UNIT-3
RANKINE ANALYSIS

Recap

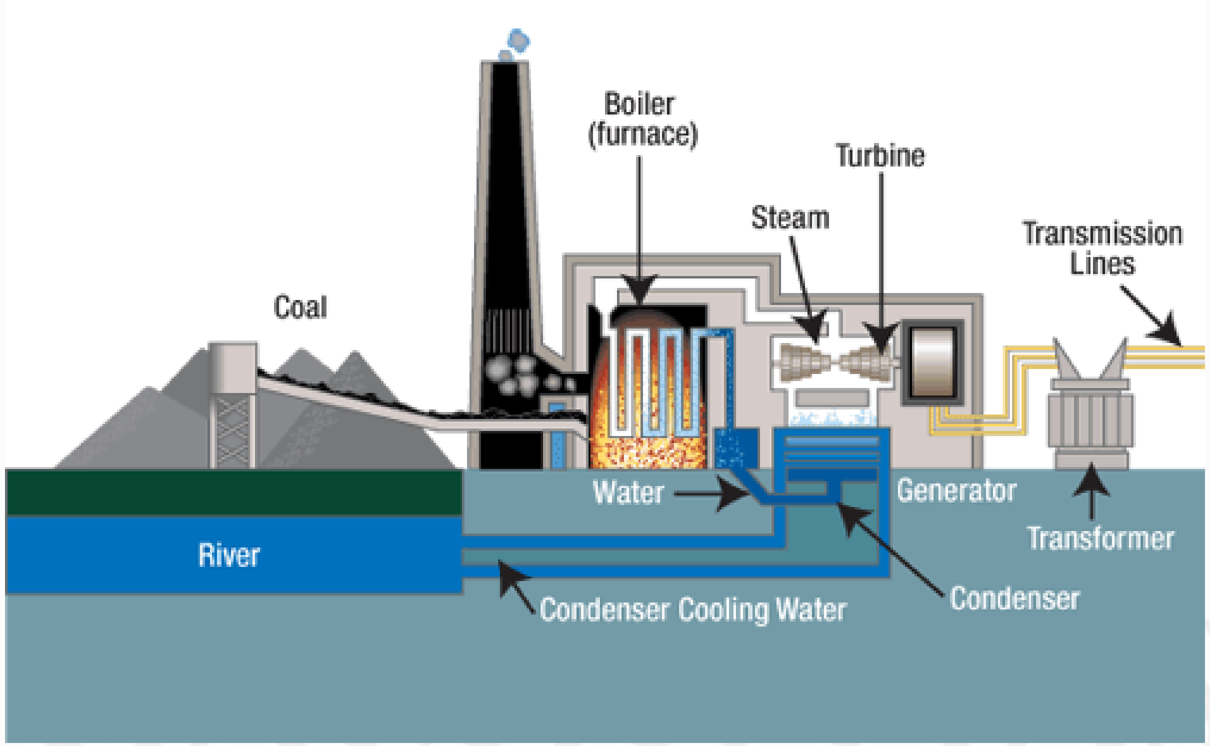
- BASIC CONCEPT OF CARNOT POWER CYCLE.
- FUNDAMENTAL OF RANKINE POWER CYCLE..

- **LEARNING OBJECTIVE OF LECTURE**

Students will be able to learn the complete thermodynamic analysis of rankine vapour power analysis.

STEAM POWER PLANT

CONVERTS THE ENERGY IN FOSSILS (COAL, OIL, GAS) OR FISSILE (URANIUM, THORIUM) INTO SHAFT AND ULTIMITELY INTO ELECTRICITY.



https://en.wikipedia.org/wiki/Fossil_fuel_power_station

The efficiency of the vapor power cycle would thus be:

$$\eta_{Cycle} = \frac{W_{Net}}{Q_1} = \frac{W_T - W_P}{Q_1} = \frac{Q_1 - Q_2}{Q_1} = 1 - \frac{Q_2}{Q_1}$$

