Applied Thermodynamics

Gas Power Cycles

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Chapter Description

- Aims
  - To identify and recognized ideal thermodynamics cycle.
  - To analyze working principle of basic thermodynamics cycle and system.

- Expected Outcomes
  - Able to describe first and second law of thermodynamics.
  - Able to described thermodynamics cycles such as heat engine cycle, heat pump cycle, carnot cycle and refrigeration cycle.

- Other related Information
  - …..
  - …..

- References

  - Yunus A. Cengel Michael A.Boles. "Thermodynamics: An Engineering Approach", 8 Edition, McGraw-Hill Education, (2014).
  - Michael J. Moran, Howard N. Shapiro, Daisie D. Boettner, Margaret B. Bailey . "Fundamentals of Engineering Thermodynamics", 8th Edition, Wiley, (2014).

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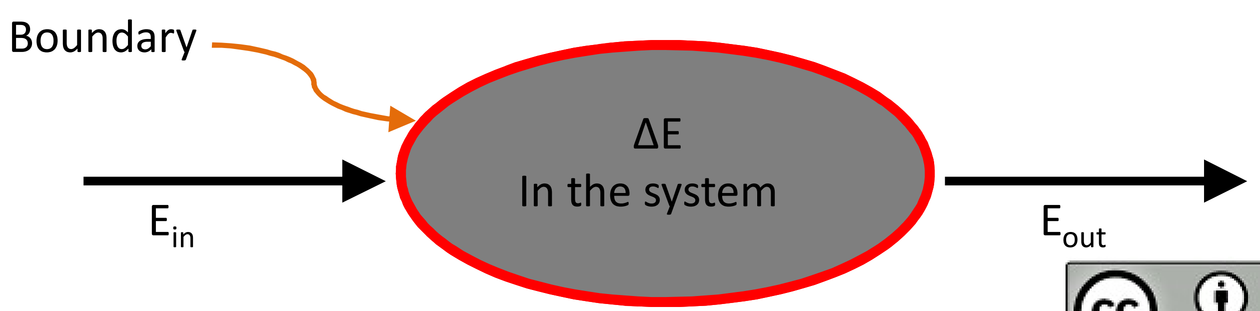
1^{st} Law of Thermodynamics (Conservation of Energy)

Conservation of Energy: Energy can neither be created nor destroyed in a process. It transforms from one form of energy to another. For example, **potential energy** can be converted into **kinetic energy** in the flow of water from upper reservoir to the lower reservoir. Energy also can be transferred to or from the boundaries of the system.

Energy balance in the system can be obtained as:

Total energy entering the system (E_{in})	-	Total energy leaving the system (E_{out})	=	Change in the total energy of the system (ΔE)



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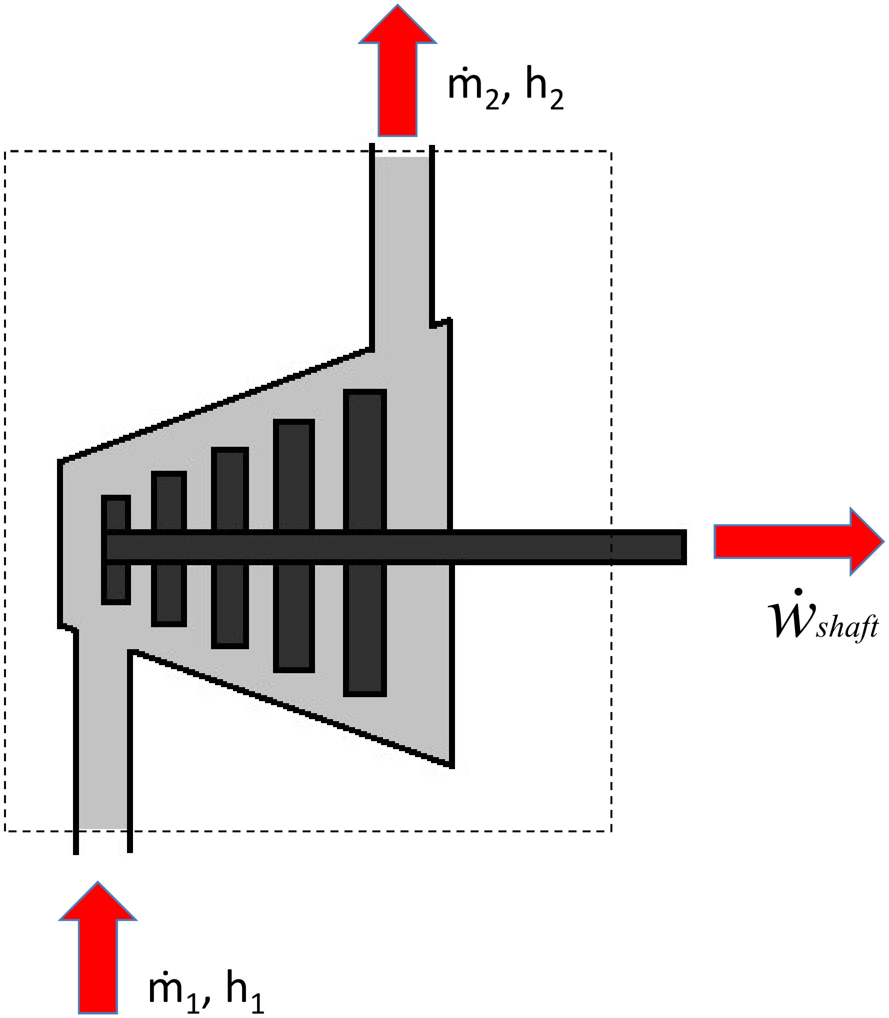
Concept of Energy Balance



