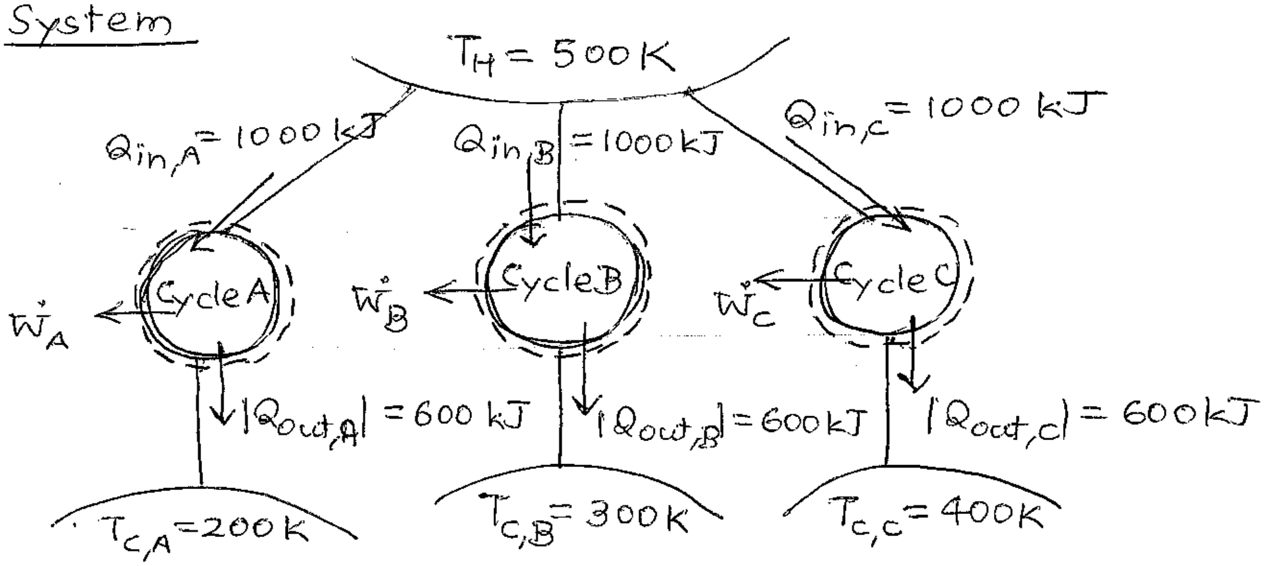
Given

Power cycles operating at steady state

Find

Power cycles irreversible/reversible/impossible

System



Assumptions

- Steady state

Basic Equations

$$\cancel{\left.\frac{dE}{dt}\right)_{system}}^{0} = \cancel{\sum_{in} \dot{m}_{in}(h+ke+pe)_{in}} - \cancel{\sum_{out} \dot{m}_{out}(h+ke+pe)_{out}} + \dot{Q} - \dot{W}$$

Solution

Considering energy balance for the cycle:

$\dot{Q}_{in} - |\dot{Q}_{out}| = \dot{W}$ Integrating: $Q_{in} - |Q_{out}| = W$

Work output of each cycle: $W = (1000 - 600)\,kJ$
$= 400\,kJ$

Actual thermal efficiency of each cycle:

$$\eta_{th,\,actual} = \frac{W}{Q_{in}} = \frac{400\,kJ}{1000\,kJ} = 0.4$$

Maximum thermal efficiency of Cycle A for a reversible (Carnot) system:

$$\eta_{th,A,\,rev} = 1 - \frac{T_{C,A}}{T_H} = 1 - \frac{200\,K}{500\,K} = 0.6$$

$$\eta_{th,\,actual} < \eta_{th,A,\,rev.} \Rightarrow \boxed{\text{Cycle A is irreversible}}$$

Maximum thermal efficiency of cycle B for a reversible (Carnot) system:

$$\eta_{th,B,\,rev} = 1 - \frac{T_{C,B}}{T_H} = 1 - \frac{300\text{ K}}{500\text{ K}} = 0.4$$

$$\eta_{th,\,actual} = \eta_{th,B,\,rev} \Rightarrow \boxed{\text{Cycle B is reversible}}$$

Maximum thermal efficiency of cycle C for a reversible (Carnot) system:

$$\eta_{th,C,\,rev} = 1 - \frac{T_{C,C}}{T_H} = 1 - \frac{400\text{ K}}{500\text{ K}} = 0.2$$

$$\eta_{th,\,actual} > \eta_{th,C,\,rev} \Rightarrow \boxed{\text{Cycle C is impossible}}$$

