INDIAN INSTITUTE OF TECHNOLOGY ROORKEE

NPTEL
NPTEL ONLINE CERTIFICATION COURSE

Refrigeration and Air-conditioning

Lecture-02
Introduction to Refrigeration

with
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Hello I welcome you all in the course on refrigeration in air conditioning today we shall be covering the introduction to refrigeration what is refrigeration.

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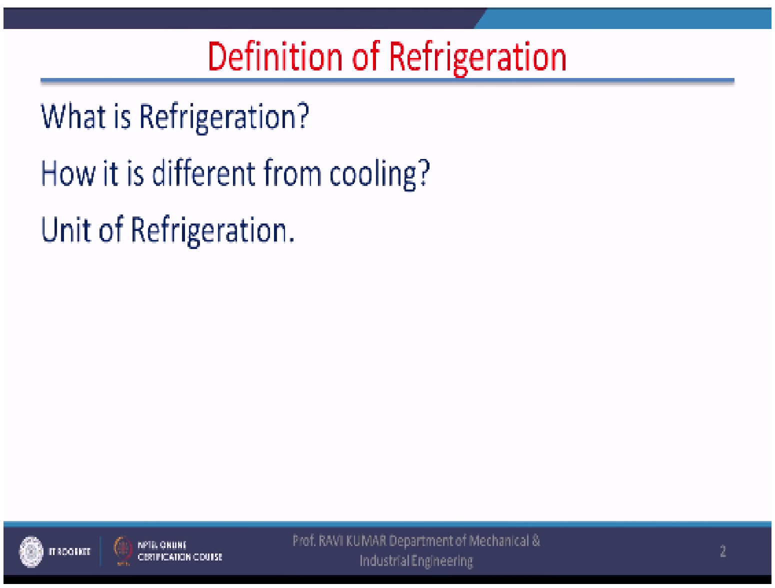

As for the definition of refrigeration it is a process of maintaining temperature of confined space lower than the surroundings so if we are able to be maintain for example if you are able to maintain the temperature of this room less than the surrounding temperature the refrigeration process has been carried out now how it is different from cooling the cooling is a process in which the heat transfer takes place from higher temperature to lower temperature.

I will give you an example suppose you have a coffee mug placed on a dining table temperature of the coffee is 80 degree centigrade surrounding temperature is let us say 30 degree centigrade the coffee the heat transmission will take place from coffee to the surroundings but this process is not refrigeration process will come into the picture when you are maintaining the temperature of the coffee lower than 30 degree centigrade by extracting heat from the coffee and pumping it to the surroundings the unit of refrigeration the refreshen process or refreshen equipments they have a unique unit which is known as terms of refrigeration.

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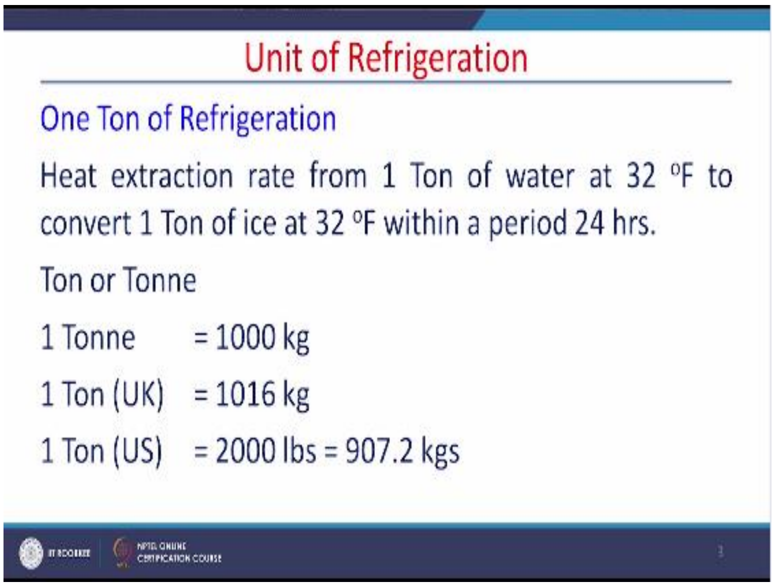

Now regarding the terms of refrigeration there are two type of tons.

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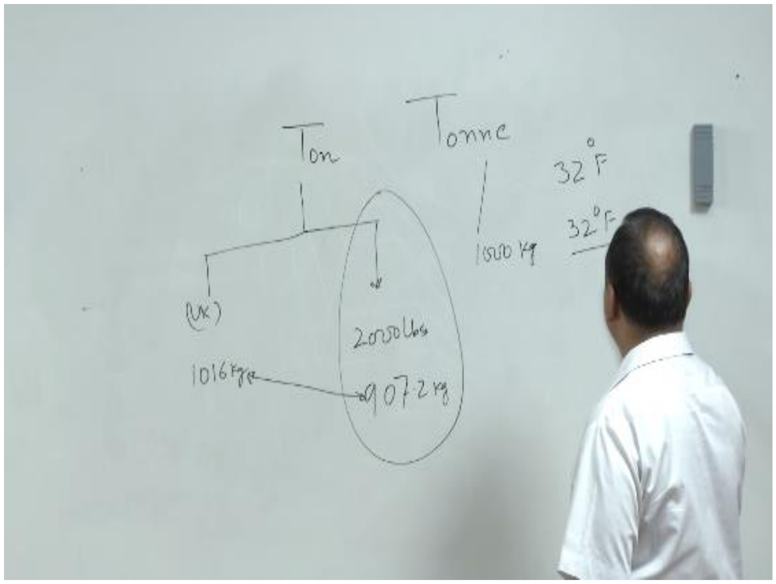

One is Ton and another is Tonne and I have found that strengths are often confused about these two terms tone and tonne this tonne is metric ton and it is 1000kgs now this turn has two values one is Imperial ton or uk ton which is 1016 kgs and this turn is 2,000 pounds and this 2,000 pounds will come around 907.2 kgs so there is a wide difference between Imperial ton or British ton and the US ton now ton of refrigeration which ton is used for defining the refrigeration effect and this ton is used for defining the refrigeration effect.

Now one ton of refrigeration means if we are able to produce one ton of ice within 24 hours from 32 Fahrenheit water available at 32 Fahrenheit degrees Fahrenheit if and this 32 degree Fahrenheit water is converted into 32 degree Fahrenheit ice so one ton of refrigeration addresses the conversion of 2000 pounds.

