CHAPTER

4

MEC Thermodynamics

Lecture Notes:
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First Law of Thermodynamics

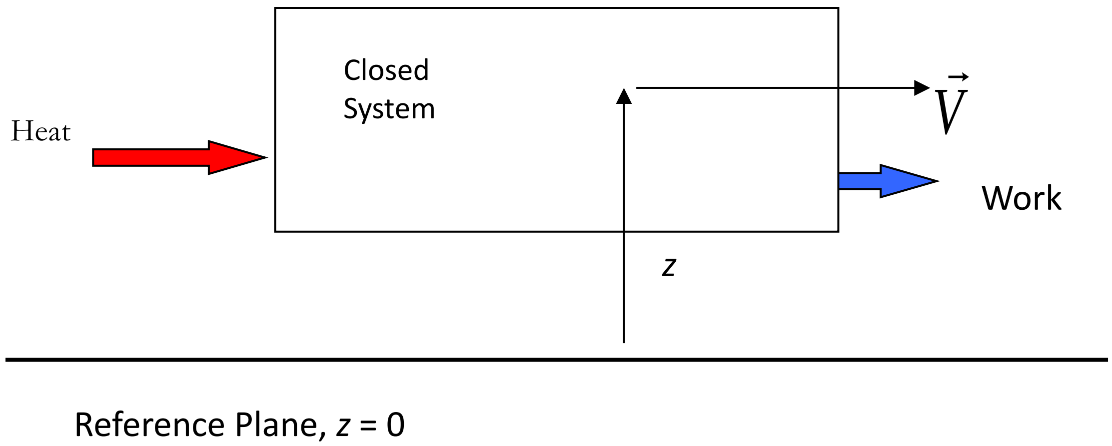
FIRST LAW OF THERMODYNAMICS

ENERGY ANALYSIS OF CLOSED SYSTEM

First Law of Thermodynamics

- The First Law is usually referred to as the Law of Conservation of Energy, i.e. *energy can neither be created nor destroyed, but rather transformed from one state to another*.
- The energy balance is maintained within the system being studied/defined boundary.
- The various energies associated are then being observed as they cross the boundaries of the system.

Energy Balance for Closed System



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

or

$$E_{in} - E_{out} = \Delta E_{system}$$

- According to classical thermodynamics

$$Q_{net} - W_{net} = \Delta E_{system}$$

- The total energy of the system, E_{system}, is given as

$$E = \textit{Internal energy} + \textit{Kinetic energy} + \textit{Potential energy}$$
$$E = U + KE + PE$$

- The change in stored energy for the system is

$$\Delta E = \Delta U + \Delta KE + \Delta PE$$

- The first law of thermodynamics for closed systems then can be written as

$$Q_{net} - W_{net} = \Delta U + \Delta KE + \Delta PE$$

- If the system does not move with a velocity and has no change in elevation, the conservation of energy equation is reduced to

$$Q_{net} - W_{net} = \Delta U$$

- The first law of thermodynamics can be in the form of

$$q_{net} - w_{net} = \left(u_2 - u_1 + \frac{V_2^{\,2} - V_1^{\,2}}{2} + g(z_2 - z_1) \right) \qquad (J/kg)$$

$$Q_{net} - W_{net} = m\left(u_2 - u_1 + \frac{V_2^{\,2} - V_1^{\,2}}{2000} + \frac{g(z_2 - z_1)}{1000} \right) \qquad (kJ)$$

- *For a constant volume process (W_{net} =0),*

$$Q_{net} - W_{net} = m\left(u_2 - u_1 + \frac{V_2^{\,2} - V_1^{\,2}}{2000} + \frac{g(z_2 - z_1)}{1000} \right)$$

$$Q_{net} = m\left(u_2 - u_1 + \frac{V_2^{\,2} - V_1^{\,2}}{2000} + \frac{g(z_2 - z_1)}{1000} \right)$$

