Question 1: [10 points]

Take both the turbine and the tank as the CV. Since the air entering the turbine has uniform properties, CV analysis gives

1^{st} law: $m_i h_i - W_{out} = m_2 u_2$

since $m_1=0$ and $Q_{in}=Q_{out}=0$

with constant Cp and Cv → $W_{out} = m_i C_p T_i - m_2 C_v T_2$

$m_2=m_i= PV/R_{air}T= 500 \times 1 /(0.287 \times 250)= 6.969$ kg

$W_{out}= 6.969$ kg x (1 kJ/kg-K x 300K– 0.713 kJ/kg-K x 250 K) = 848.5 kJ

Question 2: [10 points]

a) The energy of an isolated system must remain constant, but the entropy can only decrease.
False, entropy of an isolated system will only stay the same or increase.
b) The change in entropy of a closed system is the same for any process between two specified states.
True, entropy is a property and independent of process.
c) The entropy of a fixed amount of an ideal gas increases in every isothermal compression.
False, entropy decreases with increasing pressure.
d) Consider two different sets of reservoirs 1) T_H=675K, T_L=325K, 2), T_H=625K, T_L=275K. For the Carnot heat engine cycle, setting 1) is better than 2).
False, thermal efficiency 1)=51.9% 2)56%
e) For an ideal gas, its specific internal energy, enthalpy, and entropy depend on temperature only.
False. Even for an ideal gas, its specific entropy depends on a second intensive property.

Question 3: [10 points]

a) The process is steady flow:

$$\dot{W} = \dot{m}(h_2 - h_1) = \dot{m} \cdot c_p (T_2 - T_1), \quad \text{and } \eta_c = \frac{h_{2s} - h_1}{h_2 - h_1} = \frac{T_{2s} - T_1}{T_2 - T_1}$$

for isentropic compression from 100 kPa to 300 kPa,

$$\frac{T_{2s}}{T_1} = \left(\frac{P_2}{P_1}\right)^{(k-1)/k} = \left(\frac{300kPa}{100kPa}\right)^{0.287} = 1.37 \rightarrow T_1=293.15K,\ T_{2s}=401.24K,$$

From $\eta_c = \frac{T_{2s} - T_1}{T_2 - T_1}$, $T_2 - T_1 = \frac{T_{2s} - T_1}{\eta_c}$ → $T_2 = T_1 + \frac{T_{2s} - T_1}{\eta_c} = 293.15 + \frac{401.24 - 293.15}{0.85}$ =420.32K

$$\dot{W} = \dot{m} \cdot c_p (T_2 - T_1) = 1 kg/s \cdot 1 \frac{kJ}{kg \cdot K}(420.32 - 293.15)K = 127.2 \frac{kJ}{s} = 127.2 kW$$

b) Entropy generation between compressor inlet and outlet

$$\Delta s = c_p \ln\frac{T_2}{T_1} - R \ln\frac{P_2}{P_1} = 1 \frac{kJ}{kg \cdot K} \ln\frac{420.32K}{293.15K} - 0.287 \frac{kJ}{kg \cdot K} \ln\frac{300kPa}{100kPa} = 0.045 \frac{kJ}{kg \cdot K}$$

Question 4: [10 points]:

$$Q_H = Q_{sand} = mCdT_H$$
$$\eta_{HE,rev} = 1 - \frac{T_L}{T_H} = \frac{W_{net}}{Q_H}$$

$$\begin{aligned}
W_{net} &= mQ_H\left(1 - \frac{T_L}{T_H}\right) \\
&= mCdT_H\left(1 - \frac{T_L}{T_H}\right) \\
&= mC\left(dT_H - \frac{T_L}{T_H}dT_H\right) \\
&= mC\left(\int_{303}^{1273} dT_H - \int_{303}^{1273} \frac{T_L}{T_H}dT_H\right) \\
&= mC(1203 - 303 - T_L(\ln 1273 - \ln 303)) \\
&= mC(970 - 298(1.435)) \\
W_{net} &= 433.8kJ
\end{aligned}$$

Alternatively, one can consider the net entropy generation is zero

$W_{net} = Q_H - Q_L$

$Q_H = m_{sand} * C * (1000 - 300) = 776kJ$

$Q_L = -T_L \Delta S_{reservior}$

Need to find $\Delta S_{reservior}$, we use reversible concept

$\Delta S_{sand} + \Delta S_{reservior} = 0$

$Q_L = T_L \Delta S_{sand}$,

$\Delta S_{sand} = m_{sand} C \ln \frac{(1000 + 273)}{30 + 273} = 1.1483kJ/K$

$Q_L = T_L \Delta S_{sand} = 298 * 1.1483kJ/K = 342.199kJ$

$W_{net} = Q_H - Q_L = 776 - 342.199 = 433.801kJ$