Refrigeration and Air Conditioning
Prof. M. Ramgopal
Department of Mechanical Engineering
Indian Institute of Technology, Kharagpur
Lecture No. # 08
Methods of Producing Low Temperatures

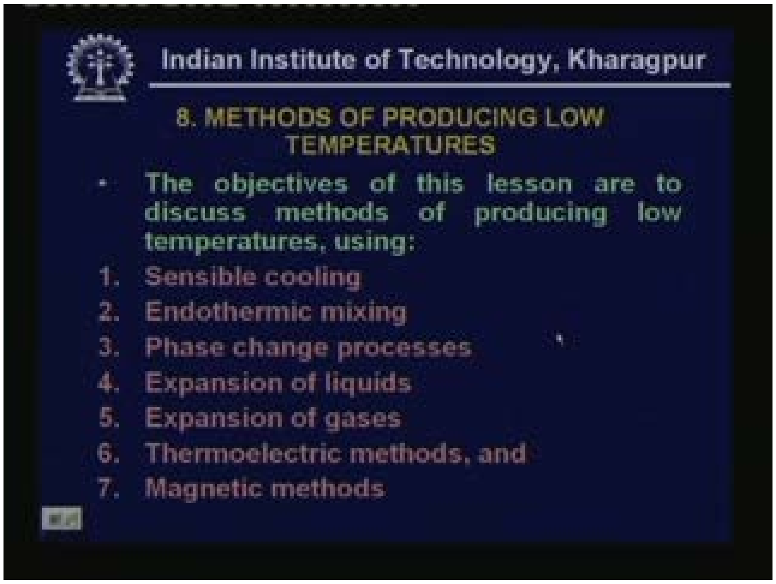
(Refer Slide Time: 00:00:40 min)

Lecture No. # 08

Methods of Producing Low Temperatures

Welcome back, in this lecture I shall discuss various methods of producing low temperatures. A specific objective of this particular lesson is to discuss methods of producing low temperatures.

(Refer Slide Time: 00:00:59 min)



Indian Institute of Technology, Kharagpur

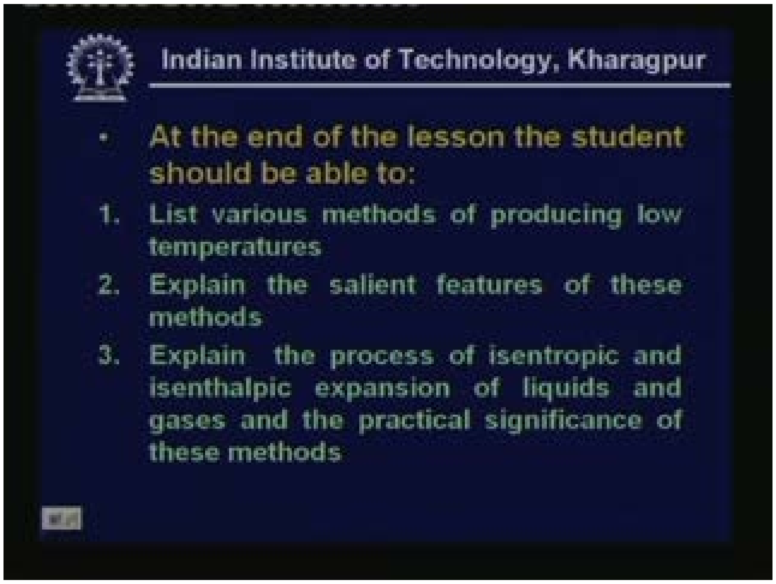
8. METHODS OF PRODUCING LOW TEMPERATURES

- The objectives of this lesson are to discuss methods of producing low temperatures, using:

1. Sensible cooling
2. Endothermic mixing
3. Phase change processes
4. Expansion of liquids
5. Expansion of gases
6. Thermoelectric methods, and
7. Magnetic methods

Using first sensible cooling, using endothermic mixing, using phase change processes, using expansion of liquids, expansion of gases, thermoelectric methods and finally magnetic methods.

(Refer Slide Time: 00:01:17 min)



Indian Institute of Technology, Kharagpur

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

1. List various methods of producing low temperatures
2. Explain the salient features of these methods
3. Explain the process of isentropic and isenthalpic expansion of liquids and gases and the practical significance of these methods

At the end of the lecture you should be able to list various methods of producing low temperatures, explain the salient features of these methods and explain the process of isentropic and isenthalpic expansion of liquids and gases and the practical significance of these methods.

(Refer Slide Time: 00:01:36 min)

Indian Institute of Technology, Kharagpur

Introduction

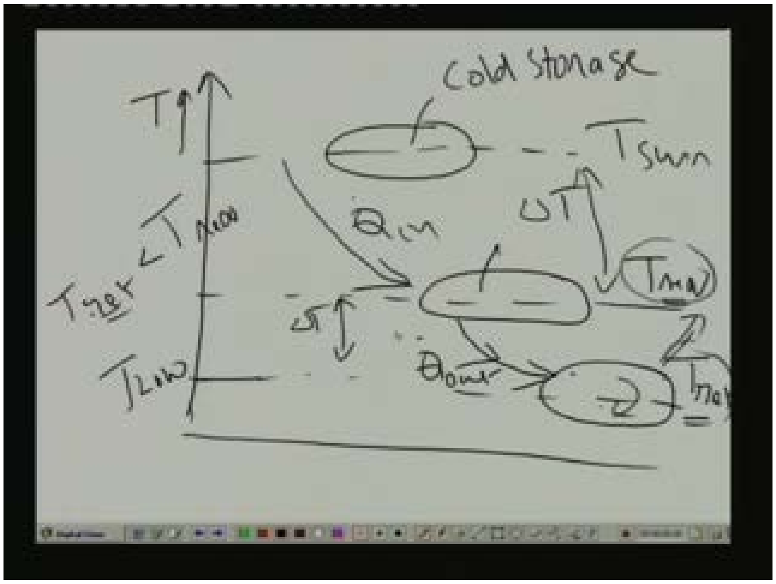
- Refrigeration is defined as "the process of cooling of bodies or fluids to temperatures lower than those available in the surroundings at a particular time and place".
- To achieve refrigeration it is essential to produce temperatures low enough for heat transfer to take place from the system being refrigerated to the system producing refrigeration

Let me give a brief introduction. First of all let us look at the definition of the refrigeration. If you remember refrigeration is defined as the process of cooling of bodies or fluids to temperatures lower than those available in the surroundings at a particular time and space. Okay.

That means the temperature of the system which is being refrigerated should be lower than the surrounding temperature that is the major point to be noted here. Okay. And to achieve refrigeration it is essential to produce temperatures low enough for heat transfer to take place from the system being refrigerated to the system producing refrigeration.

So let me explain this.

(Refer Slide Time: 00:02:24 min)



Okay let us, let me draw the temperature axis here let us say, this is your temperature axis let this be the surrounding temperature T surroundings let us say that we have a cold storage okay. This is a cold storage which is initially at the surrounding temperatures. Now we would like to reduce the temperature of this cold storage to a required level. Let us say that this is our required temperature. So the cold storage temperature has to be brought down from the surrounding temperature to this temperature okay. Temperature is increasing in this direction how this can be done in order to do this what is required is there should be heat transfer from the cold storage so that its temperature can reduce okay.

So as you kNow very well for heat transfer to take place we must have another system which is in thermal contact with this cold storage and whose temperature is lower than the required final required cold storage temperatures okay. That means let us say that we have a refrigeration system okay whose temperature T ref is less than the final cold storage temperature T required okay so this is a let us say that a cyclic device. If I bring this cyclic device in thermal contact with this cold storage then there will be heat transfer from the cold storage to this refrigeration system as a result the temperature of the cold storage drops. And if the system is designed properly the cold storage may finally settled settle at the required temperature okay. So this is our final required cold storage temperature okay. Now it is not enough that that you just reduce the temperature of the cold storage to a required level. You also have to provide refrigeration continuously okay.

That means refrigeration system is required first to reduce the temperature of a cold storage from that of the surrounding to that of the required temperature and you also have to maintain the cold storage at that particular temperature okay. What do you mean by maintaining we know very well that we do not have any perfect insulation in nature okay at the movement you bring this cold storage temperature lower than the surroundings there will be heat transfer from the surrounding to the cold storage okay. Some heat transfer continuously takes place from the surrounding to the cold storage if you do not do anything then the cold storage temperature starts increasing okay.

So if you want to maintain the cold storage at this required temperature you must take out heat from the cold storage at the rate at which it is entering or at the rate at which it is being generated inside the cold storage. That means there must be heat continuous heat transfer from the cold storage to the refrigeration system okay so this is Q out okay. That means heat transfer takes place from the surrounding to the cold storage because of this delta T and this has to be taken care by extracting heat from the cold storage using the refrigeration system again there should be some delta T temperature difference is required. So that this heat transfer can take place okay. So finally the heat is coming to the refrigeration system and if it is a cyclic device whatever heat is coming to the refrigeration system must be thrown somewhere else okay.

We will see that how it will be finally rejected okay. But what is important here is that we must be able to produce low temperatures using a refrigeration system that means this temperature okay. The low temperature or refrigeration temperature such that there a cold storage can be maintained at the required temperature okay. So this is an example of a cold storage but any refrigerated space for example in air conditioner conditioned space or a domestic refrigerator or anything okay.

What it involves is to produce low temperatures. So that heat transfer can take place from the space that is being refrigerated to the system which is doing the refrigeration okay. And the in the inside the refrigeration system we must be able to achieve low temperatures okay. So the topic of this today’s lesson is how we can achieve this low temperatures okay.

(Refer Slide Time: 00:06:32 min)

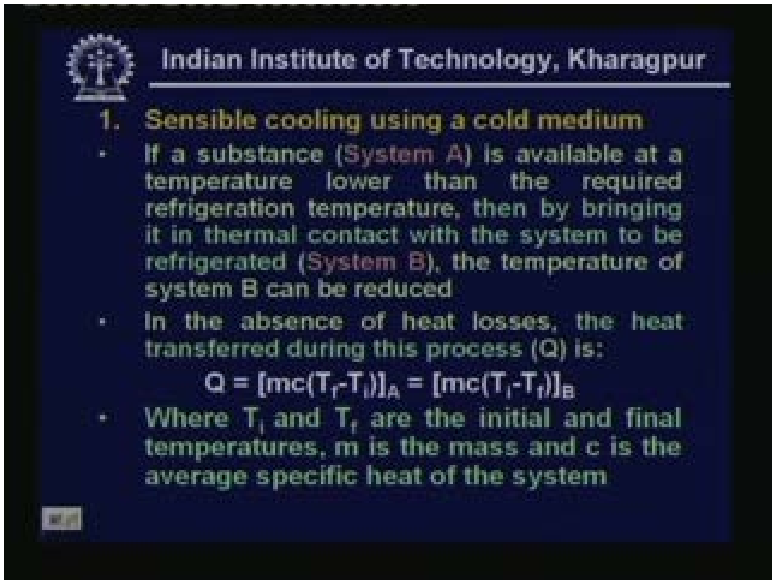
Indian Institute of Technology, Kharagpur

Various methods of producing low temperatures are:

1. Sensible cooling using a cold medium
2. Endothermic mixing of substances
3. Phase change processes
4. Expansion of liquids
5. Expansion of gases
6. Thermoelectric method
7. Magnetic method

So let us look at some of the methods of achieving low temperatures the various methods of producing low temperatures are sensible cooling using a cold medium endothermic mixing of substances phase change processes expansion of liquids expansion of gases thermoelectric method and magnetic method. First let us look at the sensible cooling method.

(Refer Slide Time: 00:06:56 min)



Indian Institute of Technology, Kharagpur

1. Sensible cooling using a cold medium
- If a substance (System A) is available at a temperature lower than the required refrigeration temperature, then by bringing it in thermal contact with the system to be refrigerated (System B), the temperature of system B can be reduced
- In the absence of heat losses, the heat transferred during this process (Q) is:

$$Q = [mc(T_f - T_i)]_A = [mc(T_i - T_f)]_B$$

- Where T_i and T_f are the initial and final temperatures, m is the mass and c is the average specific heat of the system

So producing low temperatures using sensible cooling using cold medium if a substance let us say system A is available at a temperature lower than the required refrigeration temperature then by bringing it in thermal contact with the system to be refrigerated that means system B the temperature of the system B can be reduced okay. Let me let me give an example again let us say that we have a building okay we would like to reduce the temperature of the building and at our disposal let us say that we have a large body of cold water okay. Whose temperature is much lower than the surroundings and I want to cool the building which is initially at the surrounding temperature.

So when I bring the building in thermal contact with this cold water whose temperature is lower than the surroundings heat transfer takes place from the building to the cold water and in this process the temperature of the building reduces below that of the surroundings. That means I am able to produce refrigeration okay. Because I am reducing the temperature of the system to a level lower than the surroundings okay. So how this is happening this is happening because of the sensible heat transfer between the building and the cold water okay. I have, as I said, I have cold water at my disposal so this is possible and what happens to cold water during this process?

During this process the cold water temperature has to increase okay. If it has a finite thermal capacity since it when it absorbs heat its temperature increases that means during this sensible heat transfer process the temperature of the building reduces and the temperature of the cold water increases okay.

So this is one of the simplest methods of reducing the temperature of a system okay, of course for this to happen continuously we must have a continuous supply of the cold water so that you can continuously provide the refrigeration okay. Another example is use of cold air for reducing the temperature of air in a conditions space okay. If you want to reduce the temperature of air in a condition space you can supply cold air which gets mixed with the warm air inside the room and the temperature reduces okay.