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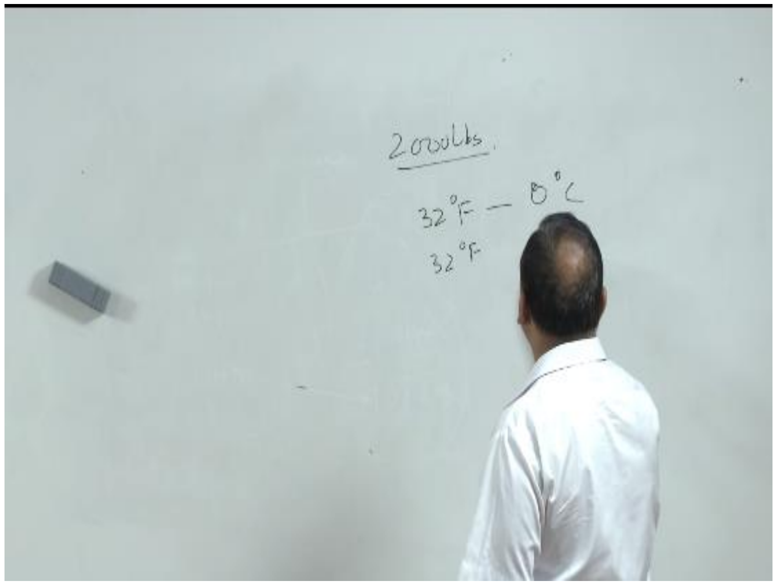

Of water into 2000 pounds of ice within 24 hours the water is available at 32 degree Fahrenheit and the ice is also formed at 32 degree Fahrenheit and this 30 degree Fahrenheit is equivalent to zero degree centigrade in SI unit it is zero degree centigrade.

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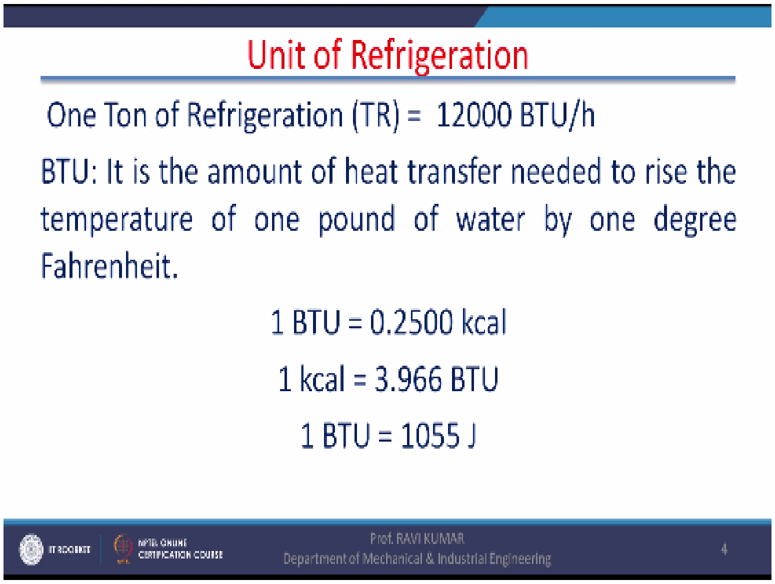

So one ton of refrigeration is equivalent to 12,000 BTU per hour now there is another term which is introduced here is BTU it is British thermal unit it is equivalent to the amount of heat required to increase the temperature of water by one degree Fahrenheit this British thermal unit if we take equivalence of British thermal unit in kilo calorie so 1BTU.

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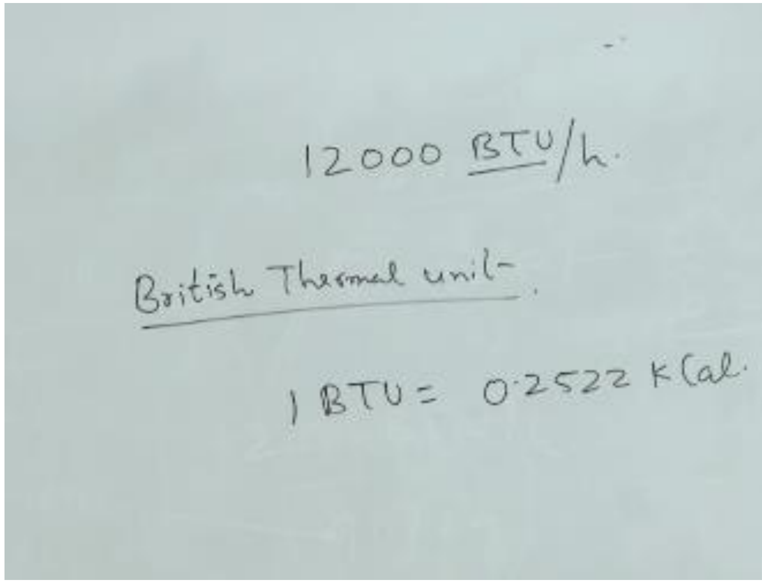

Is equal to 0.25 to 2 kilo calorie and Kia system the heat was expressed in terms of kilocalories and work was expressed in terms of joules and kilojoules.

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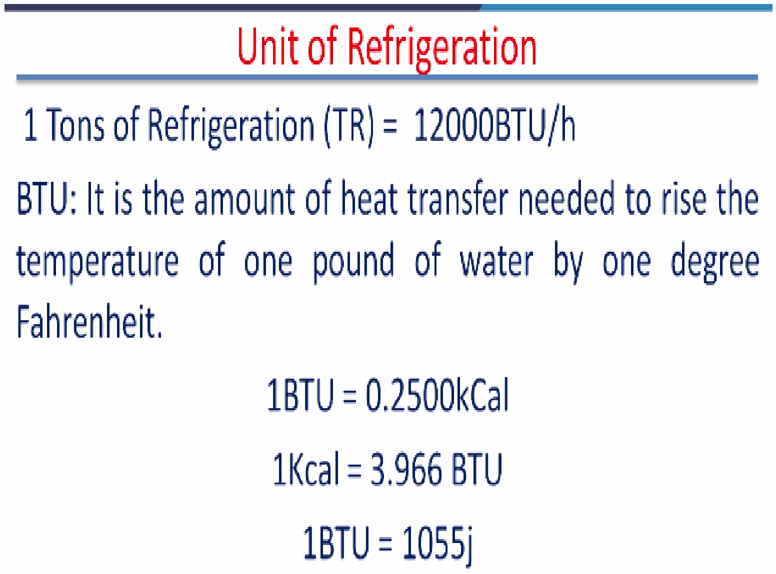

But in SI system nowadays we follow SI system they are expressed in terms of joules.

