NPTEL

NPTEL ONLINE CERTIFICATIOIN COURSE

Refrigeration and Air – Conditioning

Lecture – 15

Problem Solving

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Hello I welcome you all in this course on refrigeration and air conditioning today we will solve a numerical and some logical problems in the area of refrigeration.

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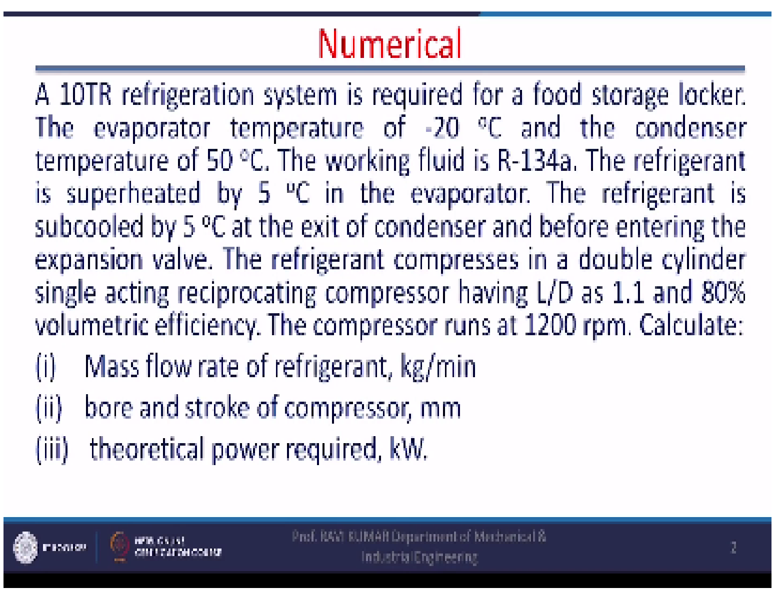

We will start with the numerical a 10 TR reflection system is required for a food storage locker the evaporator temperature is -20^{0} ^{c}entigrade and the condenser temperature is 50^{0} centigrade the working fluid is R134a the refrigerant is superheated by 5^0 centigrade in the evaporator while coming at the exit of the evaporator the refrigerant is sub cooled by 5^0 centigrade at the exit of the condenser and before entering the expansion wall the refrigerant compresses in double cylinder single acting reciprocating compressor having L / D as 1.1 L / D stands for length and diameter ratio of compressor block.

And 80% of volumetric efficiency the compressor runs at 1200 rpm calculate number one mass flow rate of refrigerant kg per minute bore and stroke of compressor in millimeters and theoretical power required in kilowatts we will start with the thermo physical properties of refrigerant and when raw the processes.

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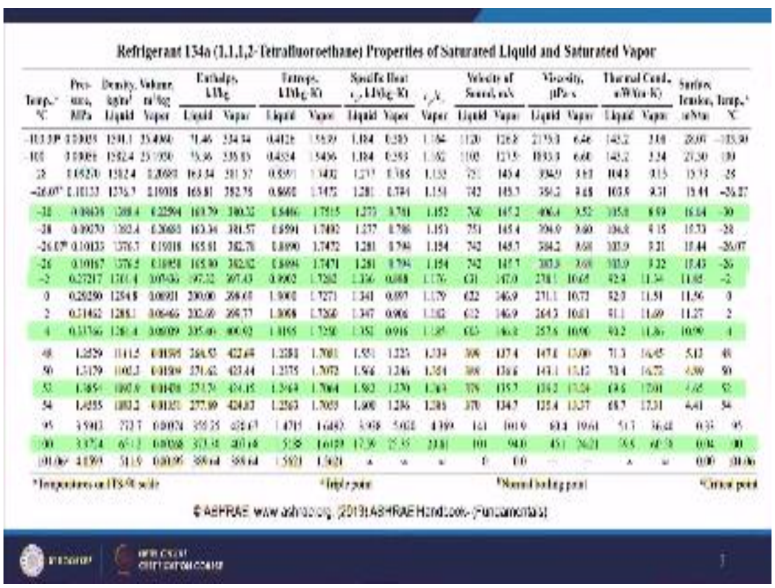

Refrigerant 134a (1,1,1,2-Tetrafluoroethane) Properties of Saturated Liquid and Saturated Vapor

