Thermodynamics

Thermodynamics

Thermodynamic is a branch of physics which mainly deals with the transformation of heat into mechanical work.

Thermodynamic System: A system may be defined as a definite quantity of matter (solid, liquid or gases) bounded by some closed surface.

The simplest example of a system is a gas contained in a cylinder with a movable piston.

There are three classes of system:

Open System:

A system which can exchange matter and energy with the surroundings is called an open system.e.g. Air compressor.

Air at low pressure enters and air at high pressure leaves the system i.e., there is an exchange of matter and energy with the surroundings.

Closed System:

A system which can exchange only energy (and not matter) with the surroundings is called a closed system.e.g. Gas enclosed in a cylinder expands when heated and drives the piston outwards. The boundary of the system moves but the matter (here gas) in the system remains constant.

Isolated system:

A system which is thermally insulated and has no communication of heat or work with the surroundings is called isolated system.

Zeroth Law of Thermodynamics(Thermodynamic Equilibrium):

Statement:

The zeroth law of thermodynamics states that if two bodies A and B are each separately in thermal equilibrium with a third body C, then A and B are also in thermal equilibrium with each other.

Explanation:

We consider two systems A and B insulated from each other but in good thermal contact with a common system C. Systems A and B will attain thermal equilibrium with third system C (Fig.-01).

First Law of Thermodynamics:

Statement:

The heat added to the system is equal to the change in internal energy of the system plus the external work done by the system.

Explanation:

Let the quantity of heat added to the system be δH, the change in internal energy of the molecules be dU and the amount of external work done be δW.

Mathematically

$\delta H = dU + \delta W$……………….(1)

Equation (1) represents the first law of thermodynamics. All the quantities are measured in heat units.

Second Law of Thermodynamics:

The second law of thermodynamics is a general principle which places constraints upon the direction of heat transfer and attainable effiencies of heat engine.

Clausius's Statement:

It is impossible to make heat flow from a body at a lower temperature to a body at a higher temperature without doing external work on the working substance.

Kelvin's Statement:

It is impossible to get a continuous supply of work from a body by cooling it to a temperature lower than that of its surroundings.

Planck's Statement:

It is impossible to construct an engine which, working in a complete cycle, will produce no effect other than the raising of a weight and the cooling of a heat reservoir.

Kelvin-Plank Statement:

It is impossible to extract an amount of heat from a hot reservoir and use it all to do work.

Edser's Statement:

Heat flows of itself from higher to lower temperature.

Reversible Process:

A process which can be retraced in the opposite direction so that the working substance passes through exactly the same states in all respects as in the direct process is called a reversible process.

Example*: A given mass of ice changes to water when a certain amount of heat is absorbed by it and the same mass of water changes to ice when the same quantity of heat is removed from it.*

Irreversible Process:

A process which cannot be retraced in the opposite direction is called an irreversible process. In an irreversible process the system with the surroundings can never be completely restored to its initial condition by reversing the controlling factors.

Example: *Exchange of heat between bodies at different temperatures by conduction or radiation.*

Isothermal Process:

If a system is perfectly conducting to the surrounding and the temperature remains constant throughout the process is called an isothermal process.

