Basics of Mechanical Engineering-3

Prof. J. Ramkumar

Prof. Amandeep Singh Oberoi

Department of Mechanical Engineering

Indian Institute of Technology, Kanpur

Week 01

Lecture 04: Thermodynamic Processes (Part 1 of 2)

Welcome to the next lecture in the course Thermodynamics and Fluid Mechanics. This lecture series is part of Basic Mechanical Engineering. In the first lecture, we went through the basics of thermodynamics. We saw what a state function, path function, and process function are. Then, we saw different types of energies: internal energy, work, and heat. We also saw different types of processes. We will try to gain a little more understanding of this subject. So, this is on Thermodynamic Equilibrium Process and Thermometry.

Contents

- Types of Thermal Equilibriums
- Reversible and Irreversible Processes
- Different Thermodynamic Processes and Graphical representations
- Cyclic Processes
- Zeroth Law of Thermodynamics: Statement, Applications, Examples
- Measurement of Temperature
- Thermometry Properties: Definition, Applications
- Common Temperature Scales and Inter-Conversion

What are the different types of thermal equilibrium? We will try to see reversible and irreversible processes. Different thermodynamic processes and graphical representation.

Cyclic processes, the zeroth law of thermodynamics—we saw what the zeroth law is in the previous lecture, very basic. Then, we will try to see the measurement of temperature. Then, we will try to move into the topic of thermometry: properties, definition, and application. Finally, common temperature scales and their interconversions because we have Kelvin, Fahrenheit, and Celsius. So, there are three different things.

By the way, when we try to measure human body temperature, we always say 104 degrees. It is 104 degrees Fahrenheit. And when we try to talk about room temperature, we talk about degrees Celsius. And when we talk about sub-zero, we always talk in terms of Kelvin. So, various applications are there. You should know the conversion scales.

Types of Thermodynamic Equilibrium

- A System is said to exist in state of thermodynamic equilibrium when no change in any macroscopic property is registered, if the system is isolated from its surroundings.

- An isolated system always reaches, in course of time, a state of thermodynamic equilibrium and can never depart from it spontaneously.

- Therefore, there can be no spontaneous change in macroscopic property if the system exists in equilibrium state. Thermodynamics studies mainly the properties of physical systems that are found in equilibrium states.

Types of Thermodynamic Equilibrium. A system is said to exist in a state of thermodynamic equilibrium when no change in any macroscopic property is registered. Macroscopic property is registered. If the system is isolated from its surroundings.

So, what we are trying to say is, you have a system, and it is isolated. Isolation is basically putting thermocol around it. That's it. A system is said to exist in a state of thermodynamic equilibrium when no change in any macroscopic property—pressure,

volume, temperature—if the system is isolated from the surroundings. If you seal it, nothing is going to happen.

An isolated system always reaches, in the course of time, a state of thermodynamic equilibrium and never departs from it spontaneously. It slowly moves out of its existing state. So, that is what happens in your thermos flask also, right? An isolated system always reaches, in the course of time, a state of thermodynamic equilibrium and never departs from it spontaneously. Therefore, there is no spontaneous change in macroscopic properties if the system exists in equilibrium.

This is very important. If the system exists in equilibrium, there is nothing called a change in macroscopic properties. For example, you take a pan which is there in normal kitchen conditions where temperature, pressure, everything is set like room temperature. Then, you keep a pan, and without heating it, you are just keeping it in place. So, therefore, there can be no spontaneous change in the macroscopic properties if the system exists in equilibrium condition.

The moment you heat it from the bottom or the moment you try to load it from the top with pressure, then you can see there is a change. So, thermodynamics mainly studies the properties of a physical system that are found in an equilibrium state. Please try to underline this because you always have to understand that what we talk about will always be in an equilibrium state. So, if there is a sudden change and all, we do not look into it for our discussion.

Types of Thermodynamic Equilibrium

A system will be in a state of thermodynamic equilibrium, if the conditions for the following three types of equilibrium are satisfied :

1. Mechanical equilibrium-------------→ Equality of pressure
2. Chemical equilibrium----------------→Equality of chemical reaction rate
3. Thermal equilibrium----------------→ Equality of temperature

- In the absence of any unbalanced force within the system itself and also between the system and the surroundings, The system is said to be in a state of mechanical equilibrium. If an unbalanced force exists, either the system alone or both the system and the surroundings will undergo a change of state till **mechanical equilibrium** is attained.
- If there is no chemical reaction or transfer of matter from one part of the system to another, such as diffusion or solution, the system is said to exist in a state of **chemical equilibrium**.

A system will be in a state of thermodynamic equilibrium if the conditions for the following three equilibria are satisfied. One is mechanical equilibrium, equality of pressure. When we say chemical equilibrium, it is the equality of chemical reaction rates. Thermal equilibrium is the equality of temperature. So, all these things are equilibrium states. In the absence of any imbalance of these forces within the system itself and also between the system and the surroundings, the system is said to be in a state of mechanical equilibrium.