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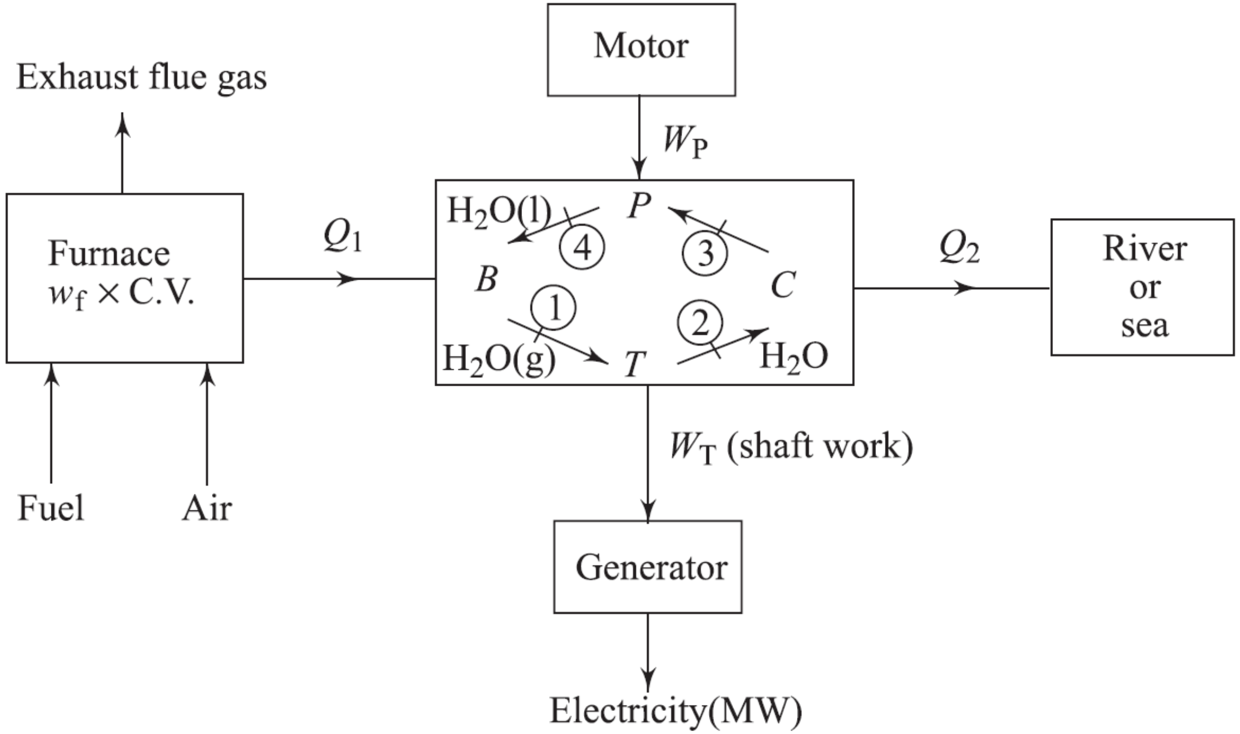

