

CLOSED SYSTEMS

HANDOUT 2

Exercise 1:

A domestic refrigerator is loaded with food and the door is closed. During a certain period, the machine consumes 1 kWh of energy and the internal energy of the systems drops by 5000 kJ. Find the net heat transferred in the system.

[Ans. -8.6 MJ]

Solution:

The refrigerator system consumes 1 kWh of work (because the work is consumed and not produced, it is work done ON the system and should therefore be considered negatively).

The units of kWh must be converted in kJ. This can be done as follows,

$$1kWh \text{ is } 1kW \cdot hr \equiv 1 \frac{kJ}{s} \cdot hr \equiv 1 \frac{kJ}{s} \cdot 3600s \equiv 3600kJ$$

Therefore, the refrigerator system produces -3600 kJ of work.

According to the non-flow energy equation,

$$\Delta U = Q - W$$

Where the internal energy of the systems drops by 5000 kJ, this means that $\Delta U = -5000 \text{ kJ}$

Thus,

$$\Delta U = Q - W$$

$$\therefore -5000 = Q - (-3600)$$

$$\therefore -5000 = Q + 3600$$

$$\therefore Q = -5000 - 3600 = -8600 \text{ kJ}$$

$$\therefore Q = -8.6 \text{ MJ}$$

Exercise 2:

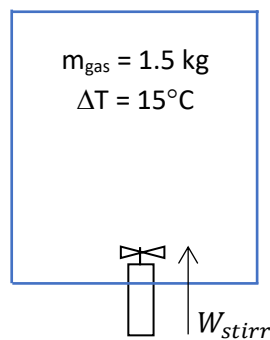
A mass of 1.5 kg of an ideal gas having a constant specific heat $c_v = 2.5 \text{ kJ/kg}^\circ\text{C}$ is stirred in a well-insulated chamber causing the temperature to rise by 15°C . Knowing that the change of specific internal energy for an ideal gas is equal to the specific heat multiplied by the change of temperature, that is,

$$u_2 - u_1 = c_v \cdot (T_2 - T_1) \quad (\text{kJ/kg})$$

Determine,

- i. Change of internal energy.
- ii. Work done for the process.

[Ans. (i) 56.25 kJ, (ii) -56.25 kJ]

Solution:

For an ideal gas the change of specific internal energy can be calculated as,

$$\begin{aligned} \Delta u &= c_v \cdot \Delta T \\ \therefore \Delta u &= 2.5 \times 15 \\ \therefore \Delta u &= 37.5 \text{ kJ/kg} \end{aligned}$$

The link between internal energy and specific internal energy is the mass,

$$\begin{aligned} \Delta U &= m \cdot \Delta u \\ \therefore \Delta U &= 1.5 \times 37.5 \\ \therefore \Delta U &= 56.25 \text{ kJ} \end{aligned}$$

According to the non-flow energy equation,

$$\Delta U = \cancel{Q} - W$$

$$\therefore 56.25 = -W$$

$$\therefore W = -56.25 \text{ kJ}$$

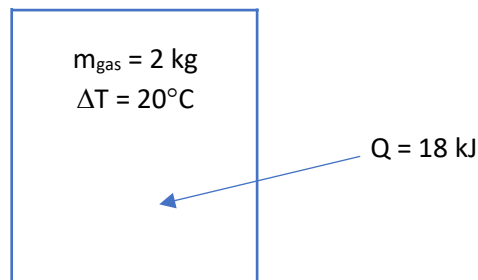
Insulated system, i.e. no heat transfer

Exercise 3:

A closed system of constant volume experiences a temperature rise of 20°C when a certain process occurs. The heat transferred in the process is 18 kJ. The specific heat at constant volume for the ideal gas comprising the system is $c_v = 1.2 \text{ kJ/kg}^{\circ}\text{C}$, and the system contains 2 kg of this gas. Determine the change in internal energy and the work done, knowing that for an ideal gas,

$$u_2 - u_1 = c_v \cdot (T_2 - T_1) \quad (\text{kJ/kg})$$

[**Ans.** $\Delta U = 48 \text{ kJ}$, $W = -30 \text{ kJ}$]