If an imbalance of forces exists, either in the system alone or in both the system and the surroundings, they will undergo a change of state until mechanical equilibrium is attained. You pull a string, you release it. It keeps on oscillating until it returns to its normal state. So, if there is no chemical reaction or transfer of matter from one part of the system to another, such as diffusion or solution, the system is said to exist in a state of chemical equilibrium. See, diffusion is a very interesting phenomenon that is extensively used in material science.

So, what happens here? There is a porous structure or a solid wherein you pressurize and push the atoms inside. You have a sponge where water diffuses inside. If all the pores are filled with water, it absorbs. So, if there is no chemical reaction or transfer of matter from one part of the system to another, such as diffusion or solution, then the system is said to exist in chemical equilibrium.

When we talk about mechanical equilibrium, it is the same. If an unbalanced force exists, either the system alone or both the system and the surrounding will undergo a change of state till mechanical equilibrium is attained.

Types of Thermodynamic Equilibrium

- When a system existing in a mechanical and chemical equilibrium is separated from its surroundings by a diathermic wall (wall which allows heat to flow). and if there is no spontaneous change in any property of the system, the system is said to exist in a state of **thermal equilibrium.** when this is not satisfied, the system will undergo a change of state till thermal equilibrium is restored.

- When the conditions for any one of the three types of equilibrium are not satisfied, a system is said to be in a **non-equilibrium state.**

When the system exists in mechanical and chemical equilibrium, it is separated from its surrounding by a diathermic wall, a wall which allows heat to flow. And, if there is no spontaneous change in any property of the system, the system is said to be in thermal equilibrium. When this is not satisfied, the system undergoes a change of state till the thermal equilibrium is restored.

So, what I am trying to tell you is, mechanical equilibrium, chemical equilibrium and thermal equilibrium, when will it be achieved and how it will be achieved. So, that is what we are saying. And, why is this important? Because later when we look into several of these cycles, we will be using these properties. So, we discussed about state till mechanical equilibrium is attained, chemical equilibrium when it will be attained and thermal equilibrium when it will be attained.

And this is pretty interesting; diathermic wall, wall which allows heat to flow. For example, you can try to have a cloth as a wall. A cloth has a barrier of a wall, so where in which heat tries to move out. For example, when we make sweets, many of the sweets what we do is we try to pour the sweet on top of a wet cloth and allow the sweet from a

hot condition to get into a cold condition and where in which the cloths, whatever we use, behaves like a diathermic wall, allows only the heat to flow through. So, when the condition of any one of the three types of equilibrium are not satisfied, then it is called as non-equilibrium state.

You have to understand the equilibrium state. So, that is what we said. Therefore, there can be no spontaneous change in macroscopic properties if the system exists in an equilibrium state. Thermodynamics mainly studies the properties of physical systems that are found in an equilibrium state. And here, we have defined all three equilibria: mechanical equilibrium, chemical equilibrium, and thermal equilibrium.

So, chemical equilibrium is, suppose you try to keep a matter which is there in an open atmosphere. So, if there is no chemical reaction or transfer of matter from one part of the system to the other, such as diffusion or solution, then it is said to be in equilibrium. For example, you keep a glass jar in a kitchen. I always give you examples of the kitchen because you can correlate it very fast. So, what happens there? It is in a neutral state, so that is called chemical equilibrium.

So, when you try to talk about a system where the conditions of any one of the three equilibria are not satisfied, then the system is said to be in a non-equilibrium state, and throughout, we only talk about the equilibrium state.

So, now, let us look into Reversible processes and Irreversible processes. Elastic limit— same analogy in design. So, where we have an elastic rubber band, we put a load, we release it, and it comes back to its same state. So, that is called a reversible process. So, in the same way, in thermal also, we have reversible processes and irreversible processes.

Reversible Process

The process in which the system and the surroundings can be rebuilt from the final state to the original state without any change in the thermodynamic properties of the universe is called a *reversible process*.

- Let us assume that the system has experienced a modification from state A to state B. However, and there is no change in the universe, the process is expressed as a reversible process if the system can be restored from state B to state A.
- The reversible process can be completely reversed and there is no track left to demonstrate that the system had experienced a thermodynamic change. For the system to sustain the reversible change, it must be infinitely sluggish.
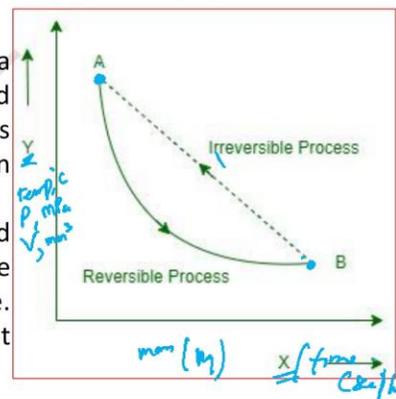
So, what is a reversible process? Before getting into the definition and other parts, we will try to understand the graph. So, you have the Y parameter and the X parameter. This Y can be temperature, and X can be taken as time.