Energy Balance:

$$\dot{m}_1 h_1 - \dot{m}_2 h_2 = \dot{W}_{shaft}$$

2^{nd} Law of Thermodynamics

Consists of two statements: 1) Kelvin Planks Statement, and 2) Clausius Statement

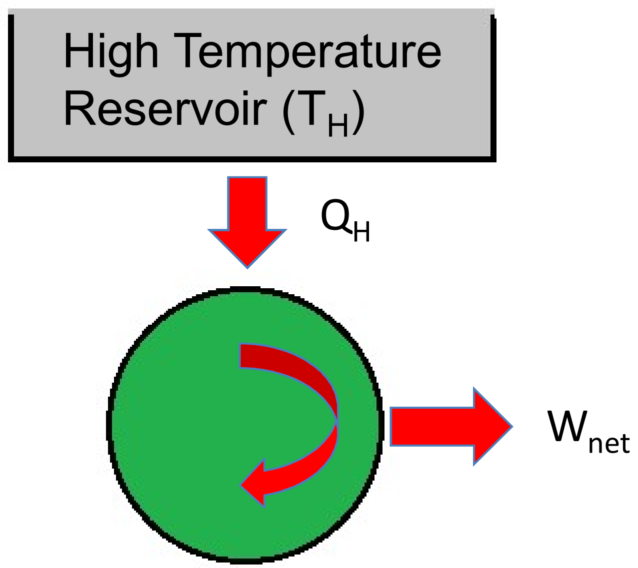
1) Kelvin-Planks Statement

It is awkward to develop a device or a system that operates with receiving heat from a high single reservoir and producing net amount of work without any side effect of loss of heat. This is because of the system is impossible to work with 100 percent of efficiency.

The system is impossible to work with thermal efficiency of 100 percent.

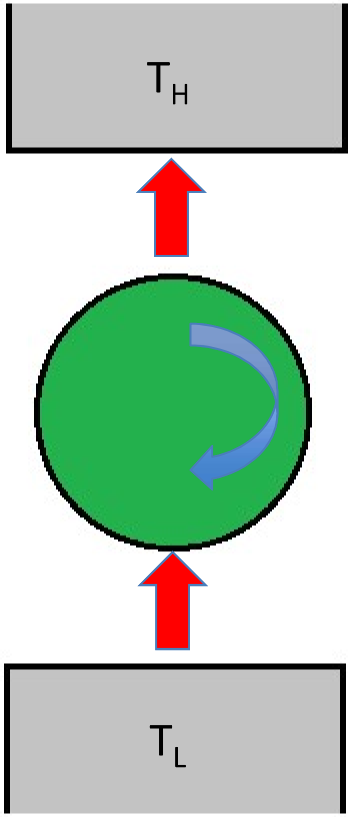
$$\eta_{thermal} \neq 100\%$$

Some amount of heat must be remove through Q_L



2) Clausius Statement

It is impossible to develop a device or a system that operates in a cycle with producing no effect when transferring heat from a low temperature reservoir to a higher temperature reservoir.



