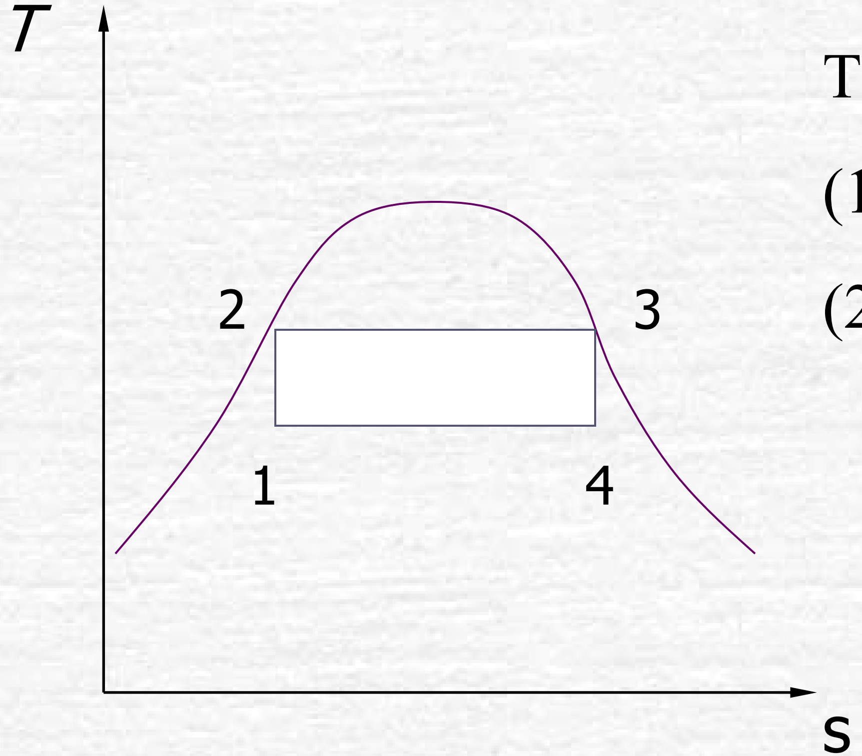
Steam Power Cycle

The Rankine Cycle

Vapor Carnot cycle

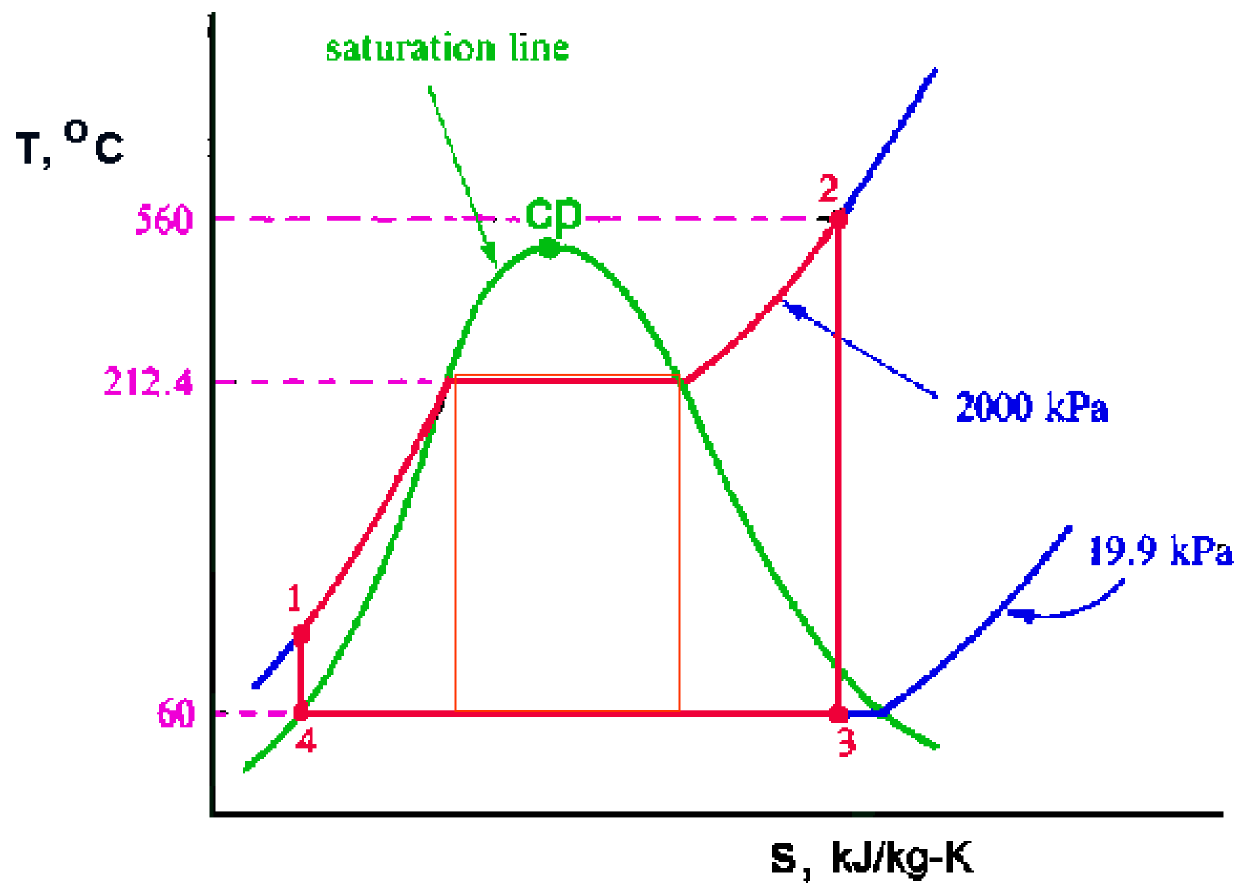


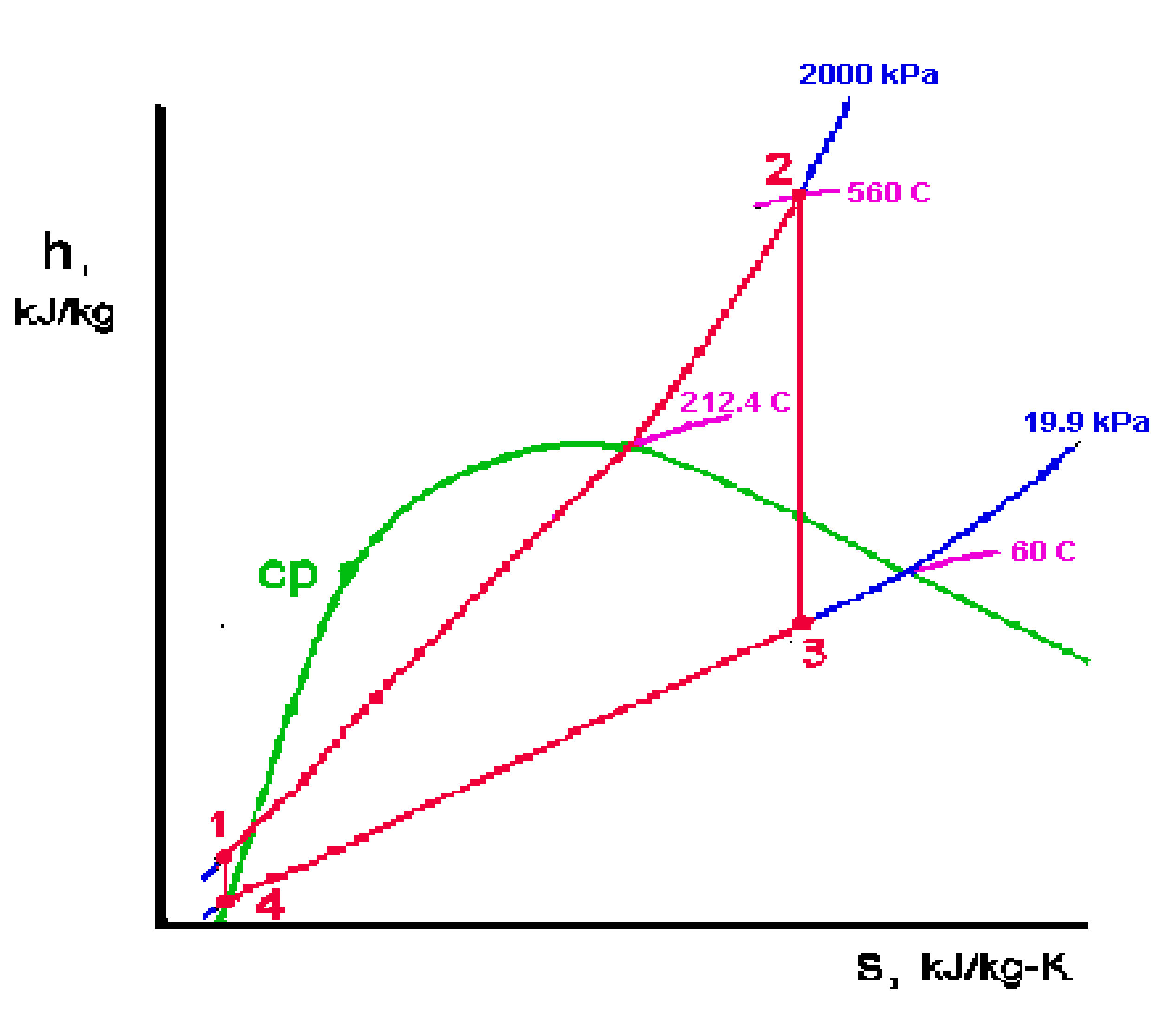
There are some problems:

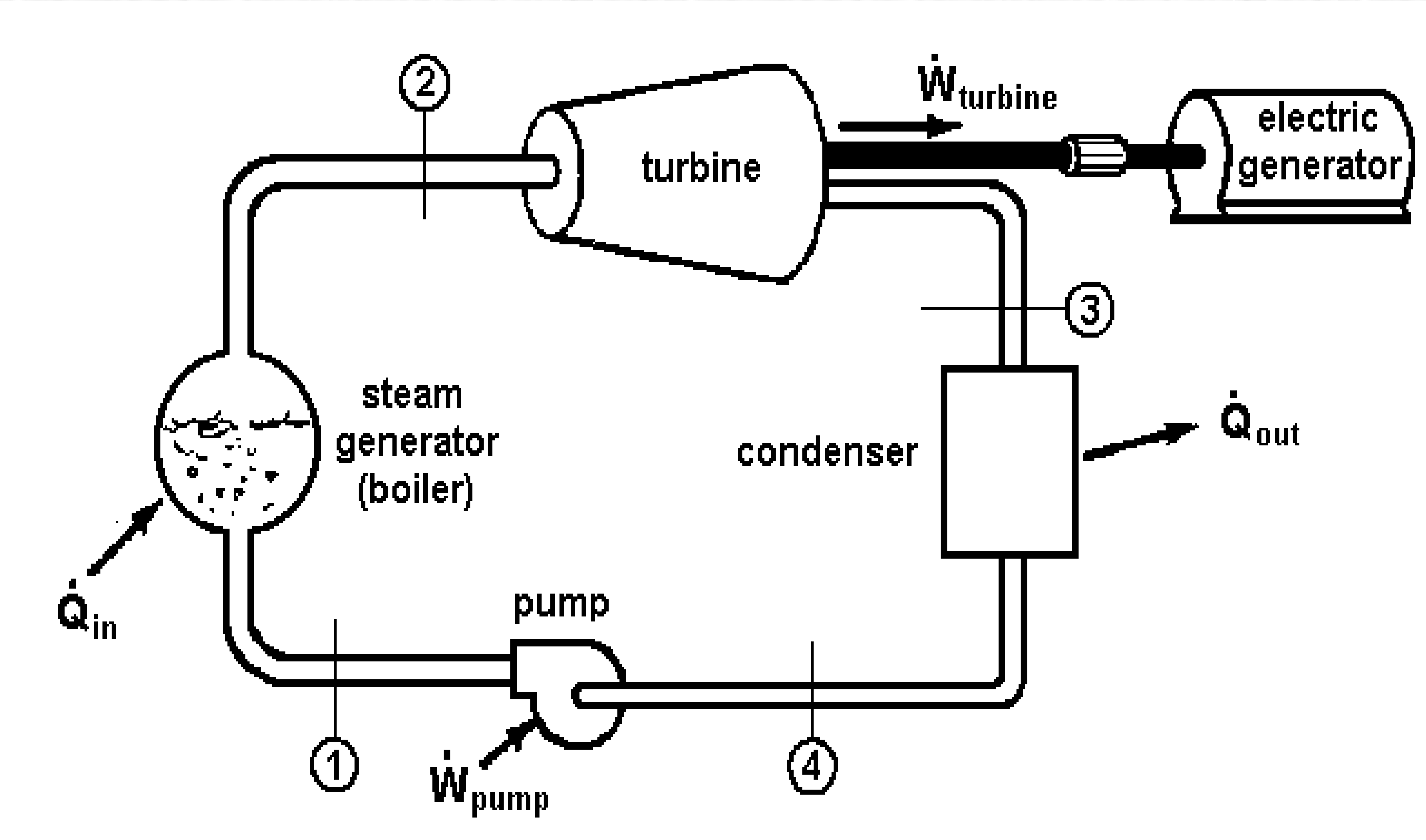
(1) Compressor

(2) turbine

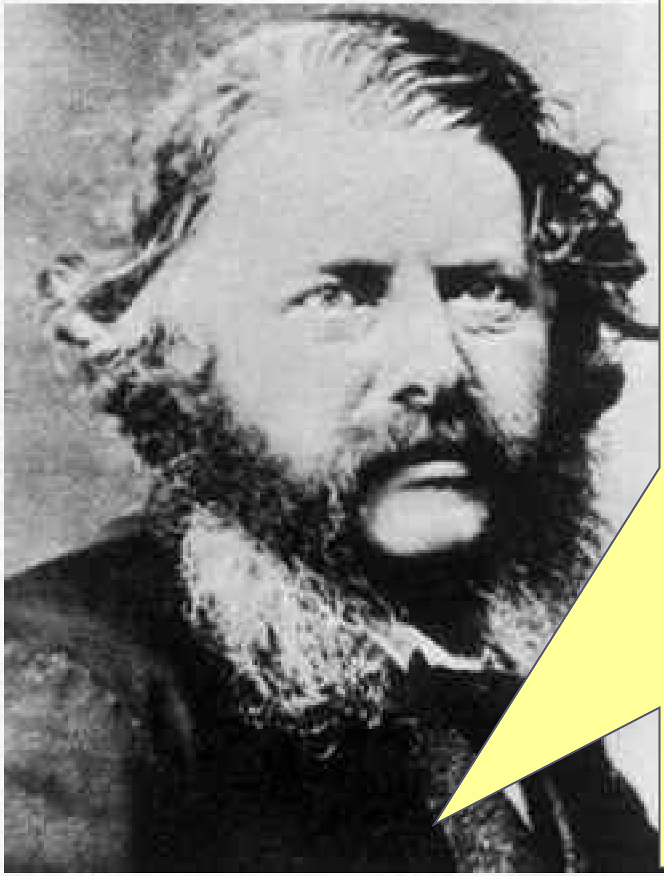
Rankine cycle




2000 kPa
2
560 C
h ,
kJ/kg
212.4 C
19.9 kPa
cp
60 C
3
1
4
s , kJ/kg-K

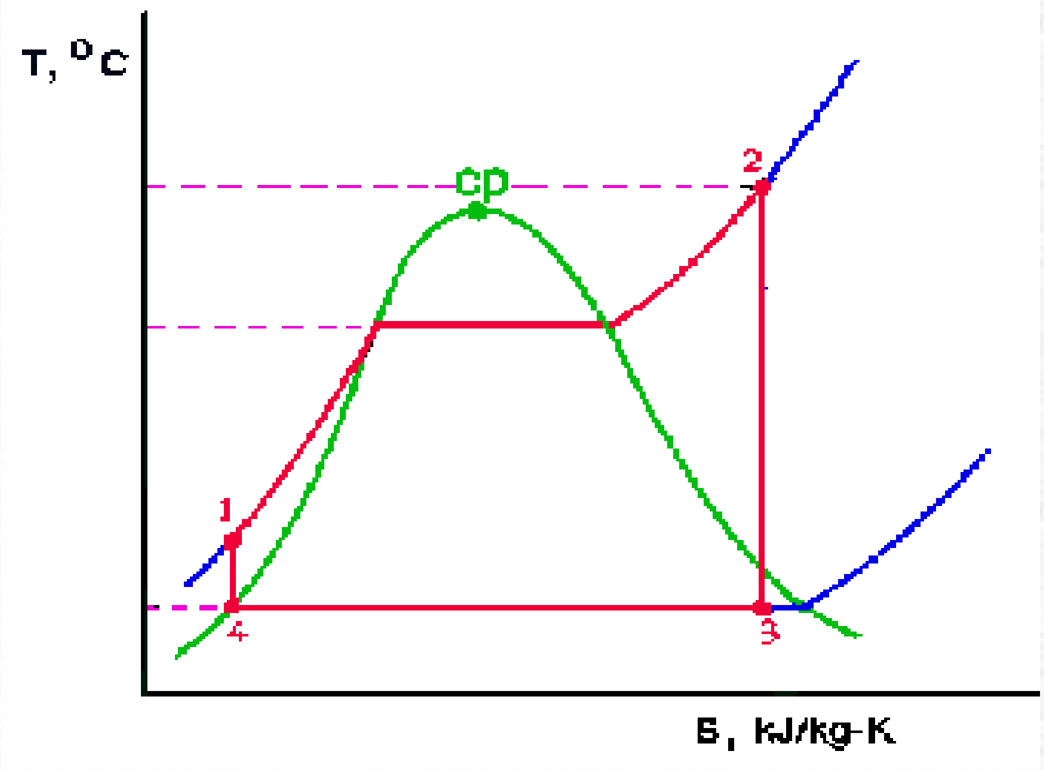


2
Ẇturbine
turbine
electric
generator
3
steam
generator
(boiler)
condenser
Q̇out
Q̇in
pump
1
Ẇpump
4



Trained as a civil engineer, **William Rankine** (1820-1872)was appointed to the chairman of civil engineering and mechanics at Glasgow in 1855. He worked on heat, and attempted to derive Sadi Carnot's law from his own hypothesis. He was elected a Fellow of the Royal Society in 1853. Among his most important works are *Manual of Applied Mechanics* (1858), *Manual of the Steam Engine and Other Prime Movers* (1859) .

