Thermodynamics I

Chapter 2

Lecture no.2

Flow Energy Equation

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2. Steady – Flow Equation (Open System)

In our previous lecture we learn the first law of thermodynamics for closed system or control mass system. But in practice most of the components like compressor, turbine, and heat exchanger has a continuous mass flow through it. For those flow processes instead of concentrating attention upon a certain quantity of mass, attention is focused upon a fixed region in space called control volume. This control volume is separated by an imaginary boundary called control surface and analysis is done considering that the energy interactions happen through this surface. In this lecturer we will know about Steady Flow Energy Equation And Its Application.

Conditions of Steady Flow System:

dt

A steady flow process should satisfy the following conditions:

i. A certain mass of the fluid is considered and this is supposed to flow through the system. The mass flow rate into and out of the system are equal and do not vary with time i.e., mass in the system does not change. If the mass flow rate at the inlet is 10 kg/sec., then the mass flow rate at the exit will be 10 kg/sec and it does not vary with time.

ii. A certain fixed volume of the system known as Control Volume (CV) is considered. The moving substance flows through this control volume.

iii. The surface of the control volume is known as Control Surface (CS).

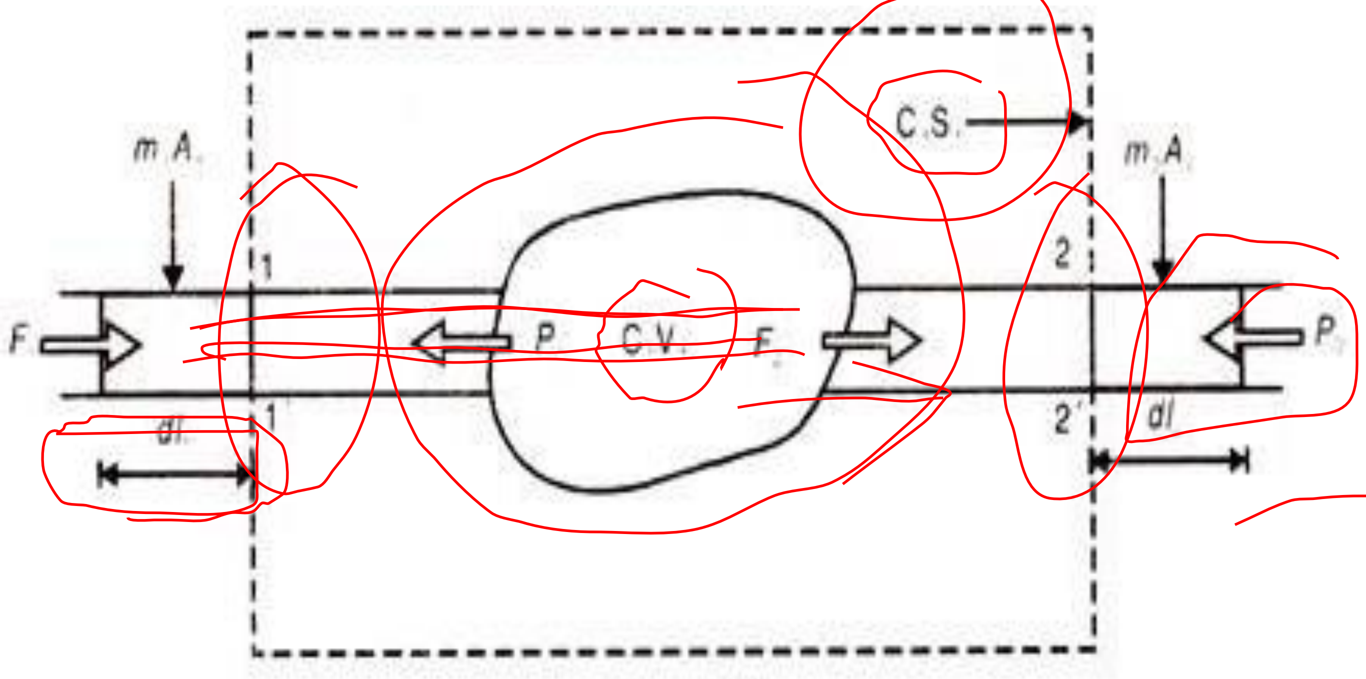
iv. The energy of the fluid at the entrance and at the exit (of the system) are same and do not vary with time.

v. The rate of heat and work transfer into and out (of the system) do not vary with time.

Steady Flow Energy Equation (S.F.E.E.)

It is the state when the thermodynamic properties will not change with time and have a fixed value at a particular location. So, analysis is done considering that there is a constant mass flow rate and the processes are steady flow process.