Fig.2.1 *Steam power plant—bulk energy converter from fuel to electricity*

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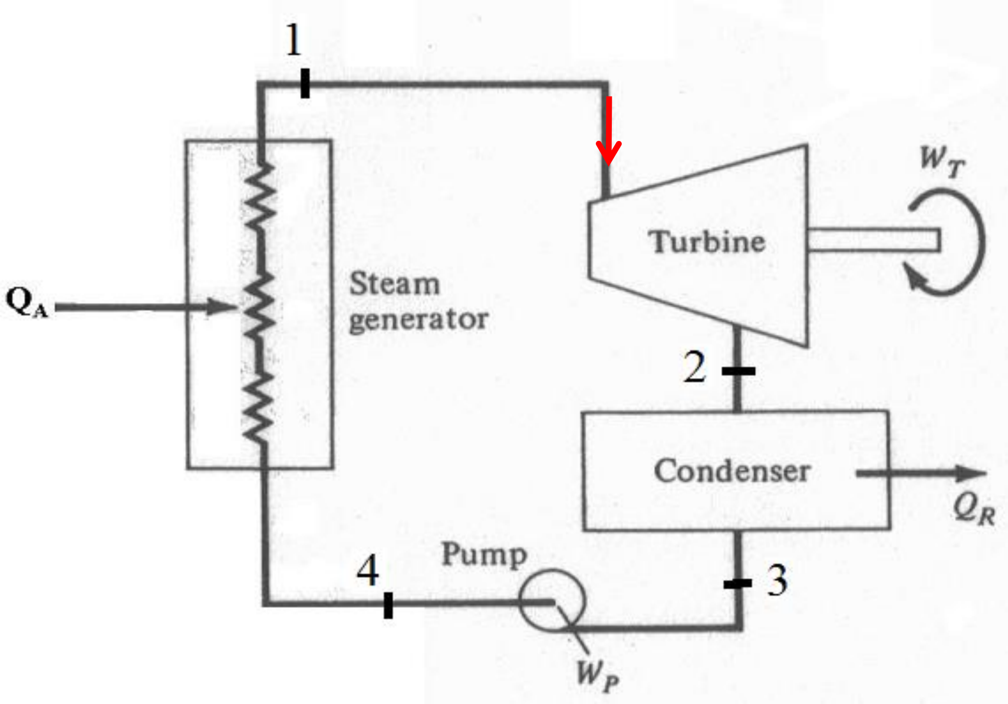


Ideal Rankine Cycle

STEAM GENERATOR: A reversible constant pressure heating process (water to steam).

TURBINE: A reversible adiabatic expansion of steam

CONDENSER: A reversible constant pressure heat rejection process (steam to saturated liquid).

PUMP: The reversible adiabatic compression. (liquid return to the initial pressure).

