Refrigeration and Air Conditioning
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Lecture No. # 19
Worked Out Examples - II

Welcome back in this lecture. I will work out few more example problems and I will also give answers to the questions given in the last lecture. So the first let us go to the first problem the first problem is like this.

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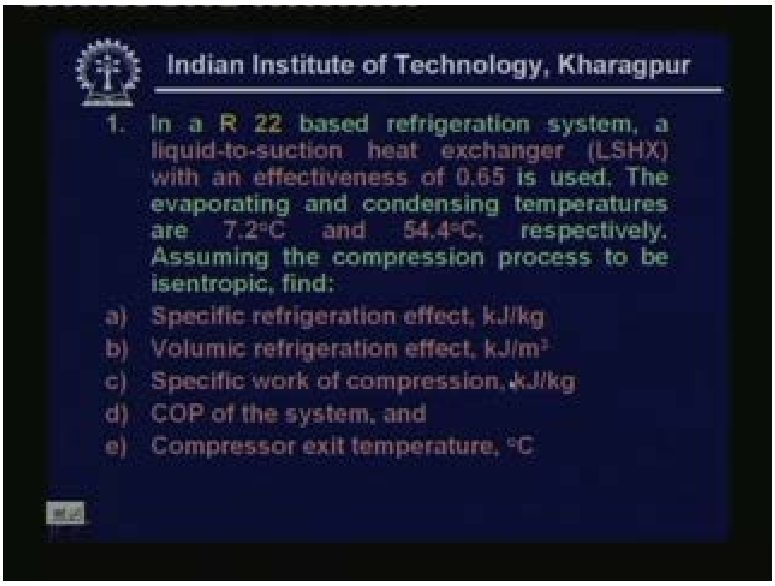

In a R twenty-two based refrigeration system a liquid to suction heat exchanger with an effectiveness of point six five is used the evaporating and condensing temperatures are seven point two degrees centigrade and fifty-four point four degree centigrade respectively. Assuming the compression process to be isentropic find specific refrigeration effect volumic refrigeration effect specific work of compression COP of the system and finally compressor exit temperature.

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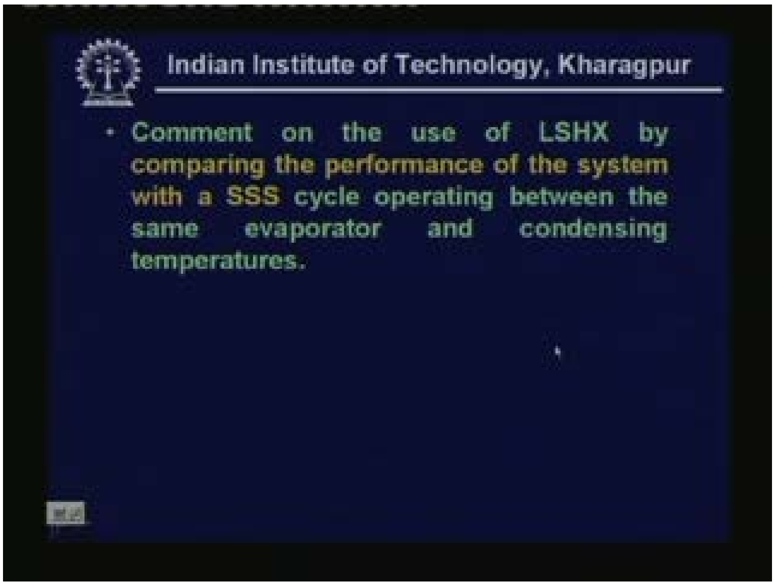

And comment on the use of liquid suction heat exchanger by comparing the performance of the system with a SSS cycle operating between the same evaporator and condensing temperatures. That means basically it is a single stage system. We have to make performance comparison between a system with liquid suction heat exchanger and the system without liquid suction heat exchanger. Both of them are operating between the same evaporator and condensing temperatures. Now let us see how we can work it out.

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So the given information is like this refrigerant is R twenty-two evaporator temperature is seven point two degree centigrade condenser temperature is fifty-four point four degree centigrade and effectiveness of liquid suction heat exchanger is point six five.

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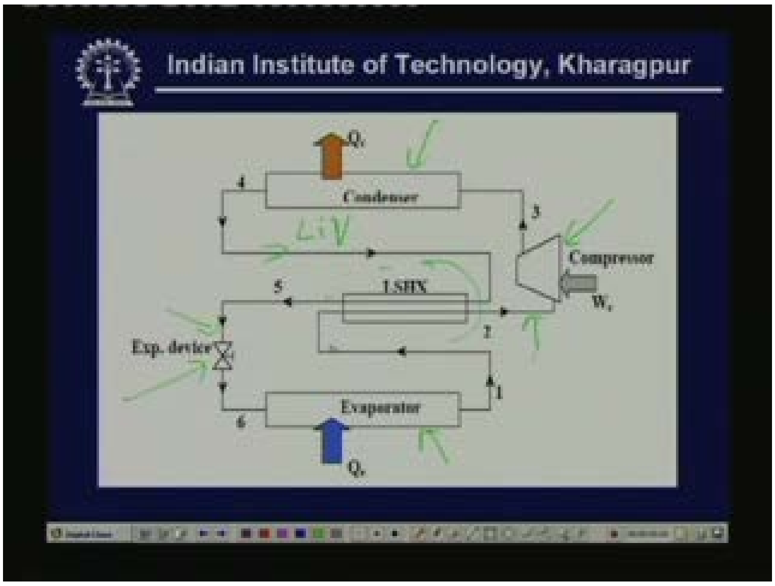

So this is the schematic of the system. As you have already studied this you can see there again you have the four basic components evaporator compressor condenser and the expansion device. In addition to this we have the liquid suction heat exchanger. As you know in the liquid suction heat exchanger the refrigerant liquid that is coming from the condenser. That means this liquid, this get sub cooled and sub cooled liquid enters into the expansion device. At the same time the vapour that is going to the compressor low temperature low pressure vapour going to the compressor gets superheated in the liquid suction heat exchanger and enters into the compressor in a superheated state okay. So basically the liquid since it is at higher temperature it exchanges heat with the low temperature vapour and it gets sub cooled and the vapour get superheated.

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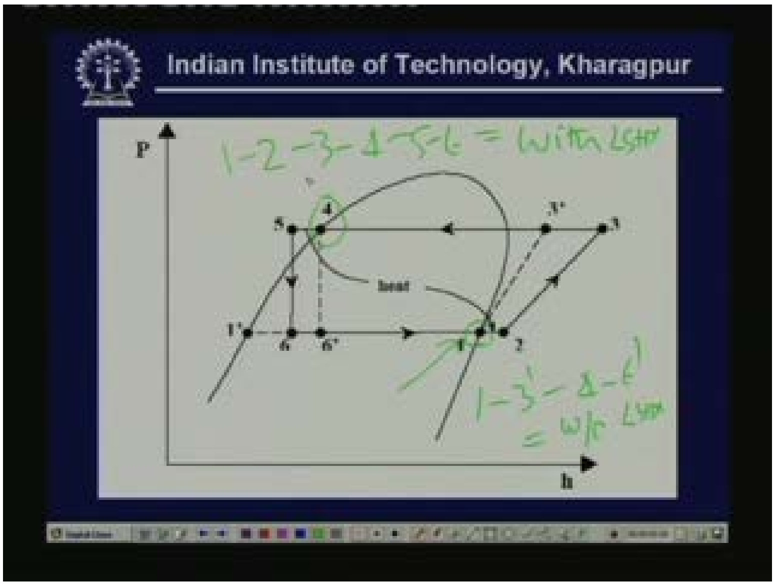

So here the cycle is shown on P-h diagram here cycle one two one two three four five six is a cycle with liquid suction heat exchanger and cycle one three dash four and six dash. As you can see is without liquid suction heat exchanger okay. So here we have made one assumption which is not mentioned in the problem. We assume that for both the cycles the exit condition of the evaporator is saturated vapour similarly the exit condition of condenser is saturated liquid okay. So these two are the common conditions for both the cycles.

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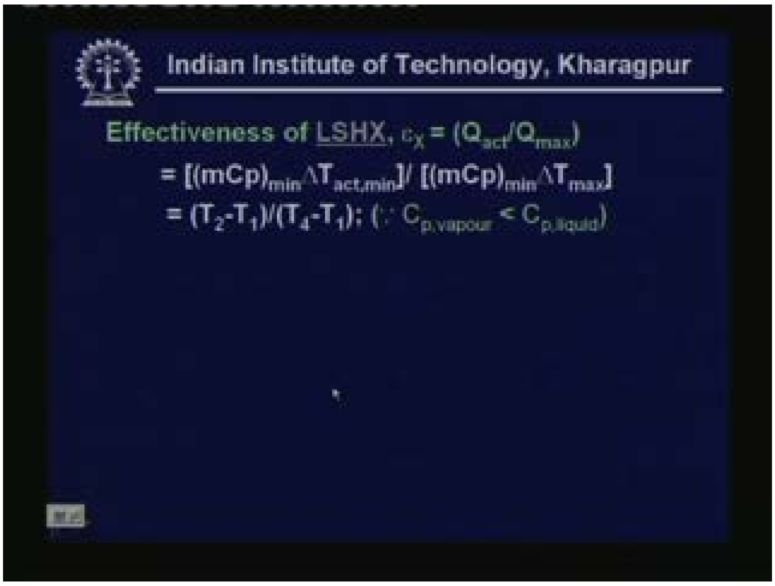

Now from the definition of effectiveness of heat exchanger we can write as you know effectiveness as Q actual divided by Q maximum. And Q actual in this case is mCp minimum into delta T actual divided by mCp minimum into delta T maximum and for our this thing.

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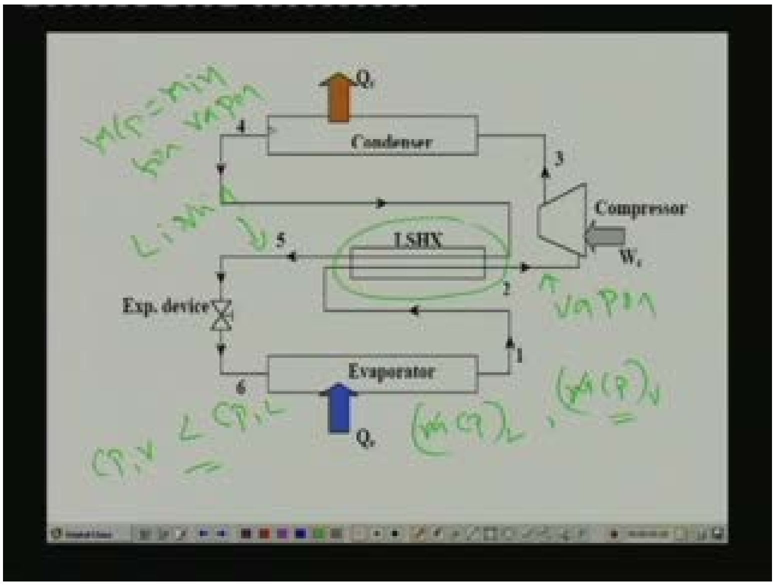

You can see that this is the liquid suction heat exchanger. And what is the fluid that has lower mCp you can that on one side you have vapour okay. On the other side you have liquid and mass flow rates are same okay. You have mCp of liquid and mCp of vapour okay. mCp of the liquid is the hot stream and mCp of this vapour is a cold stream and mass flow rate is same because same mass is flowing throughout the circuit. So we can see that the vapour is having the minimum mCp V because Cp of vapour is always lower that Cp of liquid. So as a result mCp is minimum for the vapour okay. This is minimum for vapour okay. So if this is minimum for vapour.

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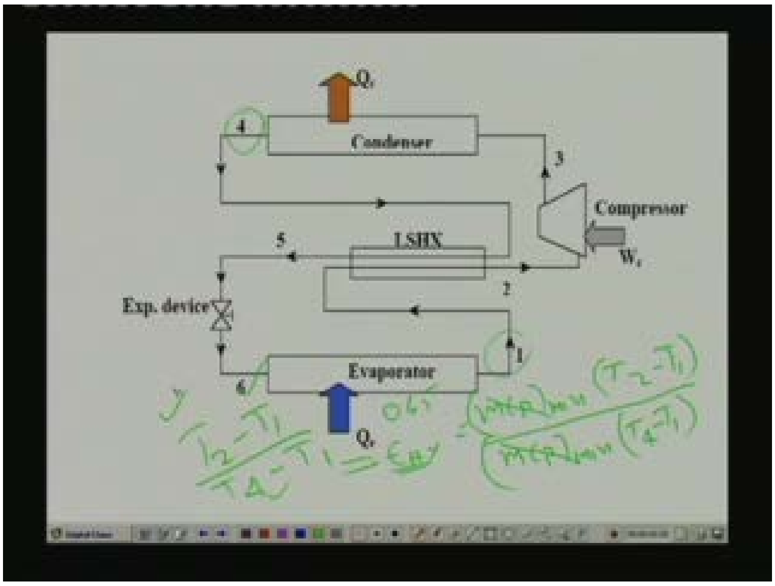

We define heat exchanger effectiveness as effectiveness of heat exchanger is as you know mCp minimum into delta T actual and what is the delta T actual delta T actual is nothing but T two minus T one. That is the actual temperature change of the vapour divided by mCp minimum into delta T maximum here the delta T maximum is difference between the maximum temperature which is nothing but the outlet temperature of the condenser and the minimum temperature which is the outlet temperature of the evaporator. So mCp delta T maximum is T four minus T one okay. So these mCp mCp get cancelled finally you find that effectiveness of heat exchanger is simply given by T two minus T one divided by T four minus T one and from the data we know T one and we also know T four. So T one and T four are known to us and effectiveness is given as point six five okay. So we can find out what is the exit temperature T two.