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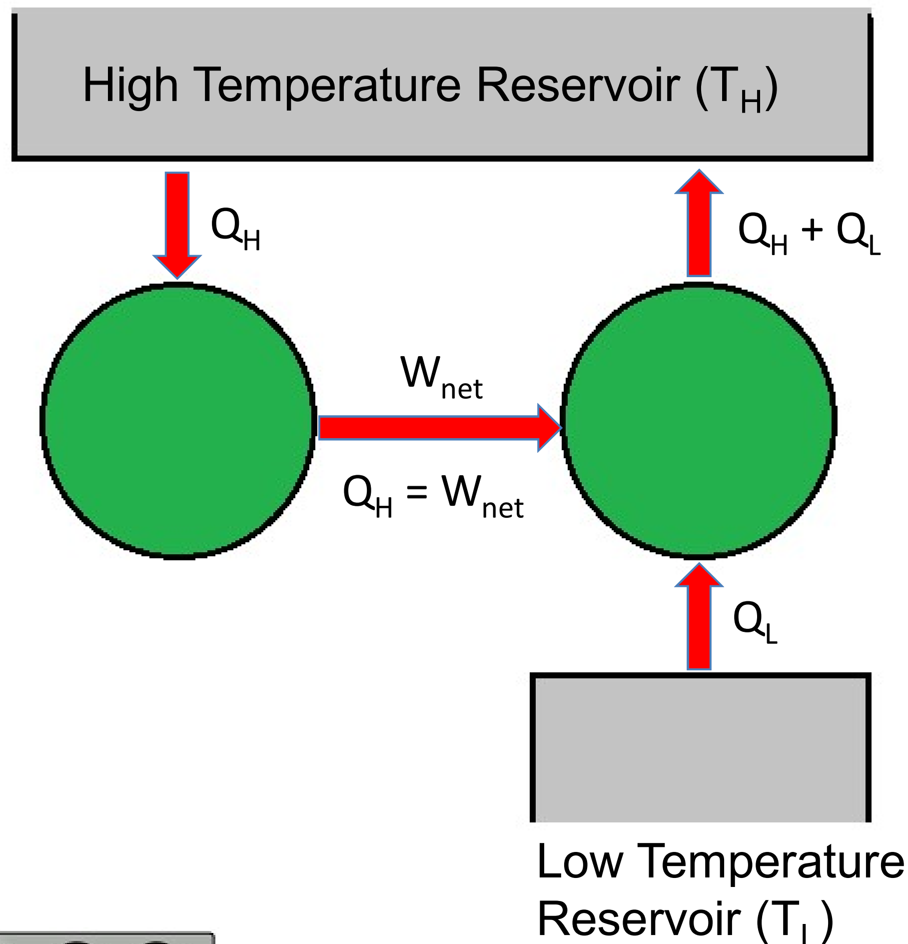
Equivalence of the Kelvin-Planck and Clausius Statements

In violating the Kelvin statement, imagine that there is an engine which used to drain and converts heat from high temperature reservoir into work. Then the engine is paired with reserve carnot engine which used to transfer heat from low temperature reservoir to high temperature reservoir. These two statement is said to be equivalent since the violation of the Kelvin statement implies a violation of the Clausius statement, and vice versa. This equivalent will remain constant in case of ideal and steady state condition.



Thus, the 2nd law of thermodynamic is the equivalent of two statements, it can be summarized that the total entropy can remain constant in case of ideal and steady state condition. The total entropy in a system will be increased over time for a system.

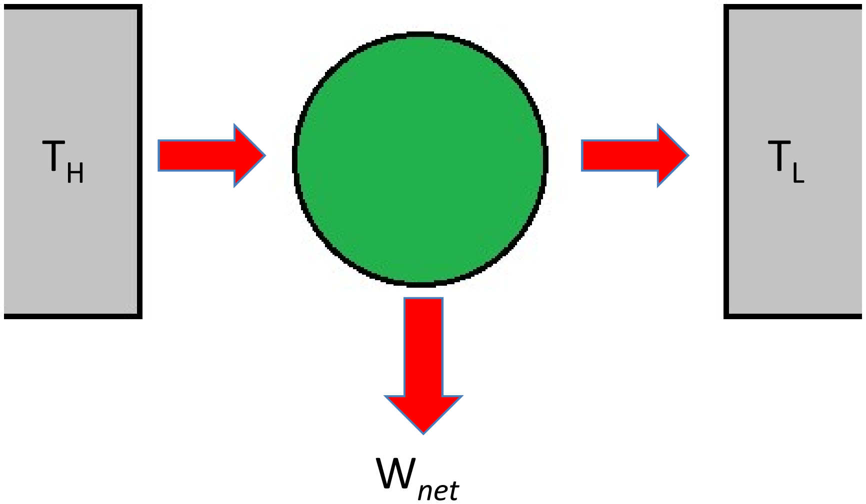
Carnot Cycle

The **Carnot cycle** is a theoretical thermodynamic cycle and the most efficient cycle in thermodynamics system. It provides an upper limit on the efficiency that any classical thermodynamic engine can achieve during the conversion of thermal energy into work, or conversely.