Temp.,* °C	Pressure, MPa	Density, kg/m³ Liquid	Volume, m³/kg Vapor	Enthalpy, kJ/kg Liquid	Enthalpy, kJ/kg Vapor	Entropy, kJ/(kg·K) Liquid	Entropy, kJ/(kg·K) Vapor	Specific Heat c_p, kJ/(kg·K) Liquid	Specific Heat c_p, kJ/(kg·K) Vapor	c_p/c_v Vapor	Velocity of Sound, m/s Liquid	Velocity of Sound, m/s Vapor	Viscosity, µPa·s Liquid	Viscosity, µPa·s Vapor	Thermal Cond., mW/(m·K) Liquid	Thermal Cond., mW/(m·K) Vapor	Surface Tension, mN/m	Temp.,* °C
-103.30a	0.00039	1591.1	35.4960	71.46	334.94	0.4126	1.9639	1.184	0.585	1.164	1120	126.8	2175.1	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	1893.3	6.60	143.2	3.24	27.50	-100
-28	0.09270	1382.4	0.20680	163.34	381.57	0.8591	1.7492	1.277	0.786	1.153	751	145.4	394.9	8.60	104.8	9.15	15.73	-28
-26.07b	0.10133	1376.7	0.19018	165.81	382.75	0.8690	1.7475	1.281	0.794	1.154	742	145.7	384.2	8.68	103.9	9.21	15.44	-26.07
-30	0.08438	1388.4	0.22594	160.79	380.32	0.8486	1.7515	1.273	0.781	1.152	760	145.2	406.4	8.52	105.8	8.99	16.04	-30
-28	0.09270	1382.4	0.20680	163.34	381.57	0.8591	1.7492	1.277	0.786	1.153	751	145.4	394.9	8.60	104.8	9.15	15.73	-28
-26.07b	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	8.68	103.9	9.21	15.44	-26.07
-26	0.10167	1376.5	0.18958	165.90	382.82	0.8694	1.7471	1.281	0.794	1.154	742	145.7	383.8	8.68	103.9	9.22	15.43	-26
-2	0.27217	1301.4	0.07436	197.32	397.43	0.9902	1.7282	1.336	0.888	1.176	631	147.0	278.1	10.65	92.9	11.34	11.85	-2
0	0.29280	1294.8	0.06931	200.00	398.60	1.0000	1.7271	1.341	0.897	1.179	622	146.9	271.1	10.73	92.0	11.51	11.56	0
2	0.31462	1288.1	0.06466	202.69	399.77	1.0098	1.7260	1.347	0.906	1.182	612	146.9	264.3	10.81	91.1	11.69	11.27	2
4	0.33766	1281.4	0.06039	205.40	400.92	1.0195	1.7250	1.352	0.916	1.185	603	146.8	257.6	10.90	90.2	11.86	10.99	4
48	1.2529	1111.5	0.01595	268.52	422.64	1.2281	1.7081	1.551	1.225	1.334	398	137.4	147.8	13.00	71.3	16.45	5.12	48
50	1.3179	1102.3	0.01509	271.62	423.44	1.2375	1.7072	1.566	1.246	1.351	388	136.6	143.1	13.12	70.4	16.72	4.90	50
52	1.3851	1092.9	0.01428	274.74	424.15	1.2469	1.7064	1.582	1.270	1.368	379	135.7	139.2	13.24	69.6	17.01	4.65	52
54	1.4555	1083.2	0.01351	277.89	424.83	1.2563	1.7059	1.600	1.296	1.385	370	134.7	135.4	13.37	68.7	17.31	4.41	54
95	3.5912	772.7	0.00374	355.35	418.67	1.4715	1.6482	3.938	5.018	4.399	161	101.9	60.4	19.61	51.7	36.42	0.35	95
100	3.9724	651.2	0.00268	373.30	407.68	1.5188	1.6109	17.30	25.35	20.81	101	94.0	45.1	26.21	59.5	60.70	0.04	100
101.06c	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 aTriple point bNormal boiling point cCritical point

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On temperature entropy diagram.

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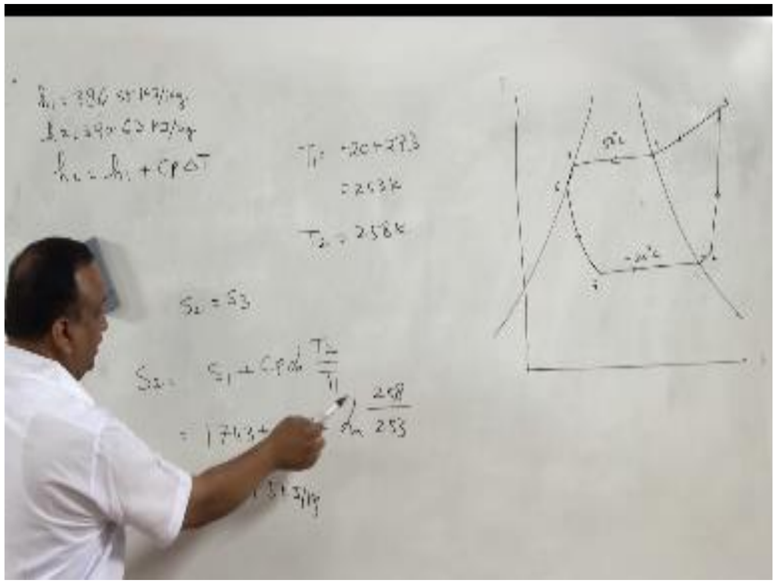

Temperature and entropy diagram and the vapor coming from the neck evaporator is superheated by 5^0centigrade so state 1 is a saturation State 2 is the superheated state then the vapor is compressed in a compressor state 2 to state 3 from state3 to state 4 D super heating takes place T super heating of the vapor takes place four to five condensation of vapor in a condenser and then sub cooling five to six and six to seven is expansion in expansion wall and then boiling of refrigerant in the evaporator from state seven to state two to produce a refrigerating effect.

This is the entire cycle now in this cycle enthalpy of state one that is H 1 H one is the enthalpy of saturated vapor at -20^0 centigrade this is 50^0 centigrade so enthalpy is vapor at -20^0 centigrade that is 386.55 kilojoules per kg enthalpy of state two is not known to us but we know that from state one to state two there is a sensible heating and the heating temperature difference between state two and state one is 5^0 centigrade.

So H 2 can be H $_{1\,+}$ CP δ T now n H one is enthalpy at state one that is 386.55 CP is the specific heat of vapor at state one saturated vapor at -20^0 centigrade this value can be taken from the properties chart at -20^0 centigrade a specific heat ofr134a is 0.816 δ T is 5^0 centigrade that gives the value of enthalpy at state two as 390.63 kilo joules per kg we noted here H two is equal to

390.63 kilo joules per kg in order to find the compressor work we need to have the enthalpy at state 3also since it is in a superheated state we do not have properties of superheated state here but we have enthalpy at state4.

