INDIAN INSTITUTE OF TECHNOLOGY ROORKEE

NPTEL
NPTEL ONLINE CERTIFICATION COURSE

Refrigeration and Air-conditioning

Lecture-10
Actual Vapour Compression Cycle - 1

with
Prof. Ravi Kumar
Department of Mechanical and Industrial Engineering
Indian Initiation of technology, Rookee

Hello I welcome you all in this course on definition in air conditioning, today we shall start with the actual vapor compression cycle. In this lecture we will be depicting actual refraction cycle on T-S diagram.

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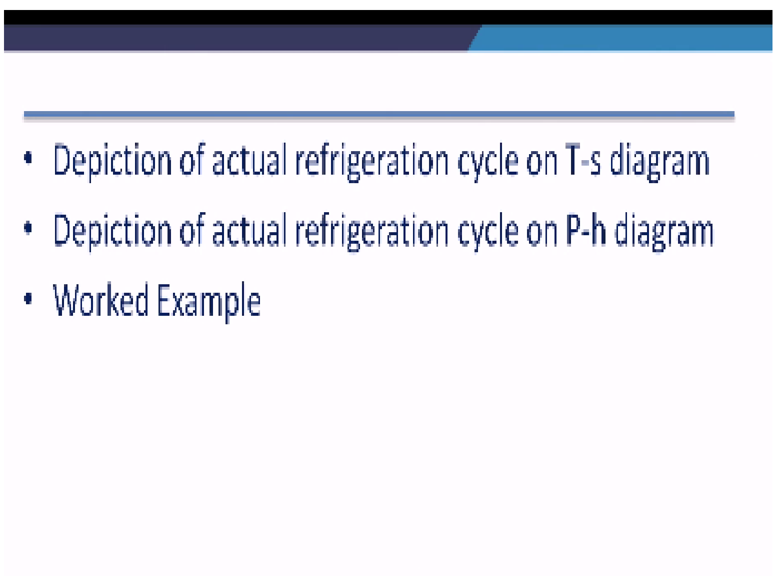

And we will transfer these cycles on pressure enthalpy diagram as well and we will take work example in this case.

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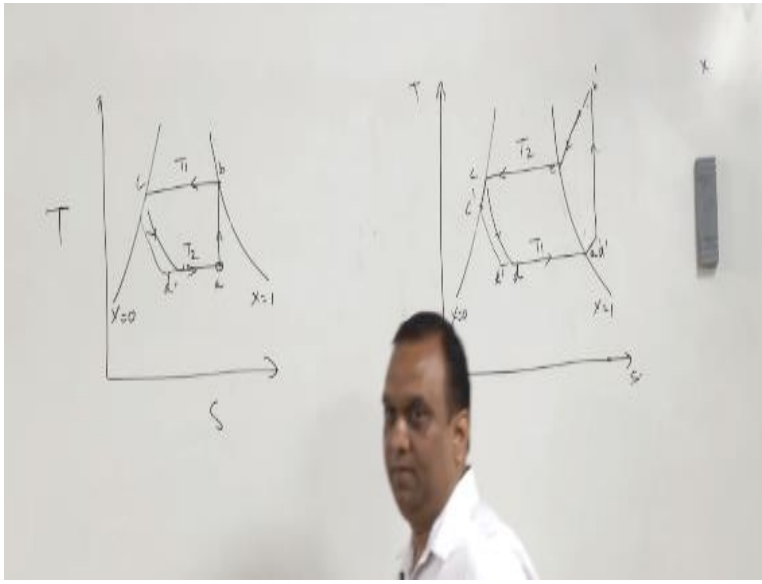

Now as we know on A temperature entropy diagram temperature entropy diagram so far we have analyzed A vapor compression cycle operating between two temperatures t1 and t2 and the vapor is saturated after the compression it means the vapor which is coming from the evaporator and entering the compressor is wet vapor, in actual practice this situation is avoided this situation is avoided because if the wet vapor enters the compressor.

It will carry itself droplets of the liquid and these liquid droplets first of all they will damage the compressor walls secondly they may wash away also the lubricant in the compressor, so this situation is always avoided it is always ensured that the vapor which is and in actual cycle the vapor which is entering the compressor is either saturated or it is superheated, so this state let us say A b c d.

