Applied Thermodynamics for Marine Systems

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Lecture - 17

Pipeline and Pipe Network

Let us start. Power needed is the rate of energy. Power needed is equal to Q into delta P; we can write this as Q into rho g h_l. So, one can use both these equations for the calculation of power.

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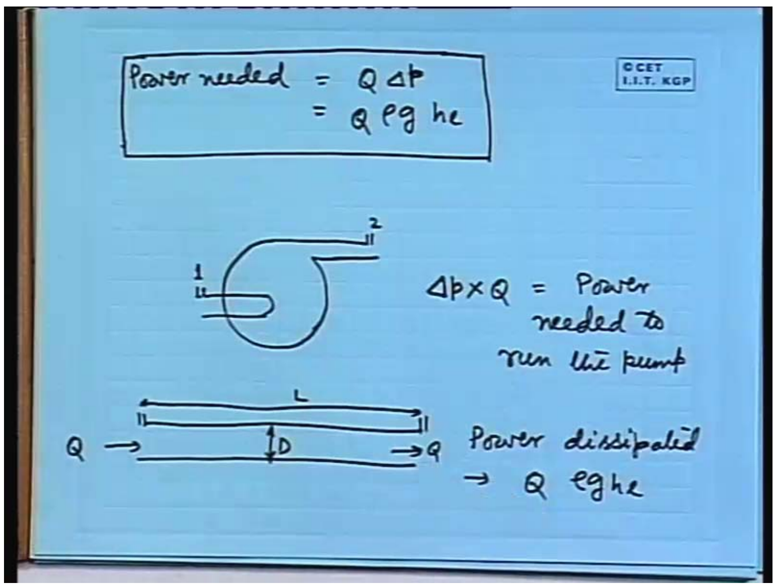

Let us say we have got a pump. This is the representation of a pump, this is 1 and this is 2. From here, we can get delta p. We neglect other heads, so delta p is the main contribution of the pump as far as change in head is concerned. Delta p, we will get from these two. Delta p multiplied by Q, will give you the power needed to run the pump. If you know delta p and if you know the volume flow rate, one can calculate what is the power needed to run the pump. Then, we can use the second equation also. Suppose we have got a pipeline. For this we have calculated what h_l is; this is L, this is D; all these we know and we have calculated what the head loss is. In this case, we can get the power dissipated from this equation, Q into rho g h_l. So, this is Q; flow is going through this pipe line. We can use this equation in different places as and when required. We can use this equation to estimate the power. Let us take one example where we will apply some of the things which we have learnt.

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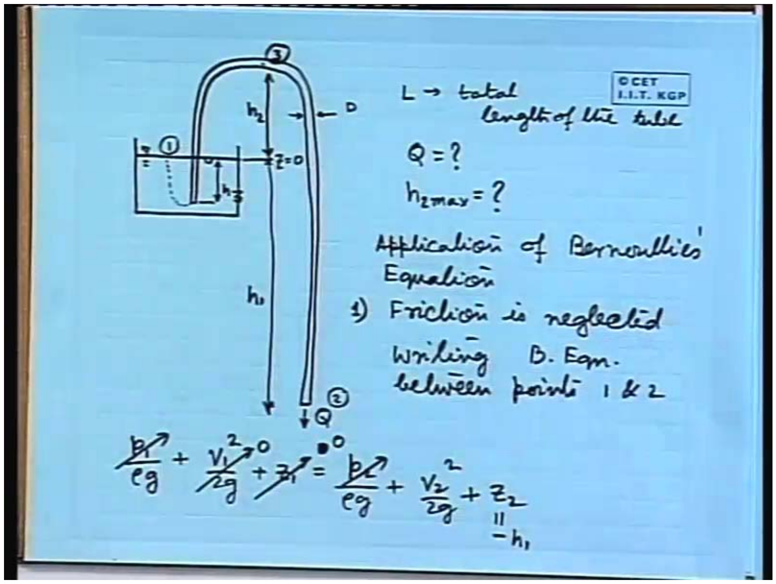

Let us say, we have got a reservoir and in the reservoir we have a siphon like this. Let us say this is h_1, this is h_2 and this is h_3. The diameter of the siphon is D, the inner diameter. In fluid flow through pipe, we are not interested in outer diameter and we are interested in inner diameter. Let us say L is the total length of the siphon tube. At this instant when this is h_3, what will be the value of Q? I want to find out what will be the value of Q? This is water and it is flowing through this tube. Then I want to find out what is the maximum value of h_2, h_{2max}? What is the maximum permissible value of h_2 so that there is flow through the siphon?