If we know the temperature at state 3we can find this enthalpy at state free as well temperature at state 3 is not known to us we know one thing that property at state 2 is equal to property at state 3 so property sorry the entropy not property entropy at state through 2is equal to entropy at state 3 so s 2 is equal to s 3 now s 2 we can find as s 1plus CP natural log T 2 by T 1 this is a sensible heating process in during sensible heating the change in entropy can be written like this now s 1 again at my left was -20^0 centigrade can be taken from here -20^0 centigrade and entropy of vapor is 1.7413 specific heat at $-20^{0\ c}$entigrade is again 0.816 natural log of t2 by t1.

Now t1 is equal to - oh sorry – seven -10 + 273 that is 253 Kelvin it is superheated here by 5^0 centigrade so t2 is 258 Kelvin now we will be putting here 258 / 253 and this will give us s 2 s 1.7573 kilo joules per kg that is the value of entropy at two so from here we have calculated the entropy at state two and how we have calculated we have take the entropy and state one from the properties child plus change in entropy CP natural log t2 t 2 by t1 using this relation we have calculated the entropy at state two and entropy at state two is one point seven five seven three kilojoules per kg Kelvin kg Kelvin now property at this entropy at state 2 is equal to entropy at state three so s3 is equal to sorry s3 is equal to s2.

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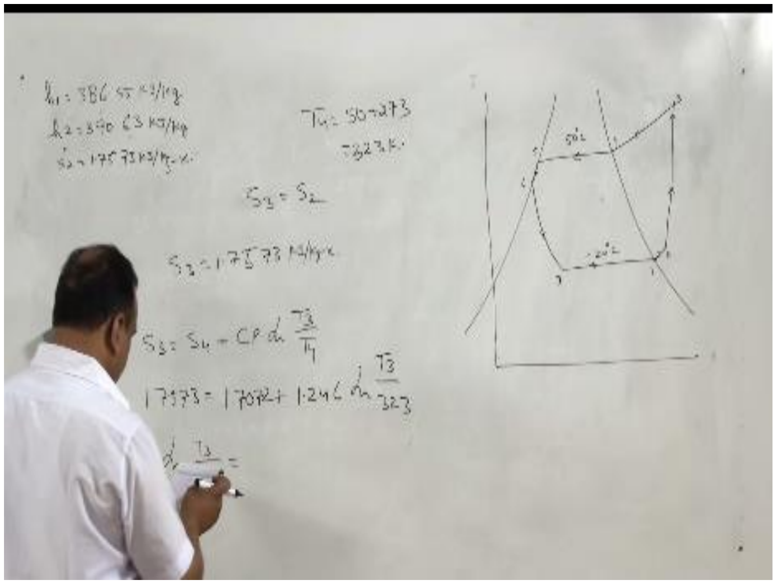

So S3 is equal to 1.7573 kilo joules per kg Kelvin S4 is we know the value of S4 that can be taken from the properties of R134A. And S4 is going to be is equal to sorry S3 is going to be equal to S4 plus CP natural log T3 by T4. Now in this case P4 is 50 + 273 = 323 Kelvin. S3 is given here 1.7573.

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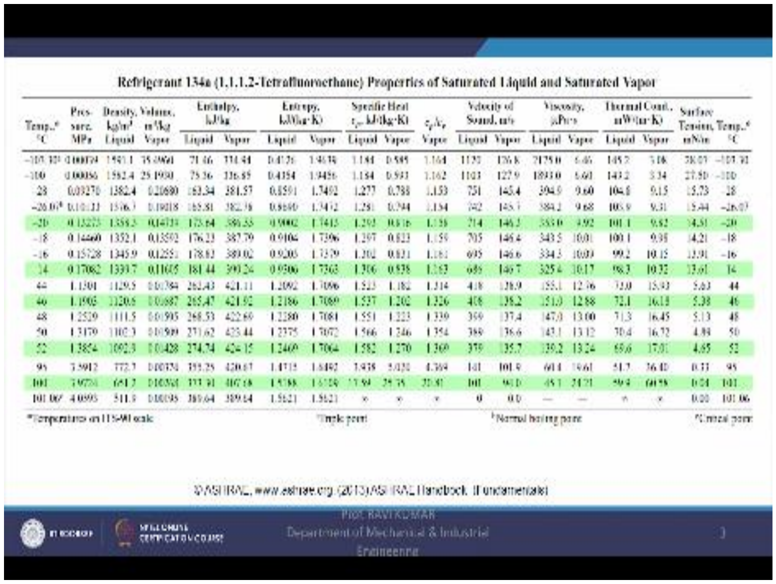

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−103.30[a]	0.00039	1591.1	35.4960	71.46	334.94	0.4126	1.9639	1.184	0.585	1.164	1120	126.8	2175.0	6.46	145.2	3.08	28.07	−103.30
−100	0.00056	1582.4	25.1930	75.36	336.85	0.4354	1.9456	1.184	0.593	1.162	1103	127.9	1893.0	6.60	143.2	3.34	27.50	−100
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−26.07[b]	0.10133	1376.7	0.19018	165.81	382.74	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	146.2	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
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
52	1.3854	1092.9	0.01428	274.74	424.15	1.2469	1.7064	1.582	1.270	1.369	379	135.7	139.2	13.24	69.6	17.01	4.65	52
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	0.00250	373.30	407.68	1.5188	1.6109	17.59	25.35	20.81	101	96.0	45.1	24.21	59.4	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

S4 can be taken from here at 50°C entropy at 50°C entropy of the saturated require is 1.7072 + specific heat 1.246 six natural log T3 by T4 is 323. So we have taken entropy at this point plus change in entropy while heating from here to here and. We got this expression and from this expression natural log of P 3x3 23 is going to be equal to 0.04037.

