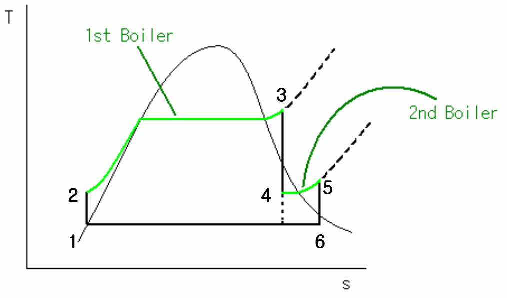
Chapter 8 Vapor Power Cycles continued...

- Reheat cycle

  Increased efficiency with higher-p, and yet avoid excessive moisture in the low-p stages of the turbine.

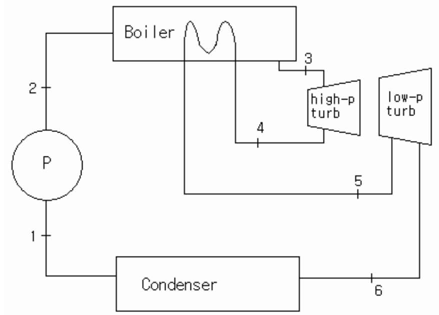


Main advantage:
↓ the moisture content in low-p exit stages of the turbine. → Rust.

- Example

  Reheat cycle utilizing steam. Find cycle efficiency!

$p_3 = 4MPa,\ T_3 = 400°C$	Superheat
$p_4 = 400kPa$	Turbine expansion
$T_5 = 400°C$	Reheated steam
$p_6 = 10kPa$	Exits low-p turbine



- High-p turbine

  1st: $w_{h-t} = h_3 - h_4$

  2nd: $s_3 = s_4$

  Find quality x_4

$$s_4 = s_3 = 6.7690 = 1.7766 + x_4 5.1193$$

$$x_4 = 0.9752$$

$$h_4 = 604.7 + 0.9752(2133.8) = 2685.6$$

- Low-p turbine

  1st and 2nd Laws:

$$w_{l-t} = h_5 - h_6$$

$$s_5 = s_6$$

h_5 is known from T_5, P_5!

For quality x_6

$$s_6 = s_5 = 7.8985 = 0.6493 + x_6 7.5009$$

$$and\ \ x_6 = 0.9664$$

$$\therefore h_6 = 191.8 + 0.9664(2392.8) = 2504.3$$

For both turbines

$$w_t = w_{h-t} + w_{l-t}$$

$$= 1297.1 kJ/kg$$

- Pump

p_1 Known saturated liquid, assume incompressible ($v_1 = v_2 = v$)

1st: $w_p = h_2 - h_1$

$$s_2 = s_1$$

$$\therefore h_2 - h_1 = \int_1^2 v\,dp = v(p_2 - p_1)$$

$$w_p = v(p_2 - p_1)$$

$$= (0.00101)(4000 - 10) = 4kJ/kg$$

$$h_2 = 191.8 + 4 = 195.8$$

- Boiler

All states known from above,

q_H of reheat cycle→ 1st Law: $q_H = (h_3 - h_2) + (h_5 - h_4)$

$$= 3605.6kJ/kg$$

$$\therefore w_{net} = w_t - w_p = 1297.1 - 4 = 1293.1kJ/kg$$

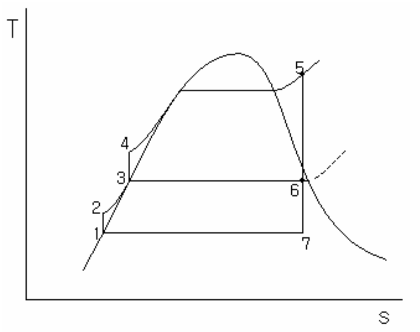
$$\eta_{th} = \frac{w_{net}}{q_H} = 35.9\%$$

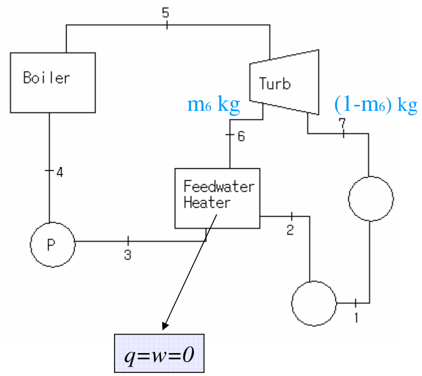
Note η_{th} is not that better than Rankine cycle, but the moisture content of the turbine exit is reduced from 18.4% to 3.4%.