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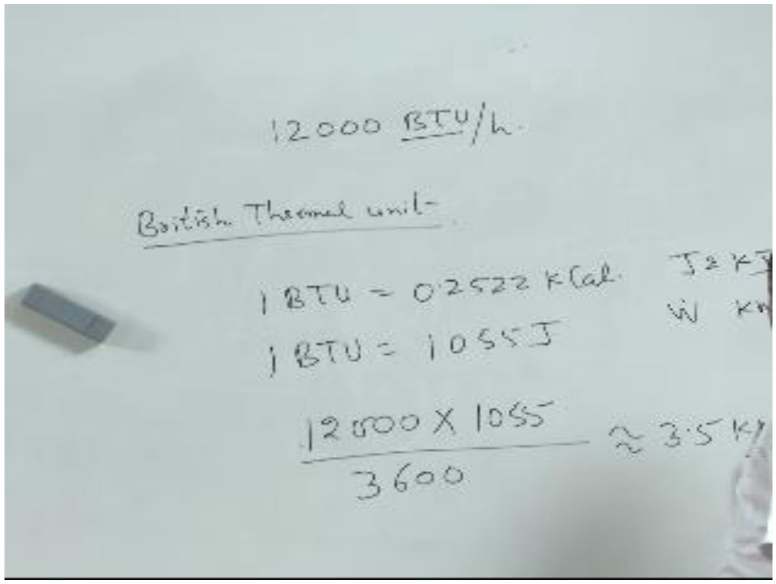

And kilojoules or watts and kilowatts that is heat transfer rate, so 1 BTU 1 BTU in SI system work and heat both are mutually convertible that is why both are expressed in terms of joules or kilojoules or heat transfer rate or work transfer by watts and kilowatts, so one PTY as I said in NGS system it is 0.25 to do kilocalories in SI system one BTU is equivalent to 1055 joules, right. So now if we have 12,000 BTU per hour if we multiply this 12,000 multiplied by 1055 per hour divided by 3600. What you are going to get the approximate value of 3.5kilo watt.

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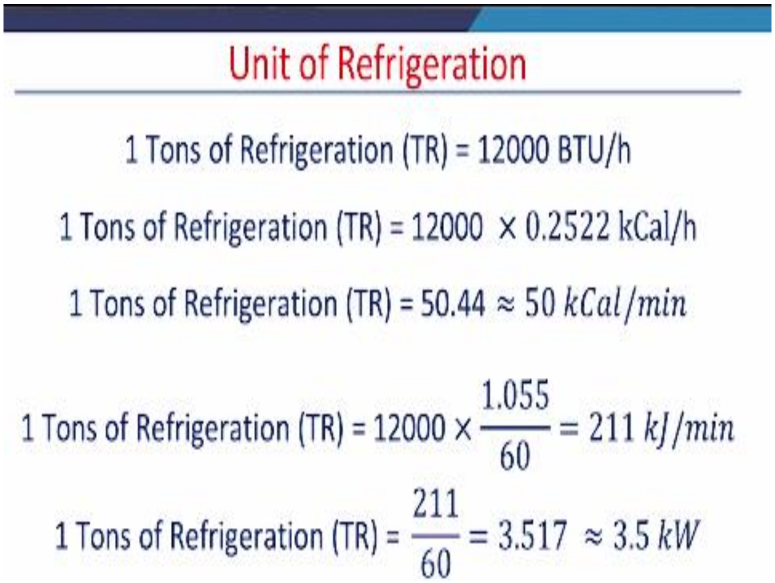

So the heat transfer rate or heat extraction rate of 3.5 kilowatt is equivalent to one ton of cooling, now if you want to have nowadays we do not use MK system but still if you want to have idea about the MKS system in that case one ton of refrigeration.

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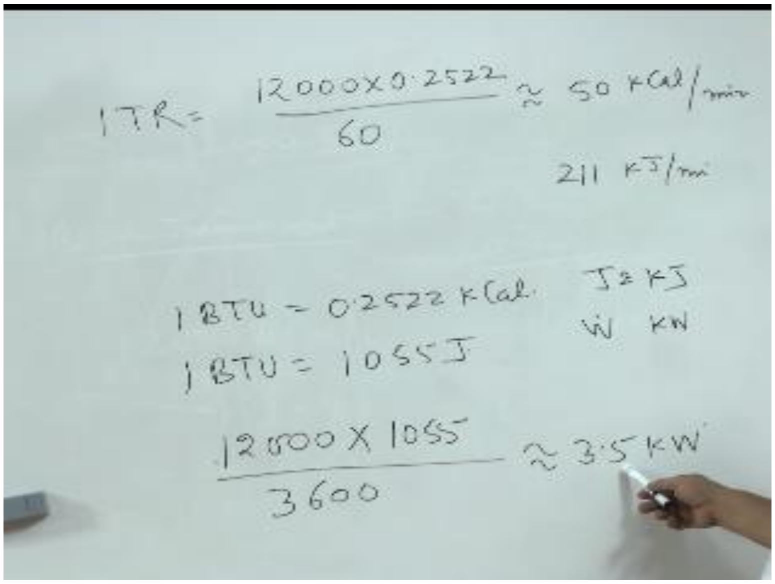

Is going to be equal to 12,000 BTU multiplied by 0.25 to 2 that is kilo calorie per hour that is 60 minutes, so it will become around I will give you approximately 50 kilo calorie per minute so the N it is also expressed in terms of kilo joules per minute also it is exactly 211 kilo joules per minute. So if you want to express per minute the in MKS system it is 50 kilo calories per minute 211 kilo juice per minute.

And nowadays we are accepting this as because if you divide this by 60 you will be getting approximate value of 3.5 kilo watt so nowadays in SI system one ton of cooling is equivalent to 3.5 kilo watt of heat extraction.

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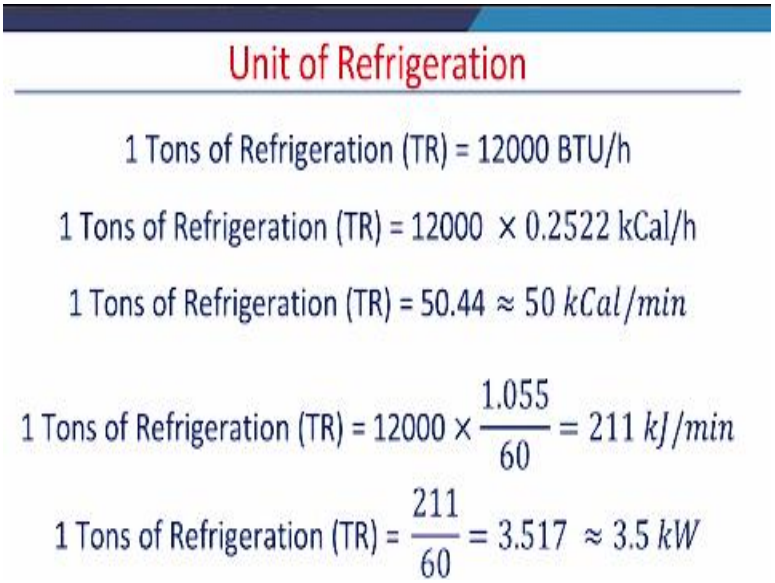

Now we will go to the Carnot cycle for power generation.