So this state A will be shifted here and where the compression takes place from A to B definitely after the compression the vapor will become superheated, this superheated vapor emerging from the compressor first of all it will be d superheated in the condenser, so temperature at B is greater than temperature at let us say E temperature at though D superheating of vapor takes place and after D superheating.

The condensation of vapor takes place inside a condenser and we attain state C, at state C there is constant enthalpy expansion or throttling of the vapor and again it enters the evaporator and evaporation takes place this is X = 0 and x = 1, now in this case also it is very difficult to ensure that the vapor which is entering the compressor is dry and saturated because exactly attaining this property is difficult.

So normally the vapor is superheated in a range of two to five degree centigrade when it enters the compressor, so instead of point a here the point A is shifted point A this is t2 this is t1 so point A is shifted and the vapor which is entering the compressor is at temperature A’ and temperature as A’ is greater than the temperature at A and from here the compression takes place and we attain temperature B the state B’.

Now you can see here that as we keep on heating the vapor so compression work was minimum when you are heat when we are compressing the vapor from this point to this point when we are compressing the vapor which is saturated the compressor work increased and when the vapor is superheated compression work further increased this is temperature and this is entropy and at the same time you can see when we are shifting towards the right.

It means when the vapor which is entering the compressor is saturated the refrigeration effect is also increased the vapor is further superheated which also increase the refrigerating effect at the same time the compression work is also increased, so there are two possibilities either their ratio shall increase or it will decrease it depends upon the thermo physical properties of refrigerant, some of the refrigerants when they have wet compression.

Their Co P is maximum say for example ammonia or r22 some of the refrigerants when they are slightly superheated or saturated their Co P is maximum for example r1, 34A or isobutane or propane one, more thing is done in actual practice the vapor is not saturated in this form of saturated liquid here it is sub cooled so cool to let us say C’ when vapor is sub cooled to c’ the ISO enthalpy expansion shifts the points D to left.

And this D point comes here D’ and this increases the refrigerating effect without any increase in work increase in the consumption of work in the compressor, so if we simply subdue the liquid instead of C if you support it up to here we can increase the refrigerating effect, now this sub cooling how to attain the sub cooling as you know in a refrigeration cycle there are four components one is compressor.

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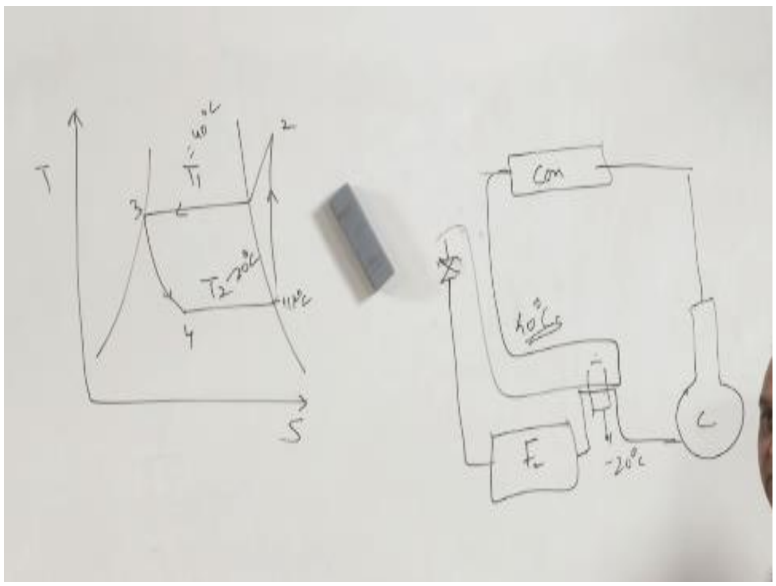

Where the vapor enters from evaporator it goes to the compressor from compressor it goes to the condenser, condenser and from condenser it goes to the expansion valve expansion were from expansion valve to the evaporator if we depict this process on temperature entropy diagram it is going to be like this, so one two three and four and this is temperature t1 and this is temperature T2.

Let us say t1 is equal to 40 degree centigrade and t2 is minus 20 degree centigrade let us as u so the vapor coming from the evaporator is minus 20 degree centigrade and vapor after condensation is at it is saturated liquid at 40 degree centigrade, now if I exchange heat a many I make an arrangement so that heat is exchanged between this and this or through a heat exchanger with the help of a heat exchanger.