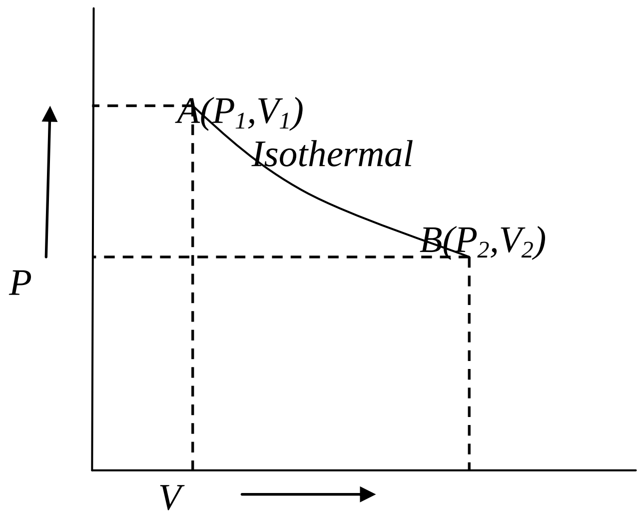


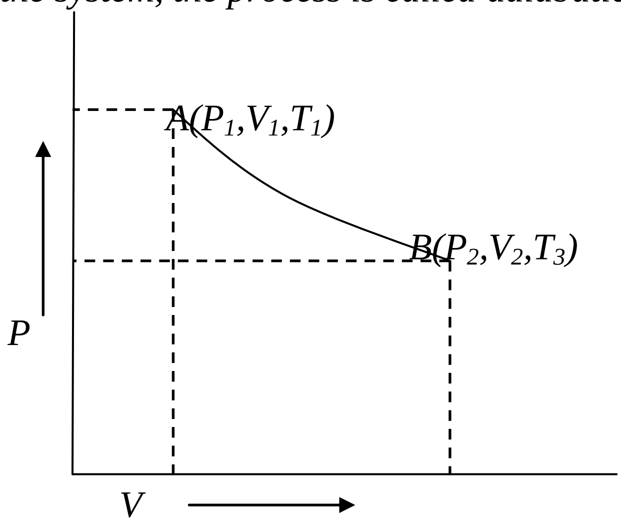
Fig.-1

Consider a working substance at a certain pressure and temperature and having a volume represented by the point A (Fig.-01).

Pressure is decreased and work is done by the working substance at the cost of its internal energy and there should be fall in temperature. But, the system is perfectly conducting to the surroundings. It absorbs heat from the surrounding and maintains a constant temperature. Thus from A to B the temperature remains constant .The curve AB is called the isothermal curve or isothermal.

Adiabatic Process:

When a system undergoes from an initial state to a final state in such a way that no heat leaves or enters the system, the process is called adiabatic process.



Thus, during an adiabatic process, the working substance is perfectly insulated from the surroundings. All along the process, there is change in temperature .A curve between pressure and volume during the adiabatic process is called an adiabatic curve or an adiabatic.

Heat Engines:

Any practical machine which converts heat into mechanical work is called a heat engine.

Heat engines in their operation absorbs heat at a higher temperature, converts part of it into mechanical work ,and rejects the remaining heat at a low temperature.

In this process, a working substance is used.In steam engines, the working substance is water vapour, and in all gas engines the working substance is a combustible mixture of gases.

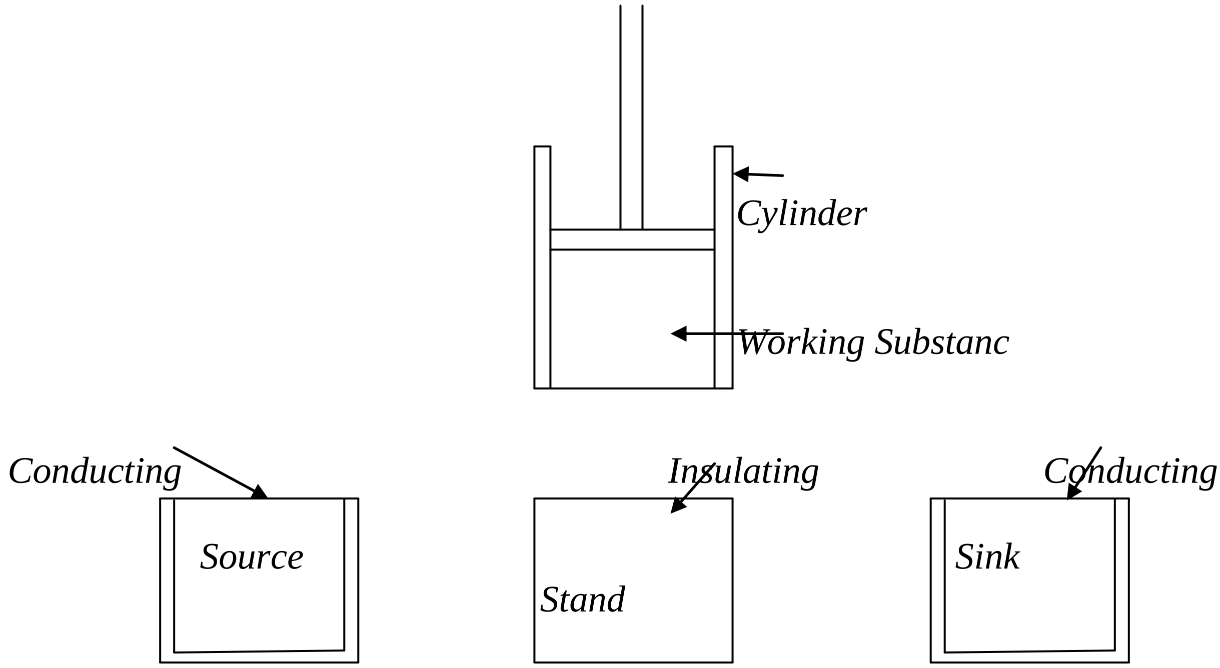
Definition of Efficiency:

