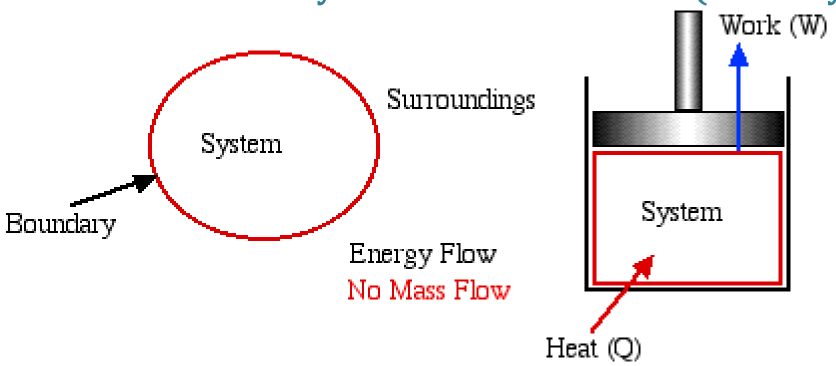
First Law of Thermodynamics

"Energy can neither be created nor destroyed but it can be transformed from one form to another."

"If something enters into the system, it comes out in any other form but does not vanish."

First Law of Thermodynamics for Control Mass (Closed System/Non Flow Process)



Let us consider a closed system with heat input and work output as shown in figure.

Using Conservation of Energy Equation,

[Energy entering into the system] – [Energy leaving the system] =

[Change in total energy of the system]

or, $E_{in} - E_{out} = \Delta E_s$

⇨ $Q - W = \Delta E_{cm}$ ....(i)

Where, total energy of control mass (ΔE_{cm}) is algebraic sum of Kinetic Energy (K.E.), Potential Energy (P.E.) and Internal Energy of the system.

Mathematically,

$E_{cm} = K.E. + P.E. + U$

⇨ $\Delta E_{cm} = \Delta K.E. + \Delta P.E. + \Delta U$

In a closed system, change in K.E. and change in P.E. are negligible as compared to change in U of the system.

Therefore, $\Delta E_{cm} = \Delta U$

So, from equation (i), we get,

$Q - W = \Delta U$

Therefore, $\boxed{\delta Q - \delta W = dU}$

Case I: If a closed system undergoes cyclic process

Conservation of Energy Equation can be written as:

$$\oint(\delta Q - \delta W) = \oint dU$$

Internal Energy is a property of thermodynamic system. From the definition of property, $\oint dU = 0$

Hence, Conservation of Energy Equation for a cyclic process becomes

$$\oint(\delta Q - \delta W) = 0$$

or, $\oint \delta Q = \oint \delta W$

Hence, $\boxed{Q_{net} = W_{net}}$

Hence, the first law of thermodynamics for a cycle states that:

"During any cycle a system (control mass) undergoes, the cyclic integral of the heat is proportional to the cyclic integral of work."

Case II: For any thermodynamic process 1-2,

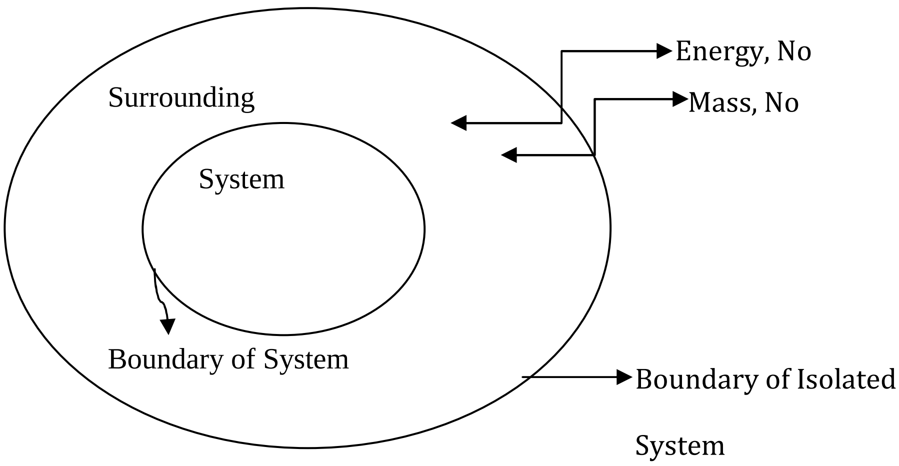
In a closed system, the conservation of energy equation becomes

$Q_{1-2} - W_{1-2} = U_2 - U_1$

$$\boxed{Q_{1-2} = W_{1-2} + U_2 - U_1}$$

Conservation of Energy Equation for Isolated System (Universe)

Let us consider an isolated system as shown in figure below.



