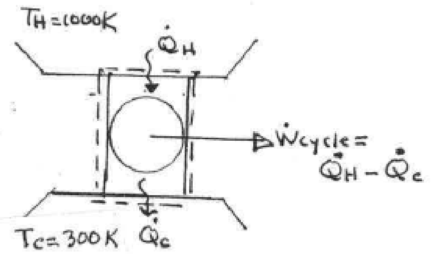
PROBLEM 5.19

KNOWN: Data are provided for a power cycle operating between hot and cold reservoirs. The data are for steady-state operation.

FIND: In each case, determine whether the cycle operates reversibly, operates irreversibly, or is impossible.

SCHEMATIC & GIVEN DATA:



ANALYSIS:

Using Eq. 5.9, the maximum theoretical thermal efficiency any such cycle can achieve is

$$\eta_{MAX} = 1 - \frac{T_C}{T_H}$$
$$= 1 - \frac{300}{1000} = 0.7\ (70\%)$$

(a) $\dot{Q}_H = 500\,kW,\ \dot{Q}_C = 100\,kW$

$$\eta = \frac{\dot{W}_{cycle}}{\dot{Q}_H}$$
$$= 1 - \frac{\dot{Q}_C}{\dot{Q}_H} = 1 - \frac{100\,kW}{500\,kW} = 0.8\ (80\%)$$

Since $\eta > \eta_{MAX}$, this case is impossible.

(b) $\dot{Q}_H = 500\,kW,\ \dot{W}_{cycle} = 250\,kW,\ \dot{Q}_C = 200\,kW$

Check energy balance:

$$\dot{W}_{cycle} = \dot{Q}_H - \dot{Q}_C$$

(c) $\dot{W}_{cycle} = 350\,kW,\ \dot{Q}_C = 150\,kW$

Using the energy balance,

$$\dot{Q}_H = \dot{W}_{cycle} + \dot{Q}_C$$
$$= 350\,kW + 150\,kW = 500\,kW$$

Then

$$\eta = \frac{\dot{W}_{cycle}}{\dot{Q}_H} = \frac{350\,kW}{500\,kW} = 0.7\ (70\%)$$

Since $\eta = \eta_{MAX}$, this case corresponds to reversible operation.

(d) $\dot{Q}_H = 500\,kW,\ \dot{Q}_C = 200\,kW$

$$\eta = \frac{\dot{W}_{cycle}}{\dot{Q}_H} = 1 - \frac{\dot{Q}_C}{\dot{Q}_H} = 1 - \frac{200\,kW}{500\,kW} = 0.6\ (60\%)$$

Since $\eta < \eta_{MAX}$, this case corresponds to irreversible operation.

PROBLEM 5.25

KNOWN: Data are provided for two reversible power cycle in series that produce the same net work.

FIND: Determine (a) the intermediate temperature T and the thermal efficiency for each of the two power cycles. (b) For a single cycle, determine the thermal efficiency and net work.

SCHEMATIC & GIVEN DATA:

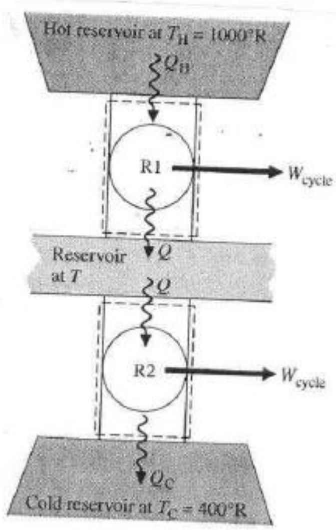


Fig. P5.25

ANALYSIS:

(a) Energy balances: Since Wcycle is the net work developed by each cycle

$$W_{cycle} = Q_H - Q = Q - Q_C$$

$$\Rightarrow \quad Q = \frac{Q_H + Q_C}{2} \qquad (1)$$

Since the cycles are reversible, Eq. 5.7 applies to each:

$$\frac{Q}{Q_H} = \frac{T}{T_H}, \quad \frac{Q_C}{Q} = \frac{T_C}{T}$$

$$\Rightarrow \quad Q_H = \frac{T_H}{T} Q$$

$$Q_C = \frac{T_C}{T} Q$$

Substituting these results into Eq. (1)

$$Q = \frac{\frac{T_H}{T} Q + \frac{T_C}{T} Q}{2}$$

$$\Rightarrow \quad T = \frac{T_H + T_C}{2} = \frac{1000°R + 400°R}{2} = 700°R$$

Then, for R1:

$$\eta_1 = 1 - \frac{T}{T_H} = 1 - \frac{700°R}{1000°R} = 0.3 \ (30\%)$$

For R2:

$$\eta_2 = 1 - \frac{T_C}{T} = 1 - \frac{400°R}{700°R} = 0.43 \ (43\%)$$

(b) For the single reversible cycle operating between T_H = 1000°R and T_C = 400°R,

① $$\eta_{MAX} = 1 - \frac{T_C}{T_H} = 1 - \frac{400°R}{1000°R} = 0.6 \ (60\%)$$

Also, the net work of this cycle is

$$W'_{cycle} = Q_H - Q_C$$
$$= (Q_H - Q) + (Q - Q_C)$$
$$= 2\,W_{cycle}$$

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1. The combined cycle thermal efficiency is greater than either of the individual cycles denoted R1 and R2.

PROBLEM 5.38

KNOWN: A system undergoes a power cycle while receiving energy by heat transfer from condensing steam and discharging energy by heat transfer to a lake.

FIND: Determine the minimum theoretical steam mass flow rate for a net power output of 1 MW.

SCHEMATIC & GIVEN DATA:

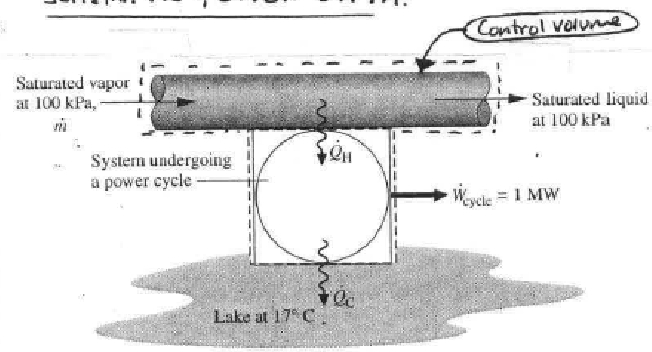

Fig. P5.38

ENGR. MODEL:

1. As shown by the sketch, two systems are under consideration, each operating at steady state.
2. The condensing steam and the lake play the roles of hot and cold reservoirs, respectively.
3. For the control volume, kinetic and potential energy effects are ignored. Steam condenses at 100 kPa.

ANALYSIS: For the system undergoing the power cycle, we have

$$\frac{\dot{W}_{cycle}}{\dot{Q}_H} \leq 1 - \frac{T_C}{T_H} \quad , \text{ where } T_C = 290\text{K} \text{ and } T_H = T_{sat}(100\text{kPa}) = 99.63°\text{C} = 373\text{K}$$

(Table A-3 at 100 kPa)

An energy rate balance for the control volume gives $\dot{Q}_H = \dot{m}[h_g - h_f]$, where $h_g - h_f$: 2258 kJ/kg. Collecting results

$$\frac{1 \text{ MW} \left| \frac{10^3 \text{ kJ/s}}{1 \text{ MW}} \right|}{\dot{m}(2258 \text{ kJ/kg})} \leq 1 - \frac{290\text{K}}{373\text{K}} = 0.223$$

Thus,

$$\frac{10^3 \text{ kJ/s}}{(2258 \text{ kJ/kg})(0.223)} \leq \dot{m}$$

$$\Rightarrow \quad \dot{m} \geq 1.99 \text{ kg/s}$$

$\dot{m}_{MIN}$