Steam Power Engineering

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Lecture -01
Review of Thermodynamics

Welcome to the class. Here we are going to deal in this course as discussed we will be dealing with the course on steam power engineering. This course basically is a part of applied thermodynamics so as a prerequisite we will have partially today discussion on review of thermodynamics. And then we will go towards the initial part of the steam power plant and there we will see what else is a steam power cycle and rest of things okay. So, we will start our class with a review of thermodynamics.

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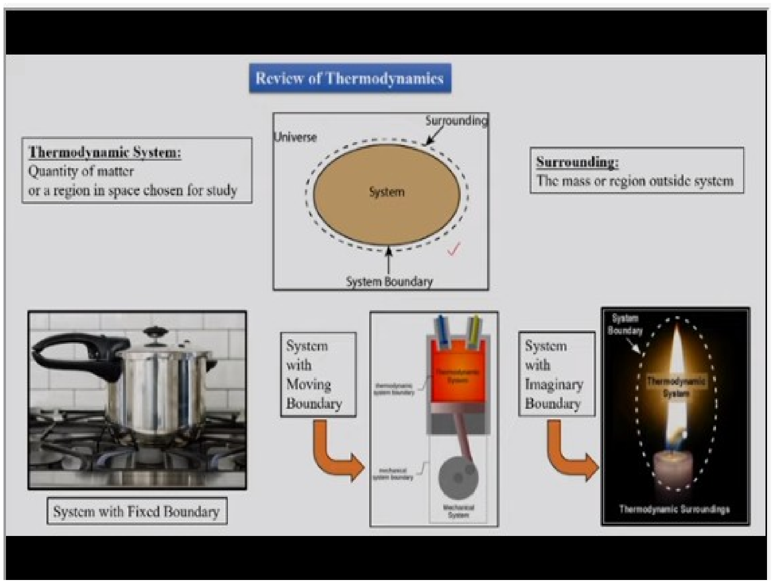

As we know in thermodynamics we have some definitions initial definitions and in those initial definitions we have first definition as thermodynamics system. So, what do you mean by thermodynamics system? We mean that it's a fixed quantity of matter or a given volume in space which is of our interest for study this is what the thermodynamic system is. And then we have definition of surrounding so whatsoever is not a system the rest of the things in the universe is surrounding.

Then a typical sketch of a system is like this so we have system here which is shown in inside in the ellipse and then we have the surrounding outside the system. But then system and surrounding together would comprise an entity which is called as universe. So, universe is system plus surrounding so for fixed thing for the example we have system with fixed boundaries.

As stated over here the ellipse shown in the figure is said as system. And then the dotted line dotted ellipse in this diagram in this diagram is basically the system boundary. But this system boundary can be stationary or can be moving so this a cooker; pressure cooker is an example of fixed boundary system. And then we have moving boundary system in case of a typical internal combustion engine the piston would move inside the cylinder and this motion of the piston would create different volumes at different instances.

So, if at all we consider cylinder as a rectangle but one side of rectangle is moving so one boundary of the cylinder is moving. So, in that case this becomes a systems example with moving boundary. But then there can be system where we do not have a fixed boundary we will have to imagine a boundary of a system and as an example of a candle. In case of a candle if candle flame is our system is our topic of study is our focus then we have to draw a arbitrary boundary around the candle flame to define who is our system.

So, system is define by the user or is by defined by the engineer or scientist as per its topic of study. So, it can be a fixed mass or it can be a fixed volume in the space.

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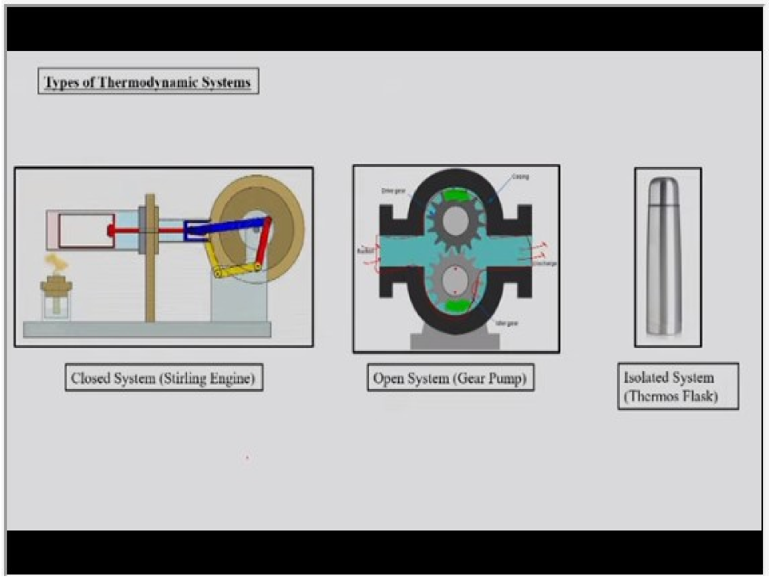