The efficiency,η of a heat engine is defined as the ratio of mechanical work done by the engine in one cycle to the heat absorbed from the high temperature source. Thus, if W be the amount of work obtainable from a heat engine in one cycle at the expense of Q amount of heat, then its efficiency, η is given by

$$\eta = \frac{W}{Q},$$

Carnot's Ideal Heat Engine:

In 1824 the French engineer Sadi Carnot conceived a theoretical engine which is free from all practical imperfections. Such an engine can not be realized in practice. It has maximum efficiency and it is an ideal heat engine. Sadi Carnot's heat engine requires the following important parts (Fig.-01)



Cylinder: *A cylinder having perfectly non-conducting walls, a perfect conducting base and is provided with a perfectly non-conducting piston which moves without friction in the cylinder. The cylinder contains one mole of perfect gas as the working substance.*

Source:

A reservoir maintained at a constant temperature T_1 from which the engine can draw heat perfect conduction. It has infinite thermal capacity and any amount of heat can be drawn from it at constant temperature T_1.

Heat Insulating Stand:

A perfectly non-conducting platform acts as a stand for adiabatic process.

Sink:

A reservoir maintained at a constant temperature T_2 ($T_2 < T_1$) to which the heat engine can reject any amount of heat. The thermal capacity of sink is infinite so that its temperature remains constant at T_2, no matter how much heat is given to it.

The Carnot Cycle:

A cycle in which the working substance starting from a given condition of temperature, pressure and volume is made to undergo two successive expansion (one isothermal and another adibatic), and then brought back finally to its initial condition, is called Carnot's Cycle (Fig.-1).

Carnot's Cycle ((Heat and thermodynamics- N. Subrahmanyam, Brijlal))

In order to obtain continuous supply of work, the working substance is subjected to the following cycle of quasi-static operations known as Carnot's cycle

1. *Isothermal expansion:*

The cylinder is first placed on the source, so that the gas acquires the temperature T_1 of the source. It is then allowed to undergo quasi-static expansion. As the gas expands, its temperature tends to fall. Heat passes into the cylinder through the perfectly conducting base which is in contact with the source. The gas therefore, undergoes slow isothermal expansion at the constant temperatureT_1.

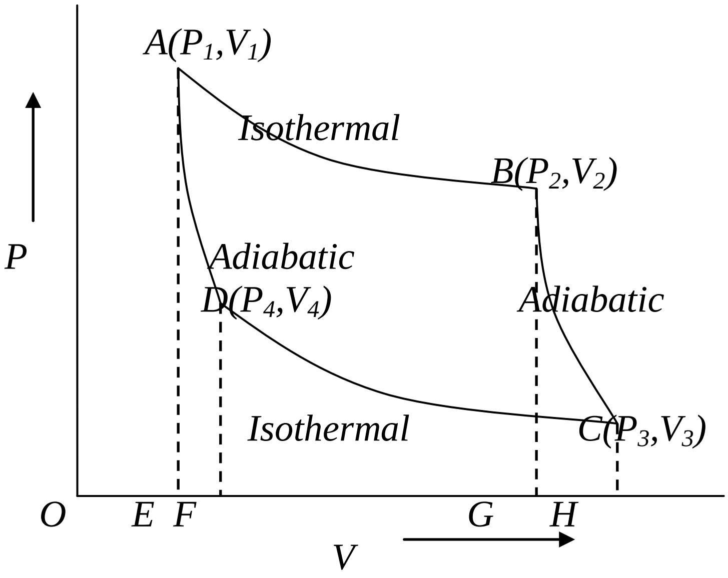


Fig.-1

Let the working substance during isothermal expansion goes from its initial state $A(P_1, V_1, T_1)$ to the state $B(P_2, V_2, T_1)$ at constant temperature T_1 along AB. In this process, the substance absorbs heat Q_1 from he source at T_1 and does work W_1 given by

