

Power Plants

Irreversibilities and losses in Rankine Cycle

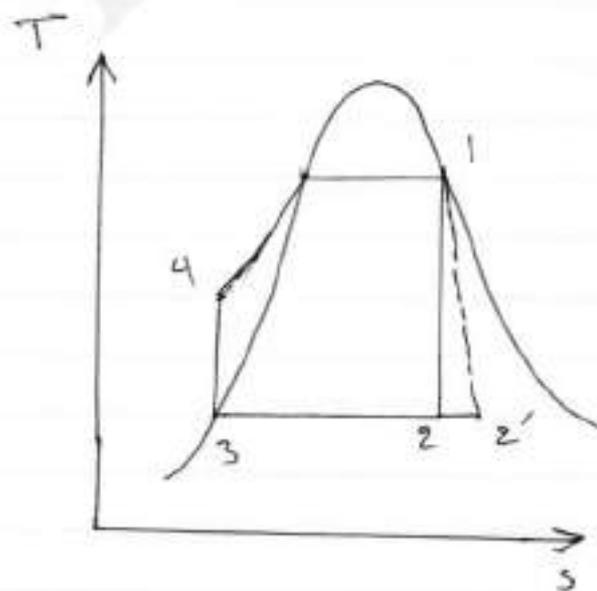
In Rankine cycle, the major irreversibility is encountered during the expansion through turbine. Irreversibilities in turbine significantly reduce the expansion work.

This deviation of expansion from ideal to actual process can be accounted for by isentropic turbine efficiency.

Ideal expansion in steam turbine is shown by 1-2 on T-s representation. Actual expansion process is shown by 1-2'

$$\eta_{isen, t} = \frac{W_{t, actual}}{W_{t, ideal}}$$
$$= \frac{W_{1-2'}}{W_{1-2}}$$

$$W_{1-2'} < W_{1-2}$$



$$\eta_{isen, t} = \frac{h_1 - h_{2'}}{h_1 - h_2}$$

Power Plants

Ex/ A steam power plant operates between a boiler pressure of 42 bar and a condenser pressure of 0.035 bar. Calculate for these limits the cycle efficiency.

- (i) for a Rankine cycle with dry saturated steam at entry to the turbine
- (ii) for Rankine cycle of (i) when the expansion process has an isentropic efficiency of 80%

Solution 8

(i) From steam table

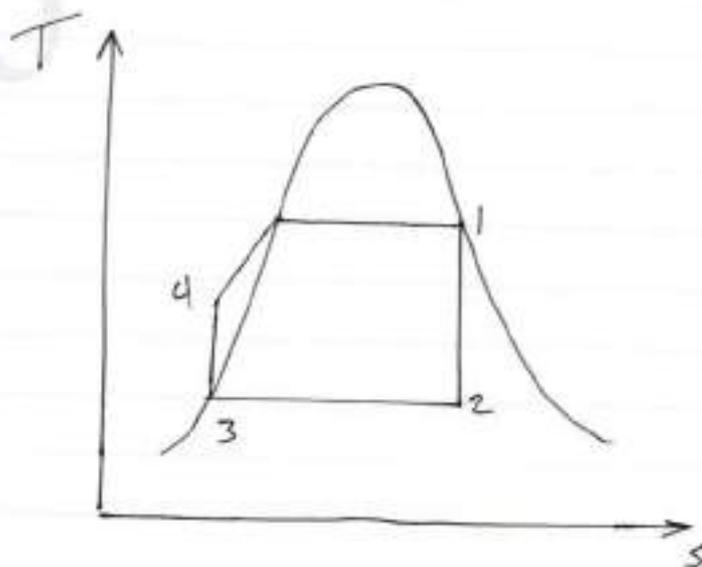
At 42 bar $T_{\text{saturation}} = 253.2^{\circ}\text{C}$

