

Stirling Cycle

In Stirling cycle, Carnot cycle's compression and expansion isentropic processes are replaced by two constant-volume regeneration processes.

During the regeneration process heat is transferred to a thermal storage device (regenerator) during one part and is transferred back to the working fluid in another part of the cycle.

The regenerator can be a wire or a ceramic mesh or any kind of porous plug with a high thermal mass (mass times specific heat). The regenerator is assumed to be reversible heat transfer device.

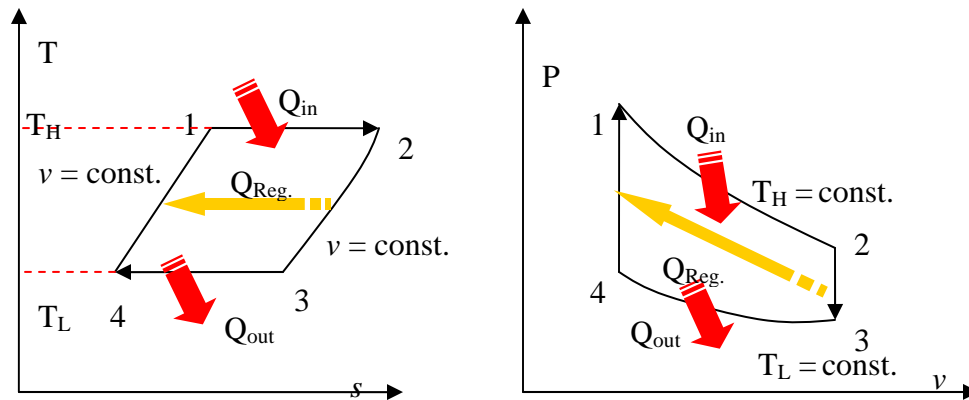


Fig. 3-2: T-s and P-v diagrams for Stirling cycle.

1-2	isothermal expansion	heat addition from external source
2-3	const. vol. heat transfer	internal heat transfer from the gas to the regenerator
3-4	isothermal compression	heat rejection to the external sink
4-1	const. vol. heat transfer	internal heat transfer from the regenerator to the gas

The Stirling cycle was invented by Robert Stirling in 1816. The execution of the Stirling cycle requires innovative hardware. That is the main reason the Stirling cycle is not common in practice.

Working Principle

The system includes two pistons in a cylinder with a regenerator in the middle. Initially the left chamber houses the entire working fluid (a gas) at high pressure and high temperature T_H .

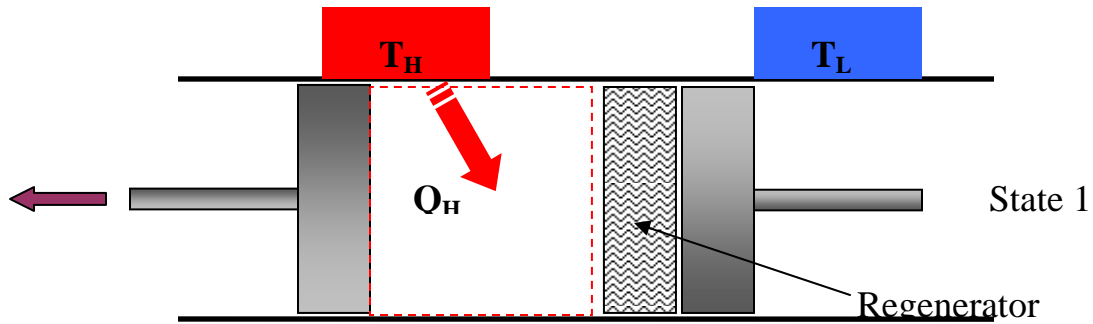


Fig 3-3a: 1-2, isothermal heat transfer to the gas at T_H from external source. As gas expands isothermally, left piston moves outward, doing work and the gas pressure drops.

