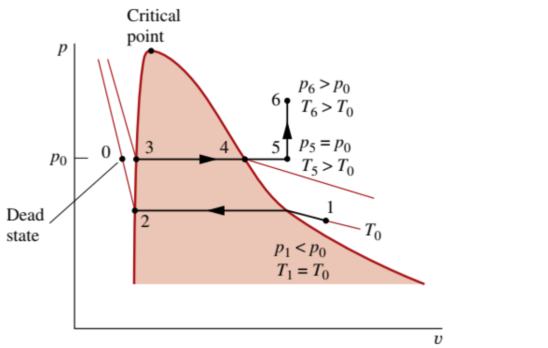
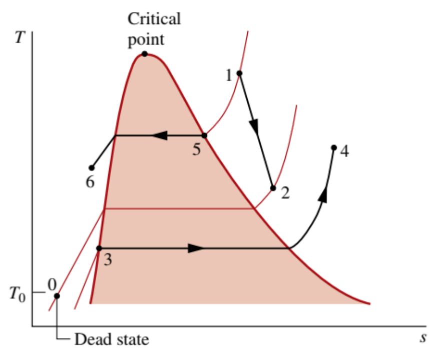
Practice Problems on Exergy/Availability Analysis

1. By inspection of Figure giving a p-v diagram for water, indicate whether exergy would increase, decrease, or remain the same in (a) Process 1–2, (b) Process 3–4, (c) Process 5–6. Explain.



2. By inspection of Figure giving a T–s diagram for R-134a, indicate whether exergy would increase, decrease, or remain the same in(a) Process 1–2, (b) Process 3–4, (c) Process 5–6. Explain



3. Two solid blocks, each having mass **m** and specific heat **c,** and initially at temperatures **T_1** and **T_2**, respectively, are brought into contact, insulated on their outer surfaces, and allowed to come into thermal equilibrium.

   (a). Derive an expression for the exergy destruction in terms of **m, c, T_1, T_2**, and the temperature of the environment, **T_0.**

   (b). Demonstrate that the exergy destruction cannot be negative.

   (c). What is the source of exergy destruction in this case?

4. A system undergoes a refrigeration cycle while receiving **Q_C** by heat transfer at temperature **T_C** and discharging energy **Q_H** by heat transfer at a higher temperature **T_H.** There are no other heat transfers.

   (a). Using energy and exergy balances, show that the network input to the cycle cannot be zero.

   (b). Show that the coefficient of performance of the cycle can be expressed as

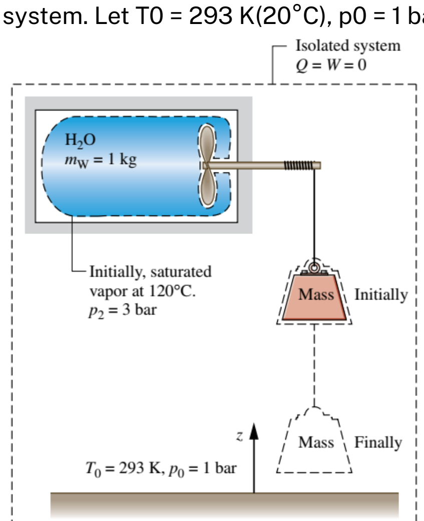
$$\beta = \left(\frac{T_C}{T_H - T_C}\right)\left(1 - \frac{T_H E_d}{T_0(Q_H - Q_C)}\right)$$

   where **E_d** is the exergy destruction and **T_0** is the temperature of the exergy reference environment.

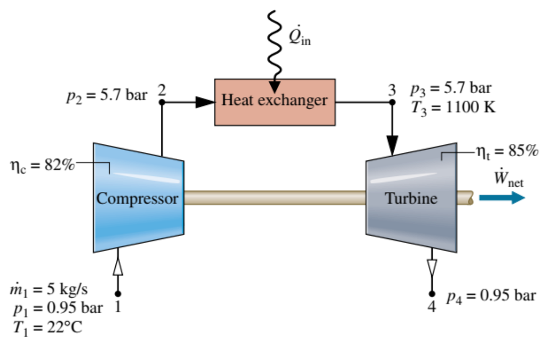
   (c). Using the result of part (b), obtain an expression for the maximum theoretical value for the coefficient of performance.

5. When matter flows across the boundary of a control volume, an energy transfer by work, called flow work, occurs. The rate is $\dot{m}(pv)$ where $\dot{m}$, p, and v denote the mass flow rate, pressure, and specific volume, respectively, of the matter crossing the boundary. Show that the exergy transfer accompanying flow work is given by $\dot{m}(pv - p_o v)$, where p_o is the pressure at the dead state.