So, what are the types of systems; so types of systems would be as one of the types is closed system. So, here in this figure we can see that there is a cylinder in which piston is oscillating in which piston is moving and then there is some lamp which is passing heat to the cylinder. In this case basically heat is supplied to the system which is a closed system so this system is a closed system where we do not have any interaction other than energy which is possible in this system.

So, example of closed system is a as in last case and then last figure we have seen that pressure cooker. It's an example of closed system or in this cycle or in this example as it is shown that closed system can be an example where in case of sterling engine. Then we have open system in case of open system not only energy interaction is possible but also mass interaction is possible with the system.

So, here we define system as the boundary of this gear pump this boundary of gear pump is our system. So, since this boundary of gear pump is our system there is mass coming into this gear pump there is mass leaving out of this gear pump. And since mass is entering and mass is leaving there is mass interaction of the system with the surrounding and in this case such system act as an open system okay.

But there is possibility that we would neither have mass interaction nor have energy interaction so such system which would not interact with mass or energy with the surrounding then it is called as an isolated system and example is thermos flask. So, thermos flask that is why we know that it will keep the temperature observe thing whatever it is kept inside as constant with time.

Since there is no possibility of heat exchange or neither there is possibility of addition of some external things into the thermos. Then as we have defined something as system we have to define the system along with its properties. So, what do you mean by properties of system? So properties of system means characteristics of the system. This is required to describe a system as what we describe when we have, suppose a mobile; then we say that this mobile has a camera of this much megapixel, this mobile has RAM of this much GB.

We define something for computer saying that this has screen, monitor of this size and this has hard disk of this size. So, these things are used to describe the computer or maybe mobile so same thing here we want to define our system so describe our system. So, while describing our system we have to take help of the properties of system.

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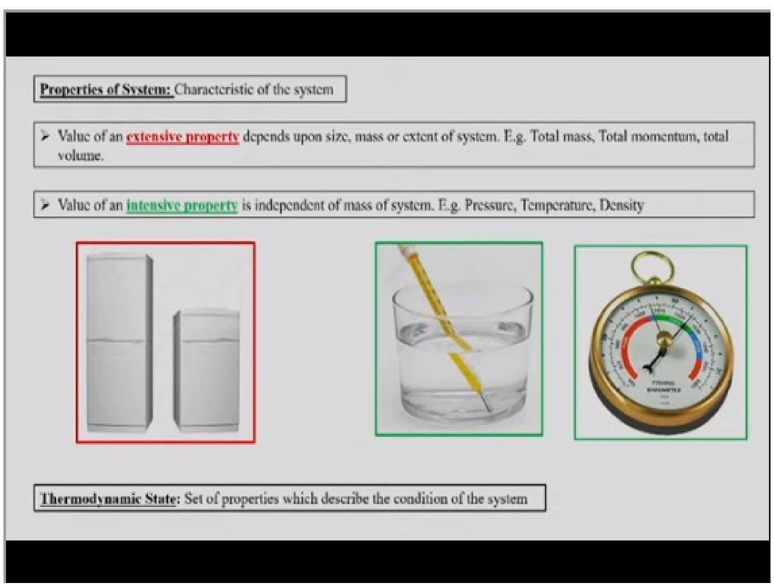

So properties of system are the characteristics of the system. If value of the property of a system is dependent on size or mass or extent of the system then it is called as extensive property of the system. Example is total mass, total momentum and total volume. So, if I say that a room is our system then room can be bigger or room can be smaller volume of room would get changed accordingly.

So, total volume is dependent upon the size of the system; total mass also equally would be dependent on the extent of the system. So, as you can see here if refrigerator is our system then there can be a small refrigerator or there can be a large refrigerator. So, size is dependent here for defining the system size is required, to define a system. Then if value of the property is not dependent on size of the system or extent or mass of a system then it is called an intensive property of the system.

And we know that example is temperature, pressure or density. So, temperature if we take a bucket of water and immerse thermometer in that bucket then we will measure certain temperature and we remove half bucket of water and then measure temperature of half bucket of water then we will see that the temperature is same. For full bucket and for half bucket since temperature is not property not a property of a system which is dependent on extent or mass.