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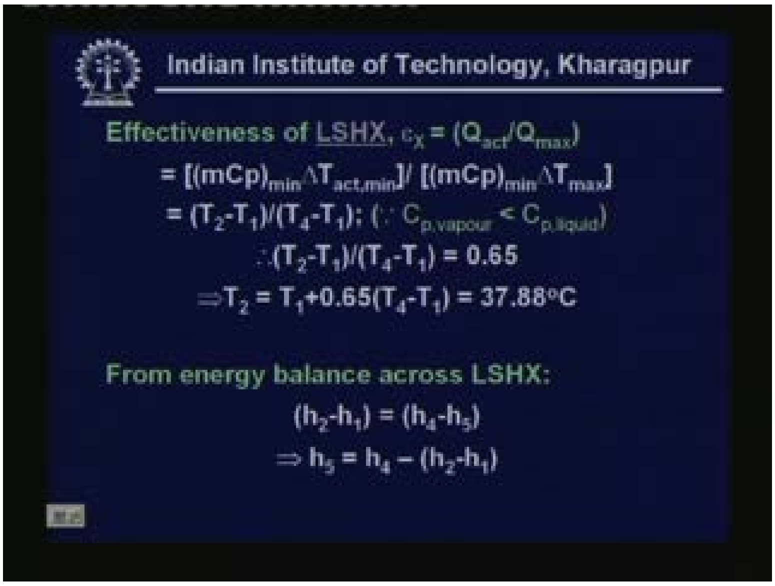

So that is what is done here the effectiveness is given by T two minus T one divided by T four minus T one. This is equal to point six five as given in the input. So from this you find that T two is equal to T one plus point six five into T four minus T one which works out to be thirty-seven point eight eight degree centigrade okay. Then from energy balance across liquid suction heat exchanger you can write h two minus h one is equal to h four minus h five because mass flow rate is same for both hot and cold streams okay. So enthalpy difference across the heat exchanger must be same for hot and cold streams. As a result you can write h five as a function of h four h two and h one that is h five is equal to h four minus h two minus h one. So we will be using these two values or these two expressions for obtaining the state properties.

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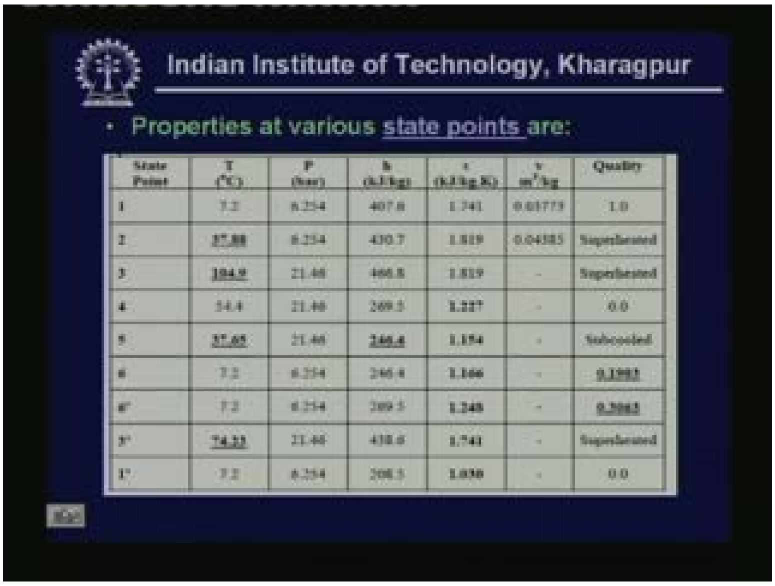
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- Properties at various state points are:

State Point	T (°C)	P (bar)	h (kJ/kg)	s (kJ/kg.K)	v m^3/kg	Quality
1	7.2	6.254	407.6	1.741	0.03773	1.0
2	37.88	6.254	430.7	1.819	0.04385	Superheated
3	104.9	21.46	466.8	1.819	-	Superheated
4	54.4	21.46	269.5	1.227	-	0.0
5	37.65	21.46	246.4	1.154	-	Subcooled
6	7.2	6.254	246.4	1.166	-	0.1983
6'	7.2	6.254	269.5	1.248	-	0.3063
3'	74.33	21.46	438.6	1.741	-	Superheated
1'	7.2	6.254	208.5	1.030	-	0.0

Now as we have done in the last lecture. The first thing we do is we find out the various properties at all the state points okay.

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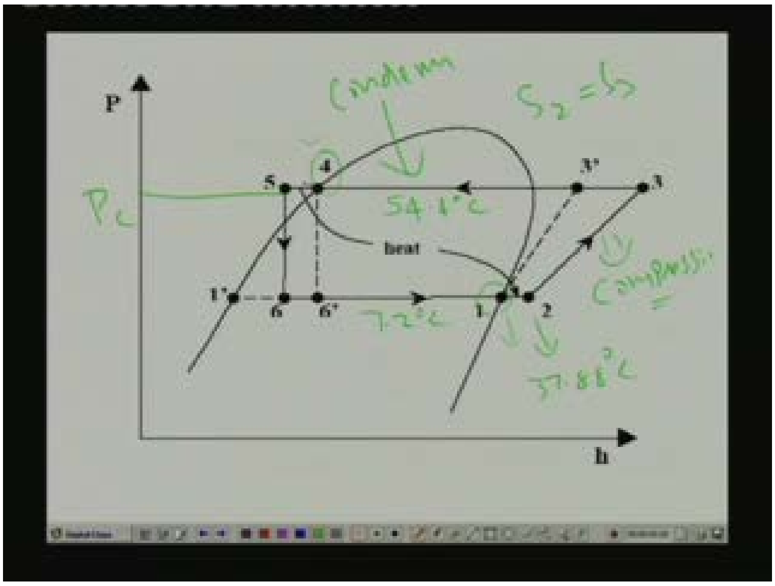

So let me first, once again show the state points. So state point one is the outlet of the evaporator and which is saturated in saturated condition and the temperature is seven point two degree centigrade okay. And state point two is a exit condition of the liquid suction heat exchanger and it has the temperature of thirty-seven point eight eight as we have now. Just now computed and process two to three is as you know is compression process. And here we are assuming the compression process to be isentropic okay. That means s two is equal to s three right? So two to three is the isentropic compression process and three to four is the heat rejection in the condenser okay.

So this is the condenser. As you know and we know that point four is a saturated liquid condition at condenser pressure and condenser is operating at a temperature of fifty-four point four degree centigrade. So we can find out the condenser pressure okay. So point four is a saturated liquid at this pressure. So we can find out the properties at this point and four to five is what is happening in the liquid suction heat exchanger.

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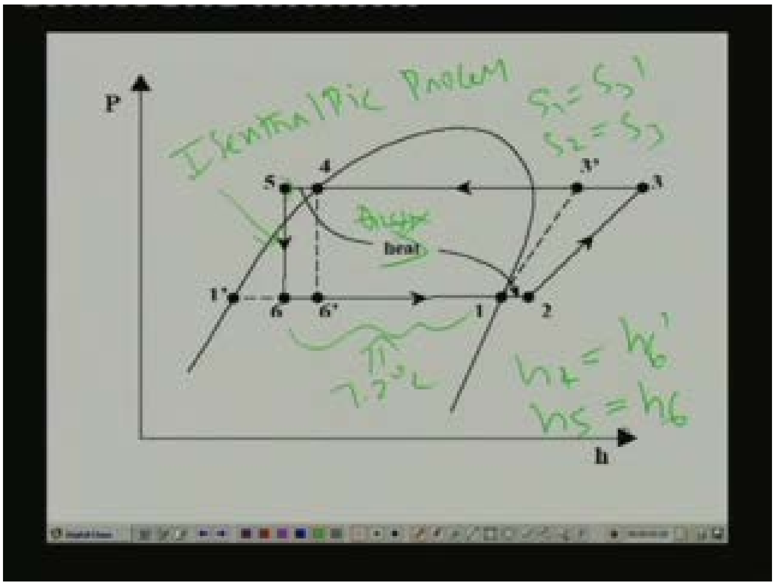

And as you can see that during the at this process four to five the hot liquid refrigerant liquid loses heat to the cold vapour okay. So that is the heat transfer in this manner the heat transfer rate is QLSHX. So there is an exchange of heat between the hot stream and the cold stream. So due to this the refrigerant liquid temperature drops from four to five and the vapour temperature increases from one to two okay. So point five is now in the sub cooled region and process five to six is isenthalpic expansion process in the expansion device isenthalpic process in the throttling process okay. And six to one is the heat extraction in the evaporator okay, at seven point two degree centigrade right. So these are the points and as I have already told you cycle one three dash four six dash is for a SSS cycle without a liquid suction heat exchanger okay.

So compression processes both the compression processes are isentropic. That means s one is equal to s three dash and s two is equal to s three okay, as I have already mentioned. Similarly processes four to six dash and five to six are isenthalpic. That means h four is equal to h six dash and h five is equal to h six okay. Now from the given input values and this information we can find out all the state points.

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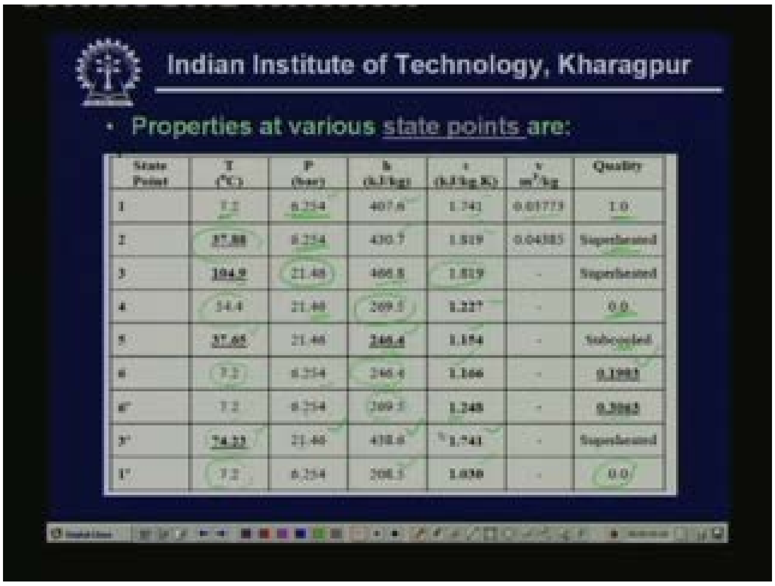

So state point one as I have already told you the exit of the evaporator which is a dry saturated vapour at seven point two degree centigrade. So at this point we find the saturation pressure to be six point two five four bar and quality as we known is one. So the, we give these two as input and we find rest of the properties. So we find the pressure we find the enthalpy four not seven point six entropy one point seven four one and specific volume point zero three seven seven three okay, point two point two is the exit of the liquid suction heat exchanger okay. So here again the pressure remains same because it is an isobaric heating process.

So pressure is same as point one and temperature. We have found from the effectiveness of heat exchanger as thirty-seven point eight eight. So using this pressure and temperature information we can find out rest of the properties okay. So from these two values we find the enthalpy to be four thirty point seven and entropy to be one point eight one nine and specific volume to be point zero three zero four three eight five and obviously this is in superheated region and point three is a exit condition for the compressor okay.

So it is compressor exit. So what do we know at this point at this point we know the pressure. Because this is nothing but the saturation pressure at fifty-four point four degree centigrade and we also know the entropy. Because this is an isentropic process so s three is equal to s two. So from the non values of pressure and entropy we find the other properties like enthalpy and temperature. So temperature works out to be one naught four point nine and enthalpy is found to be four sixty six point eight kilo joule per kg then point four point four is nothing but the exit of the condenser which is saturated liquid. So quality is zero temperature is fifty four point four.

So we can pressure is saturated pressure twenty-one point four six bar and from this information you can find out what is the enthalpy two six nine point five and entropy okay. Then point five is nothing but the exit of the liquid suction heat exchanger on the liquid side. So this we have we are obtaining using the energy balance as I have already explained across the liquid suction heat exchanger. So we find this enthalpy from the enthalpies of h four h one and h two okay. So because enthalpy difference for hot and cold streams are same. So this works out to be two forty six point four kilo joule per kg. And from the pressure value and enthalpy value we can find out what is the temperature and what is the entropy. And this is in sub cooled region and point six point six is the exit of the expansion device. So it is, temperature is same as evaporator temperature seven point two degree centigrade pressure is same as the evaporator pressure six point two five four bar and we need another additional information.

That information is provided by the isenthalpic process the enthalpy at point six is same as enthalpy at point five which is equal to two forty six point four. So using the enthalpy value and pressure value we can find out what is the entropy. And you can also find out what is the quality of the refrigerant vapour okay. Which comes out to be point one nine zero there and point six dash is for the SSS cycle without liquid suction heat exchanger. So here again the temperature is seven point two pressure is six point two five four and the enthalpy here is the enthalpy at the exit of the condenser that is two six nine point five okay. So again from the enthalpy value and the pressure you find the entropy value and you also find the quality which works out to be point three zero six three. And point three dash is for the again SSS cycle without liquid suction heat exchanger. At this point we know that the pressure is twenty-one point four six and entropy is same as a entropy at the exit of the evaporator that is one point seven four one.

So this using the entropy value and the pressure value we can find out what is the enthalpy and what is the temperature. Finally point one dash point one dash is your saturated liquid at this condition you can see that the temperature is seven point two and quality is zero. So this is the saturated liquid condition at evaporator pressure. So from this information you find the enthalpy to be two not eight point five and entropy to be one point zero three zero. So this is the major task once you find all the properties then we can easily find out the required performance parameter by applying energy balance across each component okay. That is what we will be doing.