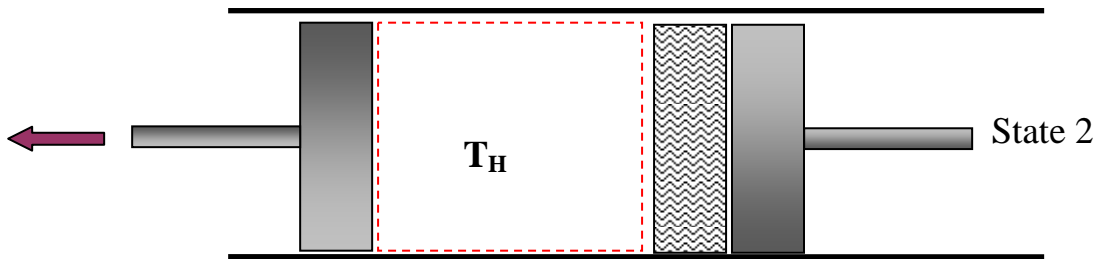


Fig. 3-3b: 2-3, both pistons move to the right at same rate, keeping const. volume, until the entire gas pushed to the right chamber (passing thru the regenerator). Heat is transferred to the regenerator and gas temperature drops to T_L .

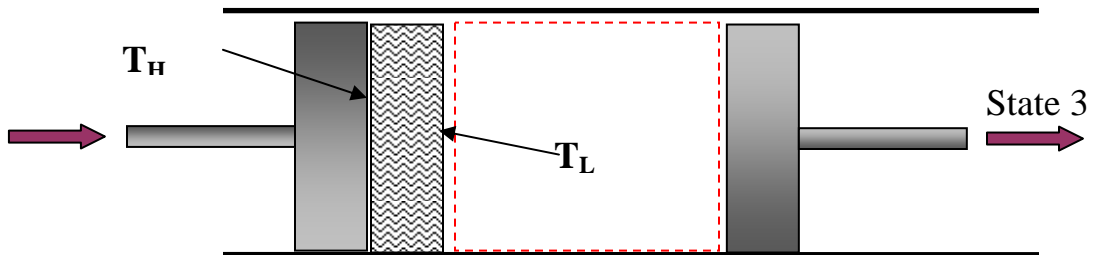


Fig. 3-3c: 3-4, the right piston is moved to the left, compressing the gas. Heat transfers (isothermally) from the gas to the external heat source at T_L , so the gas temperature remains at T_L while the pressure rises.

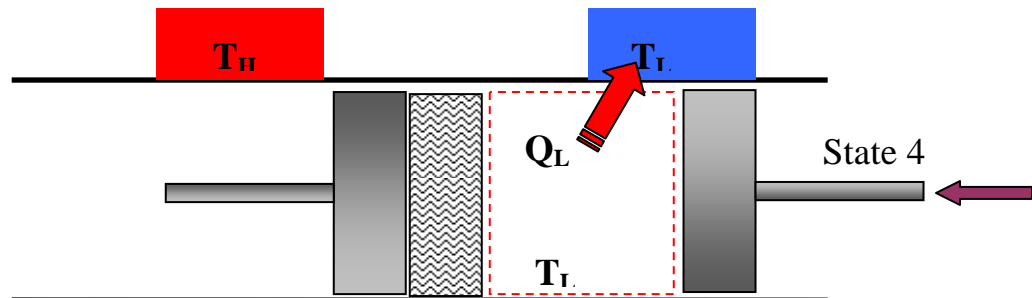


Fig. 3-3d: 4-1 both pistons are moved to the left at the same rate (keeping const volume) forcing the gas thought the regenerator into the left chamber. The gas temperature rises to T_H and cycle completes.