It's an intensive property which is not dependent on size or mass of the system; same is the case for pressure. So, all the properties generally are specified if they are specified as per **(09:12)** then they turned out to be intensive property of a system like specific entropy, specific enthalpy, specific internal energy so thermodynamics state. So, here once we got some characteristics of the system which are helpful to describe a particular system then we will describe our system.

And then that set of properties used to describe the condition of the system is called as thermodynamic state of a system. We say that this system has these set of properties then accordingly systems thermodynamic condition is defined.

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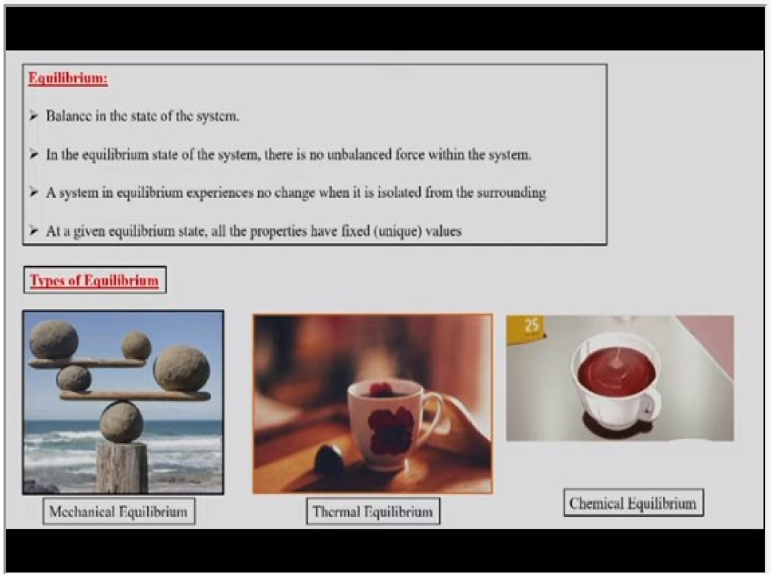

But while defining thermodynamic condition or equally or state of a system we have to take care for one thing which is equilibrium. So, equilibrium is balance in state of a system means that in the equilibrium state, there is no unbalanced force which is going to act in the system or on the system. A system in equilibrium experiences no change and when it is isolated from the surrounding.

If there is a system and it if it has property same within inside and if it isolated from the surrounding then there will not be any change in property of the system with time. In a given equilibrium state all the properties have fixed or unique values. So, on this case we can see that there are types of equilibrium as we know there is a mechanical equilibrium, there is a thermal equilibrium and then there is a chemical equilibrium.

We have mentioned a point that system is in balance state. So, equilibrium is **specially** means it's a balance state. So, if it is a mechanical equilibrium then the forces are balanced, if there is a thermal equilibrium then there is a balance with the temperature of the system within the system or may be with the surrounding. If there is a chemical equilibrium then there is a composition balance with the system such that within the system there is no movement.

If pressure is not seen within the system then there will be movement of the fluid from high pressure region to the low pressure region within the system. So system becomes unstable and it will equilibrate over the period of time such that only one unified pressure would exit in the system. Similarly is there is difference in temperature within the system as what we can see in case of mirage.

So there will be high temperature on the ground and due to high temperature there will be low density so low density mass would go up. Since there is a low density mass is of high temperature the temperature of the fluid at certain height on the earth is at low temperature. So high temperature fluid will go to the low temperature fluid as in such churning will take place due to temperature difference which is what we called as natural circulation; god natural convection.

So there has to be a temperature of unique value for definition of a system in thermal equilibrium. Similarly, as what we see in case of a scented stick or in case of a tea. So, if we you have a teabag placed in a hot water then we will see that if it is red tea then the red portion would be very much concentrated near to the teabag but if we try to mix it then whole the water will become red.

Similarly, we know that in case of chemical equilibrium system has to have unified or unique composition of the matter within itself. So in all, if system is in mechanical equilibrium, thermal equilibrium and chemical equilibrium together then such system is called as the system in thermodynamic equilibrium.

