Air expands in an air turbine from a pressure of 450 kPa and a temperature of 550 K to an exhaust pressure of 150 kPa. Assume the process is reversible and adiabatic, with negligible changes in kinetic and potential energy.

a) Sketch the system & boundary and classify the system.
b) Show initial state and final state isobars on both P-v and T-s diagrams. Sketch this process on both diagrams.
   Visualize and forecast sign of work as well as heat transfer.
c) Use the air tables to find initial and final state conditions.
d) Write the conservation of energy for this process.
e) Write the entropy balance for this process.
f) What is the specific work of air flowing through the turbine?
g) What is the specific entropy production for this turbine?
AIR TURBINE PROBLEM

$T_1 = 550 \, \text{K}$

$P_1 = 480 \, \text{kPa}$

$q = 0$

$P_2 = 10 \, \text{kPa}$

$s = ? \, (\text{kJ/kg})$

$W = ? \, (\text{kJ/kg})$

Fluid model: Ideal gas, flow through

$P_1$

$P_2$

$W = U_{1} + Q$

$q = 0$

Properties: Table C.16.b

$T_2 = 550 \, \text{K}$

$h_1 = 555 \, \text{kJ/kg}$

$P_{1\text{r}} = 11.86$

$P_{2\text{r}} = P_{1\text{r}} \left( \frac{P_2}{P_1} \right) = 11.86 \left( \frac{10}{480} \right) = 3.95$

$T_2 = 405 \, \text{K}$

$h_{2} = 405 \, \text{kJ/kg}$
On Special Energy Brs

\[ W = h_i - h_f = 555 - 405 = 150 \text{ kJ/kg} \]

Common Balance

\[ \Sigma F/L + \Sigma F_0 - \Sigma F_e + S_p = 0 \]

So \( S_p = 0 \) which is shown for a reversible process.
"AIR TURBINE PROBLEM"

"Initial State"
\( f\$ = \text{'air'} \)
\[ T[1] = 550 \text{[K]} \]
\[ P[1] = 450 \text{[kPa]} \]
\[ s[1] = \text{Entropy}(f\$, T=T[1], P=P[1]) \]
\[ h[1] = \text{Enthalpy}(f\$, T=T[1]) \]

\[ hs[1] = h[1] \]
\[ ss[1] = s[1] \]

"Final State (Isentropic Process)"
\[ P[2] = 140 \text{[kPa]} \]
\[ Ts[2] = \text{Temperature}(f\$, P=P[2], s=ss[2]) \]
\[ hs[2] = \text{Enthalpy}(f\$, T=Ts[2]) \]

"Isentropic Process Analysis"
\[ q = 0 \text{[kJ/kg]} \]
\[ q - ws + hs[1] - hs[2] = 0 \quad \text{"Energy Conservation"} \]

\[ Tb = 300 \text{[K]} \]
\[ Sp = -q/Tb + (ss[2]-ss[1]) \quad \text{"Entropy Balance"} \]

"Analysis with nt = 80%"
\[ nt = 0.8 \text{[dim]} \]
\[ nt = wa/ws \]
\[ q-wa + h[1] - h[2] = 0 \]
\[ T[2] = \text{Temperature}(f\$, h=\text{h}[2]) \]
\[ s[2] = \text{Entropy}(f\$, T=T[2], P=P[2]) \]
\[ Sp = -q/Tb + (s[2] - s[1]) \]

SOLUTION

Unit Settings: SI K kPa kJ mass deg
\[ f\$ = \text{'air'} \]
\[ Sp = 0.0764 \text{[kJ/kg-K]} \]
\[ wa = 126 \text{[kJ/kg]} \]
\[ q = 0 \text{[kJ/kg]} \]
\[ Tb = 300 \text{[K]} \]

No unit problems were detected.

\begin{tabular}{cccccccc}
\hline
\textbf{P}_i & \textbf{s}_i & \textbf{T}_i & \textbf{h}_i & \textbf{Ts}_i & \textbf{hs}_i & \textbf{ss}_i \\
\hline
1 & 450 & 5.889 & 550 & 555.1 & 550 & 555.1 & 5.889 \\
2 & 140 & 5.986 & 427.4 & 429 & 396.3 & 397.5 & 5.889 \\
\hline
\end{tabular}
REFLECTION:

1) Note slight difference between hand calculations with Air Tables and EES ideal gas model.

2) Create Ts Property Plot, specifying initial pressure, intermediate pressure, and final pressure.

3) Overlay Ts versus ss and T versus s to show ideal expansion and real expansion processes.

4) Click on each axis to modify min and max values, making it easier to distinguish between ideal and real processes.