Concepts of Thermodynamics
Prof. Suman Chakraborty
Department of Mechanical Engineering
Indian Institute of Technology, Kharagpur

Lecture - 36
Factors for Irreversibility and Introduction to Reversible Cycles

In the previous lecture, we were discussing about a Reversible process. But from the one example of reversible process that I put forward, you can clearly understand that reversible process is such a process which is so hypothetical that it might not actually occur in practice because of the extreme slowness of the process. So, in practice there are present Omni present factors that can make a process irreversible. So, let me identify some of the factors which can make a process irreversible.

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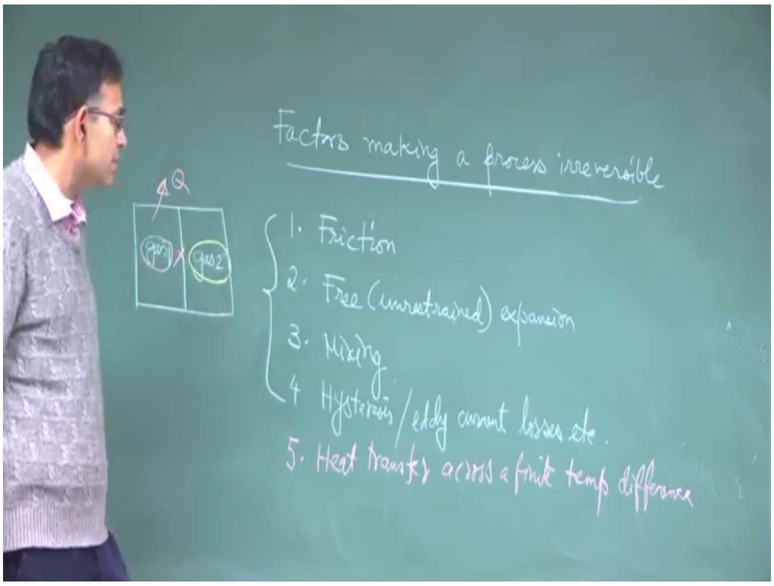

Friction; why I start with friction is because I have already given an example, why friction can make a process irreversible. Free or unrestrained expansion, mixing, non mechanical origin like his Hysteresis, eddy current loss etcetera and something very special which is little bit different from these categories, which I will write with a different color. Heat transfer across a finite temperature difference.

So, why this is of a different category? I will come to this in a moment. So, friction we have already discussed. We will come to free expansion. So, let us take an example, where you have a chamber. On one side there is gas and another side there is vacuum.

There is a thin membrane that separates these two. Suddenly, you puncture this membrane. Once you puncture this membrane, the gas fills up the entire space. So, this is called as free expansion because here there was vacuum there is no resistance against the expansion of this gas. Now, let us say you want to reverse this process. So, what you have to do? Now you have to put a compressor so that the volume of the gas is compressed up to this and then, put a chamber here and vacuum will be created here.

So, to compress the gas from this total volume to this volume, this is not a spontaneous process. So, you have to put some external work for it and when you put some external work for it. These gas will be more energized. So, it will be hotter as compared to the state at which it started. So, to bring it back to the same original state you have to transfer some heat to the surroundings. In the process the gas may come back to the original state, but the surroundings are no more back to the same state because of a net heat transfer to the surroundings. The next point is mixing and mixing is very much like free expansion, where here instead of gas and vacuum it is say gas 1 and gas 2.

So, when you have gas 1 and gas 2 and you remove the partition, they will spontaneously mix this does not require any work input. But to separate these two gases again, you require some work input like something like you know the Maxwell's demon type of thing that I talked about hypothetically in the previous class.

So, you require some energy you know to have a separation between gas 1 and gas 2. For example, in as a mechanical device often to separate a high density fluid from a low density fluid, we use a rotating device called a centrifuge. So, it creates a rotational force centrifugal force that separates the heavier fluid from a denser fluid. So, you require a some kind of external work to separate these two, but to make this you do not require any work that is the difference. Hysteresis is a eddy current losses are like friction in electrical and magnetic systems. So, their role in creating an irreversibility is like friction.