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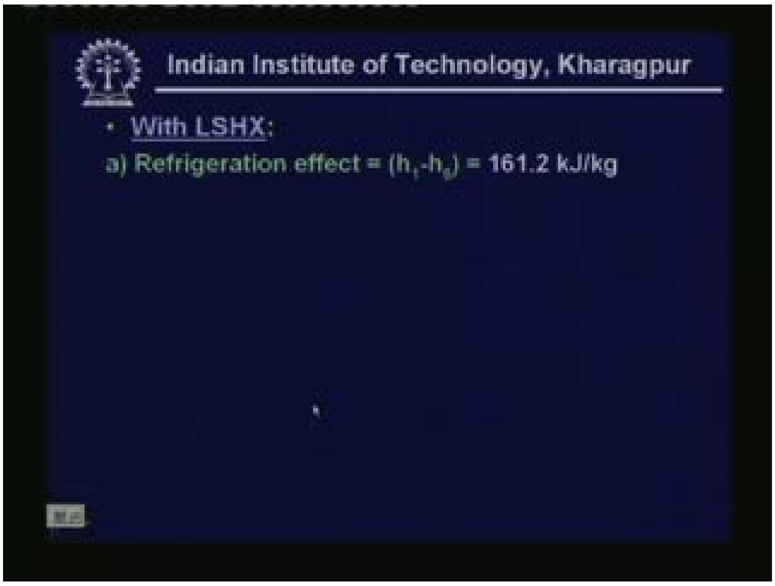

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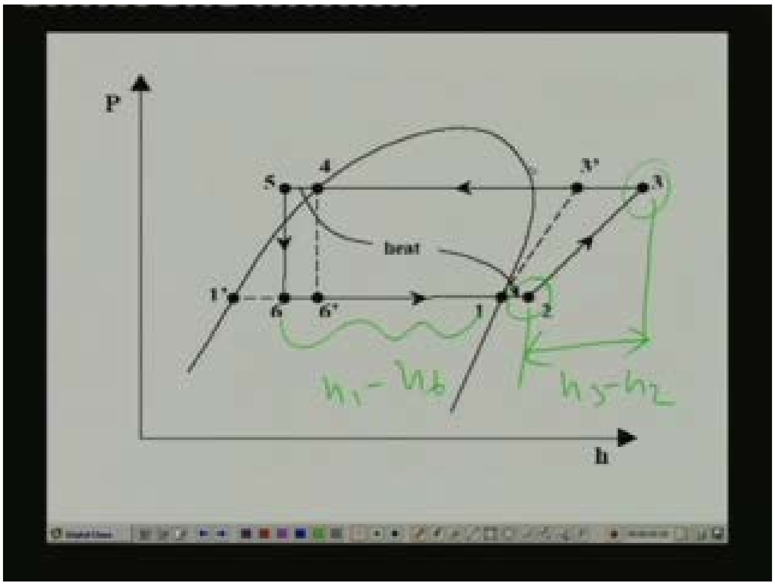

So first let us find the results for with liquid suction heat exchanger. So refrigeration effect is nothing but h one minus h six you can see that with liquid suction heat exchanger. This is the refrigeration effect h one minus h six and the work of compression is this h three minus h two and exit inlet temperature to the compressor is at point two exit is point three okay.

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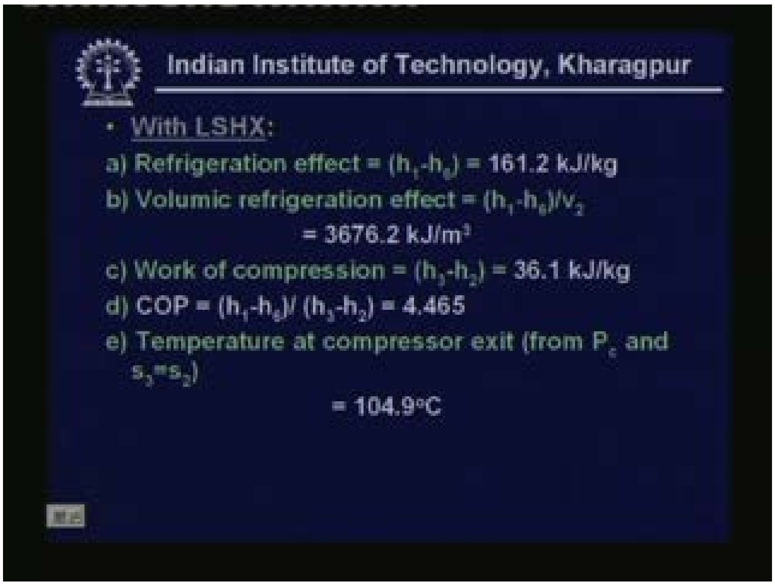

So refrigeration effect h one minus h six if you substitute the values you find that it is one sixty one point two kilo joule per kg. And volumic refrigeration effect is nothing but as you know refrigeration effect divided by the specific volume at that point okay. So specific volume we have found from the properties. So if you substitute the specific volume value there we find that the volumic refrigeration effect is three six seven six point two kilo joule per metre cube. Third is work of compression is nothing but h three minus h two and both the enthalpies are known to us. So you find that the work of compression is thirty-six point one kilo joule per kg. And then finally COP. COP is h one minus refrigeration effect divided by work of compression.

That is h one minus h six divided by h three minus h two which works out to be four point four six five then temperature at compressor exit. We find this from the pressure and the entropy values you find that it is almost one naught five degree centigrade. It is one naught point four degree centigrade okay. So this is the performance with the liquid suction heat exchanger. Now let us find out the performance without liquid suction heat exchanger. Again what we do is we apply the energy balance across evaporator compressor condenser etcetera. And then find out the required parameters okay.

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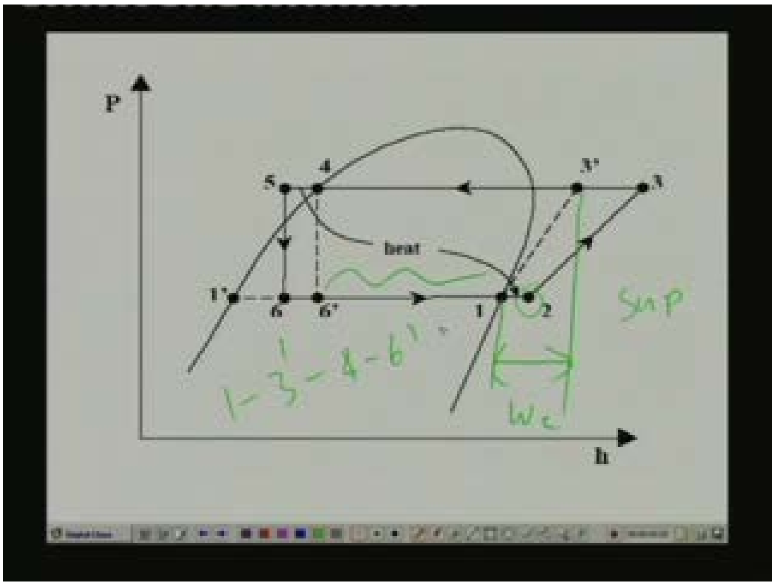

So without liquid suction heat exchanger as you know the cycle I have already told you is one three dash four six dash. So the refrigeration effect is now h one minus h six dash and work of compression is, this is work of compression h three dash minus h one okay. You can see any well let me point out at this point and this I have already discussed in the earlier lectures. When you are using a liquid suction heat exchanger what is happening is compressor inlet is entering into the super heated region. This is your superheated region. So you can see that point two is in superheated region whereas with SSS cycle the compressor inlet is a saturated vapour okay. So this will have a bearing on the performance which we shall see shortly.

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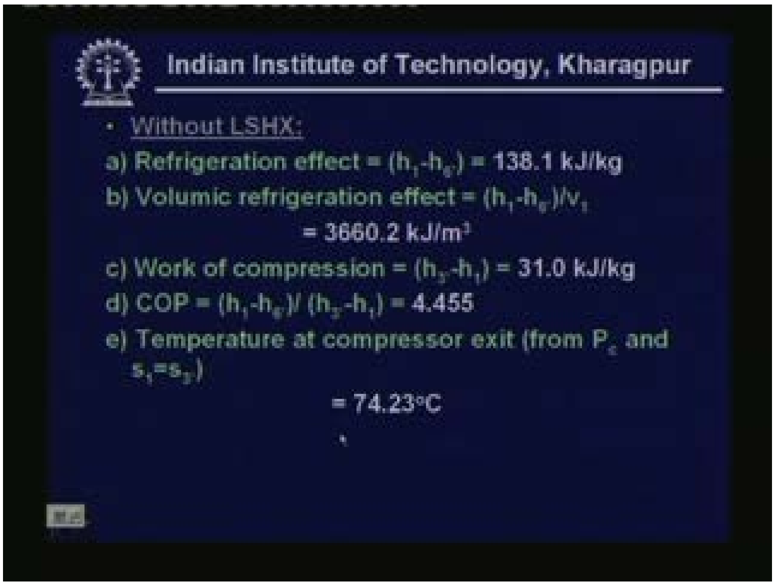

So refrigeration effect is h one minus h six dash which comes out to be one thirty eight point one kilo joule per kg. And volumic refrigeration effect is h one minus h six dash divided by V one which works out to be three six six zero point two kg kile joule per metre cube work of compression is h three dash minus h one which is equal to thirty-one kilo joule per kg and COP is found to be four point four five five. And temperature at compressor exit from the pressure and entropy values is found to be seventy-four point two three degree centigrade okay. So this is the performance without liquid suction heat exchanger. So let me show the comparison now.

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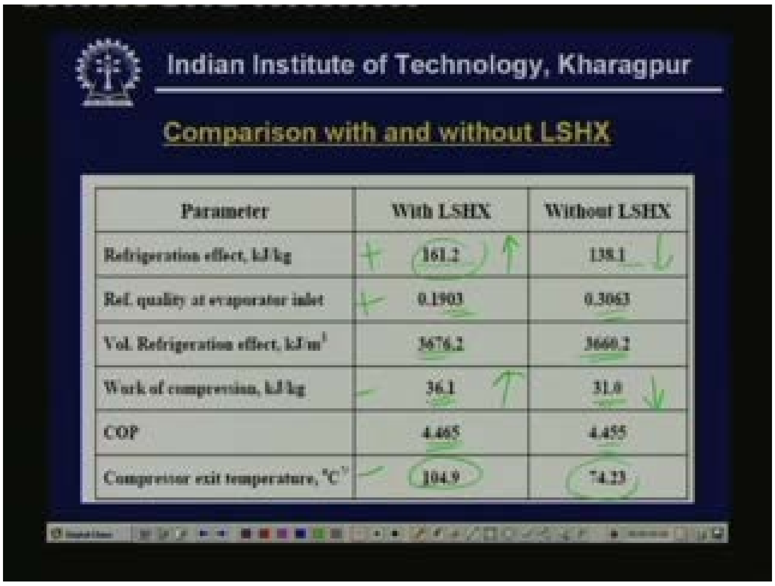

Parameter	With LSHX	Without LSHX
Refrigeration effect, kJ/kg	161.2	138.1
Ref. quality at evaporator inlet	0.1903	0.3063
Vol. Refrigeration effect, kJ/m^3	3676.2	3660.2
Work of compression, kJ/kg	36.1	31.0
COP	4.465	4.455
Compressor exit temperature, °C	104.9	74.23

So this table here shows the comparison for the same evaporator and condensing temperatures. What is the performance with and without liquid suction heat exchanger first thing you can see is that when you are using a liquid suction heat exchanger your refrigeration effect is increasing. That means a required mass flow rate will reduced okay. So this is the plus point second plus point is that the quality of vapour at the evaporator inlet has reduced okay. It is point one nine zero three with liquid suction heat exchanger and point three zero six three without liquid suction heat exchanger okay. This is also a plus point this is happening. Because the entry to the expansion device is now in sub cooled region as a result you have less vapour okay. And volumic refrigeration effect has there is a marginal increase okay. It is almost same. You can see that this is three six seven six this is three six six zero okay. So it is almost same.

So why volumic refrigeration effect is remaining same even though specific refrigeration effect has increased. This is because the inlet condition to the compressor with liquid suction heat exchanger is in superheated region. So once it goes into the superheated region. Its specific volume increases okay, density reduces. So specific volume increases. So the expression for volumic refrigeration effect as you know is nothing but the ratio of refrigeration effect divided by the specific volume okay. So with liquid suction heat exchanger both the numerator and as well as the denominator both of them increase okay. So ultimately whether the volumic refrigeration effect increases or not depends upon the relative increase of these two parameters okay. So you may not get a large benefit when you have a large super heat in fact that is what shown here okay.

Then work of compression work of compression obviously with liquid suction heat exchanger work of compression has increased. Because the isentropes in superheated region are flatter compared to the isentropes closer to the vapour dome. So this is thirty-six point one this is thirty-one. So this is actually a negative this thing and COP you can see that it is almost same okay. It is four point four six five with liquid suction heat exchanger and it is four point four five five without liquid suction heat exchanger okay. This is because COP as you know is the ratio of the refrigeration effect divided by work of compression. So when you are using liquid suction heat exchanger refrigeration effect is increasing work of compression also increasing okay.

And without liquid suction heat exchanger this is less at the same time work of compression is also less okay. As the result the net difference between these two is not much okay. And one however one significant difference between the system with liquid suction heat exchanger and without liquid suction heat exchanger is in the discharge temperature okay. You can see the, with liquid suction heat exchanger discharge temperature is about one not five degree centigrade whereas without liquid suction heat exchanger. It is about seventy-four degree centigrade. That means almost more than thirty degrees increase okay. So this is definitely a negative point as for as the liquid suction heat exchanger is concerned okay. So you have when you are using liquid suction heat exchanger particularly for R twenty-two systems there are some benefits and there are some disadvantages okay. So ultimately depending upon your requirement one has to decide whether liquid suction heat exchanger is required or not okay.

And one thing I would like to point out here is that the results or the trends may not be same for all the refrigerants it may vary from refrigerant to refrigerant okay. For some of the refrigerant liquid suction heat exchanger is found to be beneficial. For example for systems like R twelve liquid suction heat exchanger is good okay but R twenty-two they tight offer some advantages and certain disadvantages okay. So ultimately a trade off is required between the benefits and the disadvantages okay.