In case of flow processes certain amount of work or energy is required to push the fluid into and out of the system. This work energy is known as flow work or flow energy. Consider a flow process as shown in Fig.



Let F, be the force which forces the mass m_1, of cross sectional area A_1 into the system against the pressure P_1 of the system. Now consider a small amount of work done on the system in causing the displacement dl_1 for the mass m_1. Thus the small amount of work done on the system in causing the displacement dl_1,

$$\delta W = -F_1 \times dl_1$$

Note : –ve sign, since the work is done on the system.

But $$F_1 = P_1 \times A_1$$

$\therefore$ $$\delta W = -P_1 \times A_1 \times dl_1$$

Since $A_1 \times dl_1 = dV_1$ = small amount of displacement volume.

$\therefore$ $$\delta W = -P_1 \times dV_1$$

$\therefore$ Total flow work at Sec. (1) $= -P_1 V_1$

Similarly work done by the system to force the fluid out of the system at Sec. (2) $= P_2V_2$

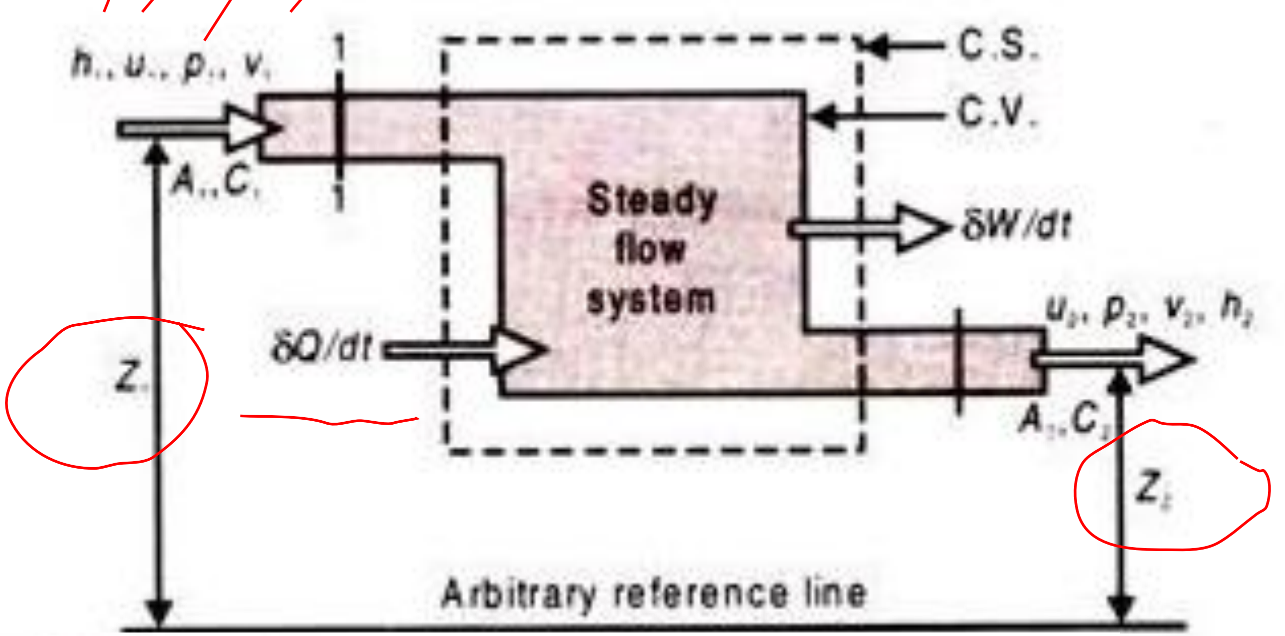
$\therefore$ **Net flow work** $= P_2 V_2 - P_1 V_1$

and **for unit mass** $= P_2 v_2 - P_1 v_1$

Note:

Since the flow work is entirely expressed in terms of properties of the system, the net flow work depends on the end states and it is a Property. Whereas the other forms of work are path functions so in problems involving flow processes, flow work is to be calculated separately.

Steady Flow Energy Equation (S.F.E.E.):
Steady flow energy equation is obtained by applying the first law of thermodynamics to a steady flow system.