Using Conservation of Energy Equation,

[Energy entering into the system] – [Energy leaving the system] =

[Change in total energy of the system]

or, $E_{in} - E_{out} = \Delta E_S$

or, $0 - 0 = \Delta ES$

or, $\Delta E_S = 0$

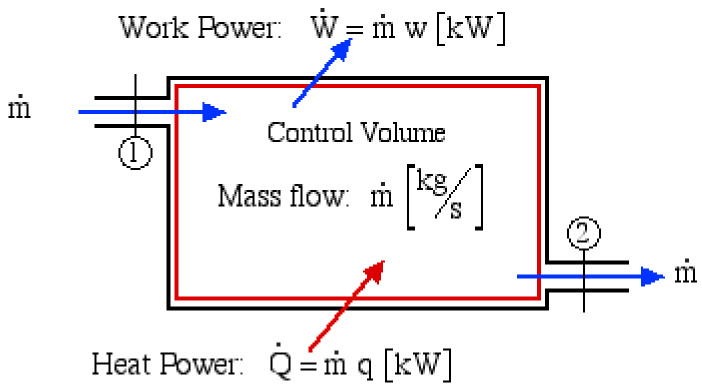
Integrating both sides,

$$\int dEs = \int 0$$

Hence, $\boxed{E_S = 0}$

Hence, total energy of isolated system (universe) is always constant.

Conservation of Energy Equation for Control Volume (Open System/Flow Process)



Let us consider an open system with single inlet (1) and outlet (2) as shown in figure. The following quantities are defined with reference to the figure.

m_1, m_2 → mass flow rate, kg/s

P_1, P_2 → pressure (absolute), N/m2

v_1, v_2 → specific volume, m^3/kg

u1, u2 → specific internal energy, J/kg

V_1, V_2 → velocity, m/s

z_1, z_2 → elevation above an arbitrary datum, m

The total power in due to heat and mass flow through the inlet port (1) must equal the total power out due to work and mass flow through the outlet port (2), thus:

$$\dot{Q} + \dot{m}\, e_1 = \dot{W} + \dot{m}\, e_2$$
$$\dot{Q} - \dot{W} = \dot{m}\,(e_2 - e_1) = \dot{m}\,\Delta e$$

Since there is no accumulation of energy(steady flow), the total rate of flow of all energy streams entering the control volume must equal to the total rate of flow of all the energy streams leaving the C.V. So,

Change in flow rate of energy = 0

Hence, energy flow rate into the system = energy flow rate out of the system

Also, Mass flow rate into the system = Mass flow rate out of the system

The specific energy e can include kinetic and potential energy however will always include the combination of internal energy (u) and flow work (PV), thus we conveniently combine these properties in terms of the property enthalpy, as follows:

$$e = \underbrace{u + P\,v}_{\substack{\Downarrow \\ h \;\Rightarrow\; \text{enthalpy}}} + ke + pe = h + \left[V^2\!/_2 \right] + g\,z$$

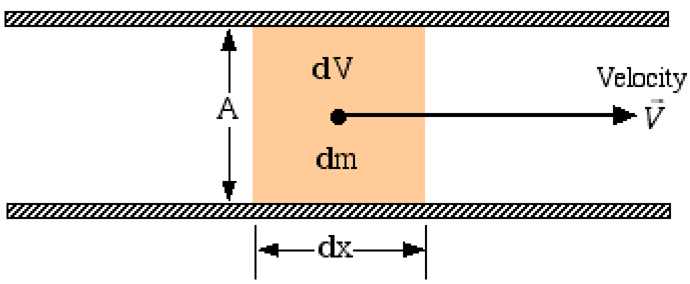
Note that z is the height of the port above some datum level [m] and g is the acceleration due to gravity [9.81 m/s2]. Substituting for energy e in the above energy equation and simplifying, we obtain the final form of the energy equation for a single-inlet single-outlet steady flow control volume as follows:

$$\boxed{\dot{Q} - \dot{W} = \dot{m}\left[\Delta h + \left(\Delta V^2\!/_2\right) + g\,\Delta z\right]}$$

Notice that enthalpy h is fundamental to the energy equation for a control volume. The above is a Steady State Steady Flow (SSSF) Energy Equation.

