1. THE FIRST LAW OF THERMODYNAMICS

The first law of thermodynamics is simply a statement of the conservation of energy principle, and it asserts that total energy is a thermodynamic property. The first law of thermodynamics, also known as the conservation of energy principle, provides a sound basis for studying the relationships among the various forms of energy and energy interactions. Based on experimental observations, the first law of thermodynamics states that energy can be neither created nor destroyed; it can only change forms. Therefore, every bit of energy should be accounted for during a process. We all know that rock at some elevation possesses some potential energy, and part of this potential energy is converted to kinetic energy as the rock falls. Experimental data show that the decrease in potential energy exactly equals the increase in kinetic energy when the air resistance is negligible, thus confirming the conservation of energy principle.

Energy Balance

The conservation of energy principle can be expressed as follows: The net change (increase or decrease) in the total energy of the system during a process is equal to the difference between the total energy entering and the total energy leaving the system during that process. That is, during a process,

$$\begin{pmatrix} Total\ energy \\ entering\ the\ system \end{pmatrix} - \begin{pmatrix} Total\ energy \\ leaving\ the\ system \end{pmatrix} = \begin{pmatrix} Change\ in\ the\ total \\ energy\ of\ the\ system \end{pmatrix}$$

Or

$$\Delta E_{system} = E_{in} - E_{out} \qquad (1)$$

Energy Change of a System, (ΔE_{system})

The determination of the energy change of a system during a process involves the evaluation of the energy of the system at the beginning and the end of the process and taking their difference. That is,

$$(Energy\ change) - (Energy\ at\ final\ state) = (Energy\ at\ initial\ state)$$

Or

$$\Delta E_{system} = E_{final} - E_{initial} = E_2 - E_1 \qquad (2)$$

Note that energy is a property, and the value of a property does not change unless the state of the system changes. Therefore, the energy change of a system is zero if the state of the system does not change during the process. Also, energy can exist in numerous forms such as internal (sensible, latent, chemical, and nuclear), kinetic, potential, electric, and magnetic, and their sum constitutes the total energy (E) of a system. In the absence of electric, magnetic, and surface tension effects (i.e., for simple compressible systems), the change in the total energy of a system during a process is the sum of the changes in its internal, kinetic, and potential energies and can be expressed as

$$\Delta E = \Delta U + \Delta KE + \Delta PE \qquad (3)$$

Where

$$\Delta U = m(u_2 - u_1) \qquad (4)$$

$$\Delta KE = \frac{1}{2} m(v_2^2 - v_1^2) \qquad (5)$$

$$\Delta PE = mg(z_2 - z_1) \qquad (6)$$

When the initial and final states are specified, the values of the specific internal energies (u_1) and (u_2) can be determined directly from the property tables or thermodynamic property relations.

Most systems encountered in practice are stationary, that is, they do not involve any changes in their velocity or elevation during a process. Thus, for stationary systems, the changes in kinetic and potential energies are zero ($\Delta KE = \Delta PE = 0$), and the total energy change relation in Eq. (3) reduces to ($\Delta E = \Delta U$)for such systems. Also, the energy of a system during a process will change even if only one form of its energy changes while the other forms of energy remain unchanged.

For stationary systems ($\Delta KE = \Delta PE = 0$)

Thus

$$\Delta E = \Delta U \qquad (7)$$

2. MECHANISMS OF ENERGY TRANSFER (E_{in} and E_{out})

Energy can be transferred to or from a system in three forms: heat, work, and mass flow. The only two forms of energy interactions associated with a fixed mass or closed system are heat transfer and work.

Noting that energy can be transferred in the forms of heat, work, and mass and that the net transfer of a quantity is equal to the difference between the amounts transferred in and out, the energy balance for closed system can be written more explicitly as

$$\Delta E_{system} = E_{in} - E_{out} = (Q_{in} - Q_{out}) + (W_{in} - W_{out}) \qquad (8)$$

where the subscripts "in'' and "out'' denote quantities that enter and leave the system, respectively.

NOTE:

1- The heat transfer (Q) is zero for adiabatic systems (isolated).
2- The work transfer (W) is zero for systems that involve no work interactions.

2.1 Energy of an Isolated System

An isolated system is one in which there is no interaction of the system with the surroundings. For an isolated system

$$\Delta Q = 0 \quad and \quad \Delta W = 0.$$

So the first law gives:

$$\Delta E = 0 \qquad or \qquad E_{in} = E_{out}$$

Thus the energy of an isolated system is always constant. This conclusion is very important since the universe is considered an isolated system, then energy is conserved in the universe which leads to the principle of conservation of energy. The principle of conservation of energy states that energy can neither be created nor destroyed rather, it transforms from one form to another.

