification column okay. That means I am taking the entire rectifying column rectification column okay. So this includes the generator here and the rectification column here and the dephlegmator okay. So dephlegmator D rectification column R and the generator G are all taken into this control volume okay. And then you apply the mass and energy balance to this control volume if you are applying the energy balance to this control volume Qg minus Qd is the net heat transfer into the into the control volume. Because you are supplying the heat Qg at the generator and you are rejecting heat Qd at the dephlegmator. So Qg minus Qd is a net heat input into the system by way of external heat supply. This should be equal to the energy leaving the control volume. And what is the energy leaving the control volume energy leaving is nothing but the energy carried by the vapour at point ten. And energy carried by the solution at point six minus energy coming into the control volume by way of mass flow okay, that is four.

So you can easily write energy balance Qg minus Qd like this okay. And again m dot ten is nothing but your refrigerant flow rate m dot if you are assuming perfect rectification. And what is the m dot six m dot six is nothing but your weak solution okay. M dot WS and m dot WS as you have seen just now is nothing but circulation ratio into mass flow rate of refrigerant and m dot four that is this okay. M dot four is nothing but your strong solution flow rate and strong solution flow rate we have seen just now is nothing but one plus circulation ratio into refrigerant flow rate. So if you are substituting these expressions in this one you can finally show that Qg minus Qd is equal to m dot into h ten minus h four plus lambda into h six minus h four so this is the expression for okay. So this is the expression for net heat flow into the control volume.

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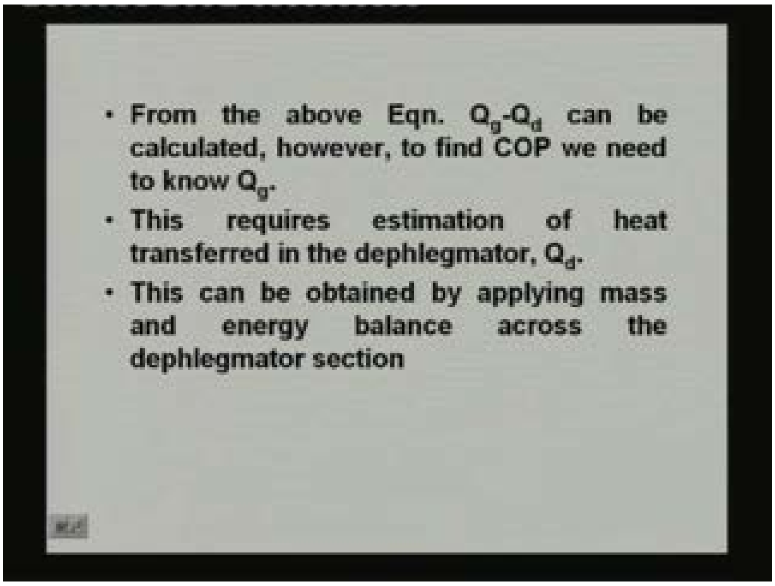

- From the above Eqn. Q_g-Q_d can be calculated, however, to find COP we need to know Q_g.
- This requires estimation of heat transferred in the dephlegmator, Q_d.
- This can be obtained by applying mass and energy balance across the dephlegmator section

Now from above equation we can calculate Qg minus Qd but if you want to find out the COP you need to know Qg because that is the finally the heat input to the system okay. So first calculate Qg minus Qd using the above energy balance equation for the control volume then you have to calculate somehow Qd. So that finally you can get Qg so how do we do this. So this requires the estimation of heat transferred in the dephlegmator obviously you have to find out what is the heat transfer or to the heat sink in the dephlegmator that is Qd okay. And this can be obtained by applying mass and energy balance across the dephlegmator section. So I will show you the dephlegmator section now.

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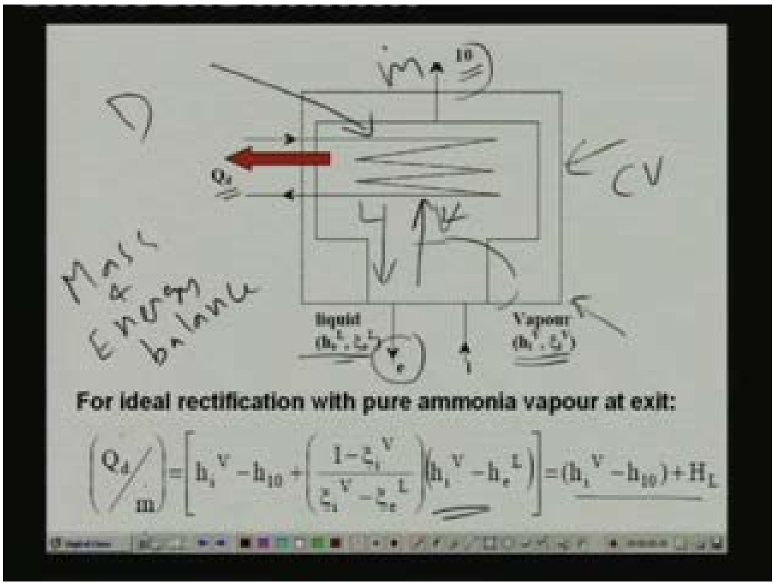

For ideal rectification with pure ammonia vapour at exit:

$$\left(\frac{Q_d}{\dot{m}}\right)=\left[h_i^V-h_{10}+\left(\frac{1-\xi_i^V}{\xi_i^V-\xi_e^L}\right)\left(h_i^V-h_e^L\right)\right]=\left(h_i^V-h_{10}\right)+H_L$$

Okay, so what we doing here is, I have taken a control volume this is again a control volume across the dephlegmator section you know remember that this is your dephlegmator. And this is a part of your rectification column you can take this control volume at any place you can include any cross section here okay. But the outlet here must include the vapour okay and you can show by from mass and energy balance for this mass and energy balance okay. For this control volume you can show that you can arrive at this expression Qd by m dot Qd is the heat rejected in the dephlegmator divided by m dot m dot is the refrigerant flow rate from the system.

So Qd by m dot is equal to hi V hi V is nothing but the vapour enthalpy at any cross section minus h ten h ten is nothing but the enthalpy of the refrigerant vapour leaving this section plus one minus zeta i V divided by zeta i V minus zeta e L into hi V minus h e L what is zeta e L and h e L zeta e L and h e L are the enthalpy. And the composition of liquid that is coming that is descending in this section okay. So zeta e L and h e L differ to the liquid properties the liquid that is descending remember that in this section liquid is descending and vapour is ascending okay, vapour is ascending they exchange heat and mass. So you can arrive at this expression easily by applying mass and energy balance. So finally this is written as hi V minus h ten plus H L okay.

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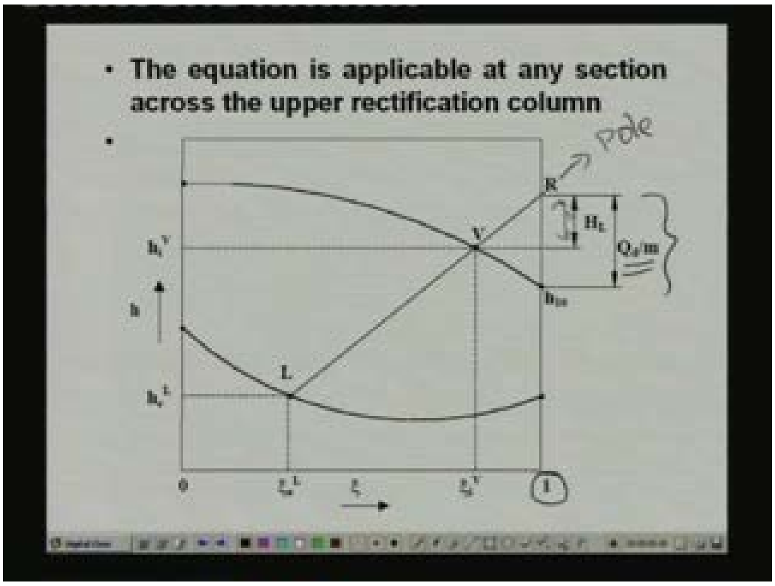

- The equation is applicable at any section across the upper rectification column
-

So if you are plotting the same thing on the enthalpy composition diagram you can show that I am plotting this, an enthalpy composition diagram. What I have done is, I have marked the condition of the vapour that is ascending and the liquid that is descending at any cross section okay. So that is shown by point V and L and then i have joined the points V and L by a straight line okay. We joined by a straight line and you extend this straight line. So that it intercepts this psi is equal to one line at this point R okay, this is an important point R okay. So this point R I will show little later is known as pole of the rectifier okay. So from the expression shown earlier it can be very easily shown that the distance between this point R and this point is nothing but Qd by m okay. Remember that these analyses are based on the assumption that the vapour that is leaving the section is pure refrigerant. That means you are assuming that vapour is leaving at a concentration of one okay, if you are assuming that then this vertical distance is nothing but Qd by m and this distance is equal to h L okay, what is HL okay.