Mass Balance

Consider an elemental mass dm flowing through an inlet or outlet port of a control volume, having an area A, volume dV, length dx, and an average steady velocity $\vec{V}$, as follows.



$$dm = \rho\, dV = \frac{dV}{v}, \qquad dV = A\, dx$$

$$\dot{m} = \frac{dm}{dt} = \rho \frac{dV}{dt} = \rho\, A \frac{dx}{dt} = \rho\, A\, \vec{V} = \frac{A\,\vec{V}}{v}$$

Thus finally the mass flow rate $\dot{m}$ can be determined as follows:

$$\boxed{\dot{m} = \rho\, \dot{V} = \frac{\dot{V}}{v} = \rho\, A\, \vec{V} = \frac{A\, \vec{V}}{v}}$$

where: $\dot{m}$ is the mass flow rate $\left[\mathrm{kg}/\mathrm{s}\right]$

$\dot{V}$ is the volumetric flow rate $\left[\mathrm{m^3}/\mathrm{s}\right]$

ρ is the density $\left[\mathrm{kg}/\mathrm{m^3}\right]$, v is the specific volume $\left[\mathrm{m^3}/\mathrm{kg}\right]$

$\vec{V}$ is the velocity $\left[\mathrm{m}/\mathrm{s}\right]$, A is the flow area $\left[\mathrm{m^2}\right]$

Steady State Work Applications	*Steady State Flow Applications*
Pump, Turbine, Fan, Compressor	Boiler, Nozzle, Heat exchanger, Diffuser, Pipe, Expansion valve/Throttling valve

Analysis of Control Volume at Steady State, Steady Flow Process

The SSSF energy equation for C.V. does not include the short-term transient start up or shut down of the devices but only the steady operating period of time.

1. The control volume is fixed i.e. it does not move relative to the co-ordinate frame. It implies that there is no work associated with the acceleration of the control volume.
2. The state of the mass at each point of the C.V. does not vary with time i.e. a steady state. To fulfill this assumption, we follow the conditions:

$\frac{d(mcv)}{dt} = 0$ and $\frac{d(Ecv)}{dt} = 0$

3. The mass that flows across the control surface i.e. mass flux and the state of this mass at each discrete area of flow on the control surface do not vary with time i.e. a steady flow. The rate of energy transfer by heat and work throughout the control surface remain constant,

Conditions for SSSF Work and Flow Devices

For all flow devices, $W = 0$

For all work devices, $W \neq 0$

Pump, compressor, fan → -ve work

Turbine → +ve work

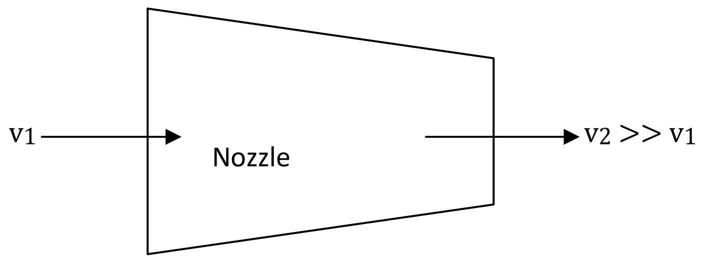
Assumptions for SSSF Work and Flow Devices

1. Except boiler and heat exchanger, all work and flow devices can be taken as adiabatic. (Q=0)
2. For all work and flow devices, change in P.E. can be neglected.
3. Except nozzle and diffuser, change in K.E. can be neglected in all work and flow devices.
4. In case of nozzle, inlet velocity can be neglected in comparison to outlet velocity.

   In case of diffuser, exit velocity can be neglected in comparison to inlet velocity.

