Lecture eight

first law of thermodynamic for the flow systems

1. STEADY AND UNSTEADY FLOW PROCESS

The **flow processes** are those processes which occur in an open system (also called control volume) which permit the transfer of mass as well as energy to/from the system *i.e.*, across its boundaries.

Steady flow process

▪ The state of the working substance in the neighborhood of a given point remains constant with time.

▪ The flow rate in and out of the system is equal and remains constant with time.

▪ There is no change of stored energy within the system.

Unsteady flow process

- The state of the working substance at the boundary of the system varies with time and mass inflow and outflow are not balanced.
- There is a change of energy stored within the system during this process. The filling of a tank is an example of an unsteady flow process.

2. ASSUMPTIONS IN STEADY FLOW PROCESS

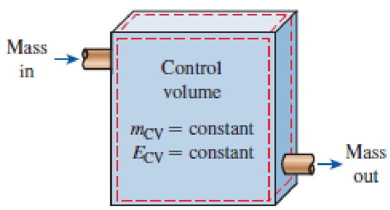
1. The mass flow through the system remains constant.

2. The rate of heat and work transfer is constant.

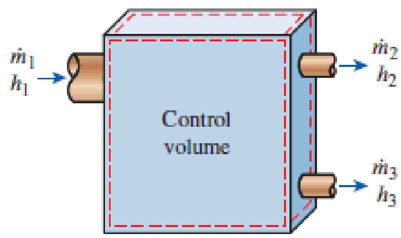
3. The working substance is uniform in composition.

4. The state of the working substance at any point remains constant with time.

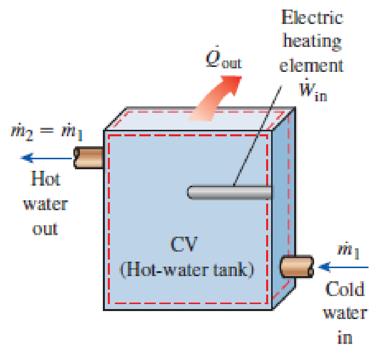
5. Potential, kinetic and flow energies are considered.



$$\underbrace{\Sigma \dot{m}}_{in} = \underbrace{\Sigma \dot{m}}_{out}$$



Under steady-flow conditions, the substance properties at an inlet or exit remain constant (do not change with time).

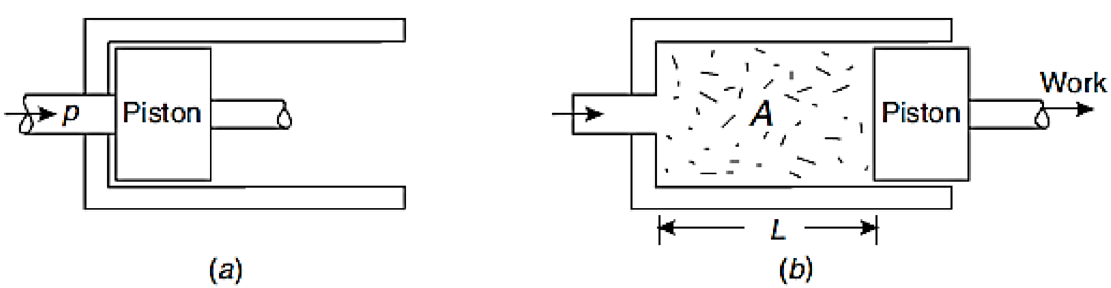


A water heater in steady operation.

3. MASS AND ENERGY ANALYSIS OF CONTROL VOLUMES (steady flow process)

The energy required to flow or move the working substance across the open system, is termed as flow energy or displacement energy. It is also known as **flow work.**

Let the working substance with pressure p (in N/m^2) pushes the piston of cross-sectional area A (in m^2) through a distance L (in meters), as shown in Fig. shown. The magnitude of the flow energy must be exactly equal to the work done by the piston.