2.2 Energy Balance for Closed Systems

Noting that a closed system does not involve any mass flow across its boundaries, the energy balance for a cycle can be expressed in terms of heat and work interactions as

$$Q_{net,in} - W_{net,out} = \Delta E_{system} \qquad (9)$$

$$Q - W = \Delta E \qquad (10)$$

$$\dot{Q} - \dot{W} = \Delta \dot{E} \qquad (11)$$

where $Q = Q_{net,in} = Q_{in} - Q_{out}$ is the net heat input

$W = W_{net,out} = W_{out} - W_{in}$ is the network output.

For constant rates, the total quantities during a time interval (Δt) are related to the quantities per unit time as

$$Q = \dot{Q}\Delta t \qquad (12)$$

$$W = \dot{W}\Delta t \qquad (13)$$

$$E = \dot{E}\Delta t \qquad (14)$$

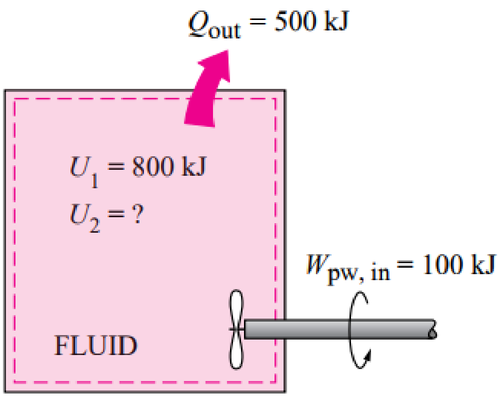
Neglecting kinetic and potential energies, and considering internal energy only ($E = U$), we have:

$$Q - W = \Delta U \qquad (15)$$

For a unit mass, we get:

$$q - w = \Delta u \qquad (16)$$

Example (1): A rigid tank contains a hot fluid that is cooled while being stirred by a paddle wheel. Initially, the internal energy of the fluid is (800 kJ). During the cooling process, the fluid loses (500 kJ) of heat, and the paddlewheel does (100 kJ) of work on the fluid. Determine the final internal energy of the fluid. Neglect the energy stored in the paddlewheel.



Solution:

The tank is stationary and thus the kinetic and potential energy changes are zero, ($\Delta KE = \Delta PE = 0$). Therefore, ($\Delta E = \Delta U$) and

$$Q - W = \Delta U = U_2 - U_1$$

Since heat is lost, then it will have a negative sign. Also work input will have a negative sign. Hence:

$$-500 - (-100) = U_2 - 800$$

$$U_2 = 400\ kJ$$

3. SPECIFIC HEAT OF GASES

3.1 Specific Heat at Constant Volume (C_v)

From the first law of thermodynamic for a closed system at constant volume:

$$Q - W = \Delta U$$

Since the volume is constant:

$$W = \int_1^2 PdV = 0$$

Then $Q = \Delta U$

$$Q = mC_v\Delta T$$

so, $\Delta U = mC_v\Delta T$

$$U = mC_vT$$

For a unit mass:

$$u = C_vT$$

3.2 Specific Heat at Constant Pressure (Cp)

From the first law of thermodynamic for a closed system at constant pressure:

$Q - W = \Delta U$

Since the pressure is constant:

$W = \int PdV = P(V_2 - V_1)$

$Q = mC_p\Delta T$

So, $mC_p\Delta T - P(V_2 - V_1) = \Delta U = U_2 - U_1$

then, $(U_2 + PV_2) - (U_1 + PV_1) = mC_p\Delta T$

since $H = U + PV$

$\Delta H = mC_p\Delta T$

then $H = mC_pT$

For a unit mass:

$h = C_pT$

4. RELATIONSHIP BETWEEN (C$_V$) AND (C$_P$)

We know that the enthalpy may be given as:

$H = U + PV$ (1)

Since

$H = mC_pT$ (2)

$U = mC_vT$ (3)

and $PV = mRT$ (4)

sub. Eqs. (2, 3 and 4) in Eq. (1)

then: $mC_pT = mC_vT + mRT$ Dividing by mT,

$C_p = C_v + R$

$R = C_p - C_v$ (17)

$\gamma = C_pC_v$ (18) where γ is the adiabatic index.