You can also try to have pressure or volume. Whatever it is, you can try to have. And here, you can try to have mass, etc., etc., etc. You can take Y as any value, X as any value or any magnitude, whatever. Value means you can try to take temperature or pressure.

You can try to take even voltage, by the way. You can try to take volume also. And please keep in mind, friends, that when you try to plot X and Y, it is always a good idea to also plot the units. So, millimeter cube, pressure in terms of MPa, temperature in terms of degrees Celsius, time in terms of seconds or hours, whatever it is, mass in terms of kg. So, it is a good idea to label the axes with the units.

So, if you see reversible, when you want to go from A to B, it follows a path. And then, if we want to reverse it in the same path, it is called a reversible process. If it tries to take another path, it is called an irreversible process. A process in which the system and the surroundings can be restored from the final state to the original state without any change in the thermodynamic properties of the universe. It is called a reversible process.

When you can try to, in which a system and the surroundings can be restored from the final to the initial or the original state without any change in thermodynamic properties, it is called reversible. Now, let us try to understand the graph. Let us assume that a system has undergone a change from state A to state B, and there is no change in the universe. The process is expressed as a reversible process if the system can be restored from B to A. A reversible process can be completely reversed, and there is no trace left to indicate the system has undergone a thermodynamic change.

So, thermodynamic change, pressure change, volume change, temperature change—nothing is there. From A, it goes to B; from B, it goes to A. For the system to sustain the reversible change, it must be infinitely slow. But generally, it is always irreversible.

Reversible Process

- All the state fluctuations that occur during the reversible process are in thermodynamic equilibrium with each other. So there are two consequent contingencies to doing the reversible process.
- Basically, the process must take place in an infinitely short path and second all the original and final states of the system must be in equilibrium with each other.
- However, if the heat content of the system remains constant during the reversible process. It is an adiabatic process, this process is also a isotropic process, i.e. the entropy of the system remains constant.
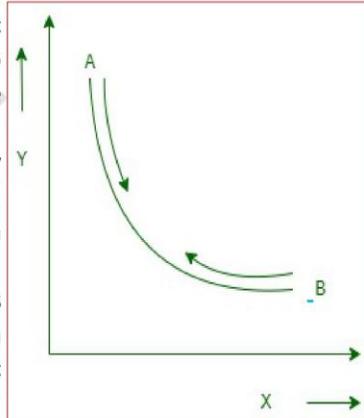
All the state fluctuations that occur during a reversible process—A to B, B to A—are in thermodynamic equilibrium with each other. So, there are two necessary conditions for a reversible process.

Basically, the process must take place in an infinitely short path, and secondly, all the original and final states of the system must be in equilibrium with each other. So, this is very important. Basically, the process must take place in an infinitely small path. So, a very small path you will try to do. However, if the heat content of the system remains constant during a reversible process, it can be an adiabatic process.

This process is also called an isotropic process. That is, the entropy of the system remains constant. So, you should understand this point. In a reversible system, the entropy of the system remains constant. Okay.

If the heat content of the system remains constant—heat content is always constant, which is very difficult in reality—remains constant during a reversible process. It can be an adiabatic process. This process is also called an isotropic process. So, entropy—when the temperature is constant, heat is constant because there is no difference in temperature—heat is constant, then the entropy of the system also remains constant.

Reversible Process

Conditions for the reversible process
There are two important conditions for the reversible process to occur.
- Firstly, the process should occur in infinitesimally small time.
- Secondly, all the initial and final states should be in equilibrium with each other.

Reversibility in thermodynamics:
The phenomenon of undergoing reversible change is also called reversibility. In actual practice the reversible process never occurs, thus it is an ideal or hypothetical process.

Example: Although no actual change is completely reversible by the process of liquefaction and evaporation of a system performed slowly are practically reversible. Similarly slow compression of the gas in a cylinder is a reversible process as gas can be expanded slowly by decreasing the weight on the piston to reverse the operation.

What are the conditions for a reversible process? There should be some condition. There are two main conditions. There are many, but the most significant conditions are two. The process should occur in infinitely small time, the process reversible process. Secondly, all the initial and the final state should be in equilibrium with each other.

So, pressure, temperature, volume, pressure, temperature, volume, in case you have a system of a three-dimensional axis presentation, then the initial and the final state should be in the equilibrium with each other. The reversibility in thermodynamics, the phenomena of undergoing reversible change is also called as reversibility. Ability to reverse, that is reversibility. In actual practice, the reversible process never occurs. But for simplification in calculation, we always try to take it as a reversible process.

In the problems you will see, they would have written in the question itself, it is a reversible process. So, the understanding what I am trying to impress you is, please assume that the other conditions are constant. There is no heat loss. That is what it is. So, the reversible process never occurs.