So, all these factors which can make a process irreversible and you can see that they are very commonly present like can you imagine a device without friction; you cannot. Without friction there is no real life situation. So, all real life processes are irreversible. So, then one important point is that when you are talking about these ones, they have a special significance. What is the special significance? Special significance is that the source of irreversibility is within the system itself.

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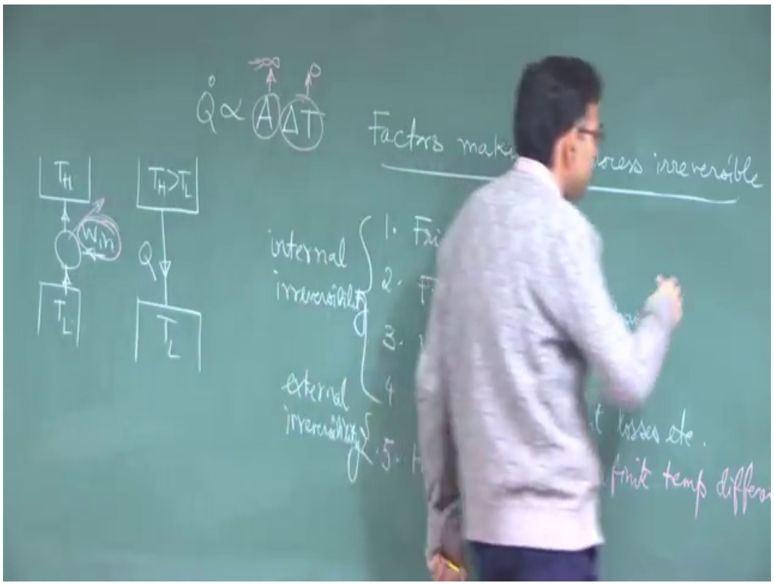

And therefore, this is called as internal irreversibility. When we talk about heat transfer, heat transfer is always you know some heat exchange between system and surrounding. So, it is not so only involving the system, it also involves the surrounding. So, heat transfer across a finite temperature difference is something that can make a process irreversible. We will first understand why and then, we will put it in for a different category which is external irreversibility. So, first why heat transfer across a finite temperature difference is irreversible? So, let us say that this is that heat source at temperature T H greater than T L.

So, if you put these two bodies in thermal contact spontaneously there will be a heat transfer from the high temperature to a low temperature body. This is spontaneous. Now if you want to bring this heat Q back from here to here that is not spontaneous; so, to do that you have to have an arrangement. What is the arrangement? The arrangement is you have to put a device which will have work input and then, only in a cycle you have heat transfer may be the same heat transferred back from these two. So, when you have this same heat transfer here back, you are also adding a net work to the system.

So, when you are adding a network to the system, the system now has more energy as compared to the state at which you know it was there when there was a spontaneous heat transfer from here to here. So, to release that energy so that the system comes back to its original state, what you have to do? You have to get rid of these heat, this work, this energy that you have put through heat transfer. If you do that, the system will come back to its original state, but the surroundings will not come back to the original state.

So, moral of the story is that because this work input is required to reverse the process that will impart additional energy to the system to bring it back to the original state, you have to release that energy through heat transfer to the surroundings. How much is that energy? That energy depends on the temperature difference between T H and T L. So, if T H and T L are very close, then this energy input is very little and then it is almost reversible.

So, what we can understand from here is that if you transfer heat across a very small temperature difference, then actually you are almost approaching a reversible heat transfer. But the problem is this is not practical; why? The heat transfer rate Q dot is proportional to the areas across which heat transfer is taking place and it is proportional to coefficient and it is; I am not let us not come to the coefficient because I still keep it proportional and it is proportional to delta T. The proportionality is replaced with an equality with a coefficient called as heat transfer coefficient. I am not coming into that. So, my point is that the heat transfer rate is proportional to area of for heat transfer and it is proportional to delta T.

