Multiple-choice questions: (35 points)

Place the best answer to the following questions (5 points each) in the blanks provided.

1. A cyclic device that takes in heat from a high temperature source, rejects heat to a low temperature sink, and performs useful work is a:
   a. refrigerator
   b. heat pump
   c. heat engine
   d. none of these

2. If all sources of irreversibility are eliminated from a heat engine operating between thermal reservoirs at $T_H = 1000 \text{ K}$ and $T_L = 300 \text{ K}$, its thermal efficiency would be:
   a. 100%
   b. 70%
   c. 30%
   d. not enough information to determine

3. It is claimed that a process occurs such that the entropy change of the defined system is -15 kJ/K and the entropy change of the surroundings is +10 kJ/K. Which of the following is true about the process?
   a. It is isentropic.
   b. It is possible and reversible.
   c. It is possible and irreversible.
   d. It is impossible.

4. Which of the following quantities must be greater than 1?
   a. thermal efficiency ($\eta_{th}$) of a heat engine
   b. coefficient of performance (COP) of a refrigerator
   c. coefficient of performance (COP) of a heat pump
   d. these all must be less than 1

5. A heat engine thermal efficiency ($\eta_{th}$) of 100% satisfies:
   a. First Law of Thermodynamics
   b. Second Law of Thermodynamics
   c. Both
   d. Neither

MORE MULTIPLE CHOICE QUESTIONS ON BACK OF PAGE
Problems: (You must show full work for full credit.)

1. (30 points) An inventor proposes a novel engine design that extracts $1.13 \times 10^6$ Btu/hr from a high temperature reservoir at 750°F, rejects heat to a low temperature reservoir at 60°F, and produces 300 hp.

a. (6 pts) heat rejection rate

$$\dot{Q}_L = \frac{3.69 \times 10^5}{\text{Btu/hr}}$$

$$\eta_{th} = \frac{67.6}{\%}$$

Possible

No. It is not possible as the efficiency is greater than the efficiency of a Carnot heat engine.

b. (6 pts) thermal efficiency for claimed performance

$$\eta_{th} = \frac{366,500}{1.13 \times 10^6} = 0.323$$

$$\eta_{th} = \frac{67.6}{\%}$$

c. (6 pts) Is this heat engine possible? (circle answer)

Possible

Why? Because the efficiency is greater than the efficiency of a Carnot heat engine.

Possible

d. (6 pts) max. power production possible, assuming same heat extraction from high-T reservoir

$$W_{max} = \frac{363.3}{\text{hp}}$$

$$\dot{Q}_L = \frac{4.85 \times 10^5}{\text{Btu/hr}}$$

CONTINUE WORK FOR PROBLEM #1 ON BACK OF PAGE
2. (35 points) Air contained in a closed piston-cylinder device undergoes a two-step process. First, the air expands in a polytropic process \( n = 1.3 \), providing 62.5 kJ of work output, until the piston hits a set of stops inside the cylinder. Initially, \( P_1 = 500 \) kPa, \( T_1 = 400 \) K, and \( V_1 = 0.2 \) m\(^3\). At the end of the polytropic process, \( P_2 = 203 \) kPa, \( T_2 = 325 \) K, and \( V_2 = 0.4 \) m\(^3\). Once the piston hits the stops, heat is transferred to the air in a constant-volume process until temperature \( T_3 \) is back to the original 400 K and \( P_3 = 250 \) kPa. For both processes, heat is transferred from the surroundings, which remain constant at 500 K.

\[
\begin{align*}
P_1 &= 500 \text{ kPa} & P_2 &= 203 \text{ kPa} \\
T_1 &= 400 \text{ K} & n &= 1.3 \\
T_2 &= 325 \text{ K} & V_1 &= 0.2 \text{ m}^3 \\
V_2 &= 0.4 \text{ m}^3 & V_3 &= \text{?} \\

\text{Assumptions:} & \\
1. \text{ Air is an ideal gas} \\
2. \text{ } R = 0.287 \frac{\text{kPa} \cdot \text{m}^3}{\text{kg} \cdot \text{K}}
\end{align*}
\]

With the assumptions listed next to the diagram, determine the following:

a. (5 pts) mass of air in the cylinder (same at all states) \( m = 1.871 \text{ kg} \)

b. (5 pts) heat transfer input for polytropic process \( Q_{in}^{1\to2} = 62.5 \text{ kJ} \)

c. (5 pts) heat transfer input for constant-volume process \( Q_{in}^{2\to3} = 62.5 \text{ kJ} \)

d. (5 pts) change in entropy of air for polytropic process \( \Delta S^{1\to2} = 42.9 \text{ J/K} \)

e. (5 pts) change in entropy of air for constant-volume process \( \Delta S^{2\to3} = 130.4 \text{ J/K} \)

f. (5 pts) total entropy generation (system + surroundings), including both processes \( S_{gen} = 173.3 \text{ J/K} \)

g. (5 pts) Is this two-step process possible? (circle answer) Possible

Why? 

CONTINUE WORK FOR PROBLEM #2 ON BACK OF PAGE