Thus, it is an ideal or hypothetical process, a reversible process. When we try to write a question, we say in a reversible process system—for example, in a refrigerator from point A to point B—whatever it is, we write. So, that means to say it is an idealistic case. For example, although no actual change is completely reversible, the process of liquefaction

and evaporation—solid to liquid liquefaction— For example, ghee or butter to ghee liquefaction, then evaporation of a system performed slowly, are practically reversible.

Similarly, slow compression of a gas in a cylinder is a reversible process. Slowly, you have to compress as gas can be expanded slowly by decreasing the weight of the piston to reverse the operation. So, you can try, but these are all idealistic cases.

Types of reversible processes. So, here we saw reversibility—the ability to reverse. Then, we saw an example. Then, types of reversible processes. So, there are two types of reversible processes. One is an internally reversible process. Another one is an externally reversible process.

Internally reversible process is a process is clarified to be internally reversible if no irreversibility occurs within the system, systems termination. No reversibility occurs within the system's termination. In this process, a system passes through a series of equilibrium state and when the process is reversed, the system passes through similar equilibrium state replacing its original state. So, you move from here to here, then you move back from A to B, then it is moving back to A, B, B to A. So if the process, a system passes through a series of equilibrium state and when the process is reversed, the system passes through similar equilibrium states replacing its original state.

What are external reversible process? In an external reversible process, no reversibility occurs outside the boundaries of the system during the process. Internal means within the system's termination, within the system, this is a system. This is a surrounding. So, within the system, it is internal.

Then, outside the boundaries, outside the boundaries of the system during the process is external reversible process. For example, if the surface of contact between a system and the force is at the same temperature, the heat transfer between the force and the system is also an external reversible process. Internal reversible, external reversible.

Irreversible Process

Irreversible processes are correspondingly called innate processes because all the actions that take place in nature are irreversible processes. The natural process is due to the finite gradient between the two states of the system.
For example, the temperature gradient between two bodies causes heat to flow between two bodies; This is actually the natural flow of heat.

Also, water flows from high level to low level, current overflows from high potential to low potential, etc. The original state of the system and the environment cannot be recreated from the final state in an irreversible process.
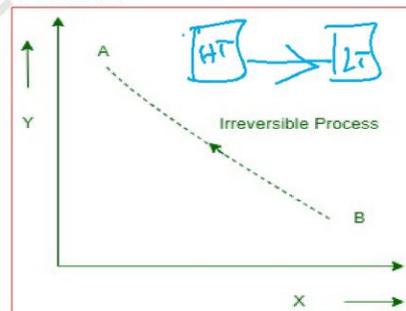
Irreversible Process

Image Source: https://www.geeksforgeeks.org/difference-between-reversible-and-irreversible-processes/   10

Now, let us get into Irreversible Process. In reality, all the processes are irreversible. Irreversible processes are correspondingly called innate processes because all the actions that take place in nature are irreversible processes. The natural process is due to the finite gradient between the two states of the system. For example, the temperature gradient between two bodies causes heat to flow from higher temperature (HT) to lower temperature (LT). There is a gradient, right? Transfer. There is a gradient.

They can be attached to each other. They can be apart. Between two bodies, heat flows between the two bodies. This is actually the natural flow of heat. Also, when water flows

from a higher level to a lower level, current flows from higher potential to lower potential, etc.

The original state of the system and the environmental conditions cannot be recreated from the final state in an irreversible process. So friends, I am making it very clear. In reality, whatever the process is, it is called an irreversible process. But for understanding, for subject simplification, and for mathematically solving, we always assume a reversible process. And a reversible process is valid when the changes are infinitesimally very, very small.

The colored state of a system is not in equilibrium with each other on the path of modification from the original state to the final state during an irreversible process. So, in an irreversible process, the entropy of the system increases significantly. This point is very important because, in a reversible process, we try to say the entropy of the system remains constant. But in an irreversible process, we try to say that the entropy keeps changing, increases significantly, and cannot be reduced back to its most critical value. Like in reversible processes, here also we have internal irreversibility and external irreversibility.

The ability to reverse is reversibility. In internal irreversibility, the disruptive effect is present within the working fluid. Convection, right? So, in external irreversibility, the

dissipators exist outside the movable working fluid. For example, you have a hot body, a fluid is flowing on top of it, so that the temperature of the body can be reduced.

Where do we use this? In metal forming, it always happens. After hot working is over, then you have the billet, which is in a red-hot condition, right? So, now what we do is, in external irreversibility, the dissipators exist outside the movable working fluid. Example, mechanical friction due to external forces. So, these are external irreversibility.

Irreversible Process

Some important points about the irreversible process
- In the irreversible process, the initial stage of the system and surroundings cannot be restored from the final stage.
- During the irreversible process of the various states of the system of the path of change from the initial stage to the final state are not in equilibrium with each other.
- During the irreversible process, the entropy of the system increases decisively and it cannot be reduced back to its initial value.
- The phenomena of a system undergoing irreversible processes are called irreversibility.