$h_{fg} = 1698 \text{ kJ/kg}$

$h_1 = h_g = 2800 \text{ kJ/kg}$

$S_1 = S_g = 6.049 \text{ kJ/kgK}$

$$S_1 = S_2$$



Power Plants

At 0.035 bar $S_f = S_g = 0.391 \text{ kJ/kgC}$
 $S_g = 8.13 \text{ kJ/kgC}$

$$S_2 = 6.049 = S_f + X_2 S_g$$

$$6.049 = 0.391 + X_2 \times 8.13$$

$$X_2 = 0.698$$

$$h_2 = h_f + X_2 h_{fg}$$

At 0.035 bar $h_f = 112 \text{ kJ/kg} = h_3$
 $h_{fg} = 2438 \text{ kJ/kg}$

$$h_2 = 112 + 0.698 \times 2438 = 1808 \text{ kJ/kg}$$

$$v(P_2 - P_1) = h_4 - h_3$$

$$0.001(4200 - 3.5) = h_4 - 112$$

$$h_4 = 116.2 \text{ kJ/kg}$$

$$W_{net} = W + -W_c$$

$$= (h_1 - h_2) - (h_4 - h_3)$$

$$= (2800 - 1808) - (116.2 - 112)$$

$$= 987.8 \text{ kJ/kg}$$

Power Plants

$$\begin{aligned} Q_{\text{add}} &= h_1 - h_4 \\ &= 2800 - 116.2 \\ &= 2683.8 \text{ kJ/kg} \end{aligned}$$

$$\eta_{\text{Rankine, ideal}} = \frac{W_{\text{net}}}{Q_{\text{add}}} = \frac{987.8}{2683.8} = 36.8\%$$

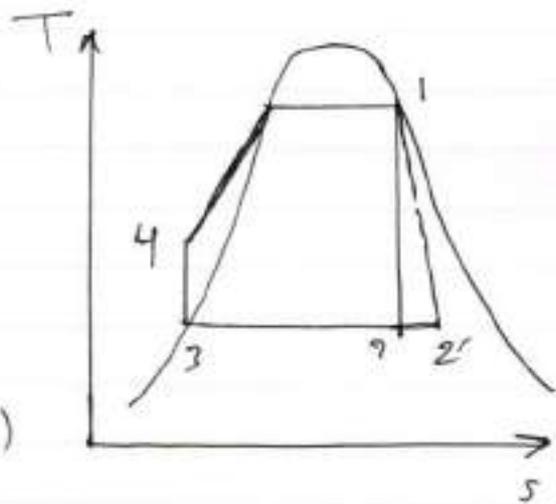
(ii) When turbine isen. efficiency is 80%

$$\eta_{\text{isen, t}} = \frac{h_1 - h_2'}{h_1 - h_2}$$

$$0.8 = \frac{2800 - h_2'}{2800 - 1808}$$

$$h_2' = 2006.4 \text{ kJ/kg}$$

$$\begin{aligned} W_{\text{net}} &= (h_1 - h_2') - (h_4 - h_3) \\ &= (2800 - 2006.4) - (116.2 - 112) \\ &= 789.4 \text{ kJ/kg} \end{aligned}$$

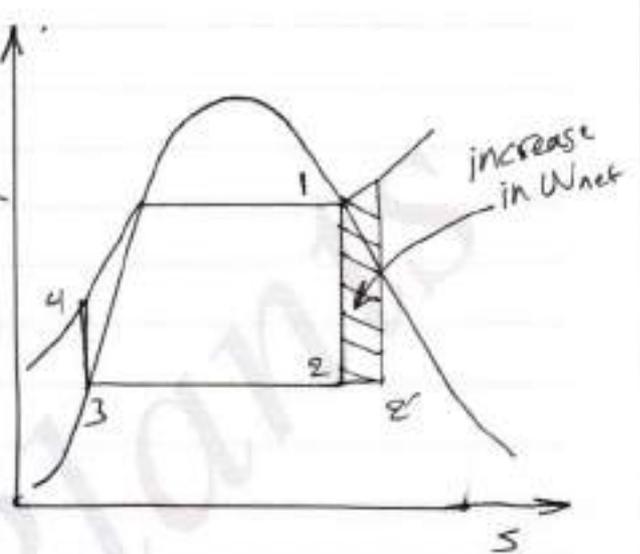


$$\eta_{\text{Rankine, actual}} = \frac{789.4}{2683.8} = 29.4\%$$

Power Plants

2. Superheating the steam to high temperature

Both the W_{net} and heat input increase as a result of superheating. The overall effect is an increase in η