Carnot Cycle can be divided into two: 1) **Carnot heat engine** and 2) **Reverse Carnot cycle**

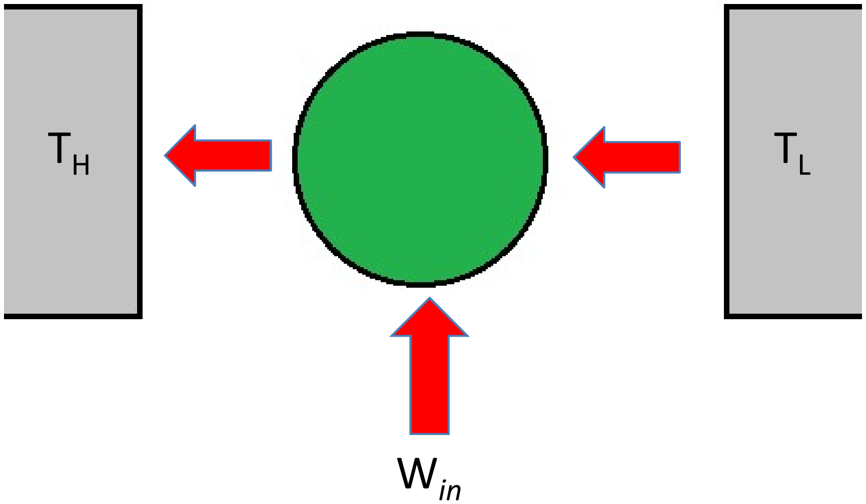
1) **Carnot heat engine:** Is a thermodynamics cycle or system which converts partly heat from high reservoir into mechanical work. Then, the remaining of the heat will be rejected into low temperature reservoir.
2) **Reverse Carnot cycle:** Describe a totally reversible Carnot heat-engine cycle. All the processes that comprise Carnot heat engine can be reversed becomes the Carnot refrigeration cycle. In this cycle, the processes are exactly the same except that the all directions are reversed.

Carnot Heat Engine



Example: Heat engine

Reverse Carnot Cycle



Example: Refrigerator

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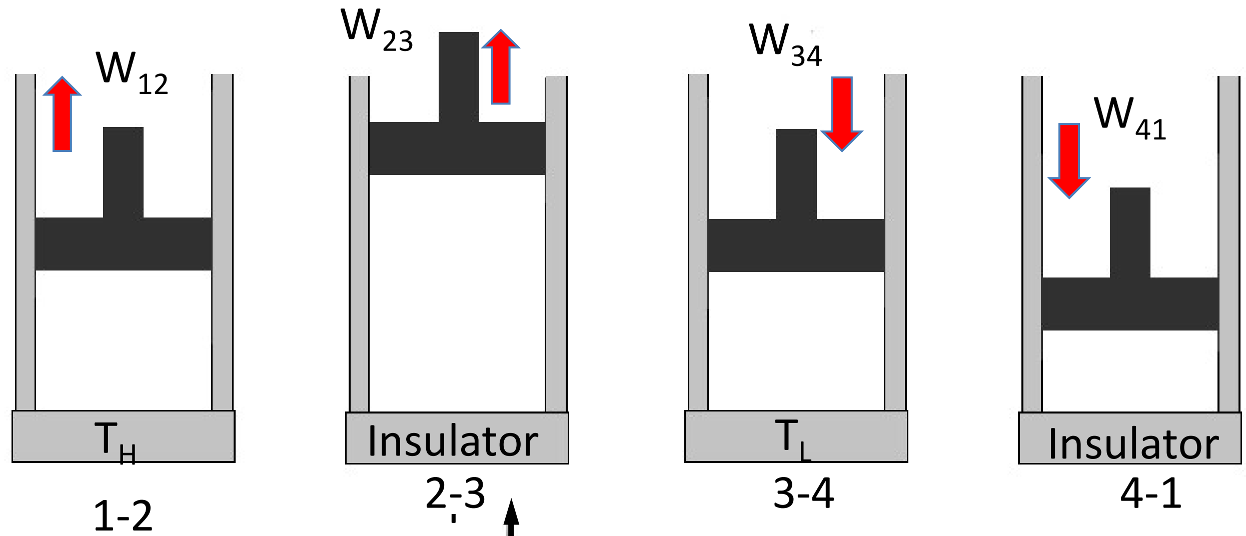
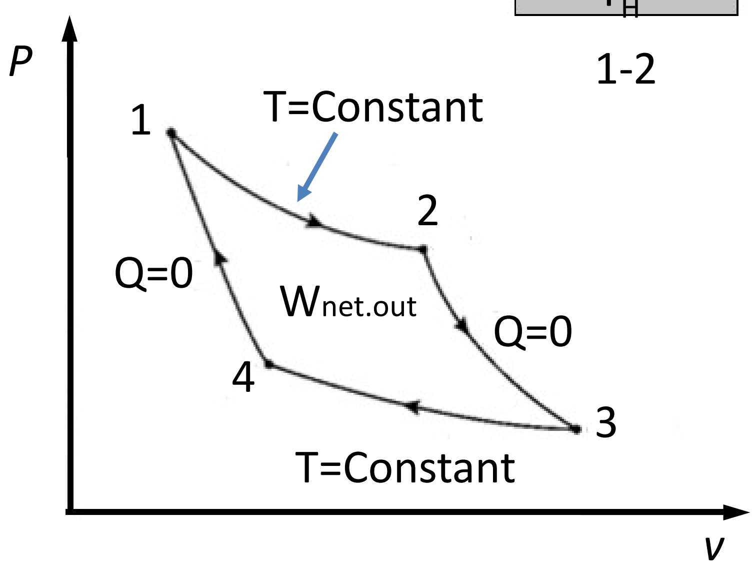
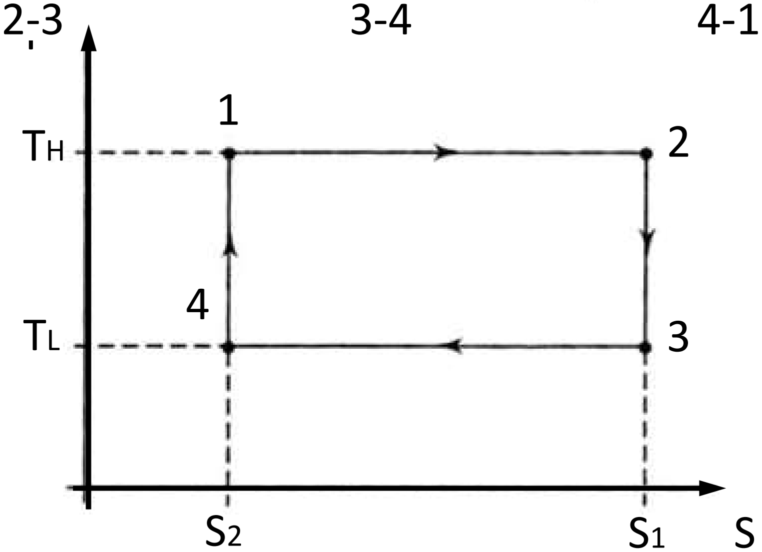
Review of Carnot Cycle