The efficiency of Rankine cycle



$$q_{absorb} = h_2 - h_1$$

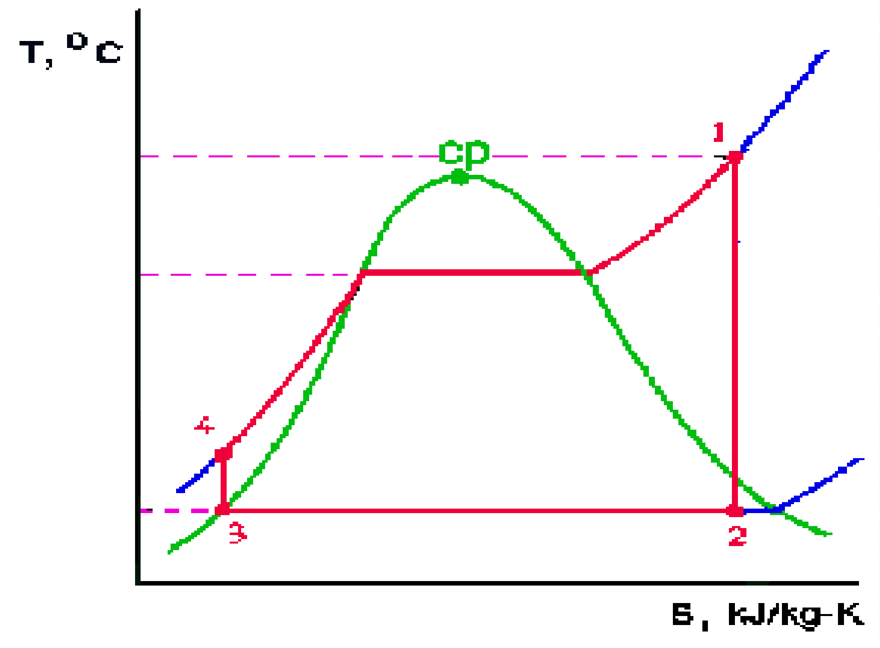
$$q_{exhaust} = h_3 - h_4$$

$$\eta = \frac{q_{absorb} - q_{exhaust}}{q_{absorb}}$$

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

$$= \frac{h_2 - h_1 - h_3 + h_4)}{h_2 - h_1}$$

Usually, The properties: p_1, t_1 and p_2 are available for a power plant,then:



h_1: From p_1, t_1 , get h_1 , s_1

h_2: From p_2 , get s_2' , s_3''

h_2' , h_2''

$$s_2 = s_1 = x s_2'' + (1-x) s_2'$$

So, x can be known

$$h_2 = x h_2'' + (1-x) h_2'$$

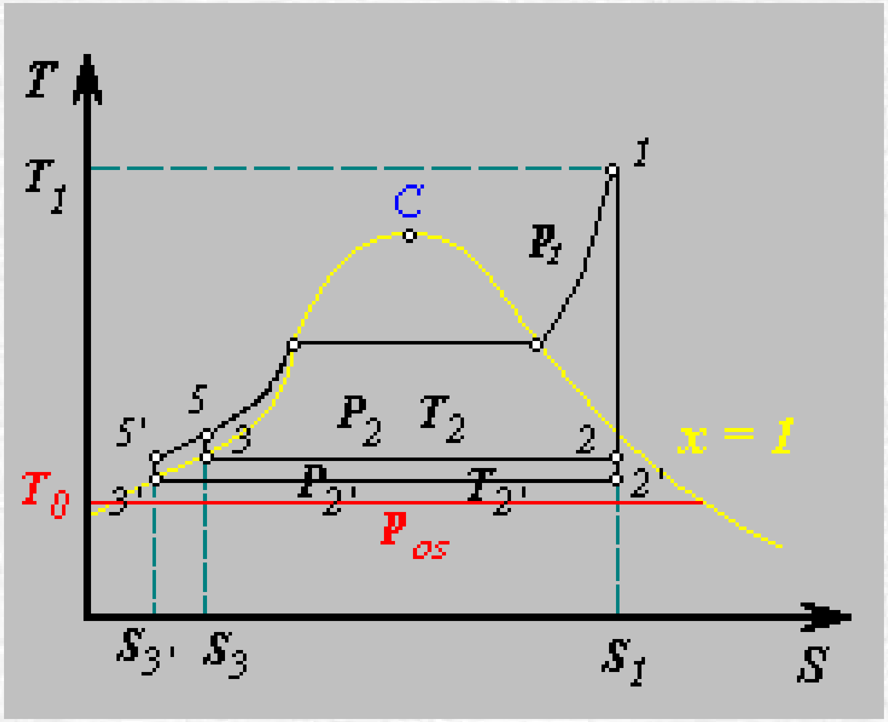
h_3: From p_2 , get h_2' , s_2' .

$h_3 = h_3'$ $s_3 = s_3'$

h_4: From p_1 , $s_1 = s_4$ get h_4

The Influence of Steam Property

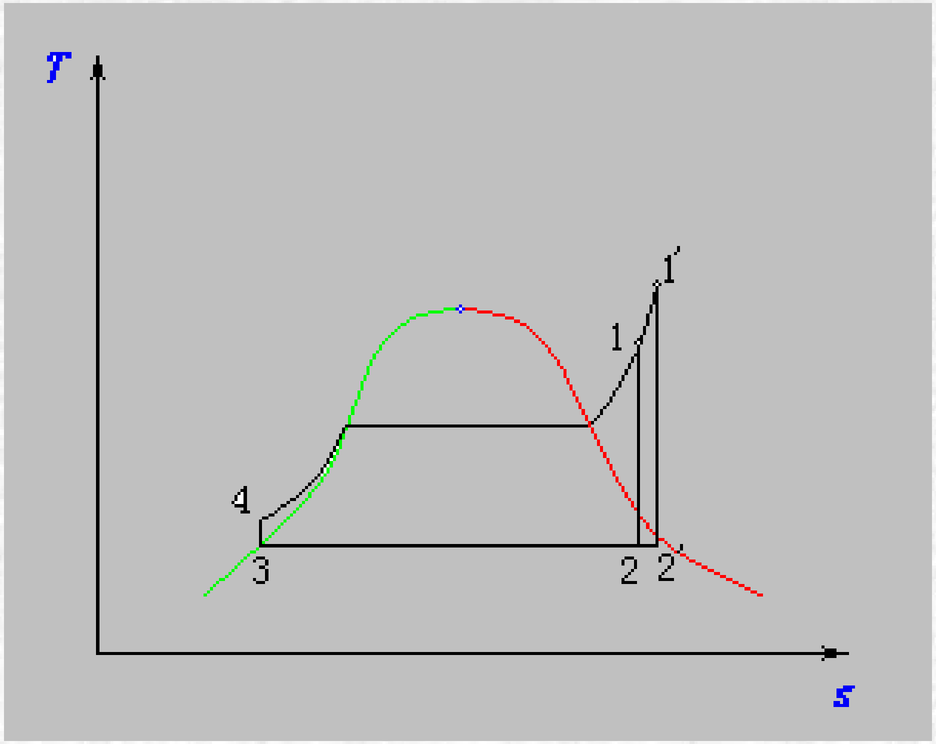
9-2-1. Exhaust Pressure



To decrease the exhaust pressure can increase the efficiency of Rankine cycle.