We managed to exchange heat between this is a cold temperature liquid which is coming at minus 20degree centigrade saturated, so this low temperature refrigerant will pick heat from the high temperature liquid and liquid which is at 40 degree centigrade and it will get superheated so instead of minus 20 it may be at let us say minus 70 for example minus 70 degree centigrade, so the vapor will get superheated here.

At the same time heat because this is saturated liquid and it is giving heat to the liquid at a lower temperature the temperature of this may also go down, so in the same process in the same process we are super heating the vapor at the same time we are supporting the liquid when we are superheating the vapor the compression work is increasing at the same time when we are sub cooling the liquid vapor the refrigerating effect is also increasing.

So here also we not through this arrangement the COP may not increase for some of the refrigerant but definitely we are getting more refrigerating effect we are getting more resonating effect with the same unit.

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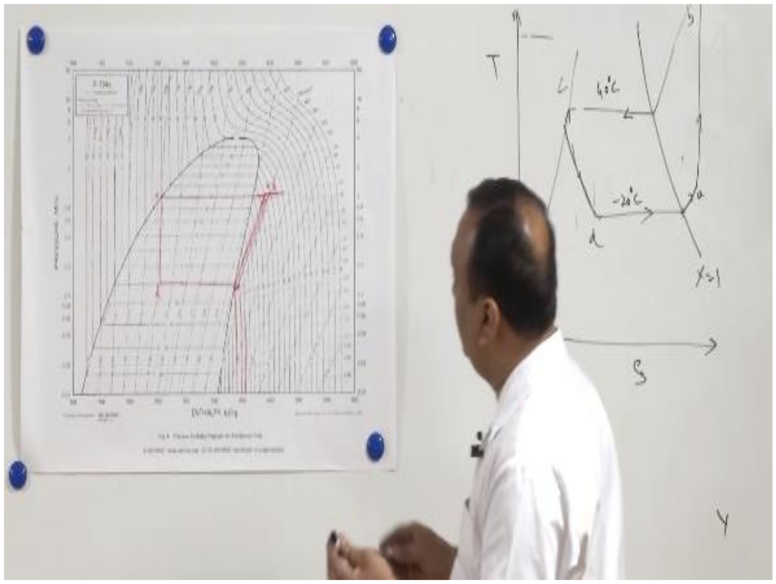

Now if I want to transfer these processes on pH diagram let us take the processes one by one, temperature entropy super heating saturated then expansion. so A b c d x = 1, x = 0 state 1 and this is 40 degree centigrade and this is minus 20 degree centigrade, now here at state 1 minus 20 degree centigrade saturated vapor we can directly take enthalpy from here state be 40 degree centigrade saturated vapor.

But pressure is remaining constant so from this is state A from state A will attain state B so this is a constant pressure line this pressure line will be extended because the pressure is going to remain constant and it is an isentropic process so there are constant entropy lines here so we will draw a line parallel to the constant entropy line and that is how we will be getting state B, now after state B the D superheating take will take place in this process the D superheating will take place.

And further removal of heat will bring the state C state C will come here now process C to D is constant enthalpy process constant enthalpy process because constant enthalpy lines are vertical lines so we will follow the vertical line here and we will be getting state D, now second case but we can simply from here if you want to find Co P simply H A- HD / H B – HE we can directly take values from here from this chart.

Now if the vapor is superheated vapor is superheated then these points will be shifted then A will be here so we are here, now here if you want to show the super heating pressure is constant here the saturation temperature is minus 20 degree centigrade, suppose the vapor is superheated by let us say 5 degree centigrade so this is constant temperature 0 10 - 20 this is minus 20 constant temperature line this is zero degree centigrade constant temperature line.

This is minus 10 degree centigrade constant temperature line, so A will be shifted somewhere here and directly we can read enthalpy from this chart and again we will follow the constant entropy line and this is going to be the shifted point B - similarly when sub cooling take place if I say sub cooling of 5 degree centigrade is taking place so here in this chart first of all I show it here.

So sub cooling is taking place so here also in this chart the temperature is 40 degree centigrade this is constant temperature 40 degree centigrade line this is constant temperature 30 degree centigrade line so another temperature is 35 so this is new point C' from this C' now expansion will take place and this point D' will attain so how this is how we can transform all the processes in this in the temperature entropy diagram.

Comfortably they can be transformed on pressure enthalpy diagram and from these charts we can definitely find the CoP relatively in an easier manner and then in the come in then comparison to the case of temperature entropy diagram sorry I have done a mistake here this point C' will not be here point C' should be here because this is a constant pressure process so Point C' should be somewhere here C' on this constant pressure line. So this is the point C' and then expansion of refrigerant take place so in a nut shell if you want to transform.