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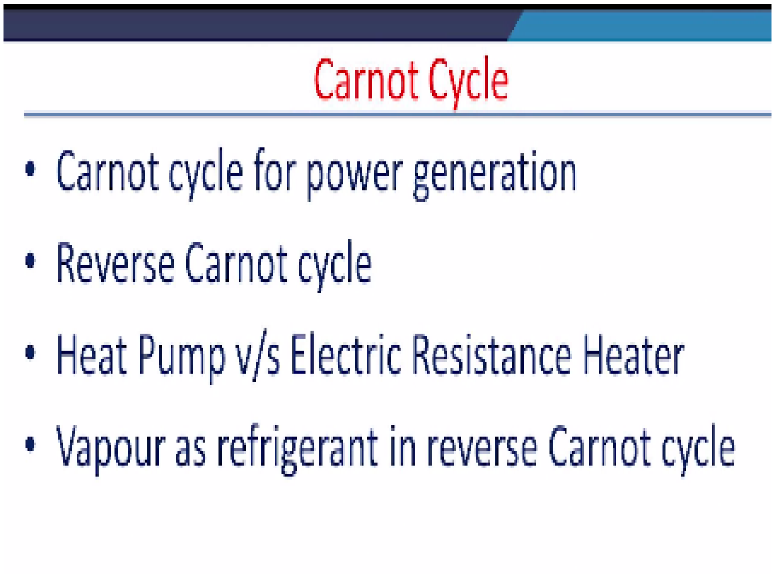

Because power because any cycle whether it is refusing cycle or power generating cycle it is compared with the its performance is always compared with the performance of Carnot cycle, so Carnot cycle for power generation consists of four processes.

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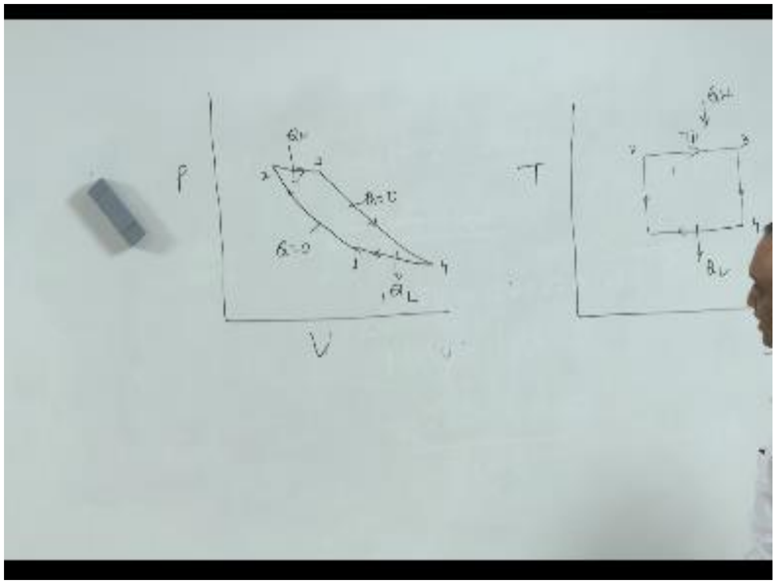

If we expressed in PV diagram there are four processes is starting from adiabatic compression state 1 to state 2, this is adiabatic compression right then isothermal heat additional right isothermal heat addition process 2 to process 3 now process 3 to process 4 again adiabatic and sorry isentropic expansion and then process 4 to process 1 constant temperature heat rejection so in the process 2 to 3 the heat added is added and process 4 to 1 heat is rejected in these two processes because they are isotropic process reversible adiabatic processes Q is 0 heat transfer is 0.

Now if we transform this Carnot cycle on temperature entropy diagram this TS diagram now process one to two is constant entropy or reversible adiabatic process this is process 1 to 2 now process 2 to 3 is constant temperature process this is TH now process 3 to 4 is again expansion process where we get the work output and process 4 to 1 is again heat rejection process so here heat is added QH and heat and heat is reacted QL.

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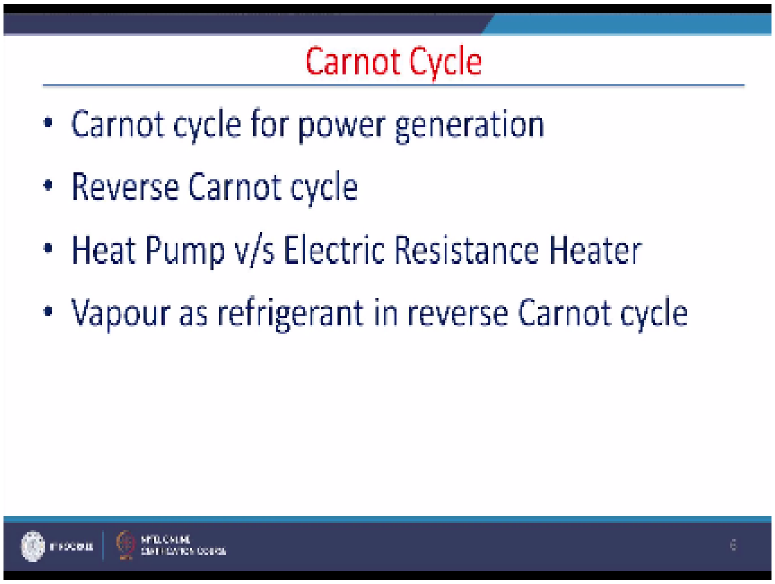

Now this is a imaginary cycle for power generation and according to the second law of thermodynamics no power generating cycle can have efficiency more than Carnot cycles and that is for this reason this cycle becomes important for the comparison of different cycles for power generation but how it is relevant in refrigeration right in refrigeration process if you reverse this cycle.

