ELEMENTS OF MECHANICAL ENGINEERING

[TH-3]

3rd SEM ELECTRICAL ENGG.

Under SCTE&VT, Odisha

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CHAPTER- 1

1.1. Thermodynamics

The heat is defined as the energy transferred, without transfer of mass, across the boundary of a system because of a temperature difference between the system and the surroundings. It is usually represented by Q and is expressed in Joule (J) or Kilo-Joule (KJ).

Work

Work is defined as the product of the force (F) and the distance moved (X) in the direction the force. Mathematically, work done, $W = F \times X$,

The unit of work depends upon the unit of force and the distance moved. In S.I. system of units, the practical unit of work is Newton-metre (N-m). The work of 1N-m is known as Joule such that 1N-m = 1J.

1st law of thermodynamics : This law may be stated as follow :

(a) The heat and mechanical work are mutually convertible. According to this law, when a closed system undergoes a thermodynamic cycle, the net heat transfer is equal to the net work transfer. In other works, the cyclic integral of heat transfers is equal to the cyclic integral of work transfers, mathematically, $\oint \delta Q = \oint \delta W$

Where symbol $\oint$ stands for cyclic integral, and δQ , δW represent infinitesimal elements of heat and work transfers respectively.

(b) The energy can neither be created nor destroyed though it can be transferred from one form to another. According to this law, when a system undergoes a change of state, then both heat transfer and work transfer takes place. The net energy transfer is stored within the system and is known as stored energy or total energy of the system. Mathematically $\delta Q - \delta W = dE$

The symbol δ is used for a quantity which is inexact differential and symbol d is used for a quantity which is an exact differential. The quantity E is an extensive property and represents the total energy of the system at a particular state.

1.2 State Laws of perfect gas.

The physical properties of a gas are controlled by the following three variables :

1. Pressure exerted by the gas

2. Volume occupied by the gas

3. Temperature of the gas

The behaviour of a perfect gas, undergoing any change in the above mentioned variables, is governed by the following laws which have been established from experimental results.

1. Boyle's Law

2. Charles's Law

3. Gay-Lussac Law

1. Boyle's Law

This law was formulated by Robert Boyle in 1662. It states, " The absolute pressure of a given mass of a perfect gas varies inversely as its volume, when the temperature remains constant".

Mathematically, $p \alpha \dfrac{1}{V}$ or $pV = \text{constant}$

2. Charles's Law

This law was formulated by a Frenchman A.c. Charles in about 1787. It may be stated in the following two different forms :

(i) The volume of a given mass of a perfect varies directly as its absolute temperature, when the absolute pressure remains constant". Mathematically, $V \alpha T$ or $\dfrac{V}{T} = \text{constant}$

3. Gay-Lussac Law

This law states, " The absolute pressure of a given mass of a perfect gas varies directly as its absolute temperature when the volume remains constant". Mathematically $p \alpha T$ or $\dfrac{P}{T} = \text{constant}$

1.3 Specific heats of a gas

The specific heat of a substance may be broadly defined as the amount of heat required to raise the temperature of its unit mass through one degree. All the liquids and solids have one specific heat only. But a gas can have any number of specific heats (lying between zero and infinity) depending upon the conditions, under which it is heated. The following two types of specific heats of a gas are important from the subject point of view.

1. Specific heat at constant volume

2. Specific heat at constant pressure

Specific heat at constant volume

It is the amount of heat required one to raise the temperature of a unit mass of gas through one degree when it is heated at a constant volume. It is generally denoted by Cv.

Consider a gas contained in a container with a fixed lid as shown in the figure. Now, if this gas is heated, it will increase

Fixed

Heat being
supplied at
constant volume
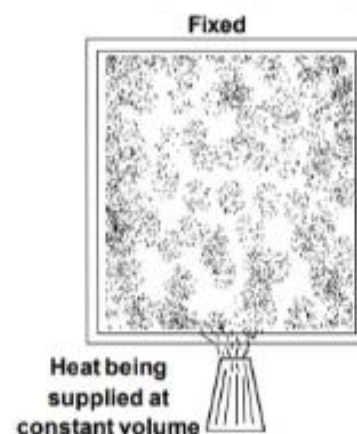
the temperature and pressure of the gas in the container. Since the lid of the container is fixed, therefore the volume of gas remains unchanged.

Let m= Mass of the gas

T_1= Initial temperature of the gas

T_2= Final temperature of the gas

Total heat supplied to the gas at constant volume Q_{1-2}= mass **x** supplied heat at constant volume **x** rise in temperature = $mC_v(T_2 - T_2)$.

It may be noted that whenever a gas is heated at constant volume, no work is done by the gas. The whole heat energy is utilised in increasing the temperature and pressure of the gas.

Specific heat at constant pressure

It is the amount of heat required to raise the temperature of a unit mass of a gas through one degree, when it is heated at constant pressure. It is generally denoted by Cp.