But the dryness fraction will increase too. This can lead some damage to steam turbine

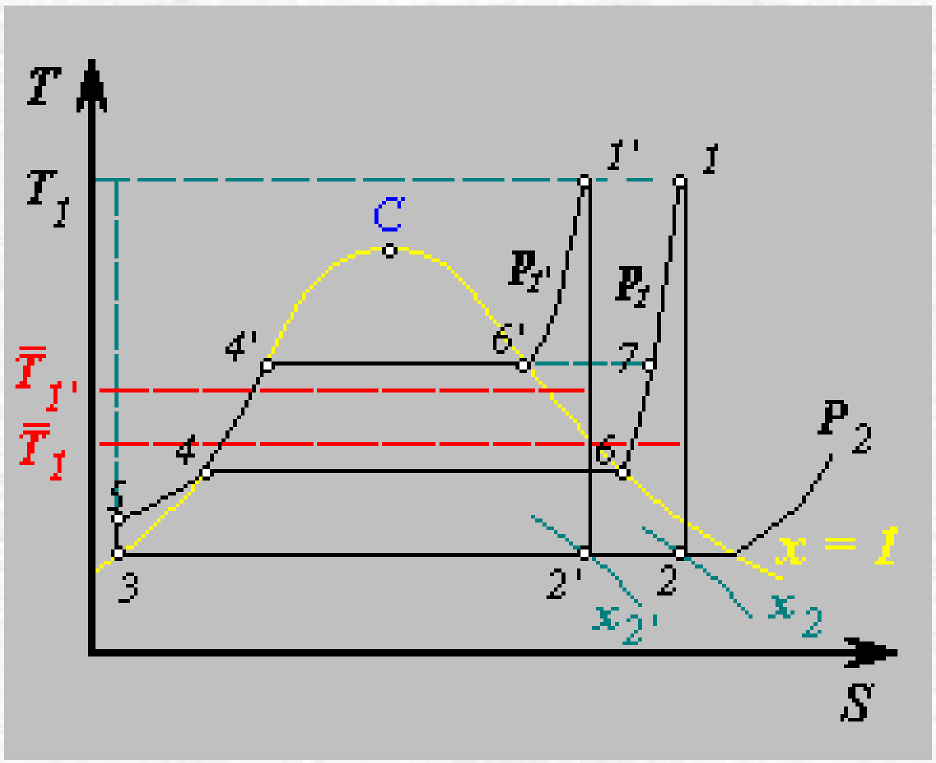
Inlet temperature



To decrease the inlet temperature can increase the efficiency of Rankine cycle.

But this increase depends on boiler material

Inlet pressure

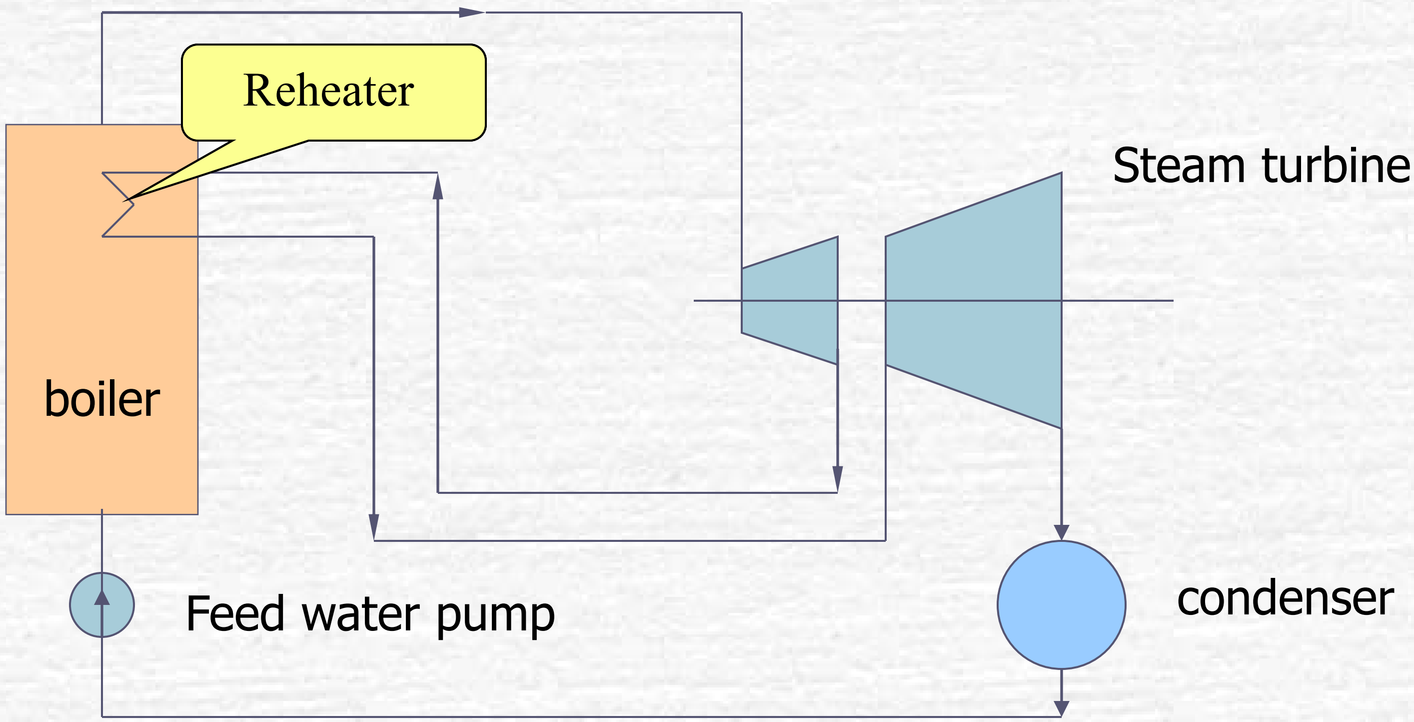


To increase the inlet pressure can increase the efficiency of Rankine cycle greatly.

But this increase also depends on boiler material

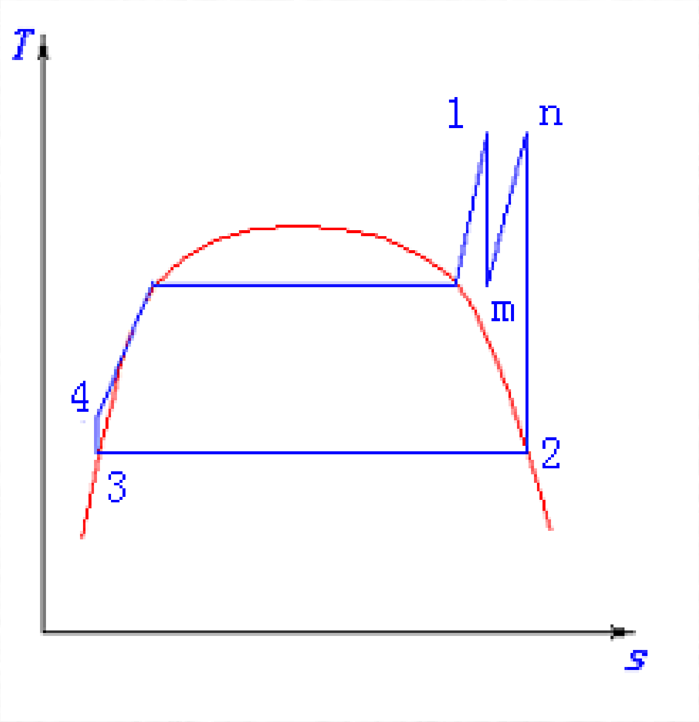
Reheat Cycle

Equipments of Reheat Cycle



Efficiency

T-s diagram



Efficiency

$$q_{in} = (h_1 - h_4) + (h_n - h_m)$$

$$q_{exhaust} = h_2 - h_3$$

$$w = q_{in} - q_{exhaust}$$

$$\eta = \frac{w}{q_{in}}$$

$$= \frac{(h_1 - h_4) + (h_n - h_m) - (h_2 - h_3)}{(h_m - h_1) + (h_1 - h_n)}$$

The properties: p_1, t_1 , p_m , t_n (equals t_1 usually), p_2 are available for a reheat power plant,then:

h_1: From p_1, t_1 , get h_1 , s_1

h_m: From p_2 , $s_2 = s_1$, get h_m

h_n: From p_m , t_n , get h_n

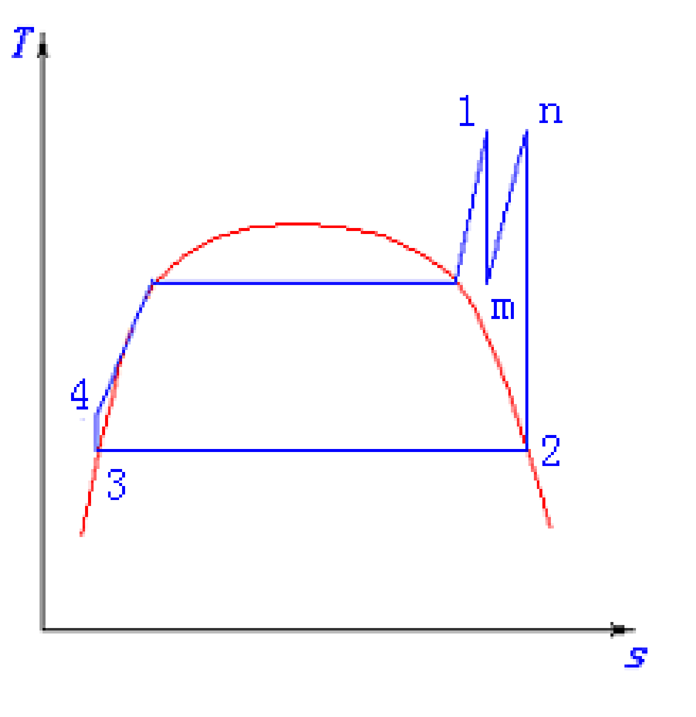
h_2: From p_2 , get s_2' , s_3''