- For a constant pressure process,

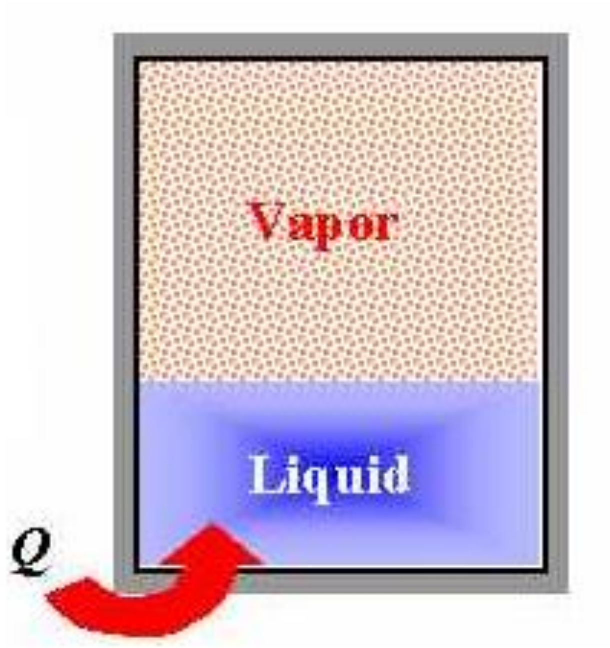
$$Q_{net} - W_{net} = m\left(u_2 - u_1 + \frac{V_2^{\,2} - V_1^{\,2}}{2000} + \frac{g(z_2 - z_1)}{1000} \right)$$

$$Q_{net} - P(v_2 - v_1) = m\left(u_2 - u_1 + \frac{V_2^{\,2} - V_1^{\,2}}{2000} + \frac{g(z_2 - z_1)}{1000} \right)$$

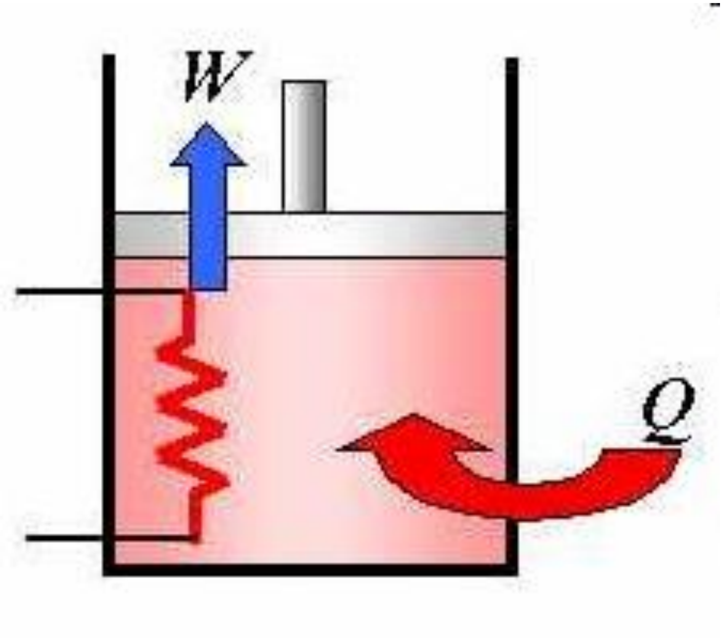
$$Q_{net} = m\left(u_2 - u_1 + P(V_2 - V_1) + \frac{V_2^{\,2} - V_1^{\,2}}{2000} + \frac{g(z_2 - z_1)}{1000} \right)$$

$$Q_{net} = m\left(h_2 - h_1 + \frac{V_2^{\,2} - V_1^{\,2}}{2000} + \frac{g(z_2 - z_1)}{1000} \right)$$

Example of Closed Systems



Rigid tank



Piston cylinder

Example 3.1

A closed system of mass 2 kg undergoes an adiabatic process. The work done on the system is 30 kJ. The velocity of the system changes from 3 m/s to 15 m/s. During the process, the elevation of the system increases 45 meters. Determine the change in internal energy of the system.