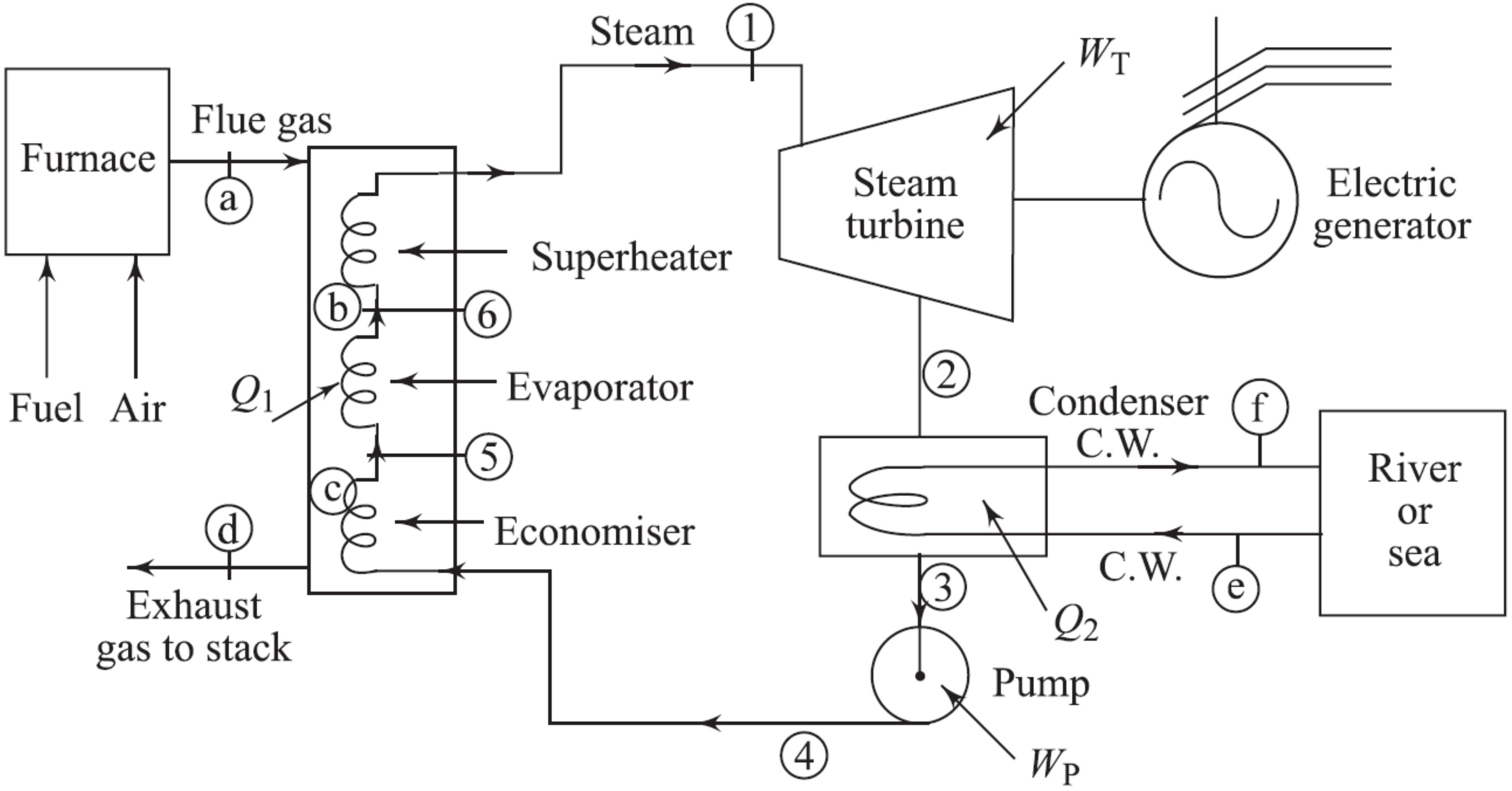
