Problem Sheet 4: Second Law of Thermodynamics (From Moran and Shapiro – 5th Ed.)

5.18 The data listed below are claimed for a power cycle operating between reservoirs at 527°C and 27°C. For each case, determine if any principles of thermodynamics would be violated.

(a) $Q_H = 700$ kJ, $W_{cycle} = 400$ kJ, $Q_C = 300$ kJ.
(b) $Q_H = 640$ kJ, $W_{cycle} = 400$ kJ, $Q_C = 240$ kJ.
(c) $Q_H = 640$ kJ, $W_{cycle} = 400$ kJ, $Q_C = 200$ kJ.

5.19 A refrigeration cycle operating between two reservoirs receives energy Q_C from a cold reservoir at $T_C = 280$ K and rejects energy Q_H to a hot reservoir at $T_H = 320$ K. For each of the following cases determine whether the cycle operates reversibly, irreversibly, or is impossible:

(a) $Q_C = 1500$ kJ, $W_{cycle} = 150$ kJ.
(b) $Q_C = 1400$ kJ, $Q_H = 1600$ kJ.
(c) $Q_H = 1600$ kJ, $W_{cycle} = 400$ kJ.
(d) $\beta = 5$.

5.20 A reversible power cycle receives Q_H from a hot reservoir at temperature T_H and rejects energy by heat transfer to the surroundings at temperature T_0. The work developed by the power cycle is used to drive a refrigeration cycle that removes Q_C from a cold reservoir at temperature T_C and discharges energy by heat transfer to the same surroundings at T_0.

(a) Develop an expression for the ratio Q_C/Q_H in terms of the temperature ratios T_H/T_0 and T_C/T_0.
(b) Plot Q_C/Q_H versus T_H/T_0 for $T_C/T_0 = 0.85$, 0.9, and 0.95, and versus T_C/T_0 for $T_H/T_0 = 2$, 3, and 4.

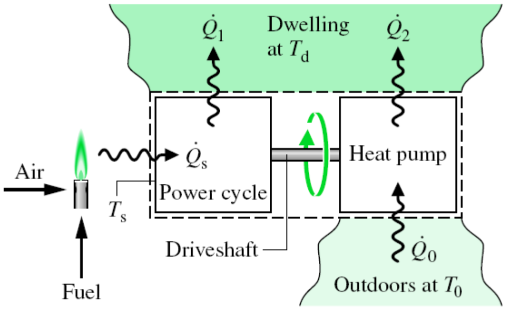
Ans

$$(a) = \frac{T_C[T_H - T_0]}{T_H[T_0 - T_C]}$$

5.21 A reversible power cycle receives energy Q_H from a reservoir at temperature T_H and rejects Q_C to a reservoir at temperature T_C. The work developed by the power cycle is used to drive a reversible heat pump that removes energy Q'_C from a reservoir at temperature T'_C and rejects energy Q'_H to a reservoir at temperature T'_H.

(a) Develop an expression for the ratio Q'_H/Q_H in terms of the temperatures of the four reservoirs.
(b) What must be the relationship of the temperatures T_H, T_C, T'_C, and T'_H for Q'_H/Q_H to exceed a value of unity?
(c) Letting $T'_H = T_C = T_0$, plot Q'_H/Q_H versus T_H/T_0 for $T'_C/T_0 = 0.85$, 0.9, and 0.95, and versus T'_C/T_0 for $T_H/T_0 = 2$, 3, and 4.

5.22 Figure P5.22 shows a system consisting of a power cycle driving a heat pump. At steady state, the power cycle receives $\dot{Q}_s$ by heat transfer at T_s from the high-temperature source and delivers $\dot{Q}_1$ to a dwelling at T_d. The heat pump receives $\dot{Q}_0$ from the outdoors at T_0, and delivers $\dot{Q}_2$ to the dwelling.



▲ **Figure P5.22**

(a) Obtain an expression for the maximum theoretical value of the performance parameter $(\dot{Q}_1 + \dot{Q}_2)/\dot{Q}_s$ in terms of the temperature ratios T_s/T_d and T_0/T_d.
(b) Plot the result of part (a) versus T_s/T_d ranging from 2 to 4 for $T_0/T_d = 0.85$, 0.9, and 0.95.

5.23 A power cycle operates between a reservoir at temperature T and a lower-temperature reservoir at 280 K. At steady state, the cycle develops 40 kW of power while rejecting 1000 kJ/min of energy by heat transfer to the cold reservoir. Determine the minimum theoretical value for T, in K. *Ans: 952*

5.24 A certain reversible power cycle has the same thermal efficiency for hot and cold reservoirs at 1000 and 500 K, respectively, as for hot and cold reservoirs at temperature T and 1000 K. Determine T, in K.