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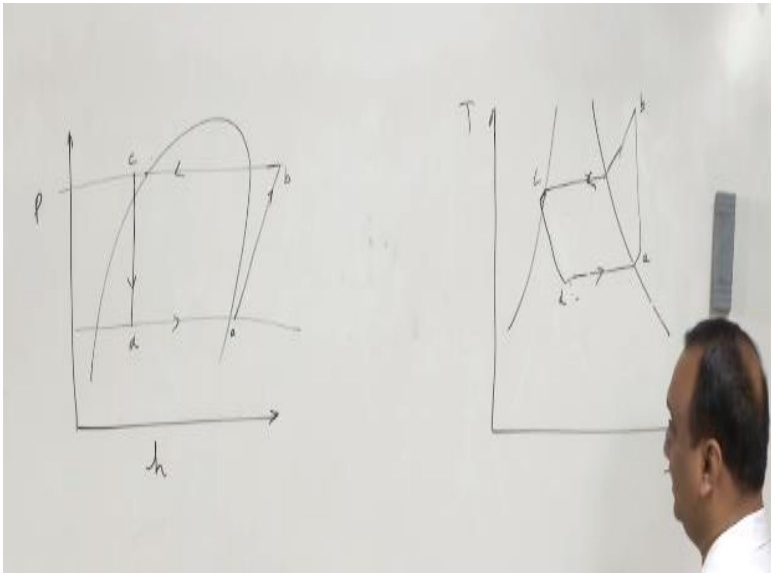

The temperature entropy the process on temperature entropy diagram that is PS A B C D sorry this direction this direction and if the liquid is sub cooled here is superheated here, so if the vapor is superheated here it will be like this A will be shifted here and if the liquid is are pooled here we assume it to be along the this liquid layer but actually it is somewhere here it is compressed liquid and expansion takes place like this.

So D point will be shifted here, similarly on pH diagram on pH diagram the A point there are two pressures lower pressure and higher pressure the A will be somewhere here A to B is entropic compression then the superheating and cooling up to C further sub cooling by some degree centigrade so C will be shifted here and then expansion D, so on pH diagram we are going to get ABC D and on this temperature entropy iti s going to be AB C D like this.

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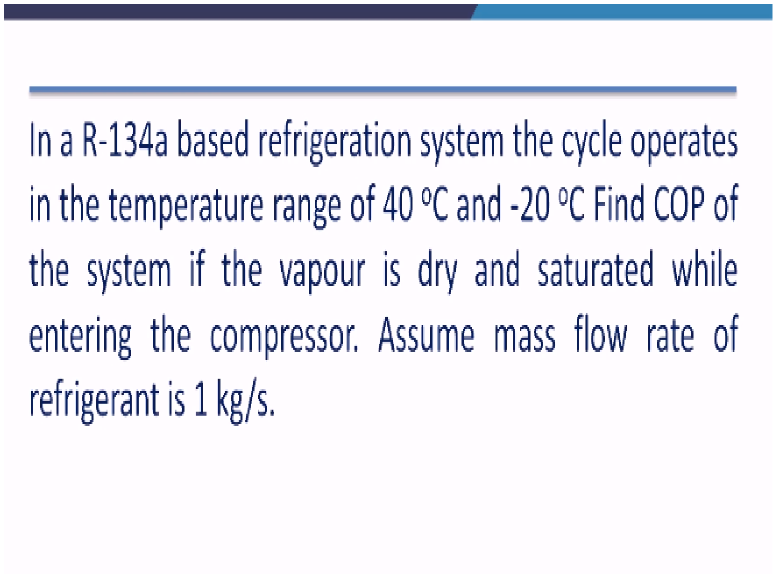

Now let us take one numerical example R-134 a working between 40 degree centigrade a minus 20 degree centigrade and the vapor is saturated before entering the compressor.

