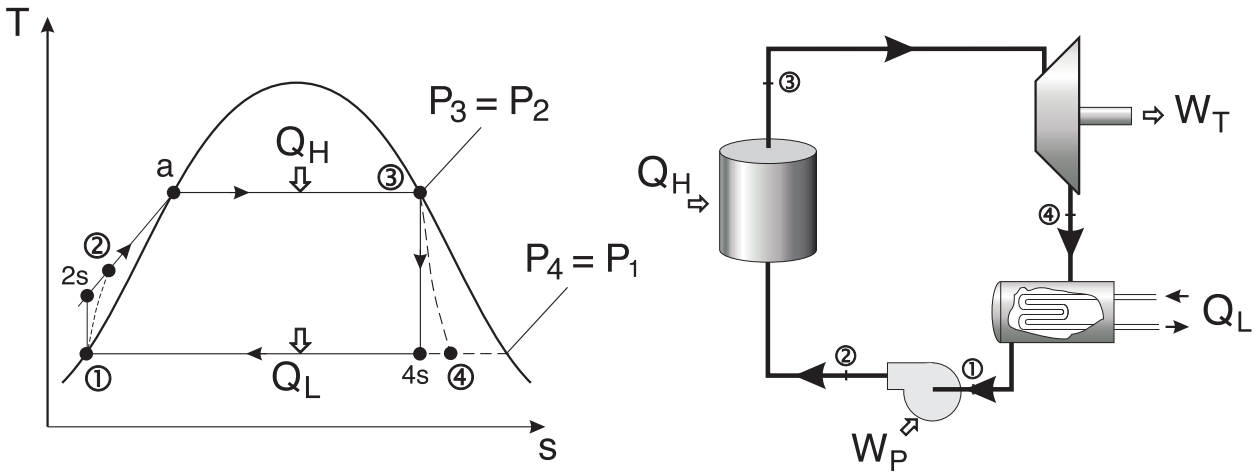
Rankine Cycle

Reading	Problems
10-2 ⟶ 10-7	10-19, 10-38, 10-41, 10-52, 10-53, 10-64

Definitions

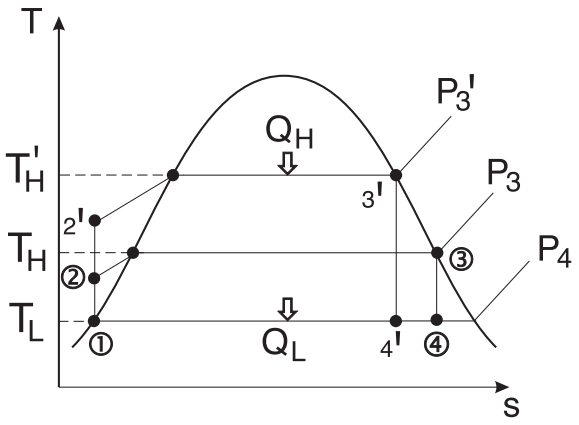
- the standard vapour cycle that excludes internal irreversibilities is called the **Ideal Rankine Cycle**



Effects of Boiler and Condenser Pressure

1. INCREASED BOILER PRESSURE:

- an increase in boiler pressure results in a higher T_H for the same T_L, therefore $\eta \uparrow$.
- but $4'$ has a lower quality than 4
  - wetter steam at the turbine exhaust
  - results in cavitation of the turbine blades
  - $\eta \downarrow$ plus $\uparrow$ maintenance
- quality should be $> 80 - 90\%$ at the turbine exhaust



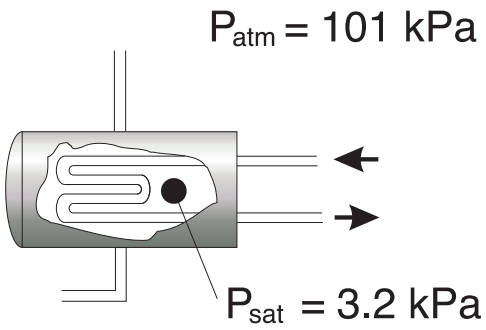
2. LOWER T_L:

- we are generally limited by the $\boldsymbol{TER}$ (lake, river, etc.)

  eg. lake @ $\mathbf{15\ °C} + \underbrace{\boldsymbol{\Delta T = 10\ °C}}_{\textit{resistance to HT}} = \mathbf{25\ °C}$

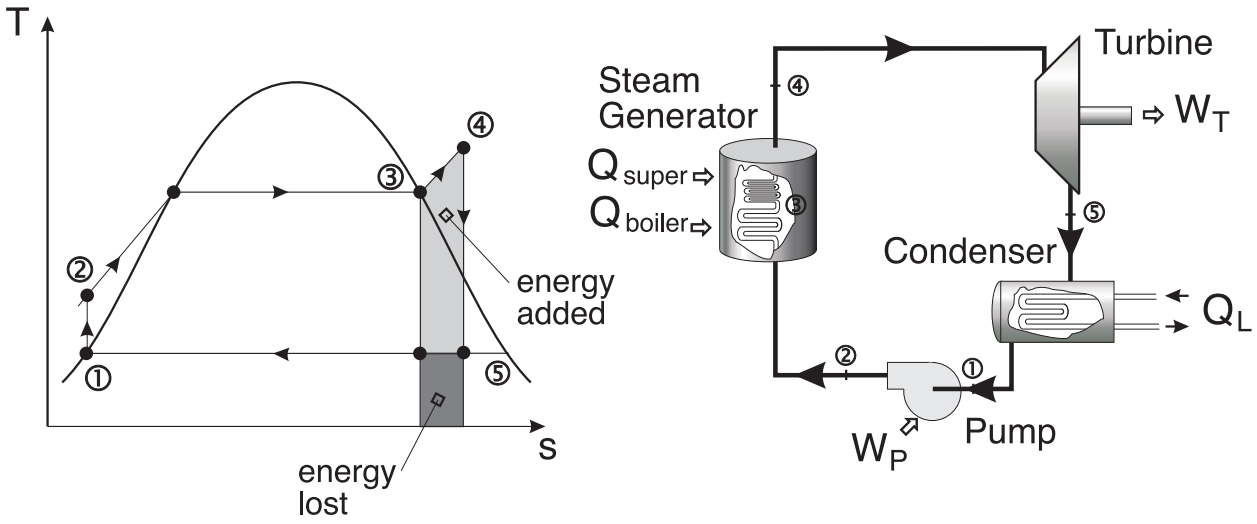
  $\Rightarrow\ \boldsymbol{P_{sat} = 3.2\ kPa}$.

- this is why we have a condenser
  - the pressure at the exit of the turbine can be less than atmospheric pressure
  - the closed loop of the condenser allows us to use treated water on the cycle side
  - but if the pressure is less that atmospheric pressure, air can leak into the condenser, preventing condensation



3. INCREASED T_H BY ADDING SUPERHEAT:

- the average temperature at which heat is supplied in the boiler can be increased by superheating the steam



– dry saturated steam from the boiler is passed through a second bank of smaller bore tubes within the boiler until the steam reaches the required temperature