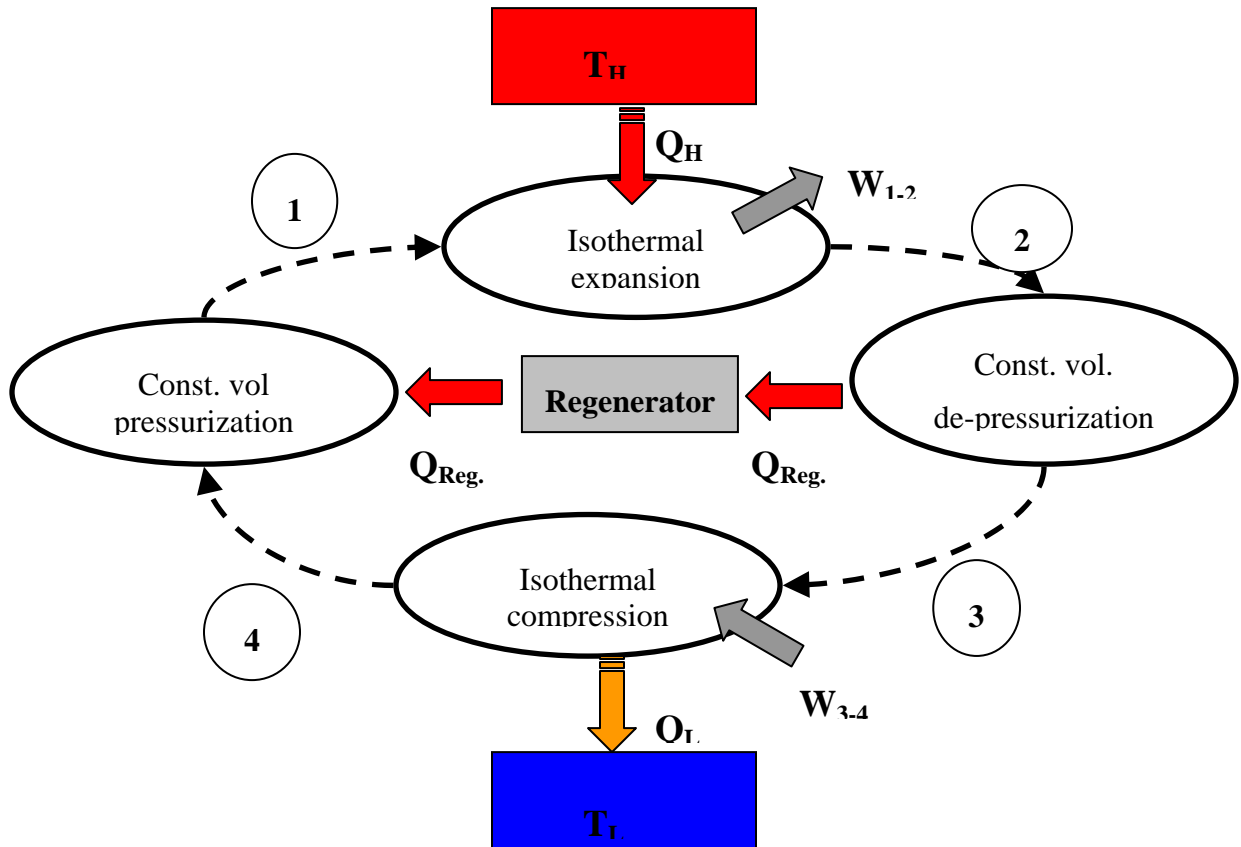


Fig. 3-4: Stirling cycle.

Notes:

- Unlike internal combustion engines, a Stirling cycle does not exchange the working gas in each cycle, the gas is permanent.
- The heat is supplied outside the engine, so any heat source can be used, e.g.: coal, gas, solar energy, nuclear power, etc.
- Stirling engine can reach higher thermal efficiencies than Otto and Diesel engines, since heat transfer occurs at constant temperatures, i.e., its thermal efficiency is the same as the Carnot cycle:

$$\eta_{th,Stirling} = 1 - \frac{T_L}{T_H}$$

- The pressure changes are very smooth and its torque is uniform, it has no valves, exhaust pipes, etc. Thus, Stirling cycle is quiet and has less maintenance points.
- To achieve competitive efficiency, it needs to work on high pressures which cause tremendous problems of sealing.

- The temperature difference $T_L - T_H$ should maintain high for acceptable thermal efficiencies, this results in large thermal stresses in the cylinder (hot and cold ends). Consequently, high strength expensive materials should be used.
- The working fluid has to be an ideal gas. Helium or hydrogen are typically used because of their high heat conductivity and low molecular masses which lead to faster heat transfer.
- Fast changes in power output are not easy to achieve which makes the Stirling cycle not so attractive for automotive applications.

The Reversed Cycle (Heat Pump and Refrigerator)

If the engine is driven by a motor, and the process curves in the T-s and P-v diagrams run counter clockwise, the Stirling cycle operates as a refrigerator and/or heat pump.

The coefficient of performance for Stirling cycle is:

$$COP_{Ref} = \frac{T_L}{T_H - T_L} \quad COP_{HP} = \frac{T_H}{T_H - T_L}$$

Note that the COP's of the Stirling cycle are the same as the Carnot cycle.