Thermodynamics

Chapter 3

Work & Heat

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Introduction

Before going into the thermodynamic process and types of thermodynamic processes, let us see what the meaning of the thermodynamic state of system is. The system has certain properties like temperature, pressure, volume, etc. The present values of the properties of the system are called as thermodynamic state of system.

When any of the properties of the system such as temperature, pressure, volume etc change, the system is said to have undergone thermodynamic process, i.e the system undergoes change from initial thermodynamic state to final state due change in properties like temperature, pressure, volume etc. Various types of thermodynamic processes are: isothermal process, adiabatic process, isochoric process, isobaric process. All processes in the thermodynamics assumed a reversible process, in simple words the process which can be revered back completely is called a reversible process. This means that the final properties of the system can be perfectly reversed back to the original properties. The process can be perfectly reversible only if the changes in the process are infinitesimally small. In practical situations it is not possible to trace these extremely small changes in extremely small time, hence the reversible process is also an ideal process. The changes which occur during reversible process are in equilibrium with each other.

Work :

Commonly, the work defined as: The work done on a system by a constant force is *the product of the component of the force in the direction of motion times the distance through which the force acts*.

In thermodynamics, work performed by a system is the energy transferred by the system to its surroundings, that is fully accounted for solely by macroscopic forces exerted on the system by factors external to it, that is to say, factors in its surroundings.

The external factors may be electromagnetic, gravitational, or pressure/volume or other simply mechanical constraints. Thermodynamic work is defined to be measurable solely from knowledge of such external macroscopic forces. These forces are associated with macroscopic state variables of the system that always occur in conjugate pairs, for example pressure and volume or magnetic flux density and magnetization. In the SI system of measurement, work is measured in joules (symbol: J). The rate at which work is performed is power.

Pressure – volume work (or *PV* work) occurs when the volume *V* of a system changes. *PV* work is often measured in units of litre-atmospheres where 1L·atm = 101.325J. However, the litre-atmosphere is not a recognised unit in the SI system of units, which measures P in Pascal (Pa), V in m^3, and PV in Joule (J), where 1 J = 1 Pa·m^3. *PV* work is an important topic in Thermodynamics.

1. Isothermal process:

When the system undergoes change from one state to the other, but its temperature remains constant, the system is said to have undergone isothermal process. For instance, in our example of hot water in thermos flask, if we remove certain quantity of water from the flask, but keep its temperature constant at 50 degree Celsius, the process is said to be isothermal process. Another example of isothermal process is latent heat of vaporization of water. When we heat water to 100 degree Celsius, it will not start boiling instantly. It will keep on absorbing heat at constant temperature; this heat is called latent heat of vaporization. Only after absorbing this heat water at constant temperature, water will get converted into steam. Isothermal, T= constant, if the gas is an ideal gas then

$$PV = RT = \text{Constant}$$

i.e $P_1V_1 = P_2V_2 = C$ and $P = C / V$ also we can say $PV = mRT = C$

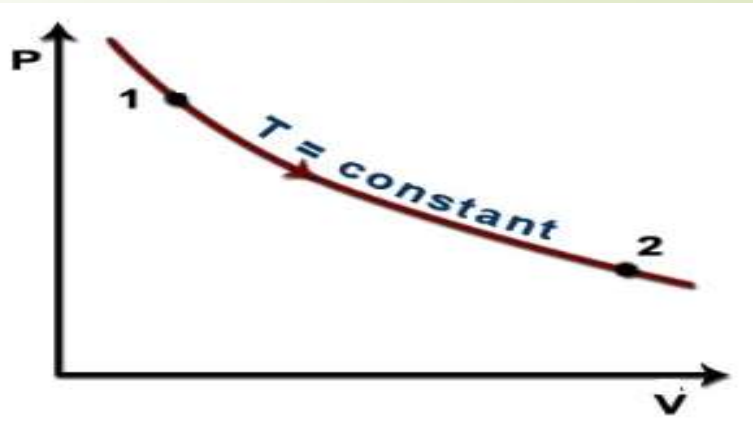
$$W = \int F\, dX = \int P\, A\, dX = \int P\, dV$$