1-2-3: work done by the gas
3-4-1: work done on the gas







4 processes:

1-2: Isothermal expansion

2-3: Adiabatic expansion

3-4: Isothermal compression

4-1: Adiabatic compression

Thus, the amount of energy transferred as work is

$$W = \oint PdV = \oint Tds$$
$$= (T_H - T_L)(S_2 - S_1)$$

The total amount of thermal energy transferred from the higher reservoir to the system is

$$Q_H = T_H (S_2 - S_1)$$

and the total amount of thermal energy transferred from the lower reservoir to the system is

$$Q_L = T_L (S_2 - S_1)$$

and the efficiency is define as:

$$\eta = \frac{W}{Q_H} = 1 - \frac{T_L}{T_H}$$

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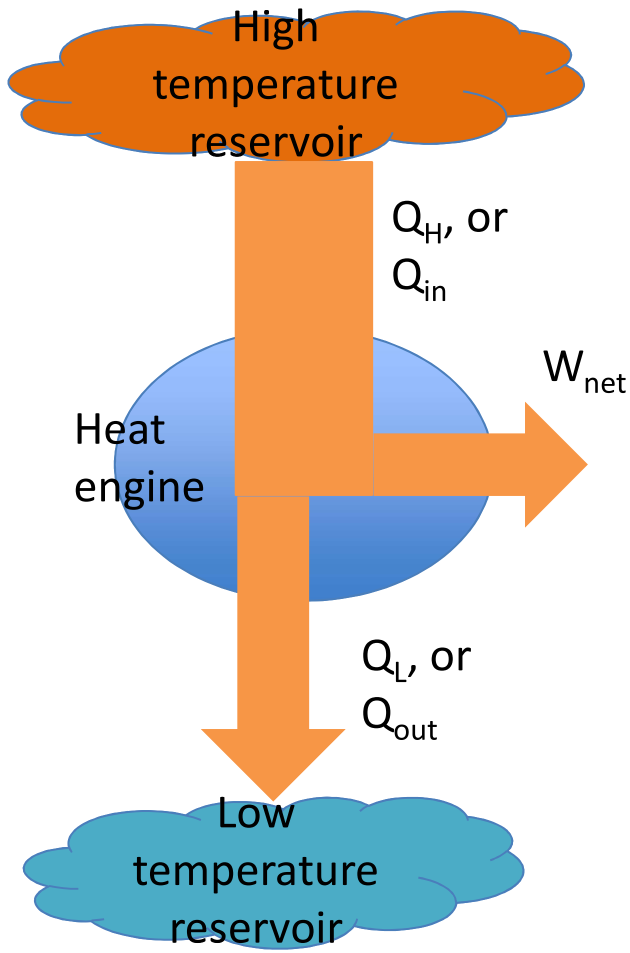
Heat Engine

Heat engine is a device or system that converts **heat** into **work**.

