Internal Combustion Engine 1

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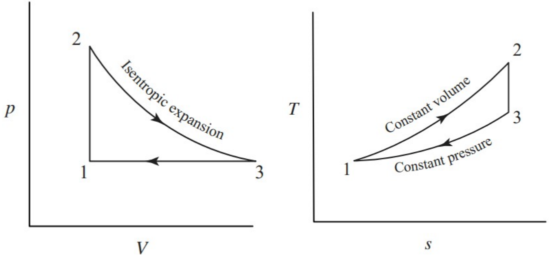
The Lenoir Cycle

The Lenoir Cycle

- The Lenoir cycle consists of the following processes:
  - Constant volume heat addition (1 → 2)
  - Isentropic expansion (2 → 3)
  - Constant pressure heat rejection (3 → 1)
- The Lenoir cycle is commonly used for pulse jet engines.



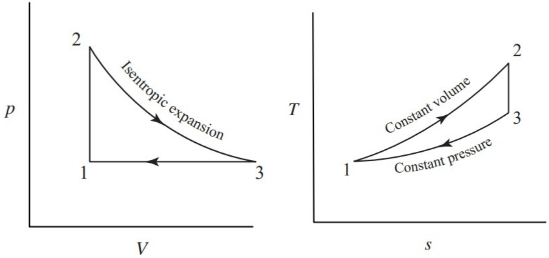
The Lenoir Cycle

- The efficiency of the Lenoir cycle is given by:

$$\eta_{\text{Lenoir}} = \frac{Q_S - Q_R}{Q_S}$$

$$Q_S = mC_v(T_2 - T_1)$$

$$Q_R = mC_p(T_3 - T_1)$$

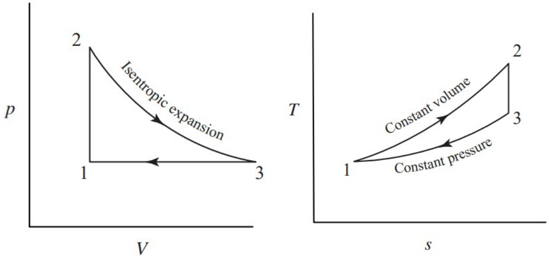


The Lenoir Cycle

- The efficiency of the Lenoir cycle is given by:

$$\eta_{\text{Lenoir}} = \frac{mC_v(T_2 - T_1) - mC_p(T_3 - T_1)}{mC_v(T_2 - T_1)}$$

$$\eta_{\text{Lenoir}} = 1 - \gamma\left(\frac{T_3 - T_1}{T_2 - T_1}\right)$$



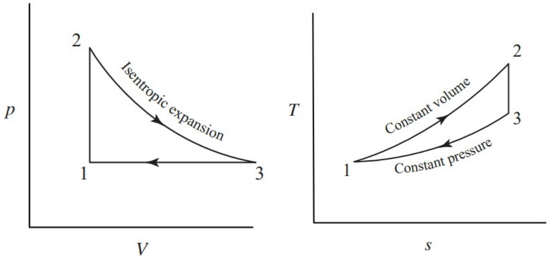
Efficiency of the Lenoir Cycle

- Given $p_2/p_1 = r_p$, the temperatures can be calculated as:

$$T_2 = T_1 r_p$$

$$T_3 = T_2 \left(\frac{p_3}{p_2}\right)^{\frac{\gamma-1}{\gamma}} = T_2 \left(\frac{1}{r_p}\right)^{\frac{\gamma-1}{\gamma}}$$

$$T_3 = T_1 r_p^{\frac{1}{\gamma}} \left(\frac{1}{r_p}\right)^{\frac{\gamma-1}{\gamma}} = T_2 r_p^{\frac{1}{\gamma}}$$

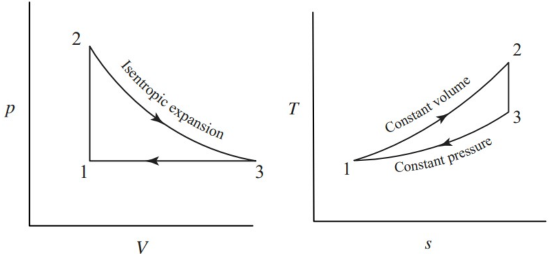


Efficiency of the Lenoir Cycle

- The efficiency formula becomes:

$$\eta = 1 - \gamma \left(\frac{r_p^{\frac{1}{\gamma}} - 1}{r_p - 1} \right)$$

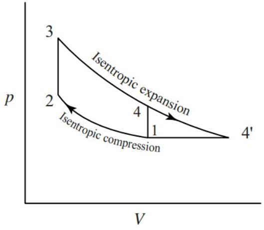
- The efficiency of the Lenoir cycle depends on the pressure ratio r_p and the ratio of specific heats γ.