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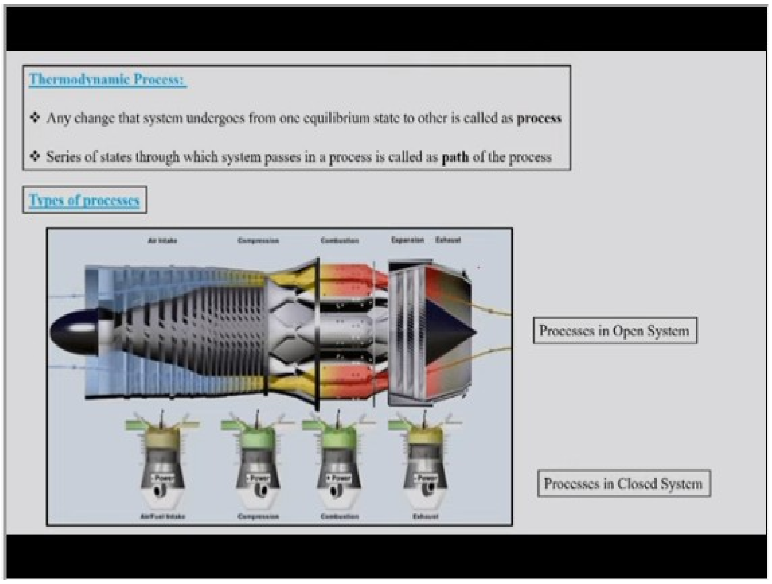

When system is in thermodynamic equilibrium we define its state by prescribed properties of the system. But by some means we have thermodynamic process and in the thermodynamic process we mean that there is change in the state of the system from one equilibrium to other equilibrium. So, process is defined as change in state of the system from one equilibrium state to other equilibrium state and then such process can be following any path.

So, the states through which the system will be undertaken in the classical process is called as path of a process. Then there are different types of processes as what we can see here in this case there are; there is a gas turbine on top and then there are 4 arrangements of piston and cylinder. So the top portion should be viewed as open system the bottom portion should be viewed as a closed system for the application which is called as processes on the system.

We know that in the gas turbine there is a compressor to start with so there will be compression process in the compressor. But in case of closed system in the piston cylinder arrangement pistons motion upward would compress the gas. So, compression pressures in open system would be undertaken by the compressor but it is undertaken by piston cylinder arrangement as we can see here in this piston cylinder arrangement.

Then there is a process of heat addition which is going to take place in the combustion chamber of gas turbine engine. So, here we are having combustion chamber for heat addition but in case of IC engine internal combustion engine of piston cylinder type there will be fuel injection and in that fuel injection would lead to combustion. In case of open cycle gas turbine plant we see that there is expansion in the turbine and this expansion would take place through some set of turbines.

But in case of piston cylinder arrangement downward motion of the piston would retain would end would lead to expansion stroke. Further there is a expansion in the nozzle also in case of gas turbine part. So, as what we see compression is a process, expansion is a process, heat addition is a process; similarly heat rejection would be the process. These are the processes which are based basically upon work and heat interaction the compression and expansion processes.

As what we can see in turbine and compressor there are they are work interaction process; expansion process in the nozzle is non work interaction process. Similarly, combustion is a process where we are having interaction of heat with the system. So, in general there are processes which are named as isentropic process where the process would retain the systems entropy throughout its path.

Similarly, the process is called as isobaric process in which system would retain its pressure through from the start to the end. Then there is isochoric process where system would retain its volume from start to end. Similarly, there is a process as what we can see in the throttling or in refrigerator it is called as isoenthalpic process where system would retain its enthalpy during the process.

So, there are different names of the process based upon the properties what are going to remain either constant or what are the properties which are going to be focused on the under the action of the system.

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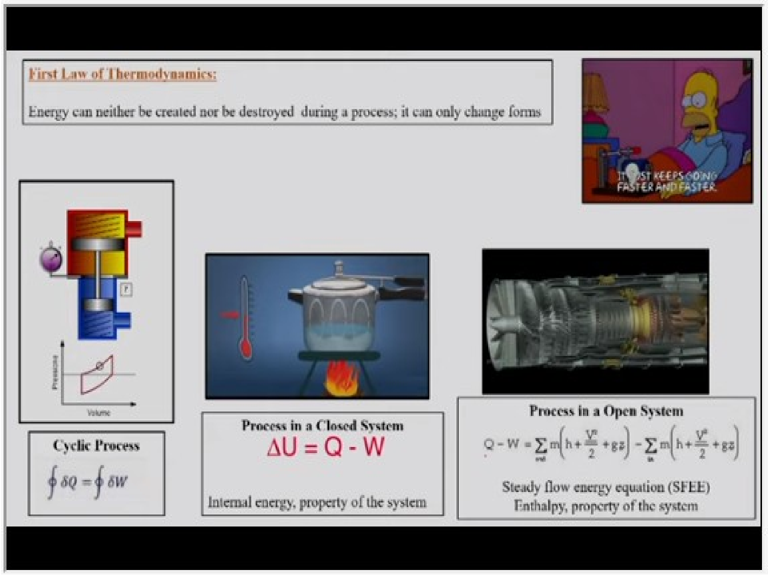

