Example

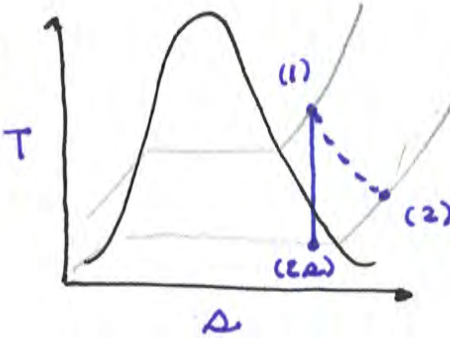
A turbine with an adiabatic efficiency of $\eta_T = 0.9$ operates between 8 MPa and 100 kPa with an inlet temperature of 700°C. The mass flow rate of steam through the turbine is 1.25 kg/s and the environment is at $T_0 = 300$ K and $P_0 = 100$ kPa.

a) Sketch the process on a *T-s* diagram.
b) Calculate:
   1) the power out of the turbine,
   2) the rate of irreversibility in the turbine, and
   3) the lost power from the turbine.
c) Calculate the quantity

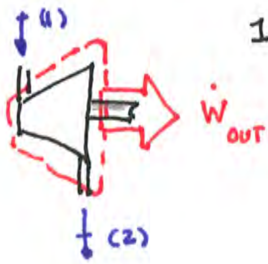
$$\varepsilon = \frac{\dot{W}_{out}}{\dot{W}_{out} + \dot{W}_{lost}}$$

How does this compare to η_T? Explain.

a).



b.)



1) Cons. of Energy

$$\frac{d}{dt}(E_{sys}) = \dot{Q}_{in} - \dot{W}_{out} + \dot{m}(h_1 + \ldots) - \dot{m}(h_2 + \ldots)$$

$\frac{d}{dt}(E_{sys}) \to 0$, $\dot{Q}_{in} \to 0$

$$\dot{W}_{out} = \dot{m}(h_1 - h_2) \quad (1)$$

$$\dot{W}_{out,s} = \dot{m}(h_1 - h_{2s})$$

$$h_1 = h(P = 8\text{ MPa}, T = 700°\text{C}) = 3881 \text{ kJ/kg}$$

$$s_1 = s(P = 8\text{ MPa}, T = 700°\text{C}) = 7.28 \text{ kJ/kg-K}$$

$$h_{2s} = h(P = 100\text{ kPa}, s = 7.28 \text{ kJ/kg·K}) = 2646 \text{ kJ/kg}$$

$$\dot{W}_{out,s} = \left(1.25 \frac{\text{kg}}{\text{s}}\right)(3881 - 2646)\frac{\text{kJ}}{\text{kg}}\left\langle \frac{\text{kW·s}}{\text{kJ}} \right\rangle$$

$\dot{W}_{OUT,s} = 1545 \text{ kW}$

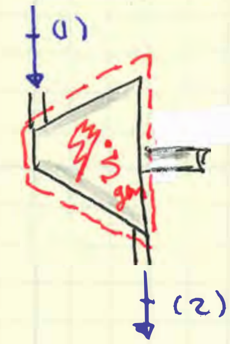
EFFICIENCY: $\eta_T = \dfrac{\dot{W}_{OUT}}{\dot{W}_{OUT,s}}$

$\dot{W}_{OUT} = \eta_T \dot{W}_{OUT,s} = (0.9)(1545 \text{ kW}) = \boxed{1390 \text{ kW}}$

2) RATE of IRREVERSIBILITY

$\dot{I} = T_0 \dot{S}_{gen}$

Acct. of Entropy



$\frac{d}{dt}(S_{SYS}) = \sum \frac{\dot{Q}}{T_j} + \dot{m}(s_1) - \dot{m}(s_2) - \dot{S}_{gen}$

$\dot{S}_{gen} = \dot{m}(s_2 - s_1)$ ✓ ? ✓

TO FIND s_2 NEED h_2 FROM (1)

$\dot{W}_{OUT} = \dot{m}(h_1 - h_2)$

$h_2 = h_1 - \dfrac{\dot{W}_{out}}{\dot{m}} = 3881 - \dfrac{1390 \text{ kW}}{1.25 \text{ kg/s}}$

$= 2769 \text{ kJ/kg}$

$s_2 = s(P = 100 \text{ kPa}, h = 2769 \text{ kJ/kg})$

$= 7.597 \text{ kJ/kg-K}$

$\dot{S}_{gen} = \left(1.25 \frac{\text{kg}}{\text{s}}\right)(7.597 - 7.28) \text{ kJ/kg-K}$

$= 0.3956 \text{ kW/K}$

$$\dot{I} = (300\ K)(0.3956\ \frac{kW}{K}) = \boxed{118.7\ kW}$$

3) LOST POWER

$$\dot{W}_{LOST} = \dot{I} = \boxed{118.7\ kW}$$

c)

$$\varepsilon = \frac{\dot{W}_{OUT}}{\dot{W}_{OUT} + \dot{W}_{LOST}} = \frac{1390\ kW}{1390\ kW + 118.7\ kW}$$

$$= \boxed{0.921} \neq \eta_{T} = 0.90!!$$ WHY?

ENDSTATE FOR $\dot{W}_{OUT,s}$ IS (2s)

" " $\dot{W}_{OUT} + \dot{W}_{LOST}$ IS (2)