  The advantage is

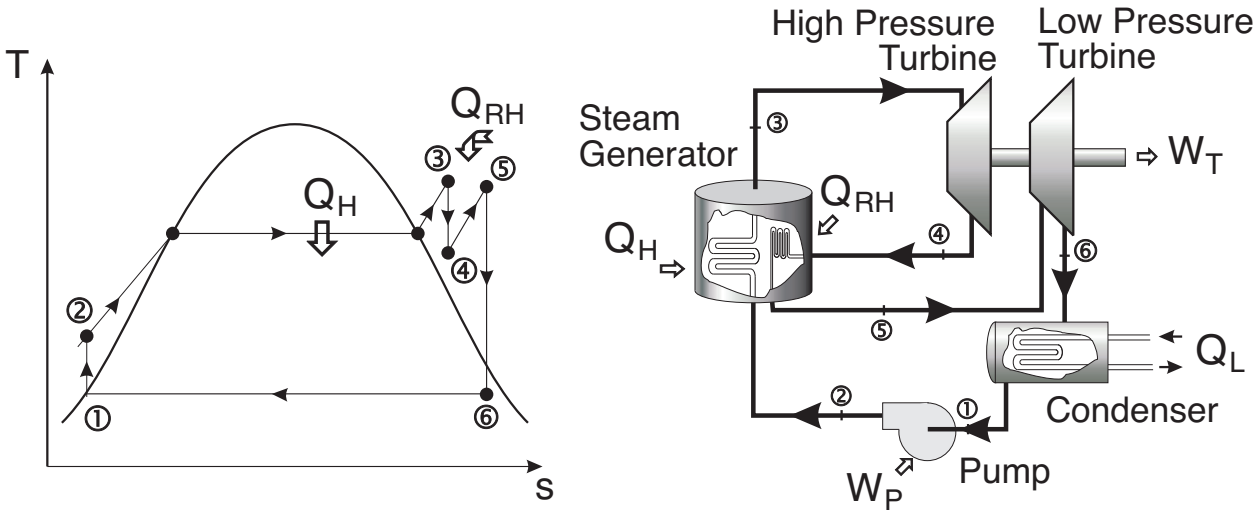
$$\eta = \frac{W_{net} \uparrow}{Q_H \uparrow} \quad overall \uparrow$$

  The value of $\overline{T_H}$, the mean temperature at which heat is added, increases, while $\overline{T_L}$ remains constant. Therefore the efficiency increases.

– the quality of the turbine exhaust increases, hopefully where $x > 0.9$
– with sufficient superheating the turbine exhaust can fall in the superheated region.

Rankine Cycle with Reheat

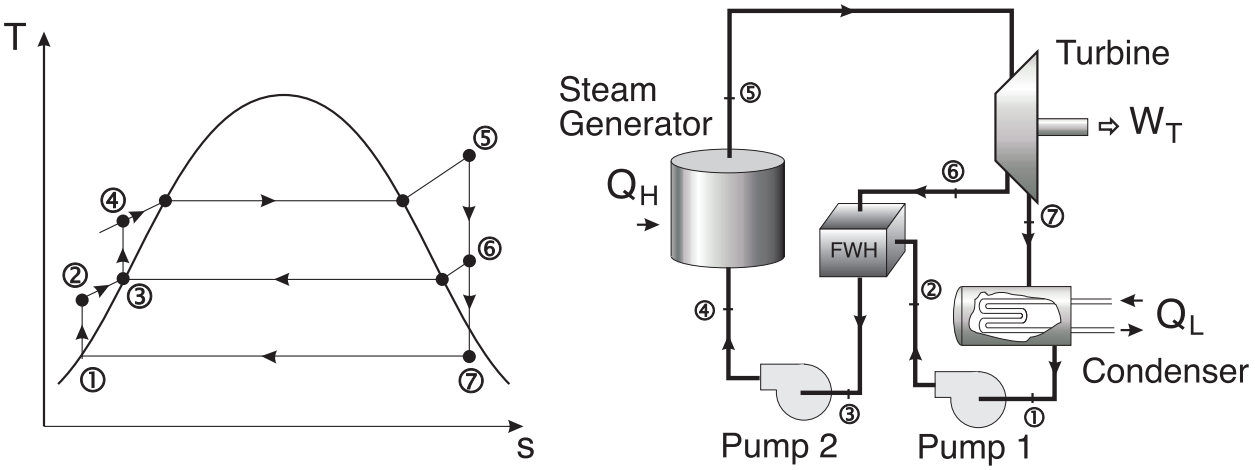
- to improve the exhaust steam conditions, the steam can be reheated with the expansion carried out in two steps



- modern boilers can handle up to $\mathbf{30}\ \boldsymbol{MPa}$ and a maximum temperature of $\boldsymbol{T_{max}} \approx \mathbf{650}\ \boldsymbol{^\circ C}$.
- newer materials, such as ceramic blades can handle temperatures up to $\mathbf{750}\ \boldsymbol{^\circ C}$.