Examples of SSSF Processes

1. Nozzle and Diffuser



A nozzle is a SSSF device having a flow-passage of varying cross-section area in which the velocity of fluid increases in the direction of flow with a corresponding drop in pressure.

a. Nozzle is flow device. So, W = 0

   Hence, SSSF energy equation reduces to

$$\dot{Q} = \dot{m}\left[\Delta h + \left(\Delta V^2/2\right) + g\,\Delta z\right] \quad \text{.. (i)}$$

b. For an adiabatic process Q = 0. Hence, equation (i) reduces to

$$0 = \dot{m}\left[\Delta h + \left(\Delta V^2/2\right) + g\,\Delta z\right]$$

$$0 = \Delta h + \left(\Delta V^2/2\right) + g\,\Delta z \quad \text{................... (ii)}$$

c. In case of horizontal nozzle, $z_1 = z_2$.

   Hence, equation (ii) becomes

$$0 = \Delta h + \left(\Delta V^2/2\right) \quad \text{................................... (iii)}$$

d. If inlet velocity of nozzle is negligible in comparison to exit velocity, equation (iii) reduces to:

$$\boxed{(h_2 - h_1) + (v_2)^2/2 = 0}$$

A diffuser is a SSSF device in which the high velocity fluid decelerates in the direction of flow with a corresponding increase in pressure.

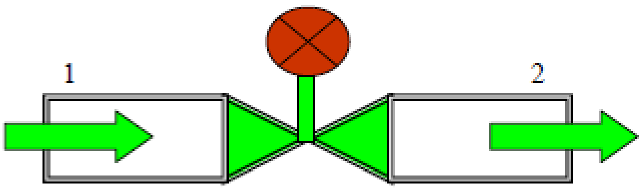
Since, $v_2 << v_1$

Hence, $\boxed{(h_2 - h_1) + (v_1)^2/2 = 0}$

2. Throttling Valve

When a fluid flows through a constricted passage, like a partially opened valve, an orifice or a porous plug, there is an appreciable drop in pressure, and the flow is said to be throttled.

Consider the flow of fluid through a small valve as shown



if the SFEE is applied between sections 1 and 2 :

$Q - W = m\,(\Delta h + \Delta ke + \Delta Pe)$

$Q = 0$ Assuming adiabatic

$W = 0$ No displacement work (no work is inputted or extracted, ie no pump or turbineis attached)

$\Delta ke = 0$ Assumed (inlet and exit velocities are similar or slow)

$\Delta Pe = 0$ Assumed (entry and exit at the same or nearly the same elevation)

Hence, The SFEE, reduces to:

$\therefore \quad m\,(h2 - h1) = 0$

divide by the mass flow m to get:

$\therefore h2 = h1$

hence for a control valve, the enthalpy of the fluid remains constant.

3. Turbine and Compressor

Turbine is a SSSF device that produces work due to the pressure drop of the working fluid when the fluid passes through a set of blades attached to a shaft free to rotate.

For a turbine, $\frac{W}{m} = \Delta h$

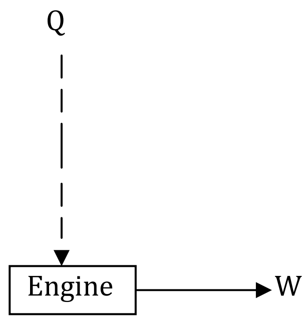
Where, $\Delta h = h_1 - h_2$ since $h_2 < h_1$ (for turbine), $W = +ve$

For a pump or compressor, $\frac{W}{m} = \Delta h$

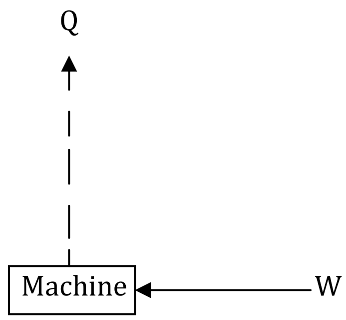
Where, $h = h_2 - h_1$ since $h_2 > h_1$ (for turbine), $W = -ve$

Perpetual Motion Machine of the First Kind – PMMI

PMMI violates First Law of Thermodynamics (Conservation of Energy).



A PMMI



The converse of PMMI

There can be no machine which could continuously supply mechanical work without some other form of energy disappearing simultaneously. Such a fictitious machine is called PMMI.

The converse of the above statement is also true.