**QUESTION 2 [15 marks]**

A piston cylinder assembly containing 0.5 kg helium gas at 100 kPa with an initial volume of 5 m³ undergoes a thermodynamics cycle consisting three processes as follows:

Process 1–2 – Isobaric compression until its volume becomes half the original volume
Process 2–3 – Polytropic expansion that obeys $PV^n = C$ where $n = -2$ until original volume
Process 3–1 – Constant volume cooling

Assuming helium behaves as ideal gas, provide the followings:

(a) The net work transfer of the cycle (in kJ), [6 marks]

(b) Sketch the $P-V$ diagram of the cycle, [3 marks]

(c) Show that the net work transfer obtained in part (a) is equal to the net heat transfer for this cycle. [6 marks]
a) Process ①→②: Isothermal compression
\[ W_{b,1-2} = \frac{p_0 (v_2 - v_1)}{1 \text{ kPa} \cdot \text{m}^3} = -250 \text{ kJ} \quad (1) \]

Process ②→③: Polytropic expansion
\[ W_{b,2-3} = \frac{p_2 v_2^\gamma - p_2 v_1^\gamma}{1 - \gamma} = 583.33 \text{ kJ} \quad (1) \]

Process ③→①: Constant volume cooling since \( \Delta H = 0 \), \( W_{b,3-1} = 0 \text{ kJ} \quad (1) \)

Net work transfer = \( W_{b,1-2} + W_{b,2-3} + W_{b,3-1} \)
\[ = -250 \text{ kJ} + 583.33 \text{ kJ} + 0 \text{ kJ} = 333.33 \text{ kJ} \quad (1) \]

b) Graph showing the change in pressure and volume.

\[ (v_{1,5} - p_{1,5}) \]

\[ (v_{2,5} - p_{2,5}) \]

\[ (v_{3,5} - p_{3,5}) \]

c) Process ①→②,
\[ E_{in} - E_{out} = \Delta E_{system} \]
\[ W_{in} - Q_{out} = \Delta U = mC_v (T_2 - T_1) \]
\[ = 250 \text{ kJ} - Q_{out} = 0.5 \text{ kg} (3.1156 \text{ kJ/kg}) (240.75 \text{ k}) \]
\[ \cdot Q_{out} = 625.04 \text{ kJ} \quad (1) \]

Process ②→③,
\[ E_{in} - E_{out} = \Delta E_{system} \]
\[ Q_{in} - W_{out} = \Delta U = mC_v (T_3 - T_2) \]
\[ Q_{in} = 583.33 \text{ kJ} = 0.5 \text{ kg} (3.1156 \text{ kJ/kg}) (1685.21) \]
\[ Q_{in} = 3208.55 \text{ kJ} \quad (1) \]

Process ③→①,
\[ E_{in} - E_{out} = \Delta E_{system} \]
\[ Q_{in} - W_{out} = \Delta U = mC_v (T_1 - T_3) \]
\[ Q_{in} = 0.5 \text{ kg} (3.1156 \text{ kJ/kg}) (1444.94) \]
\[ Q_{in} = 2250.18 \text{ kJ} \quad (1) \]