The first question is very important. How to find out Q? How should we approach this problem? Basically, this is the application of Bernoulli's equation. Case one, friction is neglected. In the first case, we are neglecting friction. If I apply Bernoulli's equation how should we apply it? Between which two points should we apply Bernoulli's equation? Let me put point 1 here and point 2 here. When I am applying it between point 1 and 2, what I am doing is, mentally I am thinking that, though I can write it here also, there is some sort of an arbitrary streamline going from point 1 to point 2. I can write that also. Assuming that there is a stream line between point 1 and point 2, I am applying Bernoulli's equation, because the fluid has to move. Let us assume that a fluid particle is moving along this path and between point 1 and point 2, I am writing Bernoulli's equation.

Writing Bernoulli's equation between points 1 and 2. I can write p_1 by rho g plus V_1 square by 2 g plus Z_1 that is equal to p_2 by rho g plus V_2 square by 2g plus Z_2. It is very convenient to take Z is equal to 0 here, because from here all the heights have been given. If I do that, then, I can write p_1 by rho g is atmospheric pressure; p_1 is atmospheric pressure and p_2 is also atmospheric pressure, so I can cancel these two. V_1 square by 2g, as the area here is very large compare to the area here, this velocity is almost equal to 0 or it is negligibly small compared to V_2 squared by 2g. So, basically this is gone. I am putting this as almost equal to 0. Z_1 is 0 because here I have taken the datum plane; so, Z_1 is equal to 0 also. Instead of Z_1…(Poor Audio) (11:09). I can write This is minus h_1; h_1 is here, h_2 is here so, Z_1 is equal to minus h_1.

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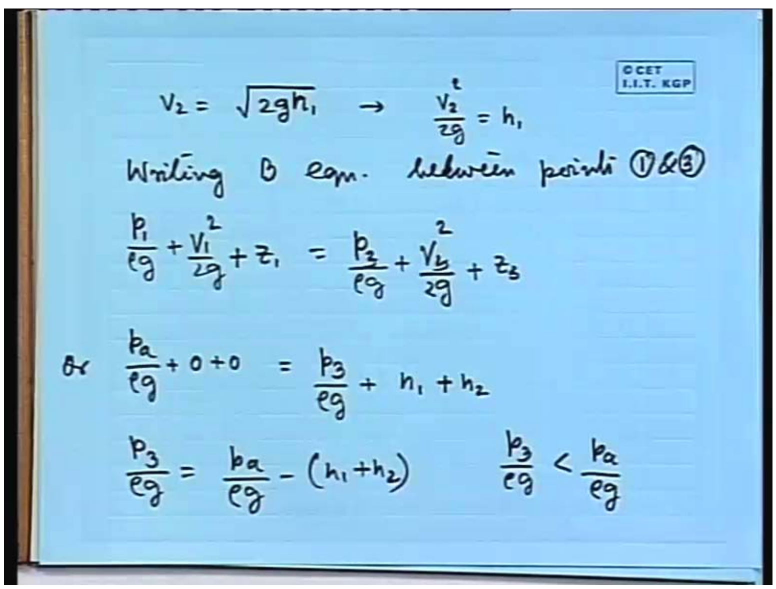

It is coming down from the datum plane so basically I can write, let me go to the next page, V_2 is equal to root over $2gh_1$. Let me see this figure once again. Basically, let us say this is a fluid particle and let us take an analogy of solid mechanics. This fluid particle is at stationary condition. It will have a potential energy compared to this datum plane; it will have a potential energy equal to mgh and when it will come here it will have a kinetic energy equal to mV square. If I compare these two, from there we will get this V is equal to root over 2gh; that is what we have got because I have neglected friction. Just like a solid particle it has moved through this distance without any friction and the entire amount of potential energy has gotten converted into kinetic energy; so, we have got the corresponding velocity. We have got V_2. From here we can calculate Q and that is the flow rate that we will get. So, the first question is answered.