5.25 A reversible power cycle whose thermal efficiency is 50% operates between a reservoir at 1800 K and a reservoir at a lower temperature T. Determine T, in K.

5.26 An inventor claims to have developed a device that executes a power cycle while operating between reservoirs at 800 and 350 K that has a thermal efficiency of **(a)** 56%, **(b)** 40%. Evaluate the claim for each case.

5.27 At steady state, a cycle develops a power output of 10 kW for heat addition at a rate of 10 kJ *per cycle of operation* from a source at 1500 K. Energy is rejected by heat transfer to cooling water at 300 K. Determine the *minimum* theoretical number of cycles required per minute. *Ans: 75*

5.30 During January, at a location in Alaska winds at −30°C can be observed. Several meters below ground the temperature remains at 13°C, however. An inventor claims to have devised a power cycle exploiting this situation that has a thermal efficiency of 10%. Discuss this claim.

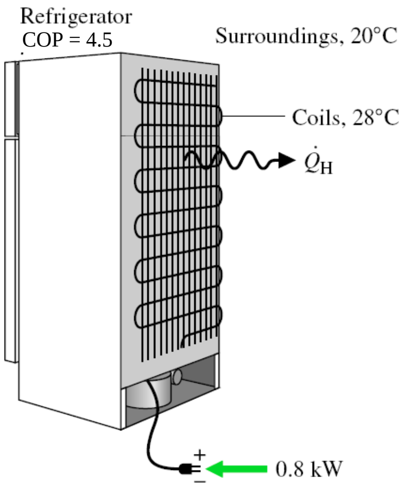
5.33 An inventor claims to have developed a refrigeration cycle that requires a net power input of 1.2 kW to remove 25,000 kJ/h of energy by heat transfer from a reservoir at −30°C and discharge energy by heat transfer to a reservoir at 20°C. There are no other energy transfers with the surroundings. Evaluate this claim.

5.35 The refrigerator shown in Fig. P5.35 operates at steady state with a coefficient of performance of 4.5 and a power input of 0.8 kW. Energy is rejected from the refrigerator to the surroundings at 20°C by heat transfer from metal coils whose average surface temperature is 28°C. Determine

(a) the rate energy is rejected, in kW.

(b) the lowest theoretical temperature *inside* the refrigerator, in K.

(c) the maximum theoretical power, in kW, that could be developed by a power cycle operating between the coils and the surroundings. Would you recommend making use of this opportunity for developing power?



◀ **Figure P5.35**

5.36 Determine the minimum theoretical power, in W, required at steady state by a refrigeration system to maintain a cryogenic sample at −126°C in a laboratory at 21°C, if energy *leaks* by heat transfer to the sample from its surroundings at a rate of 900 W. *Ans: 900*

5.37 For each kW of power input to an ice maker at steady state, determine the maximum rate that ice can be produced, in kg/h, from liquid water at 0°C. Assume that 333 kJ/kg of energy must be removed by heat transfer to freeze water at 0°C, and that the surroundings are at 20°C.

5.47 One kilogram of air as an ideal gas executes a Carnot power cycle having a thermal efficiency of 60%. The heat transfer to the air during the isothermal expansion is 40 kJ. At the end of the isothermal expansion, the pressure is 5.6 bar and the volume is 0.3 m^3. Determine

(a) the maximum and minimum temperatures for the cycle, in K.

(b) the pressure and volume at the beginning of the isothermal expansion in bar and m^3, respectively.

(c) the work and heat transfer for each of the four processes, in kJ.

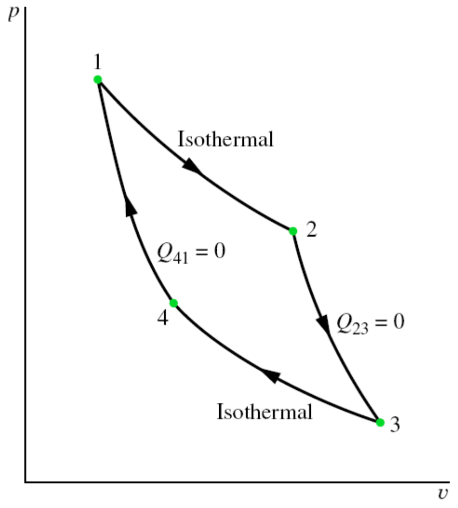
(d) Sketch the cycle on p–v coordinates.

5.48 The pressure–volume diagram of a Carnot power cycle executed by an ideal gas with constant specific heat ratio k is shown in Fig. P5.48. Demonstrate that

(a) $V_4V_2 = V_1V_3$.

(b) $T_2/T_3 = (p_2/p_3)^{(k-1)/k}$.

(c) $T_2/T_3 = (V_3/V_2)^{k-1}$.



◀ **Figure P5.48**