So here there are no latent processes all the processes are sensible heat transfer processes okay.

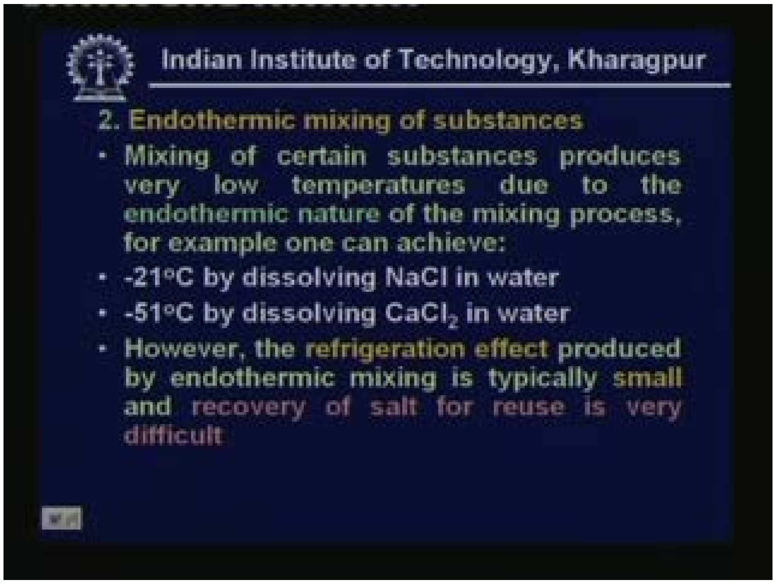
In the absence of heat losses the heat transferred during this process if the let us say that over a time period if Q is the heat transferred during this process then Q can be written as Q is equal to m c into T f minus T i of A that is equal to m c into T i minus T f of B okay. Here A is a system that is providing refrigeration that means in this example A is the cold water and B is the building okay, whose temperature is getting reduced.

So the heat transferred from the building in the absence of any losses will be exactly equal to the heat transferred to the cold water okay. And from this equation if you kNow the thermal capacities of the building and cold water and their initial temperatures and if i assume that the complete system that means the building and cold water at an equilibrium. Then you can find out what is the final equilibrium temperature okay. And as I said in this equation T i and T f are the initial and final temperatures m is the mass and c is the average specific heat of the system okay.

So this is one simple way of producing low temperatures using the cold medium.

Now let us look at the second method.

(Refer Slide: 00:10:12 min)



Indian Institute of Technology, Kharagpur

2. Endothermic mixing of substances

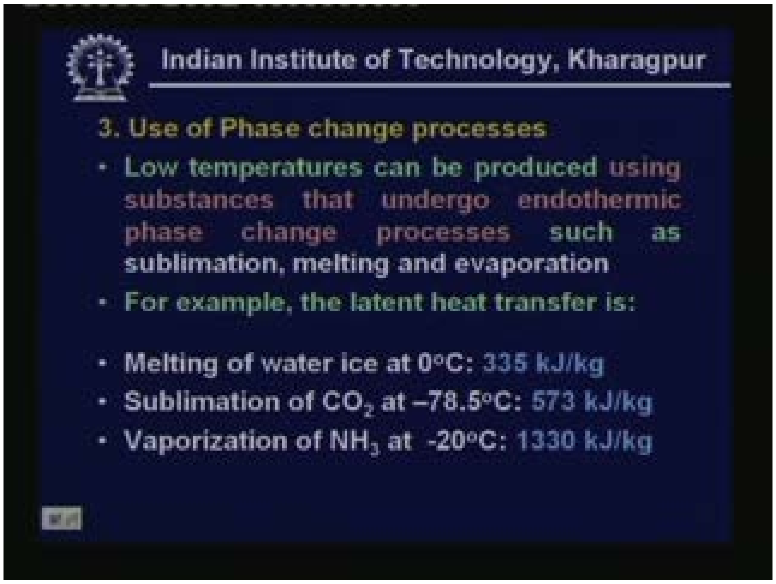
- Mixing of certain substances produces very low temperatures due to the endothermic nature of the mixing process, for example one can achieve:
- -21°C by dissolving NaCl in water
- -51°C by dissolving $CaCl_2$ in water
- However, the refrigeration effect produced by endothermic mixing is typically small and recovery of salt for reuse is very difficult

Second method is producing low temperatures using endothermic mixing of substances this is in fact one of the oldest methods known to mankind and we know that for example from experience. Let us say you take a glass of water and if i add glucose to it or sugar okay. Then we know that if I add sufficient amount of glucose or sugar the temperature of the water reduces okay. Now that means the water temperature at the end of mixing will be lower than that of the surroundings okay. Why this is happening this is happening because mixing of glucose in water is an endothermic process endothermic process means heat has got to be supplied during this mixing process okay.

So this heat is supplied from the water itself as a result water temperature drops okay. So as I said certain substances produces very low temperatures due to the endothermic nature of the mixing process. And if you want very low temperature of course we have to use certain specific materials. For example if you are dissolving sodium chloride salt in water then you can achieve a low temperature as low as minus twenty-one degree centigrade and if you are dissolving calcium chloride salt in water then you can get a temperature as low as minus fifty-one degree centigrade okay. So this is one of the simplest ways of producing very low temperatures. But this method is not very practical as far as a practical refrigerant system is concerned because it suffers from certain disadvantages what are those disadvantages. The first disadvantage is that the refrigeration effect produced by endothermic mixing is typically small okay. So you cannot have very high capacity using this method and second problem is that recovery of salt for reuse is very difficult okay.

That means if you want to provide refrigeration continuously using this method you have to have an infinite amount of salt at your disposal and infinite amount of water at your disposal okay, which is not which as you know is not possible. And if you want to recycle the same salt then you have to separate the salt from the solution okay which is very difficult right. So because of these two limitations this particular method is not used in practical continuous refrigeration systems okay.

(Refer Slide Time: 00:12:28 min)



Indian Institute of Technology, Kharagpur

3. Use of Phase change processes

- Low temperatures can be produced using substances that undergo endothermic phase change processes such as sublimation, melting and evaporation
- For example, the latent heat transfer is:
- Melting of water ice at 0°C: 335 kJ/kg
- Sublimation of CO_2 at –78.5°C: 573 kJ/kg
- Vaporization of NH_3 at -20°C: 1330 kJ/kg

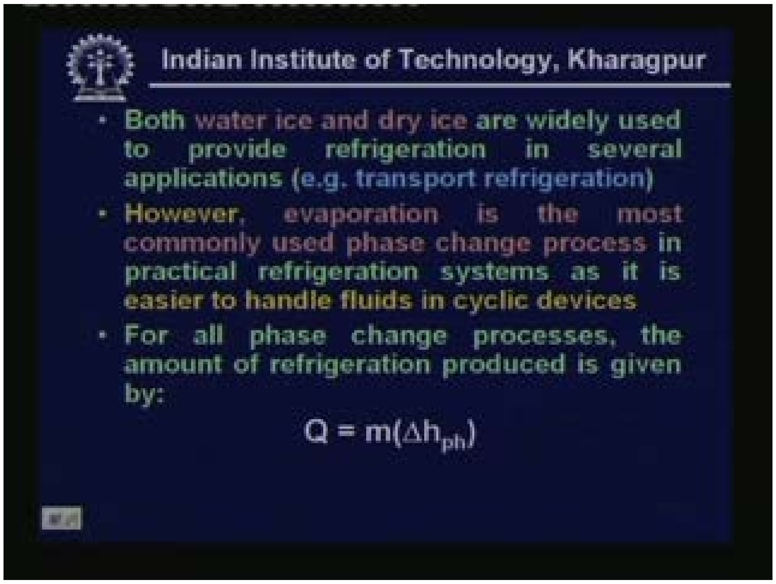
Now let us look at the third method third method is the use of a phase change processes. We know that low temperatures can be produced using substances that undergo endothermic phase change processes such as sublimation melting and evaporation okay. So as you know very well phase change means there will be a change of phase from either solid to liquid or solid to vapour or liquid to vapour okay. And due these phase change processes that means solid to liquids solid to vapour and liquid to vapour are endothermic in nature okay. That means heat has got to be supplied to the system undergoing these phase change processes okay. So during this process a large amount of heat can be transferred right.

Let me give some examples. For example the latent heat transfer let us look at the amount of heat transfer during this process. For example if I am melting water ice at zero degree centigrade then

I can get a heat transfer rate of or heat transfer of about three thirty-five kilo joules per kg of ice. That means when one kg of ice melts at zero degree centigrade three thirty-five kilo joules of heat is transferred and the second example is sublimation of carbon dioxide at minus seventy-eight point five degree centigrade. When dry ice fall in solid carbon dioxide sublimates at this temperature five seventy-three kilo joules of heat is transferred per kg of solid carbon dioxide sublimated. And the last example is vaporization of ammonia at minus twenty degree centigrade. That means when liquid ammonia vaporizes into a gas at minus twenty degree centigrade thirteen thirty kilo joule of heat is transferred for kg of ammonia vaporized okay. So these are typical examples and the typical temperatures so one thing you can notice here is that I mean compared to sensible heat transfer processes here per kg of substance a large amount of heat can be transferred. Okay. This is one of the advantages of this particular method in addition to that when we are using pure substances for phase change the temperature remains constant during the phase change processes.

Since you know very well that water boils as long as you keep the temperature constant all pure substance always boil or always condense at the same temperature. That means the heat transfer process is isothermal in nature okay so this is another advantage of the phase change process okay.

(Refer Slide Time: 00:14:50 min)



Indian Institute of Technology, Kharagpur

- Both water ice and dry ice are widely used to provide refrigeration in several applications (e.g. transport refrigeration)
- However, evaporation is the most commonly used phase change process in practical refrigeration systems as it is easier to handle fluids in cyclic devices
- For all phase change processes, the amount of refrigeration produced is given by:

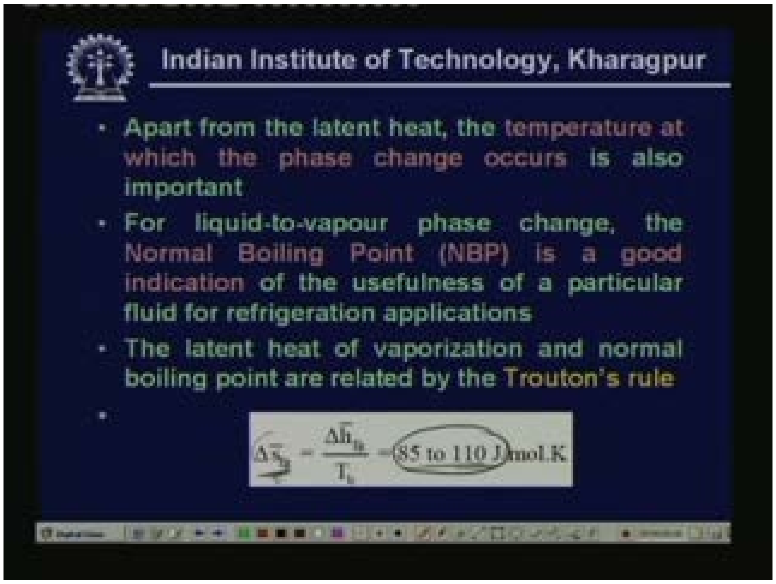
$$Q = m(\Delta h_{ph})$$

Now so let us look at this method first of all both water ice and dry ice widely used to provide refrigeration in several applications okay. We know that in many common this thing we use ice so for producing refrigerants. For example if you want to have cold water quickly okay, you can add ice blocks to water okay.

So that is the quickest way of reducing the temperature and these methods are also used in some special applications such as transport refrigeration okay. Especially solid carbon dioxide is used vary widely in transport applications to keep the products cool okay. When you are using solid carbon dioxide you can achieve temperature as low as minus seventy-eight point five degrees so, that means you can use this even for frozen food storage okay. So these refrigeration systems that means there are systems which use ice or solid carbon dioxide are known as expandable refrigeration system because at the end of the process normally the water or carbon dioxide gas is not recovered. That means the refrigerant gets expanded okay.

Now however in actual systems we do not really relay on solid ice or solid gas processes. But we use liquid vapour phase change processes that means evaporation okay. Why because evaporation is the most commonly used phase change process because it is easier to handle fluids in cyclic devices okay. If it becomes as you know most of the common refrigeration systems are cyclic in nature okay. So in cyclic systems it is much easier to handle liquid or vapour rather than a solid okay because transporting the solid around the cycle is difficult okay. So for this reason in most of the system we use evaporation and condensation okay. So for all phase change processes the amount of refrigeration produced is given by Q is equal to m into delta h subscript p h where Q is the heat transfer during the process m is the amount of substance that has under gone phase change and delta h p h is enthalpy change during the phase change okay.