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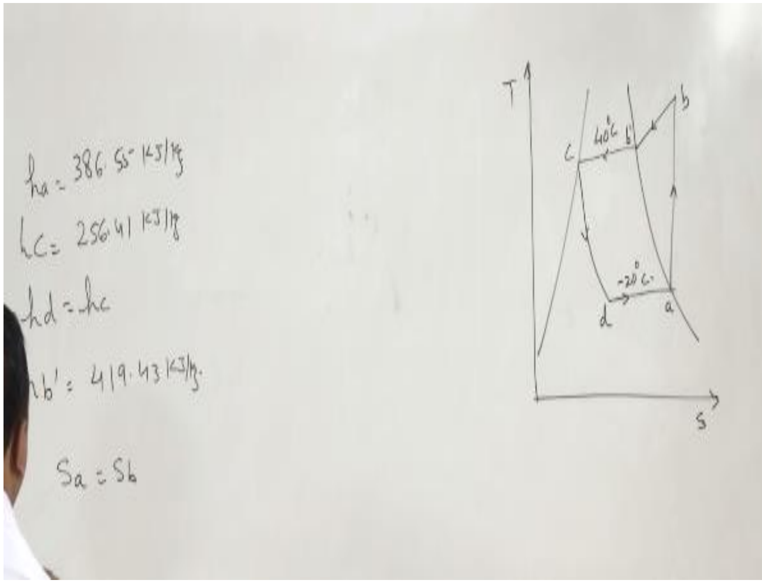

So vapor is saturated before entering the compressor that is state A then state B T superheating condensation and then expansion and then we get CD, B1 and this is temperature here it is entropy the direction of process is like this temperature is 40 degree centigrade that is and this temperature is minus 20 degree centigrade HA here again we can take directly from the properties table then HA is equal to again 386.55 kilo joules per kg.

HC enthalpy at C it is equal to 256.41 kilo joules per kg enthalpy at D is equal to enthalpy at C enthalpy at D is equal to enthalpy at C, enthalpy here B’ is also known to us that is 419.43 kilo joules per kg but for finding out the compressor work refrigerating effect we can find HA – HD, HD is here and HD is here we have taken from property stable but we do not have the value of HB. In order to find the enthalpy at B we will use the relation s is equal to SB entropy at A is equal to entropy at B entropy A at A is known to us, entropy at A is the entropy of saturated liquid.

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Refrigerant 134a (1,1,1,2-Tetrafluoroethane) Properties of Saturated Liquid and Saturated Vapor

Temp.,* °C	Pressure, MPa	Density, kg/m³	Volume, m³/kg	Enthalpy, kJ/kg		Entropy, kJ/(kg·K)		Specific Heat c_p, kJ/(kg·K)		c_p/c_v	Velocity of Sound, m/s		Viscosity, µPa·s		Thermal Cond., mW/(m·K)		Surface Tension, mN/m	Temp.,* °C
		Liquid	Vapor	Liquid	Vapor	Liquid	Vapor	Liquid	Vapor	Vapor	Liquid	Vapor	Liquid	Vapor	Liquid	Vapor		
−103.30[a]	0.00039	1591.1	35.4960	71.46	334.94	0.4126	1.9639	1.184	0.585	1.164	1120	126.8	2175.0	6.46	145.2	3.08	28.07	−103.30
−100	0.00056	1582.4	25.1930	75.36	336.85	0.4354	1.9456	1.184	0.593	1.162	1103	127.9	1893.0	6.60	143.2	3.34	27.50	−100
−28	0.09270	1382.4	0.20680	163.34	381.57	0.8591	1.7492	1.277	0.788	1.153	751	145.4	394.9	9.60	104.8	9.15	15.73	−28
−26.07[b]	0.10133	1376.7	0.19018	165.81	382.78	0.8690	1.7472	1.281	0.794	1.154	742	145.7	384.2	9.68	103.9	9.31	15.44	−26.07
−20	0.13273	1358.3	0.14739	173.64	386.55	0.9002	1.7413	1.293	0.816	1.158	714	146.3	353.0	9.92	101.1	9.82	14.51	−20
−18	0.14460	1352.1	0.13592	176.23	387.79	0.9104	1.7396	1.297	0.823	1.159	705	146.4	343.5	10.01	100.1	9.98	14.21	−18
−16	0.15728	1345.9	0.12551	178.83	389.02	0.9205	1.7379	1.302	0.831	1.161	695	146.6	334.3	10.09	99.2	10.15	13.91	−16
−14	0.17082	1339.7	0.11605	181.44	390.24	0.9306	1.7363	1.306	0.838	1.163	686	146.7	325.4	10.17	98.3	10.32	13.61	−14
−12	0.18524	1333.4	0.10744	184.07	391.46	0.9407	1.7348	1.311	0.846	1.165	677	146.8	316.9	10.25	97.4	10.49	13.32	−12
−10	0.20060	1327.1	0.09959	186.70	392.66	0.9506	1.7334	1.316	0.854	1.167	668	146.9	308.6	10.33	96.5	10.66	13.02	−10
40	1.0166	1146.7	0.01997	256.41	419.43	1.1905	1.7111	1.498	1.145	1.292	436	140.3	163.4	12.55	74.7	15.44	6.13	40
42	1.0722	1138.2	0.01887	259.41	420.28	1.1999	1.7103	1.510	1.163	1.303	427	139.7	159.2	12.65	73.9	15.68	5.88	42
44	1.1301	1129.5	0.01784	262.43	421.11	1.2092	1.7096	1.523	1.182	1.314	418	138.9	155.1	12.76	73.0	15.93	5.63	44
46	1.1903	1120.6	0.01687	265.47	421.92	1.2186	1.7089	1.537	1.202	1.326	408	138.2	151.0	12.88	72.1	16.18	5.38	46
48	1.2529	1111.5	0.01595	268.53	422.69	1.2280	1.7081	1.551	1.223	1.339	399	137.4	147.0	13.00	71.3	16.45	5.13	48
50	1.3179	1102.3	0.01509	271.62	423.44	1.2375	1.7072	1.566	1.246	1.354	389	136.6	143.1	13.12	70.4	16.72	4.89	50
95	3.5912	772.7	0.00374	355.25	420.67	1.4715	1.6492	3.938	5.020	4.369	141	101.9	60.4	19.61	51.7	36.40	0.33	95
100	3.9724	651.2	0.00268	373.30	407.68	1.5188	1.6109	17.59	25.35	20.81	101	94.0	45.1	24.21	59.9	60.58	0.04	100
101.06[c]	4.0593	511.9	0.00195	389.64	389.64	1.5621	1.5621	∞	∞	∞	0	0.0	—	—	∞	∞	0.00	101.06