The device receives heat from a high-temperature reservoir (solar energy, oil furnace, nuclear reactor, etc.), then converts part of this heat into work (**rotating shaft**.). It rejects the remaining waste heat to a low-temperature reservoir (the atmosphere, rivers, etc.).

Heat engines and other cyclic devices usually involve a fluid to and from at which the heat is transferred while undergoing a process. The fluid is called the **working fluid**.



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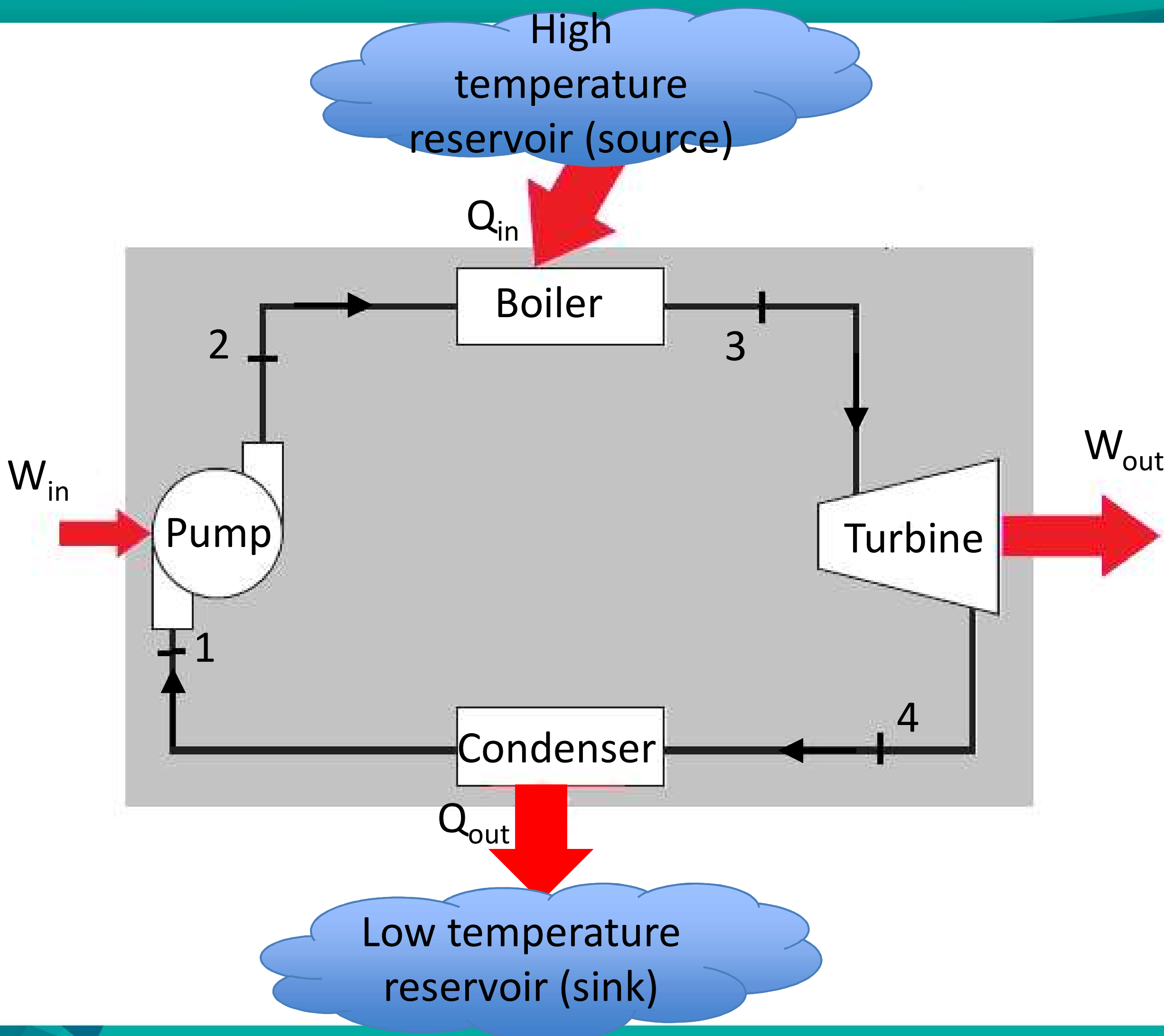
Steam Power Plant



The net work output is obtained by:

$W_{net} = W_{out} – W_{in}$ (kJ)