Some important points about irreversible processes. In irreversible processes, the initial state of the system and the surroundings cannot be restored from its final state. That is the first understanding. During an irreversible process, the various states of the system on the path of change from the initial to the final are not in equilibrium.

This is very important: they are not in equilibrium. During an irreversible process, entropy increases. The phenomenon of a system undergoing an irreversible process is called irreversibility.

Irreversible Process

Irreversible process examples

- The conduction of heat from a hot body to a cold body.
- Production of heat by the friction.
- Producing of heat by the passing of current through an electrical resistance.
- Transfer of heat by radiation.
- An explosion.
- Inelastic deformation.
- Magnetization or polarization with a hysteresis.
- Spontaneous chemical reactions.
- Spontaneous mixing of the matter of varying states.
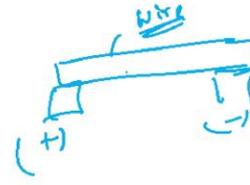
So, examples of irreversible processes: the conduction of heat from a hot body to a cold body is an irreversible process. Friction produces heat when two metal bodies rub against each other or when you rub your hands together; when two bodies rub against each other, there is friction.

This friction leads to heat. Producing heat by passing current through an electrical resistance. So, if you have a cable or a wire and connect it between positive and negative terminals, when the current flow is very high, it goes into a red-hot condition. So, producing heat by passing current through an electrical resistance, like in an incandescent bulb, which then emits light.

Transfer of heat by radiation. That is also irreversible. And explosion, irreversible. Inelastic deformation. Then, magnetization or polarization with hysteresis.

Then, spontaneous chemical reaction. Then, we have spontaneous mixing of matter of various states. And explosion and spontaneous chemical reaction are the same. For example, you try to drop sugar in a liquid, it tries to dissolve. So, spontaneous chemical reaction can happen.

And then, spontaneous mixing of matter of various states is also there. These are some of the examples of irreversible process. Now, it is very clear in reality irreversible process only exist.

Reversible v/s Irreversible Process

REVERSIBLE PROCESS	IRREVERSIBLE PROCESS
Takes place in an infinite number of infinitesimally small steps; would take infinite time to occur.	Takes place in a single step.
It is imaginary, assumes the presence of frictionless and weightless piston.	It is real and can be performed actually.
The system is in equilibrium at all stages of the operation.	The system is in equilibrium only at the initial and final stages.
All changes are reversed when the process is carried out in the reversible direction.	After the process, changes do not return to the initial state by themselves.
Extremely slow process.	Proceeds at a measurable speed.
Work done in a reversible expansion process is greater than the corresponding irreversible process.	Work done in an irreversible expansion process is smaller than the reversible one.

So, now let us try to distinguish the Reversible and Irreversible Processes. Takes place in an infinite number of infinitesimally small step. It would take infinite time to occur, a reversible process. Here, it takes place in a single step, an irreversible process. It is imaginary; it is real. It assumes the presence of a frictionless and weightless piston. It takes everything in reality, actual.

The problems you will try to understand this because when we try to solve a problem on a compressor, we will say it follows a reversible process. So, then you should understand there is no friction, and there is no weightless piston. The system is in equilibrium at all states of its operation. Here, the system is in equilibrium only at the initial and the final state in irreversible. All changes are reversible when the process is carried out in the reversible direction.

Here, after the process, changes do not return to the initial stage by themselves. Extremely slow. This proceeds at a measurable speed in reality. Work done is reversible. Work done is in an irreversible expansion.

The process is smaller than the reversible one and greater than the corresponding irreversible process. So, now it is very clear—whatever we have deliberated—you now clearly understand reversible and irreversible processes. Reversible: what are the conditions? Irreversible: what are the conditions?

A **thermodynamic process** involves the transfer of energy within a system or between systems. It involves properties like pressure, temperature and volume. The present values of the properties of a system are called the thermodynamic state of the system. An example of a thermodynamic process is food staying cold inside a refrigerator.

In a refrigerator, the heat is pulled out of the inner compartments and transferred to the outside air.

	Process	Special condition	Constraints	
1.	Isochoric process	V = constant, $\Delta V = 0$		Piston is not allowed to move
2.	Isobaric process	P = constant, $\Delta P = 0$		Piston is free to move $P = F/A$
3.	Isothermal process	T = constant, $\Delta T = 0$		diathermal wall (cloth/spong)
4.	Adiabatic process	Q = neither enter nor leaves the system		Adiabatic wall

Image Source: https://scienceinfo.com/thermodynamic-processes/

15

Now, let us try to look into the Thermodynamic process. A thermodynamic process involves a transfer of energy within a system or between systems. The transfer of energy can be heat, mechanical, or whatever it may be. So, it involves a transfer of energy within a system or between two systems—within one system or the other. It involves properties like pressure, temperature, volume (P, V, T)—these are the usual parameters—and we also have entropy, which comes into play. Later, we will see: we will draw a PV diagram and a TS diagram. The present values of the properties of a system are called the thermodynamic state of the system.