Consider a gas contained in a container with a movable lid as shown in figure. Now if this gas is heated, it will increase the temperature and pressure of the gas in container. Since the lid of the container is movable, therefore it will move upwards in order to counter balance the tendency for pressure to rise.
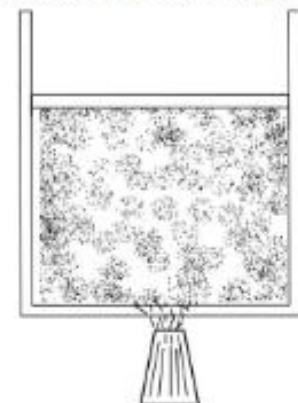
Let

m= Mass of the gas

T_1= Initial temperature of the gas

V_1= Initial volume of the gas

T_2, V_2= Corresponding values for the final condition of the gas

∴ Total heat supplied to the gas, at constant pressure.

Heat being supplied at constant pressure

Q_{1-2}= Mass **x** Sp. heat at constant pressure **x** rise in temperature = $mC_p(T_2 - T_1)$.

Whenever a gas is heated at a constant pressure, the heat supplied to the gas is utilised for the following two purposes.

1. To raise the temperature of the gas. The heat remains within the body of the gas and represents the increase in initial energy. $dU= mC_v(T_2 - T_1)$.

2. To do some external work during expansion. Mathematically, work done by the gas W_{1-2}= $P(V_2 - V_1) = mR(T_2 - T_1)$.

Relationship between specific heats

Consider a gas enclosed in a container and being heated, at a constant pressure, from the initial state 1 to the final state 2.

m = Mass of the gas

T_1 = Initial temperature of the gas

T_2 = Final temperature of the gas

V_1 = Initial volume of the gas

V_2 = Final volume of the gas

C_p = Specific heat at constant pressure

C_v = Specific heat at constant volume

P = Constant pressure

We know that heat supplied to the gas at constant pressure

$$Q_{1-2} = mC_p (T_2 - T_1)$$

A part of this heat is utilised in doing the external work, and the rest remains within the gas and is used in increasing the internal energy of the gas.

$\therefore$ Heat utilised for external work $W_{1-2} = P(V_2 - V_1)$ .... (i)

And increase in internal energy $dU = mC_v(T_2 - T_1)$ .... (ii)

We known that $Q_{1-2} = W_{1-2} + dU$ .... (iii)

$\therefore mC_p(T_2 - T_1) = P(V_2 - V_1) + mCv(T_2 - T_1)$ .... (iv)

Using characteristic gas equation (i.e. $Pv = mRT$), we have

$PV_1 = mRT_1$ ....(for initial condition)

$PV_2 = mRT_2$ ....(for final condition)

$\therefore P(V_2 - V_1) = mR(T_2 - T_1)$

Now substituting the value of $P(V2 - V1)$ in equation .... (v)

$mC_p(T_2 - T_1) = mR(T_2 - T_1) + mCv(T_2 - T_1)$

$\therefore C_p = R + C_v$ or $C_p - C_v = R$ .... (vi)

The above equation may be rewritten as

$$C_p - C_v = R \text{ or } C_v (V - 1) = R - \left[\gamma = \frac{C_p}{C_v} \right]$$

$$C_v = \frac{R}{\gamma - 1}$$ .... (vii)

The equation (v) gives an important result as it proves that characteristic constant of a gas (R) is equal to the difference of its two specific heats i.e. $(C_p - C_v)$.

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CHAPTER - 2.0

i. Wet steam

When the steam contains moisture or particles of water in suspension, it is said to be wet steam. It means that evaporation of water is not complete and the whole of the latent heat has not been absorbed. The enthalpy of wet steam is given by: $h = h_f + Xh_{fg}$ where x is the dryness fraction of steam.

ii. Dry saturated steam

When the wet steam is further heated and it does not contain any suspended particles of water, it is known as dry saturated steam. The dry saturated steam has absorbed its full latent heat. The enthalpy of dry saturated steam is given by: $h = h_g = h_f + h_{fg}$ where dryness fraction X= 1.

iii. Superheated steam

When the dry steam is further heated at a constant pressure this rising its temperature, it is said to be superheated steam since the pressure is constant, therefore the volume of superheated steam increases.

The total heat required for the steam to be superheated is

h_{sup} =total heat for dry steam+ heat for superheated steam

$$= h_f + h_{fg} + C_p(t_{sup} - t) = = h_g + C_p(t_{sup} - t)$$

Where C_p = mean specific heat at constant pressure for superheated steam.

t_{sup} =temperature of the superheated steam.

t= saturation temperature at the given constant pressure.

The difference $(t_{sup} - t)$ is known as degree of superheat.

Steam table and their uses

The properties of dry superheat steam like its temperature of formation (saturation temperature), sensible heat, latent heat of vaporisation, enthalpy or total heat, specific volume, entropy etc., vary with pressure and can be found by experiments only. These properties have been carefully determined and made available in a tabular form known as steam tables.