(Refer Slide Time: 00:17:03 min)



Indian Institute of Technology, Kharagpur

- Apart from the latent heat, the temperature at which the phase change occurs is also important
- For liquid-to-vapour phase change, the Normal Boiling Point (NBP) is a good indication of the usefulness of a particular fluid for refrigeration applications
- The latent heat of vaporization and normal boiling point are related by the Trouton's rule
- $\Delta \bar{s}_{fg} = \frac{\Delta \bar{h}_{fg}}{T_b} = 85 \text{ to } 110 \text{ J/mol.K}$

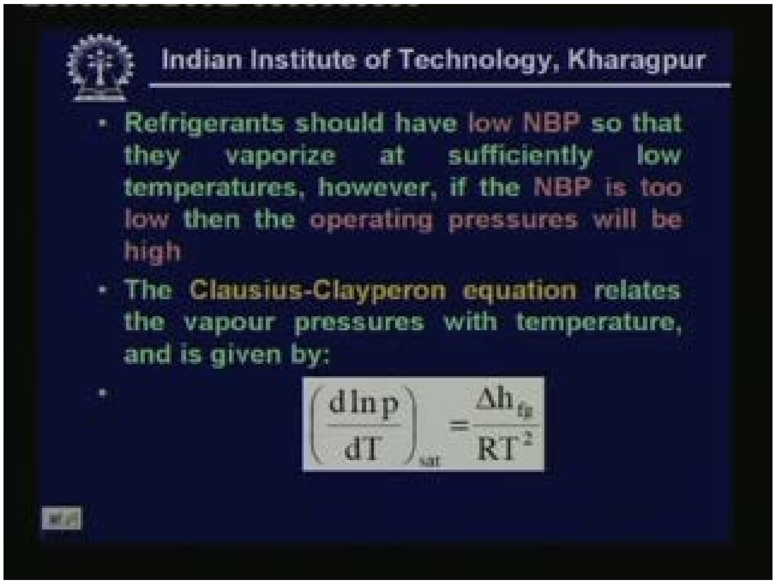
Apart from the latent heat the temperature at which the phase change occurs is also important okay, because ultimately we have to produce low temperatures okay. So the amount of heat that is transferred is important. In addition to that the temperature at which heat is being transferred is very important okay. And for liquid to vapour phase change the normal boiling point is good indication of the usefulness of the particular fluid for refrigeration applications. As you know very well a normal boiling point is the saturation temperature at one atmosphere pressure okay. This is the good indication of the usefulness of any fluid for refrigeration purposes okay. For example water has a normal boiling point of hundred degrees centigrade. That means at one atmosphere its temperature is hundred degrees centigrade which is way beyond the surrounding temperatures.

So if you want to use water as a refrigerant then you have to reduce the pressure okay. That means if a refrigeration system uses water then it will be operating at pressures very much below the atmospheric pressure okay. So this is the how the normal boiling point will tell you about the operating pressures. Now the latent heat of vaporization and normal boiling point are related by what is known as a Trouton's rule. The Trouton's rule says that delta S f g okay, delta S f g is nothing but the molar entropy of vaporization is constant for all fluids that is what the Trouton rule is all about constant means not a part single value. But it is found that this value for most of the fluids lies in this range okay.

And what is this delta S f g using your thermodynamics relations we can write delta S f g as delta h f g divided by T b where T b is the normal boiling point and delta h f g is the molar enthalpy of vaporization at normal boiling point okay. So the Trouton rule says that the ratio of the molar lay latent heat of vaporization at normal boiling point divided by the normal boiling point in Kelvin is constant for most of the fluids. This rule is very in interesting and it is also very useful because you can derive certain things from this rule. For example from this Trouton's rule you can see that the latent heat of vaporization increases as a normal boiling point increases. That means as T b increases delta h f g increases and you can also find from this equation that substances having lower molecular weight will give rise to higher specific latent heat of vaporization okay. That means on per kg basis the latent very heat of vaporization increases as the molecular weight reduces.

In fact you can compare for example water has a molecular weight of about eighteen and you compare this with any refrigerants whose molecule weight is much higher than the water. And you will find that at a normal point latent heat of water is much higher than latent heat of any other refrigerant with a higher molecular weight okay.

(Refer Slide Time: 00:20:17 min)



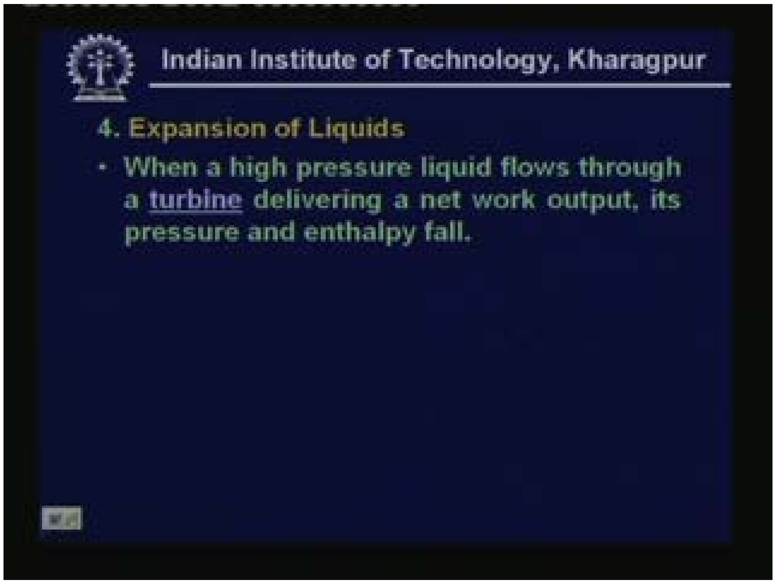
Indian Institute of Technology, Kharagpur

- Refrigerants should have low NBP so that they vaporize at sufficiently low temperatures, however, if the NBP is too low then the operating pressures will be high
- The Clausius-Clayperon equation relates the vapour pressures with temperature, and is given by:
- $$\left(\frac{d\ln p}{dT}\right)_{sat} = \frac{\Delta h_{fg}}{RT^2}$$

Now refrigerant as I said should have low normal boiling point so that they vaporize at sufficiently low temperatures okay. As I said if you want to have produced low temperatures at reasonably high pressures then the normal boiling point should be low. However if the normal boiling point is very low then the operating pressures will become very high okay. That means in all normal boiling points should lie within a certain range for the fluid to be useful in a refrigeration system. And the Clausius Clayperon equation relates the vapour pressures with temperature and it is given.

You must have studied this in your thermodynamics the Clausius Clayperon equation. This is given by d l n p by d T where l n is natural log and p is the saturation pressure at any temperature T. So the slope of saturation pressure to temperature on a semi log scale is equal to delta h f g divided by R T square where delta h f g is the latent heat of vaporization at a particular temperature T is in Kelvin and R is the gas constant okay. So this you can see that relates the saturation pressure temperature with the latent heat of vaporization this is the very useful equation. And using this equation we can find out the latent heat of vaporization if you have the saturation vapour curve right or you can find out saturation pressure at an, at a given temperature okay, from saturation pressure from a known temperature and right. Of course this equation probably remember is derived based on the assumptions that the specific volume of the vapour is much higher than the specific volume of the liquid and also that the specific the vapour behaves as an ideal gas okay. Under these assumptions this particular equation is derived okay. And this is derived from the Clausius equation okay.

(Refer Slide Time: 00:22:15 min)



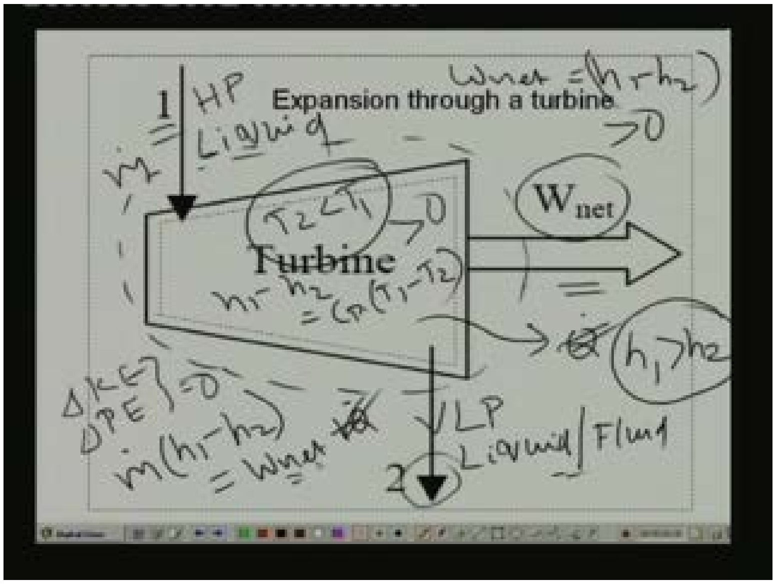
Indian Institute of Technology, Kharagpur

4. Expansion of Liquids

- When a high pressure liquid flows through a turbine delivering a net work output, its pressure and enthalpy fall.

Now let us look at the expansion of liquids when high pressure liquid flows through a turbine delivering network output its pressure and enthalpy fall okay. So if you have a high pressure liquid at your disposal okay. You can reduce the pressure of the liquid that means you can expand the liquid in two ways the first way is by using device called as a turbine okay. So let us look at a turbine.

(Refer Slide Time: 00:22:44 min)

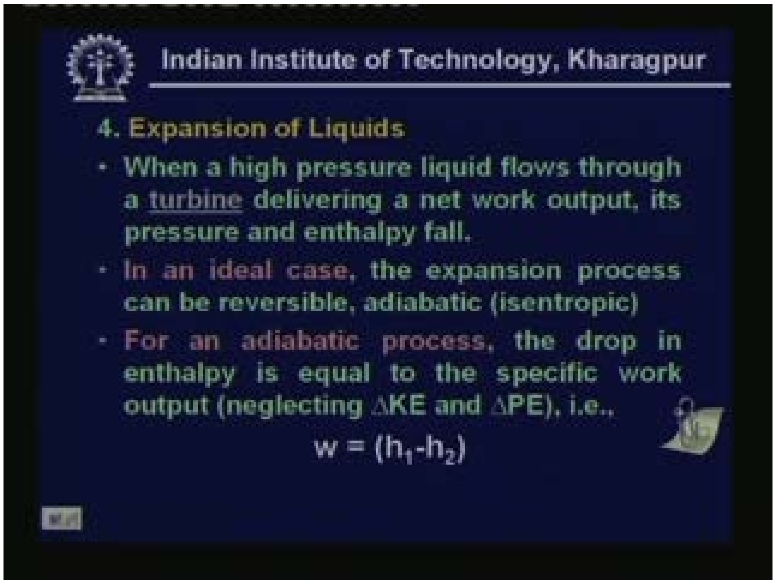


So what is the turbine do? A turbine delivers network output okay, right. So if you are talking about liquid a high pressure liquid okay. High pressure liquid at state one enters a turbine and it delivers network output W net and it exits the turbine at a low pressure okay. So low pressure liquid or low pressure fluid okay. We really do not know whether it is liquid or vapour at this point right. So you can reduce the pressure of the liquid using a turbine and if you are applying, let us say I am taking the control volume across this one. And I am applying let us say first law of thermodynamics and if I am assuming that this process is a steady state steady flow process then you can apply the first law of thermodynamics to of a steady state steady flow process and if I further assume that delta K E that means change in kinetic energy and delta P E change in potential energy both are negligible.

Then from the, from applying the steady state steady flow energy equation you can show that if m dot is a mass put it at the liquid then m dot into h one minus h two is equal to W net plus Q where Q is any heat transfer from the turbine okay. If the turbine is adiabatic then Q becomes zero right and W net is simply equal to m dot into h one minus h two or the specific work that is small w net let us says specific work is equal to h one minus h two which is nothing but the difference in the enthalpies between the inlet and the outlet. Since W net is positive that means W net is greater than zero h one will be greater than h two okay. That means the exit enthalpy will always be lower than the inlet enthalpy. And if you further assume that the specific heat of the liquid remains constant and liquid does not under undergo any phase change during the expansion.

Then you can simply write h one minus h two is equal to C P into T one minus T two right which is greater than which is greater than zero. That means T two will be lower than T one or the temperature of the liquid at the exit of the turbine will be lower than the temperature of the liquid at the inlet to the turbine okay. So expansion using a turbine always reduces the pressure it always reduces the enthalpy okay. And it always reduces the temperature. Now the point is how, what will be the temperature drop okay, is it substantial and what is it depend okay, that we shall see in the next few slides.

(Refer Slide Time: 00:25:37 min)



Indian Institute of Technology, Kharagpur

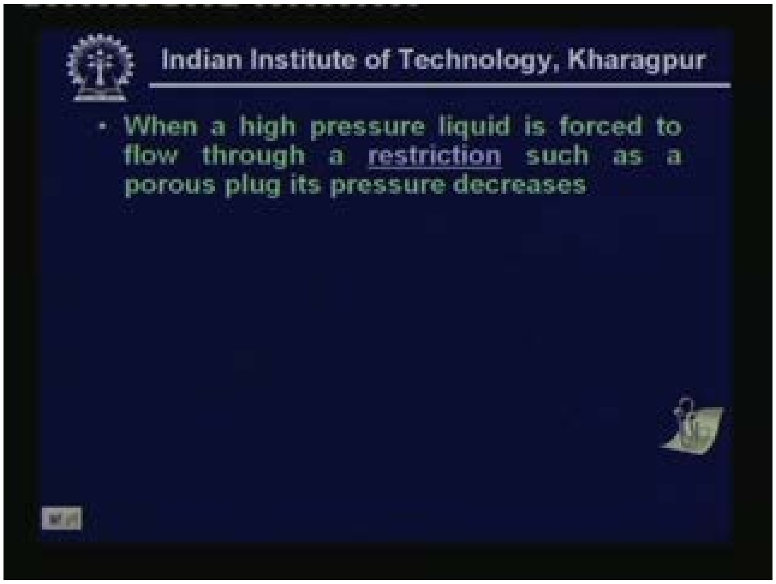
4. Expansion of Liquids

- When a high pressure liquid flows through a turbine delivering a net work output, its pressure and enthalpy fall.
- In an ideal case, the expansion process can be reversible, adiabatic (isentropic)
- For an adiabatic process, the drop in enthalpy is equal to the specific work output (neglecting ΔKE and ΔPE), i.e.,

$$w = (h_1 - h_2)$$

So in an ideal case as I have already discussed the expansion process can be reversible adiabatic. That means the process is reversible and there are no heat transfer from the turbine. That means it becomes an isentropic process and for an adiabatic process the drop in enthalpy is equal to the specific work output i. As I have already discussed and if you neglect delta K E and delta P E that means the kinetic and potential energy changes. Then the specific work output is simply equal to h one minus h two where h one and h two are the inlet and exit enthalpies of the liquid at the turbine okay.