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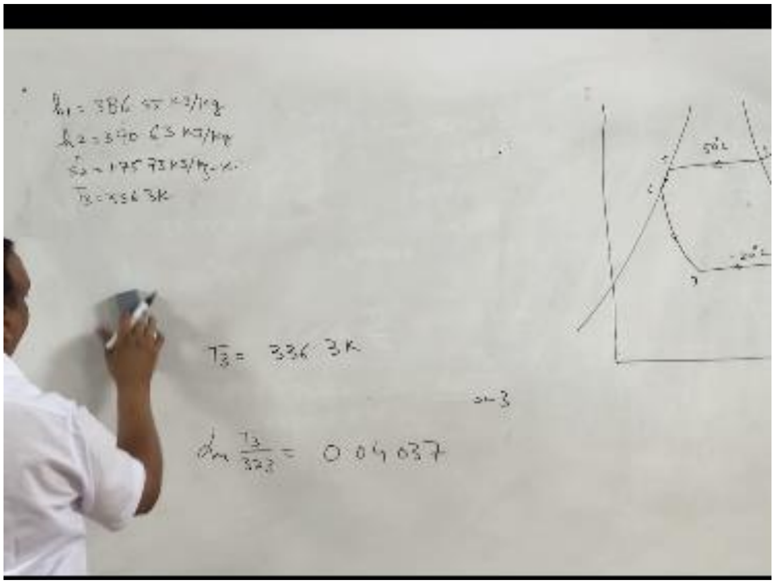

And from this we find the value of P3S 336.3 Kelvin, so T3 is 336.3 Kelvin. Once we have the value of T3 once we have temperature at this state the CPT 3 minus T 4 will give the heat rejected reheat rejected during D superheating or,

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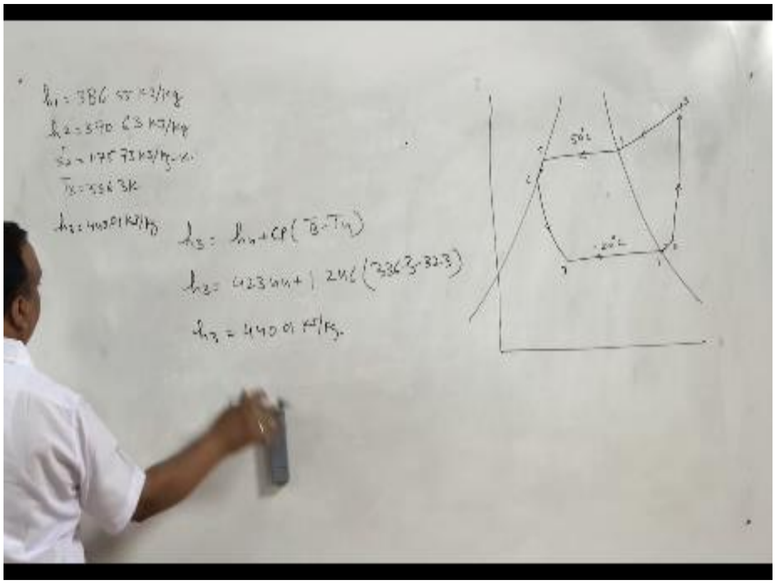

We can say that enthalpy at 3 H 3 is equal to enthalpy at 4 plus CP T 3 - T 4 enthalpy at 3 is equal to enthalpy at four enthalpy at 4 it means 50°C temperature enthalpy of saturated vapor that is 423.44 + CP 1.246 P 3 is 336.3-323. And this will give the enthalpy at 3S 440.01 kilojoules per Kg. So H3 will note down here 440.01 kilo joules per kg. Now after H3 we have to find the value of H 5.

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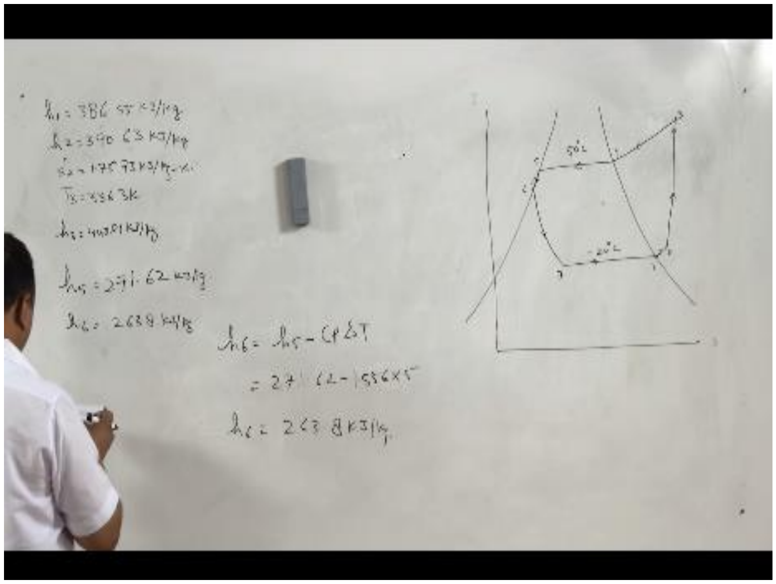

H 5 we can directly take from the properties diagram that is the enthalpy of liquid by enthalpy of R134A and 50°C that is enthalpy of saturated liquid. And this H 5 is we can take from here it is 271.62 kilojoules per kg. Now once we have the enthalpy at five the vapor is soup is sub cooled by 5°C. So it should come somewhere here but because this is very close to the saturation line we can always take this point at here on the saturation curve itself it is normally taken like this. So the enthalpy at 6 enthalpy at 6 is equal to enthalpy at 5 plus because there is a sub cooling of 5°C CP Δ T and enthalpy of 5 is sorry not minus it is minus not plus.