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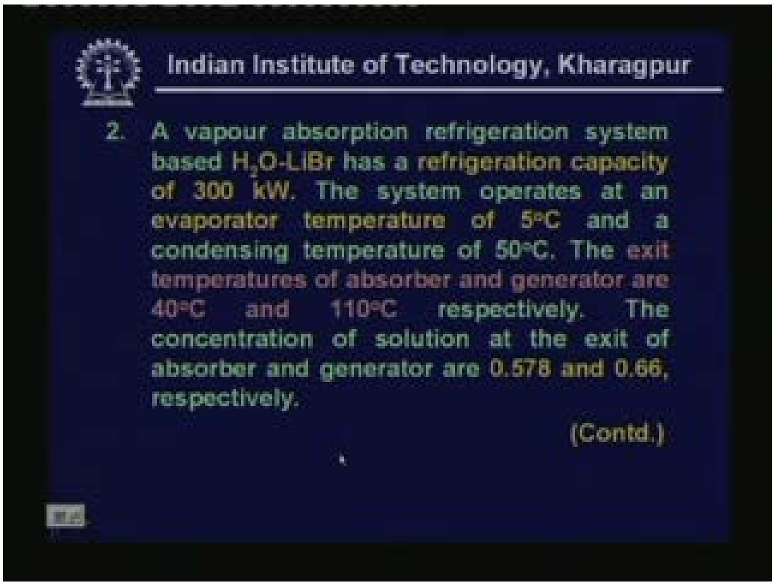

Now let us, let me discuss the second problem. This is a problem on vapour absorption refrigeration system. So let me read the problem a vapour absorption refrigeration system based on water lithium bromide has a refrigeration capacity of three hundred kilo watts. The system operates at an evaporator temperature of five degree centigrade and a condensing temperature of fifty degree centigrade the exit temperatures of absorber. And generator are forty degrees and one ten degree centigrade respectively. The concentration of solution at the exit of absorber and generator are point five seven eight and point six six respectively.

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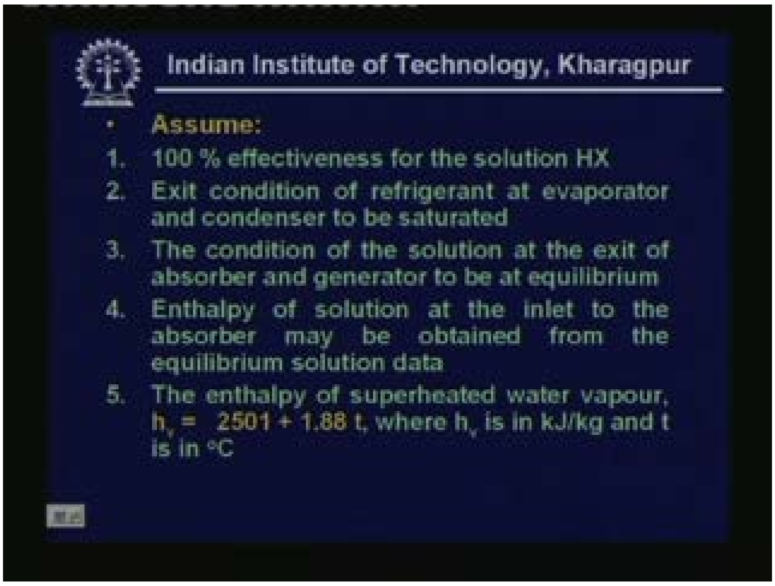

And it is also mentioned that we can assume the effectiveness of the solution heat exchanger to be hundred percent exit condition of refrigerant at evaporator and condenser to be saturated. That means you have saturated vapour at the exit of evaporator and saturated liquid at the exit of condenser okay. So the third assumption is that the condition of the solution at the exit of absorber and generator are at equilibrium okay. That means absorber exit and generator exit we you have equilibrium solutions and the enthalpy of solution at the inlet to the absorber may be obtained from the equilibrium solution data okay. That means for obtaining the enthalpies of these three points. That is at the exit of absorber and generator and also at the inlet to the absorber can be obtained from the equilibrium HTX data. That is, what it means and the enthalpy of superheated water vapour can be obtained from this equation hv is equal to two thousand five hundred one plus one point eight eight t where hv is in kilo joule kg and t is in degrees centigrade okay.

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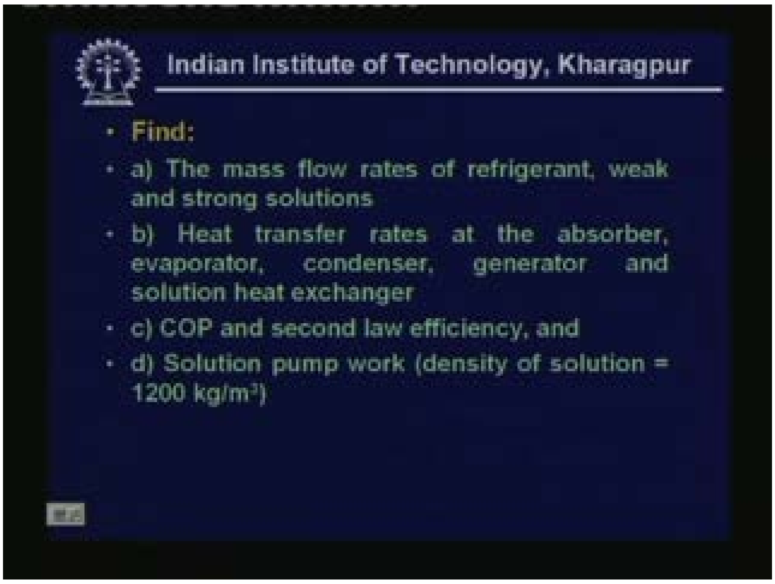

So these are the, this is the information given. And from this information we have to find out the mass flow rates of refrigerant weak and strong solutions heat transfer rates at the absorber evaporator condenser generator and solution heat exchanger COP and second law efficiency. And finally solution pump work and for obtaining the solution pump work we can take the density of solution to be constant at a value of twelve hundred kilogram per metre cube okay.

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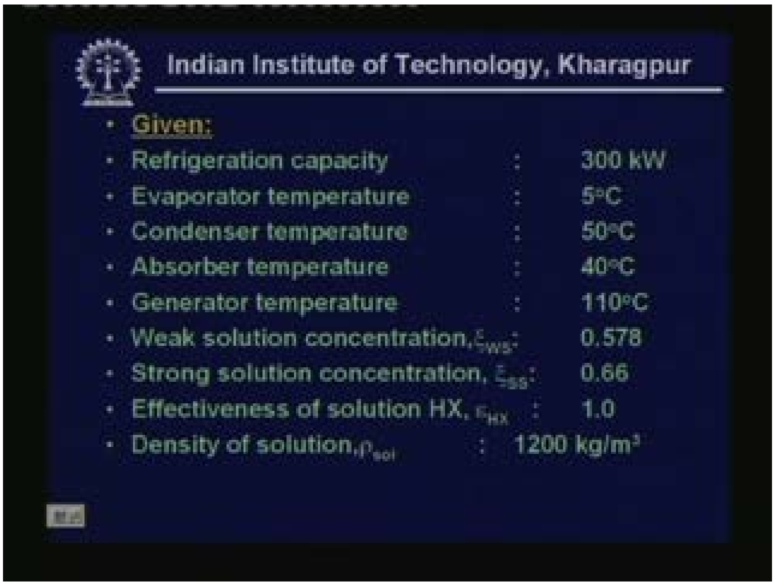

Okay, let me summarise the information given. Refrigeration capacity is given to be three hundred kilo watts evaporator temperature five hundred five degree centigrade condenser temperature fifty degree centigrade absorber temperature forty degree centigrade generator temperature one ten degree centigrade. Weak solution concentration zeta WS is point five seven eight and strong solution concentration zeta SS is point six six effectiveness of solution heat exchanger is one and density of solution is twelve hundred kilogram per metre cube. So this is the information given.

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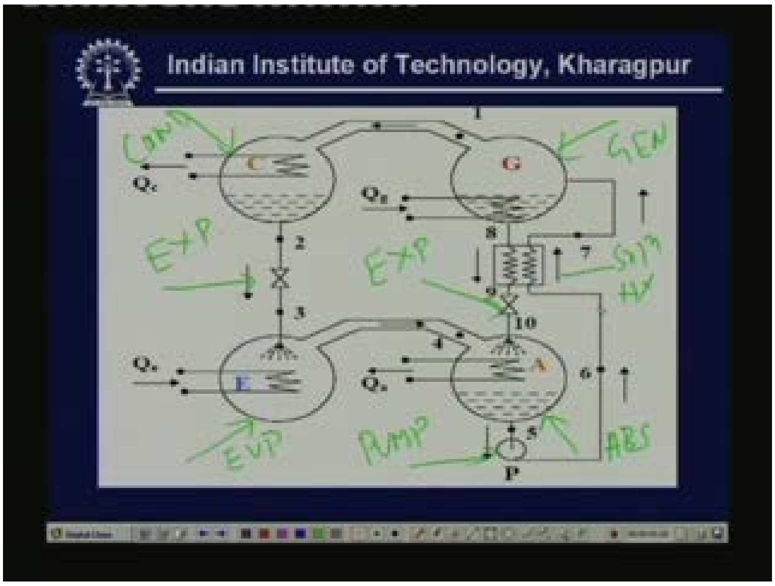

So now let me once again I have already explained this while discussing vapour absorption refrigeration systems. But let me since again quickly explain the system and show the various state points okay. So as you know we have the evaporator here. This is the evaporator. This is the absorber. This is the generator and this is the condenser. In addition you have the expansion device for the refrigerant and you have the expansion device for the solution. You have the pump for solution and this is solution heat exchanger okay.

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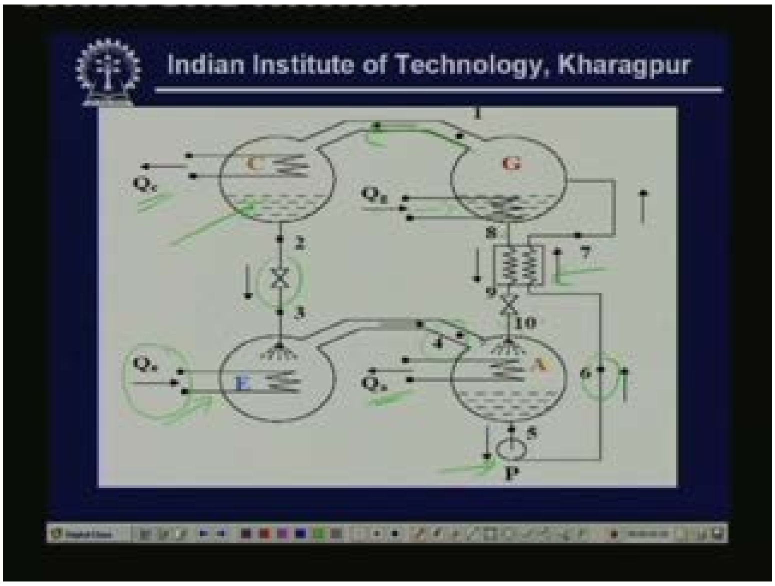

And as you know the working this thing low temperature low pressure vapour at point four enters into the absorber it comes in contact with strong solution coming from the generator at point ten. So the solution absorbs this vapour and heat of absorption is taken out Qa and the resulting weak solution is pumped in this pump to the high pressure and the high pressure weak solution flows through the solution heat exchanger where it is preheated by taking heat from the hot solution coming from the generator and this preheated solution which is weak. That means which is strong in refrigerant goes to the generator where heat is supplied to the solution. As a result of this heat supply refrigerant is separated from the solution. So refrigerant at high pressure and high temperature goes to the condenser. In the condenser it condenses and the heat of condensation is rejected to a cooling water or a heat sink. And the condensed refrigerant liquid at high pressure is throttled in the expansion device to low pressure and because of this the pressure and temperature drops.

So this low pressure low temperature refrigerant is sprayed into the evaporator where it evaporates taking heat from the external heat source. So you get the useful refrigeration effect Qe okay. And the cycle continues the vapour goes to the absorber and the cycle continues. And the solution which is now stronger in absorbent and weaker in refrigerant at point eight flows through the solution heat exchanger. Then the expansion device and is then sprayed into the absorber. So that it can again absorb the refrigerant vapour okay.

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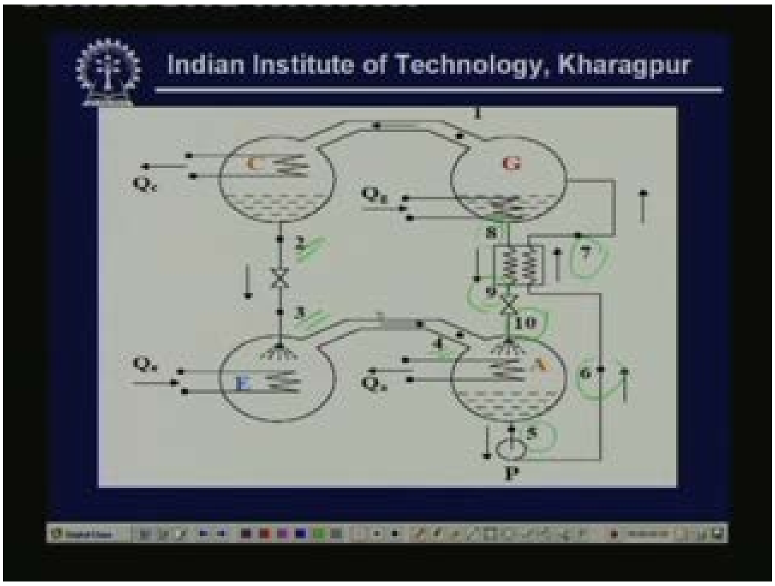

So again look at the points point one is the exit of the generator which it is pure refrigerant vapour at high pressure and high temperature at the exit of the generator point two okay. Point two is the refrigerant liquid at high pressure saturated refrigerant liquid at high pressure. And it is at the exit of the condenser point three is a low pressure refrigerant at evaporator pressure and point four is low temperature low pressure saturated vapour point five is weak solution. At evaporator pressure point six weak solution at generator pressure point seven weak preheated weak solution at generator pressure point eight strong solution at generator pressure and generator temperature point nine is a strong solution. Now cooled strong solution still at high pressure point ten is the strong solution at evaporator pressure okay. So now we will find out of properties of all these points because if you want to find out the performance we need to know the properties okay.