(Refer Slide Time: 00:26:15 min)

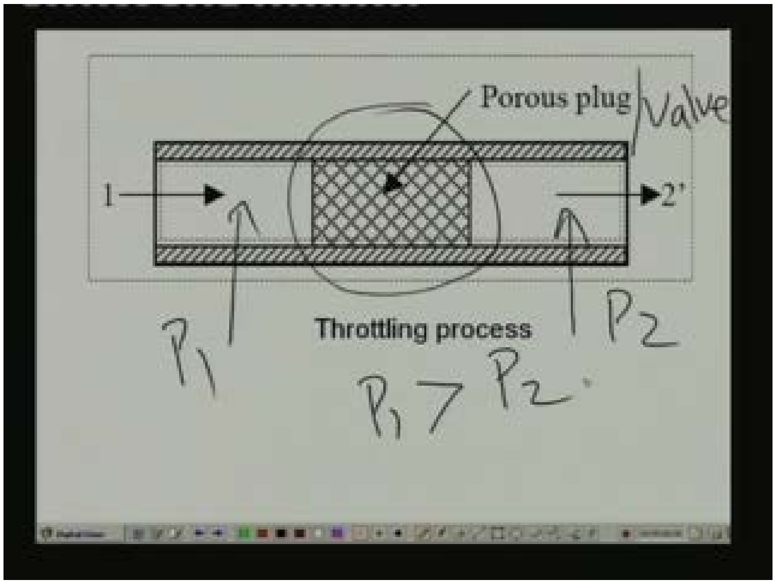


Indian Institute of Technology, Kharagpur

- When a high pressure liquid is forced to flow through a restriction such as a porous plug its pressure decreases

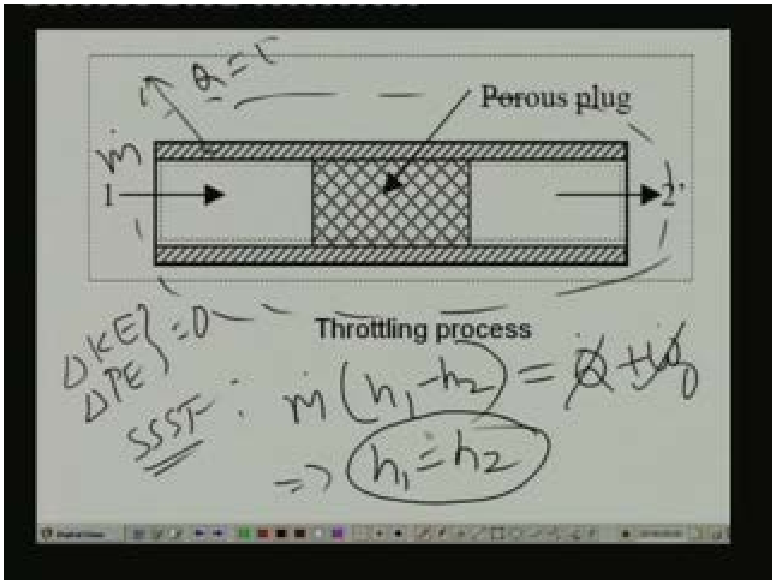
Now when a high pressure liquid is forced to flow through a restriction such as the porous plug its pressure decreases. So as I have already mentioned there are two ways by which you can reduce the pressure of a high pressure liquid one is by using a turbine and extracting useful output and the second method is using the restrictions. For example restriction means it could be a valve okay. So let us say you closed, you almost close the valve and force the fluid force the liquid to flow through the valve right. Then also its pressure drops but you do not get any work output out of these right. So one is using the turbine and the other one using a restriction okay, so let us look at this.

(Refer Slide Time: 00:26:54 min)



In general restriction could be a porous plug okay, or it could be a valve okay. Valve means fully opened valve, it is a partly closed valve right. When you have a valve and the when this provides restriction you find that there is a pressure drop okay. That means P one will be greater than P two okay.

(Refer Slide Time: 00:27:21 min)



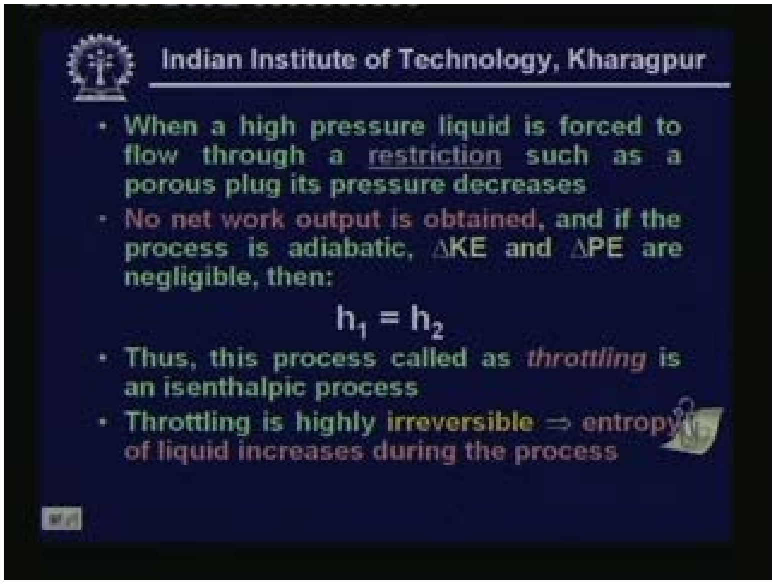
$\left.\begin{array}{l}\Delta KE \\ \Delta PE\end{array}\right\} = 0$

$\underline{\underline{SSSF}}: \dot{m}(h_1 - h_2) = \cancel{Q} + \cancel{W}$

$\Rightarrow \boxed{h_1 = h_2}$

Now again if you take a control volume across this let us say I am taking a control volume across this and I am assuming that this is the adiabatic that means there is no, Q is zero, no heat transfer between the porous plug and the surroundings right. And I also assume that potential and kinetic energy changes are negligible okay. Then I apply steady flow steady state steady flow equation to this control volume. So what do we get we find that if m dot is again the flow rate of the liquid m dot into h one minus h two okay, is equal to Q plus W but we find here that there is no heat transfer Q is zero and there is no work production. So W is also zero okay. So this implies that h one is, should be equal to h two okay. That means the expansion using the restrictions such as a porous plug or a valve leads to an isenthalpic process. That means the enthalpy of the liquid remains constant okay. Of course you must keep the assumptions in your mind under these assumptions the enthalpy of the liquid remains constant okay.

(Refer Slide Time: 00:28:42 min)



Indian Institute of Technology, Kharagpur

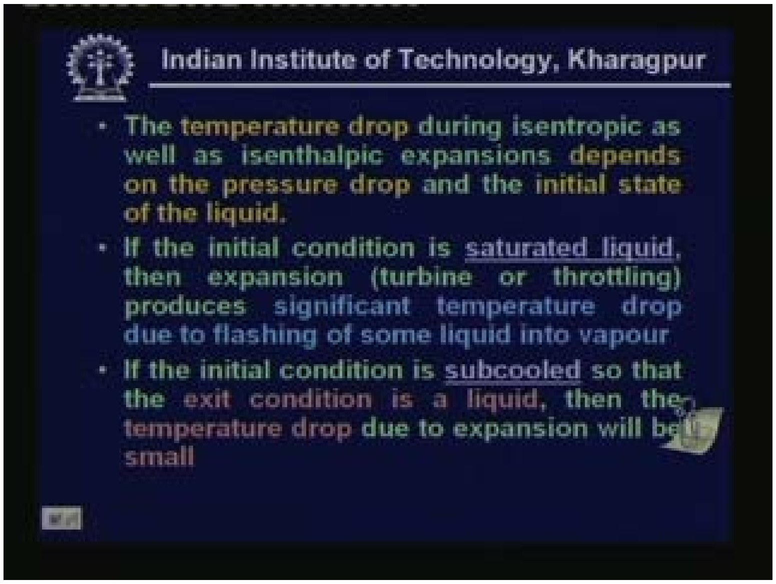
- When a high pressure liquid is forced to flow through a restriction such as a porous plug its pressure decreases
- No net work output is obtained, and if the process is adiabatic, ΔKE and ΔPE are negligible, then:

$$h_1 = h_2$$

- Thus, this process called as *throttling* is an isenthalpic process
- Throttling is highly irreversible ⇒ entropy of liquid increases during the process

So as I said no network output is obtained and if the process is adiabatic delta K E and delta P E are negligible then h one is equal to h two. Thus this process, so we normally call this process as the throttling process so a throttling process is an isenthalpic process okay. Whereas the expansion using the turbine in an ideal case is in isentropic process okay. So expansion in an ideal turbine is an isentropic process where as expansion using the throttling device is an isenthalpic process. That means in one case entropy remains constant where as in throttling case enthalpy remains constant. This is the very important difference and you must keep this in mind okay. Unlike expansion using the turbine throttling is highly irreversible. That means entropy of liquid always increases during the throttling process.

(Refer Slide Time: 00:29:37 min)



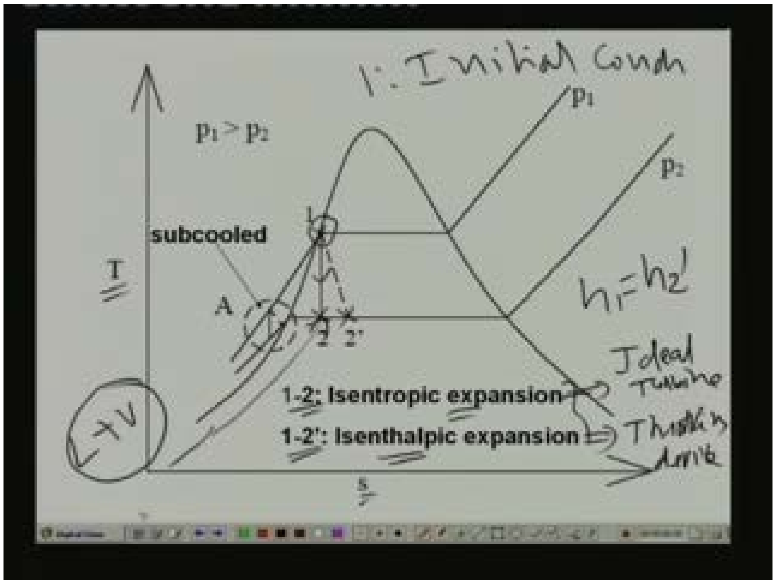
Indian Institute of Technology, Kharagpur

- The temperature drop during isentropic as well as isenthalpic expansions depends on the pressure drop and the initial state of the liquid.
- If the initial condition is saturated liquid, then expansion (turbine or throttling) produces significant temperature drop due to flashing of some liquid into vapour
- If the initial condition is subcooled so that the exit condition is a liquid, then the temperature drop due to expansion will be small

Now we are more interested in the temperature drop okay. So the temperature drop during isentropic as well as isenthalpic expansions depends on two things one is the pressure drop and the second one is the initial state of the liquid. Of course it also depends upon the nature of the liquid. So if you are fixing the liquid this depends on the pressure drop and the initial state of the liquid. Let us see how these two factors affect the temperature drop. If the initial condition is saturated liquid then expansion whether using the turbine or a throttling device produces significant temperature drop due to flashing of some liquid into vapour okay.

So let me explain this one.

(Refer Slide Time: 00:30:28 min)



1-2: Isentropic expansion

1-2': Isenthalpic expansion

Okay. As I said let us say that this is the process one to two okay. It is the expansion process so initially we are at this point one is our initial state or at the inlet of the device okay, initial condition. So process one to two okay, I am plot, I have plotted this on T s coordinates okay.

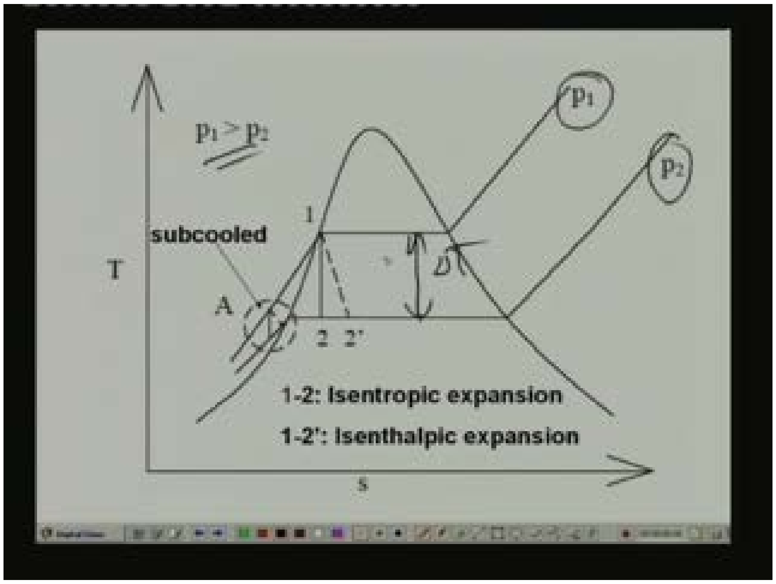
So by during process one to two entropy remains constant so this is an isentropic process expansion. That means process one to two is the process in an ideal turbine okay, and process one to two dash is an isenthalpic expansion process. That means h one is equal to h two dashes so this process one to two dash is an isenthalpic expansion. That means this is the process that occurs in a throttling device okay.