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∴ Flow energy = Workdone by the system = Force * Distance moved

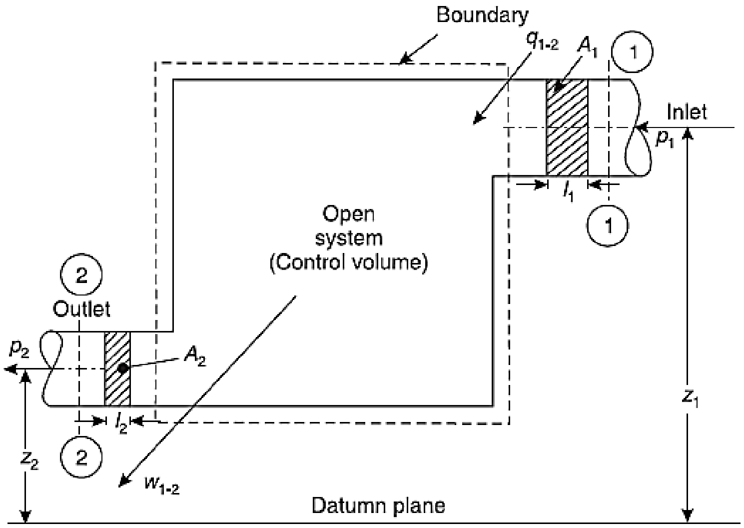
$$= P.A.L \text{ (in N.m or J)} = P.\upsilon$$

Where υ = Volume of the working substance.

For 1 kg mass of the working substance.

$$\text{Flow energy} = P\upsilon_s \text{ (in N.m/kg or J/kg)}$$

Where υ_s = Specific volume of the working substance in m^3/kg.



Energy balance: for one kg of the working substance total energy entering the system at section 1-1= total energy leaving the system at section 2-2 .

$$\Sigma e_{in} = \Sigma e_{out}$$

$$u_1 + gz_1 + \frac{1}{2}V_1^2 + p_1v_1 + q_{1-2} = u_2 + gz_2 + \frac{1}{2}V_2^2 + p_2v_2 + w_{1-2}$$

$$\text{We know that; } u + pv = h\,,$$

$$h_1 + gz_1 + \frac{1}{2}V_1^2 + q_{1-2} = h_2 + gz_2 + \frac{1}{2}V_2^2 + w_{1-2}$$

$$q_{1-2} - w_{1-2} = (h_2 + gz_2 + \frac{1}{2}V_2^2) - (h_1 + gz_1 + \frac{1}{2}V_1^2) \text{.........(SFEE) or}$$

$$q_{1-2} - w_{1-2} = g(z_2 - z_1) + \frac{1}{2}(V_2^2 - V_1^2) + (h_2 - h_1) \text{...... (kJ/s)}$$

Q= rate of heat transfers between the control volume and its surroundings.

W = Work transfer (power), for steady-flow devices, work done per unit time.

Mass conversion: $\Sigma m_{in} = \Sigma m_{out}$

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$$m_1 = m_2$$

$$\rho_1 V_1 A_1 = \rho_2 V_2 A_2 \qquad (single\ stream)$$

$$\frac{V_1 A_1}{\upsilon_1} = \frac{V_2 A_2}{\upsilon_2}$$

Example 1// In a certain steady flow process, the properties of the fluid at inlet and outlet are as follows:

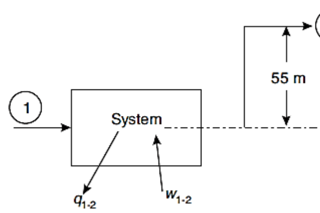
At inlet: Pressure = 1.5 bar; density = 26 kg/m^3; velocity = 110 m/s; internal energy = 910 kJ/ kg.