$$W = C \int dV / V$$

$$W = C \ln V \,]_1^2 = C (\ln V_2 - \ln V_1)$$

$$W = C \ln (V_2 / V_1) = C \ln (P_1 / P_2)$$

$$W = PV \ln (V_2 / V_1) = mRT \ln (V_2 / V_1) = mRT \ln (P_1 / P_2)$$



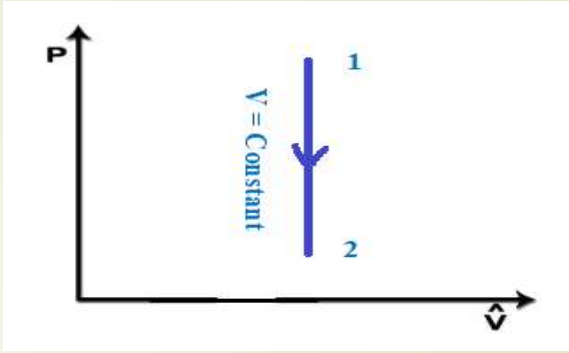
2. Isochoric process:

The process, during which the volume of the system remains constant, is called as isochoric process. Heating of gas in a closed cylinder is an example of isochoric process.

$$W = \int P \, dV$$

at isochoric, V = constant i.e dV = 0 &

$$\mathbf{dw = P\,dV = 0}$$

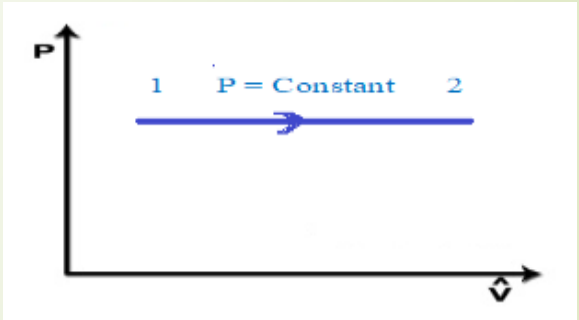


3. Isobaric process:

The process during which the pressure of the system remains constant is called as isobaric process. Example: Suppose there is a fuel in piston and cylinder arrangement. When this fuel is burnt the pressure of the gases is generated inside the engine and as more fuel burns more pressure is created. But if the gases are allowed to expand by allowing the piston to move outside, the pressure of the system can be kept constant. The work done by process is :

$$W = P \int dV$$

$$W = P (V_2 - V_1) = m R (T_2 - T_1) = \int R \, dT$$

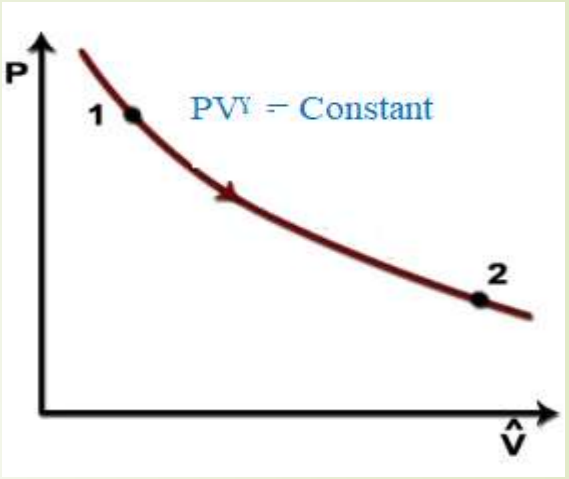


4. Adiabatic process:

The process, during which the heat content of the system or certain quantity of the matter remains constant, is called as adiabatic process. Thus in adiabatic process no transfer of heat between the system and its surroundings takes place. The wall of the system which does not allows the flow of heat through it, is called as adiabatic wall, while the wall which allows the

flow of heat is called as diathermic wall.