*Temperatures on ITS-90 scale [a]Triple point [b]Normal boiling point [c]Critical point

At minus twenty degree centigrade not certain liquid saturated vapor so that is 1.7413 kilo joules per kg Kelvin.

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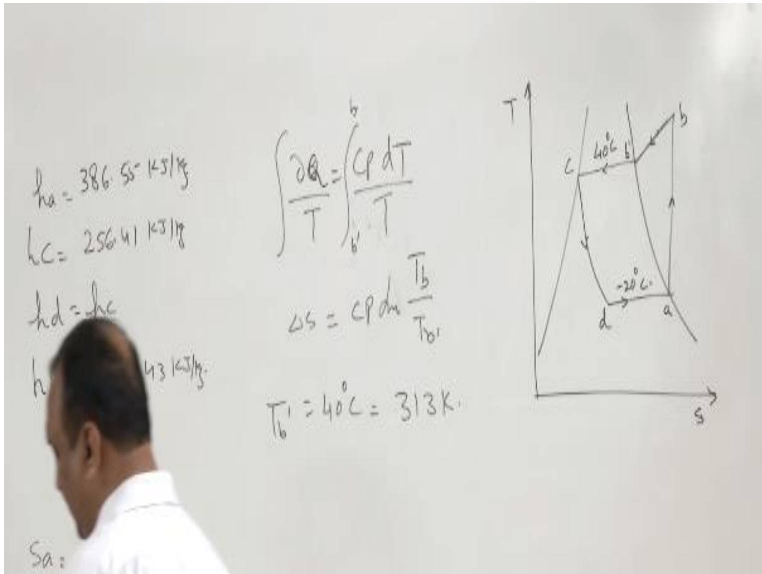

Now this entropy is equal to the entropy at B we have entropy at B' this entropy eight B' is entropy of vapor at forty degree centigrade it is 1.7111 kilo joules per kg Kelvin, now what is the change in entropy from this point to this point, now change in entropy from this is a sensible a sort of sensible heating process in this process Delta Q is equal to CP delta T sorry CP DT and Delta Q/ T again divided by T if you integrate this that is change in entropy is equal to CP natural log PV by TB dash.

Because it is from B dash to B, PB/ T V' dash now TV' with us it is forty degree centigrade so TB dash is forty degree centigrade or three one three Kelvin.