The second question is what could be the maximum value of h_2? If we calculate the pressure at this point corresponding to h_2, we will get pressure which is below atmospheric pressure. We can do that very easily. Let us say, we call this point as point 3. Then writing Bernoulli's equation between points one and three: we will have p_1 by rho g plus V_1 squared by 2g plus Z_1 that is equal to p_3 by rho g plus V_3 square by 2g plus Z_3 or we can write p_a by rho g plus 0 plus 0. V_1 is very small compared to other velocity, so we have put it as 0. Z_1 is equal to 0. So p_3 by rho g. V_3 and V_2 are the same; velocity here and velocity here are the same because the pipe diameter is identical. So, we will have the same magnitude of velocity; no change in diameter. What is V_2 square by 2g? V_2 square by 2g is equal to h_1. So, V_3 square by 2g is also equal to h_1, I can write here V_2 square by 2g is equal to h_1; that is what I have written here plus Z_3. Z_3 is equal to h_2. So, p_3 by rho g is equal to p_a by rho g minus h_1 plus h_2. That means p_3 by rho g is less than p atmosphere by rho g; so, it is less than atmospheric pressure. Here we will have a pressure which is lower than the atmospheric pressure.

Now, if I make h_2 larger and larger what will happen? It will be lesser and lesser compared to the atmospheric pressure. At one time what will happen is that this liquid at the given temperature, this pressure will be below the vapour pressure. So evaporation will start; a vapour bubble will be created and that will lock the flow; the flow continuity will be lost and we will not have the fluid flow. That is what happens in case of pumps also or in case of turbines also. But there what happens is that we have a very high kinetic energy, which means, we have a very high velocity head that is why we are having a very low pressure head. Here, what I am doing is I am having a very high static head. That is why we are having a low pressure head. This is case one where I have neglected the friction.

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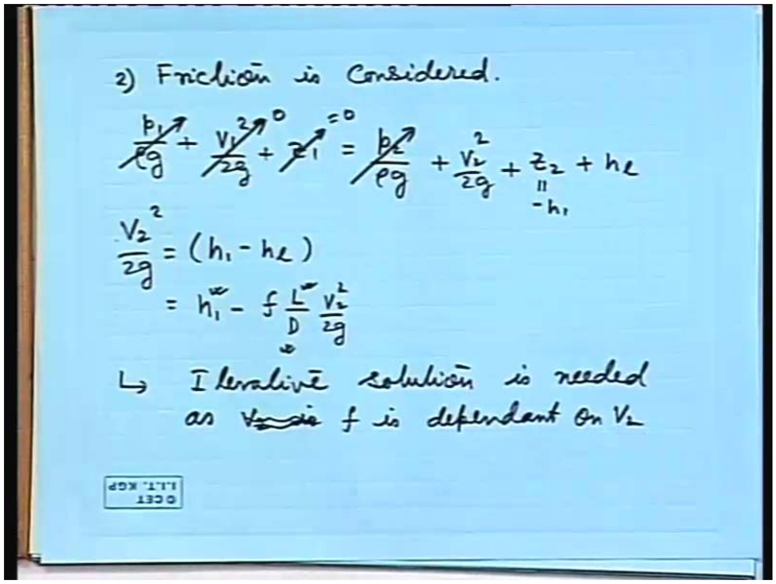

In case 2, friction is considered. If we consider friction, we will get p_1 by rho g plus V_1 square by 2g plus Z1 is equal to p_2 by rho g plus V_2 square by 2g plus Z_2 plus h_l. The first part of the problem I am doing again with friction. That means I am trying to determine Q when friction is considered. Again just like the first case, p_1 and p_2 are atmospheric pressure; so, they drop. This is negligibly small and this is equal to 0 and so this is equal to minus h_1. Basically, V_2 square by 2g is equal to h_1 minus h_l. Again this is h_1 minus f L by D into V square by 2g. I know the formula, I have written. h_1 is known to me; L, D is known to me, f is not known and V_2, I have to determine. Now the problem is f is a function of V_2. Please try to understand, f is a function of V_2. Unless I know V_2, I cannot find out f; unless I know f, I cannot find out V_2. They are interconnected and I have to have some sort of iterative solution. Iterative solution is needed as f is dependant on V_2. What are the steps?