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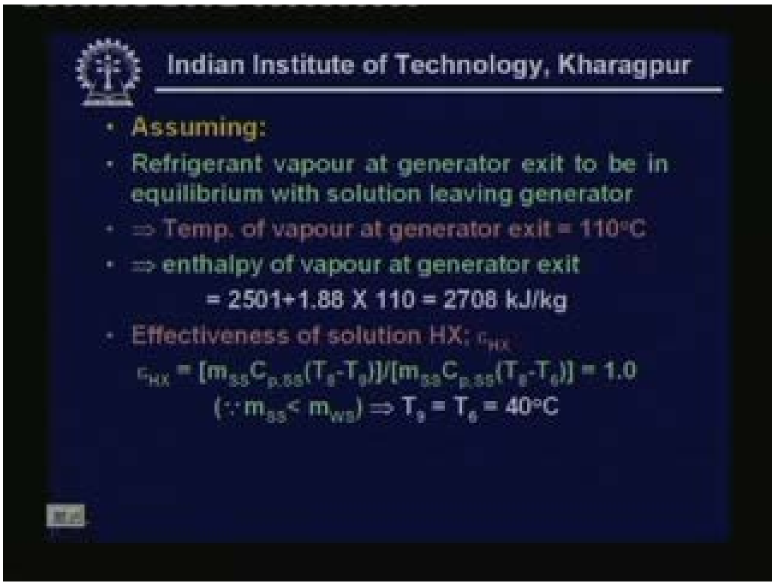

So for finding the properties we make the assumptions that the refrigerant vapour at generator exit to be in equilibrium with solution leaving generator okay. This assumption is required to find the enthalpy of the refrigerant vapour okay. That means it is given that the solution leaving the generator is one ten degree centigrade. Since the vapour is at equilibrium with this vapour also has the temperature of one ten degree centigrade. So once you know this you can find out the enthalpy of the vapour because it is given that enthalpy of the vapour can be obtained from the expression two thousand five hundred one plus one point eight eight into t where t is hundred ten degree centigrade.

So from that expression you find that the enthalpy of vapour at generator exit is two thousand seven hundred eight kilo joule per kg okay. Then from the effectiveness of solution heat exchanger again effectiveness as you know is defined as the mCp minimum into delta T actual divided by mCp minimum into delta T maximum. In this case, the mass flow rate of the strong solution is less than the mass flow rate of the weak solution. And if you are assume that the Cp values are almost same. Then you find that it is the strong solution which has the lower mCp product. As a result the effectiveness of heat exchanger is defined in terms of the strong solution flow rates and strong solution specific heat okay. So you can write effectiveness as mss into Cpss into delta T actual which is T eight minus T nine divided by mCp of strong solution into delta T maximum which is equal to T eight minus T six. And it is given that it this value is equal to one because this heat exchanger is hundred percent effective. So from this you can easily show that T nine is equal to T six is equal to forty degree centigrade. Because T eight and T eight it is very easy T six is given to be forty six forty degree centigrade.

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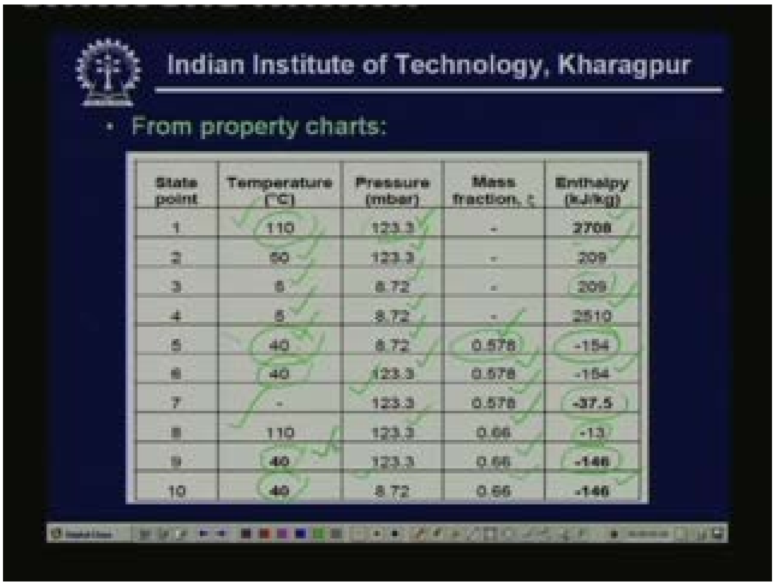

State point	Temperature (°C)	Pressure (mbar)	Mass fraction, ξ	Enthalpy (kJ/kg)
1	110	123.3	-	2708
2	50	123.3	-	209
3	5	8.72	-	209
4	5	8.72	-	2510
5	40	8.72	0.578	-154
6	40	123.3	0.578	-154
7	-	123.3	0.578	-37.5
8	110	123.3	0.66	-13
9	40	123.3	0.66	-146
10	40	8.72	0.66	-146

Now you can use the property charts and find the properties okay remember that i have discussed PTX and HTX chart. So to find this property we will be using PTX and HTX charts in addition to the refrigerant properties okay. Let me quickly go through how properties have been evaluated point one is at the exit of the generator and this is pure refrigerant vapour at this point. We know the pressure okay. Because this pressure is nothing but the saturation pressure corresponding to the condensing temperature okay, which is equal to fifty degrees. So this pressure is known to us and temperature is known to us. So from this we have found the enthalpy okay. And point two is the exit of the condenser as i have already discussed it is saturated liquid.

So we know the temperature to be fifty degree centigrade and the pressure is saturated pressure at fifty degrees which is equal to one twenty three point three mille bar. So from this equation you find the enthalpy is equal to two naught nine kilo joule per kg point. Three is the exit of the expansion device. So the temperature is same as the evaporator temperature pressure is equal to evaporator pressure. And the enthalpy is same as the inlet enthalpy which is equal to two naught nine okay. So we know the enthalpy and point four is nothing but the exit of the evaporator. So we know the temperature five degrees and pressure is eight point seven two and we know that at this condition it is dry saturated okay. That means quality is one. So from this information find out the enthalpy of saturated vapour at five degree centigrade which is two thousand five hundred ten kilo joule per kg point five is now solution okay.

This is the weak solution leaving the absorber and what do we know at these conditions we know that the temperature is forty degree centigrade. And the pressure is same as the evaporator pressure. That is eight point seven two and it is also mentioned that the concentration is point five seven eight okay. So this is given as the input concentration is given as the input temperature is given as the input. So using the concentration and temperature and concentration data you can find out the enthalpy values from equilibrium HTX chart okay. Now point six point six is nothing but the exit of the solution pump and if you assume that the solution pump work is negligible. Then you find that the enthalpy remains same as a inlet enthalpy okay.

That is the reason why we have taken enthalpy as minus one fifty- four and the pressure will be obviously the condensing pressure. That is one twenty three point three and there is no mass transfer so concentration remains same. That is point seven five eight and point seven point seven. I will explain to you. Point seven is nothing but the condition of the weak solution at the exit of the solution heat exchanger. All that we know about point seven is that the pressure is one twenty three point three and we also know the mass fraction which is equal to point five seven eight. But this information is not adequate to find the enthalpy okay. So this enthalpy has to be obtain from energy balance okay. I will show you the energy balance equation. Then point eight is the strong solution condition at the generator exit. So at this point we know the temperature to be one ten degree centigrade and we also know the concentration to be point six six.

So from the temperature and concentration data we find the enthalpy to be minus thirteen kilo joule per kg and pressure is of course same as condensing pressure and point nine is the exit of the solution heat exchanger. And from the solution heat exchanger effectiveness we find that this temperature is same as point six that is forty degree centigrade. So we know the temperature and we also know the mass fraction okay. And if you assume that you can use the equilibrium HTX chart from this and this you can find out the enthalpy which is equal to minus one forty six okay. So that is how we found find the enthalpy and point ten finally is nothing but the exit of the solution expansion device. And if you are assuming this expansion process to be isenthalpic enthalpy will remain same as minus one forty six. And we also know that the concentration is point six six. Because there is no mass transfer and pressure is same as the evaporator pressure that is eight point seven two okay. So once you have all the points and once you have the PTX and HTX charts. Then if you can locate the points carefully on the PTX and HTX chart then you can find out all the required state point property data okay.

Once you have all the property data the problem becomes very simple because all that you have to do is take each component and apply mass and energy balance across each components. So in a you might have noticed that one of the major task is to obtain the correct property values okay. If you do not get the correct property values final answers will be wrong okay. So for that reason you should know the cycle properly okay. And if you can plot the cycle on P-h and T-s and locate the points then it becomes easier okay. So once you have the properties.

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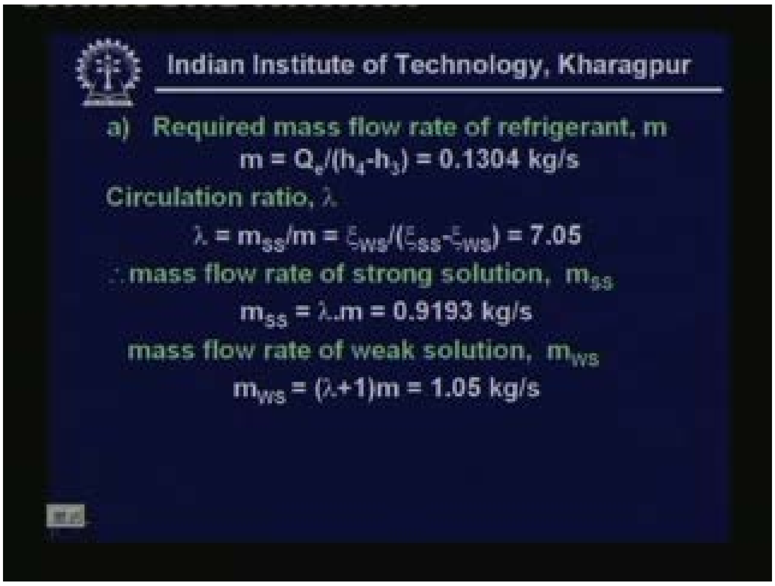

We can quickly find out the required mass flow rate of refrigerant. We apply energy balance across the evaporator this is nothing but steady-flow steady steady-flow energy equation and we assume kinetic and potential energy changes to be negligible. So mass flow rate is simply equal to Qe divided by h four minus h three which is equal to point one three zero four kg per second okay. Because Qe is given to be three hundred kilowatts and h four and h three we have obtained. Then circulation ratio because we have to find out the mass flow rates of strong and weak solutions. So first let us find the circulation ratio circulation ratio as you know is defined as the ratio of strong solution flow rate divided by the refrigerant flow rate okay. And from mass balance across the across the absorber we have seen that for water lithium bromide systems. The circulation ratio is equal to concentration of the weak solution divided by the difference between the strong and weak solution concentrations. That is zeta WS divided by zeta SS minus zeta WS okay. And zeta WS from the input data is equal to point five seven eight and zeta SS is point six six. So if you are substituting these values you find that the circulation ratio is seven point zero five. So once you know the circulation ratio you can easily find out the mass flow rate of strong solution which is nothing but circulation ratio into mass flow rate of refrigerant which is equal to point nine one nine three kg per second.

And mass flow rate of weak solution this you can easily obtain from the mass balance across the absorber. And we have shown that this is nothing but circulation ratio plus one into mass flow rate of refrigerant okay. So if you are substituting these values you find that mass flow rate of weak solution is nothing but one point zero five kg per second. Obviously the difference between the weak solution flow rate and strong solution flow rate should be equal to refrigerant flow rate okay. Because the mass has got to be balanced.

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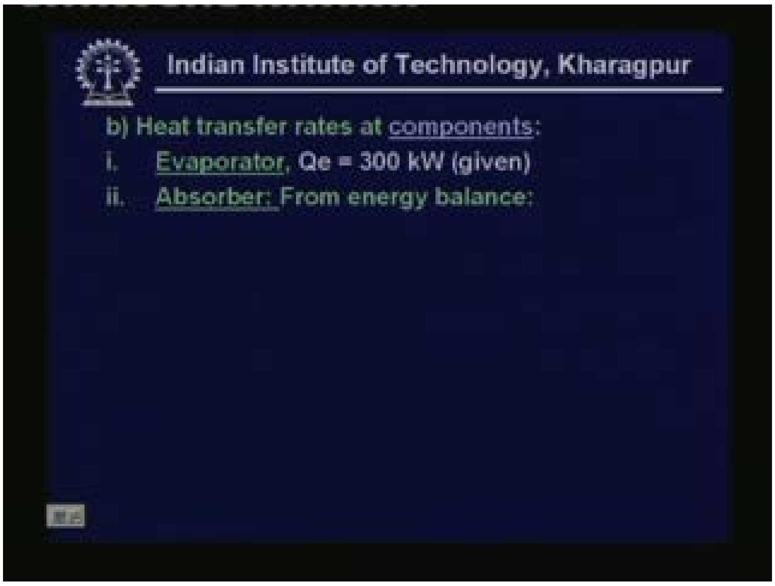

So the, we have found the required properties. Now I mean required mass flow rates, now let us find out the heat transfer rates at various components okay. Evaporator Qe is equal to three hundred kilo watt. This is the information given in the problem itself. Then let us come to the absorber and from energy balance of the absorber what is the, how do you write the energy balance of the absorber.