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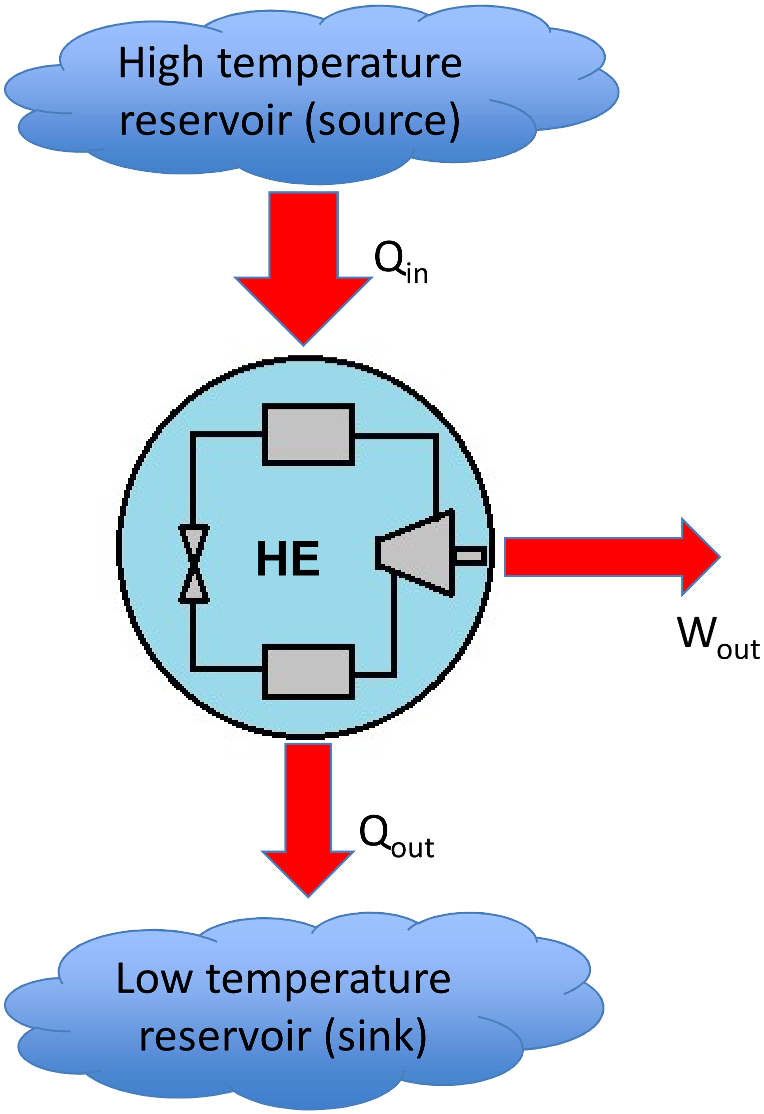
Thermal Efficiency of Steam Power Plant



$$W_{\text{net,out}} = Q_H - Q_L$$

$$\eta_{\text{th}} = \frac{W_{\text{net,out}}}{Q_H}$$

$$\eta_{\text{th}} = 1 - \frac{Q_L}{Q_H}$$

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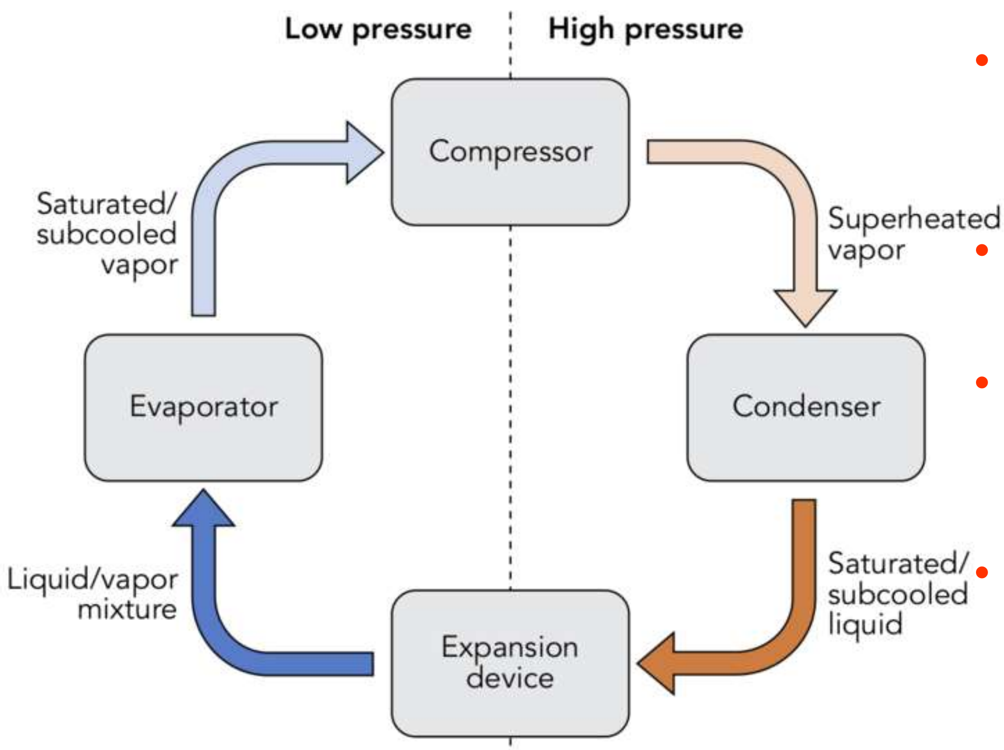
Refrigeration