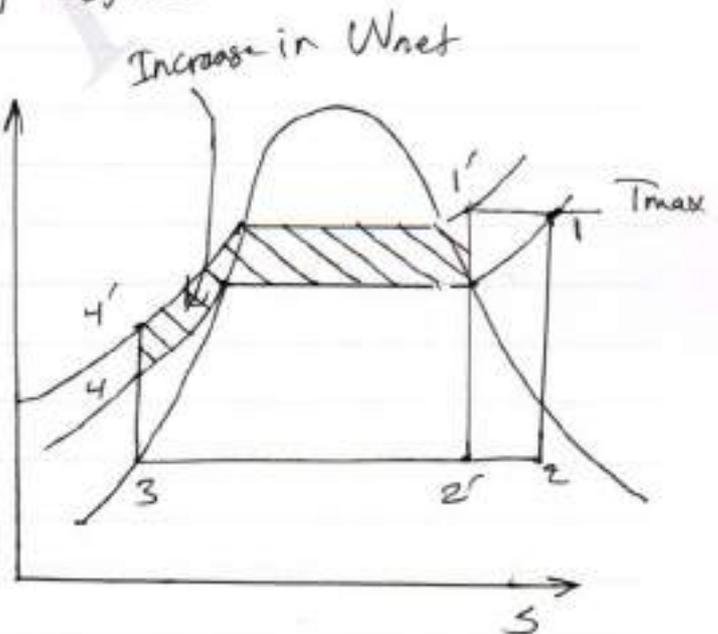


3. Increasing the boiler pressure

It raises the average temp at which heat is added to the steam and thus raises the η .

For a fixed turbine inlet temp., the cycle shifts to the left and moisture content of the steam at the turbine exit increases.

This side effect can be corrected by reheating the system

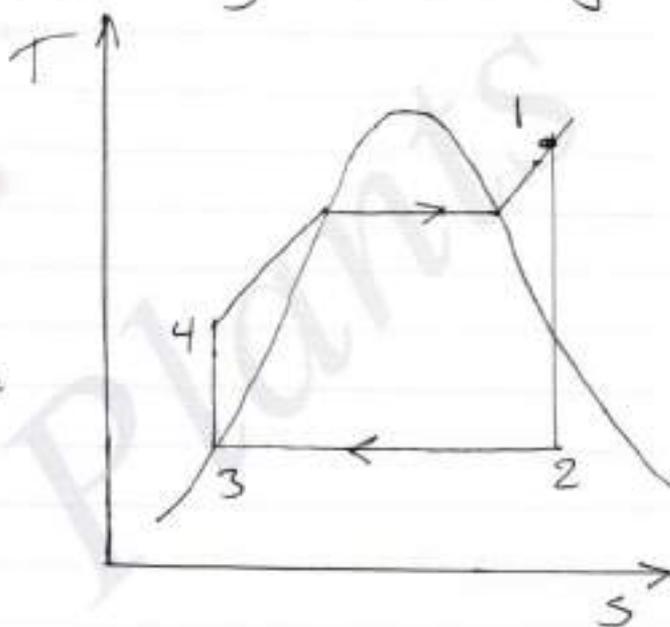


Power Plants

EX / In steam power plant, steam enters turbine at conditions of 42 bar, 500°C and exits at 0.035 bar. Calculate efficiency of the cycle?

Solution: ~

From steam table
At 42 bar, 500°C
 $h_1 = 3448.6 \text{ kJ/kg}$
 $s_1 = 7.066 \text{ kJ/kgK} = s_2$