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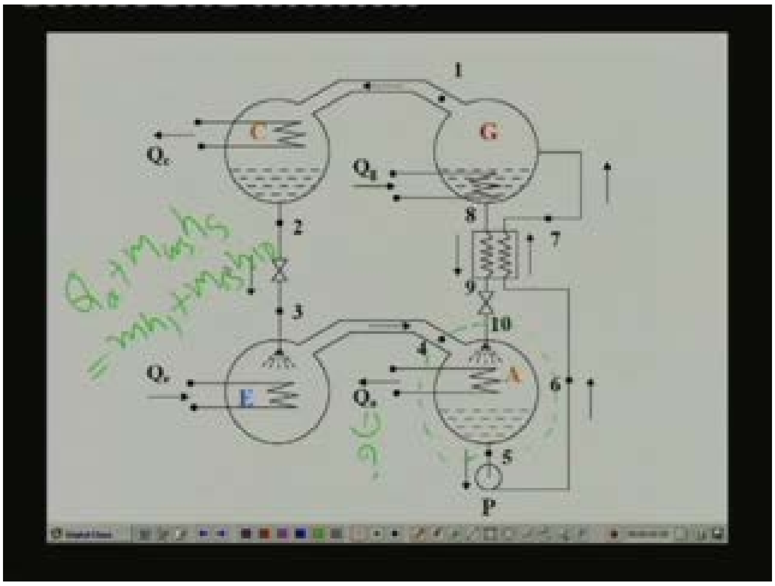

So this I have explained many times. You just take control volume across the absorber energy come in is energy going out and we want to find Qa okay. So if you are writing energy balance you find that energy going out is nothing but Qa plus mass flow rate of weak solution that is at point five into enthalpy at point five okay. This should be equal to energy coming in. So energy is coming in, by the way of mass flows. So energy coning in is m into h one is nothing but the energy contained in the refrigerant plus m strong solution into h ten okay. So this is the energy balance for the absorber. So from this equation we can find out Qa because we know all these mass flow rates and enthalpies okay.

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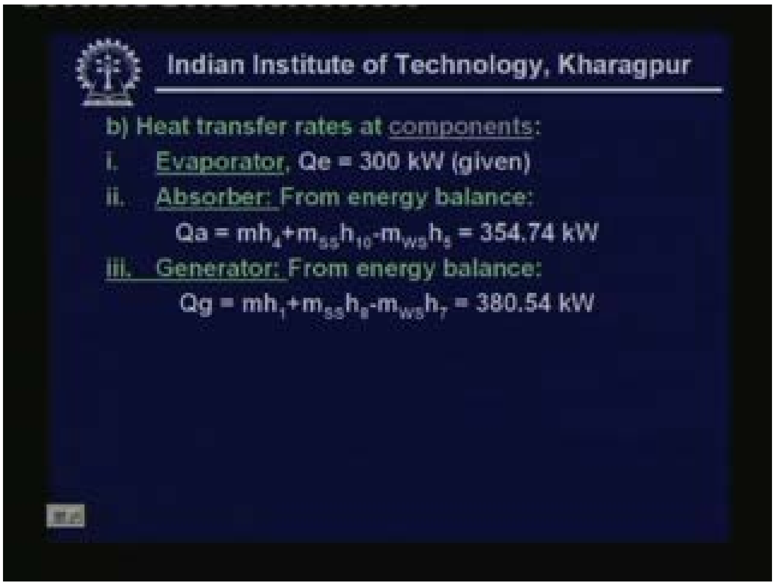

So from energy balance Qa is equal to mh four plus mss into h ten minus m WS into h five and all the mass flow rates are have been computed. And all the enthalpy values are known to us. So if you simply substitute these values you find that the required heat rejection rate at absorber is equal to three fifty four point seven four kilo watt. Similarly you apply the energy balance for the generator for the generator if you write the energy balance again you can take.

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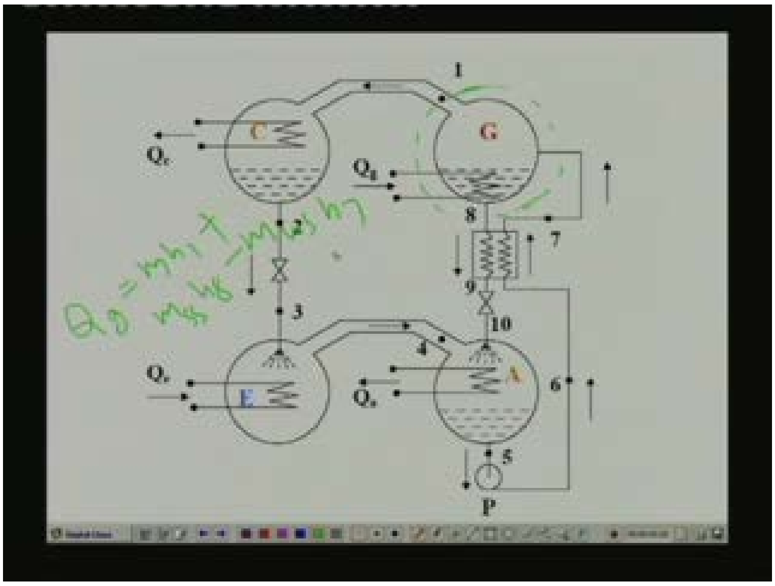

Okay, so you take again the control volume across the generator. So from this you can find that energy coming in is equal to energy going out. Energy going out is m into h one plus m eight that is m strong solution into h eight right. And energy is also coming by the way of weak solution this is m ws into h seven okay. So this is an energy balance across the generator. Similarly let me explain energy balance across the condenser and all. So we need not come here again.

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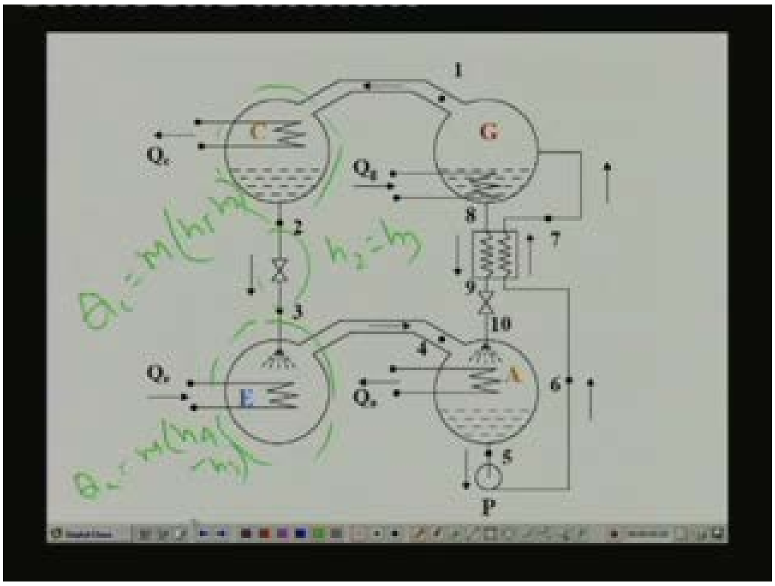

So from energy balance across the condenser you find that Qc is equal to m into h one minus h two and energy balance across the expansion device is nothing but the h two is equal to h three and across the evaporator. We have already shown Qe is equal to m into h four minus h three okay.

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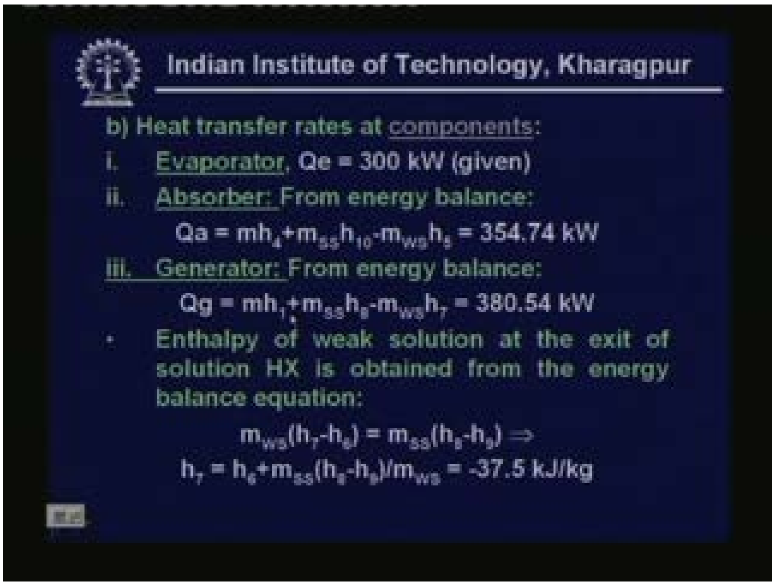

So from this you find that energy balance is m h one plus mss into h eight minus m ws into h seven. As, if you remember I said that h seven enthalpy at point seven that is the weak solution enthalpy after solution heat exchanger has got to be obtained from energy balance across the solution heat exchanger okay. So let me give that equation. So enthalpy of weak solution at the exit of solution heat exchanger is obtained from the energy balance equation. And the energy balance equation for the solution heat exchanger is very easy. Energy gained by the weak solution is equal to energy lost by the strong solution. That is what is shown here.

Energy gained by the weak solution is m m ws into h seven minus h six this is equal to energy lost by the strong solution. That is m ss into h eight minus h nine. So this gives h seven is equal to h six plus m ss into h eight minus h nine divided by m ws and we know everything on the right hand side. That means we know all the enthalpies we also know the mass flow rates. So if we substitute these values you find that the enthalpies minus thirty-seven point five kilo joule per kg. Now if you substitute these enthalpy value in the energy balanced for the generator you can find out what is the required heat input to the generator Qg okay. So we find that Qg is three eighty point five four kilo watts so this is the energy that is to be supplied to the generator.

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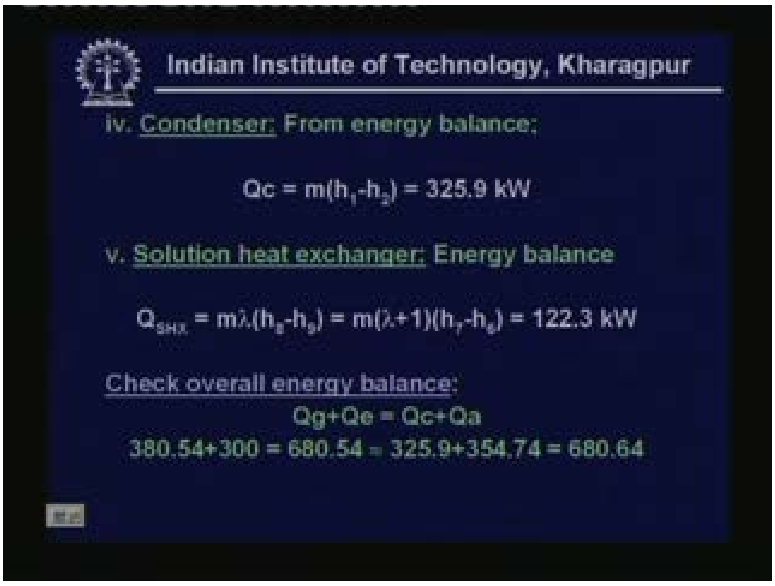

Then condenser as I have already explained Qc is equal to m into h one minus h two m is the mass flow rate of the refrigerant known to us h one and h two are enthalpy values which are also known. So if you substitute these values you find that heat rejection rate at condenser is equal to three twenty five point nine kilo watt and solution heat exchanger. So if you write the energy balance I have just explained to you from the energy balance across the solution heat exchanger QSHX is equal to energy lost by the strong solution. That is strong solution flow rate which is equal to refrigerant flow rate into circulation ratio. That is m lambda into h eight minus h nine this should be equal to energy gained by the weak solution that is m into lambda plus one into h seven minus h six.

Since everything is known to us we can substitute these values and you find that heat transfer across the solution heat exchanger is one twenty two point three kilo watt. And so we got all the required energy transfer rates across each components you can check the overall energy balance what is the overall energy balance okay. So overall energy balance is energy supplied to the system should be equal to energy rejected by the system. So the energy supplied by the system is nothing but Qg plus Qe. Because you are supplying heat to the generator and evaporator is extracting heat from the low temperature heat source. So energy into the system is Qg plus Qe what is the energy rejected out of the system out of the system is, energy rejection is taking place at the condenser. That is Qc plus heat rejection is also taking place at the absorber Qa. So Qg plus Qe should be equal to Qc plus Qa if this equation is satisfied. That means your answers are correct okay.

So you can easily check Qg plus Qe is equal to three eighty point five four plus three hundred which works out to be six eighty point five four and what is Qc plus Qa Qc plus Qa is three twenty five point nine plus three fifty four point seven four. So this works out to be six eighty point six four. So you can see there on the right hand side you have six eighty point five four. On the left hand side you have six eighty point six four. So small difference the negligible difference is could be due to of a due to the rounding of errors or slight mismatch in the property values okay.

So this is one very important thing whenever you do the problems finally you can check the, your answers by seeing whether total energy balance is taking place or not. That means what you have to do is you have to take that entire system as a control volume okay. Then it becomes a close system. Because there is no mass interactions. So once you take the entire system as a control volume and if you apply the energy balance. And if this energy balance is matching that means your answers are correct okay.

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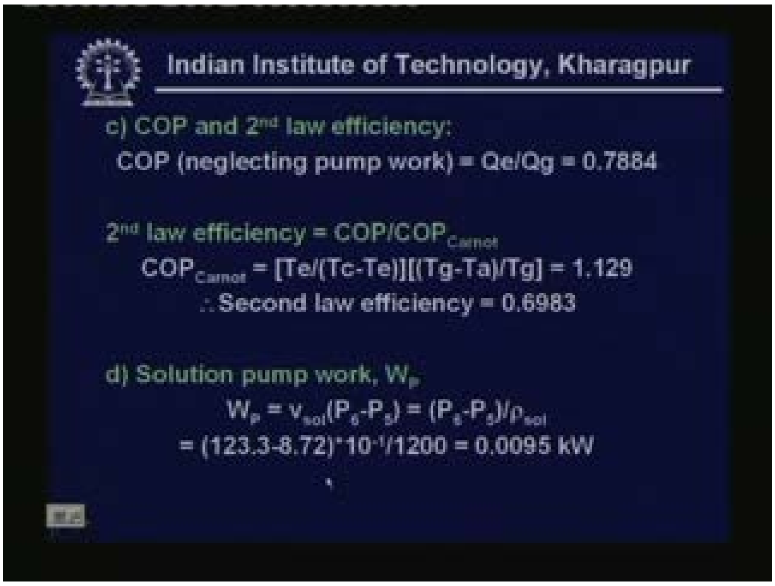

Now we have to find the COP and second law efficiency. So we find the COP by neglecting pump work because we will I will show you that the pump work is really negligible. So COP is defined as Qe divided by Qg Qe three hundred kilo watts Qe Qg is three eighty eight point five four kilo watts. So the COP is found to be point seven eight eight four and second law efficiency as you know is nothing but the ratio of COP of the system divided by the maximum possible COP. That is nothing but equivalent Carnot COP okay. So for three temperature system the maximum possible COP is nothing but the ratio, nothing but the product of a Carnot reverse Carnot refrigeration system into a Carnot heat engine system. This is what we have shown in fact okay.