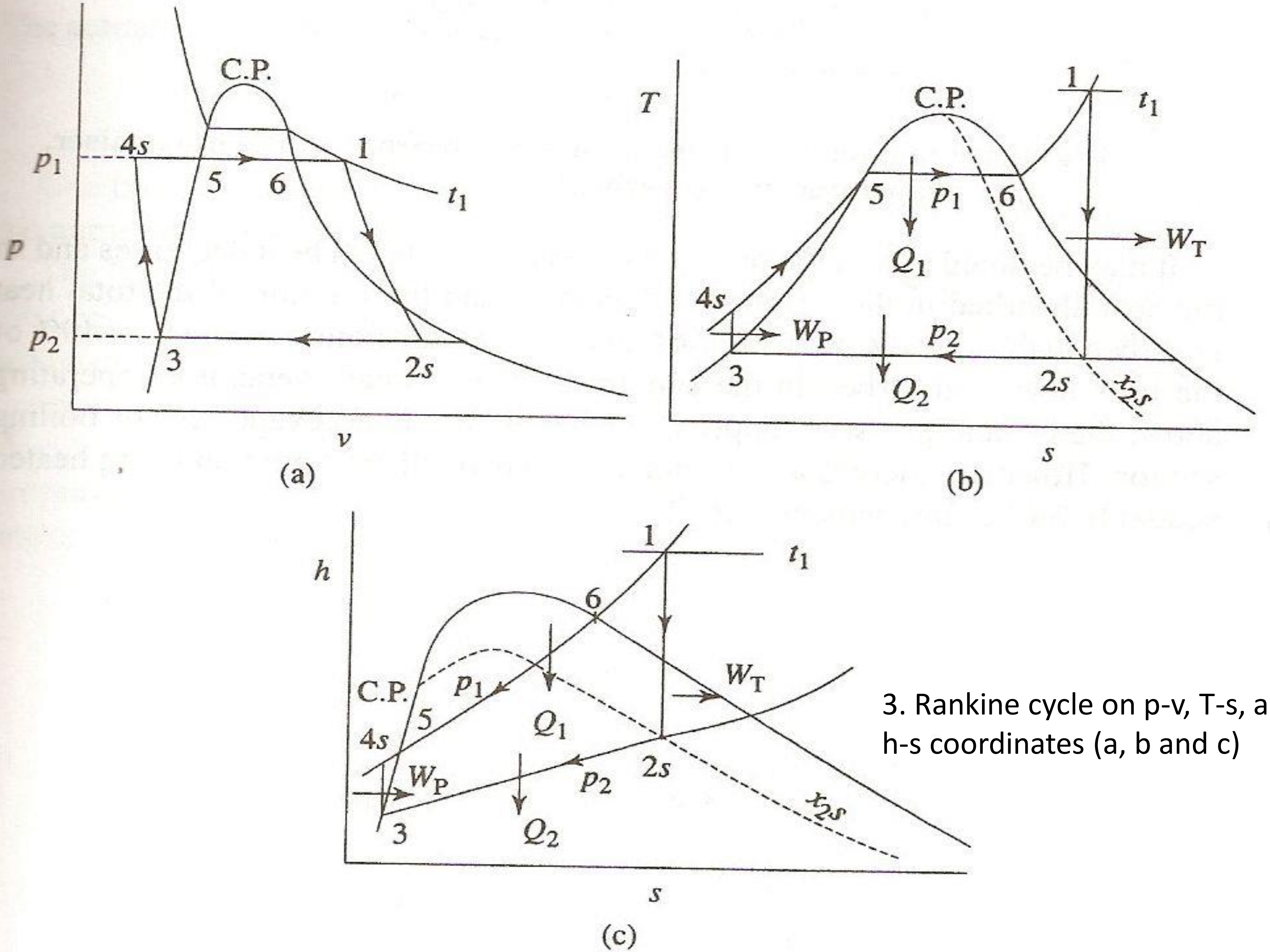