At exit: Pressure = 5.5 bar; density = 5.5 kg / m^3; velocity = 190 m/s; internal energy = 710 kJ/kg. During the process, the fluid rejects 55 kJ/s of heat and rises through 55metres. The mass flow rate of the fluid is 10 kg / min. Determine:

1. Change in enthalpy; and
2. Power developed during the process.

Solution:

Properties of the fluid at inlet	Properties of the fluid at outlet
$p_1 = 1.5\ bar = 150\times10^3 N/m^2$	$p_2 = 5.5\ bar = 550\times10^3 N/m^2$
$\rho_1 = 26 kg/m^3$	$\rho_2 = 5.5 kg/m^3$
$V_1 = 110\ m/s$	$V_2 = 190\ m/s$
$u_1 = 910\ kJ/kg$	$u_2 = 710\ kJ/kg$



Inlet specific volume, $v_{s1} = \frac{1}{\rho_1} = \frac{1}{26} = 0.038 m^3 kg$

Outlet specific volume, $v_{s2} = \frac{1}{\rho_2} = \frac{1}{5.5} = 0.182\ m^3/kg$

Heat rejected by fluid, $Q_{1\text{-}2} = 55\ kJ/s$

Rise in elevation = 55 m

Mass flow rate = 10 $kg/min = \frac{10}{60} = 1/6 kg/s$

1. *Change in enthalpy*

Enthalpy at inlet, $h_1 = u_1 + p_1 v_{s1} = 910 + (150 \times 0.038)$

= 915.7 kJ / kg

Enthalpy at outlet, $h_2 = u_2 + p_2\, v_{s2} = 710 + (550 \times 0.182) = 810.1\ kJ/kg$

Change in enthalpy, $dh = h_2 - h_1 = 810.1 - 915.7 = -105.6\ kJ/kg$

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2. Power developed during the process

Let w_{1-2} = Work done or power developed during the process in kJ / kg.

We know that heat rejected by the fluid.

$$q_{1-2}=\frac{Q_{1-2}}{m}=\frac{55}{(1/6)}=-55\times 6=-330\ kJ/kg$$

The –ve sign is due to heat rejected.

Using the steady flow energy equation, we have:

$$q-w=g(z_2-z_1)+\frac{1}{2}(V_2^2-V_1^2)+(h_2-h_1)$$

$$-330-w_{1-2}=9.81(55-0)+\left(\frac{(190^2)-(110^2)}{2*1000}\right)+(-105.6)$$

$$-330-w_{1-2}=0.54+12-105.6=-93.06$$

$$w_{1-2}=-330+93.06=-236.94\ kJ/kg$$

The –ve sign indicates that work is done on the system.

Since the mass flow rate is 1/6 kg / s, therefore work done or power developed during process, $W_{1-2}=m\times w_{1-2}$= 39.54 kJ/s = 39.54 kW

4. STEADY FLOW ENERGY EQUATION APPLED TO VARIOUS PROCESSES:

The work done for various steady flow processes, like non-flow processes are as follows:

For constant volume process, $W_{1\text{-}2}=0.$

For constant pressure process, $W_{1\text{-}2}=P(\upsilon_2-\upsilon_1).$

For constant temperature process, $W_{1\text{-}2}=P_1\upsilon_1 \ln\left(\frac{\upsilon_2}{\upsilon_1}\right).$

For constant adiabatic or isentropic process, $W_{1\text{-}2}=\frac{P_1v_1-P_2v_2}{\gamma-1}$

For constant polytropic process, $W_{1\text{-}2}=\frac{P_1v_1-P_2v_2}{n-1}$

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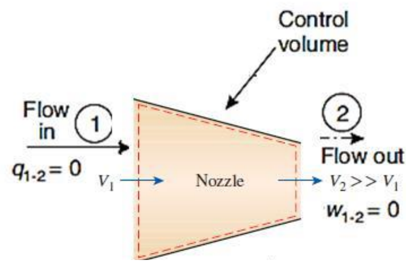
5. ENGINEERING APPLICATIONS OF STEADY FLOW ENERGY EQUATION

1. **Nozzle:** A nozzle is a passage of varying cross-section by means of which the pressure energy of the flowing fluid is converted into kinetic energy. The main use of the nozzle is to produce a jet of high velocity to drive a turbine and to produce thrust.