So COP Carnot is nothing but Te divided by Tc minus Te into Tg minus Ta by Tg okay. And all the temperatures are known to us all four temperatures. So if you substitute these values you find that the maximum possible efficiency is one point one two nine. So the second law efficiency is the ratio of these two which is found to be point six nine eight three okay. This second law efficiency values is quite high. Because here we have assume the solution heat exchanger to be hundred percent effective one but in actual this thing it may not be the case okay. And the will there will always be pressure drops and all that as the result the actual COP's will be little lower than this. Finally we have been asked to find out the solution pump work for finding the solution pump work we assume the solution to be incompressible. So once you assume the solution to be incompressible work input to the pump is given by integral vdp okay.

So integral vdp is weak solution into P six minus P five this is P six minus P five divided by the density is given as twelve hundred kilogram per metre cube okay. So from this expression you can find out the specific work input to the, a pump okay. This is found to be there is a small this thing here this is actually kilo joule per kg okay. So because and you want to find out the actual work input to this you have to multiply this. So the actual work input W is WP into weak solution flow rate okay. You are multiply that into weak solution flow rate. So if you multiply the, in this into weak solution flow rate you will find that weak solution flow rate is about one okay, one kg per second okay.

So you will find that this is almost equal to point zero one kilo watt okay which is really negligible okay. So this is the, but typical problem on absorption systems okay. The procedure is almost same as compression systems. But absorption system is little more complicated. Because you have to deal with the solutions and you have to find the properties of refrigerant as well as solutions okay. For that you have to have PTX and HTX data okay. Once you have the data and once you identify the state points properly you can easily calculate the required performance parameters okay. So these are the two typical problems.

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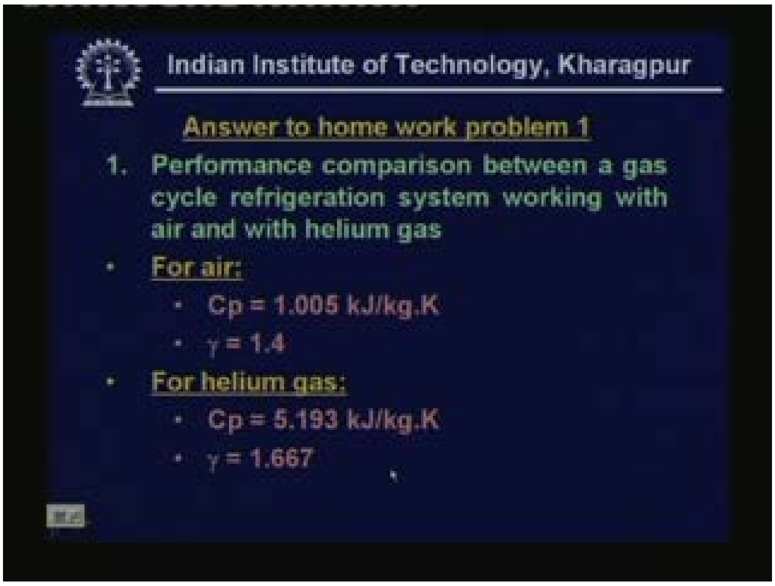

Now let me give the answers to homework problems the first problem if you remember was a problem on gas cycle refrigeration system. And I have worked out system working with air as a working fluid and I asked you to rework the problem by replacing air with helium gas okay. And the only different between these two is their properties because rest of the temperatures and pressures are same for both the systems okay. So the, what are the differences in properties for air the specific heat Cp is one point zero zero five kilo joule per kg Kelvin. And the specific heat ratio is one point four whereas for helium gas the specific heat is five point one nine three kilo joule per kg Kelvin and specific heat ratio is one point six six seven okay. And the procedure is exactly same as what I have shown in last lecture okay. So if you follow the exact procedure and if you take these property values of helium then you will get the answers okay. So I will show you the answers in fact I will show the not the answers only but I will show the comparison between of the air cycle and the helium cycle okay.

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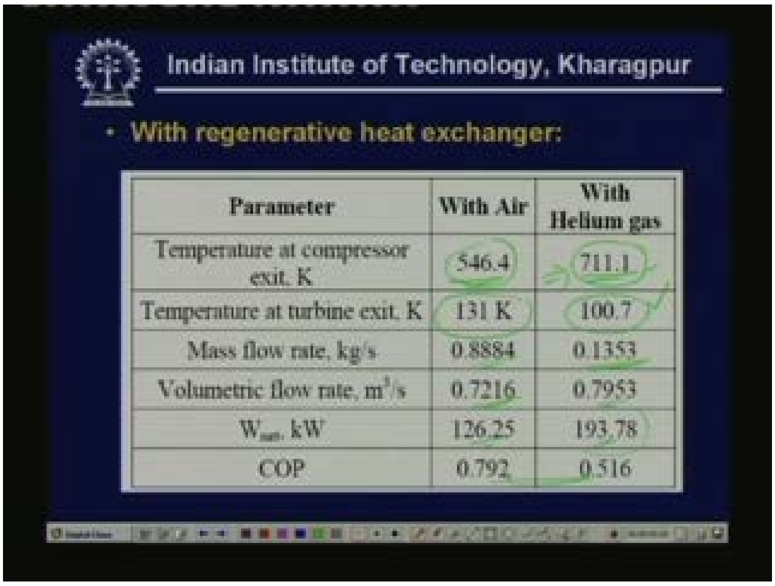

First you can look at the system with regenerative heat exchanger okay. That means both the cycles used regenerative heat exchangers and if you remember in the problem it was mentioned that the regenerative heat exchanger efficiency of point eight that is effectiveness of point eight okay. Now the first column shows the performance with air and the second one shows with helium gas okay. So first you can see the temperature at compressor exit with air it is five forty six point four and with helium gas it is seven hundred eleven point one oaky. So that means there is a big jump in the exit temperature which is actually a negative this thing as far as helium gas system is concerned this is happening. Because helium has much higher specific heat ratio compared to air okay.

Next is temperature at turbine exit temperature at turbine exit with air is found to be one thirty one Kelvin and with helium gas it is found to be hundred point seven Kelvin okay. So the high specific heat ratio is advantage is here because for the same inlet temperatures you get a lower turbine exit temperature with helium gas okay. So this is an advantage and the mass flow rates there is a big difference between air system and helium system. Because for the same refrigeration capacity helium gives you larger temperature difference. That means larger refrigeration effect because of two reasons the first reason is it has much higher Cp compared to air has the Cp of one point zero zero five where as helium has a Cp value of five point one nine three that means more than five times okay.

In addition the delta T is also slightly higher as a result you find that the required flow rate with helium is much lower compared to air okay. However the required volumetric flow rate for air is lower than helium. This is because helium has much lower density compared to air okay. Next net work input net work input is there is a big difference. Because the compressor exit temperature is very high for helium and Cp value is also high you find that required work input to the compressor is very high even though the mass flow rate is low okay. So as a result the COP of the system is less with helium gas okay. So you can see by replacing air with helium you are gaining by way of lower turbine exit temperatures and lower mass flow rates but you are paying by means of high lower COP's okay.

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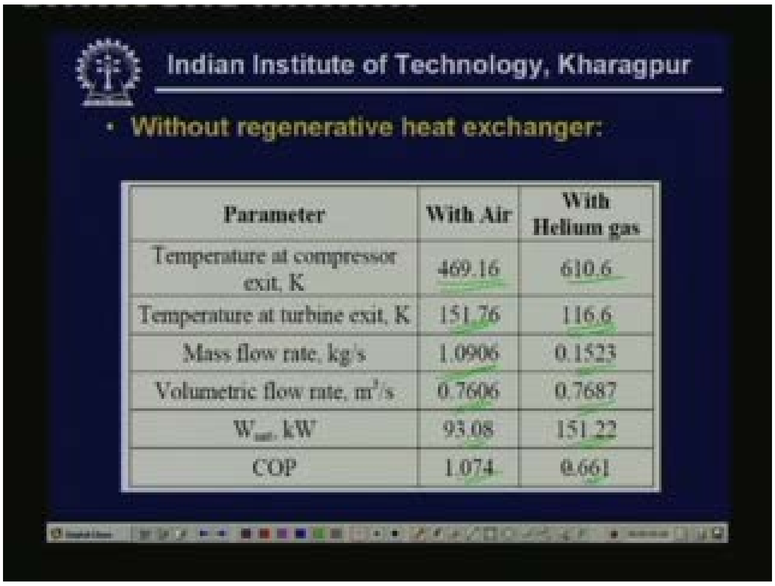

Parameter	With Air	With Helium gas
Temperature at compressor exit, K	469.16	610.6
Temperature at turbine exit, K	151.76	116.6
Mass flow rate, kg/s	1.0906	0.1523
Volumetric flow rate, m^3/s	0.7606	0.7687
W_{net}, kW	93.08	151.22
COP	1.074	0.661

Next without regenerative heat exchanger, again you can see the performance trend is almost same with air you get a exit temperature of four six nine. And with helium you get about six ten degree Kelvin. And temperature at the exit of the turbine is one fifty one point seven six with air an hundred sixteen point six with helium gas and mass flow rate is again about one point one kilogram per second with air. And it is point one five two three with helium. And volumetric flow rate is point seven six zero six with air point seven six eight seven with helium. And net work input is ninety three with kilo watts with air and one fifty one kilo watts with helium COP is one point zero seven four with air and point six six one with helium okay. So this is the performance comparison.

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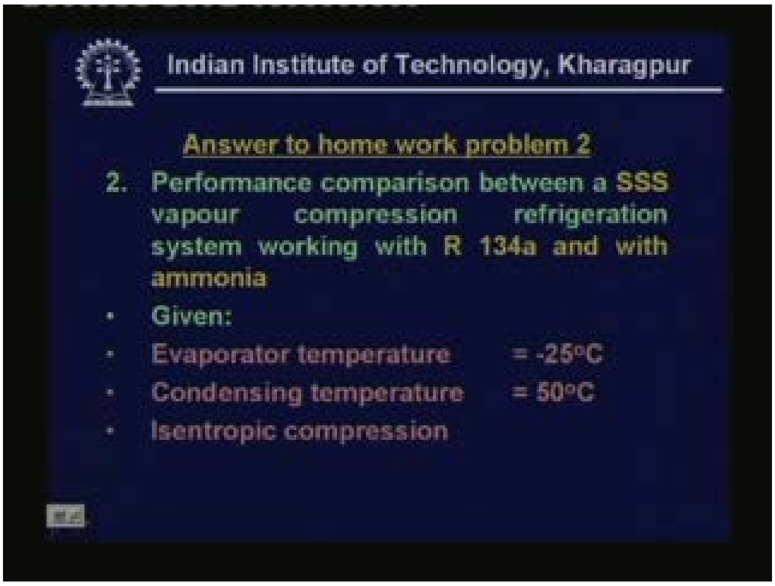

Second problem was the comparison between SSS vapour compression system working with R one thirty-four a and with ammonia okay. And for the same evaporator and condensing temperatures and isentropic compression the evaporator temperature is given as minus twenty-five degree centigrade and condensing temperature is given as fifty degree centigrade.

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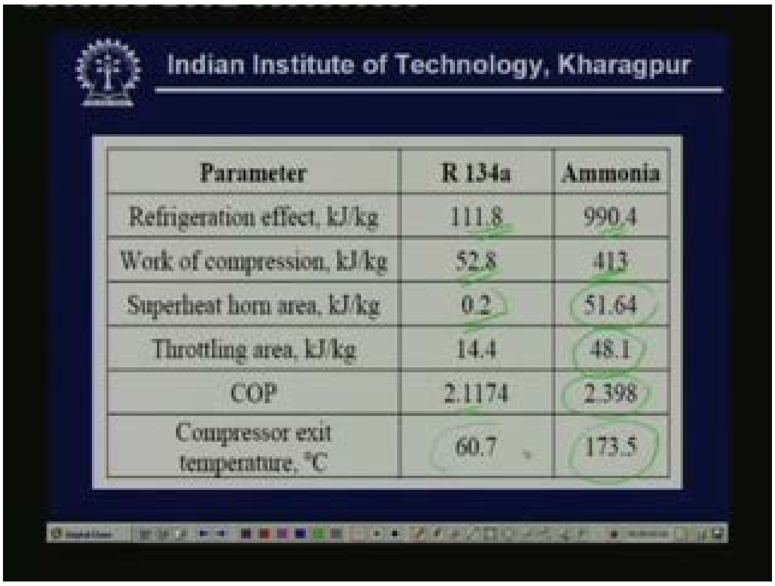

Parameter	R 134a	Ammonia
Refrigeration effect, kJ/kg	111.8	990.4
Work of compression, kJ/kg	52.8	413
Superheat horn area, kJ/kg	0.2	51.64
Throttling area, kJ/kg	14.4	48.1
COP	2.1174	2.398
Compressor exit temperature, °C	60.7	173.5

So again here the performance comparison is shown in fact this is for R one thirty-four a I have worked out in the last class okay. So I asked you to work out for ammonia you can see the refrigeration effect for ammonia is very large compare to R one thirty-four a, okay. So as a result the required mass flow rate will be very low with ammonia. This is the plus point and work of compression is also quite high for ammonia and superheat horn is in fact negligible in case of one the one thirty four a its only point two kilo joule per kg whereas it is very high in case of ammonia. This is because ammonia has symmetrical vapour dome on T-s diagram as explained in the earlier lectures okay. And throttling area is also quite high for ammonia when compared to R one thirty four a, and COP is marginally higher for ammonia compared to R one thirty four a, and compression exit temperature is very high with ammonia. In fact this is the major problem in ammonia systems okay. Whereas with R one thirty four a system it is quite low right.