The thermodynamic state of the system is defined by the present values of its properties. An example of a thermodynamic process is food staying cold inside a refrigerator. If you switch it off, it returns to normal. But when energy is applied—energy that generates cold air inside the refrigerator—the food you keep inside and the outside temperature remain almost in equilibrium. That is what they say.

An example of a thermodynamic process is food staying inside a refrigerator. In a refrigerator, the heat is pulled out of the inner compartment and transferred to the outside air. So, what happens? How does the heat get extracted? In a refrigerator, the heat is pulled out because when you keep hot milk inside the refrigerator, the hot milk's temperature has to be reduced, right?

The heat is pulled out of the inner compartment and transferred to the outside air. That is what also happens in the refrigerator, as well as in the AC. So, the heat is extracted from the inner compartment and transferred to the outside area. You can also use an AC as a heater. So, when we use the AC as a heater, what happens now is it tries to expel the cold air inside the room outside and give you hot air.

So, you have dual modes available today. In a refrigerator, it is only hot to cold, but here in an AC, you can have hot to cold or cold to hot. So, these are the different types of processes. We already had a small introduction. So, isochoric process, isobaric process, isothermal process, adiabatic process.

What is an isochoric process? Volume is constant. dV is 0. So, the constraint will be that the piston is not allowed to move in an isochoric process. So, here, whatever happens when heat is applied, the piston is locked. The piston is locked. So, whatever happens has to happen. The temperature has to increase, pressure has to increase, but the volume remains constant.

Isobaric Process (Constant Pressure)

Definition: An isobaric process is one in which the **pressure remains constant** throughout the process.

Key Characteristics:
- Volume and temperature may change.
- Common in systems with movable boundaries, like pistons.

Examples:
- Boiling water in an open container at atmospheric pressure.
- Heating air in a piston-cylinder assembly with a freely moving piston.
- Steam generation in boilers operating at constant pressure.

When we talk about isobaric, P is constant. So, there is no change in pressure P. So, what happens is the piston is allowed to move up and down freely. As and when you try to heat it, what happens? It tries to expand, right? So, the moment there is an expansion, the pressure is nothing but force applied per unit area. So, now the area, in turn, we can

connect it with volume. The volume gets expanded. So, the pressure remains constant. So, isobaric P constant, dP is also constant.

Isothermal Process (Constant Temp)

Definition: An isothermal process is one in which the **temperature remains constant** throughout the process.

Key Characteristics:
- Internal energy remains unchanged for ideal gases.
- Requires slow processes with efficient heat exchange to maintain constant temperature.

Examples:
- Melting of ice at 0°C under atmospheric pressure.
- Slow expansion or compression of gas in a thermostat-controlled environment.
- Evaporation of water at its boiling point under constant pressure.

When we talk about temperature, it is an isothermal process, delta T is equal to 0. So, when delta T is equal to 0, the temperature of the system is constant, the volume can expand, the pressure can change, but the temperature is always constant.

When we talk about adiabatic, neither entry nor exit of heat (Q) from the system occurs. So, adiabatic means Q. Whatever is there, it will neither enter nor leave the system; the Q is maintained. So, that is the adiabatic process. Friends, I understand, or I also request you to see what Q is. So, go back to the previous lecture, and you will see what Q is. So, these are the four different types of processes in thermodynamics.

An isobaric process is one in which the pressure remains constant throughout the process; the key characteristics are volume and temperature may change. Common in systems with movable boundaries like pistons. If you go back, an isobaric piston can move up and down, and here we also assume there is no friction between the piston and the valves. Example: boiling water in an open container at atmospheric pressure is an isobaric process. Because the atmospheric temperature is constant.

Heating air in a piston-cylinder assembly with a freely moving piston. When you try to inflate or push air into a tube, then steam generation in a boiler operating at constant

pressure occurs. Why are we operating at constant pressure? Because what happens is the materials always put a restriction on the increasing pressure. So, up to a certain level, they try to use a very good material, and then this material can withstand up to a certain pressure.

So, now what we do is try to control the process by maintaining it at a constant pressure. So, that is what steam generation in boilers operating at a constant pressure means. Now, let us look at the isothermal process, which is nothing but a constant temperature process. So, an isothermal process is one in which the temperature remains constant throughout the process. So, here, internal energy remains unchanged in an ideal gas.

It requires a slow process with efficient heat exchange to maintain constant temperature. The heat has to be dissipated, and when the heat has to be dissipated, you cannot do it instantly. It requires a slow process with efficient heat exchange to maintain a constant temperature throughout the process. So, here, internal energy does not change. So, if you go back to the figure of the isothermal process, you can see here again there is a wall.