So, what it means is that if delta T is tending to 0 for finite heat transfer, this must tend to infinity right. So, you must have say an infinitely large surface area of a boiler to have a reversible heat transfer. So, that is something that may not be possible. Practical engineering constraint is that you have a limited area over which you can build up your heat transfer devices; limited surface area. So, all the practical heat transfer processes are irreversible. So, this being a source of irreversibility external to the system; you can imagine this as a system. So, external to the system because heat transfer is taking place external to the system this is called as externally reversible.

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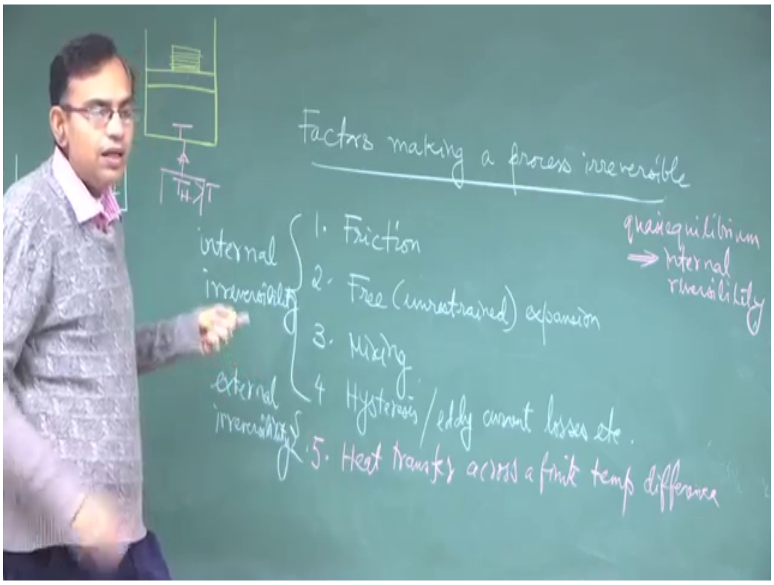

So, quasi equilibrium process will ensure internal reversibility, but it does not ensure external irreversibility; external reversibility. For example, let me give you one example. So, you have a cylinder in which you have a piston. This piston moves very slowly with you knows successive addition or removal of this weight. But it is exchanging heat with a reservoir T H and here the temperature is T and T H is greater than T.

So, this heat transfer we will make the process undertaken by the fluid between the piston and the cylinder effectively irreversible; although it is internally reversible which is due to quasi equilibrium nature of the process, but it is externally irreversible and because it is externally irreversible either externally or internally reversible means the net process will be reversible.

In thermodynamics, there are certain types of processes where certain physical and mathematical inferences can be drawn for which it is sufficient that the process is internally reversible; externally irreversibility is not into purview while developing those theories and those are called as internally reversible or endo reversible processes; either internally reversible or endo reversible processes, where external irreversibility is not under the purview. It is the internal reversibility that is what is ensured.

So, with this basic understanding of reversible processes, we will imagine. So, reversible is something which is ideal right. So, we will imagine; now, a cycle which comprises only reversible processes.

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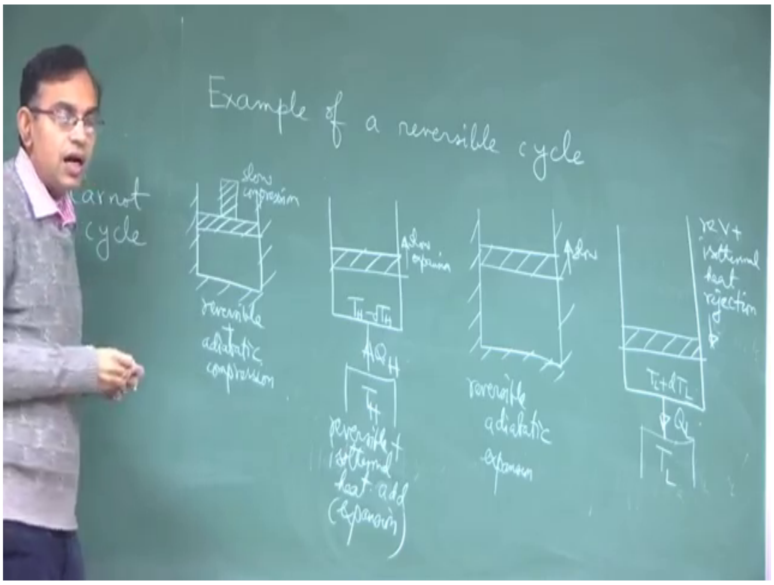

So, example of a reversible cycle.