$$Q_1 = W_1 = \int_{V_1}^{V_2} PdV = RT_1 log_e \frac{V_2}{V_1} = area\ ABGEA$$

2. ***Adiabatic expansion:***

The cylinder is now removed from the source and is placed on the insulating stand. The gas is allowed to undergo slow adiabatic expansion, performing external work at the expense of its internal energy, until its temperature falls to T_2, the same as that of the sink.

This operation is represented by the adiabatic BC, starting from the state B (P_2, V_2, T_2) to the state C (P_3, V_3, T_3). In this process, there is no transfer of heat, the temperature of the substance falls to T_2 and it does some external work W_2 given by

$$W_2 = \int_{V_2}^{V_3} PdV = K\int_{V_2}^{V_3} \frac{dV}{V^\gamma}$$

($\therefore$During adiabatic process, PV^γ =constant=K

$$= \frac{KV_3^{1-\gamma} - KV_2^{1-\gamma}}{1-\gamma}$$

$$= \frac{P_3V_3 - P_2V_2}{1-\gamma} \qquad \left(\therefore P_2V_2^\gamma = P_3V_3^\gamma = K\right)$$

$$= \frac{RT_2 - RT_1}{1-\gamma}$$

$$= \frac{R(T_2 - T_1)}{1-\gamma} = Area\ BCHGB$$

3. *Isothermal Compression:*

The cylinder is now removed from the insulating stand and is placed on the sink which is at a temperature T_2. The piston is now very slowly moved inwards so that the work is done on gas. The temperature tends to increase due to heat produced by compression since the conducting base of the cylinder is in contact with the sink, the heat developed passes to the sink and the temperature of the gas remains constant at T_2. Thus the gas undergoes isothermal compression at a constant temperature T_2 and gives up some heat to the sink.

This operation is represented by the isothermal CD, starting from the state C (P_3, V_3, T_2) to the state D (P_4, V_4, T_2). In this process, the substance rejects heat Q_2 to the sink at T_2 and work W_3 is done on the substance given by

$$Q_2 = W_3 = \int_{V_3}^{V_4} PdV = RT_2 log_e \frac{V_4}{V_3} = area\ CHFDC$$

(-ve sign indicates that work is done on the working substance)

4. *Adiabatic Compression*

The cylinder is now removed from sink and again placed on the insulating stand. The piston is slowly moved inwards so that the gas is adiabatically compressed and the temperature rises. The adiabatic compression is continued till the gas comes back to its original condition i.e., state $A(P_1, V_1, T_1)$, thus completing one full cycle.

This operation is represented by adiabatic DA, starting D (P_4, V_4, T_2) to the final state $A(P_1, V_1, T_1)$. In this process, work W_4 is done on the substance and is given by

$$W_3 = \int_{V_4}^{V_1} PdV$$

$$= -\frac{R(T_1 - T_2)}{\gamma - 1} = Area\ DFEAD$$

(-ve sign indicates that work is done on the working substance. Since W_2 and W_4 are equal and opposite, they cancel each other)

Work done by the engine per cycle:

See-Lecture.((Heat and thermodynamics- N. Subrahmanyam, Brijlal))

Efficiency:

See-Lecture. Heat and thermodynamics- N. Subrahmanyam, Brijlal))

Entropy:

In thermodynamical processes we must search for a quantity which tells about the direction of flow of heat and which could efficiently define the thermodynamical state of any working substance. The required quantity was supplied by Clausius who called it entropy.

It is denoted by the symbol S. For infinitesimal small change in entropy is given by,

$$S = \frac{dQ}{T}.$$

The total change in entropy is given by

$$S = \int \frac{dQ}{T}.$$