That means one to two stands for turbine ideal turbine one to two dash stands for an isenthalpic expansion of throttling device right. And as you can see that the initial condition lies on the saturated liquid region. That means initial state is saturated liquid. Now as the process takes place the pressure drops and let the two or two dash with the final condition. You find that at the final condition whether it is, two or two dash the nature of the fluid is not liquid but it is a mixture of liquid plus vapour okay. So at the inlet to this turbine or throttling device we have a saturated liquid but at the exit we have the mixture of liquid plus vapour right. That means during this process some of the liquid got converted into vapour, okay, or some of the liquid flashed into vapour.

Now we know that this process is a phase change process. That means liquid has become the vapour and this is an endothermic process. That means heat must be supplied or energy must be supplied okay. And since we are assuming that the turbine and throttling device both are adiabatic. That means there is no heat transfer from this the surrounding to the system. So whatever heat transfer has taken place must be from within the system right only then vaporization or flashing can take place right. So when some liquid flashes into vapour in an adiabatic device like a turbine or a throttling device then the temperature of the rest of the fluid has to reduce. Because it has to supply the energy required for the vaporization okay. As a result the temperature of the entire system reduces so here the system means the fluid which is undergoing the expansion okay.

So you must keep this in mind the significant drop in temperature is taking place because during the expansion process vapour is being generated okay. And the energy required for vapour generation is supplied by the liquid itself as a result its temperature drops right. So this is the principle okay.

(Refer Slide Time: 00:33:27 min)

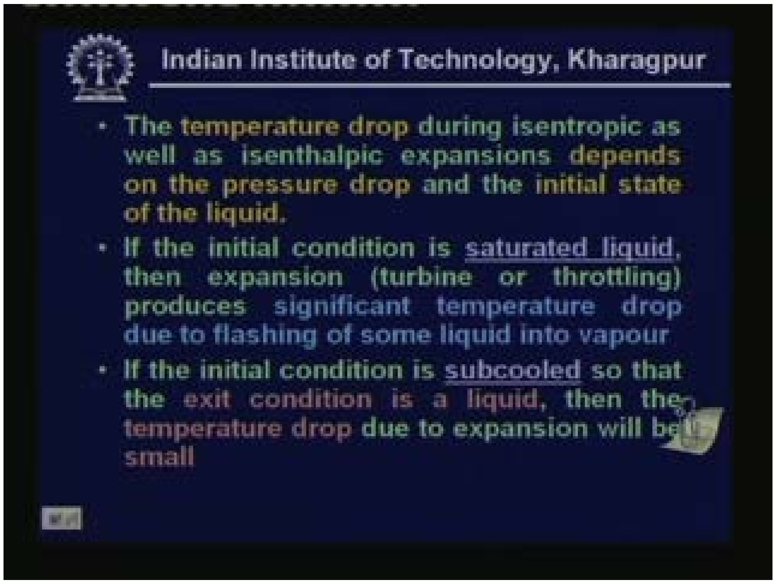


1-2: Isentropic expansion

1-2': Isenthalpic expansion

So you can see that P one and P two are the initial and final pressures. And P one is greater than P two so for a given pressure drop this is the temperature drop okay, delta T okay. You can see that temperature drop is significant as long as the initial condition is saturated liquid and the final condition lies in the two phase region okay.

(Refer Slide Time: 00:33:51 min)

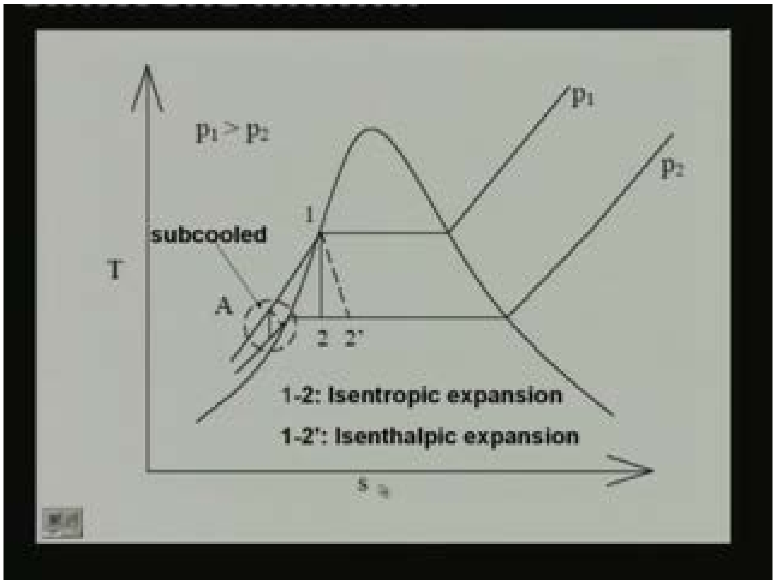


Indian Institute of Technology, Kharagpur

- The temperature drop during isentropic as well as isenthalpic expansions depends on the pressure drop and the initial state of the liquid.
- If the initial condition is saturated liquid, then expansion (turbine or throttling) produces significant temperature drop due to flashing of some liquid into vapour
- If the initial condition is subcooled so that the exit condition is a liquid, then the temperature drop due to expansion will be small

Now as I said if the initial condition is saturated liquid then expansion produces significant temperature drop due to flashing of some liquid into vapour. Another thing I would like to point out is that the temperature drop.

(Refer Slide Time: 00:34:07 min)

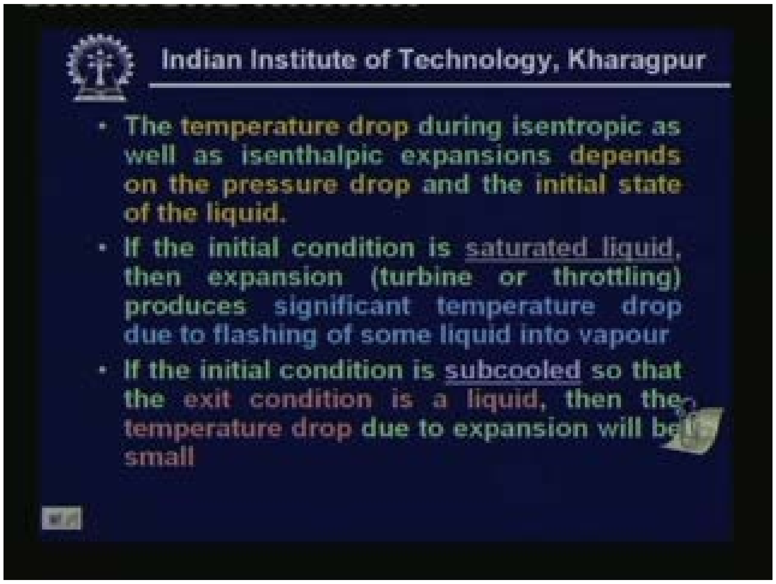


1-2: Isentropic expansion

1-2': Isenthalpic expansion

So this is the temperature drop. The temperature drop is same whether you use the turbine that means whether use a process one to two or one to two dash rights. That means for the given pressure drop the temperature drop will always remains same irrespective of the device. That means irrespective of whether you are using turbine or a throttling device as long as the final condition lies in the two phase region okay.

(Refer Slide Time: 00:34:38 min)

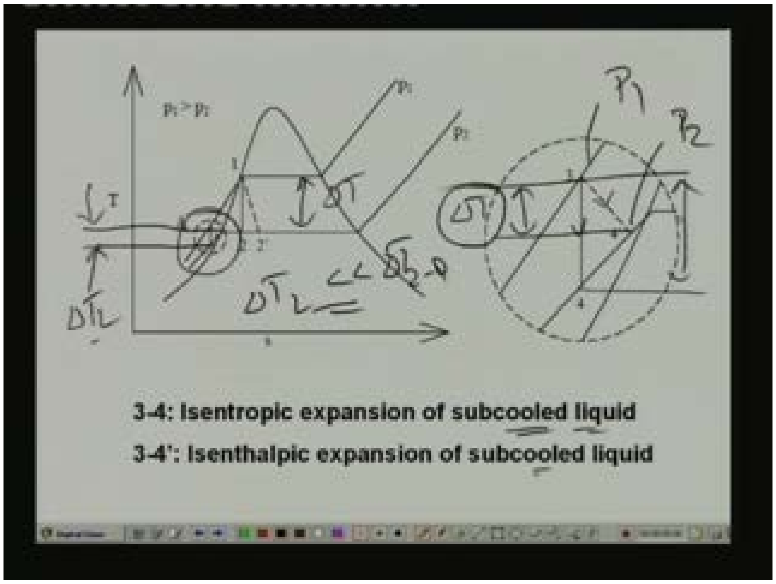


Indian Institute of Technology, Kharagpur

- The temperature drop during isentropic as well as isenthalpic expansions depends on the pressure drop and the initial state of the liquid.
- If the initial condition is saturated liquid, then expansion (turbine or throttling) produces significant temperature drop due to flashing of some liquid into vapour
- If the initial condition is subcooled so that the exit condition is a liquid, then the temperature drop due to expansion will be small

Now if the initial condition is sub cooled so we have considered the case of where the initial condition is saturated liquid. Let us say what is the initial condition is not saturated but it is sub cooled okay. So that the exit condition is liquid then we find that the temperature drop due to expansion is small okay. Again let me explain this one.

(Refer Slide Time: 00:35:05 min)



3-4: Isentropic expansion of subcooled liquid

3-4': Isenthalpic expansion of subcooled liquid

Okay. For the same pressure drop P one to P two now the expansion is taking place not in the saturated or vapour dome region. But it is taking place in the liquid region itself that means here, okay. So I have magnified this. You can see that this is again P one and this is again P two. Now the expansion process is taking place and the expansion process in a turbine this is of the liquid is given by three to four and the expansion process in a throttling device is given by three to four dash okay. So the dash line is for throttling the solid line is for expansion in a turbine. So compared to this temperature drop okay, you can see that for the same pressure drop the temperature drop obtained here is very small okay. For example if I am talking about expansion in a turbine this is the delta T in the liquid region okay. So you can see that this delta T L is much smaller than delta T in the two phase region okay.

And another thing you can see here that the delta T gets reduced further if you are replacing the turbine by a throttling device okay. So this delta T which is the temperature drop produced when you are using the throttling device in a in place of a turbine is much smaller than the temperature the drop that you would get when use the turbine okay. That means there are two changes compared to the earlier case first case is that the magnitude of the temperature for the same pressure drop is very much reduced mow and unlike the previous case here the nature of the process also affects the temperature drop okay.

If the temperature drop takes place in a turbine it will be slightly higher compared to the temperature drop that takes place in a throttling device. So as far as the refrigeration system is concerned we find that expanding the liquid only in the sub cooled or compress liquid region is not of much use. Because we are not really able to produce very low temperatures or we are not able to produce large temperature drops okay. So normally in all refrigeration systems low temperatures are produced by flashing some of the liquid into vapour okay. So that is how we get low temperatures right.

(Refer Slide Time: 00:37:25 min)

Indian Institute of Technology, Kharagpur

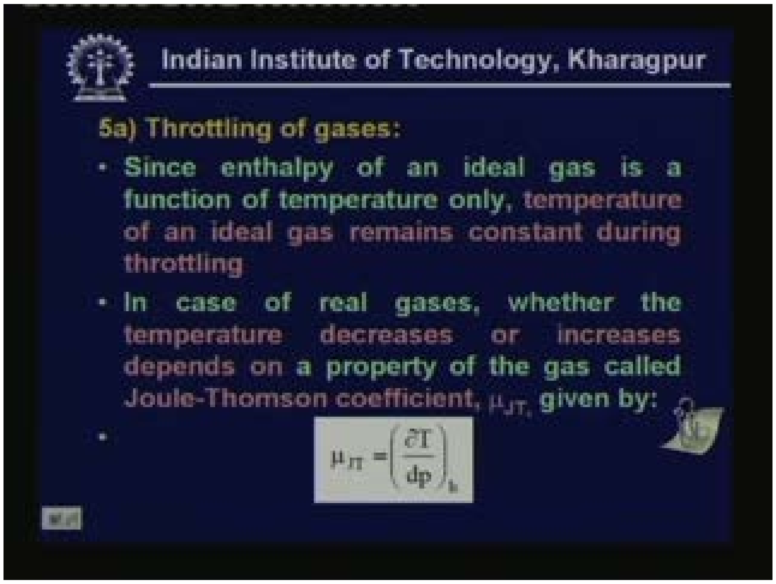
5. Expansion of gases

- Similar to liquids, gases can also be expanded from high pressure to low pressure either by using:
- a turbine (isentropic expansion), or
- a throttling device (isenthalpic process)
- Temperature of the gas always decreases during isentropic expansion
- Whether temperature decreases during throttling or not depends on the nature of the gas and its initial state

So we will come back to this when we discuss the practical refrigeration system. Now let us look at the next method of reducing the temperature that is by using expansion of gases. Now similar to liquids gases can also be expanded from high pressure to low pressure either by using a turbine. That means either you can use an isentropic expansion using a turbine or get net work output or you can also use a throttling device. That means an isenthalpic process okay. So just like liquids you can reduce the pressure either by using it a gas turbine or either by using a throttling device right. But there is an important different difference temperature of the gas always decreases during isentropic expansion.