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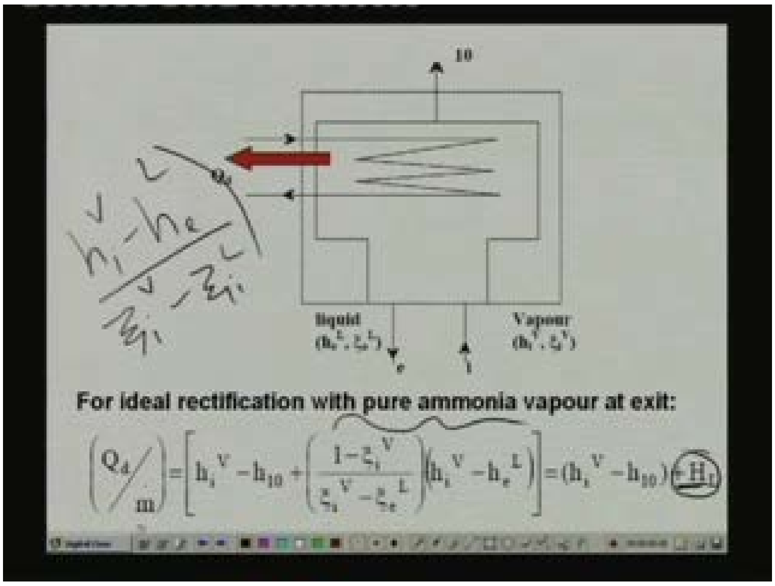

For ideal rectification with pure ammonia vapour at exit:

$$\left(\frac{Q_d}{m}\right) = \left[h_i^V - h_{10} + \left(\frac{1-\xi_i^V}{\xi_i^V - \xi_e^L}\right)\left(h_i^V - h_e^L\right)\right] = \left(h_i^V - h_{10}\right) + H_L$$

So HL is this okay, this is HL and this is given by this expression okay. Whatever is there in the bracket that is one minus zeta i V divided by zeta i V minus zeta e L and h i V minus h e L and what is this? You can easily see from the above from enthalpy composition diagram that h i V minus h e L divided by psi i V minus psi i L okay. This is nothing but the slope of the line okay, let me show that.

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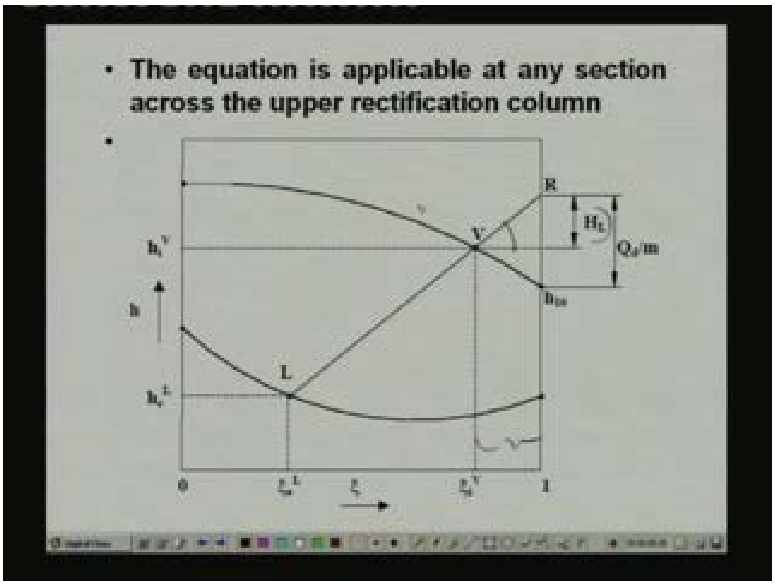

- The equation is applicable at any section across the upper rectification column
-

So this is nothing but the expression in the bracket is nothing but the slope of this line. So obviously the slope of that line into this distance will give you the enthalpy difference between this point and this point that is known as HL okay. So this is how you can plot the enthalpy composition diagram of this dephlegmator section and you can arrive at these points. So how do we calculate Qd because ultimately we would like to calculate Qd okay?

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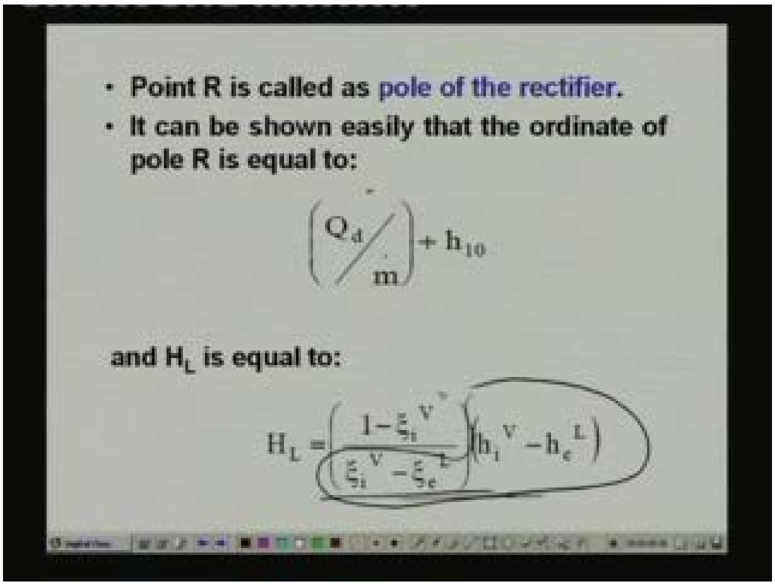

- **Point R is called as pole of the rectifier.**
- **It can be shown easily that the ordinate of pole R is equal to:**

$$\left(\dot{Q}_d/\dot{m}\right)+h_{10}$$

and H_L is equal to:

$$H_L=\left(\frac{1-\xi_1^V}{\xi_1^V-\xi_e^L}\right)\left(h_1^V-h_e^L\right)$$

So point R as I said is called as pole of the rectifier and it can be shown easily that the ordinate of pole are is equal to Qd by m plus h ten okay. So h ten is nothing but the enthalpy of the vapour leaving the dephlegmator section which can be easily obtained from refrigerant property table so you know h ten. So if you can find out the ordinate R then you can easily find out Qd by m dot okay. So this is the principle. And as I have already said this HL is equal to this quantity where this one is your slope of the line that multiplied this will give you the enthalpy difference.

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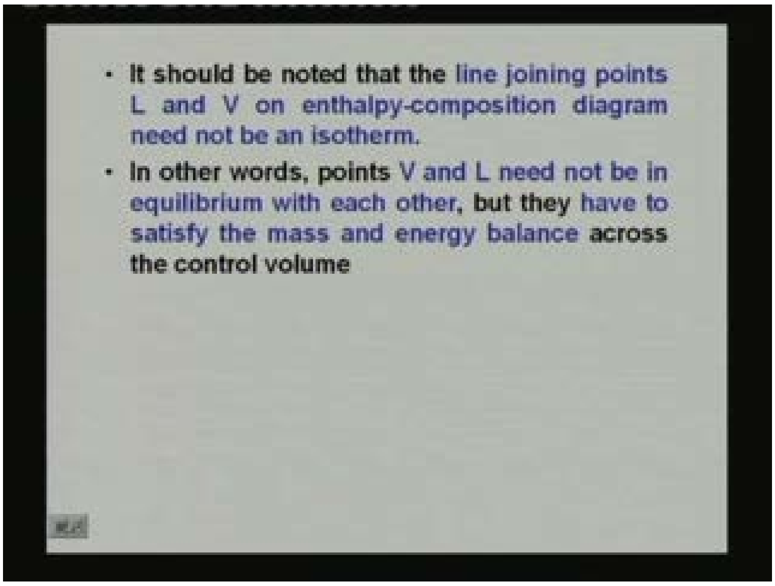

- It should be noted that the line joining points L and V on enthalpy-composition diagram need not be an isotherm.
- In other words, points V and L need not be in equilibrium with each other, but they have to satisfy the mass and energy balance across the control volume

And it should be noted that the line joining points L and V on enthalpy composition diagram need not be an isotherm. What it means is that points V and L need not be in equilibrium with each other. That means we have drawn the enthalpy composition diagram by not assuming any equilibrium or anything you need not assume anything okay. You simply say you take one section of the lower part of the dephlegmator and then simply apply the energy and mass balance and the V and L need not be in equilibrium. But they have to satisfy the mass and energy balance. So that is the only requirement okay.