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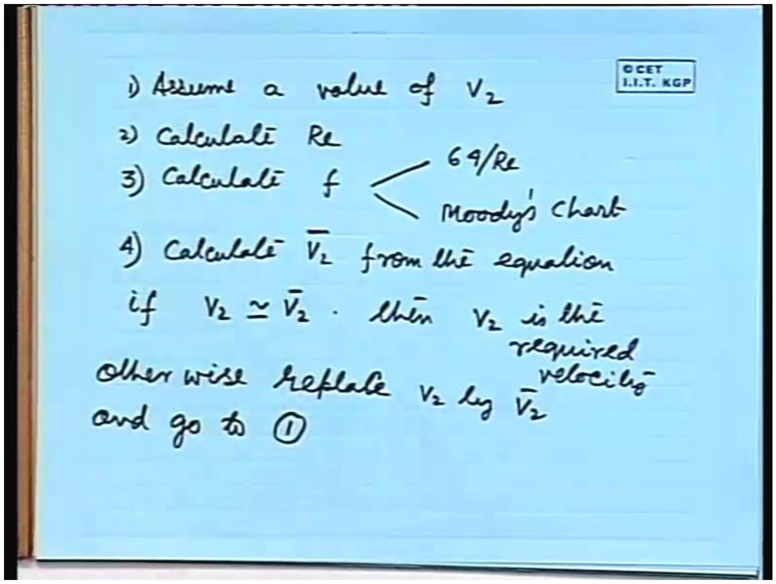

First, you have to assume a value of V_2. Calculate R_e, the Reynolds number. Calculate f; either this is 64 by R_e or Moody's chart. Then calculate V_2 from the equation or let us call it V_2 bar from the equation. If V_2 is approximately equal to V_2 bar, then V_2 is the required velocity, otherwise, replace V_2 by V_2 bar and go to 1. So, then, you will get like this. This is how most of the problems we have to do where head loss is involved. Because we will see that unless we know velocity, we cannot find out the friction factor and again friction factor is needed for determining velocity. Normally, practical flows are turbulent. So above that, we will assume. this type of velocity. What happens is practical flows are in turbulent so we will assume.

I will tell you. Suppose for this problem, what I can do? This term, I can first neglect. I will get some sort of a value of V that could be our guess value. Whatever I have said, that could not be a general guideline. There are some other problems where we cannot do that. But for this problem we can do this, because I'll tell you definitely that this head is much larger compared to the head loss term. This is our h_1 and this is much larger compared to the head loss term. Let me do another example.

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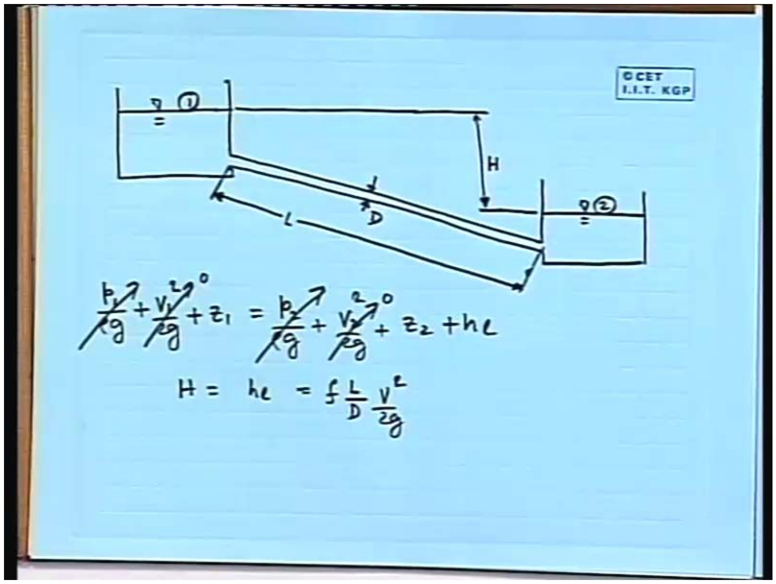

Let us say we have got two reservoirs. The height difference between the reservoirs is capital H and then this length is L and the diameter of the pipeline is D. Here again we want to know what the flow rate will be. This is a problem of hydraulic network and it is similar to some sort of electrical network. Though it is a very simple network, only one element is there, but it is similar to an electrical network. We can take the analogy and do the problem but we can do it using Bernoulli's equation also. So if I use Bernoulli's equation I will take one point here, I will take another point here and I can write Bernoulli's equation between these two points. That means p_1 by rho g plus V_1 square by 2g plus Z_1 is equal to p_2 by rho g plus V_2 square by 2g plus Z_2 plus h_l. Again these two pressures are same; these two velocities are negligibly small. Actually, these reservoir areas are very large so that is why we are telling that they are negligibly small. I am just putting 0 approximately. So Z_1 minus Z_2 is H. H is equal to h_l is equal to f L by D into V square by 2g.