So H5 is 271.62 minus CP of liquid refrigerant at 50°C and CP of liquid represent at 50°C 1.556 into 5, and that will give the value of H6S 263.8 kilojoules per kg. So H6 is 263.8 kilo joules per kg. Now we have to find the refrigerating effect because superheating is taking place inside the evaporator.

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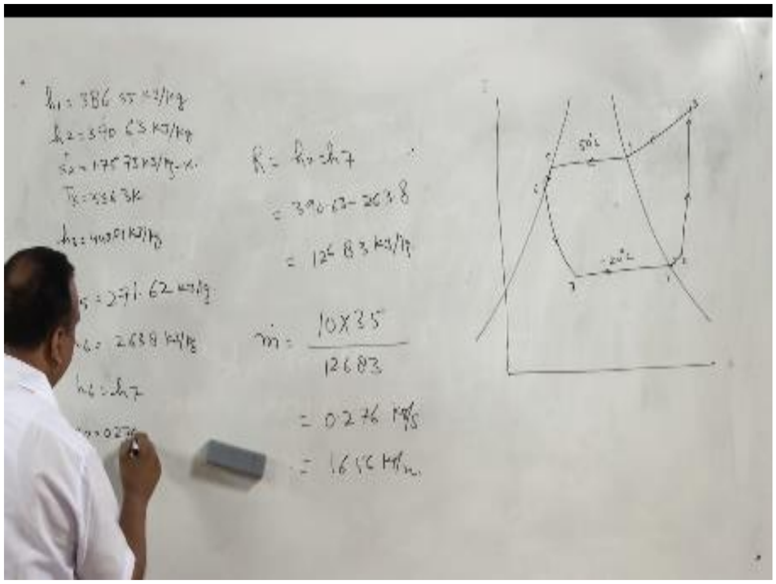

So refrigerating effect will be H2 minus H7 S6 is equal to S7 S6 is equal to S7 because it is an isenthalpic expansion process and that is equal to 390.63 – 2603.8 and =126.83 kilo joules per kg. In order to find the mass flow rate of refrigerant the total refrigerating capacities 10 tones of refrigeration 10 tones of resolution means 10x3.5 kilowatts of heat removal rate multiplied by R that is 126.83. And this will give the mass flow rate as 0.276 kg per second or 16.56 kg per minute. So mass flow rate is 0.276 kg per second or 16.56 kg per minute.

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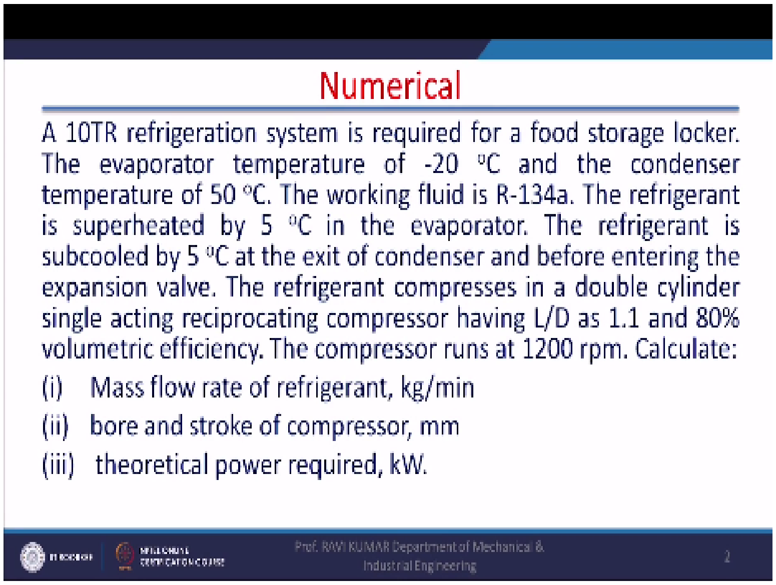

Now we have mass flow rate of refrigerant with us with this mass flow rate of refrigerant we can always find the power consumed inside the compressor and with this mass flow rate we can also find the size of the compressor. Now in order to find the dimensions of the cylinder as we have to find in this numerical bore and stroke of the compressor. So first of all will calculate the swept volume of each compressor that is Л by 4 D^2 square into stroke of the compressor.

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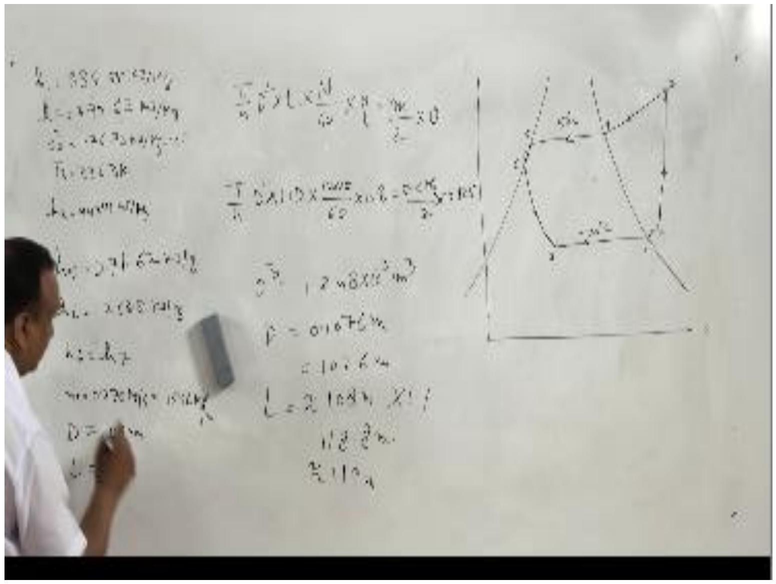

Multiplied by RPM divided by 60 that is revolution per second that is a total volume handed by the compressor it is a double cylinder compressor this is the total volume handed by per compressor per second meter cube per second multiplied by volumetric efficiency will give us. The actual volume of refrigerant vapor handed by the compressor per second and that is going to be equal to zero point there is going to be equal to mass flow rate of refrigerant divided by two because there are two compressors so each compressor is handing half of the refrigerant multiplied by specific volume of vapor.