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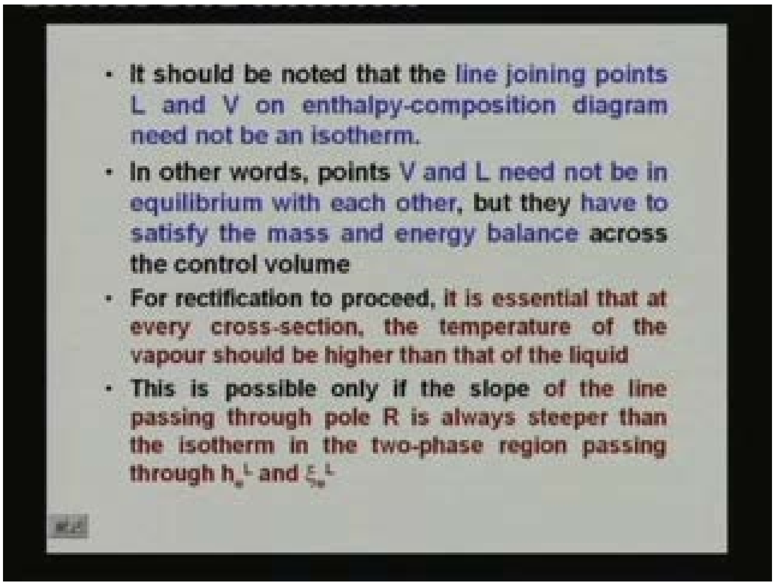

- It should be noted that the line joining points L and V on enthalpy-composition diagram need not be an isotherm.
- In other words, points V and L need not be in equilibrium with each other, but they have to satisfy the mass and energy balance across the control volume
- For rectification to proceed, it is essential that at every cross-section, the temperature of the vapour should be higher than that of the liquid
- This is possible only if the slope of the line passing through pole R is always steeper than the isotherm in the two-phase region passing through h_w^L and ξ_w^L

And for rectification to proceed it is essential that at every cross section the temperature of the vapour should be higher than that of the liquid. This is an essential condition otherwise rectification cannot proceed. That means the vapour should always be hotter than the liquid. So this is possible only if the slope of the line passing through the pole R is always steeper than the isotherm in the two phase region passing through the liquid state points he L and zeta e L okay. So this condition has to be met that means when you are taking out some heat in the dephlegmator you have to make sure that the line joining points V and L are always steeper than the isotherms in the two phase region okay. Only then vapour will be hotter than the liquid okay. Only when vapour is hotter than the liquid then heat transfer can take place from the vapour 8and liquid and mass transfer can take place from the liquid to vapour okay. So this has to be ensured and this has to be ensured only by controlling your heat rejected in the dephlegmator okay, as I said.

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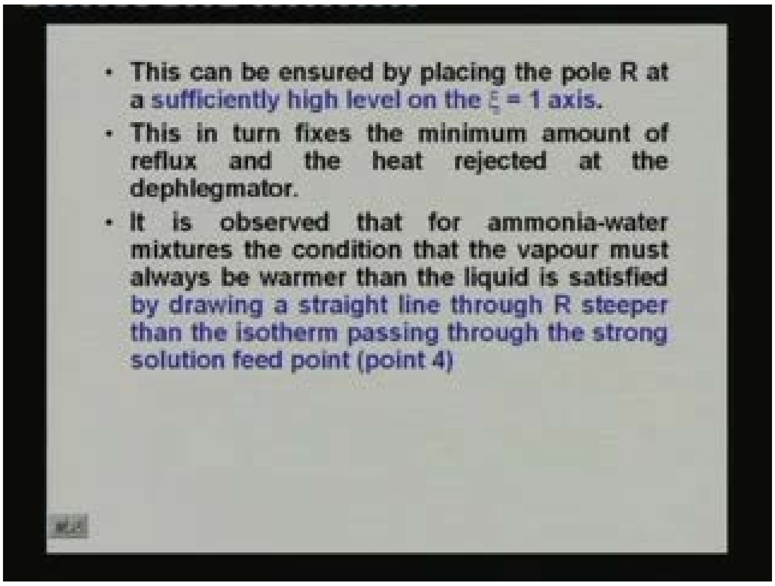

- This can be ensured by placing the pole R at a sufficiently high level on the $\xi = 1$ axis.
- This in turn fixes the minimum amount of reflux and the heat rejected at the dephlegmator.
- It is observed that for ammonia-water mixtures the condition that the vapour must always be warmer than the liquid is satisfied by drawing a straight line through R steeper than the isotherm passing through the strong solution feed point (point 4)

This can be place ensured by placing the pole R at a sufficiently high level on the zeta is equal to one axis and this in turn fixes the minimum amount of reflux and heat rejected at the dephlegmator. It is observed that for ammonia water mixtures the condition that the vapour must always be warmer than the liquid is satisfied by drawing a straight line through R steeper than the isotherm passing through the strong solution feed point four. So that means what you have to do is normally a from the properties and from the operating temperatures and pressures. We know the condition of the feed and what is the feed means strong solution that is entering into the rectification system okay.

So you know the condition of that so you can mark that point on the enthalpy composition diagram okay. So first mark the condition of the feed on the enthalpy composition diagram then draw an isotherm passing through this point okay. And then you have to choose the condition of the pole in such a way that the line joining the vapour and liquid points at any part of the dephlegmator section is steeper than the isotherm passing through the feed point four okay. So this is the, this, what you have to do okay. Once you do this you can find the uh pole because pole is nothing but the interception between the point joining the vapour and liquid and zeta is one line okay. So you can find out the position of the pole once you find the position of the pole you can find Qd by m okay. And where we are doing this because you want to find out Qg because you know Qg minus Qd and and if you know Qd you can find out Qg okay. So this is the procedure here a complicated procedure.

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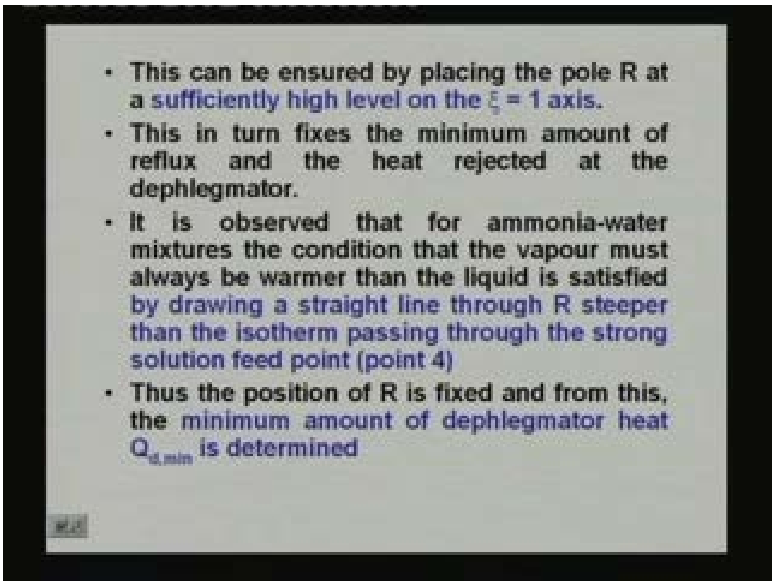

- This can be ensured by placing the pole R at a sufficiently high level on the $\xi = 1$ axis.
- This in turn fixes the minimum amount of reflux and the heat rejected at the dephlegmator.
- It is observed that for ammonia-water mixtures the condition that the vapour must always be warmer than the liquid is satisfied by drawing a straight line through R steeper than the isotherm passing through the strong solution feed point (point 4)
- Thus the position of R is fixed and from this, the minimum amount of dephlegmator heat $Q_{d,min}$ is determined

The position of R is fixed from this and the minimum amount of dephlegmator heat Qd minimum is determined.

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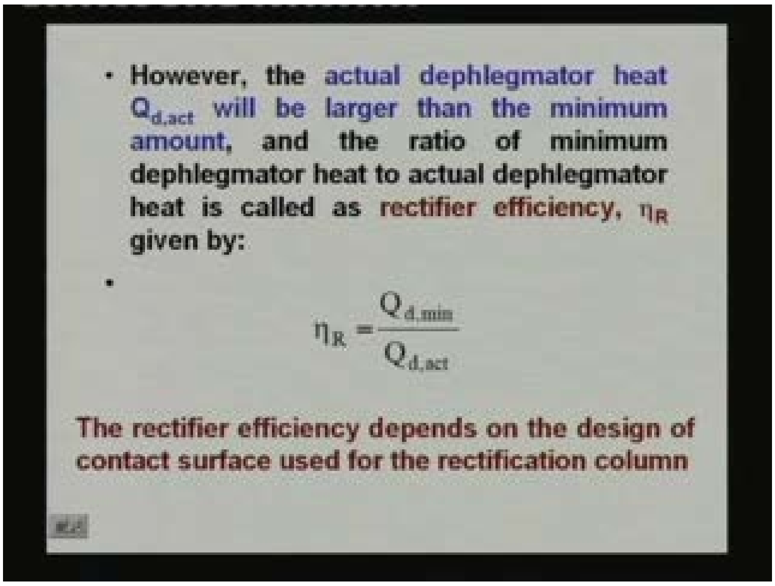

- However, the actual dephlegmator heat $Q_{d,act}$ will be larger than the minimum amount, and the ratio of minimum dephlegmator heat to actual dephlegmator heat is called as rectifier efficiency, η_R given by:
- $$\eta_R = \frac{Q_{d,min}}{Q_{d,act}}$$

The rectifier efficiency depends on the design of contact surface used for the rectification column

However we find that in actual case the actual dephlegmator heat will be larger than the minimum amount obtained in this manner okay. And the ratio of minimum dephlegmator heat to actual dephlegmator heat is called as rectifier efficiency eta R. So rectifier efficiency eta R is defined as Qd minimum by Qd actual so Qd minimum can be determined from the procedure explained now and you have to know eta R. So that you can find out Qd actual and it is observed that the rectifier efficiency eta R depends on the design of contact surface used for the rectification column. That means what kind of a surface you are using is it a plate column or is it a packed bed or is it a spray column. So depending upon that you have to find the eta R and once you know the eta R in Qd minimum find Qd actual.

