Calculation of pump (Outline). The specific volume of saturated water at 1 bar is $V = 0.00104\ \mathrm{m^3/kg}$. The work in the pump is

$$W_{\mathrm{pump}} = \frac{V(P_1 - P_4)}{\eta} = 8.18133\ \mathrm{kJ/kg}.$$

The enthalpy of stream 1 is

$$H_1 = H_4 + W_{\mathrm{pump}} = 425.621\ \mathrm{kJ/kg}.$$

The temperature and entropy of stream 1 is obtained by interpolation in the saturated liquid tables at $H_L = H_1 = 425.621$ kJ/kg. We find

$$T_1 = 101.5\ ^\circ\mathrm{C}, \quad S_1 = 1.3245\ \mathrm{kJ/kg\ K}.$$

Summary of results. The results of these calculations are summarized in the table below:

	1	2	3	4
P (bar)	60	60	1	1
T (°C)	101.5	500	126.2	99.61
H (kJ/kg)	425.621	3422.9	2728.72	417.44
S (kJ/kg K)	1.3245	6.8824	7.4942	1.3026
phase	comp. liq.	comp. liq.	superh'd vap.	sat. liq

The energy balances are:

2997.28 kJ/kg

Q_B	$= H_2 - H_1$	$=$	~~-2311.28~~ kJ/kg
W_{turb}	$= H_3 - H_2$	$=$	-694.18 kJ/kg
W_{pump}	$= H_1 - H_4$	$=$	8.18 kJ/kg
W	$= W_{\mathrm{turb}} + W_{\mathrm{pump}}$	$=$	-686.00 kJ/kg
plant efficiency	$= \lvert W\rvert / \lvert Q_B\rvert$	$=$	22.9 %

add row:

To see how the plant efficiency compares to the theoretical maximum, we take T_B to be the temperature of stream 2 (T_B must be at least as high as T_2) and T_C to be T_4 (T_C should be at most as high as T_4):

$$\eta_{\max} = 1 - \frac{(101.5 + 273.15)\ \mathrm{K}}{(500 + 273.15)\ \mathrm{K}} = 52\%.$$

The actual efficiency is less than half of the theoretical. If we take into account that the theoretical value is in fact a *low* estimate (T_B is actually higher than T_2 and T_C is lower than T_4), the actual operation fares even worse in comparison to the maximum possible. To assess the sources of this inefficiency, we perform an entropy analysis for each unit of the process.

Entropy Analysis The entropy generation in the boiler is

$$S_{\mathrm{gen}}\Big|_{\mathrm{boiler}} = S_2 - S_1 - \frac{Q_B}{T_B} = 1.6812\ \mathrm{kJ/kg\ K}.$$

Q_C = H_4 - H_3 = -2311.28 kJ/kg

Similarly for the condenser:

$$S_{\text{gen}}\Big|_{\text{cond}} = S_4 - S_3 - \frac{Q_C}{T_C} = 0.0089 \text{ kJ/kg K}.$$

The turbine operates adiabatically, therefore, the entropy generation is

$$S_{\text{gen}}\Big|_{\text{turb}} = S_3 - S_2 = 183.5 \text{ kJ/kg K},$$

and similarly for the pump:

$$S_{\text{gen}}\Big|_{\text{pump}} = S_1 - S_4 = 0.0219 \text{ kJ/kg K},$$

These results are summarized below, along with the corresponding value for the lost work ($T_0 = 300$ K):

	S_{gen} (kJ/kg K)	$T_0 S_{\text{gen}}$ (kJ/kg)
Boiler	1.6812	504.4
Condenser	0.0089	2.7
Turbine	0.6118	183.5
Pump	0.0219	6.6
Total	2.3237	697.1

The largest contribution to entropy generation comes from the boiler. This is due to the large temperature difference between the temperature of the heat source and the stream that is being heated. The second most important contribution comes from the turbine, whose efficiency is 75%. The pump contributes very little because the work in the pump is pretty small. The condenser generates very little entropy because the temperature of the fluid changes very little between inlet and outlet, and since T_C has been assumed to be equal to the exit temperature, the overall gradient between the heat sink and the stream being cooled is small. In reality, T_C is closer to room temperature, as the condenser probably operates using ambient cooling water. In such case, the losses in the condenser would be larger. The ideal work, calculated using $T_0 = 300$ K, translates the entropy generation into a more tangible quantity, work. This is an estimate of the work that would be produced if the corresponding entropy generation term were driven to zero. The total lost work is about the same as the work produced, which is another way of saying that the plant operates at about half of its maximum efficiency. If we should commit the resources to improve the process, most effort should focus on the boiler and the turbine, since these are the major contributors to lost work. Improving the turbine amounts to replacing it with a unit with better efficiency. With respect to the boiler, one must reconsider the entire design of the plant in order to achieve a more efficient operation.