Rankine Cycle with Regeneration

- the Rankine cycle can be used with a ***Feedwater Heater*** to heat the high pressure sub-cooled water at the pump exit to the saturation temperature
  - most of the heat addition (Q_H) is done at high temperature



Feedwater Heaters

There are two different types of feedwater heaters

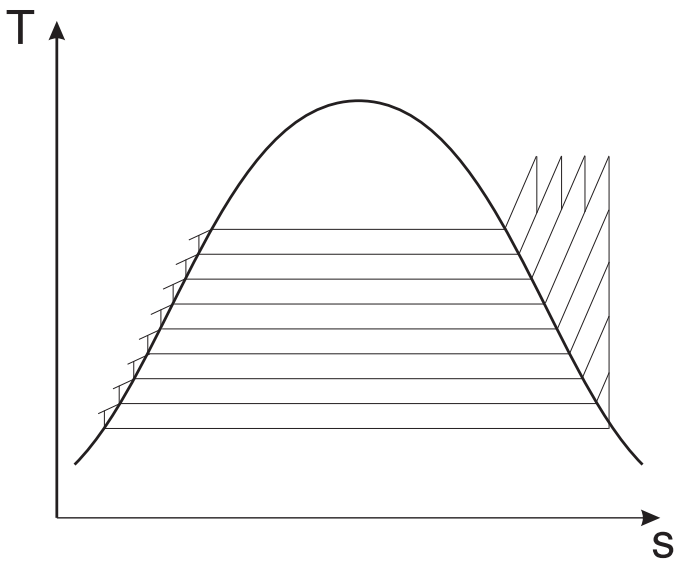
1. ***OPEN FWH:*** the streams mix → high temperature steam with low temperature water at constant pressure
2. ***CLOSED FWH:*** a heat exchanger is used to transfer heat between the two streams but the streams do *not* mix. The two streams can be maintained at different pressures.

Other Topics

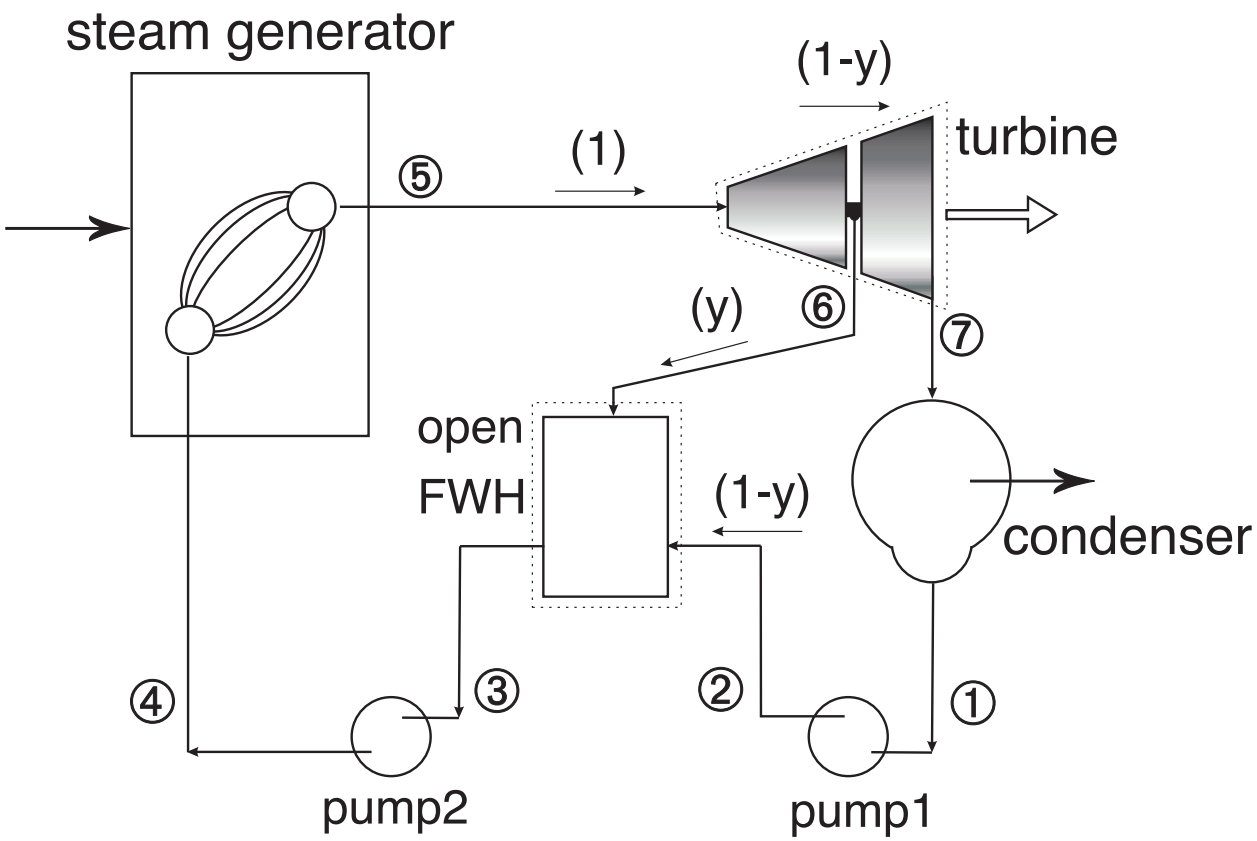
"IDEAL" RANKINE CYCLE:

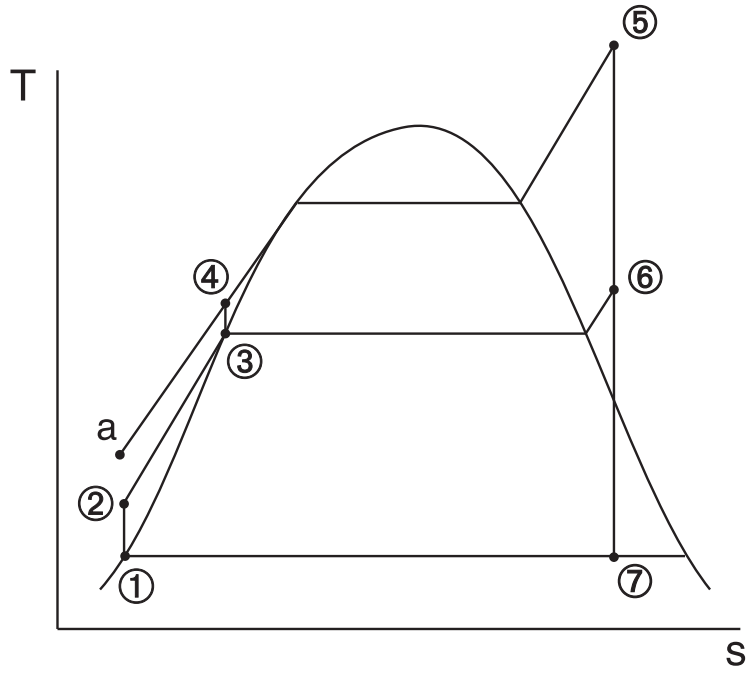
- too expensive to build
- requires multiple reheat and regeneration cycles
- approaches Carnot efficiency

TOPPING CYCLE (BINARY CYCLE):



- involves two Rankine cycles running in tandem with different working fluids such as mercury and water