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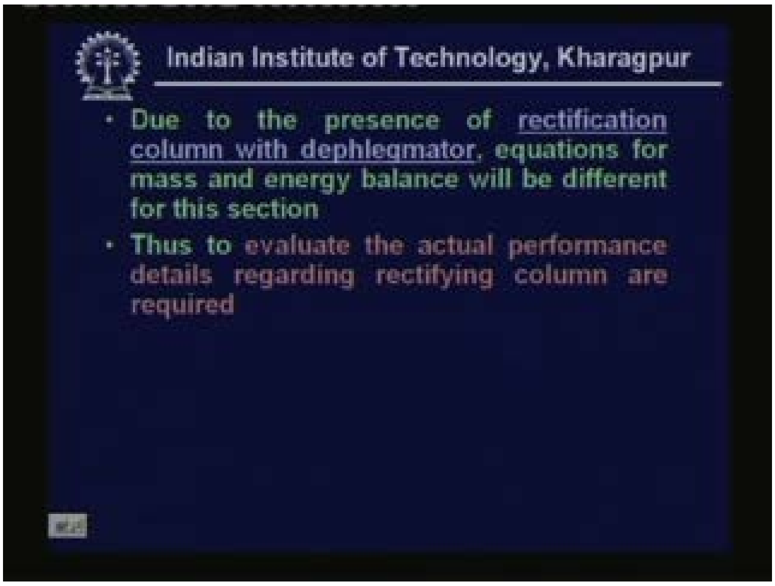

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- Due to the presence of rectification column with dephlegmator, equations for mass and energy balance will be different for this section
- Thus to evaluate the actual performance details regarding rectifying column are required

Okay, so this is the procedure. So thus to evaluate the actual performance details regarding rectifying column are required you must have noticed that the calculations for ammonia water systems are much more complicated compared to water lithium bromide systems. All this complication is coming because of the lower boiling point temperature different between ammonia and water. But this is something which cannot be avoided okay. Because if you neglect this you find that there is lot of water in the refrigerant circuit. And if you do not consider the presence of water there then the first of all the system may not function properly. And the calculations will be different from the actual calculations okay. So if you want to predict the performance properly you have to have the details of the rectification column the construction column details and all that. And then you have to carry out this complicated analysis presented. Now and only then you can arrive at reasonably accurate values okay. Sometimes details may not be available and you have to do calculations without these details.

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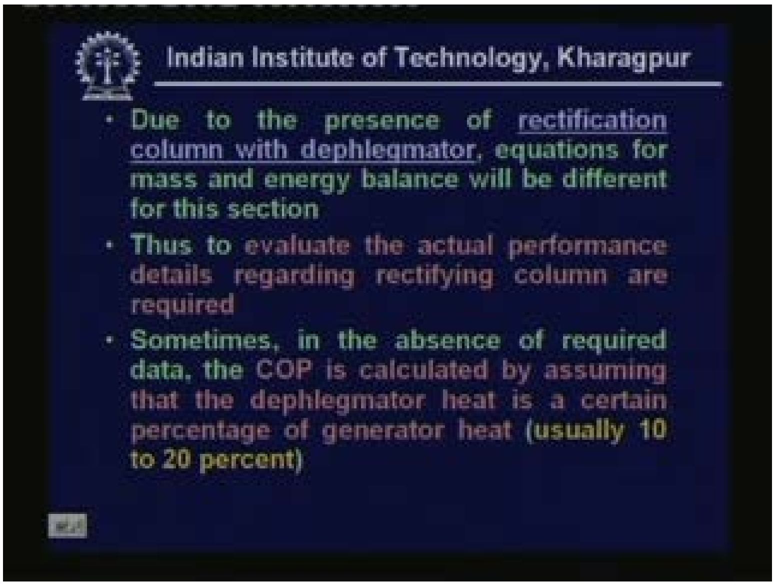

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- Due to the presence of rectification column with dephlegmator, equations for mass and energy balance will be different for this section
- Thus to evaluate the actual performance details regarding rectifying column are required
- Sometimes, in the absence of required data, the COP is calculated by assuming that the dephlegmator heat is a certain percentage of generator heat (usually 10 to 20 percent)

So what is done in such cases is when you in the absence of required data the COP is calculated by assuming that the dephlegmator heat is a certain percentage of generator heat okay. You take a value of about ten to twenty percent. That means what you do is you carry out the steady flow analysis of the system okay. Taking the control volume across the entire rectifying system okay. So as we have seen that will give you Qg minus Qd okay which can be obtained easily then you assume that Qd is certain percentage of Qg okay. So if we are making these assumptions then you can calculate Qg okay. So this is the faster way of calculating of course this is not very accurate and also you want to know what is the percentage.

So normally a value of ten to twenty percent is taken in actual calculations okay. Now let us the system discussed so for both water lithium bromide system as well as ammonia water systems are known as conventional absorption refrigeration systems. And you have seen that they do not run purely on heat because you also have to have for certain amount of mechanical energy to run the solution pump okay. So they are not purely heat operated systems because certain amount of mechanical energy is also required okay. So you also have absorptions system known as pumpless absorption systems okay. As a name implies a pumpless absorption refrigeration system does not have a pump okay. Let us look at some of these systems and what are the features of this system.

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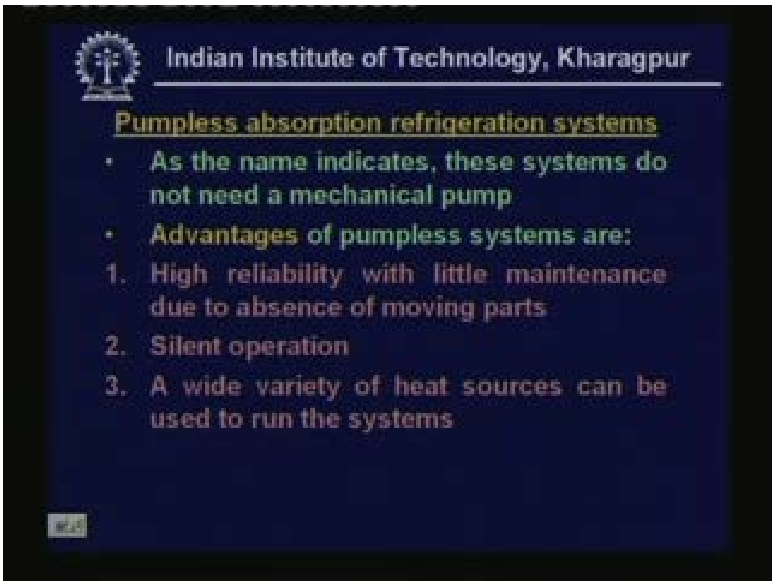

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Pumpless absorption refrigeration systems

- As the name indicates, these systems do not need a mechanical pump
- Advantages of pumpless systems are:

1. High reliability with little maintenance due to absence of moving parts
2. Silent operation
3. A wide variety of heat sources can be used to run the systems

So as the name indicates these systems do not need a mechanical pump. And what are the advantages of not having a pump the advantages are high reliability with little maintenance due to absence of moving parts. So in a pump less refrigerant system you do not have a moving component at all okay. So once you do not have any moving component reliability will be extremely high okay. Because there is the frankly speaking there is nothing can go wrong in a pumpless system okay. And practically no servicing is also not is required okay. So no maintenance is required no servicing is required and very high reliability okay. This one major advantage of pumpless system okay. And since you do not have any moving parts the operation will be perfectly silent in fact you do not know the system is working or not because the system does not make any noise okay. Only when you feel he inside you know that its working and a wide variety of heat sources can be used to run the systems.

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- Applications of pumpless systems are:
- Refrigerators for remote and rural areas
- Portable refrigerators
- Refrigerators for luxury hotel rooms etc

So what are the applications of pumpless systems the applications are as refrigerators for remote and rural areas in portable refrigerators and as refrigerators for luxury hotel rooms etcetera okay. In luxury hotel rooms the customers do not want to have any noise okay. So it has to be perfectly noiseless inside the room okay. So if you are using a normal mechanical vapour compression system the compressor will be making noise okay. So sometimes this will be disturbing okay. So in five star hotels and all they use the pumpless absorption systems. As I said since it does not have any moving components, it does not make any noise okay. So this is one of the major applications of pumpless absorption systems okay.