Here again we have got the same problem. First, you have to assume the value of V and then we have to see whether it is matching or not. This is how this problem can be done. What I was telling is that this pipeline problem is similar to or they can be reduced to some sort of electrical network problem.

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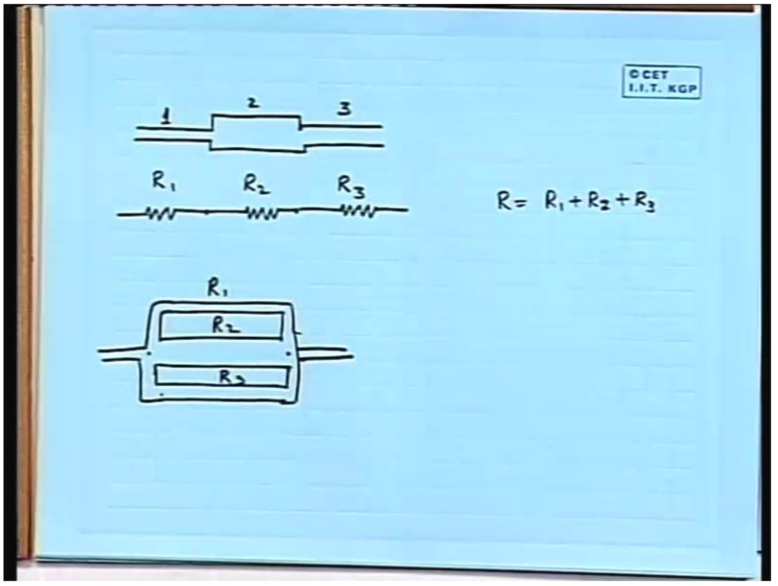

We have got a pipe line where we have got pipe elements like this. This is element 1, this is element 2 and this is element 3. We can assume that there are three resistances R_1, R_2 and R_3 and they are all in series. They are all in series and the equivalent resistance R will be R_1 plus R_2 plus R_3. Similarly, if there are three pipelines, one is like this, one is like this and one is like this, and they are connected, let us say, by some header. So here again this is R_1, R_2 and R_3. These three are in parallel, meaning that all are having the same head, but the only thing is that flow rates will be different through these pipelines. Just like our electrical network we can do the analysis that we can do in this case.

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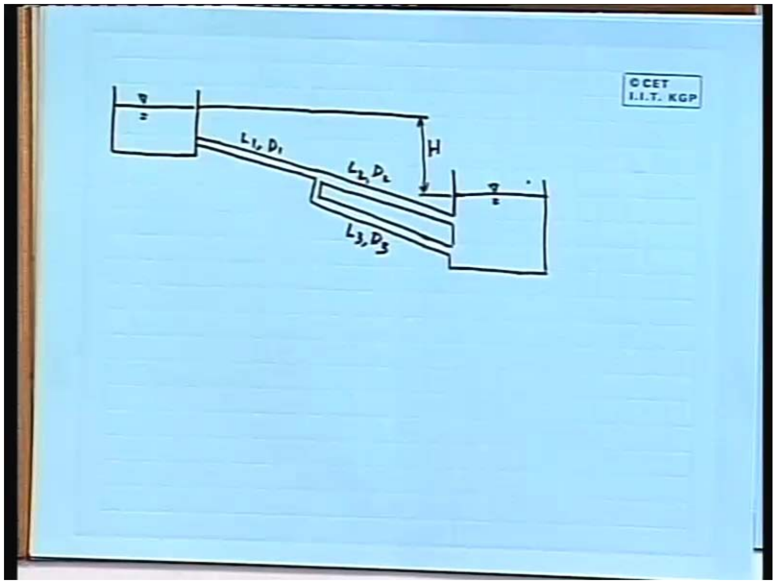

We take up a problem like this. We have got a pipeline and then let us say at some distance we have laid a parallel pipeline. Both are going to the same reservoir at same level. In a two dimensional diagram, it may appear that it is going to a different level but it is going to the same level, that is, they are having same length. It does not matter if it has different length. Let us say again we are having the head difference is equal to H. We are interested to determine how much fluid will be transported in this pipeline system. We are having parallel here and series here. Let us say all these are different pipelines; let us say it is L_1 D_1, L_2 D_2 and L_3 D_3. We want to find out what the flow rate from reservoir 1 to reservoir 2 is. How can we do this problem?