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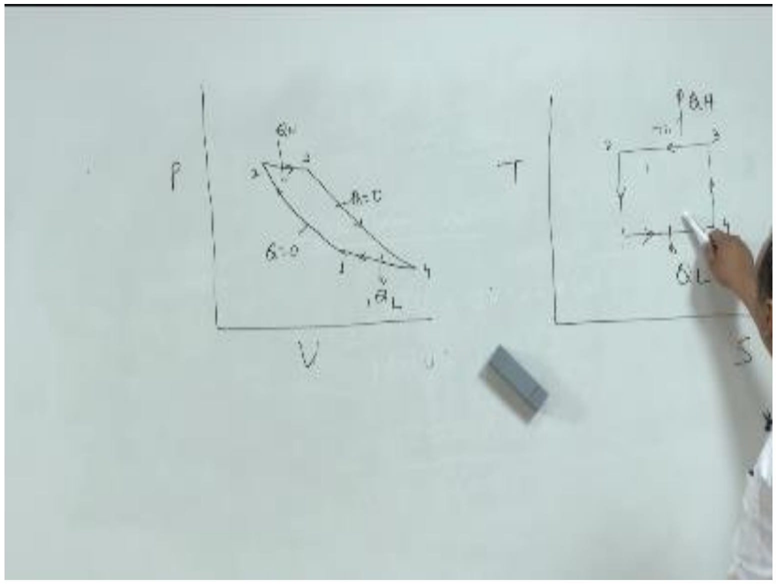

If you reverse this cycle in that case at lower temperature heat will be added instead of removal of heat the heat will be added to the cycle the direction will change cross process 1to 4 4 to 3 again the direction will change instead of expansion in reverse cycle the compression of fluid will take place and from 3 to 2 again instead of heating the cooling of fluid will take place and instead of heat peak added heat will get rejected and from 2 to 1 the expansion of the fluid will take place so we have another cycle which is a reverse Carnot cycle and in this cycle the net effect is transfer of heat from lower temperature to higher temperature.

And this cycle can produce the refrigerating effect right there are certain drawbacks of Carnot second in Carnot engine also there are certain drawbacks right we will not discuss all those robux here because we are not here using a Carnot engine we are using reverse Carnot cycle and this reverse Carnot cycle is often referred as a standard cycle for comparing the performance of different refrigeration cycles now in this cycle the heat is taken at the lower temperature and it is rejected at the higher temperature now performance of this cycle normally in engines the performance is expressed by a thermal efficiency.

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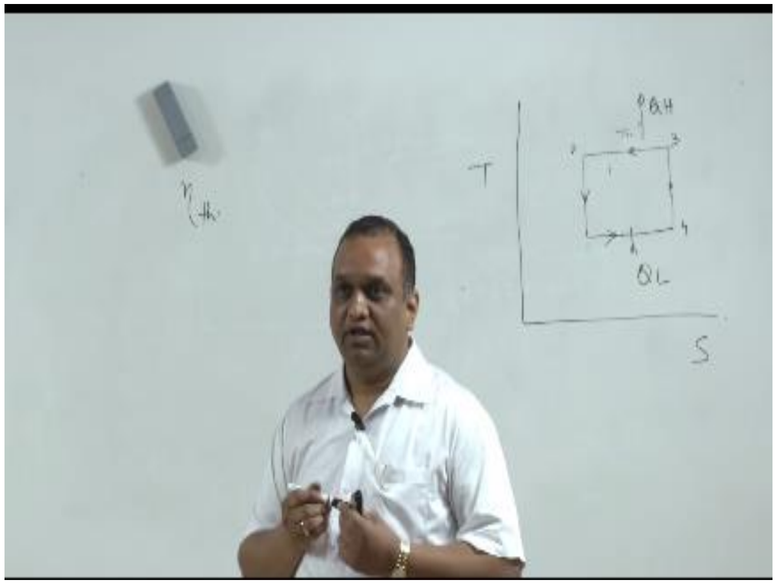

The efficiency of any instrument or any equipment is very important whether it is a refreshing cycle refrigerator or a compressor or an engine. So as an engineer we should have fairly good idea about the efficiencies of the system for example, if I say I have a compressor which has efficiency of 70% is it acceptable or not. The compressor is reciprocating compressor another case I have an engine which has efficiency of 40% is it acceptable or not.

Remember in engines we are converting heat into the useful work when we are converting heat into the useful work in that course we are able to convert 35% of heat into the useful work that is good efficiency normally in a normal engine one-third of energy is converted into the useful work one-third of energy goes with the exhaust and one-third of energy goes with the cooling water which is circulated in the jacket water jacket around the covering the cylinder.

So for compressors, let us take example of compressor if it is a reciprocating compressor if I have 70 efficiency is 65% or 70% this efficiency is a poor efficiency, because in a compressor we are converting there is a work to work interaction right, in work to work interaction we are losing 30% or 35% so the efficiency is low and that too in responding compressor in if we take the axial flow compressor or the centrifugal compressor the efficiencies are high even axial compression or compressor the efficiency can go up to 90%.

But the 90% efficiency for a transformer is a poor efficiency, because in transformer again we are converting electrical one form of electrical energy to another form of electrical energy and in that course if we are losing 10% that is also I mean this is poor performance, transformers have 99% of efficiencies it can be up to 90 it is more than 99% of efficiency. So efficiencies are important so I say as in practicing engineer we should have fairly good ideas about the efficiencies of the system. Now here in Carnot cycle now the efficiency of a cooling system or refrigeration system is expressed by coefficient of performance.

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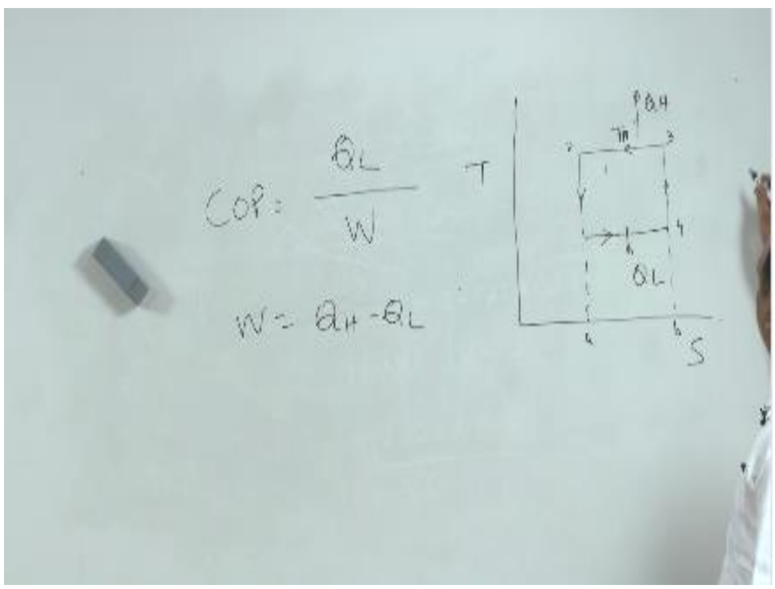

Now coefficient of performance is here it will be the cooling effect Q_L divided by the work spent for this cooling effect, now as you know in a Carnot cycle in a Carnot cycle the work is equal to, sorry the work is equal to Q_H-Q_L we can draw from the principles of the first law of thermodynamics cyclic integral of work is equal to cyclic integral of heat transfer. Now let us try to found the value of Q_H in Q_L if we are able to find the value of Q_H and Q_L we can find the COP of the system.

