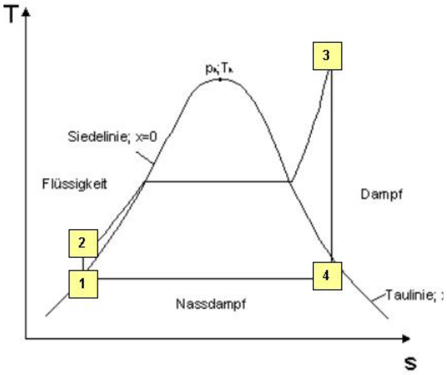
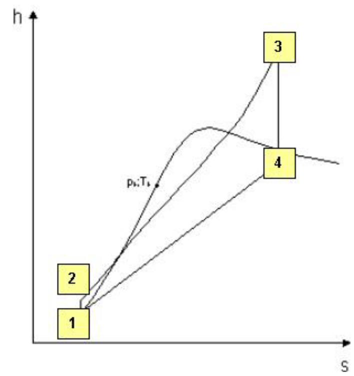
Solution to Exercise Nr. 10: Solar Thermal Power

1)





2) Condenser outlet at saturated steam conditions:

$T_1 = 310K = 36.85°C$, $x_1 = 0 \rightarrow$ Steam tables (interpolation): $p_1 = 0.0624 bar$, $h_1 = 154.4\frac{kJ}{kg}$, $v_1 = 1.0067 \cdot 10^{-3}\frac{m^3}{kg}$

Pump outlet: $p_2 = 150 bar \rightarrow h_{21} = h_2 - h_1 = v_1 \cdot (p_2 - p_1) = 1.0067 \cdot 10^{-3}\frac{m^3}{kg} \cdot (150 - 0.0624) bar = 15.1\frac{kJ}{kg}$,

$\therefore h_2 = h_{21} + h_1 = 169.5\frac{kJ}{kg}$

Solar receiver outlet at superheated steam conditions (no pressure drop through receiver):

$p_3 = p_2 = 150 bar$, $T_3 = 800K = 526.85°C \rightarrow$ Steam tables (interpolation): $h_3 = 3382.1\frac{kJ}{kg}$

Turbine outlet at saturated steam conditions (no pressure drop through condenser):

$p_4 = p_1 = 0.0624 bar$, $x_4 = 0.8$, $T_4 = T_1 = 36.85°C \rightarrow$ Steam tables (interpolation): $h_{fg,4} = 2413.5\frac{kJ}{kg}$

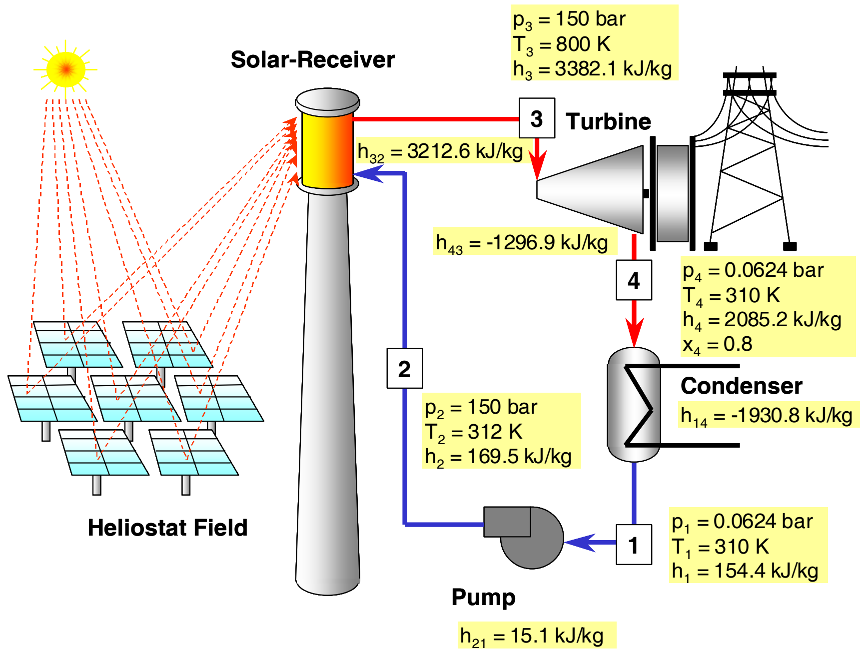
$\therefore h_4 = h_1 + x_4 \cdot h_{fg,4} = (154.4 + 0.8 \cdot 2413.5)\frac{kJ}{kg} = 2085.2\frac{kJ}{kg}$

3) $h_{32} = h_3 - h_2 = 3212.6\frac{kJ}{kg}$

$h_{43} = h_4 - h_3 = -1296.9\frac{kJ}{kg}$

$h_{14} = h_1 - h_4 = -1930.8\frac{kJ}{kg}$

$h_{21} = h_2 - h_1 = 15.1\frac{kJ}{kg}$



4) $\dot{W}_{el} = \dot{W}_{Turbine} - \dot{W}_{Pumpe} = \left(\left|h_{43}\right| - \left|h_{21}\right|\right)\dot{m} \rightarrow \dot{m} = \dfrac{\dot{W}_{el}}{\left|h_{43}\right| - \left|h_{21}\right|} = \dfrac{10MW}{(1296.9 - 15.1)\dfrac{kJ}{kg}} = 7.80\dfrac{kg}{s} = 28.1\dfrac{t}{h}$

5) $\dot{Q}_{net} = \dot{m} \cdot h_{32} = 7.80\dfrac{kg}{s} \cdot 3212.6\dfrac{kJ}{kg} = 25.1\,MW$

6) $\eta_{absorption} = \dfrac{\dot{Q}_{solar} - \dot{Q}_{reradiated}}{\dot{Q}_{solar}} = 1 - \left(\dfrac{\sigma T^4}{I\rho C}\right) = 1 - \left(\dfrac{5.67 \cdot 10^{-8} \cdot 800^4}{1000 \cdot 0.9 \cdot 600}\right) = 95.7\%$

7) $\dot{Q}_{net} = \dot{Q}_{solar} - \dot{Q}_{reradiated} \rightarrow \dot{Q}_{solar} = \dfrac{\dot{Q}_{net}}{\eta_{absorption}} = \dfrac{25.1MW}{0.957} = 26.2MW$

8) $A_{hel,tot} = \dfrac{\dot{Q}_{solar}}{I\rho} = \dfrac{26.1MW}{1kW/m^2 \cdot 0.9} = 29100m^2 \rightarrow n = \dfrac{A_{hel,tot}}{A_{hel}} \approx 291$

9) $\eta = \dfrac{\dot{W}_{el}}{I \cdot A_{Hel,tot}} = \dfrac{10\,MW}{1kW/m^2 \cdot 29100m^2} = 34.4\%$

10) $\eta_{Carnot} = 1 - \dfrac{300K}{5780K} = 94.8\%$

Sources of energy losses:
- imperfections of the solar concentration system (heliostat reflectivity, shadowing, blocking, angular and tracking errors)
- radiation losses in the solar receiver
- Rankine cycle