steam generator
(1-y)
turbine
⑤
(1)
(y)
⑥
⑦
open
FWH
(1-y)
condenser
④
③
②
①
pump2
pump1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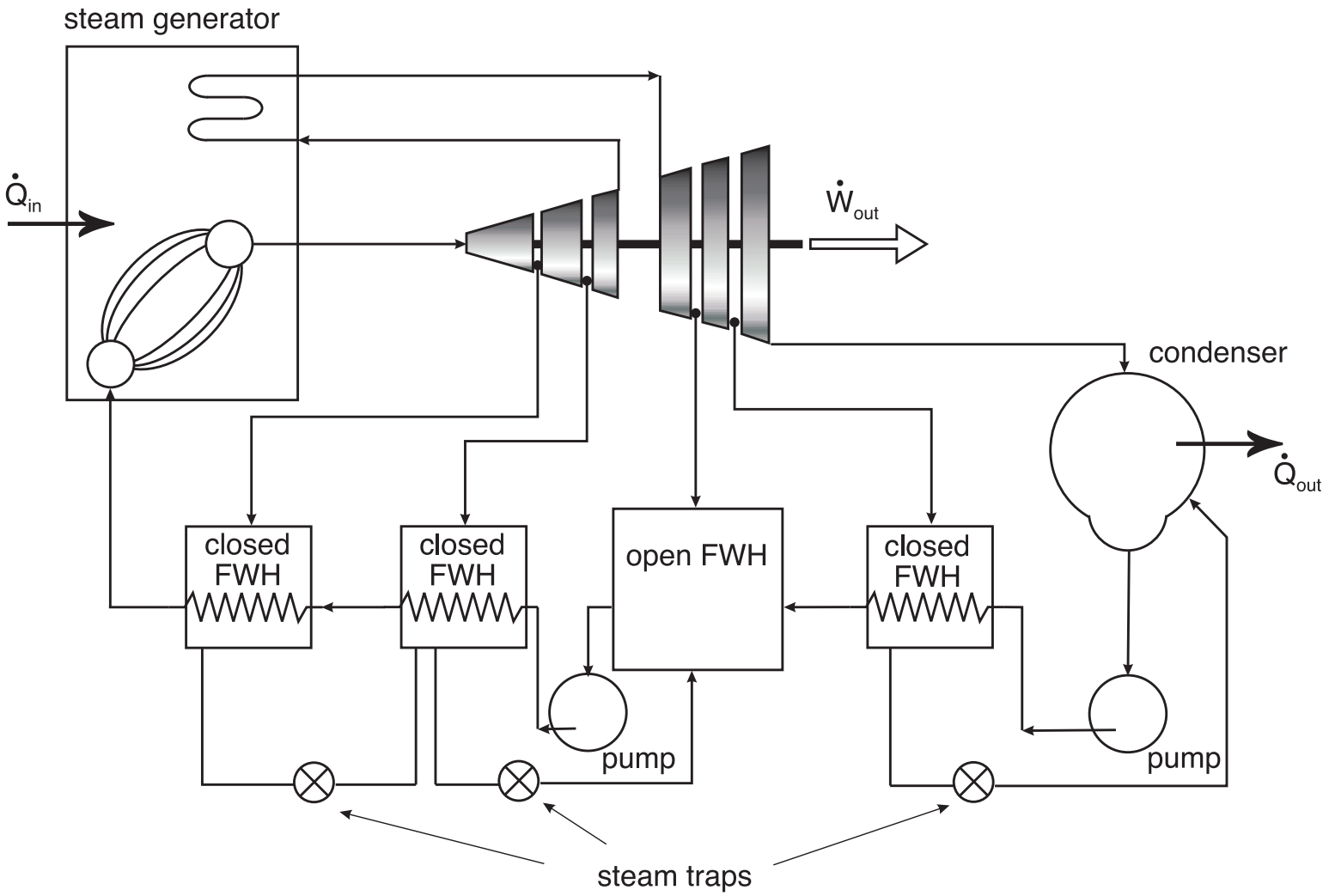
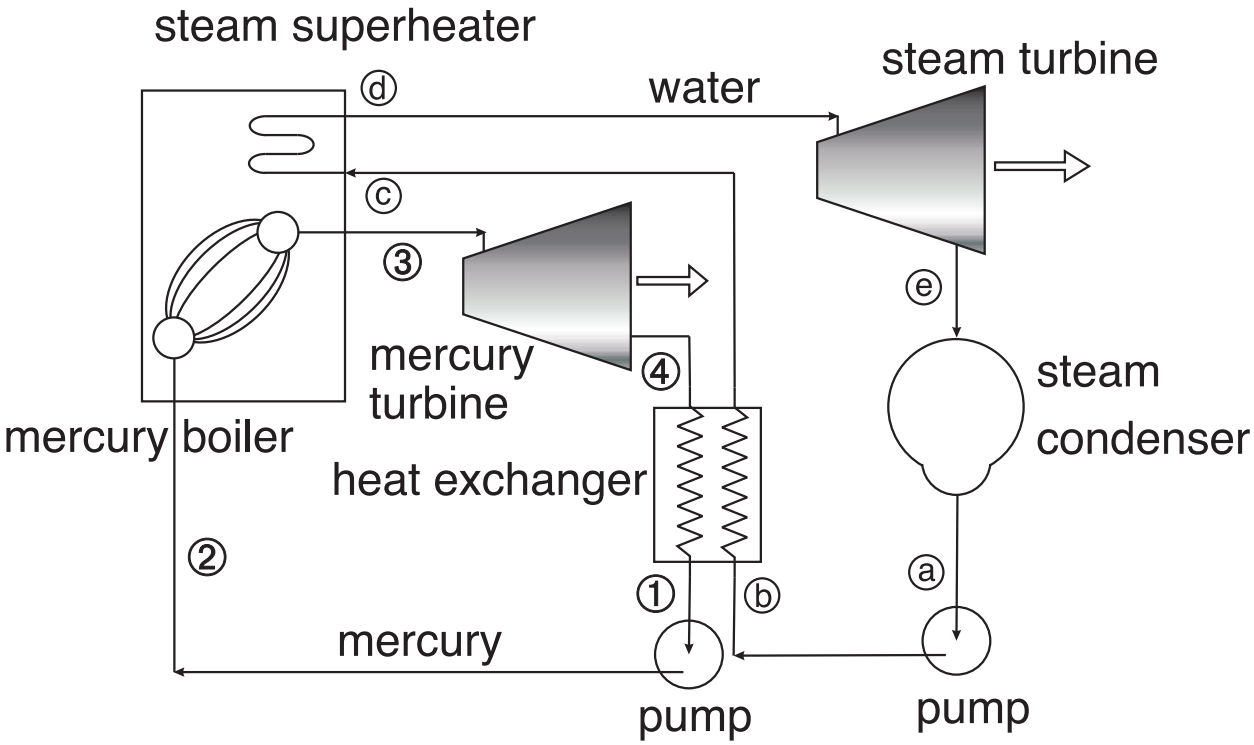