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Refrigerant 134a (1,1,1,2-Tetrafluoroethane) Properties of Saturated Liquid and Saturated Vapor

Temp.,* °C	Pressure, MPa	Density, kg/m³	Volume, m³/kg	Enthalpy, kJ/kg		Entropy, kJ/(kg·K)		Specific Heat c_p, kJ/(kg·K)		c_p/c_v	Velocity of Sound, m/s		Viscosity, μPa·s		Thermal Cond., mW/(m·K)		Surface Tension, mN/m	Temp.,* °C
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−100	0.00056	1582.4	25.1930	75.36	336.85	0.4354	1.9456	1.184	0.593	1.162	1103	127.9	1893.0	6.60	143.2	3.34	27.50	−100
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100	3.9724	651.2	0.00268	373.30	407.68	1.5188	1.6109	17.59	25.35	20.81	101	94.0	45.1	24.21	59.9	60.58	0.04	100
101.06[c]	4.0593	511.9	0.00195	389.64	389.64	1.5621	1.5621	∞	∞	∞	0	0.0	—	—	∞	∞	0.00	101.06

*Temperatures on ITS-90 scale [a]Triple point [b]Normal boiling point [c]Critical point

The value of CP at forty degree centigrade vapor is 1.145 kilojoules per kg Kelvin.

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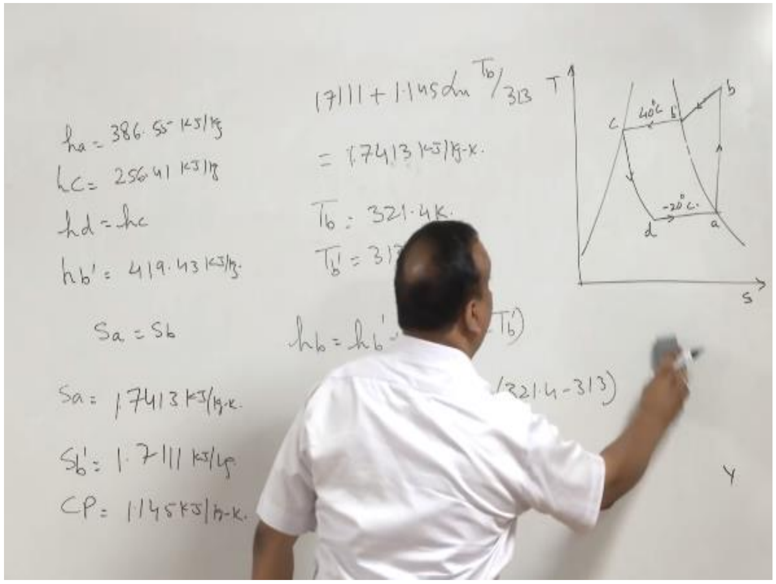

Change in entropy Delta s is going to be equal to 1.145 natural log PB/ 313 and this change in entropy plus entropy at state B dash will give if we add this Delta s to entropy at B dash the entropy at B dash is 1.7111 + 1.145 natural log PB/ 3 1 3 we will be getting entropy at A, entropy at A is equal to 1.7413 kilo joules per kg Kelvin, if you solve this and the value of PB is going to be 321.4 Kelvin.

Once we have the value of T B we have the tenth value of T V dash that is 313.0 Kelvin so enthalpy at B dash plus so enthalpy at B is equal to enthalpy at B dash plus CP TV dash minus TB it means the enthalpy at B is equal to enthalpy at B dash plus sensible heat it or CPT V dash minus TB so enthalpy at B Dash is 419.43 plus CP is 1.145 TB dash is sorry it is TB minus TB' so TB is 321.4 – TB' is 313. So this the value of HB is going to be equal to 429.05 kilo joules per kg.

Now we have the value of enthalpy at B and enthalpy at s at A as well so the compressor work is going to be equal to HB minus HA and that is 429.05 – 386.55 and that is going to be equal to 42.50 kilo joules per kg right now if you multiply this by mass flow rate that is one kg per second you will be getting 42.5 kilo watt of compressor work the refrigerating effect is HA – HC.