Now we know the relation between l and l by D is equal to one point one so we can always write PI by 4d square into 1 point 1 D into 1200 divided by 60 volumetric efficiency is 0.8 mass flow rate is point .76 divided by 2 multiplied by 0.125 and this will give us the D cube s 1 point 2 4 8 into10 to power minus 3 P to Q or D s 0.1076 meter or 107 point 6 millimeter or approximately 108 millimeter.

So D is equal to of each compressor is 108 millimeter multiply this D by in to 1*1.1 in point will give us length of the stroke is 118.8 millimeter and that is approximately 1.9 millimeter so length of the stroke is 119 millimeter.

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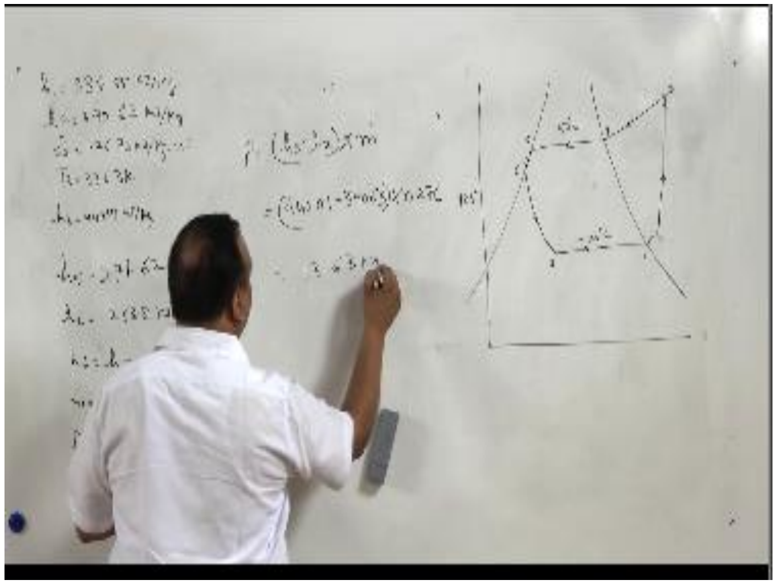

Now the last one is power consumed by the compressor power consumed by the compressor is h3 minus h2 x mass flow rate of refrigerant now h3 is 4 for 0.01minus H 2 H 2 is 390 point 6 3multiplied by mass flow rate that is 0.276 and this will give the power consumed by the compressor S 13.63 kilowatt so power consumed by the compressor is you will get 13.63 kilowatt now we have answers for all parts of this numerical now the same numerical can be you can be solved by using pH diagram we can also show these processes.

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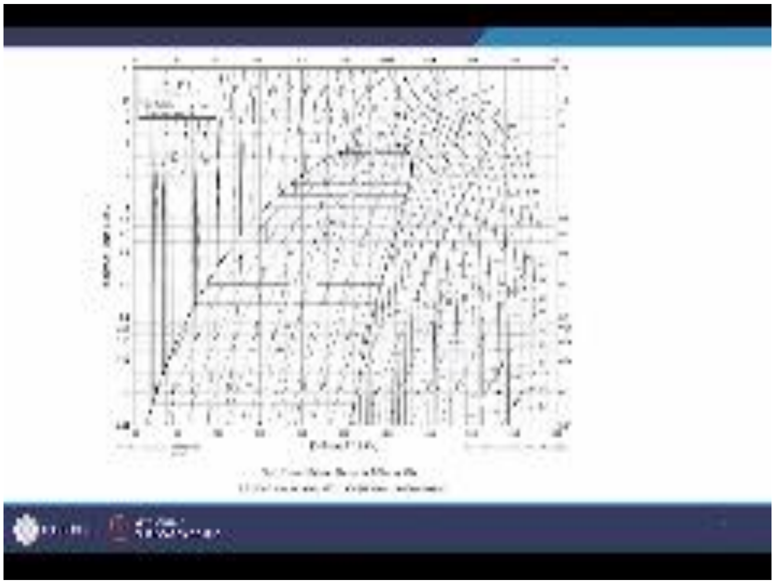

Now in pH diagram now in creation diagram this is 23^{0}C and this is 50^{O}C vapor is super heated by 5^{O}C in evaporator this minus 20^{O}C constant temperature line this is minus constant temperature line so 50^{O}C constant temperature line will lie somewhere here and if you extend this line this is the state to so this is state one and this one is state two now after history to it is getting compressed.

And we attain state three so this 50^{O}C line constant pressure line is extended and a line is drawn along the constant entropy line and we will be getting this point somewhere here that is the state that is state three that is state three now after it's read super heating and state four is at a state 4 is attained and after it straight for further condensation of refrigerant.