So, we have first law of thermodynamics; energy as we know this is the law for energy and which states that energy can neither be created nor be destroyed but one form of the energy can be changed into other form of energy. So it is not possible to generate any energy. So we have to actually consume energy to have one form of energy gets converted into another form of energy. So, as what we can see that in case of cyclic process; cyclic integral of heat is equal to cyclic integral of work.

So, we have to add certain heat into the system and then we might have to reject certain heat from the system so net heat addition and heat subtraction is equal to net work addition and net work subtraction. This is what when we apply first law of thermodynamics to the cyclic process. But we can as well apply first law of thermodynamics to a process which is non cyclic so in such case if we apply to a closed system.

Then if we take a particular example of cooker where we are supplying heat to a pressure cooker then there will be suppose water or food element inside the cooker then it would change its internal energy by the virtue of the heat addition. In this particular case we would not have any work interaction but in a closed system there is possibility then there will be work interaction by motion of system boundaries since this is a closed system with fixed boundary.

Similarly, if we apply first law of thermodynamics to an open system then as contrary in the closed system heat addition minus work; heat interaction minus work interaction what change in internal energy. Similarly, here heat and work interaction there subtraction leads to change in total energy of the system between inlets and outlets. So what are the different energies we would have to consider at the inlet; we are to consider enthalpy of the system.

Then we have to consider a kinetic energy of the system and then we have to consider potential energy of the system. And then we have to consider the as many inlets as what we can have and they will have different mass flow rates to those inlets so enthalpy plus specific kinetic energy plus specific potential energy obviously specific enthalpy then they will be summed into mass flow rate from that specific inlet.

And such summation for all inlets would lead to total energy contained in the inlet. Similar summation would be done at the outlet then that can be equated to heat addition and work interaction of the system. We know in thermodynamics we follow a sign convention that heat addition to the system is positive it release from the system or systems heat rejection is taken as negative work done by the system is taken parallel as positive and work done on the system is taken as negative.

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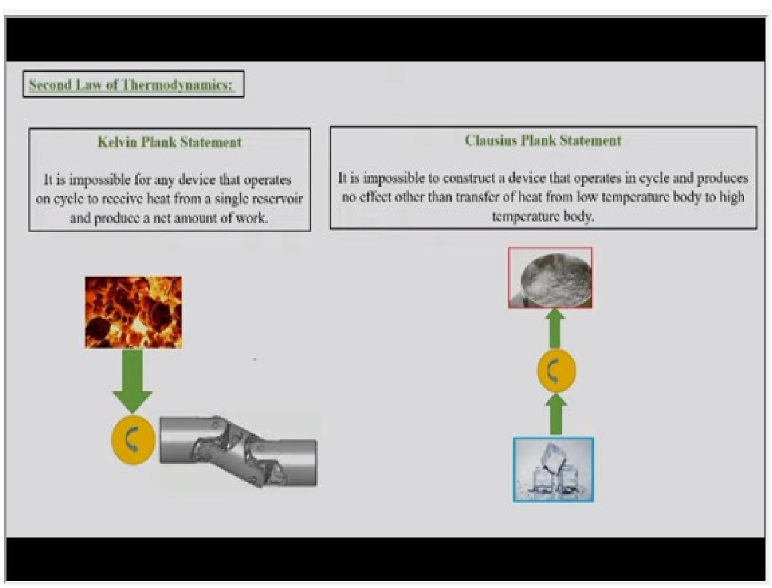

Then we have second law of thermodynamics as per the second law of thermodynamics we have two statements. Very first statement is Kelvin Plank statement it says that it is impossible for any device that operates on a cycle to receive heat from single reservoir and produce net amount of work. Means insist this laws states that if we want to work in a cycle and if you want to produce some work then you have to take the heat and also release the heat you cannot just release the heat just take the heat and do complete heat energy conversion into work is not possible.

This is the brief discussion of Kelvin Plank statement of second law thermodynamics. Parallelly, there is Clausius statement of second law of thermodynamics; it states that it is impossible to construct a device that operates in a cycle and produces no effect other than heat transfer from low temperature to high temperature. So, as it is shown in this figure we have ice at one end and we are boiling water at the other end but it is not possible for us to fetch the heat from ice and put it into the case where we want to heat the water.