Let

$\dot{m}$	=	Mass flow rate in kg/sec
A_1 A_2	=	Cross sectional areas at sec 1–1 and 2–2 respectively in m^2
C_1 C_2	=	Velocities in m/sec
P_1 P_2	=	Absolute pressures in N/m^2
v_1 v_2	=	Specific volumes in m^3/kg
u_1 u_2	=	Specific internal energies in J/kg
h_1 h_2	=	Specific enthalpies in J/kg
Z_1 Z_2	=	Elevations above arbitrary reference datum line in *m*
Q	=	Net heat transfer in Joules

$$\frac{\delta Q}{dt} = \text{Net rate of heat transfer in J/sec}$$

$$\frac{\delta Q}{dm} = q = \text{Net rate of heat transfer in J/kg}$$

$$W = \text{Net work transfer in joules}$$

$$\frac{\delta W}{dt} = \text{Net rate of work transfer in J/sec}$$

$$\frac{\delta W}{dm} = w = \text{Net rate of work transfer in J/kg}$$

$$t = \text{time in seconds}$$

Figure shows a steady flow system. Fluid enters section 1 – 1 and leaves at section 2 – 2 . Since it is a steady system. According to the 2nd condition :

Total energy at the entrance = Total energy at the exit

Then , We can rite :

$$\dot{m}\begin{bmatrix}\text{Energy carried}\\ \text{into the system}\end{bmatrix} + \dot{m}\begin{bmatrix}\text{Specific enthalpy}\\ \text{of entering fluid}\end{bmatrix} + \begin{bmatrix}\text{Net rate of heat}\\ \text{transfer into}\\ \text{system}\end{bmatrix}$$

$$= \dot{m}\begin{bmatrix}\text{Energy carried}\\ \text{out of the system}\end{bmatrix} + \dot{m}\begin{bmatrix}\text{Specific enthalpy}\\ \text{of the fluid}\\ \text{at the exit}\end{bmatrix} + \begin{bmatrix}\text{Net rate of work}\\ \text{transfer by the}\\ \text{system}\end{bmatrix}$$

i.e. , $$\dot{m}[KE_1 + PE_1] + \dot{m}(h_1) + \frac{\delta Q}{dt} = \dot{m}[KE_2 + PE_2] + \dot{m}(h_2) + \frac{\delta W}{dt}$$

i.e., $$\dot{m}\left[\frac{C_1^2}{2} + g\,Z_1\right] + \dot{m}(h_1) + \frac{\delta Q}{dt} = \dot{m}\left[\frac{C_2^2}{2} + g\,Z_2\right] + \dot{m}(h_2) + \frac{\delta W}{dt}$$

Note: *m* of KE and PE will be unity, since we are deriving the S.F.E.E. for unit mass.

$$\therefore \quad \dot{m}\left[\frac{C_1^2}{2} + g\,Z_1 + h_1\right] + \frac{\delta Q}{dt} = \dot{m}\left[\frac{C_2^2}{2} + g\,Z_2 + h_2\right] + \frac{\delta W}{dt} \qquad \ldots(1)$$

This is steady flow energy equation on *time basis*.

Also, since $h_1 = u_1 + P_1 v_1$ and $h_2 = u_2 + P_2 v_2$

$\therefore$ Equation (1) becomes,

$$\therefore \quad \dot{m}\left[\frac{C_1^2}{2} + g\,Z_1 + u_1 + P_1 v_1\right] + \frac{\delta Q}{dt} = \dot{m}\left[\frac{C_2^2}{2} + g\,Z_2 + u_2 + P_2 v_2\right] + \frac{\delta W}{dt}$$

or $$\dot{m}[KE_1 + PE_1 + IE_1 + FE_1] + \frac{\delta W}{dt} = \dot{m}[KE_2 + PE_2 + IE_2 + FE_2] + \frac{\delta W}{dt} \qquad \ldots(2)$$

Steady Flow Energy Equation on Mass Basis:

For deriving this, we have to consider m = 1 kg/sec and all other quantities will be for per kg mass such as δW/dm and δQ/dm.

∴ Equation becomes,

$$\left[\frac{C_1^2}{2} + gZ_1 + h_1\right] + \frac{\delta Q}{dm} = \left[\frac{C_2^2}{2} + gZ_2 + h_2\right] + \frac{\delta W}{dm}$$

$$\therefore \quad \left[\frac{C_1^2}{2} + gZ_1 + h_1\right] + q = \left[\frac{C_2^2}{2} + gZ_2 + h_2\right] + w$$

This is the SFEE on mass basis.

In a Steady Flow System W.D.= -∫ vdp when Changes in KE and PE are Neglected: We know that, SFEE on mass basis. From Equation

$$\left[\frac{C_1^2}{2} + gZ_1 + h_1\right] + q = \left[\frac{C_2^2}{2} + gZ_2 + h_2\right] + w$$

$$\text{i.e.,} \quad \left[\frac{C_1^2}{2} + gZ_1 + u_1 + P_1v_1\right] + q = \left[\frac{C_2^2}{2} + gZ_2 + u_2 + P_2v_2\right] + w$$

$$\therefore \quad q = u_2 - u_1 + P_2v_2 - P_1v_1 + \frac{C_2^2 - C_1^2}{2} + g(Z_2 - Z_1) + w$$