We can consider what is the total resistance is from there we can determine what the flow rate is. If you try to solve this problem just think over it; it involves lot of iterations. In case of any iteration, it depends on how intelligently we had the initial guess. So if we have made a good guess, within a few cycles we will have it converge, otherwise, we have to go for a number of cycles. A similar numerical problem we may take up when we will have the tutorial class and we may discuss this. I think that is the end of our discussion for fluid mechanics. We have got sometime so let us start our refrigeration and air conditioning.

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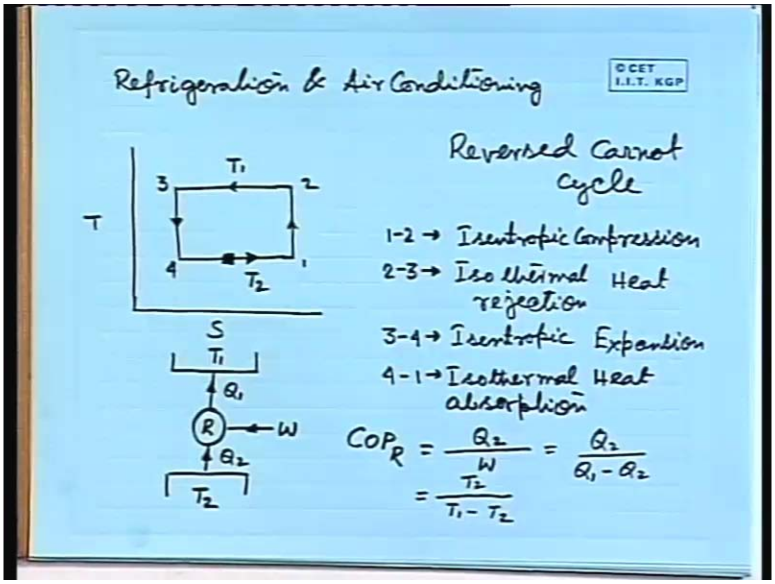

Refrigeration is creation of low temperature or creation of cooling effect. Though we can use the same principle for heating also with the help of heat pump but in general refrigeration means that we are extracting heat from some sort of a low temperature body; we are extracting heat. The basic principle of refrigeration, we can start from the reverse Carnot cycle. If a Carnot cycle can be used, that is the ideal cycle for heat engine cycle then a reverse Carnot cycle can be used as an ideal cycle for refrigeration. If we have the TS diagram of a reverse Carnot cycle, let me write it, If we have the reverse Carnot cycle and TS diagram of it, we will have these four points and four processes. 1 to 2 we will have isentropic compression; then, 2 to 3 what we will have is isothermal heat rejection; 3 to 4, I will have isentropic expansion and then 4 to1 I will have isothermal heat addition or heat absorption. So these are the four processes I will have. We can see the directions of the processes are just the reverse of our Carnot cycle for heating engine.

I can diagrammatically represent it like this. Basically, this is T_2, this is T_1; so let me write this is T_1, this is T_2 and we need some work to run this. So, this is your refrigeration cycle. It is between these two temperature limits T_1 and T_2 and we will have COP of refrigeration - coefficient of performance of refrigeration; so, COP_R I will have; the desired effect produced by the energy input, not heat input but by the energy input. The energy input is equal to W and desired effect produced, I am taking certain amount of heat which is Q_2; this is Q_1, so Q_2 by W. So, I can write Q_2 by Q_1 minus Q_2 and for reversible cycle I can write T_2 by T_1 minus T_2. I do not want to discuss regarding the heat pump but the same cycle can be used as heat pump cycle; only the COP definition or COP expression will be different, otherwise, the same cycle can be used as a heat pump cycle. Nowadays, heat pumps are becoming very prominent because of energy recovery and other usage. So, same cycle can be used. We can see that in principle, a Carnot cycle can be used as a refrigeration cycle and it will give you, for the given temperature limit, the highest COP.

What is the problem of Carnot cycle? Why cannot we use Carnot cycle as a practical refrigeration cycle? Let us see that.