If we are not having any other interaction and only heat interaction is possible it is not such thing is not possible. So, second law of thermodynamics add just and shrinks into these two laws one is Kelvin Plank's statement another is Clausius statement.

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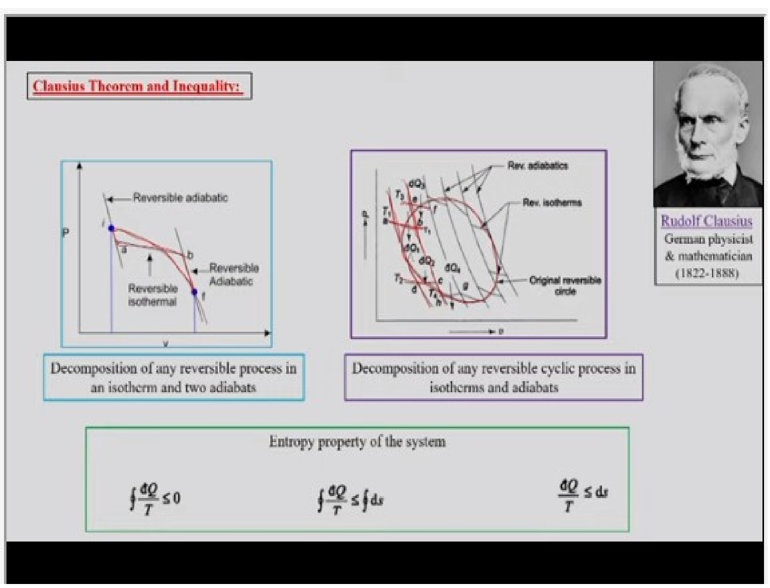

Then we have Clausius theorem and inequality. So, Clausius inequality states that $\oint \frac{dQ}{T} \leq 0$; basically $\left(\frac{dQ}{T}\right)$ would be defined a change in entropy(ds). So$\frac{dQ}{T} \leq ds$ for a system in a cyclic process. But in a non cyclic process $\frac{dQ}{T} \geq ds$; this $\frac{dQ}{T}$ term is related with entropy transfer.

But if system undergoes a reversible process then total entropy changes $ds = \frac{dQ}{T}$ which is only entropy in transfer. But if system undergoes an irreversible process then $\frac{dQ}{T} \neq ds$; then in that case we will have some entropy generated due to the irreversibility of the process. So, we will have basically $\frac{dQ}{T} + s_{gen} = ds$. One more important fact from Clausius theorem an inequality is any process which is reversible we can decompose that process into an isothermal process and two adiabatic processes.

Here $i-f$ is a process as per this figure $i-f$ is a process which is an arc and this arc process is getting $i-f$ is a process. This process is getting decomposed into 3 processes $i-a$ and this $i-a$ is a reversible adiabatic process. Then we will have process $a-b$, then this is isothermal process and then we have process $b-f$ which is adiabatic process again. So, any reversible process can be disintegrated into an isothermal process and to adiabatic process this is very much required for us.

This fact if we apply for any closed process cycle or for a cyclic process then we can see that any any cyclic process can be decomposed into 2 isothermal multiple processes which would multiple cycles. One cyclic process can be decomposed into multiple cyclic processes where one cyclic process of this decomposition would have 2 isothermal processes and 2 adiabatic processes.

So, as what we can see here that this **abrupt** shape is a process of our interest and this is getting decomposed using multiple adiabatic processes like this and isothermal processes like this. So, we have in a particular case this as adiabatic process, this as isothermal process, this is adiabatic process and this a isothermal process. So, this is 1 such cycle, this is 2 such cycle, this is 3 cycle, 4 cycle and 5 cycle. Our basic cyclic process will gets decomposed into 5 cycles where each cycle has 2 isotherms and 2 adiabats.