So, in this, you have a boundary around the boundary, and you have a diathermal wall. So, this diathermal wall means these walls are an example of a cloth. You can also have a sponge or a cloth. So, there is a transfer of heat happening here. So, it requires a slow process with efficient heat exchange to maintain a constant temperature. Melting of ice at 0 degrees under atmospheric pressure falls under the example of an isothermal process.

Melting of ice at 0 degrees Celsius under atmospheric pressure, 0 degrees Celsius, right? It can happen very slowly. Slow expansion or compression of gas in a thermostat-controlled environment. Slow expansion or compression of a gas, which is used in AC cooling. Evaporation of water at its boiling point under constant pressure.

All these things are isothermal processes. It is pretty interesting. Evaporation of water at a boiling point, 100 degrees Celsius, under constant pressure. So, you have a piston. You put a weight on the piston.

You keep the heating on. So, you see the pressure is constant. And the volume you will try to play with. Then, you try to get whatever it is. So, an isothermal process.

Definition: An isochoric process is one in which the **volume remains constant** throughout the process.

Key Characteristics:
- No work is done since the volume doesn't change.
- Any heat added or removed changes the internal energy and pressure.

Examples:
- Heating of gas in a sealed, rigid container.
- Combustion of fuel in an engine cylinder before the piston moves.
- Pressure increase in a pressure cooker before the safety valve operates.

Then, an isochoric process is constant volume. An isochoric process is one in which the volume remains constant throughout. So, you put a stopper. And you have the volume remain constant. So, no volume change.

Since the work done does not change, any heat added or removed changes the internal energy and the pressure. Any heat you add or remove changes the internal energy and pressure. Heating of a gas in a sealed rigid container. So, you put it in an isolated system. Heating of a gas in a sealed container, then combustion of fuel in an engine cylinder before the piston moves is also constant volume. When you go to IC engines, we will see that.

Basics of IC engine, we will see the constant volume process. The pressure increases in a pressure cooker before the safety valve operates, which is a constant volume process because the pressure cooker's volume is constant. So, before it can push the safety valve, it is considered. So now, friends, you will be able to distinguish isobaric, isochoric, and isothermal processes.

Definition: An adiabatic process is one in which **no heat is transferred** to or from the system.

P, V, T, S

Key Characteristics:
- Temperature changes due to internal energy variations.
- Occurs in insulated systems or during rapid processes where heat exchange is negligible.

Examples:
- Rapid compression of air in a bicycle pump.
- Sudden expansion of gas when a pressurized container is opened.
- Expansion of gases in turbines where insulation minimizes heat exchange.

Then, let us see the last one, which the adiabatic process. So, in the three, what did we see? P constant, V constant, T constant. Now, what is pending is S constant. That is entropy. Adiabatic process.

An adiabatic process is one in which no heat is transferred to or from the system. No heat is transferred from one energy to the other, or up to down, whatever. No heat is transferred to or from the system. We have a constant entropy here. The temperature changes due to internal energy variation. It occurs in an insulated system or during a rapid process where heat exchange is negligible. So, rapid compression of air in a bicycle pump is an adiabatic process.

Rapid compression of air. Why? An adiabatic process is one in which no heat is transferred to or from the system. So, here, rapid compression of the air in a bicycle pump. Sudden expansion of gas when the pressurized container is opened.

When you open, for example, a Pepsi bottle, sudden expansion of gas occurs when a pressurized container is opened. The expansion of gas in a turbine where insulation minimizes heat exchange. So, these three are there. So, most of the time, we will try to specify which process the system follows so that it becomes easy for you to use the equation. So, it can be isobaric, isochoric, isothermal, or adiabatic.

Adiabatic friends, keep in mind entropy. So, what is entropy? We have seen it in the previous lecture.

Polytropic Process

Polytropic is a thermodynamic process that obeys the relation;

$$PV^x = C.$$

$$PV^x = C$$

Here, P is the Pressure
     V is the Volume
     x is the Polytropic Index
     C is the Constant

The polytropic index will take any value *between 0 and ∞*, depending on the process.

So, now, the polytropic process. Polytropic is a thermodynamic process that obeys the relationship: $PV^x = C$. So, P is pressure, V is volume, x is the polytropic index, $PV^x = C$, C is a constant. So, now the question is: what is the value of x? So, the polytropic index can take a value between 0 and infinity, depending on the process. So, now let us see what we do in each process.

Polytropic Process

$$PV^x = C$$

$$PV^{\textcircled{2}} = Const$$

Value of x (PVˣ = C)	Process
x = 0	Isobaric (dP = 0)
x = 1	Isothermal (dT = 0)
x = n	Polytropic
x = γ	Adiabatic (δQ = 0)
x = ∞	Isochoric (dV = 0)

If x = 0, it is called an isobaric process, PV^x equals a constant. When x = 0, P becomes 0. So, in an isobaric process, dP = 0. When x = 1, then it is PV = C. So, then it is called an isothermal process. When x = n, then it is called a polytropic process.