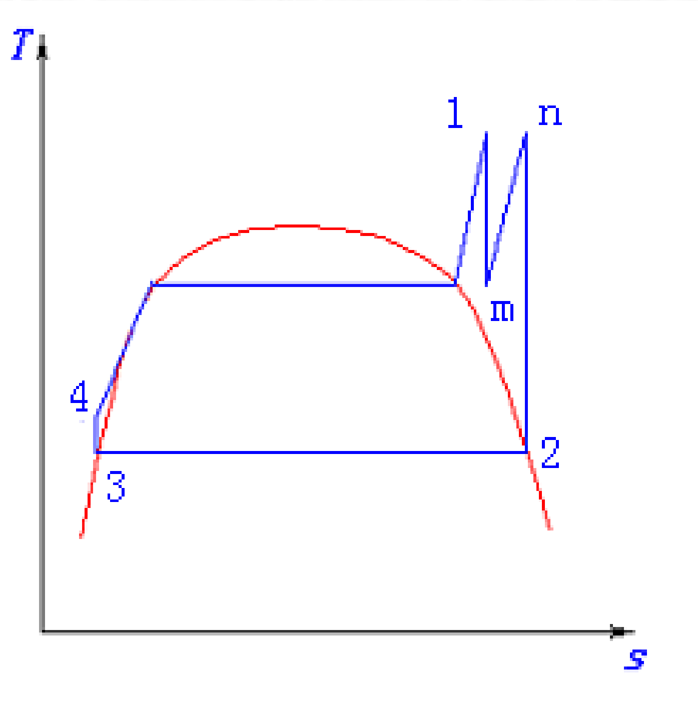
h_2' , h_2''

$$s_2 = s_n = x s_2'' + (1-x) s_2'$$

So, x can be known

$$h_2 = x h_2'' + (1-x) h_2'$$





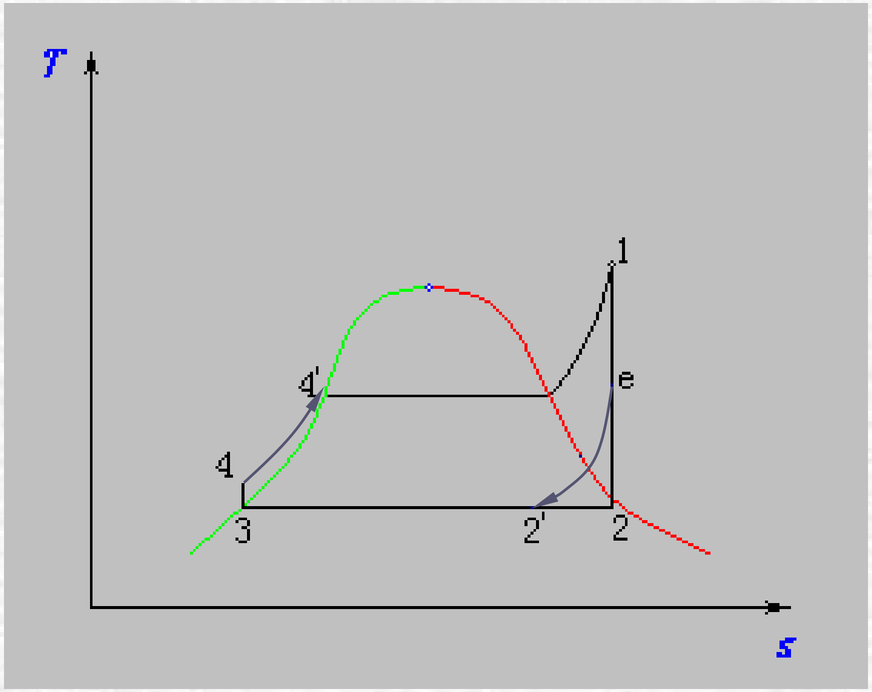
h_3: From p_2, get h_2', s_2'.

