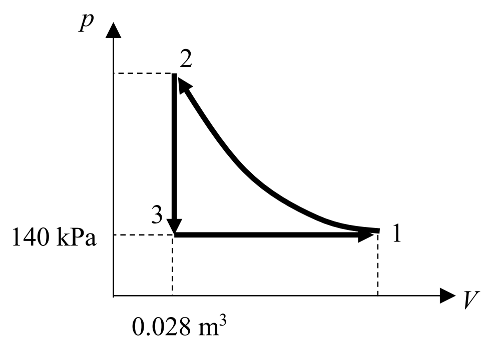
A gas within a piston-cylinder assembly undergoes a thermodynamic cycle consisting of three processes in series:

Process 1 – 2: Compression with constant internal energy (*pV* = constant)
Process 2 – 3: Constant volume cooling to a pressure of 140 kPa (abs) and a volume of 0.028 m^3
Process 3 – 1: Constant pressure expansion with a total work of 10.5 kJ acting on the piston

For the cycle, the net amount of work done by the gas on the piston is -8.3 kJ. There are no changes in kinetic or potential energy.

a. Sketch the processes on a *p*-*V* diagram.
b. Determine the volume at state 1, in m^3.
c. Determine the work and heat transfer for process 1 – 2, each in kJ.
d. Is this a power cycle or a refrigeration/heat pump cycle? Explain.

SOLUTION:



The volume at state 1 may be found by knowing that the work in going from state 3 to state 1 is 10.5 kJ,

$$W_{\substack{\text{by gas}\\\text{on piston,}\\3\to1}} = \int_3^1 p\,dV = p\int_{V=V_3}^{V=V_1} dV = p\left(V_1 - V_3\right), \quad \text{(since the pressure is constant from 3 to 1)} \tag{1}$$

$$V_1 = V_3 + \frac{W_{\substack{\text{by gas}\\\text{on piston,}\\3\to1}}}{p}. \tag{2}$$

Using the given parameters,

V_3 = 0.028 m^3

$W_{\substack{\text{by gas}\\\text{on piston,}\\3\to1}}$ = 10.5 kJ

p = 140 kPa (abs)

$$\Rightarrow \boxed{V_1 = 0.103\ \text{m}^3} \tag{3}$$

The work in going from state 1 to state 2 can be found by knowing that the total work done by the gas on the piston over the whole cycle is -8.3 kJ, because the volume remains constant in going from state 2 to state 3, the corresponding work is zero, and the work on the piston in going from state 3 to state 1 is 10.5 kJ,

$$\underbrace{W_{\substack{\text{by gas}\\\text{on piston,}\\\text{cycle}}}}_{=-8.5\text{ kJ}} = W_{\substack{\text{by gas}\\\text{on piston,}\\1\to2}} + \underbrace{W_{\substack{\text{by gas}\\\text{on piston,}\\2\to3}}}_{=0} + \underbrace{W_{\substack{\text{by gas}\\\text{on piston,}\\3\to1}}}_{=10.5\text{ kJ}}, \tag{4}$$

$$\boxed{W_{\substack{\text{by gas}\\\text{on piston,}\\1\to2}} = -18.8\text{ kJ}}. \tag{5}$$

The heat transferred in the process from state 1 to state 2 can be found using the 1st Law of Thermodynamics and noting that the energy remains unchanged in going from 1 to 2,

$$\underbrace{\Delta E_{\substack{\text{gas,}\\1\to2}}}_{=0} = Q_{\substack{\text{into gas,}\\1\to2}} - \underbrace{W_{\substack{\text{by gas,}\\1\to2}}}_{=-18.8\text{ kJ}} \quad \Rightarrow \quad \boxed{Q_{\substack{\text{into gas,}\\1\to2}} = -18.8\text{ kJ}} \tag{6}$$

Since $W_{\text{by gas,cycle}}$ = -8.3 kJ < 0, this is a refrigeration (or heat pump) cycle.