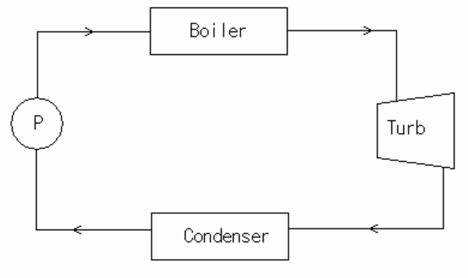
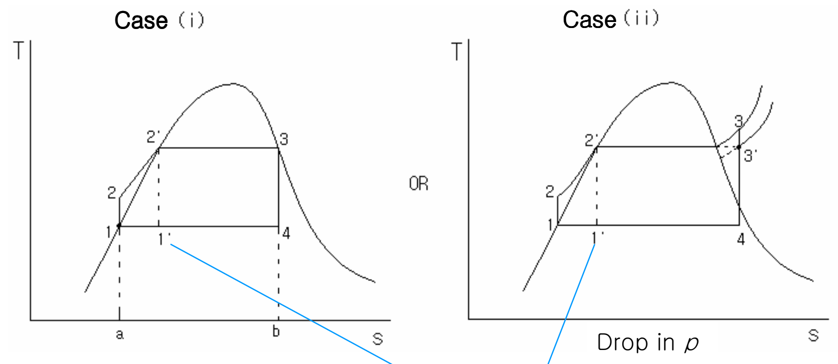
Chapter 8 Vapor Power Cycles

- Rankine Cycle

1–2	: Rev + adiabatic pump
2–3	: Constant –p transfer of heat in the boiler (not isothermal)
3–4	: Rev + adiabatic expansion in the turbine
4–1	: Constant –p transfer of heat in the condenser





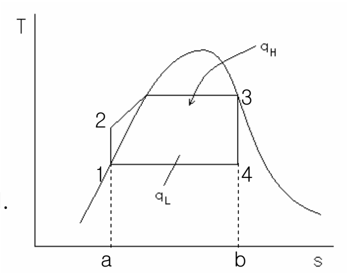
Rankine: $1 \to 2 \to 3 \to 4$

Carnot: $1' \to 2' \to 3 \to 4$
$\sim 1' \to 2' \to 3' \to 4$

- Example

Find the efficiency of a Rankine cycle using steam as the working fluid.

$p_4 = p_1 = 10kPa$, $p_2 = p_3 = 2MPa$ — Case (i)



Let w_p be the work into the pump per kg of fluid.

Let q_L be the heat rejected from the fluid.

Assume SS SF.

The thermal efficiency of Rankine cycle is

$$\eta_{th} = \frac{w_{net}}{q_H} = \frac{area\,1-2-3-4-1}{area\ a-2-3-b-a}$$

Note: $q_h = \int_a^b Tds,\ q_l = \int_a^b Tds$

$w_{net} = q_h - q_l$

i.e. the area below

- Pump (1–2)

Liquid $v_1 = v_2 = v$ sat. liquid

1st Law: $w_p = h_2 - h_1$

2nd Law: $s_2 = s_1$

thus, $h_2 - h_1 = \int_1^2 v\,dp$ (Recall, since isentropic!)

$$w_p = v(p_2 - p_1) = (0.00101)(2000 - 10kPa)$$
$$= 2kJ/kg$$

$$h_2 = h_1 + w_p = 191.8 + 2 = 193.8kJ/kg$$

- Boiler (2–3)

Exits sat. vapor, 1st Law: $q_H = h_3 - h_2$

$$q_H = 2799.5 - 193.8 = 2605.7kJ/kg$$

- Turbine (3–4)

Sat. vap. – Sat. steam

1st Law: $w_t = h_3 - h_4$

2nd Law: $s_3 = s_4$

Determine quality at 4,

$$s_3 = s_4 = 6.3409 = 0.6493 + x_4 7.5009$$
$$or \quad x_4 = 0.7588$$
$$h_4 = 191.8 + 0.7588(2392.8) = 2007.5$$
$$w_t = h_3 - h_4 = 792.0 kJ/kg$$

- Condenser (4–1)

1st Law: $q_L = h_4 - h_1 = 2007.5 - 191.8 = 1815.7 kJ/kg$

The thermal efficiency,

$$\eta_{th} = \frac{w_{net}}{q_H} = \frac{q_H - q_L}{q_H} = \frac{w_t - w_p}{q_H}$$
$$= \frac{792.0 - 2.0}{2605.7} = 30.3\%$$

or

$$\eta_{th} = \frac{(h_3 - h_2) - (h_4 - h_1)}{h_3 - h_2}$$
$$= \frac{(h_3 - h_2) - (h_2 - h_1)}{h_3 - h_2}$$

- Example

Consider a Rankine cycle. Let steam leave the boiler at $p_s = 4MPa, T_3 = 400°C$ (superheated) and $p_4 = p_1 = 10kPa$

To determine η_{net} we need w_p, w_t, q_H

- Pump 1–2

Sat. liq.

1st Law: $w_p = h_2 - h_1$

2nd Law: $s_2 = s_1$

Since isentropic,

$$h_2 - h_1 = \int_1^2 v\,dp$$
$$= v(p_2 - p_1)$$
$$= 0.00101(4000 - 10) = 4kJ/kg$$
$$h_1 = 191.8 \; sat.liq.$$

Solved for –> $h_2 = 191.8 + 4 = 195.8$

- Turbine

p_3, T_3 known

p_4 known

1st Law: $w_t = h_3 - h_4$

2nd Law: $s_4 = s_3$

$$h_3 = 3213.6, \; s_3 = 6.7690 = s_4$$
$$s_4 = 0.6493 + x_4 7.5009$$
$$or$$
$$x_4 = 0.8159$$
$$h_4 = 191.8 + 0.8159(2392.8) = 2144.1$$
$$w_t = h_3 - h_4 = 3213.6 - 2144.1 = 1069.5kJ/kg$$

- $w_{net} = w_t - w_p = 1069.5 - 4 = 1065.5kJ/kg$

- **Boiler**

1st Law: $q_H = h_3 - h_2$

$$= 3213.6 - 195.8 = 3017.8kJ/kg$$

$$\therefore \eta_{th} = \frac{w_{net}}{q_H} = 35.3\%$$