At 0.03 bar
 $h_f = 112 \text{ kJ/kg}$
 $h_{fg} = 2438 \text{ kJ/kg}$
 $s_f = 0.391 \text{ kJ/kgK}$
 $s_{fg} = 8.13 \text{ kJ/kgK}$

$$s_2 = s_f + x_2 s_{fg}$$
$$7.066 = 0.391 + x_2 \times 8.13$$

$$x_2 = 0.821$$

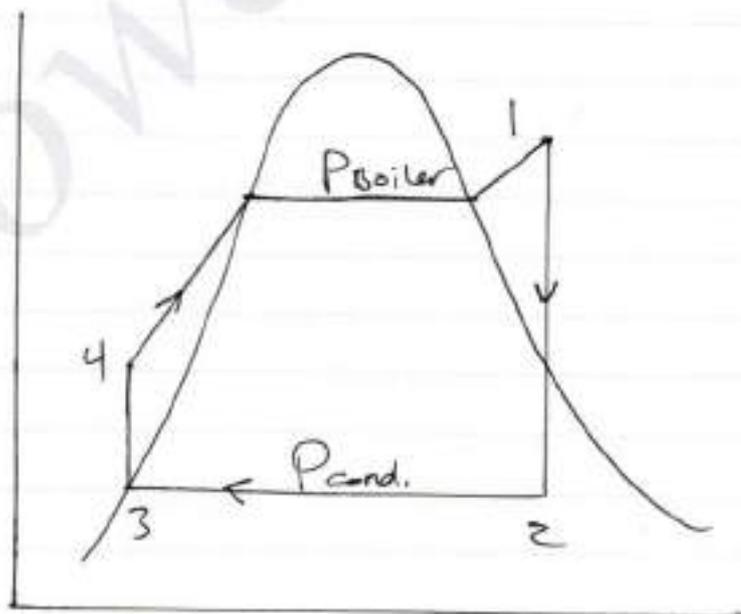
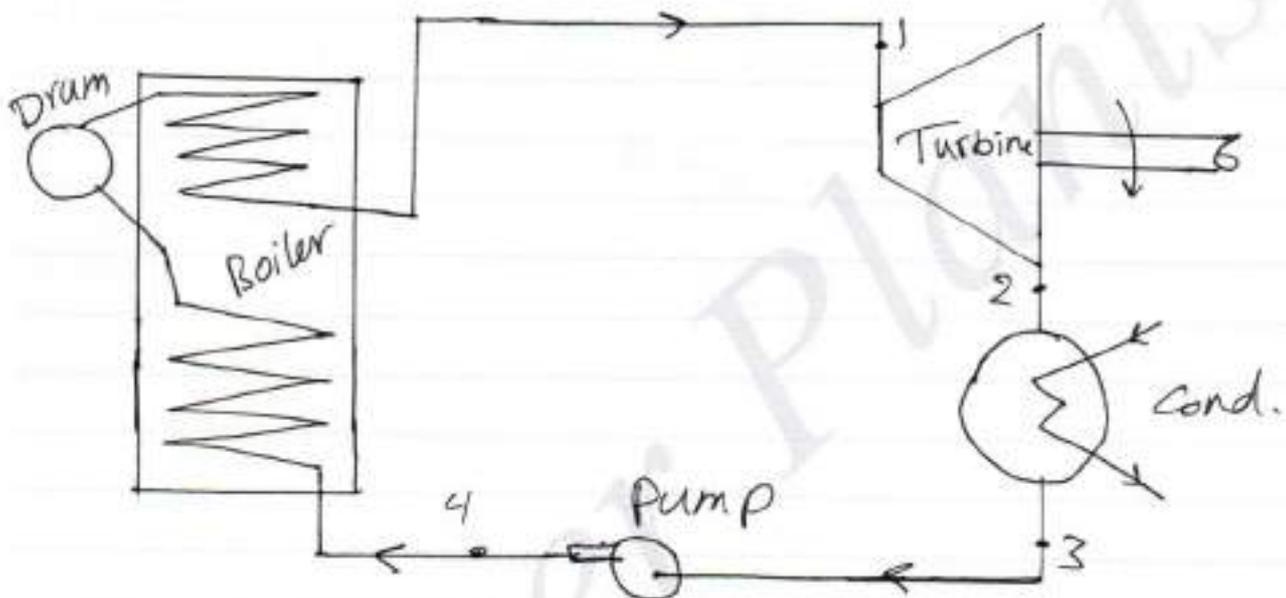
$$h_2 = h_f + x_2 h_{fg}$$
$$= 112 + 0.821 \times 2438$$
$$= 2113 \text{ kJ/kg}$$

$$h_3 = h_f = 112 \text{ kJ/kg}$$

Power Plants

* Rankine Cycle with superheating

The dry saturated steam from the boiler drum is passed through a second bank of smaller bore tubes within the boiler.



