Problem 2.34

Carbon monoxide gas (CO) contained within a piston-cylinder assembly undergoes three processes in series:

Process 1-2: Constant pressure expansion at 5 bar from $V_1 = 0.2$ m^3 to $V_2 = 1$ m^3.

Process 2-3: Constant volume cooling from state 2 to state 3 where $p_3 = 1$ bar.

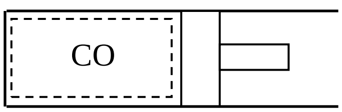
Process 3-1: Compression from state 3 to the initial state during which the pressure-volume relationship is $pV = constant$.

Sketch the processes in series on *p*-*V* coordinates and evaluate the work for each process, in kJ.

KNOWN: Carbon monoxide gas within a piston-cylinder assembly undergoes three processes in series.

FIND: Sketch the processes in series on a *p*-*V* diagram and evaluate the work for each process.

SCHEMATIC AND GIVEN DATA:



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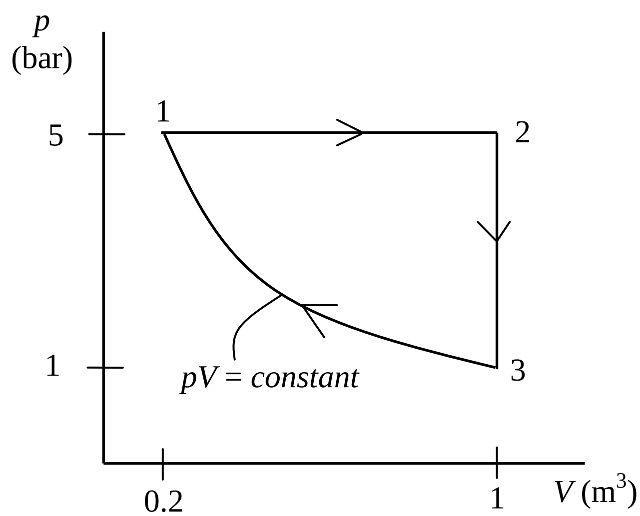

ENGINEERING MODEL: (1) The gas is the closed system. (2) Volume change is the only work mode. (3) Each of the three processes is specified.

ANALYSIS: Since volume change is the only work mode, Eq. 2.17 applies.

Process 1-2: Constant pressure processes: $W_{12} = \int_{V_1}^{V_2} p dV = p_1(V_2 - V_1)$

$$W_{12} = (5 \text{ bar})(1 - 0.2)\text{m}^3 \left|\frac{10^5 \text{N/m}^2}{1 \text{ bar}}\right| \left|\frac{1 \text{ kJ}}{10^3 \text{N}\cdot\text{m}}\right| = 400 \text{ kJ} \quad \text{(out)} \longleftarrow$$

Process 2-3: Constant volume (piston does not move). Thus $W_{23} = 0$ $\longleftarrow$

Problem 2.33 (Continued)

<u>Process 3-1</u>: For process 3-1, $pV = constant = p_1V_1$. Noting that $V_3 = V_2$, we get

$$W_{31} = \int_{V_3}^{V_1} pdV = \int_{V_3}^{V_1} \frac{C}{V} dV = C\ln\left(\frac{V_1}{V_3}\right) = (p_1V_1)\ln\left(\frac{V_1}{V_2}\right)$$

Inserting values and converting units

1 $$W_{31} = (5 \text{ bar})(0.2 \text{ m}^3)\ln\left(\frac{0.2 \text{ m}^3}{1 \text{ m}^3}\right)\left|\frac{10^5 \text{N/m}^2}{1 \text{ bar}}\right|\left|\frac{1 \text{ kJ}}{10^3 \text{N}\cdot\text{m}}\right| = -160.9 \text{ kJ (in)}$$

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1. The *net* work for the three process is

$$W_{net} = W_{12} + W_{23} + W_{31} = (+400) + 0 + (-160.9) = 239.1 \text{ kJ} \quad (\textit{net} \text{ work is positive - out})$$