$h_3 = h_3'$ $s_3 = s_3'$

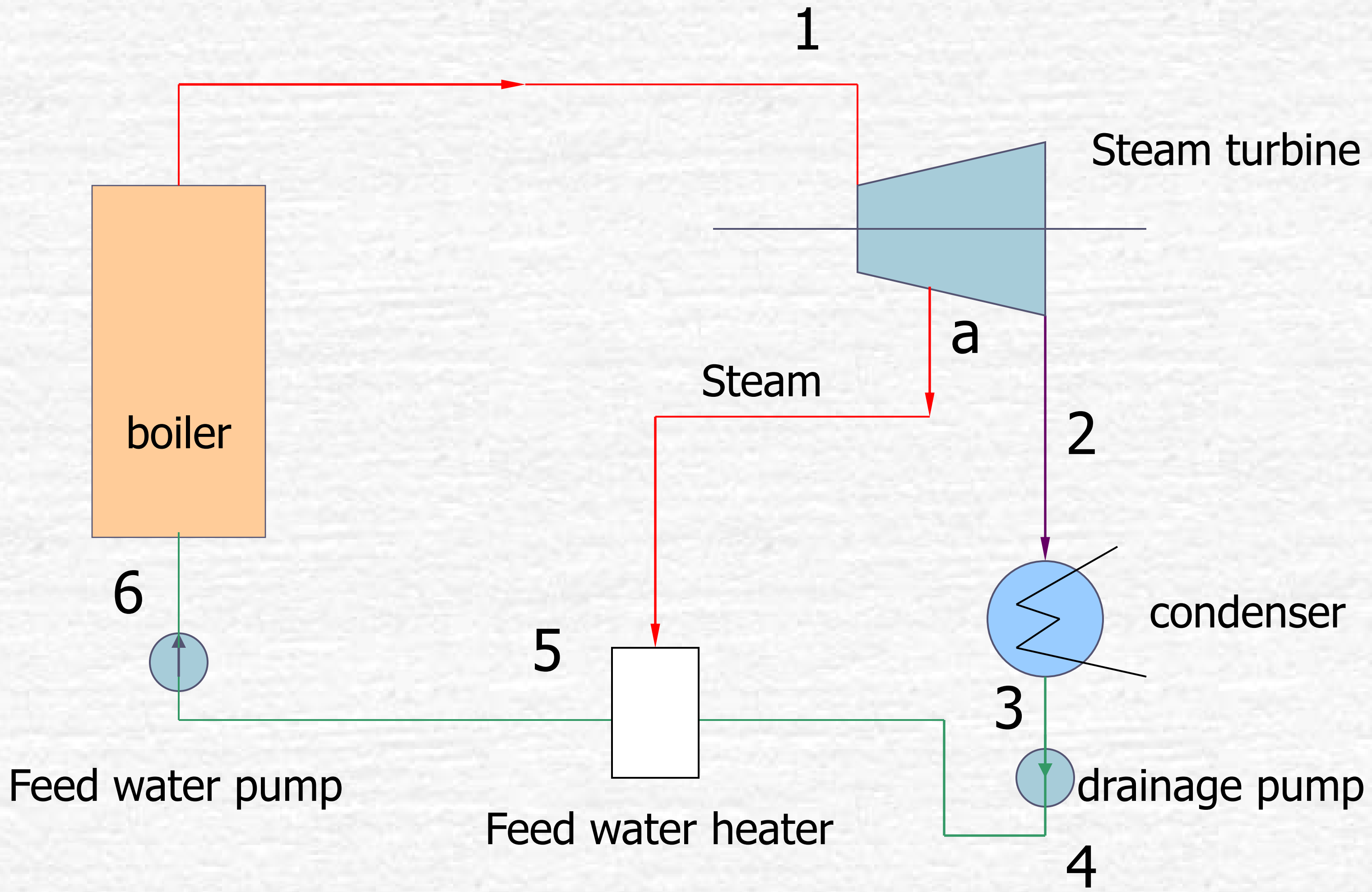
h_4: From p_1, $s_1 = s_4$ get h_4

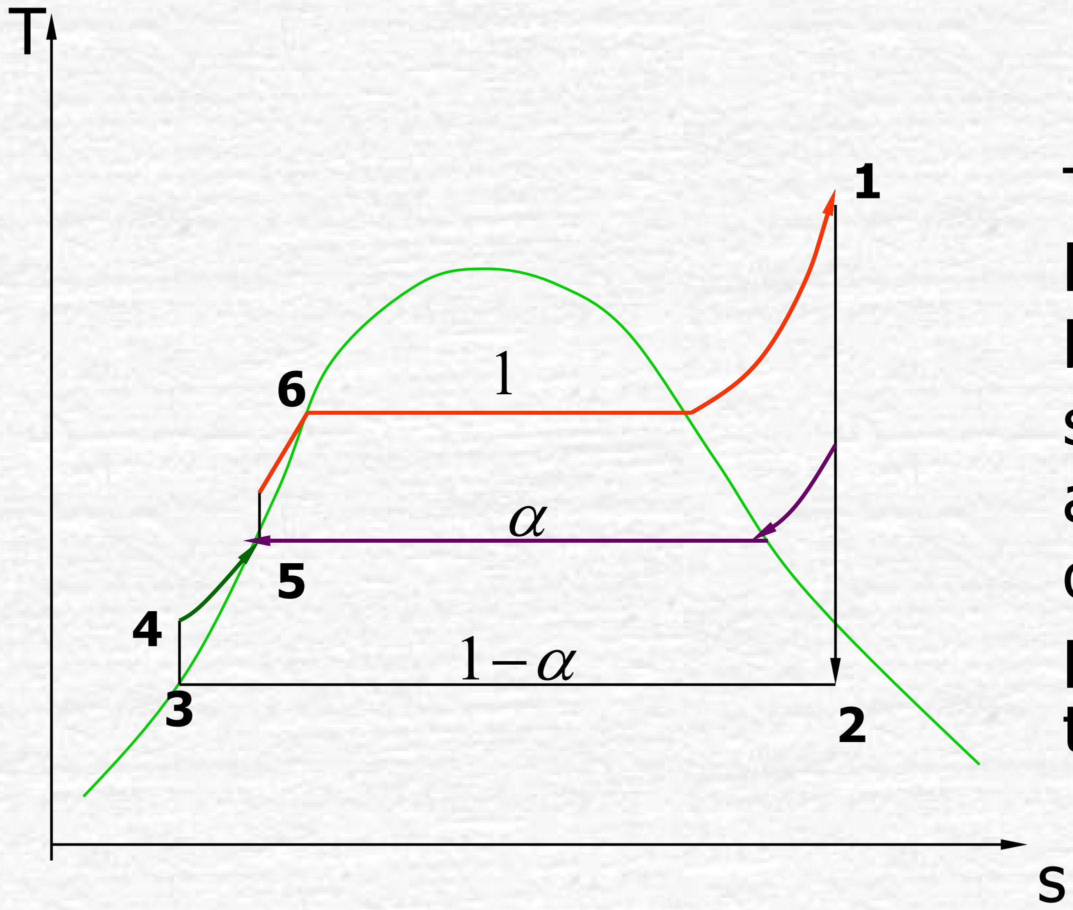
Regenerative Cycle

Ideal Regenerative Cycle



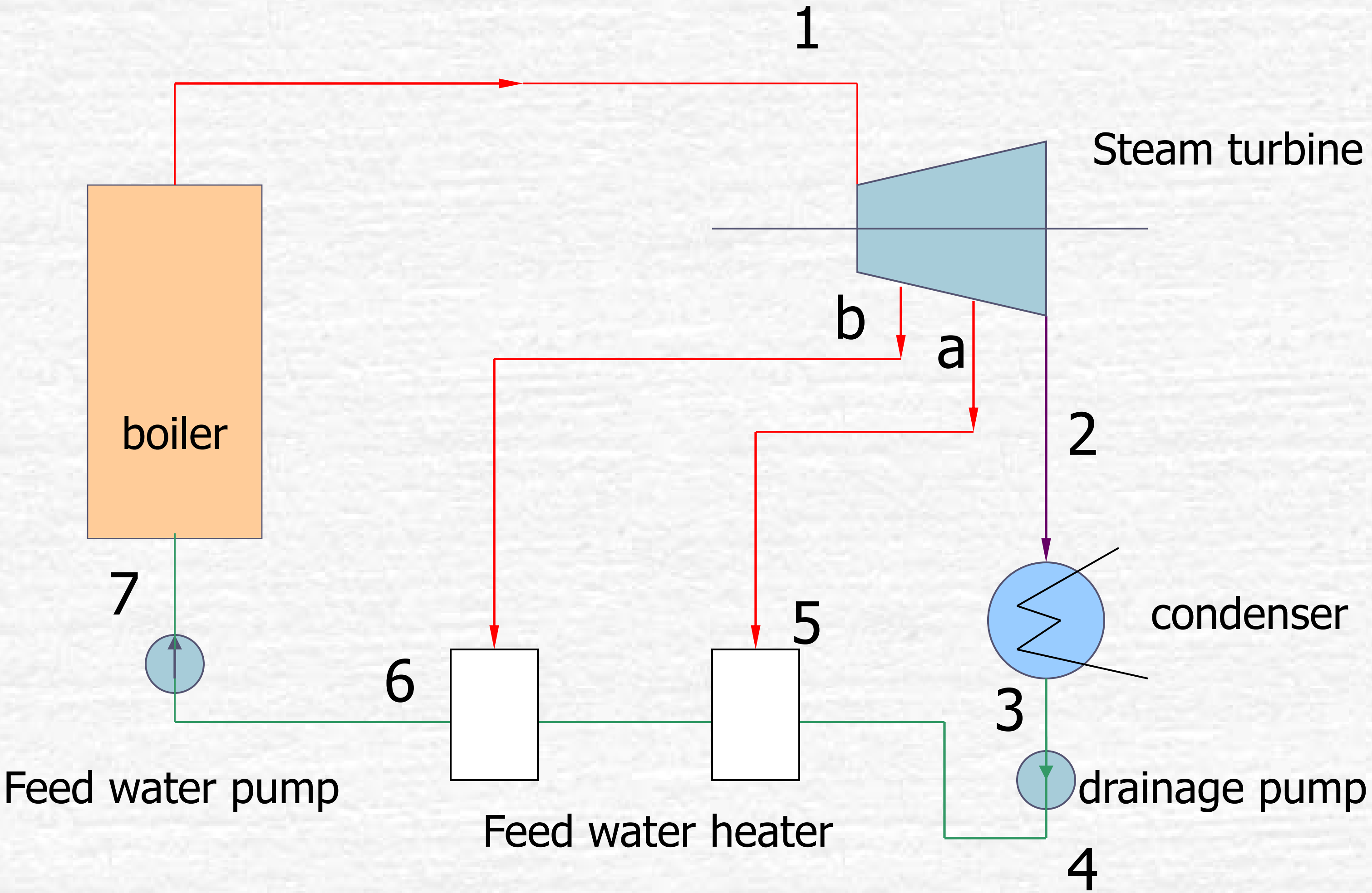
Regenerative Cycle

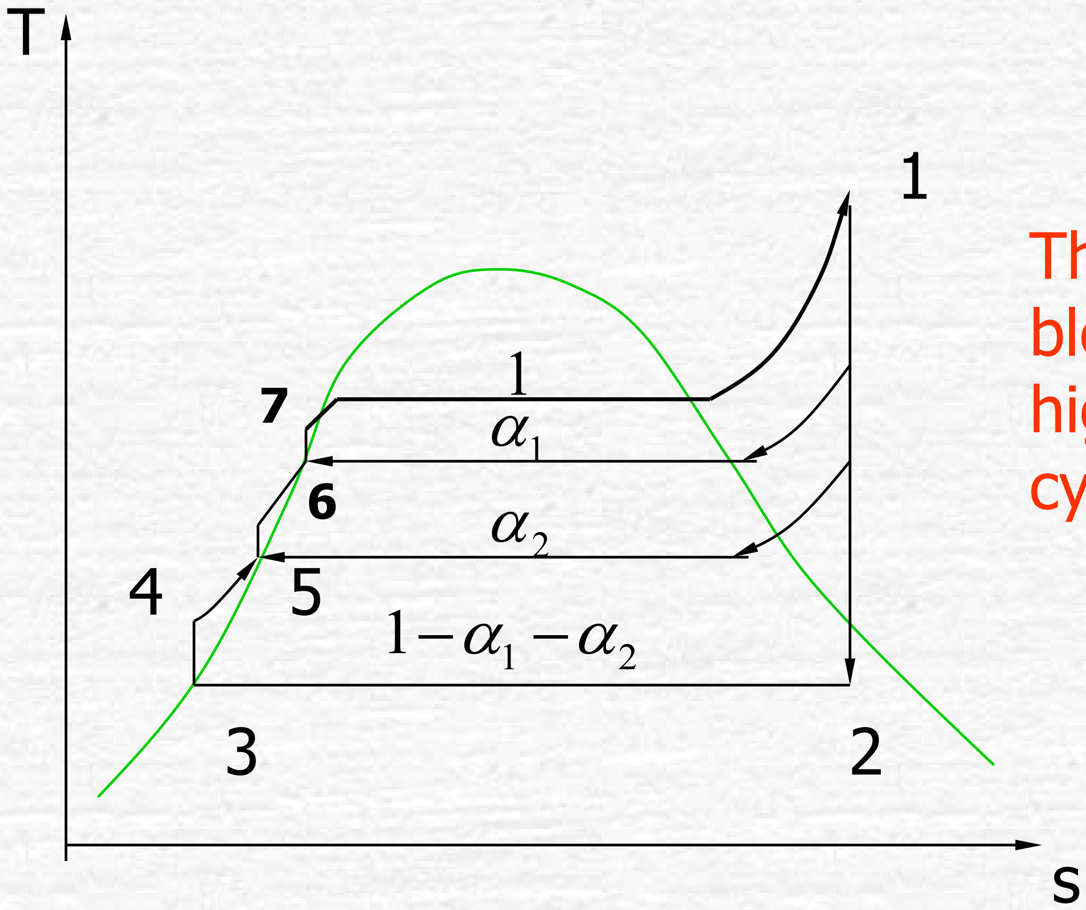




The feed water is heated by steam bleeding out from steam turbine. The average temperature of heat absorption process increases then.