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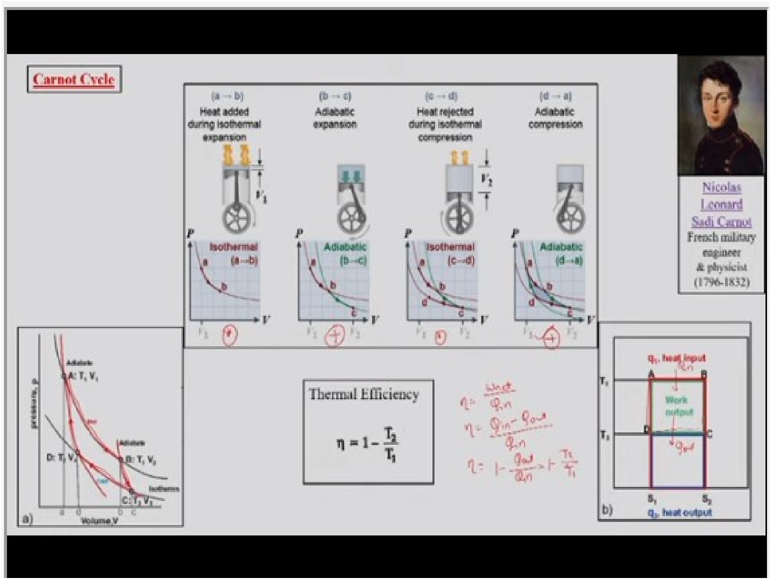

Then we have basically the Carnot cycle and this is what the origin of discussion for the Carnot cycle. We know that Carnot cycle has 4 processes where first process $a-b$ is isothermal process, then process $b-c$ is adiabatic process, process $c-d$ is again isothermal process and process $d-a$ is the process which is adiabatic process. So we have isothermal process $a-b$ and then we have so isothermal process $c-d$ then we have adiabatic process $b-c$ and then we have adiabatic process $d-a$.

So there are again going back we can see that we have said that any cyclic process gets decomposed into 2 sets of isothermal processes and two sets of adiabatic processes. So basically here we mean that any cyclic process gets decomposed into multiple Carnot cycles so this is what we had meant in this diagram. So, we have PV diagram for Carnot cycles where process $a-b$ is an adiabatic process, process $a-b$ is an isothermal process like this first $a-b$ is an isothermal process, process $b-c$ is an adiabatic process, process $c-d$is an isothermal process and process $d-a$ is again an adiabatic process okay.

But if we try to go in case in $T-s$ diagram then $a-b$ is an isothermal process straight horizontal line, $b-c$ is an isentropic process since the process is adiabatic. And then reversible it's an isentropic so vertical line, then $c-d$ is again isothermal process horizontal line and $d-e$ is a reversible adiabatic which is isentropic process. So practically $T-s$ diagram would look like either a square or a rectangle in case of Carnot cycle.

So we know that efficiency(η) is generally defined as $\eta=\frac{W_{net}}{Q_{¿}}$ but as we know from the first law of thermodynamics W_{net} is total heat interaction. So total heat interaction is basically $Q_{¿}$ and Q_{out} as per sign convention we have $W_{net}=Q_{¿}-Q_{out}$. So efficiency is generally

$\eta=\frac{Q_{¿}-Q_{out}}{Q_{¿}}=1-\frac{Q_{¿}}{Q_{out}}$ as per the application of second law of thermodynamics we can write out this in terms of $\eta=1-\frac{T_2}{T_1}$.

Since from the second law of thermodynamics we know that $\frac{Q_1}{Q_2}=\frac{T_1}{T_2}$

Or $\frac{Q_1}{T_1}=\frac{Q_2}{T_2}$; so we have this formula for efficiency of Carnot cycle.

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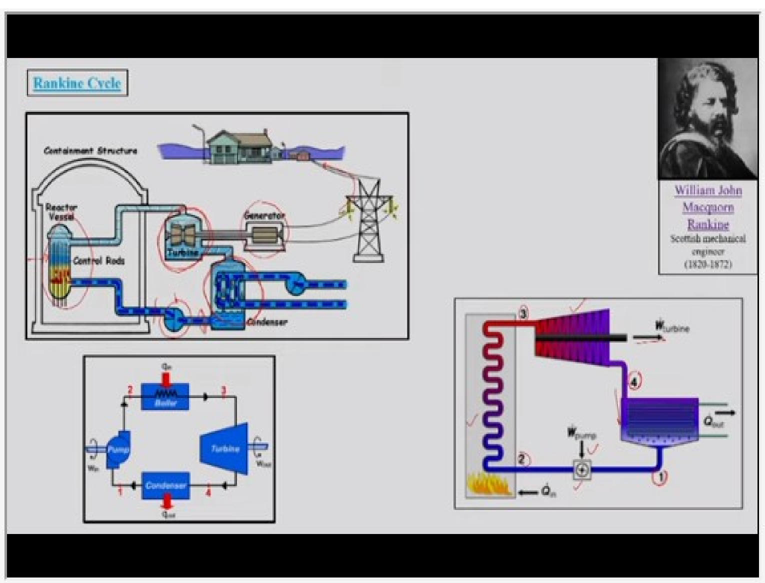

Then this is the basic topic of discussion of our course and it is the Rankine cycle; Rankine cycle is basically a power producing cycle where it would have basically 4 components where our interest is mainly to generate in most general case as generation of electricity. So, we would have a generator which is generating electricity and that electricity would pass to the consumers. But to rotate the generator or to move generator we have to first generate the mechanical power.