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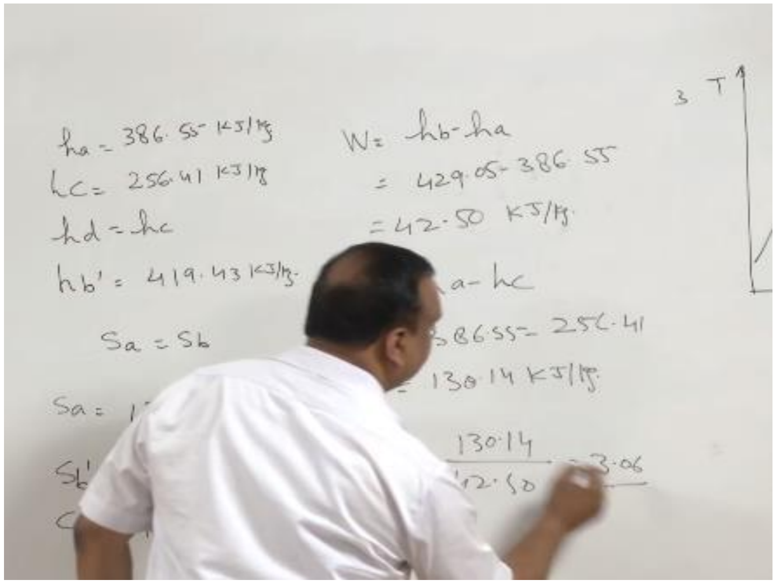

And that is going to be equal to 386.55 – 256.41 and that will give you 130.14 kilo joules per kg because mass flow rate is one kg per second so if you multiply this by 1kg per second we will be getting 130.14 kilowatt now CoP of the system 130.14 / 42.50 = 3.06.

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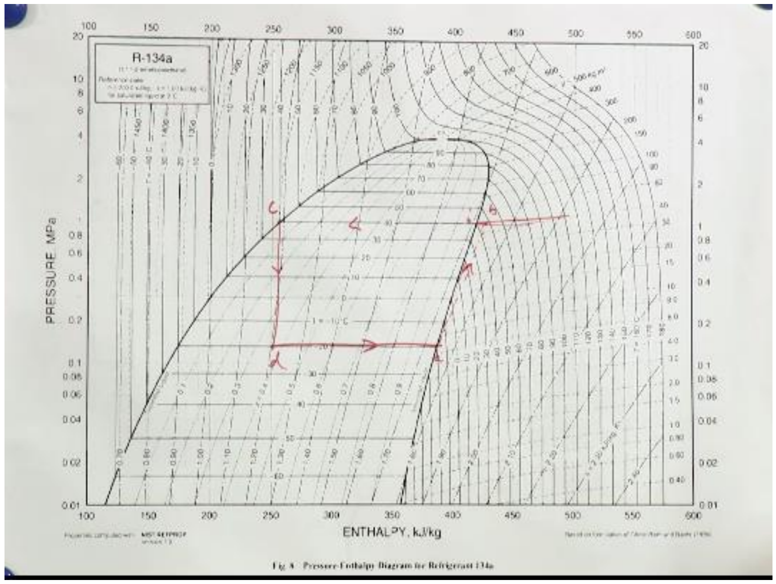

Now if I want to use pH diagram for this now in this pH diagram forty degree centigrade the vapor is saturated at the entry vapor is saturated here, now vapor that is state A now vapor is compressed it is isentropic compression and the pressure in the condenser is constant so we will follow A light which will follow the closest constant entropy line and perhaps we'll be getting A point B somewhere here point B somewhere here.

After B thus d superheating will take place will get B - here then further pulling up to the liquid state and then constant enthalpy expansion, C and D now if we take the values from this pH diagram and you can do it by yourself also as an exercise and you will find that we are getting approximately the same value for refrigerating effect and coefficient of performance. Now we have completed all the topics due for the today's lecture now next lecture we will be taking take vapor compressions cycle actual vapor compression cycle part 2.

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Coordinator, Educational Technology Cell

Indian Institute of Technology Roorkee

Roorkee – 247667

E Mail: etcell@iitr.ernet.in, etcell.iitrke@gmail.com

Website: www.nptel.ac.in

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Prof.Pradipt Banerji

Director, IIT Roorkee

Subject Expert & Script

Prof.Ravi Kumar

Dept of Mechanical and

Industrial Engineering

IIT Roorkee

Production Team

Neetesh Kumar

Jitender Kumar

Sourav

Camera

Sarath Koovery

Online Editing

Jithin.k

Video Editing

Pankaj Saini

Graphics

Binoy.V.P

NPTEL Coordinator

Prof.B.K.Gandhi

An Educational Technology Cell

IIT Roorkeee Production