$$\alpha = \frac{\text{The flow of steam bleeding out from the turbine}}{\text{The flow of steam entering the turbine}} \times 100\%$$

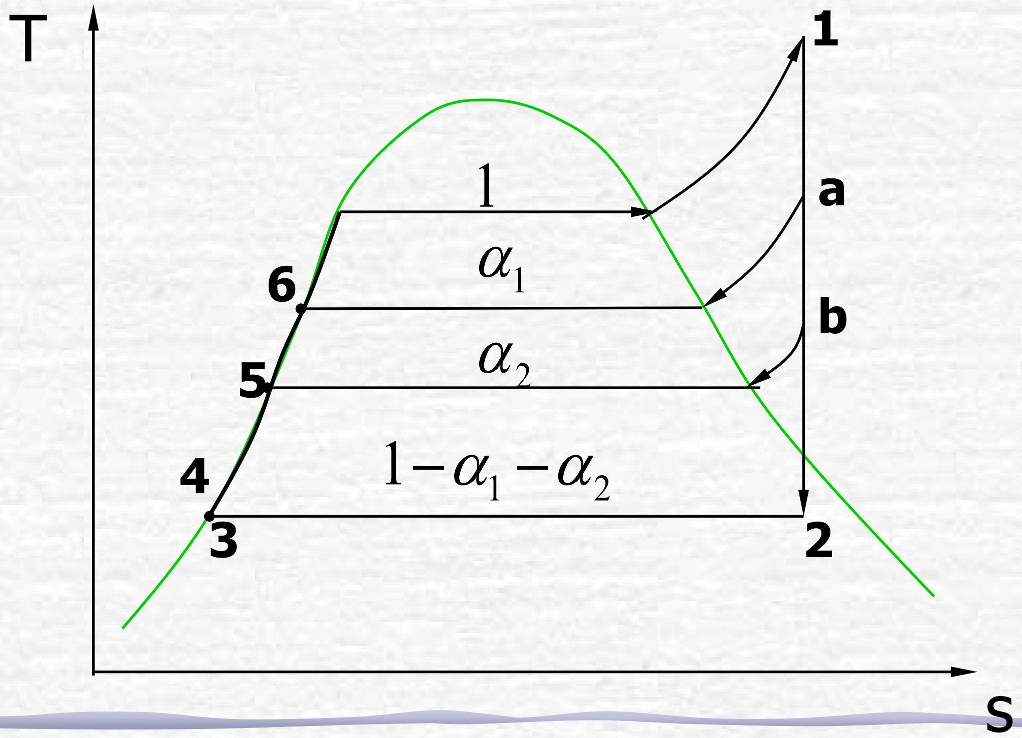

1
Steam turbine
boiler
b
a
2
7
5
condenser
6
3
Feed water pump
drainage pump
Feed water heater
4



The more stages of bleeding steam, the higher efficiency the cycle has

The efficiency of regenerative Cycle

As to a two stages regenerative cycle,the properties: p_1, t_1 , p_a , p_b , p_2 are available. If neglect the pump work, the T-s diagram should be as following.