steam generator
$\dot{Q}_{in}$
$\dot{W}_{out}$
condenser
$\dot{Q}_{out}$
closed FWH
closed FWH
open FWH
closed FWH
pump
pump
steam traps


steam superheater
steam turbine
water
d
c
③
e
mercury
turbine
④
steam
condenser
mercury boiler
heat exchanger
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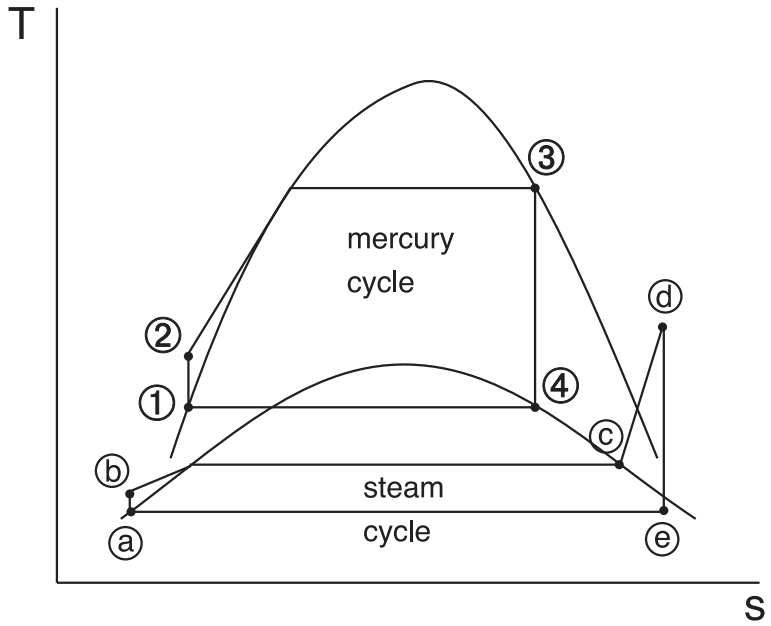
b
mercury
pump
pump


T
③
mercury
cycle
d
②
④
①
c
b
steam
cycle
a
e
s