That means just like a liquids when I am expanding a gas using a turbine its temperature always reduces okay. So in this aspect it is similar to a liquid right but when it comes to a throttling whether temperature decreases during throttling or not depends on the nature of the gas. And its initial state okay, so whenever you are throttling a liquid we know for sure that the temperature of the liquid reduces okay. The amount of reduction may not be significant but temperature always reduces when you are throttling a liquid. But when you throttle a gas whether the temperature decreases or not depends up on the nature of the gas and also depends up on the initial state of the gas. So you cannot say off hand the throttling of a gas always reduces the temperature okay.

(Refer Slide Time: 00:39:02 min)



Indian Institute of Technology, Kharagpur

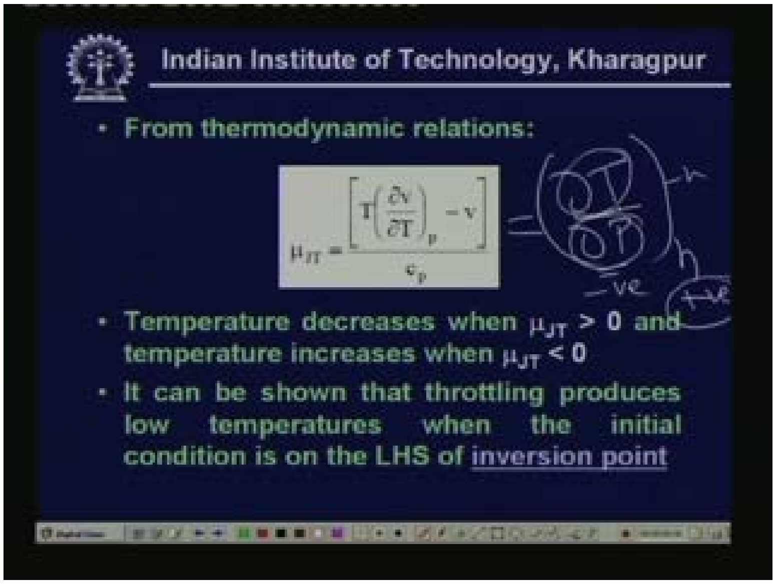
5a) Throttling of gases:

- Since enthalpy of an ideal gas is a function of temperature only, temperature of an ideal gas remains constant during throttling
- In case of real gases, whether the temperature decreases or increases depends on a property of the gas called Joule-Thomson coefficient, μ_{JT}, given by:
- $$\mu_{JT} = \left(\frac{\partial T}{dp}\right)_h$$

Now let us look at this in some detail, throttling of gases. First let us look at an ideal gas if you throttle an ideal gas what happens. Throttle means as I said reducing the pressure using a restriction okay, so that you must keep in mind. So when I am throttling the gas means when I am reducing the pressure of the gas using a restriction. So when I am throttling an ideal gas as you know the throttling process is an isenthalpic process and for an ideal gas the enthalpy is a function of temperature only okay.

So during the throttling process enthalpy remains constant right. That means temperature also has to remain constant as long as the gas behaves as an ideal gas okay. That means throttling of an ideal gas does not reduce the temperature in fact the temperature remains constant. Because the enthalpy remains constant and the enthalpy of the ideal gas is a function of temperature only okay. So this is a point number one next when we come to real gas okay. So in case of real gases whether the temperature decreases or increases depends on the property of the gas called as Joule Thomson coefficient okay. This is very important and probably you have studied this in your thermodynamics. So Joule Thomson coefficient say its symbol is mu subscripts J T it is given by mu subscript J T is given by Do T by Do p at constant enthalpy okay. That means partial derivative of temperature with respect to pressure along an isenthalpic or along a constant enthalpy line. So this is the definition of Joule Thomson coefficient.

(Refer Slide Time: 00:40:37 min)



Indian Institute of Technology, Kharagpur

- From thermodynamic relations:

$$\mu_{JT} = \frac{\left[T\left(\frac{\partial v}{\partial T}\right)_p - v\right]}{c_p} = \left(\frac{\partial T}{\partial P}\right)_h$$

-ve

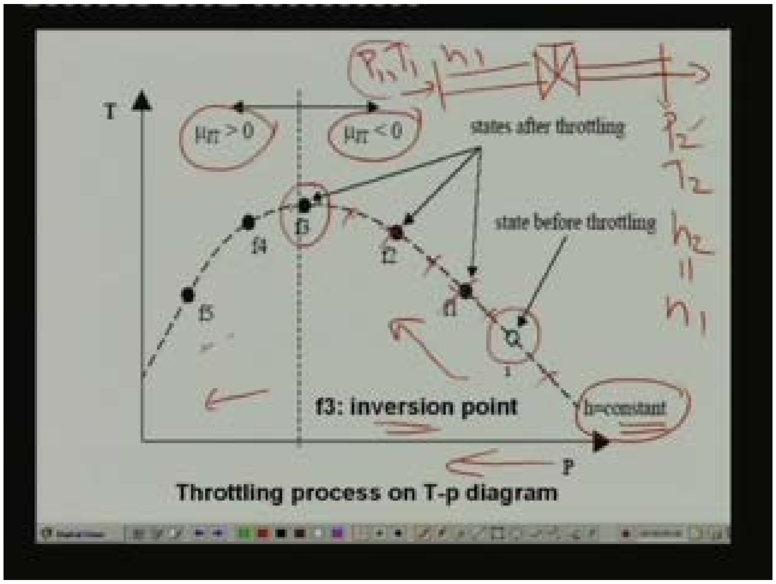
+ve

- Temperature decreases when $\mu_{JT} > 0$ and temperature increases when $\mu_{JT} < 0$
- It can be shown that throttling produces low temperatures when the initial condition is on the LHS of inversion point

From thermodynamic relations we can show that Joule Thomson coefficient mu J T is equal to T into Do v by Do T subscript p minus v divided by c p where c p is specific heat of the gas at constant pressure. V is a specific volume T is the absolute temperature and Do v by Do T subscript p is slope of isobar in a volume temperature diagram okay. So this is an expression for Joule Thomson coefficient. And you can easily see that for an ideal gas which obey the equation p v is equal to R T okay you will find the mu Joule Thomson coefficient is zero okay. So you can just check that because Do v by Do T into T works out to be v right so v minus v become zero. Now temperature from this equation you can easily see that temperature decreases when mu J T is greater than zero and temperature increases when mu J T is lower than zero, why, because we have seen that this Joule Thomson coefficient by definition is equal to Do T by Do p at constant h right.

So during expansion process pressure reduces. That means Do p will be negative okay. So if temperature also reduces then Do T also will be negative okay. That means we have Joule Thomson coefficient will be positive right. So for gases whose temperature reduce during throttling the Joule Thomson coefficient has got to be positive. If the Joule Thomson coefficient is negative that means Do p is negative so Do T has got to be positive Do T is positive means temperature at the end of the throttling device will be higher than the temperature at the inlet to the throttling device okay. That means temperature increases okay. So from this you can say that when mu J T is greater than zero temperature decreases and mu. When mu J T is less than zero temperature increases and it can be shown that throttling produces low temperatures when the initial condition is on the left hand side of what is known as an inversion point okay. So Now let me describe the inversion point.

(Refer Slide Time: 00:42:55 min)



f3: inversion point

Throttling process on T-p diagram

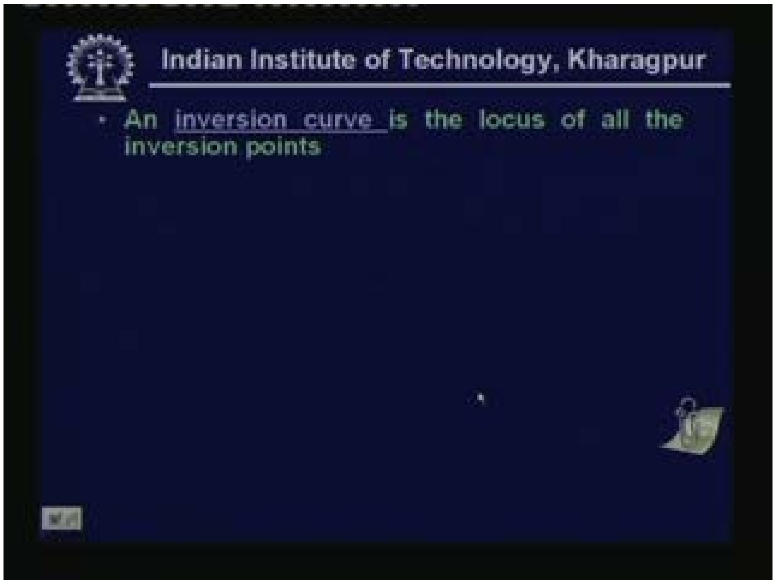
A small experiment, let us say that we have a gas okay, it flows through a pipe and we connect we put a valve in between right. So let this be the inlet condition and this is the exit condition at the inlet. Let the temperature pressure and temperature be P one and T one. So if gas is flowing through this system and let us assume that it is perfectly insulated and all there so by closing the valve. What I am doing is I am forcing the gas to undergo a throttling process okay. So what I do is I measured the exit pressure and temperatures right. So I to start with I keep the pressure and temperature the inlet constant okay.

So once you fix the pressure and temperature of the gas at the inlet as constant the enthalpy is also fixed. Let us say that enthalpy is this, okay, so the enthalpy at inlet to the throttling device which is nothing but the valve here is fixed. Since this is an isenthalpic process exit enthalpy will also is fixed is also fixed and that is nothing but inlet enthalpy okay, h one is equal to h two. So what I do is I close the valve to a certain position and measure the exit pressure and temperature and I put one curve. I mean put one point on temperature pressure chart okay. So let this be my initial state before throttling and I close the valve and I find that pressure and temperature at a certain valve position or this okay.

Then keeping the same inlet conditions I close the valves further okay. And again I measured pressure and temperature and I find that the pressure and temperature are laying at point s two okay. If I go on varying the valve position I can generate a series of points okay. Pressure and temperature and if I joined these all these points I get a curve of this nature okay. This curve has a point of infection at s three and this point is known as inversion point. So this is very important because you can see that to the left of the inversion point as the pressure is reduced. That means as the gas undergoes throttling the temperature is actually increasing that means the Joule. Thomson coefficient is negative to the left of the inversion point where as to the right of the inversion point as the pressure reduces the temperature is also reducing okay.

That means the Joule Thomson coefficient is positive to the right of the inversion point and negative to the left of the inversion point and on the inversion point obviously the Joule Thomson coefficient is zero okay. Now I can conduct carry out this experiment by varying the inlet conditions okay.

(Refer Slide Time: 00:45:43 min)

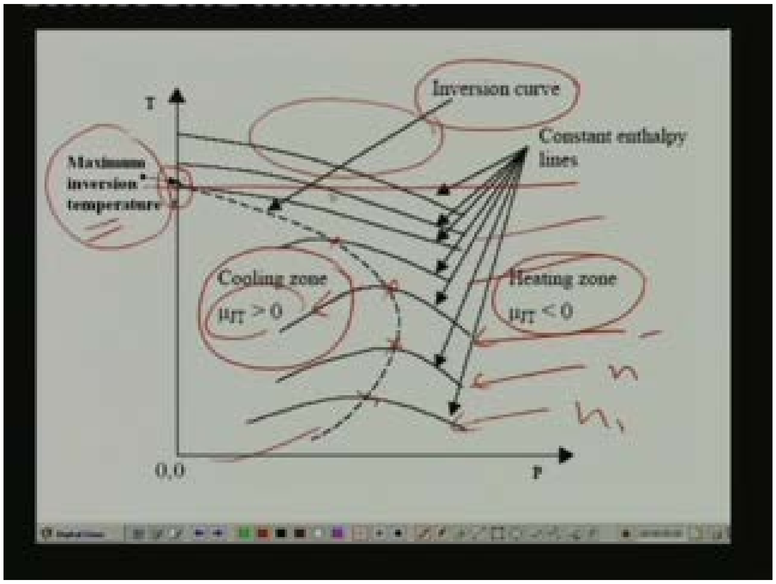


Indian Institute of Technology, Kharagpur

- An inversion curve is the locus of all the inversion points

So let us see what happens if i do that an inversion curve is, I can obtained by joining the locus of all the inversion points okay.

(Refer Slide Time: 00:45:51 min)

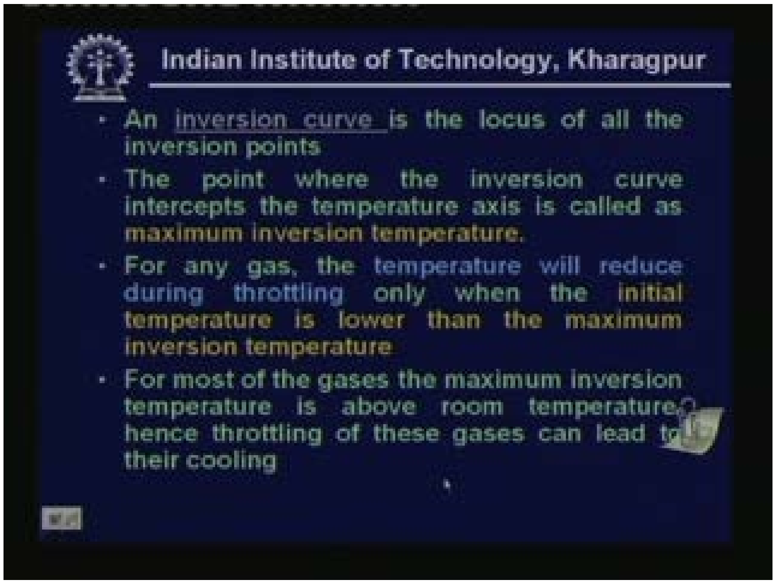


That means what I do is I vary the inlet conditions and I carry out the throttling processes at different enthalpy lines okay. So you have different enthalpy lines h one h two h three like that and each enthalpy line has an inversion point. And when we join all these inversion points you get what is known as inversion curves. So this dash line is called as inversion curve and this inversion curve intersects the temperature axis at the particular temperature and this temperature is known as maximum inversion temperature. Now you can see that to the right of within this inversion curve, within this region you have what is known as a cooling zone and in this zone the throttling always reduces temperature.

