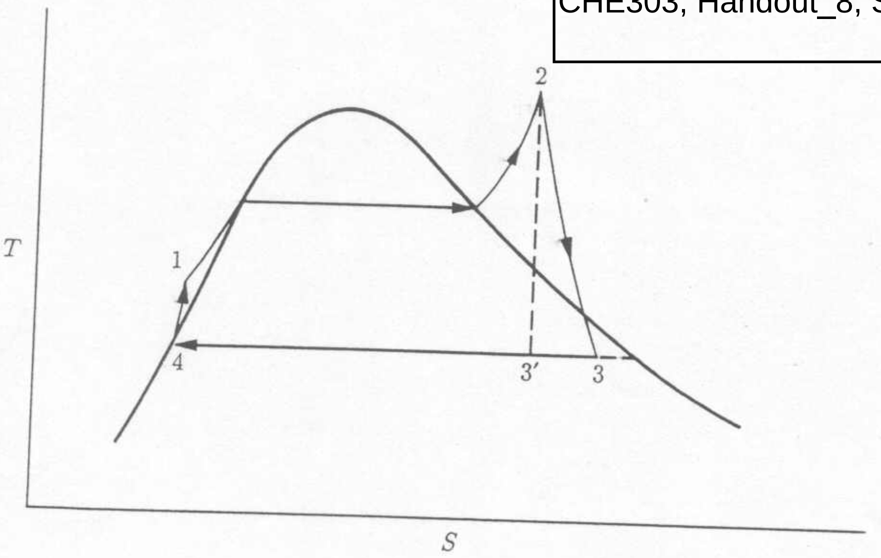
Example 8.1 Steam generated in a power plant at a pressure of 8,600 kPa and a temperature of 500°C is fed to a turbine. Exhaust from the turbine enters a condenser at 10 kPa, where it is condensed to saturated liquid, which is then pumped to the boiler.

(*a*) Determine the thermal efficiency of a Rankine cycle operating at these conditions.

(*b*) Determine the thermal efficiency of a practical cycle operating at these conditions if the turbine efficiency and pump efficiency are both 0.75.

(*c*) If the rating of the power cycle of part (*b*) is 80,000 kW, what is the steam rate and what are the heat-transfer rates in the boiler and condenser?

Chemica Engineering Dept., KFUPM, CHE303, Handout_8, Steam Power Plants



$$\eta = \frac{|W_s(\text{net})|}{|Q(\text{boiler})|}$$

state 2 $P = 8600$ kpa, $T = 500\ ^\circ C$ $\Rightarrow$ $S_2 = 6.6858\ \frac{kJ}{kg\,K}$, $H_2 = 3391.6\ \frac{kJ}{kg}$

(a) step $2 \rightarrow 3'$

state $3'$ $P = 10$ kPa   two phase fluid with $S_3' = 6.6858\ \frac{kJ}{kg\,K}$

$x_3' = 0.8047$

$H_3' = 2117.4\ \frac{kJ}{kg}$ (see example 7.6) exactly similar

$\Rightarrow W_s = H_3' - H_2 = -1274.2 \frac{kJ}{kg}$

step $3' \longrightarrow 4$

state 4 is saturated liquid at 10 kPa

$\Rightarrow H_4 = 191.8 \frac{kJ}{kg}$ (see steam tables)

step $4 \longrightarrow 1$

saturated liquid is pumped isentropically from 10 kPa to subcooled liquid at 8600 kPa

$$W_s = (\Delta H)_s = \int_{P_1}^{P_2} V \, dP$$ (adiabatic - reversible or isentropic)

$$= V (P_2 - P_1)$$

almost constant $= V^{\text{sat liquid}}$

$= 1.01 * 10^{-3} \frac{m^3}{kg}$.

$\Rightarrow W_s = 1.01 * 10^{-3} (8600 - 10) = 8.6759 \frac{kJ}{kg}$.

$\Rightarrow H_1 = H_4 + (\Delta H)_s = 191.8 + 8.7 = 200.5 \frac{kJ}{kg}$

step $1 \longrightarrow 2$

$$Q\,(\text{boiler}) = H_2 - H_1 = 3391.6 - 200.5$$
$$= 3191.1 \ \frac{kJ}{kg}.$$

now
$$W_s\,(\text{net}) = -1274.2 + 8.7$$
$$= -1265.5 \ \frac{kJ}{kg}$$

$$\eta\,(\text{Rankine}) = \frac{|W_s\,(\text{net})|}{Q\,(\text{boiler})} = \frac{1265.5}{3191.1}$$

$$= 0.3966$$

(b) Now turbine and pump are 75% efficient

step $2 \longrightarrow 3$

see (a)

$$W_s = \Delta H = 0.75\,(\Delta H)_s = -955.6 \ \frac{kJ}{kg}$$

$$\Rightarrow H_3 = H_2 + \Delta H = 2436 \ \frac{kJ}{kg}$$

step $3 \longrightarrow 4$

see (a)

$$Q\,(\text{condenser}) = H_4 - H_3 = 191.8 - 2436$$
$$= 2244.2 \ \frac{kJ}{kg}.$$

step $4 \rightarrow 1$

see (a)

$$W_s = \frac{(W_s)_s}{0.75} = 11.6 \ \frac{kJ}{kg}$$

pump

$$H_1 = H_4 + \Delta H_{4\rightarrow 1} = 191.8 + 11.6$$

$$= 203.4 \ \frac{kJ}{kg}.$$

step $1 \rightarrow 2$

$$Q(\text{boiler}) = H_2 - H_1 = 3391.6 - 203.4$$

$$= 3188.2 \ \frac{kJ}{kg}.$$

$$\eta(\text{net}) = \frac{|W_s(\text{net})|}{Q(\text{boiler})} = \frac{|-955.6 + 11.6|}{3188.2}$$

$$= 0.2961$$

(c) $\dot{W}_s(\text{net}) = 80000 \ kW \ \left(\frac{kJ}{s}\right)$

$$\Rightarrow \dot{m} = \frac{\dot{W}_s(\text{net})}{W_s(\text{net})} = \frac{80000}{(-955.6 + 11.6)}$$

$$= 84.75 \ \frac{kg}{s}$$