PROBLEM 2.74

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

FIND: Determine Q_{12}, Q_{31}, U_3. Determine if the cycle can be a power cycle.

SCHEMATIC & GIVEN DATA:

Process 1–2: Compression with $pV = constant$, $W_{12} = -104$ kJ, $U_1 = 512$ kJ, $U_2 = 690$ kJ.
Process 2–3: $W_{23} = 0$, $Q_{23} = -150$ kJ.
Process 3–1: $W_{31} = +50$ kJ.

ENGR. MODEL:

1. The gas is the closed system.
2. Volume change is the only work mode.
3. For each process, $\Delta KE = \Delta PE = 0$.

ANALYSIS: (a) Process 1-2, $\Delta U + \cancel{\Delta KE + \Delta PE} = Q_{12} - W_{12} \Rightarrow$

$$Q_{12} = [U_2 - U_1] + W_{12} = (690 - 512)\text{kJ} + (-104\text{kJ}) = +74\text{kJ}$$ ← Q_{12}

For any cycle, $W_{cycle} = Q_{cycle}$ (Eq. 2.40). Thus

$$W_{12} + W_{23} + W_{31} = Q_{12} + Q_{23} + Q_{31}$$

$$\Rightarrow \quad Q_{31} = W_{12} + W_{23} + W_{31} - Q_{12} - Q_{23}$$

$$= (-104) + 0 + 50 - 74 - (-150) = +22\text{ kJ}$$ ← Q_{31}

Process 3-1: $\Delta U + \cancel{\Delta KE + \Delta PE} = Q_{31} - W_{31} \Rightarrow U_1 - U_3 = Q_{31} - W_{31}$

(1) $\Rightarrow \quad U_3 = U_1 - Q_{31} + W_{31} = 512 - 22 + 50 = 540\text{kJ}$ ← U_3

(b) A power cycle is one for which $W_{cycle} > 0$. For the current cycle,

$$W_{cycle} = W_{12} + W_{23} + W_{31}$$

$$= +(-104) + (0) + (50) = -54\text{kJ}$$ ← *

NO. This cycle cannot be a power cycle. ←

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1. As checks on these calculations, note that

Process 2-3: $(U_3 - U_2) = Q_{23} - W_{23}$

$= (-150\text{kJ}) - 0 \Rightarrow U_3 - U_2 = -150\text{kJ}$

$\Rightarrow U_3 = 690 - 150 = 540\text{kJ}$

Since U is a property,

$$(U_2 - U_1) + (U_3 - U_2) + (U_1 - U_3) = 0$$

$$(690 - 512) + (U_3 - 690) + (512 - U_3) = 0$$

(540) (590)

$$178 + (-150) + (-28) = 0 \checkmark$$