Solution:

❖ Energy balance,

$$Q_{net} - W_{net} = m\left(u_2 - u_1 + \frac{V_2^{\ 2} - V_1^{\ 2}}{2000} + \frac{g(z_2 - z_1)}{1000}\right)$$

❖ Rearrange the equation

$$\cancel{Q_{net}} - W_{net} = m\left(u_2 - u_1 + \frac{V_2^{\ 2} - V_1^{\ 2}}{2000} + \frac{g(z_2 - z_1)}{1000}\right)$$

$$-W_{net} = m\left(u_2 - u_1 + \frac{V_2^{\ 2} - V_1^{\ 2}}{2000} + \frac{g(z_2 - z_1)}{1000}\right)$$

$$-(-30) = 2\Delta u + 2\left(\frac{15^2 - 3^2}{2000}\right) + 2\left(\frac{9.81(45)}{1000}\right)$$

$$\Delta u = \underline{\underline{14.451\ kJ}}\quad Ans..$$

Example 3.2

Steam at 1100 kPa and 92 percent quality is heated in a rigid container until the pressure is 2000 kPa. For a mass of 0.05 kg, calculate the amount of heat supply (in kJ) and the total entropy change (in kJ/kg.K).

Solution:

$$\boxed{State 1}$$

$$at \quad P_1 = 1100\,kPa, x_1 = 0.92$$

$$v_1 = v_{f1} + x_1 v_{fg1}$$
$$= 0.00113 + 0.92(0.17753 - 0.001133)$$
$$= 0.1634 \tfrac{m^3}{kg}$$

$$u_1 = u_{f,1} + x_1 u_{fg,1}$$
$$= 779.78 + 0.92(1805.7)$$
$$= 2441.024 \frac{kJ}{kg}$$

$$s_1 = s_{f,1} + x_1 s_{fg,1}$$
$$= 2.1785 + 0.92(4.3735)$$
$$= 6.20212 \frac{m^3}{kg}$$

- For a rigid container,
  $v_2 = v_1 = 0.1634\ m^3/kg$

$\boxed{State2}$

$v_2 > v_g$ superheated

$$at\ \ P_2 = 2000\,kPa, v_2 = 0.1634\,\tfrac{m^3}{kg}$$

v	u	s
0.15122	2945.9	7.1292
0.1634	u_2	s_2
0.17568	3116.9	7.4337

$$u_2 = 2945.9 + \left(\frac{0.1634 - 0.15122}{0.17568 - 0.15122}\right)(3116.9 - 2945.9)$$

$$= 3030.42\,\tfrac{kJ}{kg}$$

$$s_2 = 7.1292 + \left(\frac{0.1634 - 0.15122}{0.17568 - 0.15122}\right)(7.4337 - 7.1292)$$

$$= 7.2790\,\tfrac{kJ}{kg.K}$$

- Amount of heat supplied, Q

$$Q = m\left(u_2 - u_1\right)$$
$$= 0.05\left(3030.42 - 2441.9\right)$$
$$= \underline{\underline{29.43\,kJ}}$$

- The change in entropy, Δs

$$\Delta s = s_2 - s_1$$
$$= 7.2790 - 6.204$$
$$= \underline{\underline{1.075\,\tfrac{kJ}{kg.K}}}$$

Example 3.3

A rigid tank is divided into two equal parts by a partition. Initially one side of the tank contains 5 kg water at 200 kPa and 25°C, and the other side is evacuated. The partition is then removed, and the water expands into the entire tank. The water is allowed to exchange heat with its surroundings until the temperature in the tank returns to the initial value of 25°C. Determine (a) the volume of the tank (b) the final pressure (c) the heat transfer for this process.