- Regeneration Cycle

uses feed-water heaters

Efficiency is identical to that of Carnot cycle!





- Example of Regeneration cycle

Given steam enters turbine at $p_5 = 4MPa, T_5 = 400°C$ → superheat

$$h_5 = 3213.6$$

$$s_5 = 6.7690$$

After expansion to 400kPa, some of the steam is extracted from the turbine for the purpose of heating the feedwater in an open feedwater heater. The pressure in the feedwater heater is 400kPa and the water leaving it is saturated liquid at 400kPa. The steam not extracted expands to 10kPa. Determine the cycle efficiency.

$$x_3 = 0,\ p_3 = 400kPa = p_6 = p_2$$

$$p_7 = 10kPa = p_1 \to h_1 = 191.8$$

- Low-p Pump (1-2)

  Inlet – saturated liquid. p_1

  Exit – p_2

  1st Law: $w_{p1} = h_2 - h_1$

  2nd Law: $s_2 = s_1$

$$h_2 - h_1 = \int_1^2 v\,dp = v(p_2 - p_1)$$
$$and \;\; w_{p1} = (0.00101)(400 - 10) = 0.4kJ/kg$$
$$then \;\; h_2 = w_{p1} + h_1$$
$$= 0.4 + 191.8 = 192.2$$

- Turbine (5-6,7)

  Find x_6 , using $s_5 = s_6$

$$6.7690 = 1.7766 + x_6 5.1193$$
$$and \;\; x_6 = 0.9752$$
$$h_6 = 604.7 + 0.9752(2133.8) = 2685.6$$

  Find x_7, using $s_5 = s_7$

$$6.7690 = 0.6493 + x_7 7.5009$$
$$and \;\; x_7 = 0.8159$$
$$h_7 = 191.8 + 0.8159(2392.8) = 2144$$

  Then 1st law: $w_t = h_5 - m_6 h_6 - (1 - m_6)h_7$
  $= (h_5 - h_6) + (1 - m_6)(h_6 - h_7)$

  Fraction of 1 kg

  And 2nd law: $s_5 = s_6 = s_7$

- Feedwater Heater 6,2-3

  Saturated Liquid $q = w = 0$

  1st Law: $m_6 h_6 + (1 - m_6)h_2 = h_3 \times (1kg)$

  or $m_6(2685.6) + (1 - m_6)(192.2) = 604.7$

  $m_6 = 0.1654$

  Then the turbine work is

$$w_t = (h_5 - h_6) + (1 - m_6)(h_6 - h_7)$$
$$= (3213.6 - 2685.6) + (1 - 0.1654)(2685.6 - 2144.1)$$
$$= 979.9kJ/kg$$

- High-p Pump

  1st and 2nd Laws:

$$w_{p_2} = h_4 - h_3 \qquad s_4 = s_3$$
$$w_{p_2} = v(p_4 - p_3) = (0.001084)(4000 - 400)$$
$$= 3.9kJ/kg$$
$$h_4 = h_3 + w_{p_2} = 604.7 + 3.9 = 608.6$$
$$\therefore w_{net} = w_t - w_{p_2} - (1 - m_6)w_{p_1}$$
$$= 979.9 - (1 - 0.1654)10.4) - 3.9$$
$$= 975.7kJ/kg$$

- Boiler

$$q_H = h_5 - h_4$$
$$= 3213.6 - 608.6 = 2605.0$$

$$\therefore \eta_{th} = \frac{w_{net}}{q_H} = \frac{975.7}{2605.0} = 37.5\%$$

That is, the q of feedwater heater is zero, thus
q_high is due to boiler only -> smaller denominator
-> greater efficiency