In this case we first have pump in the Rankine cycle the pump will take water from low pressure to high pressure once water goes to the high pressure then this is called as a steam generator or boiler. So, here pump has taken the liquid water and it would increase the pressure of liquid water so pump entry is liquid, pump outlet is also a liquid.

And then in the steam generator or boiler we are liquid as the entry but at the outlet will get vapor as the outlet, in some format may be saturated or may be supersaturated. Then this vapor would go onto a turbine which is high pressure and high temperature vapor going over the turbine and rotating the turbine while getting expanded and then in the process of expansion the steam loses its enthalpy, its energy content and it would come down to the low pressure.

And hence it would come down to low enthalpy where it would come close to the saturation steam point. Then this cycle being a closed cycle it would need again same amount of liquid water at the intake. So we have a condenser here and that condenser would condense the complete steam into the liquid water and then this liquid water will be again passed to the pump. So, this is the cyclic process in which basically while the flow of steam takes place into the turbine.

Turbine rotates and this rotation of turbine generates mechanical energy and this mechanical energy is supplied to the electrical generator where this electrical generates electricity and this electricity gets transferred to the industries or to the household applications so this is the practical Rankine cycle. So, Rankine cycle has pump which executes the pressure rise of water so it’s an isentropic process where we have adiabatic compression reversible adiabatic compression of water in the pump.

Then we have steam generator or boiler, here we will have constant pressure heat addition taking place for the conversion of liquid water to steam. Then we have turbine which deals with expansion and this is again an isentropic expansion of turbine and then we have condenser where we have constant pressure heat rejection to condense the steam to liquid water. So, this is the general representation of Rankine cycle where as what we said process $1-2$ is to pump where pump would rise the pressure of water, process $2-3$is into the steam generator or boiler where it will support for constant pressure heat addition.

Then process $3-4$is into the turbine where turbine would lead to expansion of the steam and then this is work interaction process or work producing process where turbine will have some work output as contrary to the pump where pump is pump; pump is work absorbing unit. Then process $4-1$is going to take place in condenser where condenser would take away the heat of the water so that it would steam so that it would become liquid water so this is a schematic of the Rankine cycle.

Then there is one more type of schematic which is generally drawn in case of Rankine cycle where we can see $1-2$is a pump; $1-2$is pump, $2-3$is a boiler, $3-4$ is a turbine and $4-1$ is again condenser. So, in all we can see that Rankine cycle will have 4 processes and those 4 processes among those we will have first process as the pumping process which is isentropic compression, second process isobaric heat addition, third process is isentropic expansion and fourth processes is the isentropic heat rejection.

So, these are the 4 processes so for the 4 processes to take place there are 4 equipments or 4 devices, 4 parts of the Rankine cycle. The first process which is isentropic compression would be taken place in pump, second process isobaric heat addition that would be taken place in the steam generator, third processes isentropic expansion that will takes place in the turbine and then fourth process is the isothermal heat is isobaric heat rejection and **that** takes place in the condenser.

So, these are the 4 processes which are taking place into the Rankine cycle and such plant which has water as the working medium to generate electricity is called as steam power plant. So, steam is the working medium for this power plant and we can we have seen that this cycle has 2 processes which are compression and expansion which are reversible processes they are same as in case of Carnot cycle.

But Carnot cycle had heat addition as isothermal process and heat rejection as isothermal process but Rankine cycle has heat addition as isobaric process and heat rejection as isobaric process. So, this cycle which is Rankine cycle is different from the Carnot cycle since it has heat interaction in two different processes. So, here we end today's discussions on review of thermodynamics towards the entry of the Rankine cycle where we have discussed the basics of thermodynamics through definition of system surrounding properties.

State first law of thermodynamics, second law of thermodynamics and then we saw what do we mean by Rankine cycle and Carnot cycle. So, we have also seen that which are the 4 components of Rankine cycle which would execute 4 processes so that we will have Carnot cycle as a closed cycle. So we will see next details of Rankine cycle in the next class. Thank you