Reference Answers for Homework 6

1. Can a process for which the reversible work is zero be reversible? Can it be irreversible? Explain your answer.

ANS:

A processes with W_{rev}= 0 is reversible if it involves no actual useful work. Otherwise it is irreversible.

2. This is an open question. Just make sure that your designed problem is physically reasonable and the solution is correct. Below is an example for your reference.

Air enters a turbine at an initial state of 5 Mpa and 100°C, and leaves at a final state of 1 MPa. If this process is adiabatically and steadily, please find the work done by the air for a turbine with an isentropic efficiency of 80 percent.

ANS:

$$w_a = \eta w_s = \eta(h_1 - h_{2s}) = \eta c_p (T_1 - T_{2s}) \quad \text{where} \quad T_{2s} = T_1 \left(\frac{P_2}{P_1}\right)^{(k-1)/k}$$

Please finish the calculation by yourself. For air, k = 1.4 and c_p = 1.005 kJ/kg·°C.

3. A heat engine receives heat from a source at 1100 K at a rate of 400 kJ/s, and it rejects the waste heat to a medium at 320 K. The measured power output of the heat engine is 120 kW, and the environment temperature is 25 °C. Determine

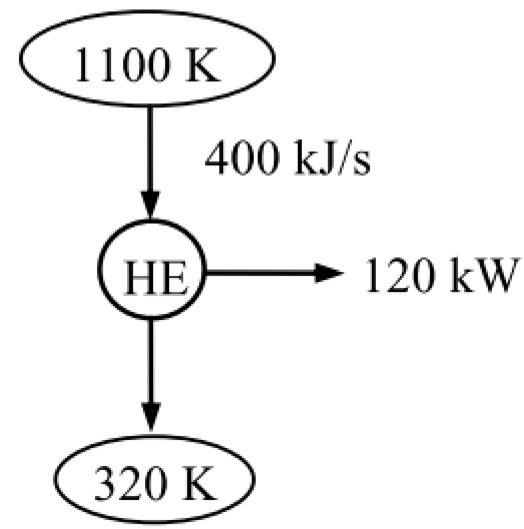
(a) the reversible power;

(b) the rate of irreversibility;

(c) the second-law efficiency of this heat engine.

ANS

(a) The reversible power is the power produced by a reversible heat engine operating between the specified temperature limits:



$$\eta_{\text{th,max}} = \eta_{\text{th,rev}} = 1 - \frac{T_L}{T_H} = 1 - \frac{320\text{ K}}{1100\text{ K}} = 0.7091$$

$$\dot{W}_{\text{rev,out}} = \eta_{\text{th,rev}}\dot{Q}_{\text{in}} = (0.7091)(400\text{ kJ/s}) = \mathbf{283.6\,kW}$$

(b) The irreversibility rate is the difference between the reversible power and the actual power output:

$$\dot{I} = \dot{W}_{\text{rev,out}} - \dot{W}_{\text{u,out}} = 283.6 - 120 = \mathbf{163.6\,kW}$$

(c) The second law efficiency is $\eta_{\text{II}} = \frac{W_{\text{u,out}}}{W_{\text{rev,out}}} = \frac{120\text{ kW}}{283.6\text{ kW}} = 0.423 = \mathbf{42.3\%}$

4. Consider a house that is losing heat at a rate of 50,000 kJ/h to the outside at a temperature of 4°C. If the house is to be heated by electric resistance heaters to maintain its temperature at 25°C for all times, determine the reversible work input for this process and the irreversibility.

ANS: We consider a reversible heat pump operation as the reversible counterpart of the irreversible process of heating the house by resistance heaters. Instead of using electricity input for resistance heaters, it is used to power a reversible heat pump. The reversible work is the minimum work required to accomplish this process, and the irreversibility is the difference between the reversible work and the actual electrical work consumed. The actual power input is

$$\dot{W}_{\text{in}} = \dot{Q}_{\text{out}} = \dot{Q}_H = 50{,}000\ \text{kJ/h} = 13.89\ \text{kW}$$

The COP of a reversible heat pump operating between the specified temperature limits is

$$\text{COP}_{\text{HP,rev}} = \frac{1}{1 - T_L / T_H} = \frac{1}{1 - 277.15/298.15} = 14.20$$

Thus, $$\boxed{\dot{W}_{\text{rev,in}} = \frac{\dot{Q}_H}{\text{COP}_{\text{HP,rev}}}} = \frac{13.89\ \text{kW}}{14.20} = \mathbf{0.978\ kW}$$

and $$\dot{I} = \dot{W}_{\text{u,in}} - \dot{W}_{\text{rev,in}} = 13.89 - 0.978 = \mathbf{12.91\ \ kW}$$