In the condenser state five this is state five at state five the temperature is 50^{O}C since sub cooling here sub cooling is taking place so this is a 50constant temperature 50^{O}C lines this is constant temperature 40^{O}C line so 45^{O}C is going to be somewhere here and this point will shift to 6 here is the point 6 now from 6 to 7 expansion takes place in the vertical line cutting horizontal – 20^{O}C line and we will be getting point sorry 0.7 somewhere here this is 0.7 so we have drawn all the points here if we take the values from this chart at different states the values are like this h2 is equal to 390 kilo joules per kg H 3 is equal to 440 kilo joules per kg H2 we can take from here it is 390 H3 is equal to 440 and H6 is equal to 265 kilojoules per kg now here if we take the refrigerating effect refrigerating effect.

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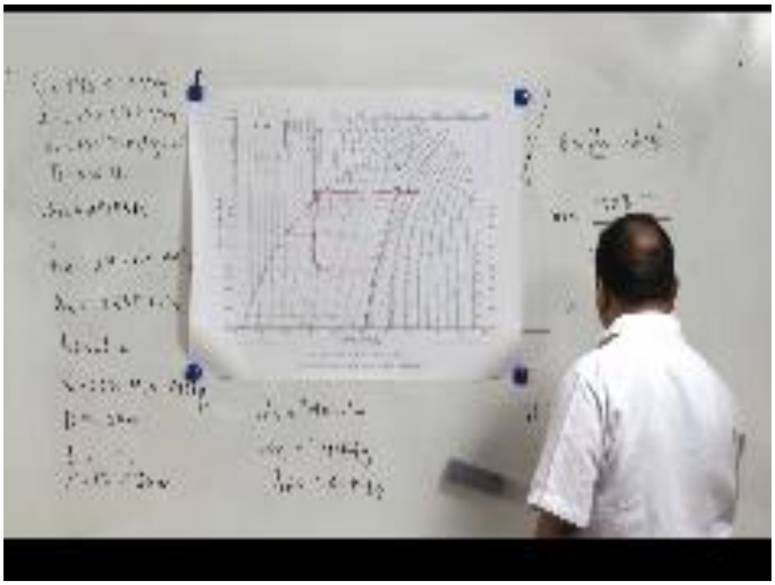

Is H2 minus H7and the terrain is 10 tones of refrigeration so mass flow rate is 10*3.5 divided by H2 minus H7 that is 390 - 265 and that is going to be equal to 0.8 kg per second from the properties chart also we are getting points 276 and this will give us is equal to 16.8 kg per minute work consume by the compressor w is equal to 0.88 H3 minus H2 so H3 minus H2 take directly from here 440 – 390 and this compressor work is coming 14 kilowatt.

So either we solve using this properties table or from ph diagram we are going to get almost the same values. But this ph diagram is very convenient to use you can see when we have taken we had we assaulted through miracle using temperature into be diagram number of iterations were done and number of equations were solved. But here from ph diagram we could directly take the values of enthalpies at different states.

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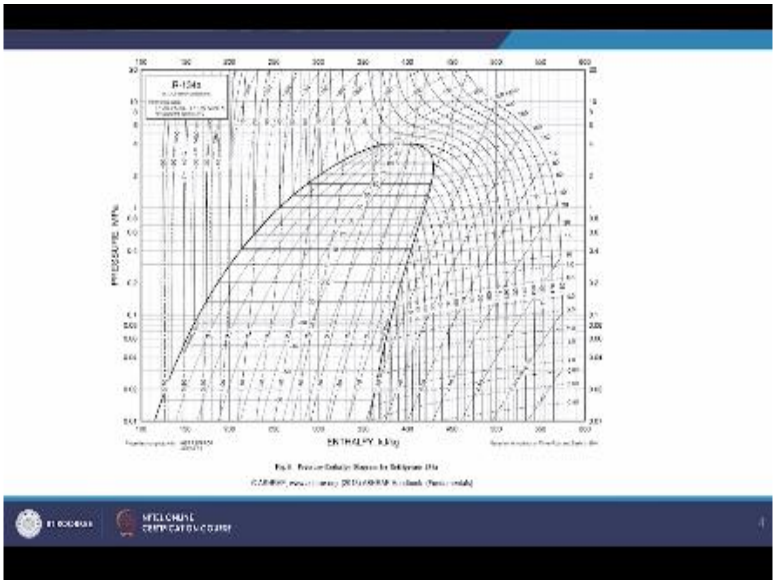

Now after the ph diagram in the area of refrigeration there is there are certain logical queries like, if we open the door if we leave the door of refrigerator open in a room will the room the temperature of the room will go down or not. In this case if in a room is a control volume if we keep a refrigerator and leave that refrigerator room door open.

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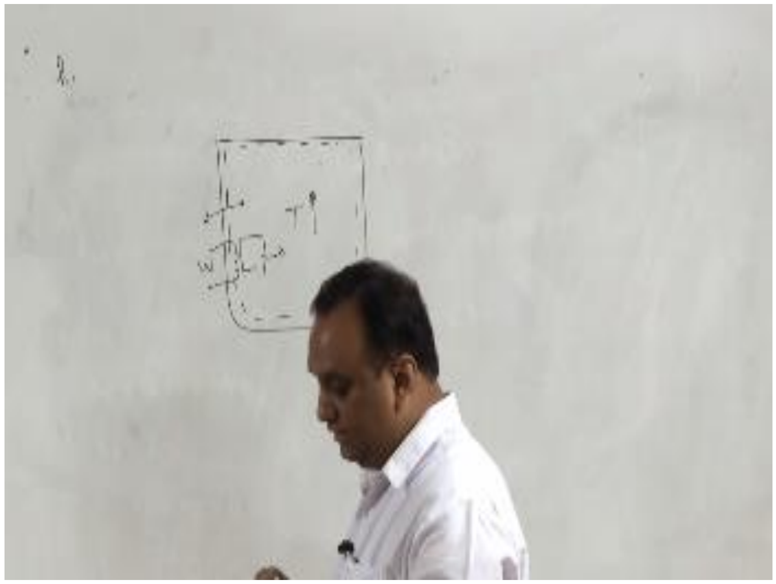

The room will not get cooled because here we consider a room as a system and there is no heat transfer across the boundary of the room right. Whatever energy is coming to the room it is in the form of electrical work and that electrical work the energy will increase the temperature of the room. So in fact if in this room if I keep a refrigerator and leave the door of the refrigerator open the temperature of this room will raise they are certain other interesting queries also in refrigeration.