Now in order to find heat transfer at higher temperature let us take the rectangle A23B now this rectangle A23B if we take area of this rectangle it will be.

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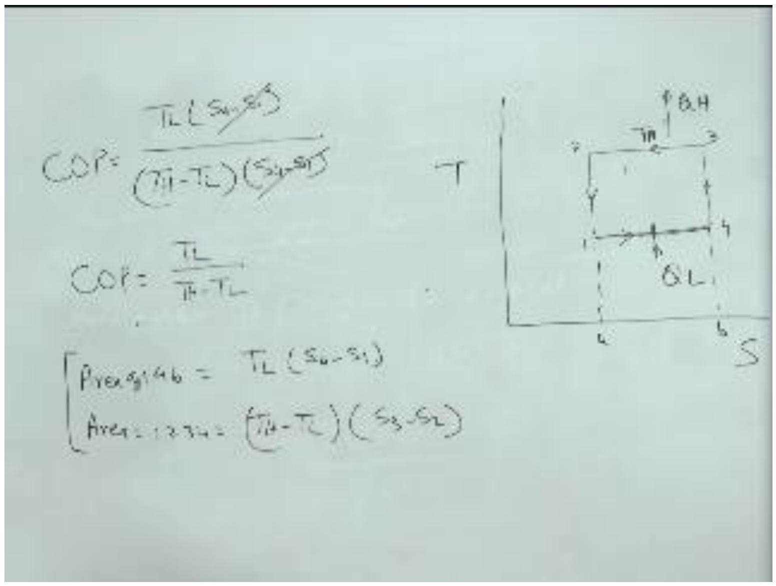

Area A23B=T_H (S_3-S_2) S_3 is entropy at this place the area of a this is a_1 / 4 B will be the heat transfer from surroundings to the fluid so this area is TL S $_4$ - s_1 a network that in this process will be given by the area of this rectangle. So the area of rectangle 1 2 3 4 = P_H - T_L x s_3 -s_2, now if you look at these two equations in order to find CoP of the cycle it is heat transfer that is QL and QL is T_l s_4 - s_1 divided by area of this rectangle which will give you which will give us the work spent in for this heat transfer and that is TH - TL s $_3$- s $_2$ because s $_3$ = s $_4$and s $_2$ = s $_1$ so we can always write s_4 - s_1 so these two will be cancelled out and we can comfortably write Co P of a Carnot cycle is PL /th-tn it is simple.

So if a corner let us say if a refrigeration cycle is a Carnot cycle working between two temperatures if you know the higher temperature and lower temperature we can find the co P of the system, now there is another device which is known as heat pump.

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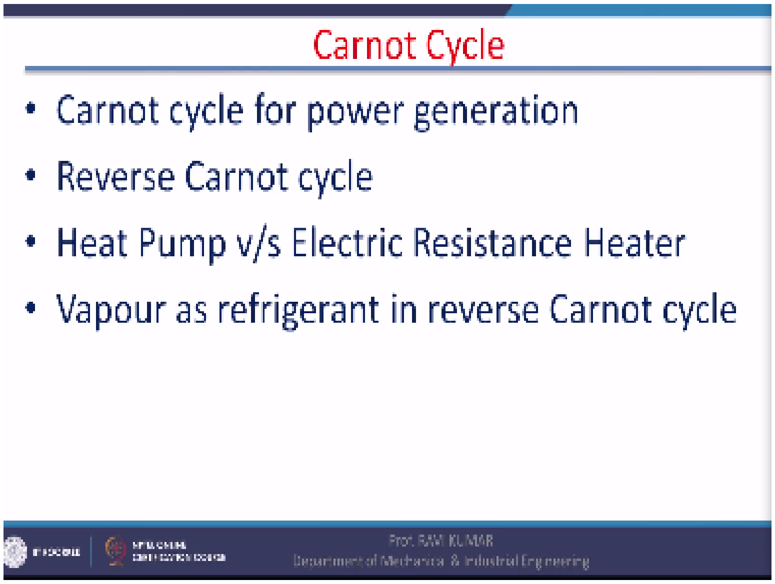

Water pump is used for pumping the water heat pump is used for pumping the heat, we are confining ourselves here our concern area of heat transfer here.

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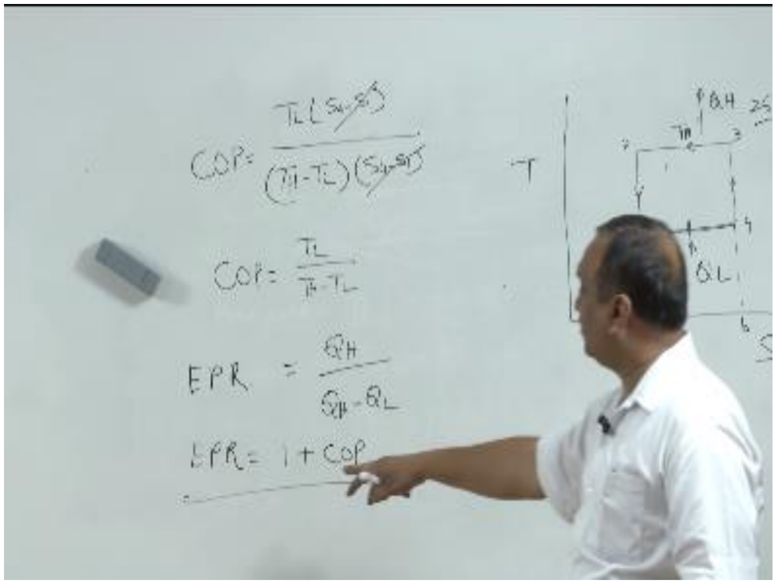

Suppose I want to heat this room I will give you an example of heat pump suppose I want to heat this room during winters outside temperature is 10^0 centigrade I want to maintain temperature here 25^0 centigrade I can use a heat pump which will work here in this case reverse Carnot cycle it will take heat from the surroundings at lower temperature at 10^0 centigrade and pump heat to the room which is at 25^0 centigrade.