Given

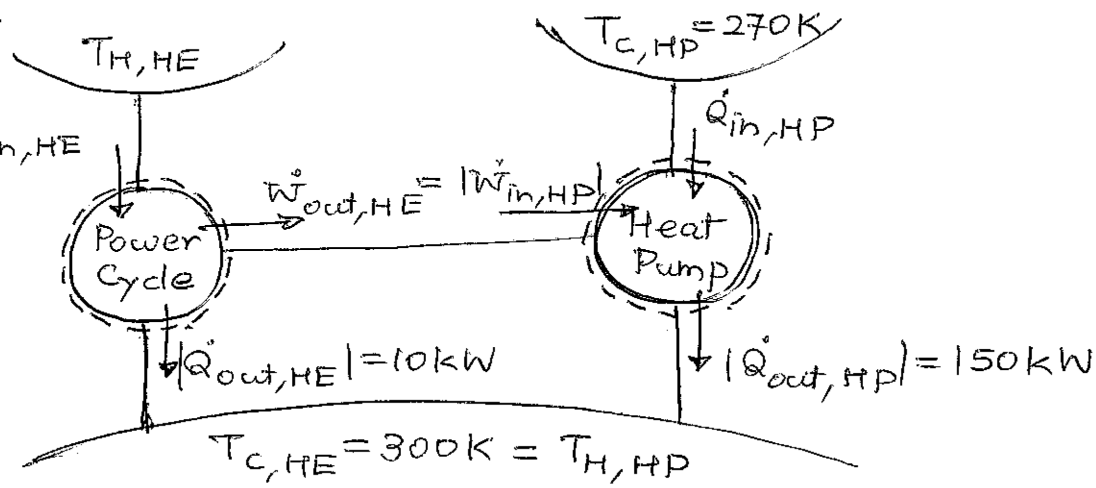
A reversible heat pump driven by a power cycle

Find

(a) Thermal efficiency (%) of the power cycle

(b) Maximum hot reservoir temperature (K) of the power cycle

System



Assumptions

- Steady state

Basic Equations

$$\left.\frac{dE}{dt}\right|_{system}^{0} = \cancel{\sum_{in} \dot{m}_{in}(h+ke+pe)_{in}} - \cancel{\sum_{out} \dot{m}_{out}(h+ke+pe)_{out}} + \dot{Q} - \dot{W}$$

Solution

(a) Thermal efficiency of the power cycle:

$$\eta_{th} = \frac{\dot{W}_{out,HE}}{\dot{Q}_{in,HE}}$$

Maximum coefficient of performance of the heat pump for a reversible (Carnot) system:

$$COP_{HP_{rev}} = \frac{T_{H,HP}}{T_{H,HP} - T_{C,HP}} = \frac{300\ K}{(300-270)\ K} = 10$$

Coefficient of performance of heat pump:

$$COP_{HP} = \frac{|\dot{Q}_{out,HP}|}{|\dot{W}_{in,HP}|} \Rightarrow 10 = \frac{150\ kW}{|\dot{W}_{in,HP}|} \Rightarrow |\dot{W}_{in,HP}| = 15\ kW$$

$\dot{W}_{out,HE} = |\dot{W}_{in,HP}| = 15 \text{ kW}$

Considering energy balance for the power cycle:

$\dot{Q}_{in,HE} - |\dot{Q}_{out,HE}| = \dot{W}_{out,HE} \Rightarrow \dot{Q}_{in,HE} = 10 \text{ kW} + 15 \text{ kW} = 25 \text{ kW}$

$\Rightarrow \eta_{th} = \dfrac{15 \text{ kW}}{25 \text{ kW}} = 0.6$ $\boxed{\eta_{th} = 60\%}$

(b) Maximum thermal efficiency of the power cycle for a reversible (Carnot) system:

$$\eta_{th,rev} = 1 - \frac{T_{C,HE}}{T_{H,HE}} = 1 - \frac{300 \text{ K}}{T_{H,HE}}$$

For the given power cycle: $\eta_{th} = 60\% = 0.6$

$$\Rightarrow 1 - \frac{300 \text{ K}}{T_{H,HE}} = 0.6$$

Maximum hot reservoir temperature of the power cycle under given conditions:

$$\boxed{T_{H,HE} = 750 \text{ K}}$$

Given

A heat pump cycle operating at steady state

Find

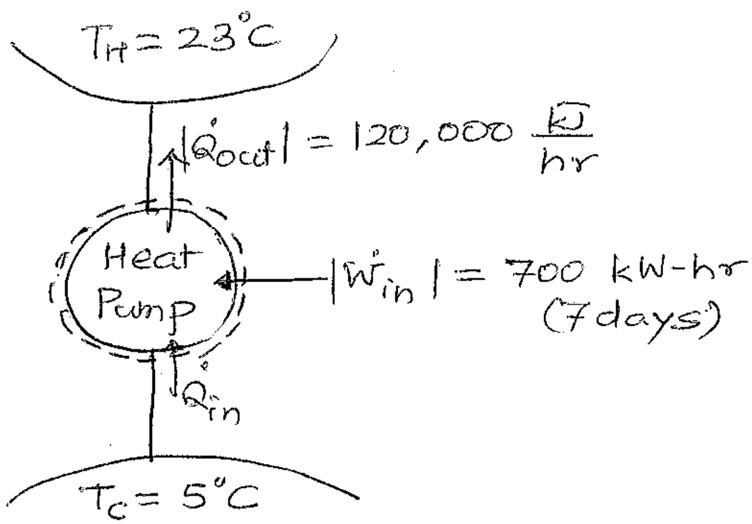
(a) Total heat transfer (kJ) into the heat pump

(b) Coefficient of performance for the heat pump

(c) Cost ($) of operating the heat pump

(d) Ratio of actual and maximum coefficient of performance for the heat pump

System



Assumptions

- Steady state

Basic Equations

$$\cancelto{0}{\left.\frac{dE}{dt}\right|_{system}} = \cancel{\sum_{in} \dot{m}_{in}(h+ke+pe)_{in} - \sum_{out} \dot{m}_{out}(h+ke+pe)_{out}} + \dot{Q} - \dot{W}$$

Solution

(a) Considering energy balance for the heat pump cycle:

$$Q_{in} + |W_{in}| = |Q_{out}|$$

$$\underset{(7\text{ days})}{|W_{in}| = 700 \text{ kW-hr}} = 700 \frac{kJ}{s} * 3600\ s = 0.252 \times 10^7 \text{ kJ}$$

$$|Q_{out}| = 120,000 \frac{kJ}{hr} * (7 \times 24)\ hr = 2.016 \times 10^7 \text{ kJ}$$

Total heat transfer into the heat pump:

$$Q_{in} = (2.016 - 0.252) \times 10^7 \text{ kJ}$$

$$\boxed{Q_{in} = +1.764 \times 10^7 \text{ kJ}}$$

(b) Coefficient of performance of the heat pump:

$$COP_{HP} = \frac{|Q_{out,HP}|}{|W_{in,HP}|} = \frac{2.016\times10^{7}\ kJ}{0.252\times10^{7}\ kJ}$$

$$\boxed{COP_{HP} = 8}$$

(c) Cost of operating the heat pump for the given 7-day period: Cost = 700 kW-hr * $\frac{\$0.15}{kW\text{-}hr}$

$$\boxed{Cost = \$105}$$

(d) Maximum coefficient of performance of the heat pump for a reversible (Carnot) system:

$$COP_{HP_{rev}} = \frac{T_H}{T_H - T_C} = \frac{(23+273)\ K}{(23-5)\ K} = \frac{296\ K}{18\ K} = 16.4$$