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So from this we can easily conclude that refrigeration effect and work of compression are much higher for ammonia. This means a required refrigerant mass flow rate is much smaller in case of ammonia and losses due to superheat horn are much larger in case of ammonia whereas they are negligible in case of R one thirty-four a. This is because of the differences in the vapour dome and T-s diagram okay. And throttling losses and superheat losses are of same order of magnitude for ammonia okay. And COP is marginally higher for ammonia and compressor exit temperature is much higher for ammonia compared to one thirty-four a okay. So these are the conclusions by comparing results of ammonia and one thirty-four a.

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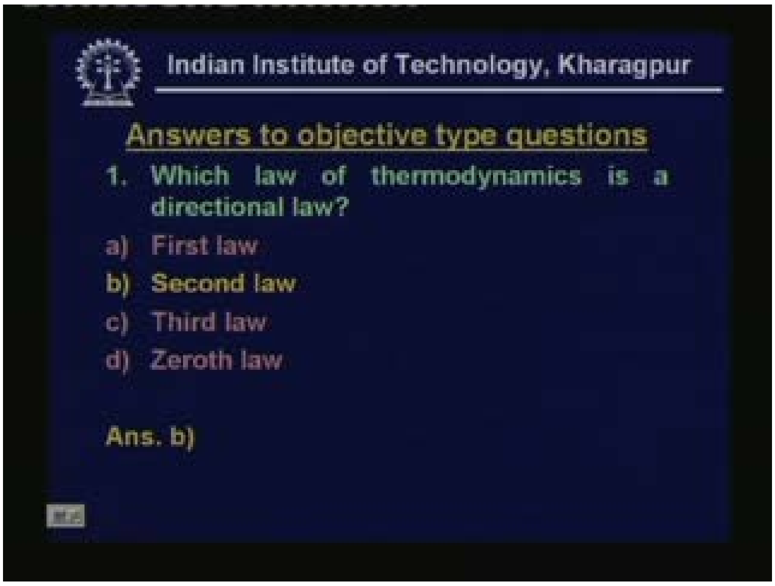

Now let me quickly give the answers to the objective type questions. I asked you which law of thermodynamics is a directional law and the choice were first law, second law, third law and fourth law for third law and zeroth law and the answer is second law. So second law of thermodynamics is a directional law.

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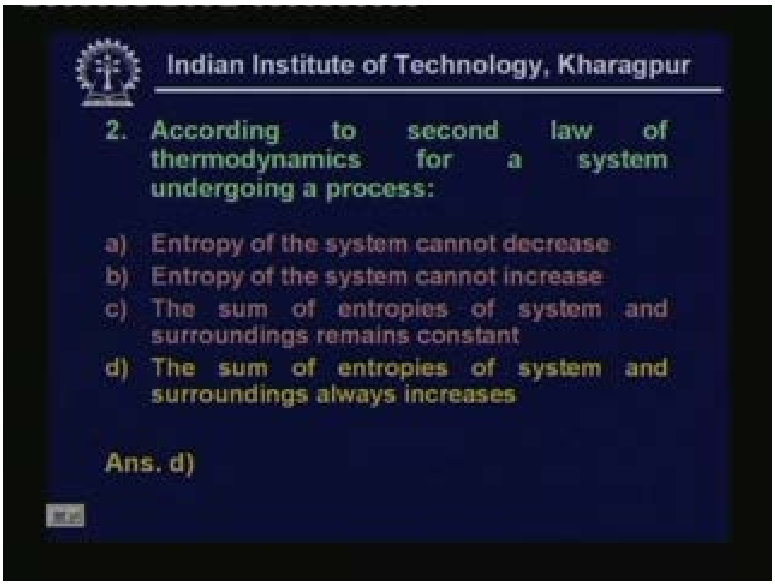

Second question was according to second law of thermodynamics for a system undergoing a process whether entropy of the system cannot decrease or entropy of the system cannot increase or the sum of entropies of system and surroundings remains constant or the sum of entropies of system and surroundings always increases. The answer is d that means according to second law the sum of entropies of system and surroundings always increases. This is the law of entropy increase okay.

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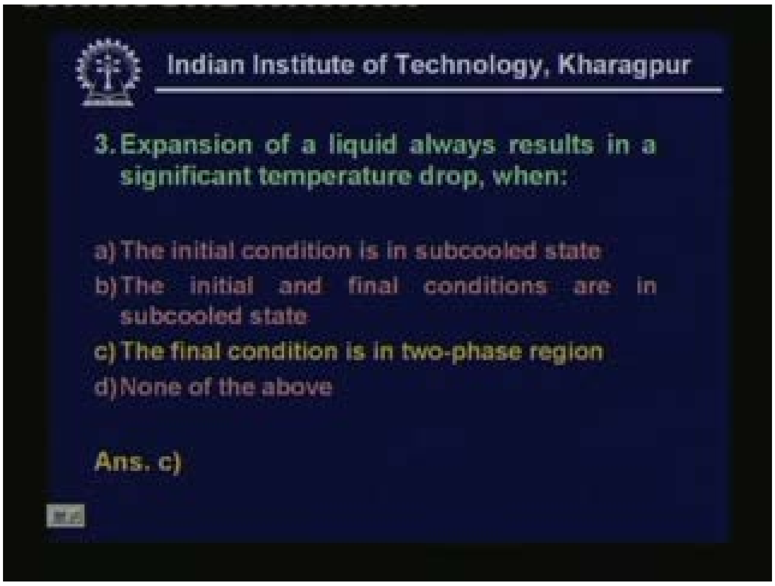

Third question was expansion of a liquid always results in a significant temperature drop when the initial condition is in subcooled state b. The initial and final conditions are in subcooled state c. The final condition is in two-phase region and d none of the above the answer is c. That means the final condition should be in two-phase region. That means some flashing of the liquid should take place for significant temperature drop to occur.

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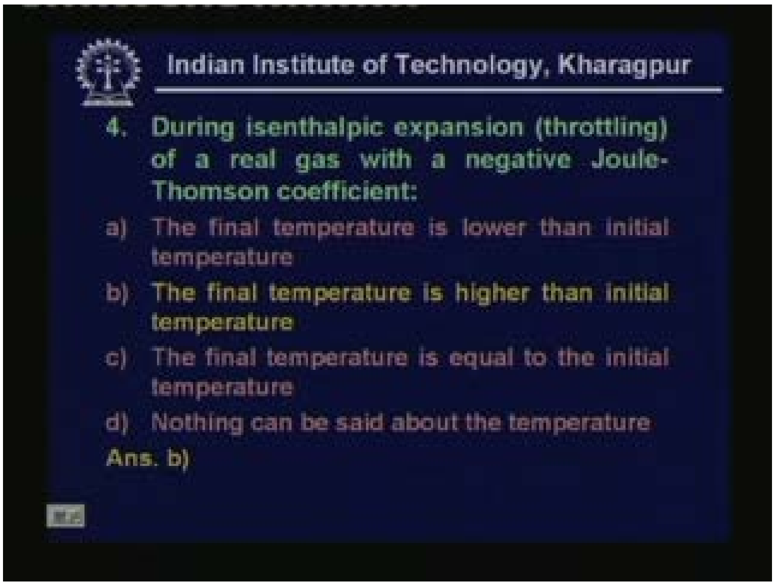

And fourth question was during isenthalpic expansion of a real gas with negative Joule-Thomson coefficient. What happens to the final temperature of the gas? The answer is the final temperature is higher than the initial temperature okay. So when you have negative Joule-Thomson coefficient for real gas the exit temperature will always be greater that the inlet temperature.

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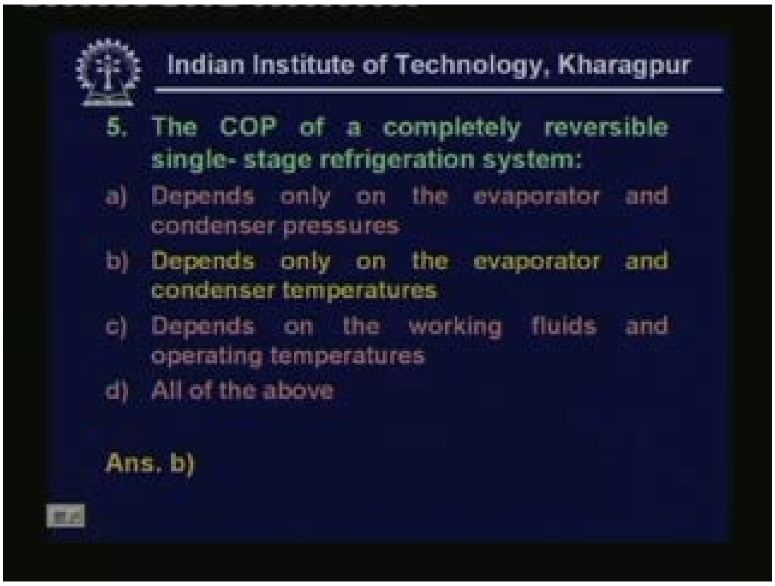

Finally I asked you the COP of a completely reversible single-stage refrigeration system depends on, what the answer is, it depends only on the evaporator and condenser temperatures. It does not depend on pressures. It does not depend on the working fluids its only a function of temperatures according to your Carnot's hypothesis okay, Carnot's theorems right.

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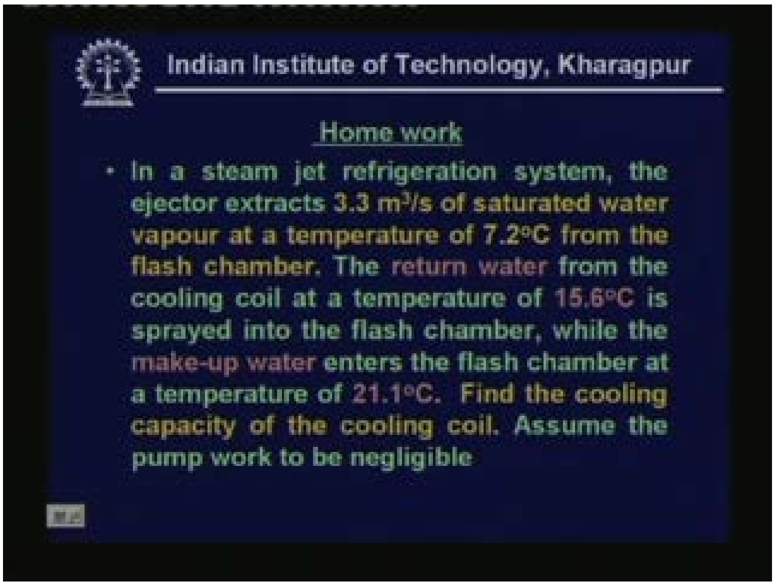

Now let me give quickly one home work problem. The problem is like this. In a stream jet refrigeration system the ejector extracts three point three metre cube per second of saturated water vapour at a temperature of seven point two degree centigrade from the flash chamber. The return water from the cooling coil at a temperature of fifteen point six degree centigrade is sprayed into the flash chamber while the make- up water enters the flash chamber at a temperature of twenty-one point one degree centigrade. So all that we have to do is find the cooling capacity of the cooling coil assume the pump work to be negligible okay. Let me show the schematic.

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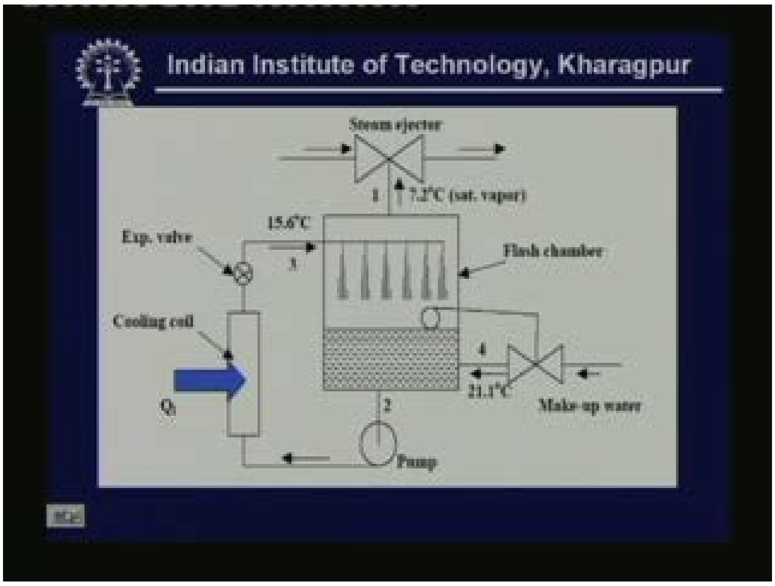

So this is the schematic of the homework problem here you need not bother about the stream ejector working. And all that what is asked is what is the refrigeration capacity of the cooling coil okay. So all that you have to do is apply mass and energy balance across the flash chamber and apply mass and energy balance across the cooling coil okay. So if you are applying this then you can easily find out the required answer.

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Indian Institute of Technology, Kharagpur

- Properties of water at various points:

State Point	T (°C)	P (mbar)	h (kJ/kg)	v m^3/kg
1	7.2	1.0285	2510	129.0
2	7.2	1.0285	30.2	-
3	15.6	-	65.4	-
4	21.1	[illegible]	88.4	-

And you can use this property data for water at various point the property data is given like this. State point one temperature is seven point two degree centigrade pressure is one point zero two eight five mille bar enthalpy is two five one zero kilo joule per kg specific volume is one twenty nine meter cube per kg. Similarly at point two you have temperature seven point two degree centigrade enthalpy is thirty point two kilo joule per kg point three temperature is fifteen point six degree centigrade. And enthalpy is sixty five point four kilo joule per kg point four temperature is twenty one point one and enthalpy is eighty eight point four degrees four kilo joule per kg. So this information is sufficient for you to work out this problem. I will give you the answer to this problem in the next class okay.

Thank you.