Power Plants

$$v(P_2 - P_1) = h_4 - h_3$$
$$0.001 (4200 - 3.5) = h_4 - 112$$

$$h_4 = 116.2$$

$$W_{net} = W_t - W_c$$
$$= (h_1 - h_2) - (h_4 - h_3)$$
$$= (3442.6 - 2113) - (116.2 - 112)$$
$$= 1325.4 \text{ KJ/Kg}$$

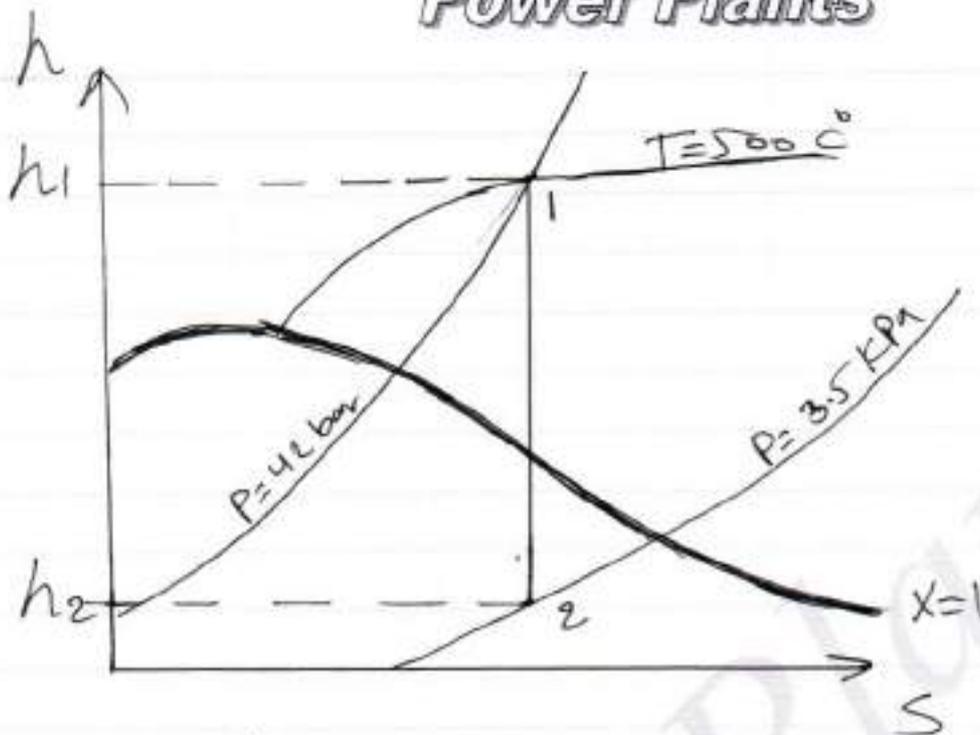
$$Q_{add} = h_1 - h_4$$
$$= 3442.6 - 116.2$$
$$= 3326.4 \text{ KJ/Kg}$$

$$\eta_{Rankine} = \frac{W_{net}}{Q_{add}}$$
$$= \frac{1325.4}{3326.4} = 39.8 \%$$

Or,

If we use Mollier Chart to estimate the values of enthalpy instead of steam table, the results will be as follows.

Power Plants



Directly from the chart

$$h_1 = 3450 \text{ kJ/kg}$$

$$h_2 = 2120 \text{ kJ/kg}$$

$$h_3 = 112 \text{ from steam table}$$

$$h_4 = 116.2$$

$$W_{net} = (3450 - 2120) - (116.2 - 112)$$

$$= 1325.8 \text{ kJ/kg}$$

$$Q_{add} = 3450 - 116.2$$

$$= 3333.8$$

$$\eta = \frac{1325.8}{3333.8} = 39.7\%$$

you can notice that the difference between the two η are very small = 0.1% which is acceptable

Mohamad Alhoegy