Student: Internally as well as externally?

Internally as well as externally. This is a complete reversible cycle. So, let us say that you have a piston cylinder arrangement. You compress this very slowly, slow compression; some gas is there and you insulate this. So, if it is slow and you insulate this; so, there is no question of external irreversibility because heat transfer is 0. So, it is adiabatic and it is slow. So, quasi equilibrium is assured. So, it is internally reversible plus externally reversible. So, we can say that this is reversible plus adiabatic compression. Next what we do is that the same piston cylinder.

Now, we take away the insulation, before that let me tell you a very interesting thing. When I was a school student, the way in which adiabatic process was explained to me was something like this. That adiabatic process is such a fast process, where there is insufficient time for heat transfer. So, that you know effectively the heat transfer during the process can be neglected. So, that is definitely true as an example of an adiabatic process. But you can achieve adiabatic process in many ways. So, sometimes that first level of information that you gather from school level study it becomes so emphatic that you lose the perception that well that is true, but that is just an example.

Another example of reversible process; another example of adiabatic process could be that you instead of very fast, you can have something very slow; diametrically opposite, but you put an insulation around the cylinder. So, that there is no heat transfer ok. Then, next is you take away these insulation and transfer some heat from this heat source reversibly to this allowing it to slowly expand. So, to have reversible process, what kind of heat transfer you should have? You should have heat transfer with minimal temperature difference between these two. So, infinitesimal; so these temperature at the system boundary will be say T H minus d T H.

In books we normally do not write d T H because this is differentially small, but conceptually this is if this is T H this is T H minus d T H. If both are T H you cannot have heat transfer because heat transfer requires a temperature difference. So, with this and the temperature of the entire system during this slow expansion remains constant which is T H minus d T H. So, for all practical purposes d T T H, this is reversible isothermal heat addition and in this process, it will expand right. If you heat, it will expand in a reversible adiabatic process. So, this is the expansion.

Then, we put back the insulation again and keep on expanding it slowly. So, this is reversible adiabatic expansion. So, after all these expansion; so all these are reversible processes. After all this expansion, you know the gas in terms of pressure volume temperature is not at the same initial state. So, to bring it back to the initial state you require another process and that process has to be heat rejection. So, that so that you know it can get compressed and come back to the original state.

So, in this process, it will reject heat. So, if this is T L. So, this is Q H. If this is Q L, then this what is this temperature? This is T L plus d T L. So, this is reversible plus isothermal heat rejection; reversible plus isothermal heat rejection. So, you have a cycle in which the fluid operates between two temperature limits and does a network. So, it satisfies the Kelvin Planck statement. Essentially the cycle has 2 reversible adiabatic processes and 2 reversible isothermal processes.

So, this kind of cycle, where all the processes are reversible is a reversible cycle and there could be different reversible cycles. This is an example of a reversible cycle; when two of the processes are reversible adiabatic and two of the processes are reversible isothermal. This cycle is called as the Carnot Cycle. Keep one thing in mind Carnot cycle is not the only reversible cycle in the world. So, this is just an example of a reversible cycle, but there could be several other reversible cycles all hypothetical, but still possible where all the processes comprising the cycle are reversible. Carnot cycle is a special example of a reversible cycle, where two processes are reversible adiabatic and two processes are reversible isothermal and these 4 processes comprise a cycle.

Now, I started with an example of a Carnot Cycle with an understanding that you know this gives you transition from school level understanding to you know more advanced understanding in concepts of thermodynamics. But in practice there could be other examples, where Carnot cycle could be a cycle involving a flow process instead of a control mass system. Here, the substance undergoing the cycle is a control mass system. So, I will now give you an example where the Carnot cycle can be conceptualized for a flow process.