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- Applications of pumpless systems are:
- Refrigerators for remote and rural areas
- Portable refrigerators
- Refrigerators for luxury hotel rooms etc
- Several pumpless systems using both water-lithium bromide and ammonia-water have been developed over the last many decades
- The most popular among these is the system known as Platen-Munters or Triple Fluid Vapour Absorption Refrigeration Systems (TFVARS)

There are several pumpless systems using both water lithium bromide and ammonia water okay. so people have been working on this systems for last many decades. But out of these systems the most popular one is what is known as Platen-Munters system or triple fluid vapour absorption refrigeration systems oaky. So let us look at Platen-Munters systems now.

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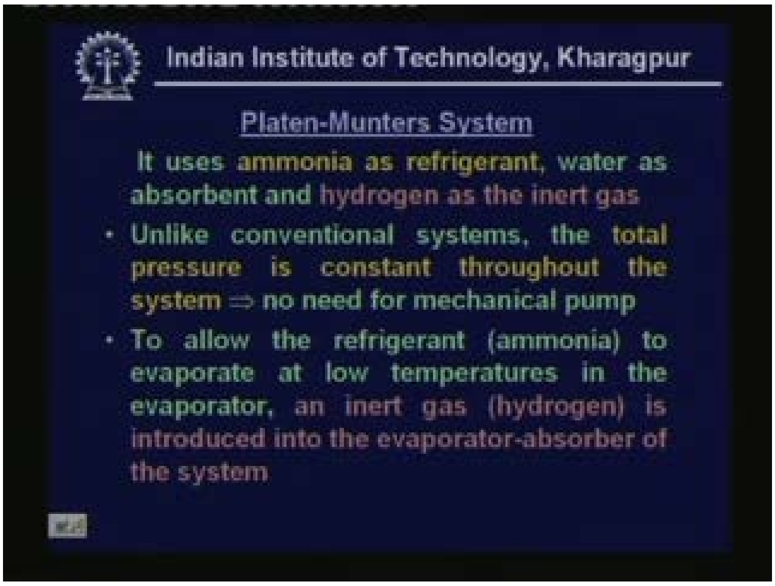

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Platen-Munters System

It uses ammonia as refrigerant, water as absorbent and hydrogen as the inert gas

- Unlike conventional systems, the total pressure is constant throughout the system ⇒ no need for mechanical pump
- To allow the refrigerant (ammonia) to evaporate at low temperatures in the evaporator, an inert gas (hydrogen) is introduced into the evaporator-absorber of the system

Platen-Munters system if you remember from our first lecture is a name of the inventers platen and Munters. And this system uses ammonia as refrigerant water as absorbent and a third fluid hydrogen as the inert gas. That is the reason why you call these systems as triple fluid vapour absorption system okay. Because you have three fluids unlike conventional systems the total pressure is constant throughout the system. So since a total pressure is constant throughout the system you do not require a compressor or pump for pressurising okay. So you at the same time you also do not require any expansion valve because entire system operates at a single pressure. So you do not require anything for pressurising the working fluid okay.

So this is the major principle behind the, these systems okay. So no need for mechanical pump and to allow the refrigerant to evaporate at low temperatures in the evaporator an inert gas is introduced into the evaporator absorber of the system okay. So if the, you have to when you are discussing pumpless systems particularly Platen-Munters systems you have to make a distinction between total pressure and partial pressure. So far we have been talking about the pressure okay. So in this particular system you have a partial pressure and a total pressure okay. So total pressure is same inside the system inside the entire system okay, but the partial pressure will be different okay. So let us look at this let me first explain the principle.

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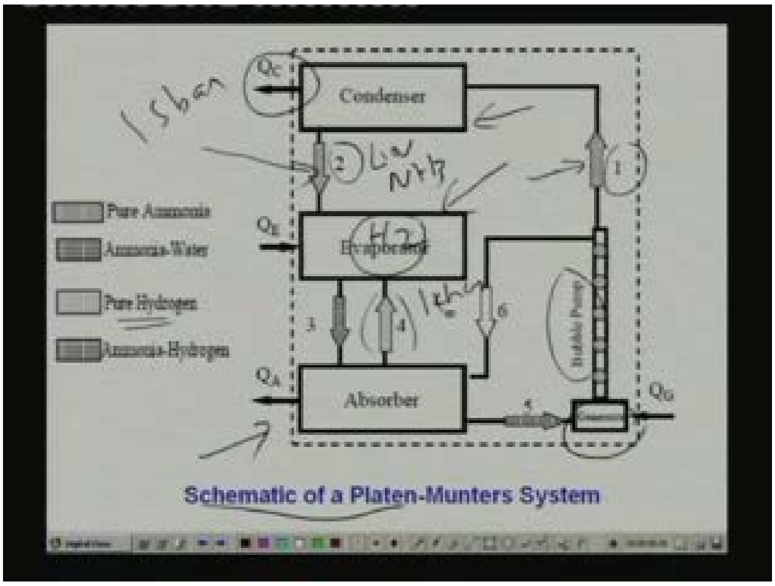

Schematic of a Platen-Munters System

Okay, this is the schematic of typical Platen-Munter system this consist of a condenser an evaporator an absorber a generator here and another component called as bubble pump okay. For the sake of simplicity I have not shown the rectification column dephlegmator and all that but in actual systems those things will be there okay. So we are assuming that we do not have any of those things at the same time we are getting pure ammonia at the end of this bubble pump okay. So let me explain the working principle starting with this point. So at this point you have pure ammonia refrigerant okay, and this is at high pressure. So this pure ammonia refrigerant at high pressure enters into the condenser where it rejects the heat of condensation okay. And what you have at the exit of condenser is liquid ammonia okay liquid ammonia at high pressure.

Now this liquid ammonia at high pressure enters into the evaporator okay. So in the evaporator in addition to ammonia we also have a third fluid called hydrogen okay. So you have pure hydrogen here right in fact this pure hydrogen makes up for most of the pressure in the evaporator since total pressure is same for example pressure at this point let us say fifteen bar okay. So fifteen bar liquid is entering into the evaporator and in fact the evaporator the partial pressure of hydrogen is fourteen bar let us say okay.

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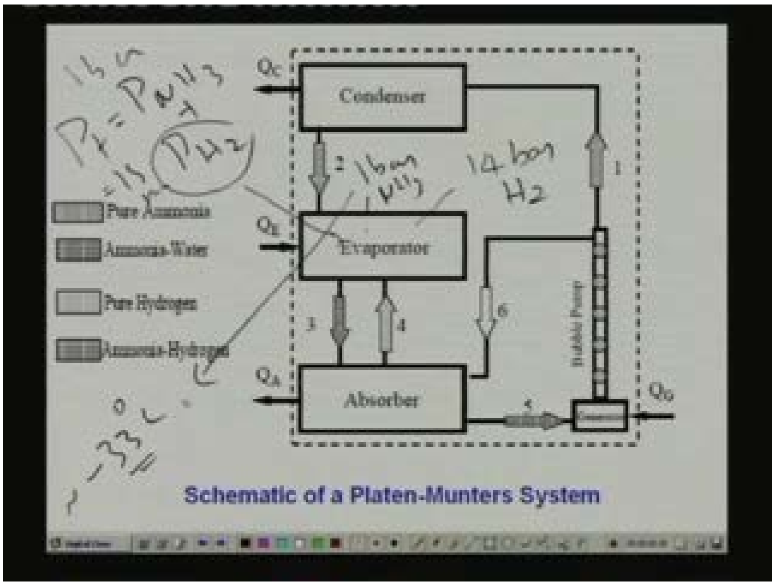

Schematic of a Platen-Munters System

So hydrogen is exerting a partial pressure of fourteen bar here. So fourteen bar is because of hydrogen. So what will be the pressure of ammonia here the pressure of ammonia has to be the partial pressure of ammonia. Because the total pressure is constant so in evaporated section you find that P total is equal to P ammonia plus P hydrogen okay and P total as we have seen is equal to fifteen bar and out of this fifteen bar hydrogen is making up for the fourteen bar okay. That means the partial pressure of ammonia has to be one bar okay. So there is a sudden this is somewhat similar to an expansion but it is not by throttling or anything but it is by simply expanding by simply entering into a vessel where a third fluid is exerting a major portion of the pressure okay.

So during this process the ammonia pressure drops from fifteen bar to fourteen bar. So here you have liquid ammonia at one bar one bar ammonia liquid okay. Now this one bar ammonia liquid can evaporate at very low temperature. Because you find that at one bar it has an evaporation temperature of about minus thirty three degree centigrade okay. So in the evaporator it can evaporate.