PV^{γ} = Constant i.e P = C / V^{γ}



$$W = \int P\, dV$$

$$W = C \int_{V1}^{V2} \frac{dV}{V^{\gamma}}$$

$$W = \frac{C}{1-\gamma}\left(V_2^{1-\gamma} - V_1^{1-\gamma} \right)$$

$$W = \frac{PV^{\gamma}}{1-\gamma}\left(V_2^{1-\gamma} - V_1^{1-\gamma} \right)$$

$$W = \frac{P2\,V2 - P1V1}{1-\gamma} = \frac{P1\,V1 - P2V2}{\gamma - 1}$$

$$W = m\,\frac{R\,(T2-T1)}{1-\gamma} = m\,\frac{R\,(T1-T2)}{\gamma - 1}$$

at adiabatic process **dq = 0**

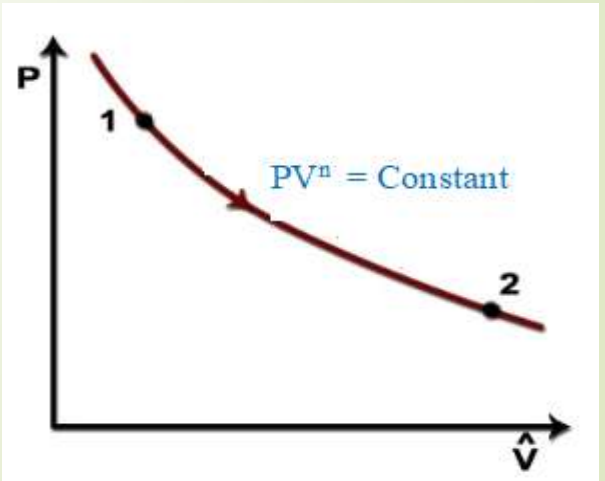
5. Polytropic Process:

Its P-V relation can be expressed as

PV^n = constant

$$W = \int P\, dV$$

$$W = C \int_{V1}^{V2} \frac{dV}{V^{n}}$$



$$W = \frac{C}{1-n}\left(V_2^{1-n} - V_1^{1-n}\right)$$

$$W = \frac{PV^n}{1-n}\left(V_2^{1-n} - V_1^{1-n}\right)$$

$$W = \frac{P2\,V2 - P1V1}{1-n} = \frac{P1\,V1 - P2V2}{n-1}$$

$$W = \frac{mR\,(T2-T1)}{1-n} = \frac{mR\,(T1-T2)}{n-1}$$

Heat :

When heat (**Q**) is added to or lost from an object, its temperature changes. The change in the temperature is proportional to the amount of heat added, the process may be occur at constant pressure or constant volume, i.e used C_p or C_v