Fig. 2.2 *A simple steam plant representing Rankine cycle*



3. Rankine cycle on p-v, T-s, and h-s coordinates (a, b and c)

Steady Flow Energy Equation (SFEE)

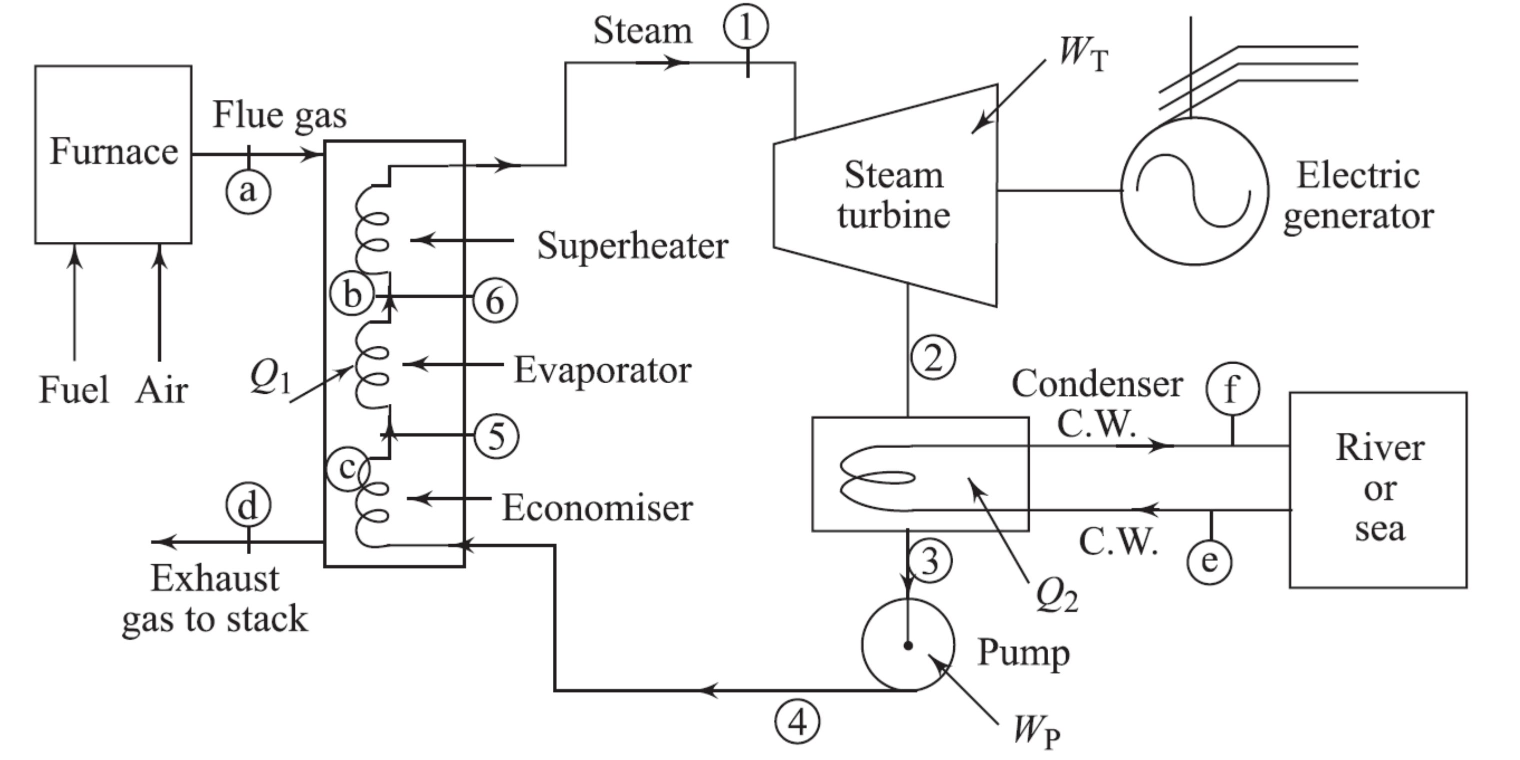


Fig. 2.2 *A simple steam plant representing Rankine cycle*

BOILER: $h_4 + Q_1 = h_1 \rightarrow Q_1 = h_1 - h_4$

TURBINE: $h_1 = W_T + h_2 \rightarrow W_T = h_1 - h_2$

$$\eta_{Cycle} = \frac{W_{Net}}{Q_1} = \frac{W_T - W_P}{Q_1} = \frac{Q_1 - Q_2}{Q_1} = 1 - \frac{Q_2}{Q_1}$$

CONDENSER: $h_2 = Q_2 + h_3 \rightarrow Q_2 = h_2 - h_3$

PUMP: $h_3 + W_P = h_4 \rightarrow W_P = h_4 - h_3$

The efficiency of the Rankine cycle

$$\eta = \frac{W_{Net}}{Q_1} = \frac{W_T - W_P}{Q_1} = \frac{(h_1 - h_2) - (h_4 - h_3)}{(h_1 - h_4)}$$

For reversible adiabatic compression:

$$Tds = dh - vdp$$ Since $$ds = 0$$

$$\int_3^4 dh = \int_3^4 vdp$$

$$h_4 - h_3 = v_3(p_4 - p_3) = W_P$$

The pump work (W_P) is usually very small as compared to the turbine work (W_T), and therefore it is often neglected.

Steam plant capacity is often expressed as steam rate or specific steam consumption (SSC). It is defined as rate of steam flow (kg/s) needed to generate unit shaft output (1 kW).

So, Steam rate (S.R.) $= \frac{1}{W_{Net}} \frac{kg}{kWs}$ (9)

The efficiency is sometimes expressed as heat rate

Heat rate (H.R.) $= \frac{Q_1}{W_T - W_P} = \frac{1}{\eta} \frac{kJ}{kWs}$ (10)