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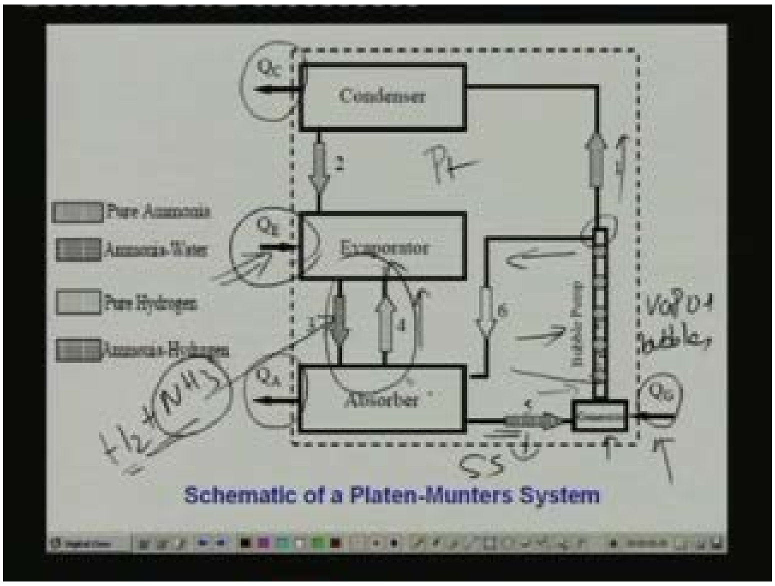

Schematic of a Platen-Munters System

At minus thirty three degree centigrade by taking heat from the refrigerated space okay. So that is how you get the refrigeration effect now as it evaporates what happens a vapour is formed okay. So you see that at point three vapour of hydrogen and ammonia which are cooler because they are in the evaporator they go down because of buoyancy okay. So this vapour consisting of ammonia and hydrogen goes to the absorber in the absorber what happens is the weak solution that is coming from the bubble pump okay. The weak solution coming from the bubble pump comes in contact with the mixture of hydrogen and ammonia okay.

So when the come in contact what happens is ammonia is taken out from this mixture. That means this solution absorbs ammonia and it cannot absorb hydrogen. So hydrogen is left out and ammonia is absorbed okay and in this process hydrogen temperature increases okay. Since its temperature increases it becomes lighter and its moves up to the evaporator okay. So that's how the hydrogen circulation is maintained from. So you have closed hydrogen circulation from the evaporator to the absorber because of the buoyancy effects okay. Now what happens the solution here you have solution. Now which is now stronger in this is the strong solution stronger in ammonia. Now this is also at fifteen bar. So this goes to the generator in the generator heat is supplied. So when heat is supplied in the generator vapour bubbles are generated okay.

So you have vapour bubble generated in the okay. In the generator and vapour bubbles because of buoyancy they move up, so as they move up they carry some liquid along with them okay. So that is the function of the bubble pump so in what are we doing in a bubble pump in the bubble pump the vapour bubbles move the liquid from the bottom to the top because of buoyancy okay. So this goes on till the end of the till the top of the bubble pump at the top of the bubble pump liquid goes down. Because of the gravity and vapour moves up because of the buoyancy okay.

So that is how the whole system works and you can see here that we are rejecting heat at absorber rejecting heat at condenser supplying heat in the form of low temperature heat at evaporator. And high temperature heat input takes place at the generator in addition to that you also have to supply certain energy for the bubble pump to operate okay. So here energy is required for generating the vapour as well as for operating the bubble pump okay. And remember that the total pressure is constant at every point when I say constant there will be small differences. Because of the gravity heads and all for example if you look at this one pressure at this point will be higher that the pressure at this point because of the gravity head okay.

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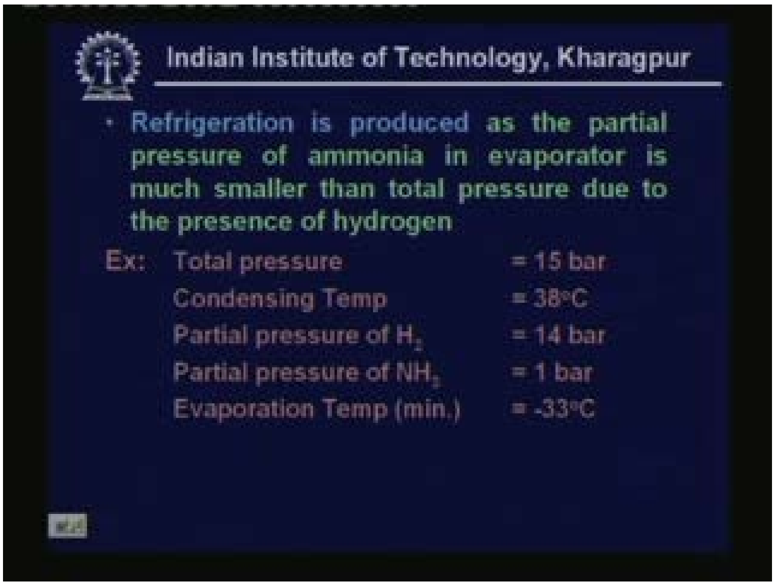

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- Refrigeration is produced as the partial pressure of ammonia in evaporator is much smaller than total pressure due to the presence of hydrogen

Ex: Total pressure = 15 bar
Condensing Temp = 38°C
Partial pressure of H_2 = 14 bar
Partial pressure of NH_3 = 1 bar
Evaporation Temp (min.) = -33°C

So this is the working principle of this and refrigeration is produced as the partial pressure of ammonia in evaporator is much smaller than the total pressure due to the total presence of hydrogen. As I have already explained and if i am giving just an example if the total pressure. As I said is fifteen bar then it can condense at thirty eight degree centigrade and the partial pressure of hydrogen is fourteen bar. So partial pressure of ammonia is one bar in the evaporator. That means it can evaporate at a minimum temperature of minus thirty three degree centigrade.

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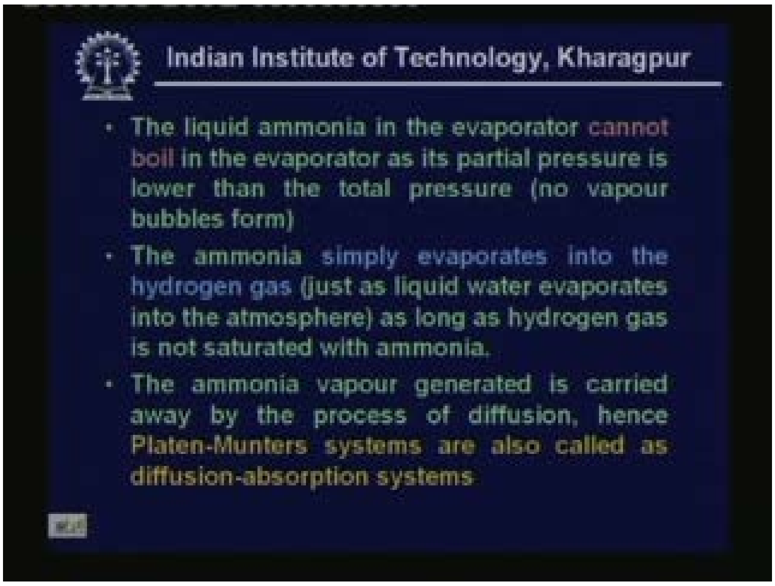

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- The liquid ammonia in the evaporator cannot boil in the evaporator as its partial pressure is lower than the total pressure (no vapour bubbles form)
- The ammonia simply evaporates into the hydrogen gas (just as liquid water evaporates into the atmosphere) as long as hydrogen gas is not saturated with ammonia.
- The ammonia vapour generated is carried away by the process of diffusion, hence Platen-Munters systems are also called as diffusion-absorption systems

Now the liquid ammonia in the evaporator cannot boil in the evaporator as its partial pressure is lower than the total pressure. So this one certain difference is there between this system and the earlier system here because of the presence of hydrogen boiling cannot take place what takes place is evaporation. That means you will not find any vapour bubbles here simply the ammonia liquid evaporates into the hydrogen gas. So this is somewhat similar to the evaporation of liquid water in atmosphere okay. This takes place as long as hydrogen gas is not saturated with ammonia and the ammonia vapour generated is carried away by the process of diffusion.

Hence Platen-Munters systems are also called as diffusion absorption systems sometimes people use the name diffusion absorption systems for Platen-Munters systems. So as I said why do we call it as diffused absorption system because here the process is not one of boiling but it is one of evaporation and then diffusion okay? So this is a certain difference right so that is why we call it as diffusion absorption systems okay.