1. At constant pressure

$$dq = dh = \int C_p\, dT$$

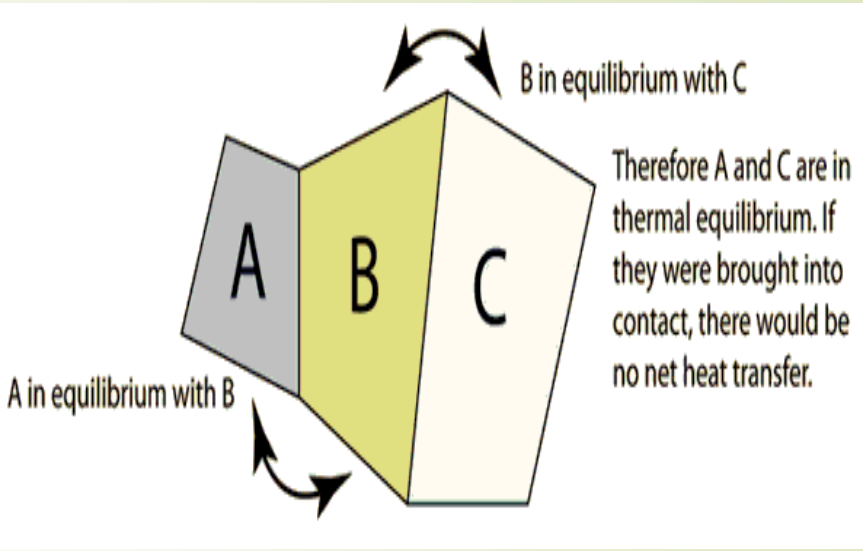
2. At constant volume

$$dq = du = \int C_v\, dT$$

laws of Thermodynamics

a. Zeroth Law of Thermodynamics

The Zeroth Law of Thermodynamics states that if two bodies are each in thermal equilibrium with some third body, then they are also in equilibrium with each other. Thermal equilibrium means that when two bodies are brought into contact with each other and separated by a barrier that is permeable to heat, there will be no transfer of heat from one to the other. This says in essence that the three bodies are all the same *temperature*.



b. First law of Thermodynamics

Many power plants and engines operate by turning heat energy into work. The reason is that a heated gas can do work on mechanical turbines or pistons, causing them to move. The first law of thermodynamics applies the conservation of energy principle to systems where heat transfer and doing work are the methods of transferring energy into and out of the system.

The First Law of Thermodynamics states that heat is a form of energy, and thermodynamic processes are therefore subject to the principle of conservation of energy. This means that heat energy cannot be created or destroyed. So, The First Law says that :

" The internal energy change of a system has to be equal to the work that is being done on the system, plus or minus the heat that flows in or out of the system and any other work that is

done on the system,"

$$\Delta U = W \pm Q$$

The general form of the first law of thermodynamics is :

$$dq = dw + du$$

1. Isobaric process:

according to the first law of thermodynamics, at constant pressure P = C and $W = P (V_2 - V_1)$

$$dq = du + dw$$

$$C_p\, dT = C_v\, dT + P (V_2 - V_1)$$

$$C_p\, dT = C_v\, dT + R\, dT$$

$$C_p = C_v + R$$

The constant pressure and volume processes are very important. The Otto and diesel cycle, which are used in the petrol and diesel engine respectively, have constant volume and constant pressure processes. In practical situations ideal constant pressure and constant pressure processes cannot be achieved.

Isothermal process:

according to the first law of thermodynamics, at isothermal, T = constant i.e dT = 0 & $du = C_v\, dT = 0$

$$dq = dw$$

$$dq = P\, dV$$

3. Isochoric process:

according to the first law of thermodynamics, at isochoric, V = constant i.e dV = 0 & dW = P dV = 0

$$dq = du$$

$$dq = C_v\, dT$$

4. Adiabatic process:

according to the first law of thermodynamics, at Adiabatic process (No heat gain or lost heat) dq = 0