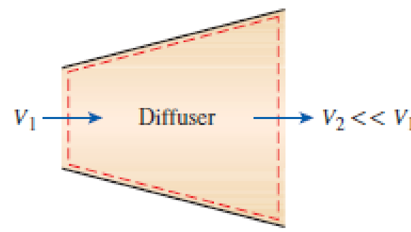


$$q_{1-2} - w_{1-2} = [(h_2 + gz_2 + \frac{1}{2}V_2^2) - (h_1 + gz_1 + \frac{1}{2}V_1^2)]$$

$$z_1 = z_2$$

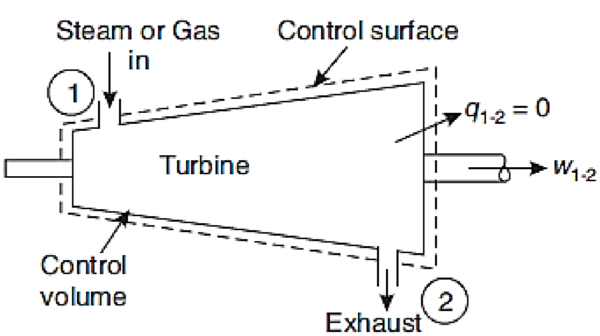
In case V_1 is very small as compared to V_2, then V_1 may be neglected. $q_{1-2} - w_{1-2} = 0$ Thus; $V_2 = \sqrt{2(h_1 - h_2)}$.

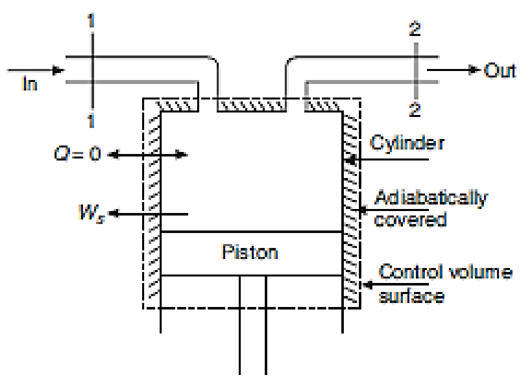
2. **Diffuser:** A diffuser is a passage of varying cross-sectionby means of which the kinetic energy of the flowing fluid is changed into pressure energy. The energy equation for steady flow may be applied in the similar way as for the nozzle but



$$V_1 = \sqrt{2(h_2 - h_1)}.$$

3. **Steam or Gas turbine (Or IC engines)**: A turbine is used to convert the heat energy of steam or gas into useful work. $z_1 = z_2$, $V_1 = V_2$, and $q_{1-2} = 0$ (insulated i.e., adiabatic flow)





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$$q_{1-2}+(h_1+gz_1+\frac{1}{2}V_1^2)=(h_2+gz_2+\frac{1}{2}V_2^2)+w_{1-2}$$

$$W_{1-2}=m(h_1-h_2)$$

4. Compressors:

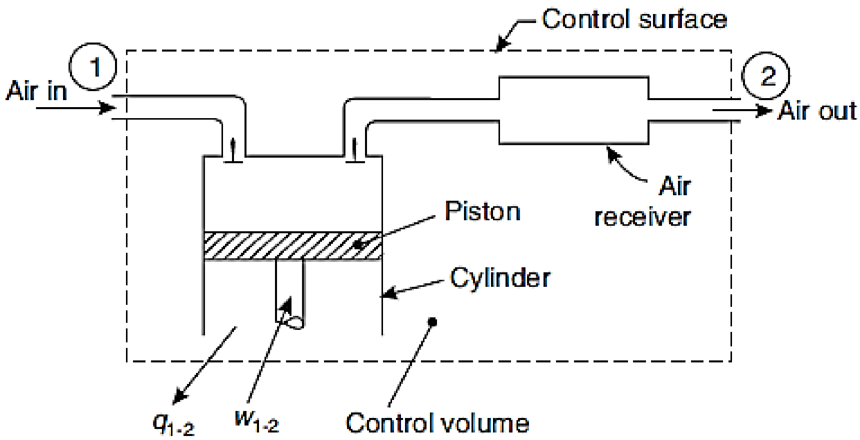
• **Reciprocating compressor:** A reciprocating compressor is used to compress air or gas from low pressure to high pressure with the help of work input