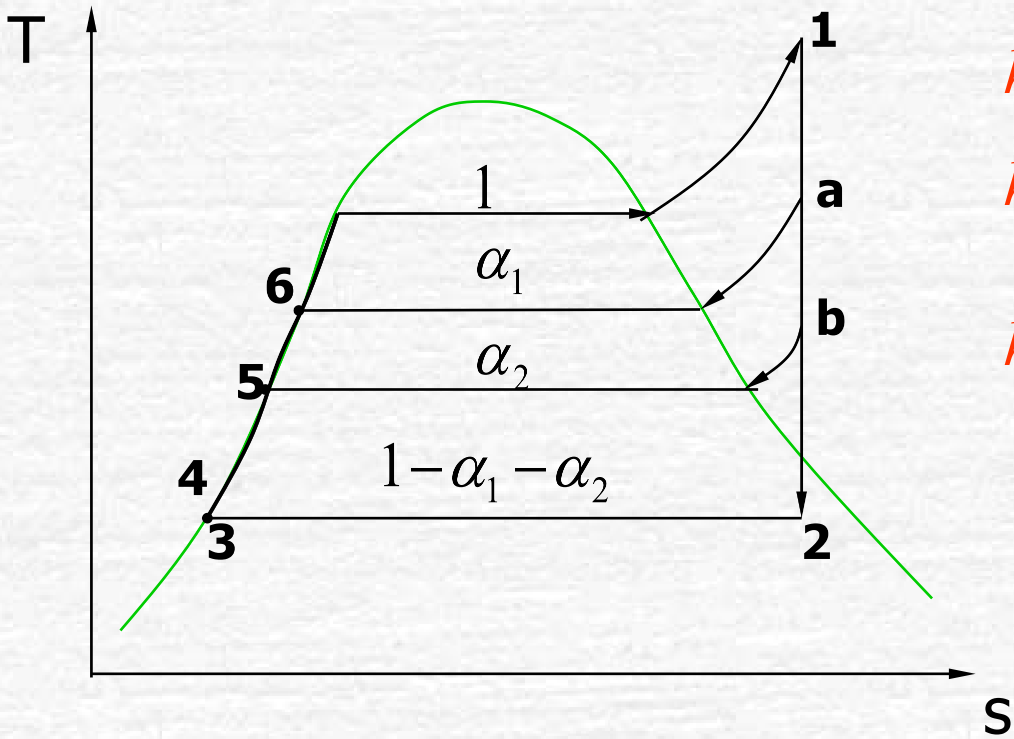
$$q_{in} = h_1 - h_6$$

$$q_{exhaust} = (h_2 - h_3)(1 - \alpha_1 - \alpha_2)$$

$$w = q_{in} - q_{exhaust}$$

$$\eta = \frac{q_{in} - q_{exhaust}}{q_{in}}$$

The enthalpy of each point



h_1: From p_1, t_1, get h_1, s_1

h_a: From p_a, s_1, get h_a

h_b: From p_b, s_1, get h_b

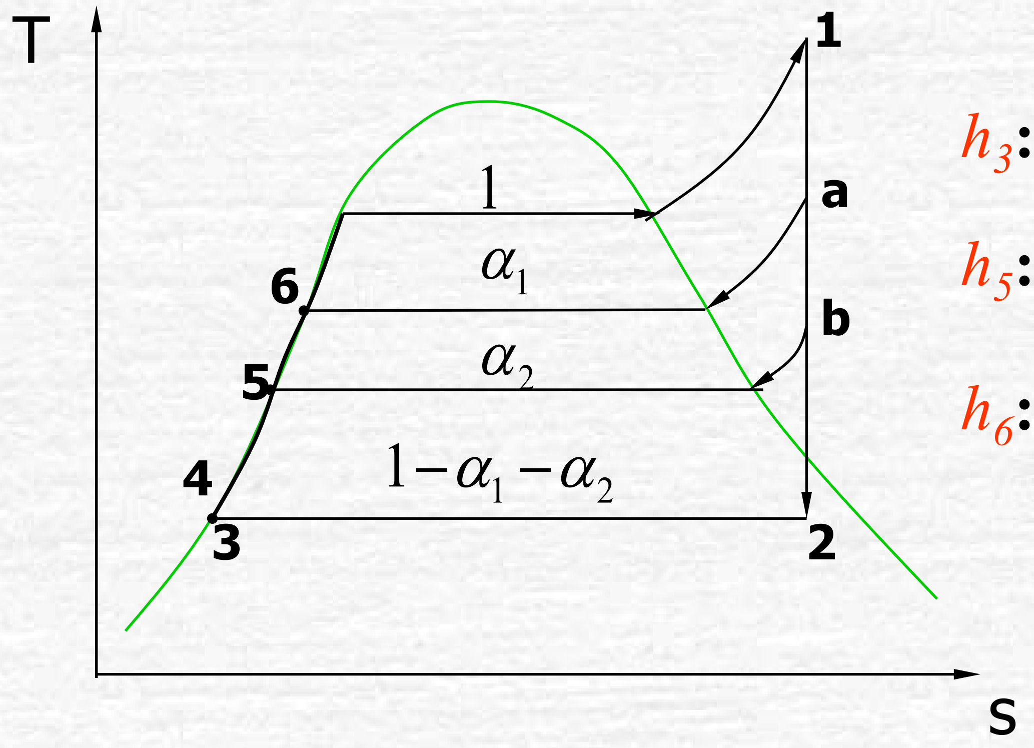
h_2: From p_2, get $s_2{}'$, $s_3{}''$

$h_2{}'$, $h_2{}''$

$$s_2 = s_1 = xs_2'' + (1-x)s_2'$$

So, x can be known

$$h_2 = xh_2'' + (1-x)h_2'$$



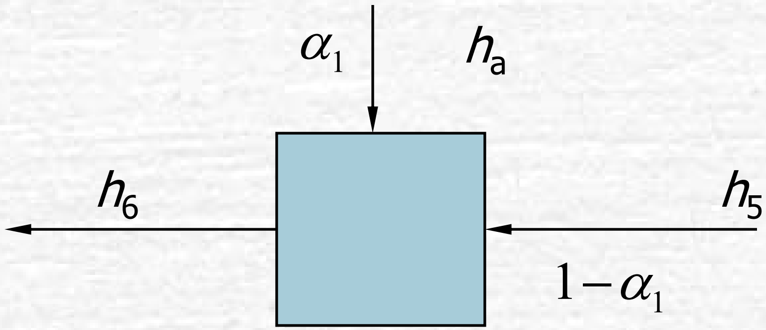
h_3: From p_2, get h_2', $h_3 = h_2'$

h_5: From p_b, get h_b', $h_5 = h_b'$

h_6: From p_a, get h_a', $h_6 = h_a'$

α_1 and α_2

As to the 1st stage heater

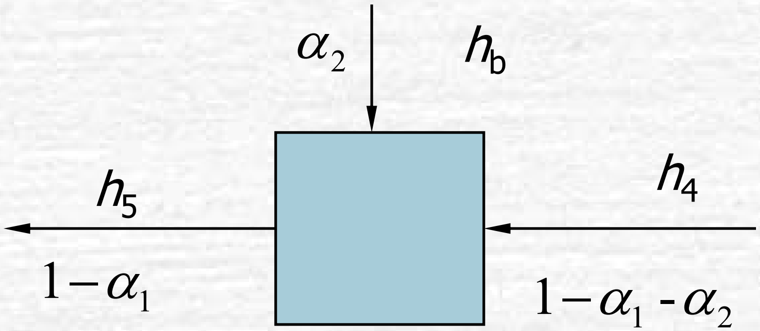


According to the first law of thermodynamics

$$h_6 = h_5(1-\alpha_1) + \alpha_1 h_a$$

$$\alpha_1 = \frac{h_6 - h_5}{h_a - h_5}$$

As to the 2nd stage heater



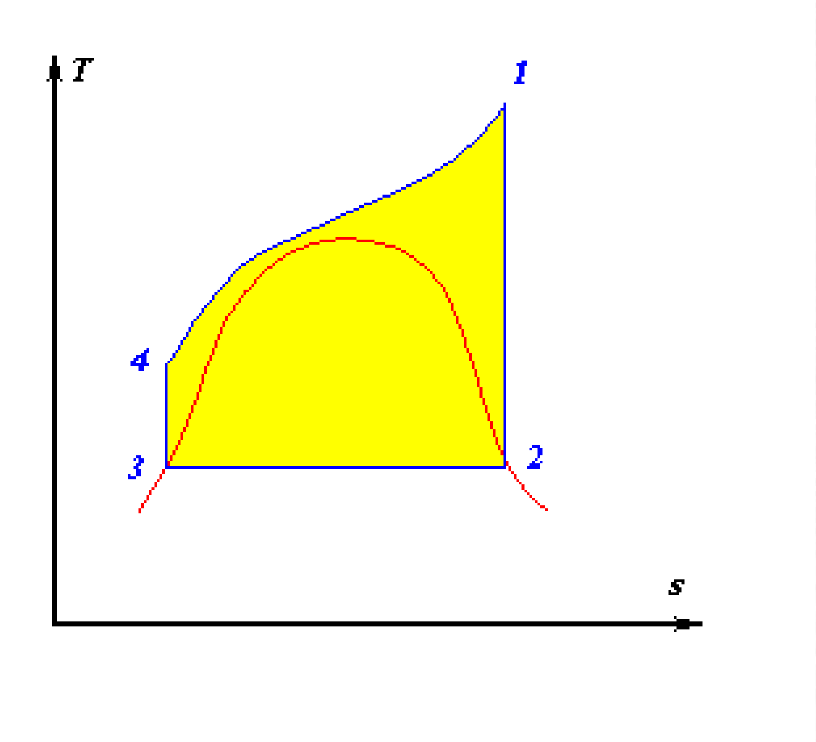
According to the first law of thermodynamics

$$h_5(1-\alpha_1) = h_4(1-\alpha_1-\alpha_2)+\alpha_2 h_b$$

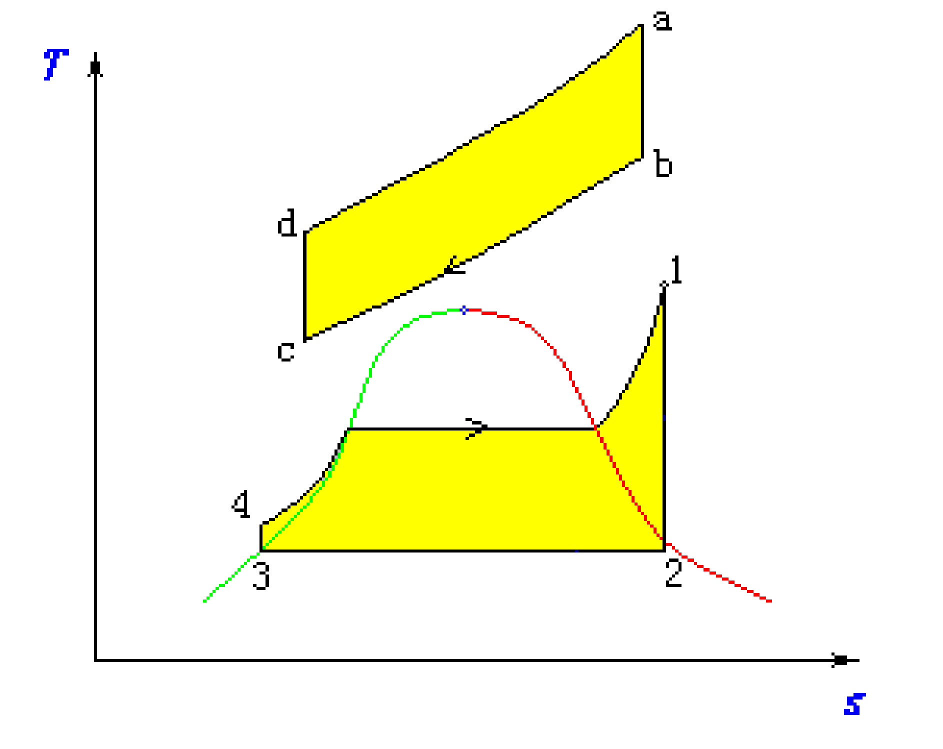
$$\alpha_2 = \frac{(1-\alpha_1)(h_5-h_4)}{h_b-h_4}$$

Other Steam Power Cycle

Super-critical Cycle



The Combined Gas-Vapor Power Cycle



Binary-vapor Cycle