Source: https://en.wikipedia.org

- System that transfer the heat from a low-temperature reservoir to a high-temperature one.
- Refrigerators, like heat engines, are cyclic devices.
- The working fluid used in the refrigeration cycle is called a refrigerant.
- The most frequently used refrigeration cycle is the vapor-compression refrigeration cycle.

Coefficient of Performance

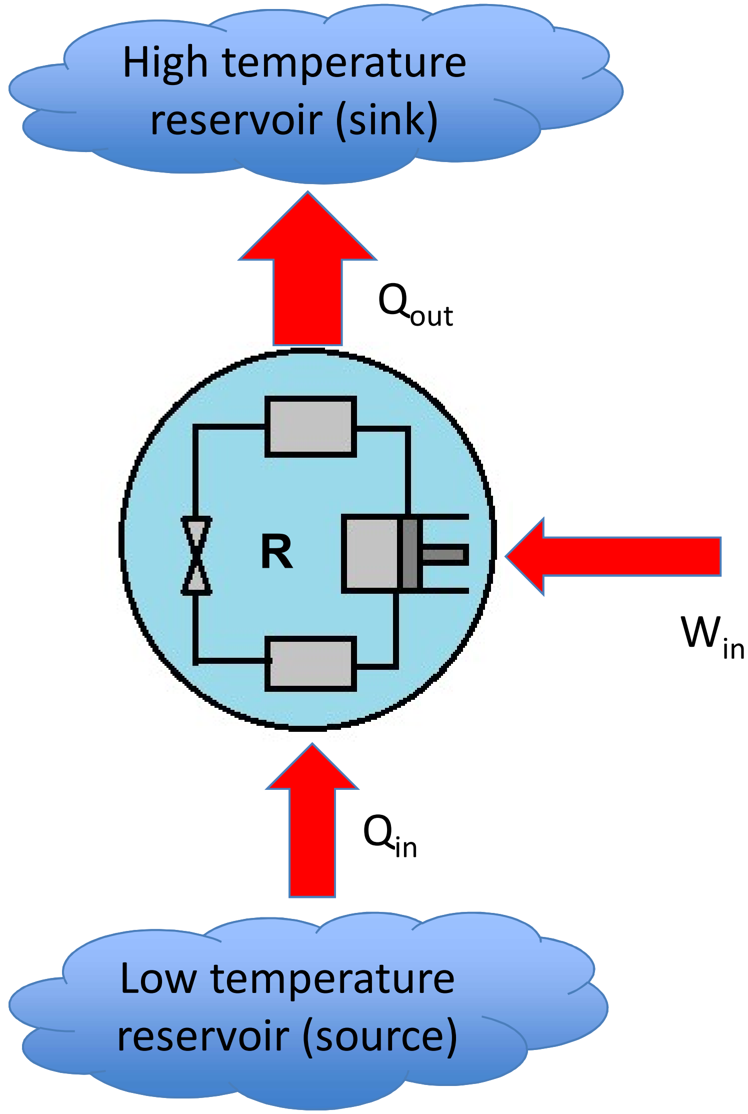
The *efficiency* of a refrigerator is expressed in terms of the coefficient of performance (COP).

The objective of a refrigerator is to remove heat (Q_L) from the refrigerated space. Thus:

$$\text{COP}_\text{R} = \frac{\text{Desired output}}{\text{Required input}} = \frac{Q_L}{W_{\text{net,in}}}$$

$$W_{\text{net,in}} = Q_H - Q_L \qquad (\text{kJ})$$

$$\text{COP}_\text{R} = \frac{Q_L}{Q_H - Q_L} = \frac{1}{Q_H/Q_L - 1}$$



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Conclusion

- Conclusion #1
  - First law thermodynamics concern on conservation of energy which applied to the thermodynamics cycles.
  - The second law thermodynamics establish based on Kelvin and Clausius statements. These two statements are said to be equivalent since the violation of the Kelvin statement implies a violation of the Clausius statement, and vice versa. This equivalent will remain constant in case of ideal and steady state condition.

- Conclusion #2
  - Carnot cycle is the most efficient thermodynamics cycle.
  - It can be applied to heat engine, steam power plant and refrigeration system.

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