If x = γ, then it is called an adiabatic process, where dQ (entropy) is 0. When x = infinity, then it is an isochoric process, dV = 0. So, friends, keep this in mind: the basic formula is PV^x = C. Now, depending on whether it is isobaric, isothermal, isochoric, or adiabatic, you change the value of x.
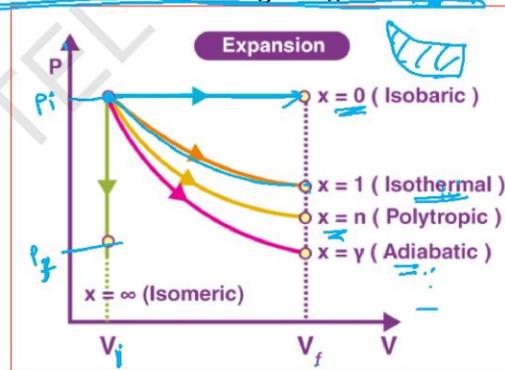

Graphical representation of expansion. Compression, expansion. So, the change in pressure with respect to volume—change in pressure, I told you, y and x—change in pressure to volume is represented in this graph. So, that means to say this: let us take it as P1, right, and let us take it as P2. Let us take it as V1, and let us take it as V2. V1 and V2 are V initial and V final.

So, then this becomes initial, then you try to take it as pressure final, whatever it is, right. So, you try to take it. So, now let us try to understand the process of expansion graphically. The change in pressure with respect to volume is given in a PV diagram. So, whenever we try to call it a PV diagram, it is pressure versus volume.

The efficiency of a system can be determined using the PV diagram. The area under the curve of a PV diagram gives the work done to or by the system. Please understand this point. The area under the curve of a PV diagram gives the work done to or by the system. For a PV diagram of expansion, it is clear that for the same volume of expansion, the area under the isotherm curve is more than the adiabatic curve.

So, now what is expansion? So, when in the PV diagram, when expansion happens at a given pressure, the volume goes to the final state, right? From a PV diagram of expansion, this is expansion. It is clear that for the same volume of expansion, the area under the isothermal curve is more than the adiabatic curve. So, this is what it is. So, you see the slope here.

The slope of isothermal is higher compared to that of adiabatic. Therefore, isothermal work is more than adiabatic work. So, what we are trying to say is, this is the area. So, let us draw it like this, right. This is one, this is something like this.

So, this is the area we are talking about. So, this is the area under the curve. Therefore, the isothermal work is more than the adiabatic work because the area under the curve is very low. When expansion happens, the volume changes. When expansion happens, volume changes. So, V1 to V2. So, the pressure will fall from P1 to P2, whatever. Therefore, the isothermal work is more than the adiabatic.

Graphical Representation: Compression

From the compression curve, it can be seen that the area under the adiabatic curve is more than the isothermal curve. In the case of compression, the work done is calculated by adding a negative sign. Therefore, even in compression, isothermal work will be more than adiabatic work.
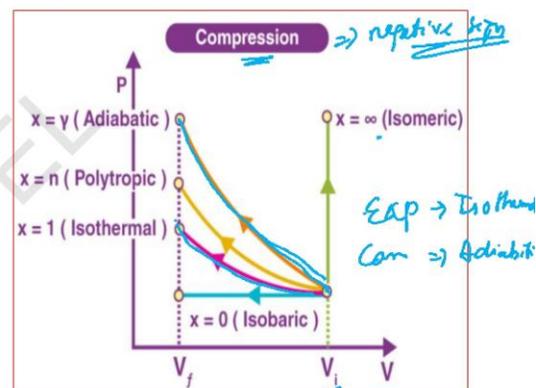
For the compression curve, this is expansion. Expansion means moving, right. So, you can see isobaric pressure is constant. Then, what happens to the volume? It changes. Then, x equals to n is polytropic. This is for expansion. What happens when you reverse it? Compression means from Vf it is going to, from Vf it goes to V1.

Vf to Vi, right. It is compression. So, now for the compression curve, you can see everything goes from Vf or this I have put it as Vi. So, if you compare with the previous graph, it is Vf, Vi. So, you are trying to compress from here volume to reduce the volume.

From the compression curve, it may be seen that the area under the adiabatic curve does more work than the isothermal curve. So, you see here, it is for compression. This is for isothermal; this is for that. So, during expansion, isothermal does more energy, more work, and during compression, the adiabatic curve does more work. It can be seen that the area under the adiabatic curve is more than that under the isothermal curve.

In the case of compression, the work done is calculated by adding a negative sign because it is compression. So, compression has a negative sign. Please keep that in mind. Right. Therefore, even in compression, isothermal work will be more than adiabatic work.

Therefore, even in compression, the isothermal work will be more than the adiabatic work.

Thank you very much.