The key to most of these problems is \( \text{adiabatic + reversible} = \text{isentropic} \). An isentropic process has \( s_2 = s_1 \), and this information will allow you to fix the sought state in the process.

1. A closed system contains 1 kg of water, initially at 450°C and 2 MPa. The system is surrounded by an environment at \( T_0 = 25°C = 298 \text{ K} \).

(a) Say heat is transferred from the system to the environment in a constant-volume process, and the final temperature of the system is 25°C. Calculate the entropy change of the system, the environment, and the total entropy generation. How much work is done by the system (this has a trivial answer)? Is this a reversible or irreversible process?

(b) Say the system starts from the same initial state, and undergoes the same constant volume process to the environment temperature. The heat transferred from the system, however, is now fed into a reversible heat engine, and the engine rejects heat to the environment. How much work is produced by the engine? To work this problem, note that the total process is now reversible: the entropy change of the system is the same as in a), yet a smaller net amount of heat has been transferred to the environment, because some of the heat transferred from the system has been converted into work. Therefore,

\[
S_{\text{gen}} = m(s_2 - s_1) + \frac{Q_L}{T_0} = 0
\]

and

\[
W = Q_H - Q_L = (-Q_{1-2}) - Q_L
\]

I am taking \( Q_H \) and \( Q_L \) to be positive quantities, as usual, and \( Q_{1-2} \) (which is the heat transferred from the system) to be negative. Solve for \( Q_L \) using the first equation, get \( Q_{1-2} \) from the first law, and solve for \( W \) using the second equation.

(c) Say the system undergoes an adiabatic and reversible process from the initial state to a final temperature of 25°C. How much work can now be produced?

Parts a-b: State 2 is fixed by \( T_2 \) and \( v_2 = v_1 \). Properties are

\[
\begin{align*}
    u_1 &= 3030.4 \text{ kJ/kg}, \quad s_1 = 7.2844 \text{ kJ/kg K} \\
    u_2 &= 113.6 \text{ kJ/kg}, \quad s_2 = 0.398 \text{ kJ/kg K}
\end{align*}
\]

There is no work for the constant volume process, and the heat transfer is

\[
Q_{1-2} = m(u_2 - u_1) = -2917 \text{ kJ}
\]

The system, environment, total entropy changes are

\[
\begin{align*}
    \Delta S_{\text{sys}} &= m(s_2 - s_1) = -6.886 \text{ kJ/K} \\
    \Delta S_{\text{env}} &= -\frac{Q_{1-2}}{T_0} = 9.788 \text{ kJ/K} \\
    S_{\text{gen}} &= \Delta S_{\text{sys}} + \Delta S_{\text{env}} = 2.902 \text{ kJ/K}
\end{align*}
\]

The entropy generation is greater than zero, and the process is irreversible.

In the hypothetical reversible process, the work that could be derived from the process is

\[
W_{\text{rev}} = m(u_1 - u_2 - T_0(s_1 - s_2)) = 864.7 \text{ kJ}
\]

Part c): The process now is entirely different. The system starts from the same initial state, yet it now undergoes a reversible and adiabatic expansion to the final state. This process is isentropic, so \( s_2 = s_1 \), and state 2 is fixed by \( T_2 \) and \( s_2 \). The internal energy at state 2 is therefore

\[
u_2 = 2051.4 \text{ kJ/kg}
\]

(this is a saturated mixture state, with \( x_2 = 0.845 \)). There is no heat transfer (adiabatic), and the work is

\[
W = m(u_1 - u_2) = 979 \text{ kJ}
\]

The processes for part b) and c) are both reversible, yet they are also different processes; they follow a different path and end up at different final states. In this regard, it is really not relevant to compare the work from b) to that from c).

2. Steam enters an adiabatic and reversible turbine at 500 kPa, 350°C. The exit pressure is 50 kPa. Find the work produced per unit mass.

Inlet properties are \( h_1 = 3168 \text{ kJ/kg}, \quad s_1 = 7.6328 \text{ kJ/kg K} \). The turbine is reversible and adiabatic, hence isentropic. The exit state is fixed by \( P_2 \) and \( s_2 = s_1 \). Since \( s_2 > s_y(50 \text{ kPa}) \) the exit is superheated. The exit enthalpy is \( h_2 = 2660 \text{ kJ/kg} \), and

\[
w = h_1 - h_2 = 507.8 \text{ kJ/kg}
\]

3. The exit pressure of an adiabatic and reversible turbine is 50 kPa, and the inlet temperature is 350°C. Ideally, the exit state of the turbine should be a saturated vapor \((x_2 = 1)\); liquid in a turbine can be damaging. Determine the inlet pressure which gives the sought exit state. What happens to the exit state when the inlet pressure is increased above this amount?

The sought exit state is a saturated vapor at 50 kPa, for which \( s_2 = 7.5938 \text{ kJ/kg K} \). The inlet state is fixed by \( s_1 = s_2 \) and \( T_1 = 350°C \); this gives \( P_1 = 542 \text{ kPa} \). If \( T_1 \) is held at 350°C, and \( P_2 \) is increased, the liquid content at the turbine exit will increase: this can be viewed on a \( T - s \) diagram. The isentropic process is a vertical line, state 1 is in the superheated region, and increasing \( P_1 \) will move state 1 to the left (i.e., decreasing entropy); this will have the effect of moving state 2 into the vapor dome.
4. A volumetric flow of 30 L/s of air enters a compressor at 300 K, 1 atm. The exit pressure is 8 atm. Assuming the compressor is adiabatic and reversible, calculate the power input to the compressor and the exit temperature using

(a) The air tables,
(b) A constant specific heat, with \( C_P = 1.005 \text{ kJ/kg K} \) and \( k = 1.4 \)

The mass flow rate is

\[
\dot{m} = \frac{P_1 \dot{V}_1}{RT_1} = 0.0353 \text{ kg/s}
\]

The air tables have at 300 K: \( h_1 = 300.2 \text{ kJ/kg}, s_1^0 = 1.702 \text{ kJ/kg K} \). Since the process is isentropic, then

\[
s_2 - s_1 = s_2^0 - s_1^0 - R \ln \left( \frac{P_2}{P_1} \right) = 0
\]

or

\[
s_2^0 = s_1^0 + R \ln \left( \frac{P_2}{P_1} \right) = 2.299 \text{ kJ/kg K}
\]

and interpolating gives \( T_2 \approx 540 \text{ K}, h_2 = 544.4 \text{ kJ/kg} \).

The power is

\[
\dot{W} = \dot{m}(h_1 - h_2) = -8.62 \text{ kW}
\]

The constant heat approximation, applied to an ideal gas isentropic process, has

\[
T_2 = T_1 \left( \frac{P_2}{P_1} \right)^{(k-1)/k} = 543 \text{ K}
\]

\[
\dot{W} = \dot{m} C_p(T_1 - T_2) = -8.64 \text{ kW}
\]

5. Air enters a reversible and adiabatic nozzle at 800°C, 4 atm, and with negligible velocity. The exit pressure is 1 atm. Assuming a constant specific heat, calculate the exit velocity.

This is an isentropic, ideal gas process. Assuming constant specific heats,

\[
T_2 = T_1 \left( \frac{P_2}{P_1} \right)^{(k-1)/k} = 538 \text{ K}
\]

There is no work and no heat transfer. The exit velocity is obtained from the first law:

\[
\mathcal{V}_2 = \sqrt{2 \cdot 1000 \cdot C_p(T_1 - T_2) \frac{1}{\mathcal{g}}} = 508 \text{ m/s}
\]

The 1000 is the required conversion factor, from kJ/kg to J/kg = m²/s².