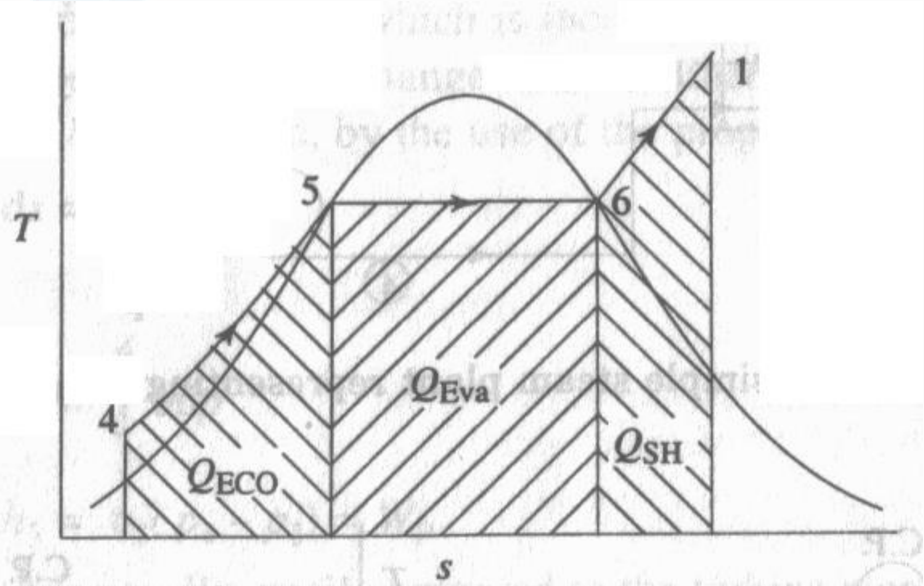
Economizer, Evaporator and Superheater

Heat transfer in a steam generator has three different regimes

$$Q_{Eco} = h_5 - h_4$$

$$Q_{Eva} = h_6 - h_5 = h_{fg}$$

$$Q_{SH} = h_1 - h_6$$



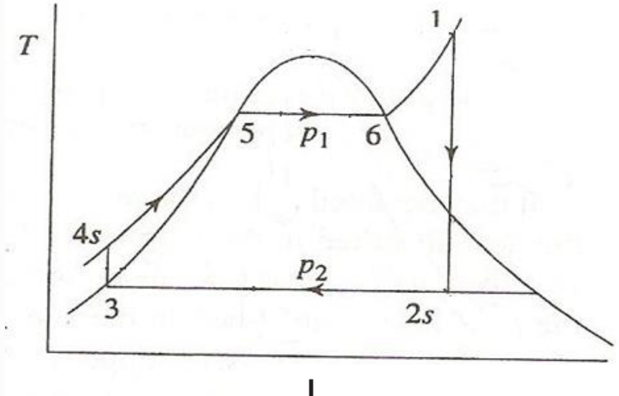
$$\frac{Q_{ECO}}{Q_1} = \frac{h_5 - h_4}{h_1 - h_4} = \frac{\text{area under } 4-5}{\text{area under } 4-1}$$

$$\frac{Q_{EVA}}{Q_1} = \frac{h_6 - h_5}{h_1 - h_4} = \frac{\text{area under } 5-6}{\text{area under } 4-1}$$

$$\frac{Q_{SH}}{Q_1} = \frac{h_1 - h_6}{h_1 - h_4} = \frac{\text{area under } 6-1}{\text{area under } 4-1}$$

CARNOT CYCLE AND ITS LIMITATION

Carnot cycle is an **ideal** (△T=0 and △Q=0, reversible) cycle that produce maximum possible efficiency on selected maximum- temperature. However, in real practice it cannot be achieved because the irreversibilities (friction, expansion, mixing of two fluids, heat transfer, resistance, chemical reaction, etc).