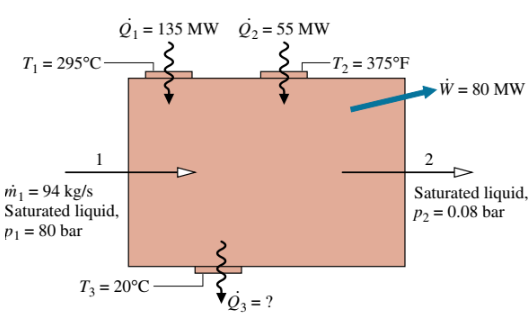
6. As shown in Figure, 1 kg of H_2O is contained in a rigid, insulated cylindrical vessel. The H_2O is initially saturated vapor at 120°C. The vessel is fitted with a paddle wheel from which a mass is suspended. As the mass descends a certain distance, the H_2O is stirred until it attains a final equilibrium state at a pressure of 3 bar. The only significant changes in state are experienced by the H_2O and the suspended mass. Determine, in kJ (a). the change in exergy of the H2O. (b). the change in exergy of the suspended mass.
   (c). the change in exergy of an isolated system of the vessel and pulley–mass assembly. (d). the destruction of exergy within the isolated system. Let T0 = 293 K(20°C), p0 = 1 bar



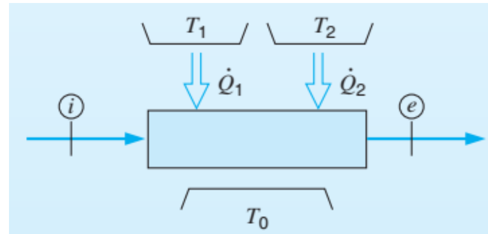
7. A gas turbine operating at steady state is shown in Figure. Air enters the compressor with a mass flow rate of 5 kg/s at 0.95 bar and 22°C and exits at 5.7 bar. The air then passes through a heat exchanger before entering the turbine at 1100 K, 5.7 bar. Air exits the turbine at 0.95 bar. The compressor and turbine operate adiabatically and the effects of motion and gravity can be ignored. The compressor and turbine isentropic efficiencies are 82 and 85%, respectively. Using the ideal gas model for air, determine, each in kW, (a). the net power developed. (b). the rates of exergy destruction for the compressor and turbine. (c). the net rate exergy is carried out of the plant at the turbine exit. Let T_0 = 22°C, p_0 = 0.95 bar.



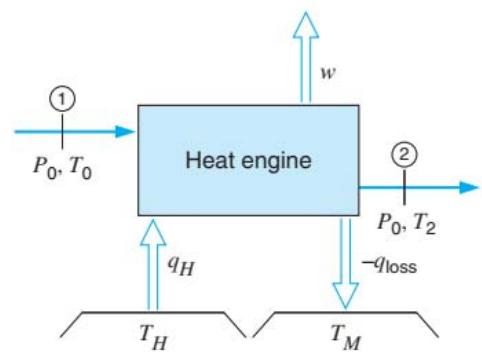
8. Figure shows a power-generating system at steady state. Saturated liquid water enters at 80 bar with a mass flow rate of 94 kg/s. Saturated liquid exits at 0.08 bar with the same mass flow rate. As indicated by arrows, three heat transfers occur, each at a specified temperature in the direction of the arrow: The frst adds 135 MW at 295°C, the second adds 55 MW at 375°C, and the third removes energy at 20°C. The system generates power at the rate of 80 MW. The effects of motion and gravity can be ignored. Let T_0 = 20°C, p_0 = 1 atm. Determine, in MW,
(a) the rate of heat transfer Q3 and the accompanying rate of exergy transfer
(b) a full exergy accounting of the total exergy supplied to the system with the two heat additions and with the net exergy, carried in by the water stream as it passes from inlet to exit.



9. A feed water heater has 5 kg/s water at 5 MPa and 40°C flowing through it, being heated from two sources, as shown in Figure. One source adds 900 kW from a 100°C reservoir, and the other source transfers heat from a 200°C reservoir such that the water exit condition is 5 MPa, 180°C. Find the reversible work and the irreversibility and second law efficiency.



10. Air flows into a heat engine at ambient conditions of 100 kPa, 300 K, as shown in Figure below. Energy is supplied as 1200 kJ per kilogram of air from a 1500 K source, and in some part of the process a heat transfer loss of 300 kJ/kg air occurs at 750 K. The air leaves the engine at 100 kPa, 800 K. Find the first- and second-law efficiencies.



11. Air in a piston/cylinder arrangement, shown in Figure, is at 200 kPa, 300 K with a volume of 0.5 m³. If the piston is at the stops, the volume is 1 m³ and a pressure of 400 kPa is required. The air is then heated from the initial state to 1500 K by a 1700 K reservoir. Find the total irreversibility in the process, assuming the surroundings are at 20°C.