(w_{1-2}). $z_1 = z_2$, $V_1 = V_2$

$$q_{1-2}-(-w_{1-2})=(h_2-h_1)$$

$$w_{1-2}=(h_1-h_2)-q_{1-2}$$

"Work done on the system (-ve) & heat rejection (-ve)"



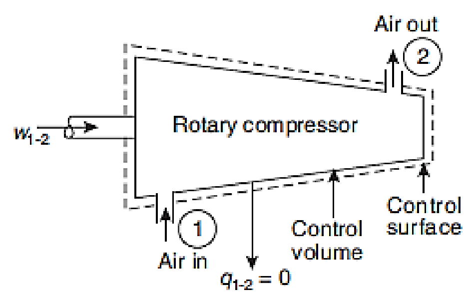
• **Rotary compressor:**

Adiabatic process, insulated system so q_{1-2}=0

$w_{1-2}=-(h_1-h_2)$

$W=-m\,(h_1-h_2)$

"Work done on the system"

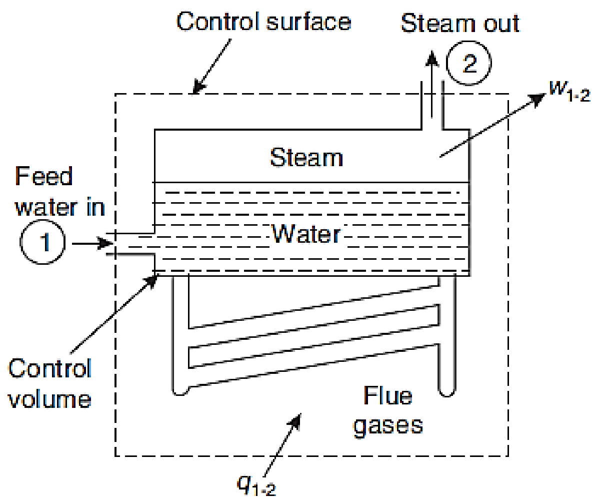


6. **Boiler:** A boiler is used to generate steam from feed water by heating due to burning of a fuel. The steam may be used to drive steam engine or a steam turbine.

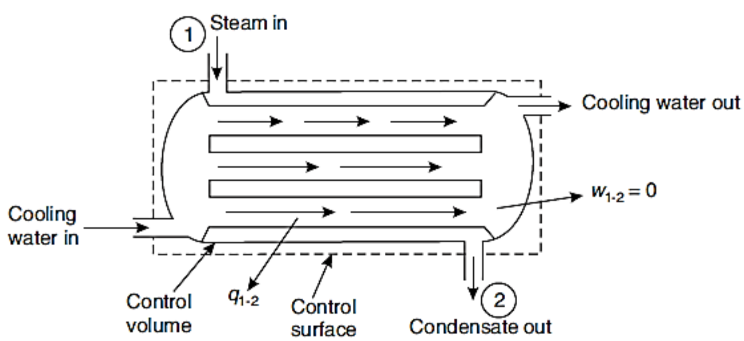
$z_1 = z_2$, $V_1 = V_2$, and $w_{1-2} = 0$,

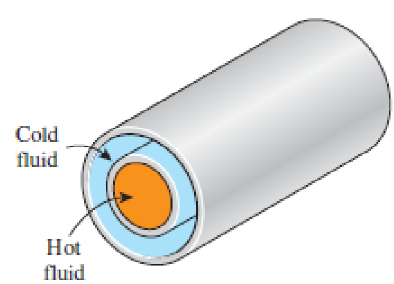
$q_{1-2}=(h_2- h_1)$

$Q=m(h_2- h_1)$



7. Condensers & heat exchangers: A condenser (or a heat exchanger) is a device used to condense steam by rejecting heat from the steam to the cooling water.





$q_{1-2}=-(h_2- h_1)$, $Q=-m(h_2- h_1)$

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