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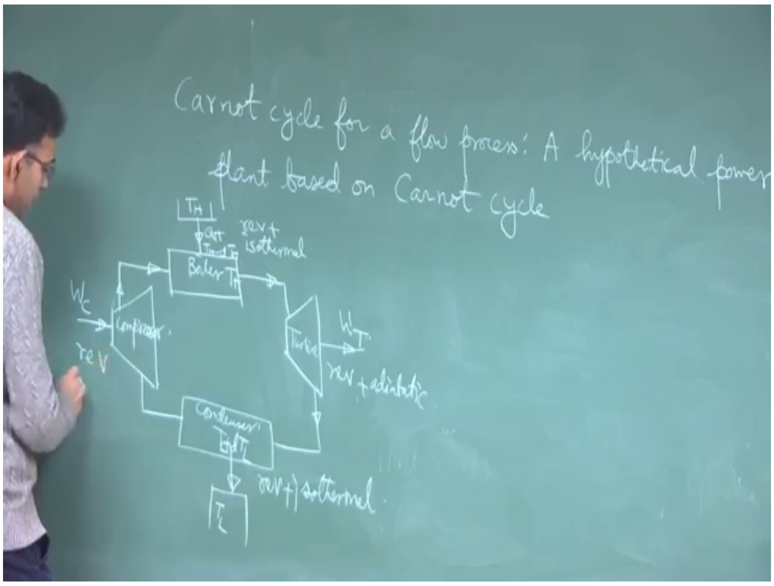

A hypothetical power plant based on Carnot cycle. So, to understand that see we have already through the first law of thermodynamics steady state steady flow processes what introduce two different types of devices like boiler, turbine, condenser, compressor. So, we will combine all those to form a cycle. So, what we will do is we will draw a diagram say you have a Boiler at temperature T H; how do you maintain the boiler at a constant temperature T H? Very simple, you allow the water by heating to get converted into steam. So, from water to water vapor, it will change its phase at constant temperature because water is a simple compressible pure substance.

So, there is a heat source at T H. So, the there will be a heat transfer to the boiler. So, this is T H minus d T H; then from the boiler, fluid enters the turbine that fluid undergoes. So, this is reversible plus isothermal, then the fluid undergoes are reversible and adiabatic expansion in a turbine and there is an work output. So, this is reversible plus adiabatic, then the fluid enters the condenser and it rejects heat so that you know steam condenses and typically there is a river, water to which it rejects heat. So, if this temperature is T L. This is if this is T L; this is T L plus d T L.

So, this is condenser and then, now the fluid is at a lower pressure because after expansion in the turbine the pressure has reduced. So, it requires a compression process. So, this is compressor which requires. So, I will not write W net here; I will write W turbine which is the work output and there is a work input which is the compressor work. So, the net work is W turbine minus W compressor that you get from the cycle and then it n it is back to the boiler. So, this is reversible plus isothermal. This is reversible plus adiabatic compression.

So, what we can gather from this example is that this is a flow process right. So, this is not a control mass system undergoing any process, but still out of the 4 components which constitute this cycle, you have two processes which are taking place at reversible isothermal condition and two processes at reversible adiabatic condition. So, by definition this is also a Carnot cycle.

Now so far so good, but we will see later on that why practically it is impossible to set up such a cycle in a thermal power plant. When we will study the thermal power plant cycles towards the end of this course, we will revisit that, but you know even though we cannot practically construct this; this remains like a benchmark. So, that you can compare the performances of various cycles; practical cycles with respect to this ideal, but still very hypothetical.

We come to a conclusion of today’s discussion here and in the next lecture, we will learn two things; one is what are the constraints governing the efficiencies of reversible and irreversible cycles operating between two given temperature limits and number 2, based on that how we can construct an absolute temperature scale independent of the properties of a thermometric substance. These two things we will take up in the next lecture.

Thank you very much.