Problem: 3-3

Given: Steam expands adiabatically in a turbine from 2 MPa, 400 °C to 0.4 MPa, 250 °C.

Find: Calculate

i) the isentropic efficiency of the process

ii) the loss of exergy of the system assuming an atmospheric temperature of 15 °C

iii) the effectiveness of the process

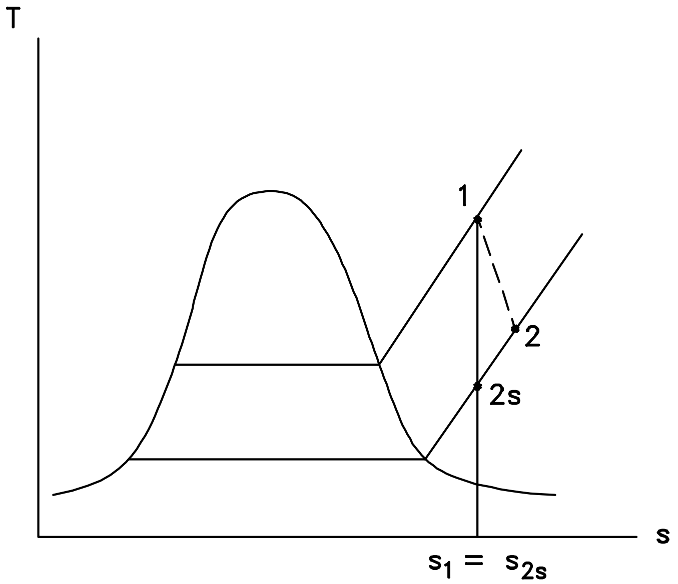
Part i) Initially the steam is superheated at 2 MPa and 400 °C, hence from the steam tables

$$h_1 = 3248 \; kJ/kg$$
$$s_1 = 7.126 \; kJ/kg \cdot K$$

Finally the steam is superheated at 0.4 MPa and 250 °C, hence from the steam tables

$$h_2 = 2965 \; kJ/kg$$
$$s_2 = 7.379 \; kJ/kg \cdot K$$

The process is shown as $1 \rightarrow 2$ below



$$s_1 = s_{2s} = 7.126 \; kJ/kg \cdot K$$

By interpolating

$$
\begin{aligned}
h_{2s} &= 2753 + \left(\frac{7.126 - 6.929}{7.172 - 6.929}\right)(2862 - 2753) \\
&= 2841.4\ kJ/kg
\end{aligned}
$$

The isentropic efficiency is defined as

$$
\begin{aligned}
\text{isentropic efficiency} &= \frac{\text{actual work output}}{\text{isentropic work}} \\
&= \frac{h_1 - h_2}{h_1 - h_{2s}} \\
&= \frac{3248 - 2965}{3248 - 281.4} = \frac{283}{406.6} \\
&= 69.6\%
\end{aligned}
$$

Part ii) The loss of exergy is defined as:

$$
\begin{aligned}
\psi_1 - \psi_2 &= h_1 - h_2 + T_0(s_2 - s_1) \\
&= 283 + 288(7.379 - 7.126) \\
&= 355.9\ kJ/kg
\end{aligned}
$$

Part iii): The effectiveness is defined as:

$$
\begin{aligned}
\epsilon &= \frac{-W}{\psi_1 - \psi_2} \\
&= \frac{h_1 - h_2}{\psi_1 - \psi_2} \\
&= \frac{283}{355.9} \\
&= 79.6\%
\end{aligned}
$$

Note: the effectiveness is greater than the isentropic efficiency; this is because the steam at state 2 has a higher exergy than that at state 2s due to the heating effect of the irreversibilities in the expansion process.