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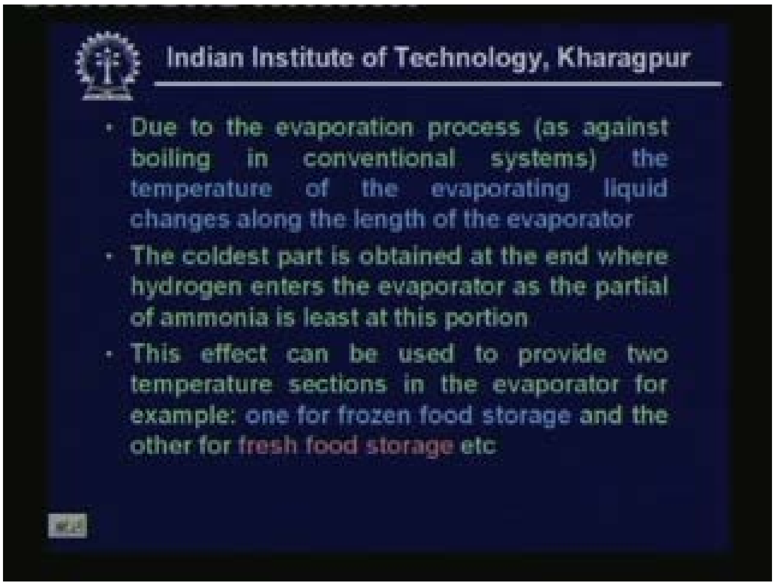

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- Due to the evaporation process (as against boiling in conventional systems) the temperature of the evaporating liquid changes along the length of the evaporator
- The coldest part is obtained at the end where hydrogen enters the evaporator as the partial of ammonia is least at this portion
- This effect can be used to provide two temperature sections in the evaporator for example: one for frozen food storage and the other for fresh food storage etc

Due to the evaporation process the temperature of the evaporating liquid changes along the length of the evaporator. This is the another difference you will find that inside the evaporator the temperature is not constant okay. You have a cold region and you have a progressively increasing region with progressively increase in temperature and the coldest part is obtained at the end where hydrogen enters the evaporator. So why that this part is coldest because at this part the partial pressure of ammonia is least okay. So it can evaporate at lowest temperature this can be beneficially used to provide two temperature sections in the evaporator. For example if you are using this system for a refrigerator you can use the coldest part for frozen food storage and the relatively warmer parts for fresh food storage this is what is done in commercial refrigerators.

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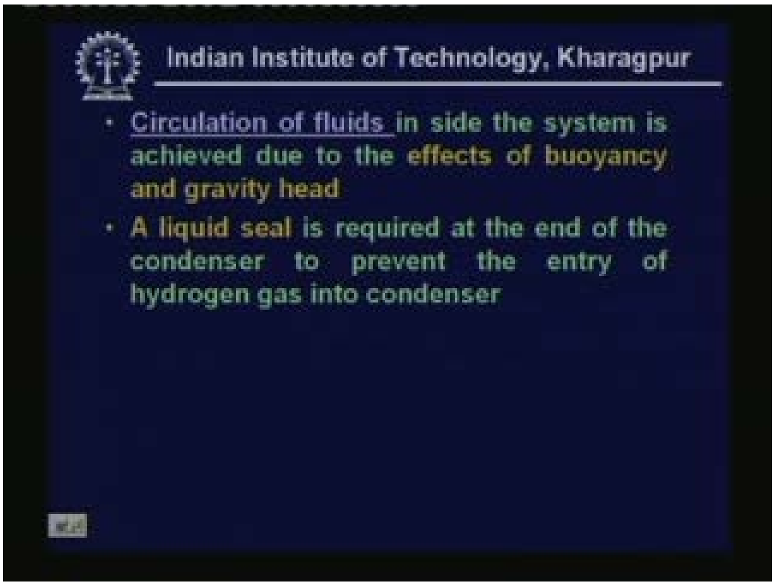

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- Circulation of fluids in side the system is achieved due to the effects of buoyancy and gravity head
- A liquid seal is required at the end of the condenser to prevent the entry of hydrogen gas into condenser

And this circulation of fluids inside the system is achieved as I said due to the effects of buoyancy and gravity head and a liquid seal is required at the end of the condenser to prevent the entry of hydrogen gas into the condenser.

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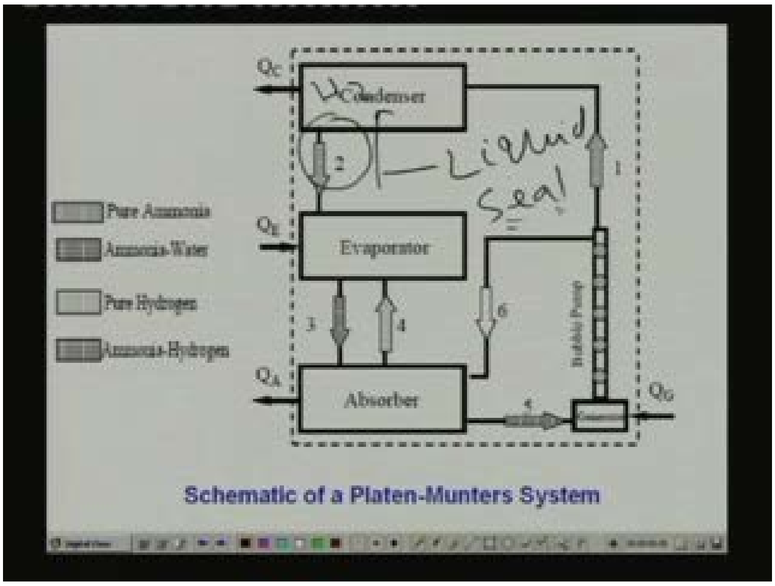

Schematic of a Platen-Munters System

That means at this point you have to have a liquid seal okay. If you do not have this liquid seal what happens is some of the hydrogen can enter into the condenser okay. Hydrogen can enter into the condenser to prevent the hydrogen entry we have to provide a liquid seal.

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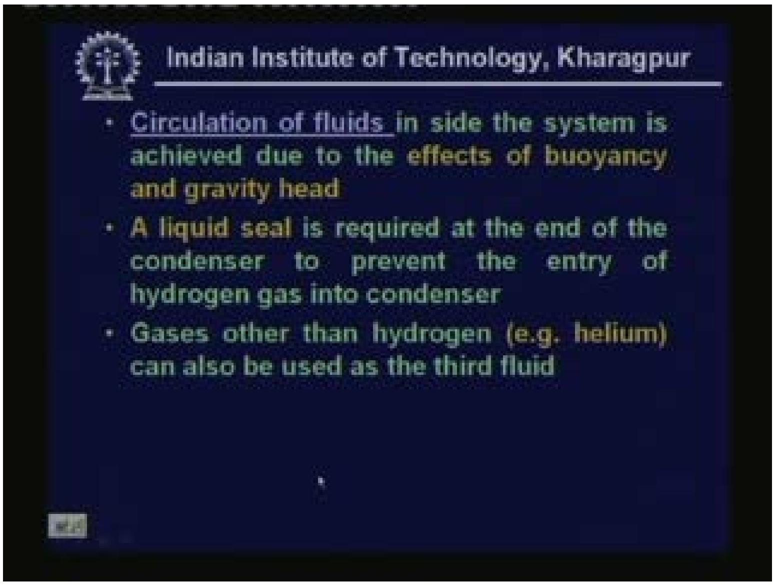

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- Circulation of fluids in side the system is achieved due to the effects of buoyancy and gravity head
- A liquid seal is required at the end of the condenser to prevent the entry of hydrogen gas into condenser
- Gases other than hydrogen (e.g. helium) can also be used as the third fluid

Okay, gases other than hydrogen can also be used even though the original system used hydrogen gas people also tried other gases such as helium.

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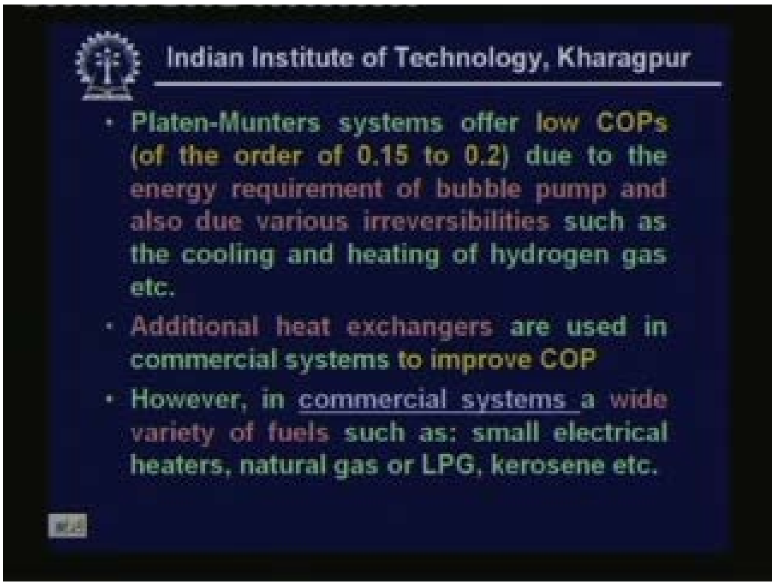

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- Platen-Munters systems offer low COPs (of the order of 0.15 to 0.2) due to the energy requirement of bubble pump and also due various irreversibilities such as the cooling and heating of hydrogen gas etc.
- Additional heat exchangers are used in commercial systems to improve COP
- However, in commercial systems a wide variety of fuels such as: small electrical heaters, natural gas or LPG, kerosene etc.