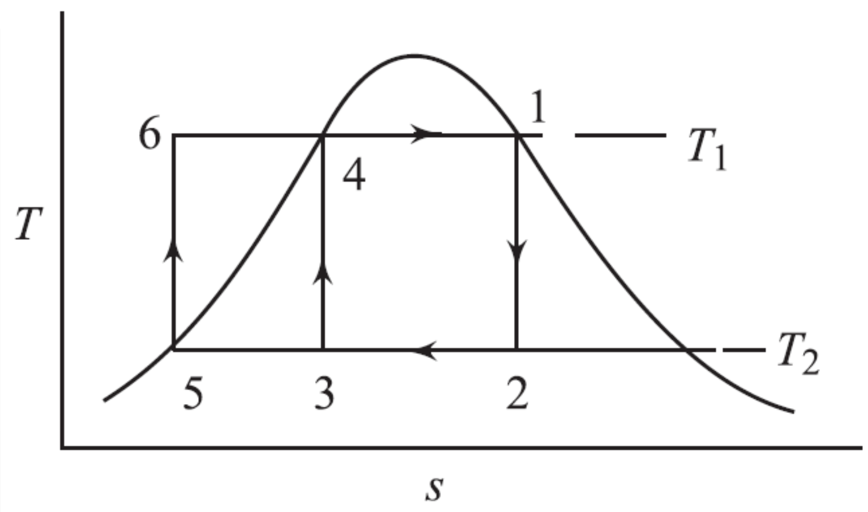


Fig. 2.8 *Carnot cycle*

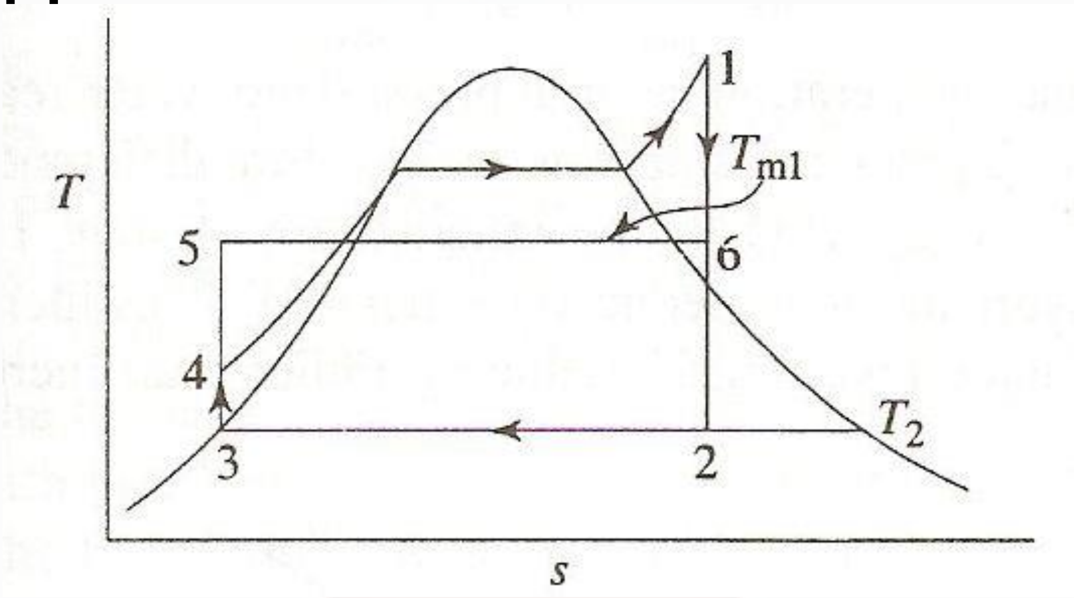
Process1-2-3-4

- 3-4 requires a large compressor to be run at very wet steam. Problem with blade erosion and cavitations will be occurred.

Process 1-2-5-6-1

- 5-6 involves with very high pressure for pump work.
- 6-4 is impossible because usually heat cannot be supplied at infinite pressure and constant temperature.

Mean Temperature of Heat Addition



Heat added reversibly at a constant pressure at 5-6 and T_{m1} is called mean temperature of heat addition.

So, the total area under 5-6 is equal to the area under 4-1. Then, heat added is:

$$Q_1 = h_1 - h_4 = T_{m1}(s_1 - s_4)$$

Since heat rejected $Q_2 = h_2 - h_3 = T_2(s_1 - s_4)$

$$\eta_{Rankine} = 1 - \frac{Q_2}{Q_1} = 1 - \frac{T_2(s_1 - s_4)}{T_{m1}(s_1 - s_4)} = 1 - \frac{T_2}{T_{m1}}$$

$$\eta_{Rankine} = f(T_{m1})$$

Cycle efficiency increases when the mean temperature of heat addition increases

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1-https://energyeducation.ca/encyclopedia/Rankine_cycle.
2-http://www.thermopedia.com/content/1072/
3-Çengel, Yunus A., and Michael A. Boles. Thermodynamics: An Engineering Approach. 7th ed. New York: McGraw-Hill, 2011. p. 299. Print.
4-N. A. Sinitsyn (2011). "Fluctuation Relation for Heat Engines". J. Phys. A: Math. Theor. 44 (40): 405001. arXiv:1111.7014. Bibcode:2011JPhA...44N5001S. doi:10.1088/1751-8113/44/40/405001. S2CID 119261929.
5-Carnot, Sadi, Reflections on the Motive Power of Fire