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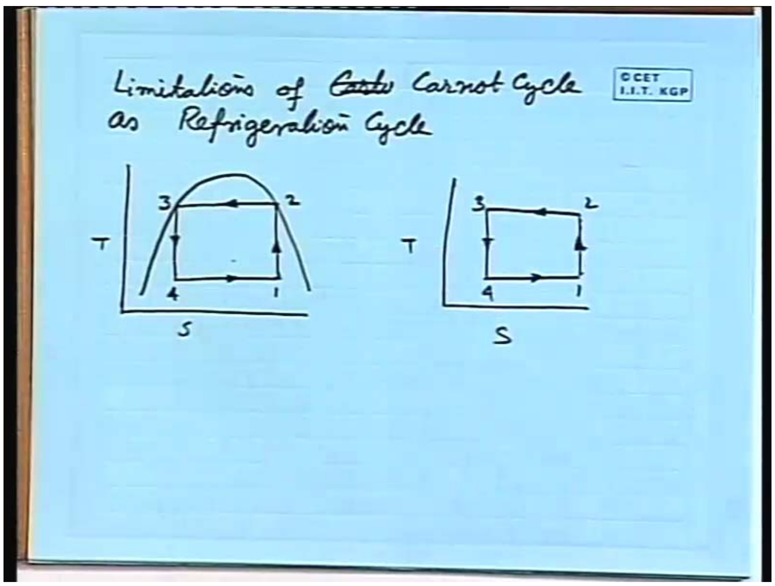

The limitations of the Carnot cycle as a refrigeration cycle: Let us say, we are using the Carnot cycle but we can use different type of working substance. We can use a two phase working substance where there is a change of phase during the cycle or we can use a gas as the working substance for Carnot cycle. Let us see these two cases separately.

If we use a two phase working fluid for reverse Carnot cycle, we have got TS diagram. We have got this two phase dome, any arbitrary fluid in two phase situation and then we have got 4, 1, 2 and 3. I have explained the Carnot cycle. We will have two isothermal heat transfer processes, one heat addition and one heat rejection. When I am having a two phase working fluid, two phase working fluid means there will be a phase change, so this heat addition and heat rejection processes are easy to achieve. They can be achieved as a boiling process or a condensation process. Here we can see this is a condensation process and this is an evaporation process. So, we will have the condenser here, we will have an evaporator here and these two are reversible adiabatic expansion process and compression process. This is the reversible adiabatic expansion process (Refer Slide Time 44:42) and this is reversible adiabatic expansion process.

We can see here, we are compressing a mixture of liquid and gas or liquid and vapour and we are compressing it such that at the end of the compression we are getting saturated liquid only. Here we are starting from the saturated liquid, we are expanding so that we are getting a mixture of liquid and gas, that too mixture of liquid and gas at a fixed proportion, at a given proportion. Both the expander design and the compressor design become very difficult. Practically, we cannot design such type of expander or compressor. In any practical compressor, if we have this type of design, the liquid refrigerant will collide with the valve and the piston head and it will make ……, damage and all these things. There is this difficulty and in this case also this type of expanded design is almost next to impossible, we cannot do it. That is why we will not be able to operate this thing as a reverse Carnot cycle, and that too if we design this type of thing we will see that a lot of work input is needed. We will not be able to do this.

In case of gas, if we design this, we have got a gas and we have got this 4, 1, 2 and 3. What happens in case of gas? When it is a single phase fluid isothermal heat addition and isothermal heat rejection becomes impossible. Whenever we add heat or whenever we reject heat, there will be some temperature gradient across which heat transfer will take place. So, this becomes very difficult. That is one thing. Another thing, also we will have lot of energy expenditure for the compression of the gas. Here, there is no concept of condenser because here we are taking gas only. But to create some sort of reasonable refrigeration effect we have to spend a lot of energy. First thing is that isothermal heat addition and isothermal heat rejection, we cannot realize. Then if at all we can make some sort of a cycle, to create some sort of reasonable refrigeration effect we have to spend lot of energy or we will have very low COP.

Here we will not have condensers or evaporator but some sort of heat exchanger we will have; those heat exchangers will be very large. As I have discussed earlier that here we need isentropic expansion and isentropic compression. So, here the process should be very fast. Here we need isothermal heat addition and isothermal heat rejection; here the process should be very slow. In a cycle, part of the processes I need it to be very fast and part of the processes I need it to be very slow. It is difficult to design. We can see that both for vapour as the working fluid and for gas as the working fluid, Carnot cycle or reverse Carnot cycle is not an ideal candidate for refrigeration, just like it was not a good candidate for heat engine cycle. We have to look for some other cycle.

In the next class, we will see what type of modification in Carnot cycle will give us good result.