And Platen-Munters systems are simple and good in many ways one major disadvantage of this system is that they offer very low COPs okay. And the COPs are of the order of point one five to point two and this is because of the energy requirement of bubble pump. And also due to various irreversibilities one such irreversibility is due to the cooling and heating of hydrogen gas in the evaporator absorber section. And additional heat exchangers are used in commercial systems to improve COP okay, commercial systems will be different from the schematic shown earlier okay. However in commercial systems a wide variety of fuels such as electrical heaters in small systems or you can also use natural gas or LPG or kerosene in larger systems okay, again let me okay, typical as I was mentioning.

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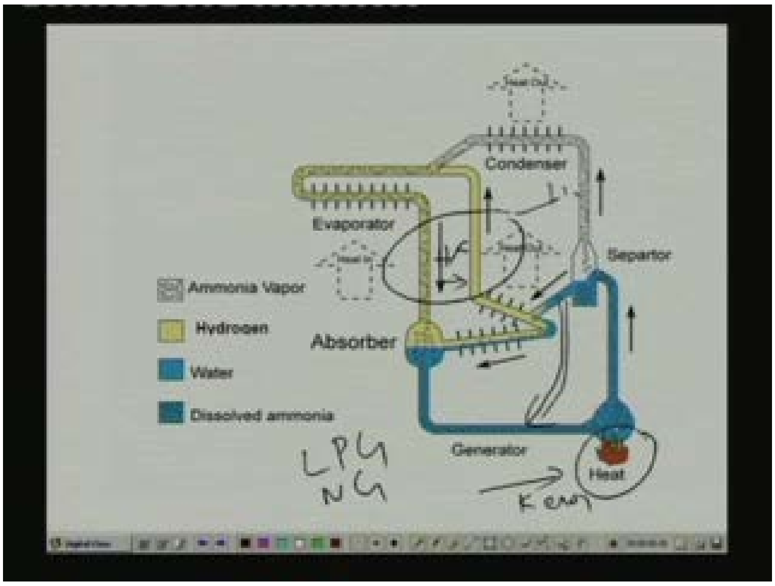

Heat exchanger part you have a in a commercial system you can have a heat exchanger here where the cold vapour that is going to the absorber section can transfer heat can take heat from the hot vapour that is going to the hot hydrogen gas that is going to the evaporator. So you will have one heat exchanger here okay. Similarly you can have another heat exchanger here okay. That means you can preheat the solution that is going to the generator okay. And the heat source here can be anything you can use for example LPG gas or you can use natural gas you can also use kerosene you can use hot water or you can use hot oil or anything okay.

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Solar energy driven heat operated systems

- Absorption systems can be run purely based on solar energy
- In conventional absorption systems the solution pump can be driven by using:

1. A turbine driven by the high pressure vapour generated in the generator, or
2. Photovoltaic cells

- Pumpless systems can be operated using solar energy alone

And let me very briefly explain solar energy driven systems I will not explain but I will just state absorption systems can also be run purely on solar energy if you are using a conventional system. Then the solution pump requires which requires mechanical energy can be driven using a turbine driven by the high pressure vapour generated in the generator. That means you can have a turbine which utilizes some of the high pressure vapour generated in the generator or you can also use photovoltaic cells and have a motor and run the pump using that motor okay. And if you are using a pumpless system of course you do not require any mechanical energy and you can operated purely on solar energy alone.

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- Solar energy driven refrigeration systems using solid adsorbents have also been developed. For example:
  - Water - Silica gel
  - Water- Zeolites
  - Methanol-activated carbon
  - Ammonia-calcium chloride
  - Hydrogen-Metal hydrides etc.
- However, these systems have not been commercialized on a large scale

And solar energy driven refrigeration systems it can also use what is known as solid adsorbents. So of the examples of the solid adsorbents are water silica gels where water is a refrigerant silica gel is the adsorbent water zeolites. Zeolite is an adsorbent methanol activated carbon system methanol is the refrigerant and activated carbon is a refrigerant ammonia calcium chloride system hydrogen metal hydrides systems okay. However these systems have not been commercialized on a large scale let me just show a table where compression systems are compared with absorption systems.

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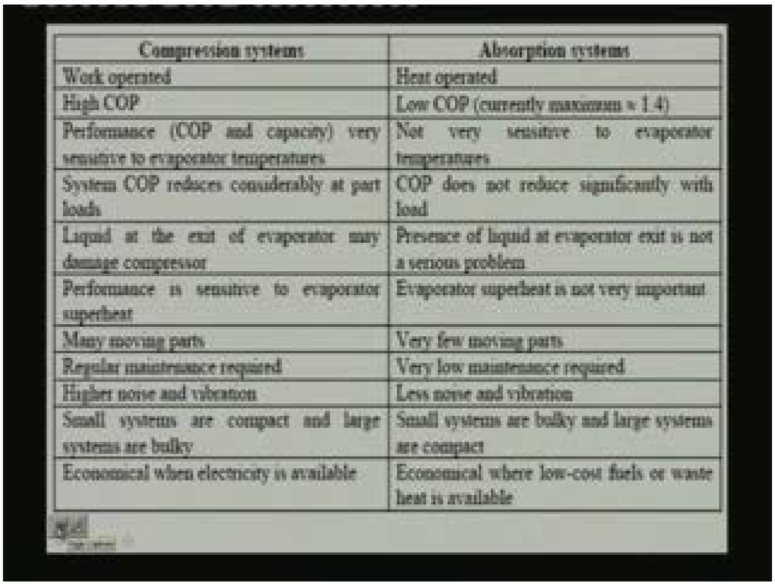

Compression systems	Absorption systems
Work operated	Heat operated
High COP	Low COP (currently maximum ≈ 1.4)
Performance (COP and capacity) very sensitive to evaporator temperatures	Not very sensitive to evaporator temperatures
System COP reduces considerably at part loads	COP does not reduce significantly with load
Liquid at the exit of evaporator may damage compressor	Presence of liquid at evaporator exit is not a serious problem
Performance is sensitive to evaporator superheat	Evaporator superheat is not very important
Many moving parts	Very few moving parts
Regular maintenance required	Very low maintenance required
Higher noise and vibration	Less noise and vibration
Small systems are compact and large systems are bulky	Small systems are bulky and large systems are compact
Economical when electricity is available	Economical where low-cost fuels or waste heat is available

Okay, so this table shows the comparison between compression and absorption systems. So you can see that compression systems are work operated absorption systems are heat operated compression systems offer high COP absorption system offer low COP. Now let me quickly summarise.

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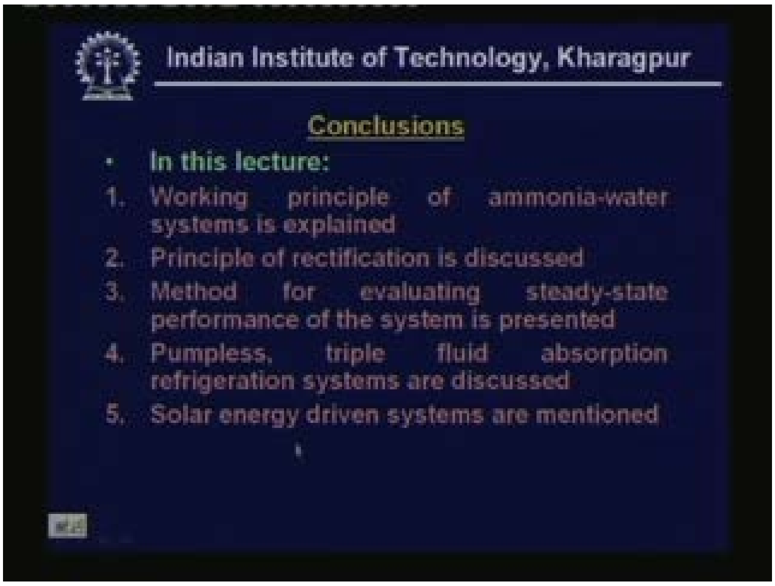

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Conclusions

- In this lecture:

1. Working principle of ammonia-water systems is explained
2. Principle of rectification is discussed
3. Method for evaluating steady-state performance of the system is presented
4. Pumpless, triple fluid absorption refrigeration systems are discussed
5. Solar energy driven systems are mentioned

What you have learnt in this lesson in this lecture working principle of ammonia water systems is explained principle of rectification is discussed method for evaluating steady state performance of the system is presented and pumpless systems are discussed. And solar energy driven systems are mentioned and finally comparison is made between compression and absorption systems. In the next lecture we will look at some of the problems on compression and absorption systems.

Thank you.