So our heat transfer of concerns become this right in that case the efficiency of the heat pump can be expressed as QH / QH – QL, so this is known as energy performance ratio of heat pump now if you compare these two that energy performance ratio turns out to be 1 + co P suppose for an air conditioner reparations I Gail the CoP is 3 energy performance ratio if you use it that cycle as a heat pump the energy performance ratio will become 4. Now instead of using a room heater suppose we want to heat a high-rise building, with thousand kilowatt heater electrical heater the energy consumed by the heater is 1000 KW, instead of using a thousand kilowatt heater if you if you use a reverse Carnot.

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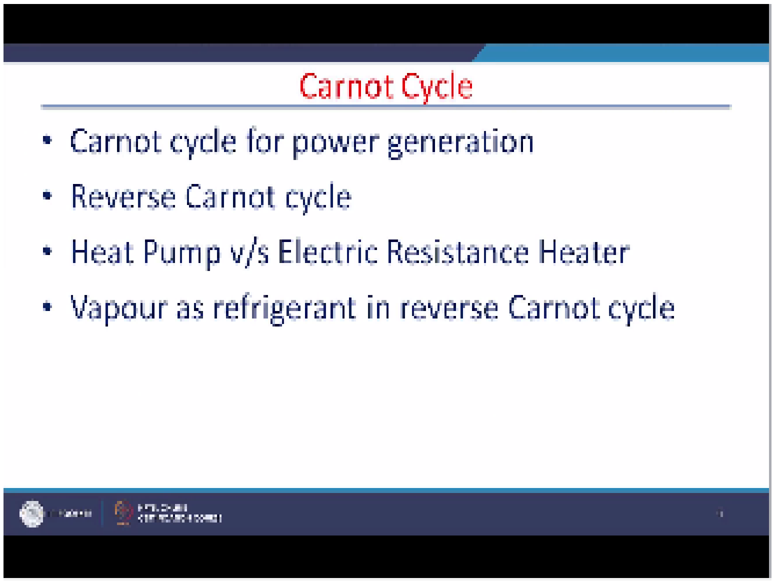

Cycle for the heat transfer of thousand kilowatts, so let's go back to the thermal cycle again.

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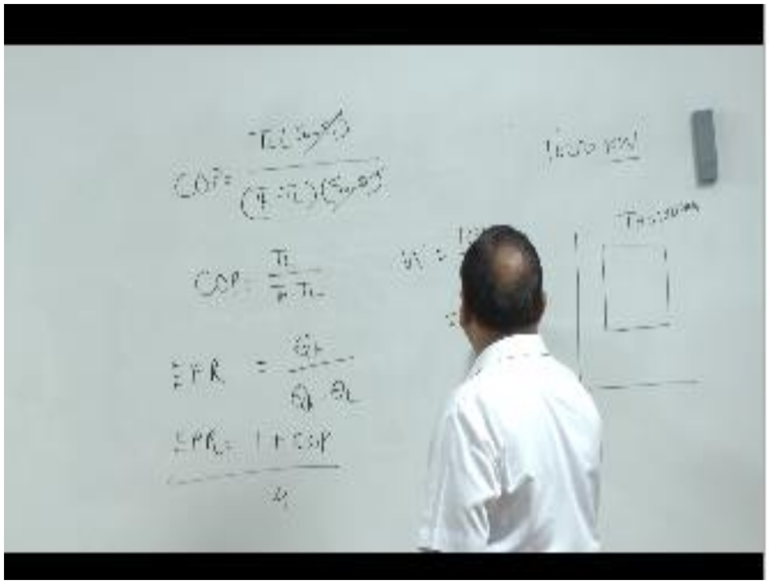

So this T_H is 1000 KW right, and EPR energy performance ratio is for the second let us say it is four, because COP of refusing cycle is normally three so energy performance the ratio of heat from let us take four, so the total energy required that is work it will be 1000kw / 4 = 250 KW. So we will be basically in this case, we will be saving 75percent of the energy, so it is always advisable to use heat pump in place of electrical resistance heating of the room, now in Carnot cycle there are some inherent problems, for practical application. But with certain modifications this cycle can be used for, practical purpose for example in reverse Carnot cycle it is said if you use gas, then there are certain problems because.

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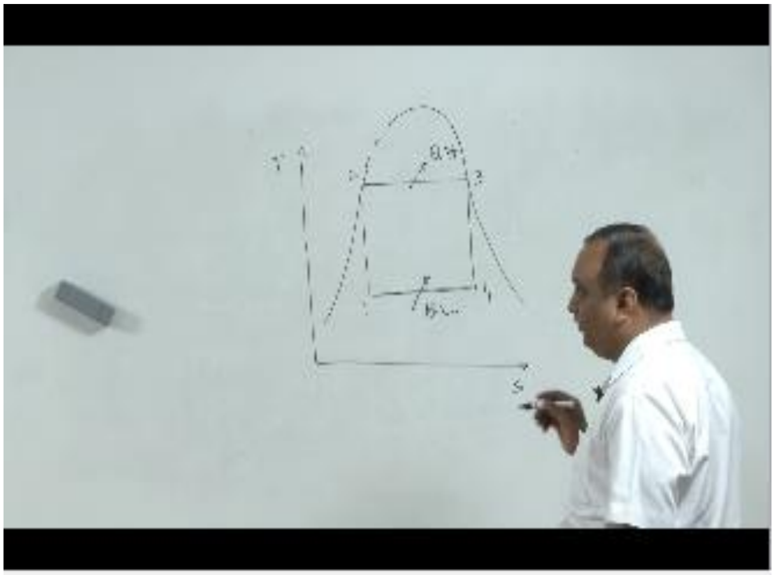

Constant temperature heat addition and heat rejection, Q_H and Q_L, so constant temperature heat addition and heat rejection is a problem because, process has to be very slow, in order to avoid this if instead of using a gas if you use vapour, and we operate in the zone where phase change of vapour takes place right this, Because during as we know during boiling and condensation process the temperature remains same.

So heat rejection if heat rejection takes place during condensation of the vapour, and this heat transfer rate to the fluid takes place for the boiling of the vapour, during the boiling of the vapour, we come close to the practicality of the cycle, so instead of gas if we use vapour in place of gases in the cycle it becomes easier for additional rejection of heat in the cycle, So reverse Carnot cycle is an imaginary cycle, which can produce the refrigerating effect, now method of refrigeration.