$$0 = du + dw$$

$$du = -\ dw$$

$$C_v\, dT = \frac{R\,(T1 - T2)}{\gamma - 1}$$

$$C_v\, dT = \frac{-R\,dT}{1-\gamma}$$

$$C_v = \frac{R}{\gamma - 1}$$

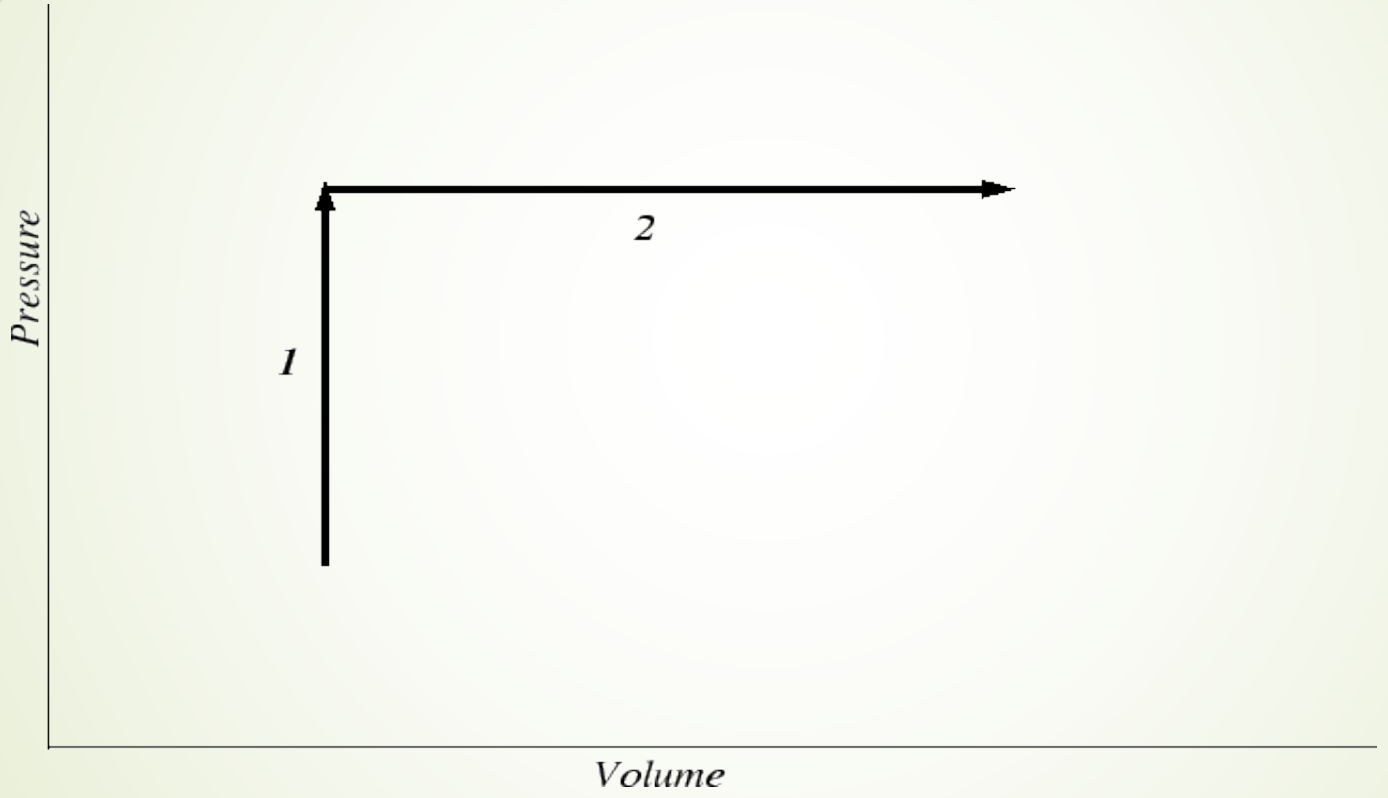
Internal Energy of an Ideal Gas

We will show that the internal energy of an ideal gas is a function of temperature only. This makes physical sense because there is an assumption in ideal gas behavior that there is no interaction between the molecules when we write $P\overline{V} = RT$

Start with a reversible process for an ideal gas: $dU = dq + dw = dq - PdV$

Consider two processes: one occurring at constant volume,
the other occurring at constant pressure.

Figure : Two consecutive processes, constant volume followed by constant pressure.



For process 1: At constant V (PdV = 0)

$$dU = C_V dT + 0$$

i.e U is f (T) only $dU = C_v\, dT$

This can be integrated because T is the only thing that is changing on the right hand side (C_v is assumed to be independent of T and V).

For process 2:

$$dU = C_P dT - PdV$$

P is constant (i.e., not a function of T or V) so it can be integrated directly. Using the ideal gas law:

$$PV = nRT$$

For one mole of gas (i.e n = 1)

$$PdV + VdP = RdT$$

At constant P (VdP = 0)

$$PdV = RdT$$

Then

$$dU = C_p\,dT - RdT$$

$$dU = (C_p - R)\,dT$$

So $C_v = C_p - R$

and also $dU = C_v\,dT$, U is f (T) only.

Note : that $\gamma = \frac{Cp}{Cv}$

Summary

$$\mathbf{dU = C_v\,dT}$$

$$\mathbf{dU = (C_p - R)\,dT}$$

$$\mathbf{dU = (C_p / \gamma)}\,Dt$$