$$\Rightarrow \frac{COP_{HP}}{COP_{HP_{rev}}} = \frac{8}{16.4}$$

$$\boxed{\frac{COP_{HP}}{COP_{HP_{rev}}} = 0.488}$$

Given

Two irreversible refrigeration cycles operating at steady state

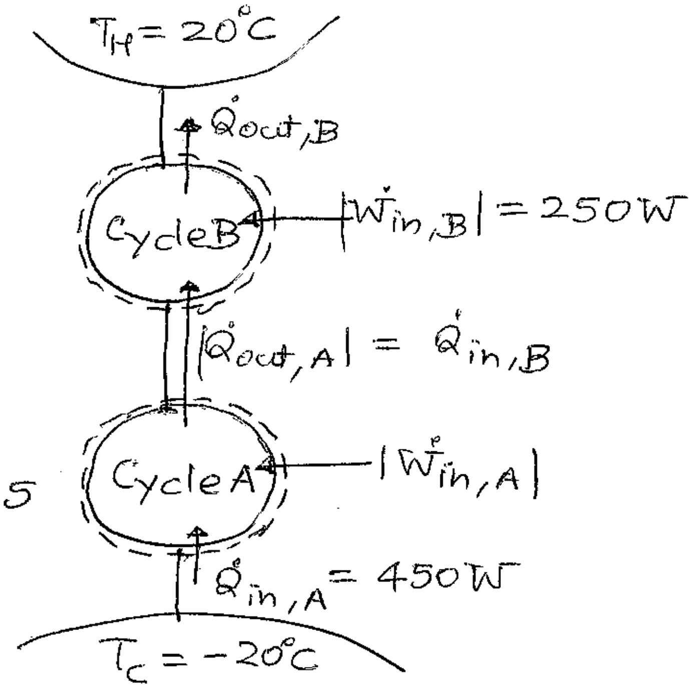
Find

(a) Power input (W) of Cycle A

(b) Coefficient of performance of Cycle B

(c) Rate of heat transfer (~~kW~~) to the environment

System



$COP_{R,A} = 2.5$

Assumptions

- Steady state

Basic Equations

$$\underbrace{\frac{dE}{dt}\bigg|_{system}}_{0} = \cancel{\sum_{in} \dot{m}_{in}(h+ke+pe)_{in} - \sum_{out} \dot{m}_{out}(h+ke+pe)_{out}} + \dot{Q} - \dot{W}$$

Solution

(a) Coefficient of performance of the refrigeration cycle A: $COP_{R,A} = \frac{\dot{Q}_{in,A}}{|\dot{W}_{in,A}|} \Rightarrow 2.5 = \frac{450W}{|\dot{W}_{in,A}|}$

Power input for Cycle A:

$$\boxed{|\dot{W}_{in,A}| = 180\ W}$$

(b) Considering energy balance for the refrigeration cycle A: $\dot{Q}_{in,A} + |\dot{W}_{in,A}| = |\dot{Q}_{out,A}|$

$$|\dot{Q}_{out,A}| = 450\,W + 180\,W = 630\,W = \dot{Q}_{in,B}$$

Coefficient of performance of the refrigeration cycle B: $COP_{R,B} = \dfrac{\dot{Q}_{in,B}}{|\dot{W}_{in,B}|} = \dfrac{630\,W}{250\,W}$

$$\boxed{COP_{R,B} = 2.52}$$

(c) Considering energy balance for the refrigeration cycle B: $\dot{Q}_{in,B} + |\dot{W}_{in,B}| = |\dot{Q}_{out,B}|$

Rate of heat transfer to the environment:

$$|\dot{Q}_{out,B}| = 630\,W + 250\,W \Rightarrow \boxed{|\dot{Q}_{out,B}| = 880\,W}$$

(a) Propane, $T = 20^\circ C$, $x = 1$

$\Rightarrow$ $\boxed{\text{saturated vapor}}$

$P = P_{sat}(20^\circ C) \Rightarrow \boxed{P = 8.3654 \text{ bar}}$

$s = s_g(20^\circ C) \Rightarrow \boxed{s = 1.7295 \frac{kJ}{kg-K}}$

(b) Propane, $T = 20^\circ C$, $s = 1.2066 \frac{kJ}{kg-K}$

$s_f(20^\circ C) < s < s_g(20^\circ C) \Rightarrow \boxed{\text{saturated liquid-vapor mixture}}$

$P = P_{sat}(20^\circ C) \Rightarrow \boxed{P = 8.3654 \text{ bar}}$

$$s = x s_g + (1-x) s_f$$

$$\Rightarrow x = \frac{s - s_f}{s_g - s_f} = \frac{1.2066 - 0.55440}{1.7295 - 0.55440}$$

$\boxed{x = 0.555}$

(c) Propane, $P = 1$ bar, $T = 40^\circ C$

$T_{sat}(1 \text{ bar}) = -42.414^\circ C \Rightarrow T > T_{sat}(1 \text{ bar})$

or

$P_{sat}(40^\circ C) = 13.70 \text{ bar} \Rightarrow P < P_{sat}(40^\circ C)$

$\Rightarrow \boxed{\text{superheated vapor}}$

$\boxed{x = N/A}$

$\boxed{s = 2.3057 \frac{kJ}{kg-K}}$

(d) Propane, $P = 10$ bar, $v = 0.0019393 \frac{m^3}{kg}$

$v_f(10\text{ bar}) = 0.0020435 \frac{m^3}{kg} \Rightarrow v < v_f(10\text{ bar})$

$\Rightarrow$ $\boxed{\text{compressed liquid}}$

$\boxed{x = N/A}$

$\boxed{T = 10^\circ C}$

$\boxed{s = 0.46239 \frac{kJ}{kg-K}}$

(a) False

Heat transfer can be equal to work in a single process. Kelvin-Planck statement applies only to a thermodynamic cycle

(b) False

Throttling process involves very high pressure gradients and may also involve temperature gradients. This makes the process irreversible

(c) False

A reversible power cycle with 100% efficiency implies that thermal energy transfer into the cycle is completely converted into mechanical work. This does not violate the first law of thermodynamics

(d) True

A reversible power cycle with 100% efficiency implies that thermal energy transfer into the cycle is completely converted into mechanical work. This is impossible even with no friction and violates Kelvin-Planck statement of the second law of thermodynamics