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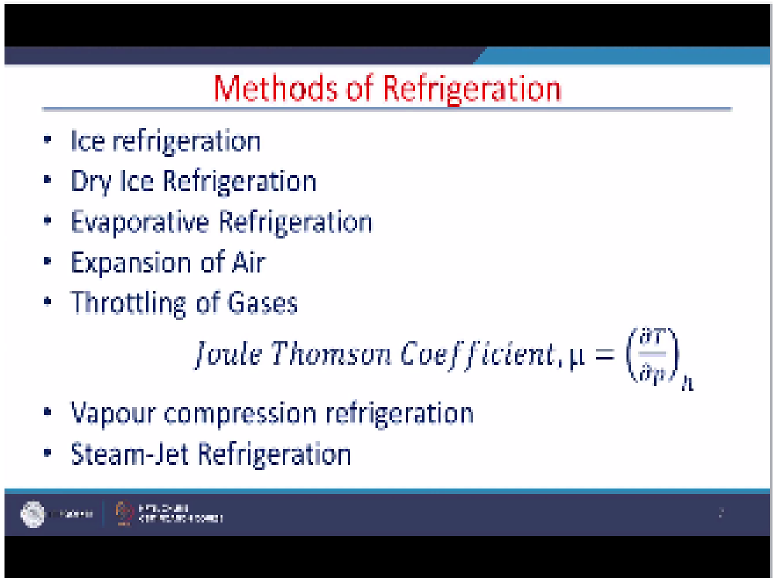

Now different there are different methods of refrigeration first of all ice sterilization in old days there used to be cabinets, in cabinets ice was put and foodstuff was foot and other drawers of the cabinet, and by natural solution of air the temperature was maintained in the cabinet, so this type of refrigeration method is known as ice station method.

Dry ice definition that is very popular is nothing but solid carbon dioxide, so when this ice takes heat from the surrounding the solid is sublimated into the carbon dioxide, so this type of refrigeration is very helpful in transportation of foodstuffs, because if we keep dry ice in the wagon if we keep water ice in the wagon after melting the it will the water will spread on the floor. But in this case the carbon dioxide, will free form and it will be vented to the surroundings.

The third one is evaporative refrigeration evaporative refrigeration methods are, widely used in India the cooling of water in the earthen pots is a very good example of evaporative cooling. Now expansion of air suppose, we take air at 300 Kelvin that is 27 degree centigrade and pressure is 1 bar, pressurize into 3 bar, using the relation t2/t1 = p2/p1 raised to power, γ-1 over γ for air, it is if it is a isotropically compressed to 3 bar the temperature will become 410.75 Kelvin right?

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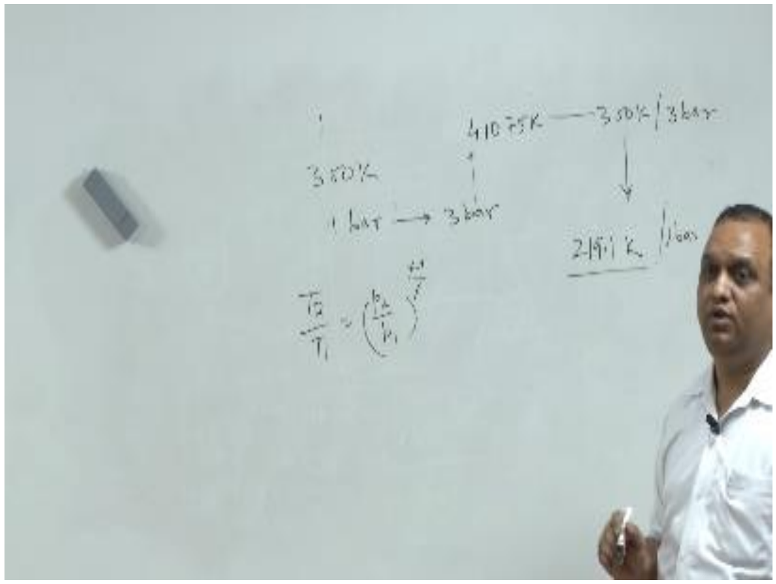

Now if we cool again this air to 300 Kelvin at 3bar pressure and expand it to 1 bar the temperature will be reduced to 219 point1 Kelvin 291 point 1 Kelvin is very low temperature. So this is how we can get low temperature by expansion of air, by throttling of gases, now for throttling of the gases there is a Joule Thomson coefficient for, if we have a characteristic curve between temperature and pressure and there is a constant enthalpy lines.

So was there is a constant enthalpy line and if we increase enthalpy the characteristic curve become like this, if you further increase enthalpy the characteristic curve become like this, so characteristic curve is attaining a peak right, and H1 and it is less than H2 and it is less than H3. Now Joule Thomson coefficient, if you look Joule Thomson coefficient this is point, if we are expanding the gases, if we are throttling the ideal gas there is no change in temperature. Throttling of ideal gas will not lead any change in temperature.

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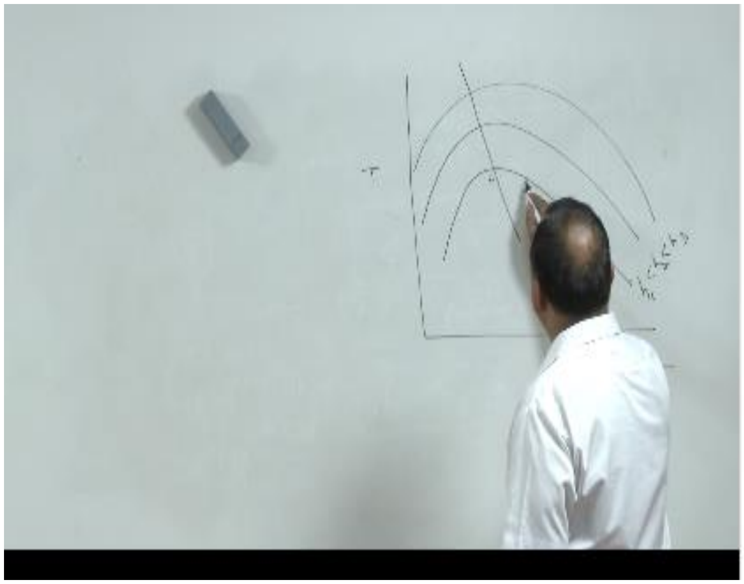

But if it is a real gas then if we are throttling from B to A because in throttling the pressure will reduce. If you are throttling from B to a temperature will rise but if you are operating in this reason. When we are throttling from A to C, A to C the temperature is the temperature will fall, so by using the throttling of real gases we can get the cooling effect. Now remaining to vapor compression refrigeration in steam refrigeration there are there are two methods of producing refrigeration effect, we will be discussing these two methods in details in subsequent lectures thank you.

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