Solution:

$\boxed{State 1}$

$$\left.\begin{array}{l} P_1 = 200\,kPa, \\ T_1 = 25^o C \end{array}\right\} \begin{array}{l} T_1 < T_{sat} \text{ Comp. liquid} \\ v_1 = v_{f\,@\,25^\circ C} = 0.001003 \frac{m^3}{kg} \end{array}$$

initial volume of half resevoir

$$V_1 = mv$$
$$= 5(0.001003)$$
$$\square\ 0.005\,m^3$$

❖ The initial volume for entire tank

$$V_{resevoir} = 2(0.005)$$
$$= \underline{\underline{0.01\,m^3}}$$

- The final pressure

State 2

$$T_2 = 25^\circ C$$

$$v_2 = \frac{0.01}{5} = 0.002 \,\tfrac{m^3}{kg}$$

$$\left.\begin{matrix} v_f = 0.001003 \,\tfrac{m^3}{kg} \\ v_g = 43.34 \,\tfrac{m^3}{kg} \end{matrix}\right.$$

check region!

$v_f < v < v_g \rightarrow$ *saturated mixture*

$$then: P_2 = P_{sat} = \underline{\underline{3.169\, kPa}}$$

- The heat transfer for this process

$$Q_{net} - W_{net} = m(\Delta u + \Delta ke + \Delta Pe)$$

$$Q_{net} - \cancel{W_{net}} = m(\Delta u + \cancel{\Delta ke} + \cancel{\Delta Pe})$$

$$Q_{net} = m\Delta u = m(u_2 - u_1)$$

$$u_1 = u_{f\,@\,25^\circ C} = 104.83 \,\frac{kJ}{kg}$$

$$u_2 = u_f + x_2 u_{fg}$$

$$x_2 = \frac{v_2 - v_f}{v_{fg}}$$

$$= 2.3\times 10^{-5}$$

$$\therefore u_2 = 104.83 + 2.3\times 10^{-5}\ (2304.3)$$

$$= 104.88 \,\tfrac{kJ}{kg}$$

Then:

$$Q_{net} = 5\ (104.88\text{-}104.83)$$

$$= \underline{\underline{0.25\ kJ}}$$

- *+ve sign indicates heat transfer into the system.*

Supplementary Problems 1

1. Two tanks are connected by a valve. Tank A contains 2 kg of carbon monoxide gas at 77°C and 0.7 bar. Tank B holds 8 kg of the same gas at 27°C and 1.2 bar. Then the valve is opened and the gases are allowed to mix while receiving energy via heat transfer from the surrounding. The final equilibrium temperature is found to be 42°C. Determine (a) the final pressure (b) the amount of heat transfer. Also state your assumption. [P_2=*105 kPa, Q = +37.25 kJ*]

2. A piston cylinder device contains 0.2 kg of water initially at 800 kPa and 0.06 m^3. Now 200 kJ of heat is transferred to the water while its pressure is held constant. Determine the final temperature of the water. Also, show the process on a T-V diagram with respect to saturation lines. [*721.1°C*]

Supplementary Problems 1

3. A piston-cylinder device contains 6 kg of refrigerant-134a at 800 kPa and 50°C. The refrigerant is now cooled at constant pressure until it exist as a liquid at 24°C. Show the process on T-v diagram and determine the heat loss from the system. State any assumption made.

   [*1210.26 kJ*]

4. A 0.5 m^3 rigid tank contains refrigerant-134a initially at 200 kPa and 40 percent quality. Heat is now transferred to the refrigerant until the pressure reaches 800 kPa. Determine (a) the mass of the refrigerant in the tank and (b) the amount of heat transferred. Also, show the process on a P-v diagram with respect to saturation lines.

   [*12.3 kg, 2956.2Kj]*

5. An insulated tank is divided into two parts by a partition. One part of the tank contains 6 kg of an ideal gas at 50°C and 800 kPa while the other part is evacuated. The partition is now removed, and the gas expands to fill the entire tank. Determine the final temperature and the pressure in the tank.

   [*50°C, 400 kPa*]