That means Joules Thomson coefficient is always positive inside the inversion curve and outside the inversion curve we have a heating zone. That means Joules Thomson coefficient is always negative. That means if throttling takes place outside the inversion curve temperature always increases during throttling. Whereas temperature always reduces during throttling when throttling takes place inside the cooling zone. And what is significance of this maximum inversion temperature? You will see that when throttling takes place when the initial temperature is higher than the maximum inversion temperature. That means throttling it is taking place in this region you will find that it always increases the temperature okay. So if you want to reduce the temperature of a gas during throttling its initial temperature must always be lower than the maximum inversion temperature this is a necessary condition for reducing the temperature during throttling okay.

Of course this is not sufficient condition okay. I will show the maximum inversion temperature has a physical significance. We find that for most of the gases the maximum inversion temperature is much higher than the room temperature. So when you expand these gases by using a throttling device their temperature drops. For example nitrogen air carbon dioxide etcetera okay. Of course there are some exceptions like helium hydrogen etcetera whose inversion temperature maximum inversion temperature is very low. That means very much lower than the room temperature. So when you expand or when you throttle a helium gas then you find that its temperature increases. So if you want to reduce the temperature of a helium gas using throttling processes, first you must bring the inlet temperature of the helium gas below its maximum inversion temperature okay.

(Refer Slide Time: 00:48:13 min)



Indian Institute of Technology, Kharagpur

- An inversion curve is the locus of all the inversion points
- The point where the inversion curve intercepts the temperature axis is called as maximum inversion temperature.
- For any gas, the temperature will reduce during throttling only when the initial temperature is lower than the maximum inversion temperature
- For most of the gases the maximum inversion temperature is above room temperature, hence throttling of these gases can lead to their cooling

So let me just summarize the point where the inversion curve intercepts the temperature axis is called as maximum inversion temperature. For any gas the temperature will reduce during throttling only when the initial temperature is lower than the maximum inversion temperature.

For most of the gases the maximum inversion temperature is above room temperature hence throttling of these gases can lead to their cooling.

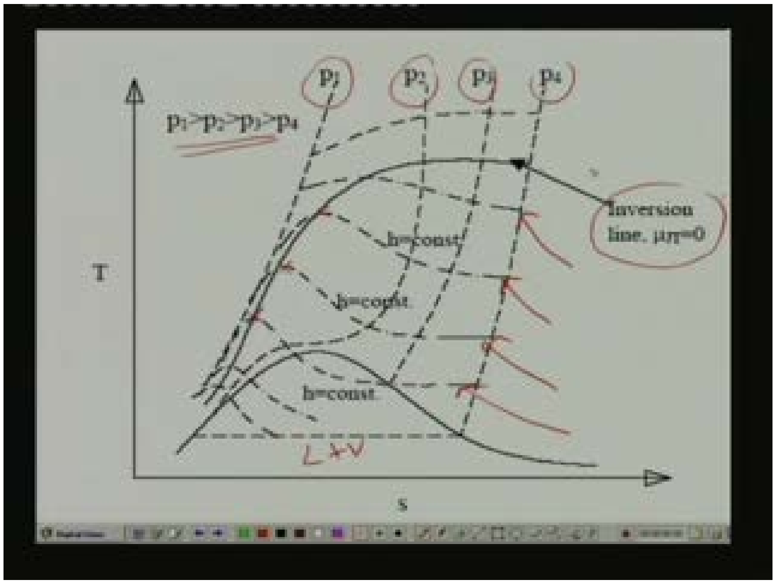
(Refer Slide Time: 00:48:40 min)

Indian Institute of Technology, Kharagpur

- Typical T s diagram of a fluid indicates that:

The same thing can be indicated on a typical T s diagram let us look at the typical T s diagram of a fluid okay.

(Refer Slide Time: 00:48:46 min)

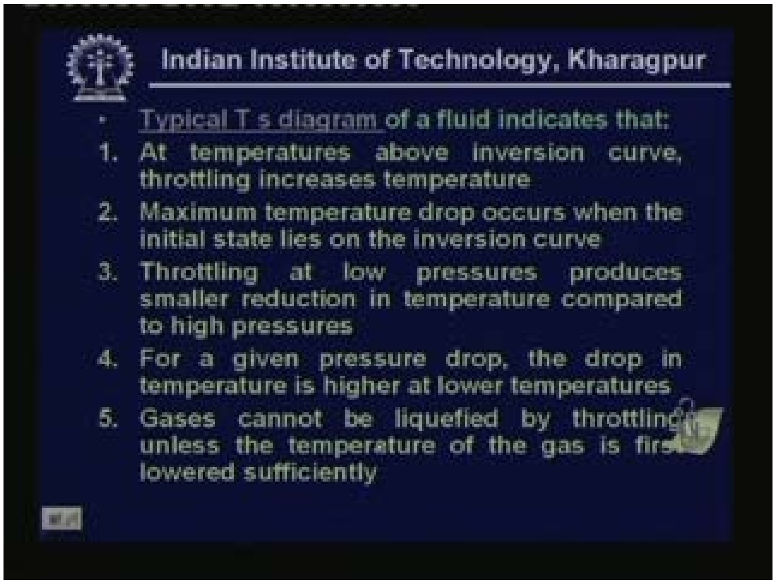


And what does it tell us, so on this T s diagram as you know this within the vapour dome we have liquid plus vapour region in this dome and above the vapour dome we have a single phase region okay. And on this T s diagram I have shown isobars. That means constant pressure lines P one P two P three P four and P one is greater than P two is greater than P three is greater than P four okay. And I have also shown constant enthalpy lines. So these are the constant enthalpy lines. So throttling as you know takes place along the constant enthalpy line okay and each constant enthalpy line gives me a point of point of inversion okay. So if i join all these points of inversion I get what is known as inversion line and on this inversion line the Joules Thomson coefficient is zero okay. So if you look at this T s diagram you can arrive at some important conclusions. First conclusion is that the throttling takes place above the inversion curve the temperature always increases during throttling.

For example if I am throttling from P one to P two okay, starting with this temperature you find the temperature always increases that is the first observation. Second observation is that for a given pressure drop let us say that P two to P three the temperature drop increases as the throttling takes place at lower temperatures okay. So for a given pressure drop as the throttling takes place at lower temperatures temperature drop increases. So this is the second conclusion.

Third conclusion is that okay, so third conclusion is that temperature drop becomes higher when throttling takes place at higher pressures. For example if you look at this one between P two and P three this is the temperature drop. But between P three and P four sorry, and between P two and P three the temperature drop is higher if the throttling takes place. let us say from some pressure this one to P three this temperature drop is still higher okay. So throttling at higher pressures provides higher temperature drop.

(Refer Slide Time: 00:50:52 min)



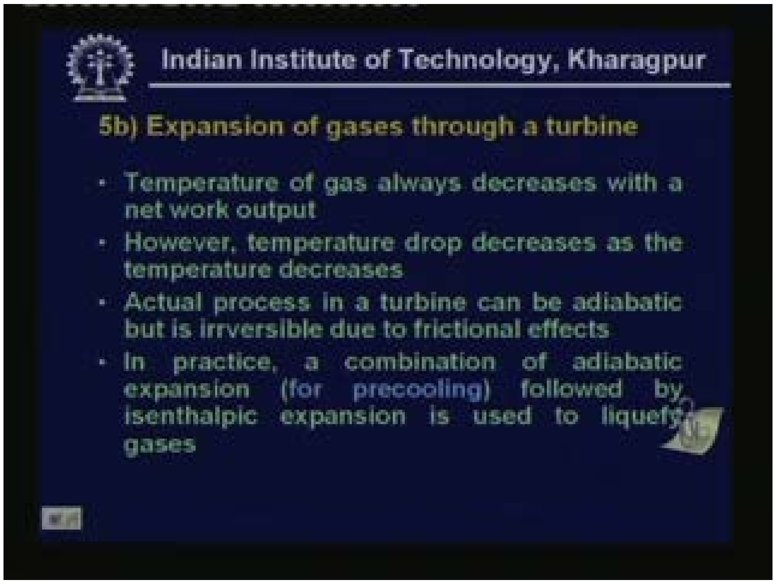
Indian Institute of Technology, Kharagpur

- Typical T s diagram of a fluid indicates that:

1. At temperatures above inversion curve, throttling increases temperature
2. Maximum temperature drop occurs when the initial state lies on the inversion curve
3. Throttling at low pressures produces smaller reduction in temperature compared to high pressures
4. For a given pressure drop, the drop in temperature is higher at lower temperatures
5. Gases cannot be liquefied by throttling unless the temperature of the gas is first lowered sufficiently

So these are summarized here at temperatures above inversion curve throttling increases temperatures maximum temperature drop occurs from the initial state lies on the inversion curve all these conclusions are based on our T s diagram okay. Throttling at low pressures produces smaller reduction temperature compare to high pressures for a given pressure drop the drop in temperature is higher at lower temperatures and finally the gases cannot be liquefied by throttling unless the temperature of the gas is first lower sufficiently. So in the liquefaction plants what is done is the pressure of the gas is increased first and then its temperature has to be reduced sufficiently. So that when you throttle it its temperature exit temperature is such that the exit condition lies in the two phase region and liquid is produced okay.

(Refer Slide Time: 00:51:40 min)



Indian Institute of Technology, Kharagpur

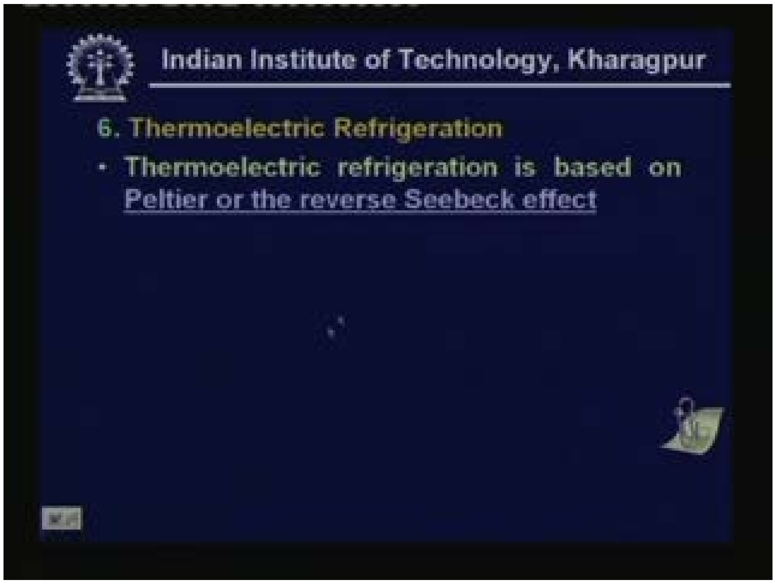
5b) Expansion of gases through a turbine

- Temperature of gas always decreases with a net work output
- However, temperature drop decreases as the temperature decreases
- Actual process in a turbine can be adiabatic but is irrversible due to frictional effects
- In practice, a combination of adiabatic expansion (for precooling) followed by isenthalpic expansion is used to liquefy gases

Now let us look at expansion of gases using a turbine. So as I have already mentioned temperature of gas always decreases with a net work output. That means whenever you are expanding a gas using a turbine its temperature always drops. However the temperature drop decreases as the temperature decreases. This is unlike your isenthalpic expansion where the temperature drop decrease increases as the temperature decreases. But in case of expansion of gases through turbine the temperature drop decreases as the temperatures decreases okay, this is actually disadvantage.

Actual process in a turbine can be adiabatic but is irreversible due to frictional effects and in practical liquefaction plants and all a combination of adiabatic expansion followed by isenthalpic expansion is used to liquefy gases. So the adiabatic expansion used primarily for precooling the gas then the precooled gas is expanded using a throttling device so that the final condition lies in the two phase region okay.