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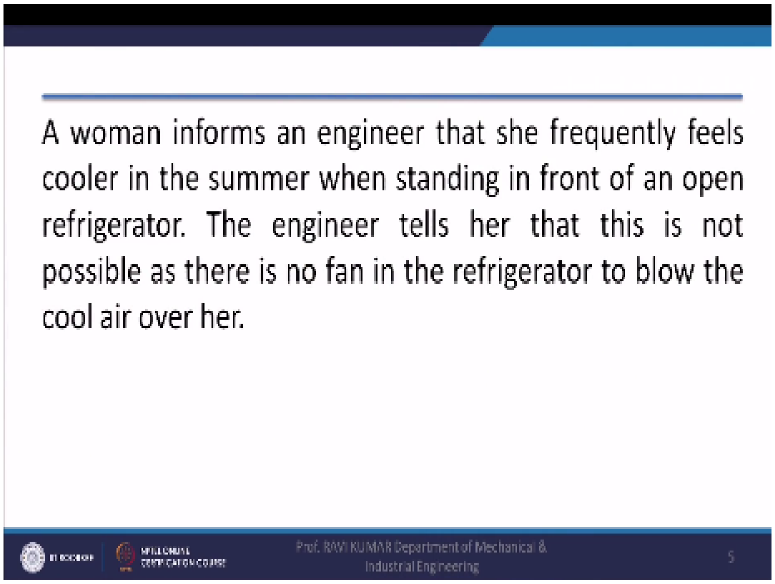

A woman informs an engineer that she frequently feels cooler in summer when in standing in front of an open refrigerator. The engineer tells her that this is not possible as there is no fan in the refrigerator to blow the cold air over her. So when you must have also felt when you open the refrigerator door you feel is to get a feeling of low temperature from the refrigerator side. The reason being when you are standing in front of an open door refrigerator the temperature inside the refrigerator is low so the heat loss from your body in form of conduction and convection heat transfer takes place and that gives you the feeling of coldness in front of a refrigerator.

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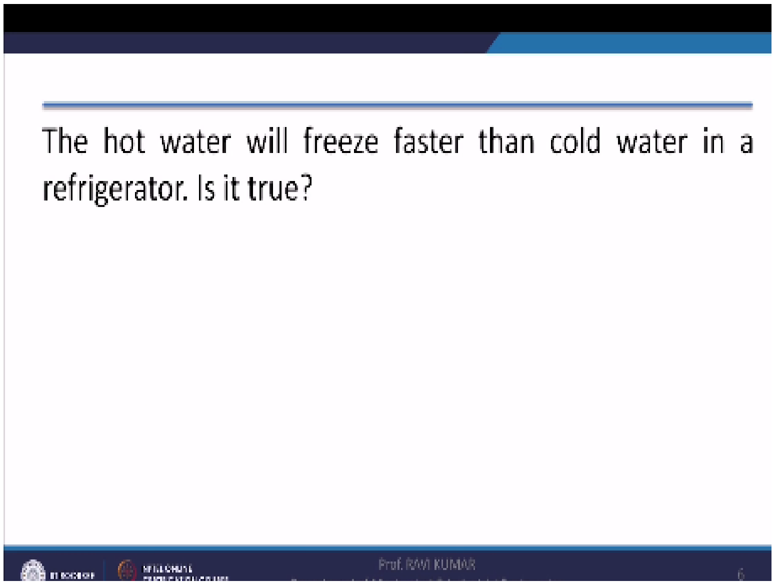

Now in third query which is the hot water will freeze faster than cold water in the refrigerator is it true some people conducted the experiment and what they took they took hot water in a tray and placed in the refrigerator freezer. And noted the time for the ice formation then they took the tap water placed inside the freezer of a refrigerator and noted the ice formation time ice formation time for hot water was less than the ice formation time for cold water so in this case actually this is thermodynamically it is not possible if the temperature is high definitely more time will be taken by the machine to remove the heat.

But what happens when you keep the hot water tray in the freezer this happens in old refrigerator where refreezing the arrangement was not there. So the all the ice which is formed on the evaporator coil gets melted. So the moments you place the hot water plate inside the freezer the all the eyes on the freezer coil gets melted that is why the refrigerating effect is improved and the formation of ice is faster. However in the case when you place the normal water inside the freezer this ice layer on the or the frosting on the evaporator coil remains there.

And that hampers the heat transfer of the cooling rate and we get the feeling that the hot temperature ice is faster than the coldwater wise but this is not thermodynamically or scientifically it is not possible and it happens only in the case when there is a no defrosting arrangement because in the old refrigerator there was no arrangement for defrosting. So in those refrigerators the defrosting arrangement not there this type of elusive effect can be witness. Now I end my lecture here and from the next lecture we will start with the properties of refrigerants.

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Acknowledgement

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