Problem: 3-2

Given:	Steam is expanded in an adiabatic steady-flow turbine from 1000 kPa at 280 $°C$ to 120 $°C$.
Find:	Calculate the second law effectiveness when the turbine efficiency is 70%

Fluid kinetic and potential energies will be neglected

$$\Delta ke = \Delta pe = 0$$

From Table B.2 @ 1000 kPa and 280 $°C$

$$\begin{aligned} h_1 &= 3007.76\ kJ/kg \\ s_1 &= 7.0444\ kJ/kg \cdot K \end{aligned}$$

The quality at $2s$ can be determined by

$$x_{2s} = \frac{s_1 - s_{f,2s}}{s_{fg,2s}} = \frac{(7.0444 - 1.5280)\ kJ/kg \cdot K}{5.6024\ kJ/kg \cdot K} = 0.9846$$

The enthalpy at $2s$ is given by

$$\begin{aligned} h_{2s} &= h_{f,2s} + x_{2s} h_{fg,2s} \\ &= 503.7\ kJ/kg + 0.9846 \cdot 2202.6\ kJ/kg \\ &= 2672.38\ kJ/kg \end{aligned}$$

From Table B.2 @ 120 $°C$

$$\begin{aligned} P_2 &= 198.79\ kPa \\ h_2 &= h_1 - \eta_T(h_1 - h_{2s}) \\ &= 3007.76\ kJ/kg - 0.7(3007.76 - 2672.38)\ kJ/kg \\ &= 2772.99\ kJ/kg \end{aligned}$$

Entering the steam tables with $P_2 = 198.79\ kPa$ and $h_2 = 2772.99\ kJ/kg$, we obtain

$$\begin{aligned} T_2 &\approx 152.06\ °C \\ s_2 &\approx 6.9406\ kJ/kg \cdot K \end{aligned}$$

When the first law is applied to the turbine, the actual specific work produced is

$$
\begin{aligned}
-w_{1\rightarrow 2,act} &= h_1 - h_2 \\
&= (3007.76 - 2772.99)\ kJ/kg \\
&= 234.77\ kJ/kg
\end{aligned}
$$

When the steam at the inlet and outlet is reduced to 101 kPa and 25 $^\circ C$, it will have condensed to a liquid. The incompressible-liquid allows us to use the saturated liquid properties at 25 $^\circ C$ of the steam tables for the dead state. Hence

$$
\begin{aligned}
h_0 &= 104.9\ kJ/kg \\
s_0 &= 0.3672\ kJ/kg \cdot K
\end{aligned}
$$

The flow exergy at the inlet is

$$
\begin{aligned}
\psi_1 &= (h_1 - h_0) - T_0(s_1 - s_0) \\
&= (3007.76 - 104.9)\ kJ/kg - (298\ K)(7.0444 - 0.3673)\ kJ/kg \cdot K \\
&= 913.1\ kJ/kg
\end{aligned}
$$

The flow exergy at the exit can be calculated in a similar manner

$$
\begin{aligned}
\psi_2 &= (h_2 - h_0) - T_0(s_2 - s_0) \\
&= (2722.69 - 104.9)\ kJ/kg - (298\ K)(6.9406 - 0.3673)\ kJ/kg \cdot K \\
&= 658.95\ kJ/kg
\end{aligned}
$$

Using the definition of second law effectiveness

$$
\begin{aligned}
\epsilon &= \frac{-w_{1\rightarrow 2,act}}{\psi_1 - \psi_2} \\
&= \frac{234.77\ kJ/kg}{(913.1 - 658.95)\ kJ/kg} \\
&= 0.924
\end{aligned}
$$