Solution:

For an ideal gas the change of specific internal energy can be calculated as,

$$\begin{aligned}\Delta u &= c_v \cdot \Delta T \\ \therefore \Delta u &= 1.2 \times 20 \\ \therefore \Delta u &= 24 \text{ kJ/kg}\end{aligned}$$

The link between internal energy and specific internal energy is the mass,

$$\begin{aligned}\Delta U &= m \cdot \Delta u \\ \therefore \Delta U &= 2 \times 24 \\ \therefore \Delta U &= 48 \text{ kJ}\end{aligned}$$

According to the non-flow energy equation,

$$\begin{aligned}\Delta U &= Q - W \\ \therefore 48 &= 18 - W \\ \therefore W &= 18 - 48 \\ \therefore W &= -30 \text{ kJ}\end{aligned}$$

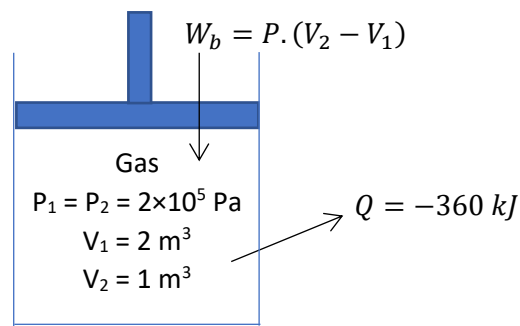
Exercise 4:

A stationary mass of gas is compressed without friction from an initial state of 2 m^3 and $2 \times 10^5 \text{ N/m}^2$ to a final state of 1 m^3 and $2 \times 10^5 \text{ N/m}^2$, the pressure remaining the same. There is a transfer of 360 kJ of heat from the gas during the process. Knowing that for a constant pressure process the boundary work W_b is equal to the pressure time the volume change, that is,

$$W_b = P \cdot (V_2 - V_1)$$

How much does the internal energy of the gas change?

[Ans. $\Delta U = -160 \text{ kJ}$]

Solution:

According to the non-flow energy equation,

$$\Delta U = Q - W$$

$$\therefore \Delta U = Q - P \cdot (V_2 - V_1)$$

$$\therefore \Delta U = -360 - 200 \cdot (1 - 2)$$

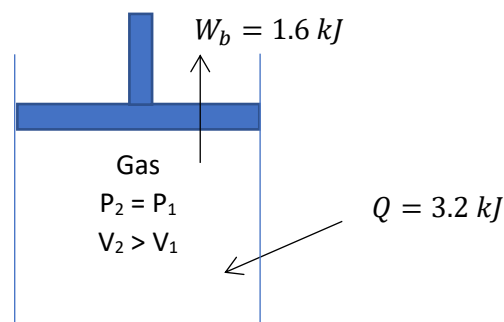
$$\therefore W = -160 \text{ kJ}$$

Pressure must be converted from Pa to kPa to be consistent unit wise.

Exercise 5:

A piston cylinder arrangement has a gas in the cylinder space. During a constant pressure expansion to a larger volume the work effect for the gas is 1.6 kJ, the heat added to the gas and cylinder arrangement is 3.2 kJ, and the friction between the piston and cylinder will amounts to 0.24 kJ. Determine the change in internal energy of the entire apparatus.

[Ans. $\Delta U = 1.84 \text{ kJ}$]

Solution:

The friction between the piston and cylinder will be turned into heat transferred to the gas. Therefore, there is an extra 0.24 kJ of heat added to the gas.

According to the non-flow energy equation,

$$\Delta U = Q - W$$

$$\therefore \Delta U = (Q_{in} + Q_{friction}) - W$$

$$\therefore \Delta U = (3.2 + 0.24) - 1.6$$

$$\therefore \Delta U = 1.84 \text{ kJ}$$