(Refer Slide Time: 00:52:42 min)



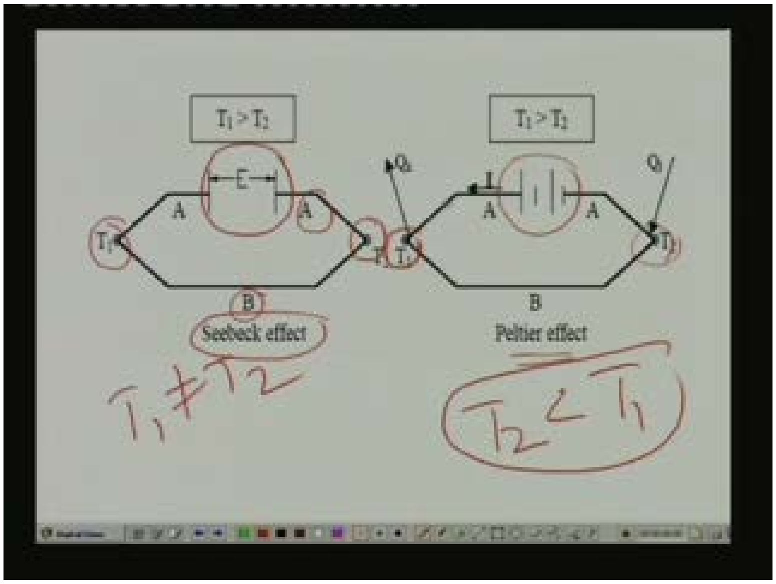
Indian Institute of Technology, Kharagpur

6. Thermoelectric Refrigeration

- Thermoelectric refrigeration is based on Peltier or the reverse Seebeck effect

Now let us look at thermoelectric refrigeration thermoelectric refrigeration is based on what is known as Peltier or reverse Seebeck effect.

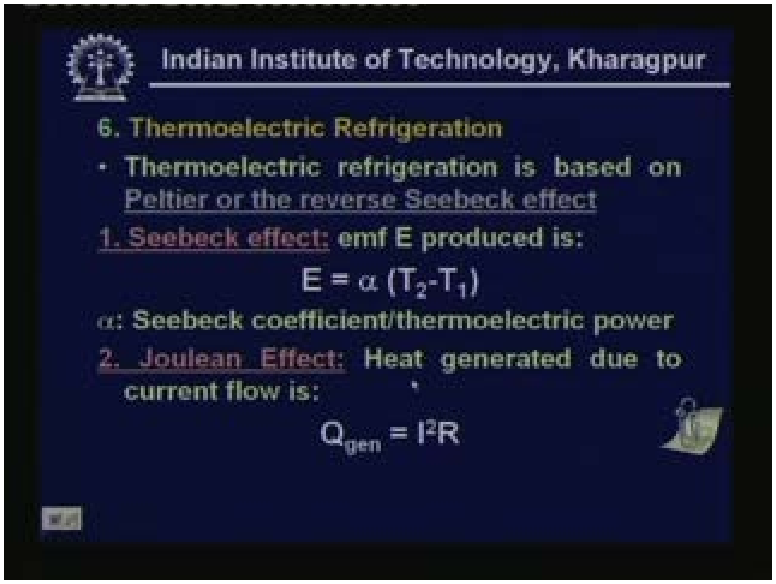
(Refer Slide Time: 00:52:52 min)



So what is Reverse Seebeck effect? Suppose we have two materials dissimilar materials A and B and these two materials are joined. So we have, we get two junctions, junction one and two okay. And if you maintain these two junctions at two different temperatures that means T one is not equal to T two then you find that an emf is developed, okay, because of this temperature difference.

This effect is known as Seebeck effect and this is the principle behind temperature measurement using thermocouples. Now the Peltier effect this is the reverse of Seebeck effect okay, Peltier effect is reverse Seebeck effect. Here what we do is initially the two junctions are at the same temperatures. Then we give connect, a voltage supply and pass current through this. So when a current passes through these two dissimilar materials you find that at the junctions the temperature will become different. So in this case you will find that T two is lesser lower than T one okay. So as long as the current is flowing through it you will find that there is the temperature difference. So as a result at T two you can get refrigeration effect and heat rejection takes place at T one okay. So this is known as Peltier effect.

(Refer Slide Time: 00:54:01 min)



Indian Institute of Technology, Kharagpur

6. Thermoelectric Refrigeration

- Thermoelectric refrigeration is based on Peltier or the reverse Seebeck effect

1. Seebeck effect: emf E produced is:

$$E = \alpha (T_2 - T_1)$$

α: Seebeck coefficient/thermoelectric power

2. Joulean Effect: Heat generated due to current flow is:

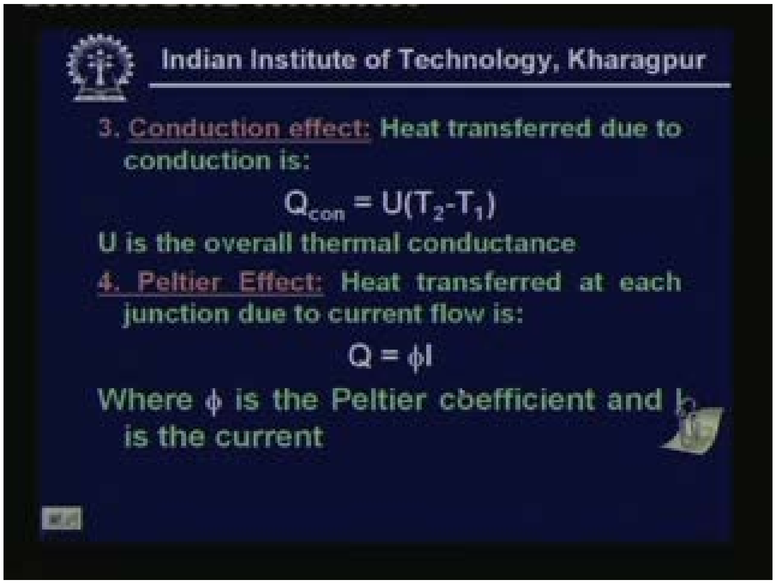
$$Q_{gen} = I^2R$$

The thermoelectric refrigerant systems are subject to five different effects. First is known as Seebeck effect which I have already described in the Seebeck effect. As I said emf is produced and this emf produced is equal to alpha into temperature difference T two minus T one where alpha is called as Seebeck coefficient or thermoelectric power and the next effect is known as

Joulean effect this is nothing but the generation of heat due to flow of current through a resistor okay.

All these materials have resistance finite resistance. So as the current flows through it heat is generated and this heat generation rate is given by Q gen is equal to I square R where I is the current and R is the resistance.

(Refer Slide Time: 00:54:38 min)



Indian Institute of Technology, Kharagpur

3. Conduction effect: Heat transferred due to conduction is:

$$Q_{con} = U(T_2-T_1)$$

U is the overall thermal conductance

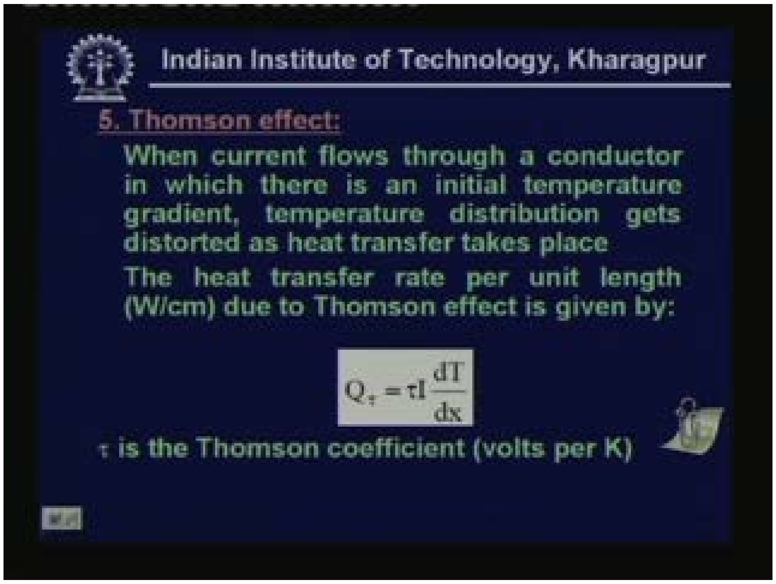
4. Peltier Effect: Heat transferred at each junction due to current flow is:

$$Q = \phi I$$

Where ϕ is the Peltier coefficient and I is the current

Third effect is known as conduction effect when you are maintaining the junctions at two different temperatures heat conduction takes place along the material and this heat transfer rate is given by Q conduction is equal to U into T two minus T one where U is the overall thermal conductance and T two minus T one is the temperature difference. The fourth effect is the Peltier effect which i have already described and heat transferred during Peltier effect at each junction is given by Q is equal to phi into I where I is the current and phi is the Peltier coefficient okay.

(Refer Slide Time: 00:55:11 min)



Indian Institute of Technology, Kharagpur

5. Thomson effect:

When current flows through a conductor in which there is an initial temperature gradient, temperature distribution gets distorted as heat transfer takes place

The heat transfer rate per unit length (W/cm) due to Thomson effect is given by:

$$Q_{\tau} = \tau I \frac{dT}{dx}$$

τ is the Thomson coefficient (volts per K)

And the last effect is known as Thomson effect. What is this effect? When current flows through a conductor in which there is an initial temperature gradient temperature distribution gets distorted okay. As a result heat transfer takes place and this heat transfer rate per unit length due to Thomson effect is given by Q tau is equal to tau into I into d T by d x where tau is the Thomson coefficient okay.

(Refer Slide Time: 00:55:35 min)

Indian Institute of Technology, Kharagpur

- A relationship can be developed among the Seebeck, Peltier and Thomson coefficients
- In practice, p -and n-type semiconducting materials are used
- From a simple analysis expressions for temperature lift, heat extraction and heat rejection rates and COP can be obtained in terms of design and material parameters
- It is possible to optimize the current either for maximum temperature lift, heat transfer rates or system COP

So it can be easily shown that a relationship exist between the Seebeck Peltier and Thomson coefficients and in practice we do not use pure metals because pure metals have high thermal conductivity which is not desirable. What we require is the material having high electrical conductivity but low thermal conductivity okay. So metals are not used we use semiconductor materials p and n type semiconductor materials in actual thermoelectric refrigeration systems and from a simple analysis we can derive expressions for temperature lift heat extraction and heat rejection rates and COP okay. In terms of the design and material parameters and it is also possible to optimize the current either for a maximum temperature lift or for maximum heat transfer rates or for maximum system COP.

(Refer Slide Time: 00:56:23 min)

Indian Institute of Technology, Kharagpur

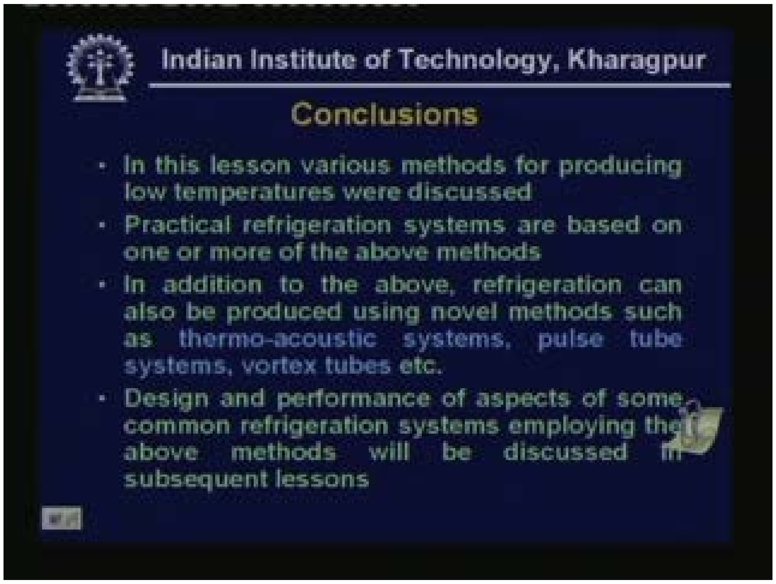
7. Adiabatic demagnetization:

- Magnetic refrigeration is based on the magnetocaloric effect, discovered by Warburg in 1881.
- Paramagnetic materials raise their temperatures when adiabatically magnetised, and reduce their temperature when adiabatically demagnetised

The last effect is what you known as adiabatic demagnetization or magnetic effect the magnetic refrigeration is based on the magneto caloric effect discovered by Warburg in eighteen eighty-one. What is the principle of this the principle of this is that paramagnetic materials raise their temperatures when adiabatically magnetized and reduce their temperature when adiabatically demagnetized. Let us say that I have a paramagnetic material and I suddenly expose it to a very strong magnetic field so the atoms of the paramagnetic material align themselves in the direction of the magnetic field. This is an exothermic process that during this process the entropy of the material reduces and heat is rejected okay.

So this is and reverse effect that means suddenly if i withdraw the magnetic effect then the atoms get realigned to the original orientation. And this is an endothermic process and during this process entropy of the material increases okay. So as a result the material absorbs heat from the surroundings the surroundings get cooled and if you are not providing any surroundings or if it is isolated from the surroundings it takes heat from itself. That means the temperature of the materials itself drops right. So the principle of magnetic refrigeration is that you alternatively expose the material to strong magnetic field and withdraw the magnetic field okay. So during this process you can produce very low temperatures temperate down absolute zero can be produced using this method okay.

(Refer Slide Time: 00:58:00 min)



Indian Institute of Technology, Kharagpur

Conclusions

- In this lesson various methods for producing low temperatures were discussed
- Practical refrigeration systems are based on one or more of the above methods
- In addition to the above, refrigeration can also be produced using novel methods such as thermo-acoustic systems, pulse tube systems, vortex tubes etc.
- Design and performance of aspects of some common refrigeration systems employing the above methods will be discussed in subsequent lessons

So let me quickly conclude in this lesson various methods are producing low temperatures were discussed. A practical refrigeration system are based on one or more of these methods. And in addition to the above refrigeration can also be produced by other methods which I have not discussed these are namely thermo acoustic systems pulse tube method vortex tubes etcetera, okay, and design and performance of aspects of some of the common refrigeration systems employing the above methods will be discussed in subsequent lessons okay.

Thank you.