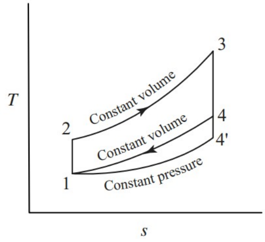


The Atkinson Cycle

The Atkinson Cycle

- The Atkinson cycle is an ideal cycle for an Otto engine exhausting to a gas turbine.
- In this cycle, the isentropic expansion $(3 \rightarrow 4)$ of an Otto cycle (1234) is extended.
- This extension allows the expansion to proceed to the lowest cycle pressure, increasing work output.

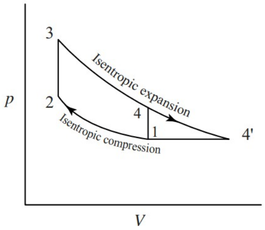


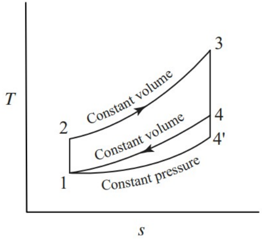


The Atkinson Cycle

- With this modification, the cycle is known as the Atkinson cycle.
- The efficiency of the Atkinson cycle is given by:

$$\eta_{\text{Atkinson}} = \frac{Q_S - Q_R}{Q_S}$$



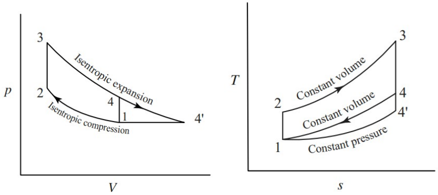


The Atkinson Cycle

- Substituting heat quantities:

$$\eta_{\text{Atkinson}} = \frac{mC_v(T_3 - T_2) - mC_p(T_4' - T_1)}{mC_v(T_3 - T_2)}$$

$$\eta_{\text{Atkinson}} = 1 - \gamma\left(\frac{T_4' - T_2}{T_3 - T_2}\right)$$



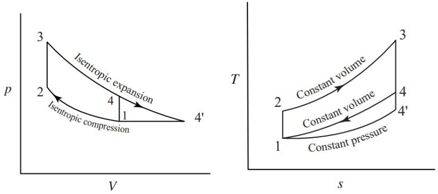
The Atkinson Cycle

- Define compression ratio:

$$r = \frac{V_1}{V_2}$$

- Define expansion ratio:

$$e = \frac{V_4'}{V_3}$$

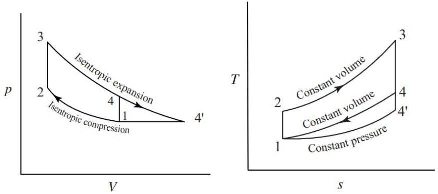


The Atkinson Cycle

- For temperature relations:

$$\frac{T_2}{T_1} = \left(\frac{V_1}{V_2}\right)^{\gamma-1}$$

$$T_2 = T_1 \left(\frac{V_1}{V_2}\right)^{\gamma-1} = T_1 r^{\gamma-1}$$



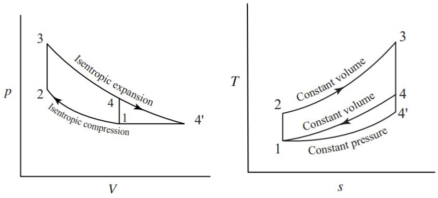
The Atkinson Cycle

- For temperature relations:

$$\frac{T_3}{T_2} = \frac{p_3}{p_2} = \left(\frac{p_3}{p_{4'}}\frac{p_{4'}}{p_2}\right) = \left(\frac{p_3}{p_{4'}}\frac{p_1}{p_2}\right)$$

$$\frac{p_3}{p_{4'}} = \left(\frac{V_{4'}}{V_3}\right)^{\gamma} = e^{\gamma}$$

$$\frac{p_1}{p_2} = \left(\frac{V_2}{V_1}\right)^{\gamma} = \frac{1}{r^{\gamma}}$$

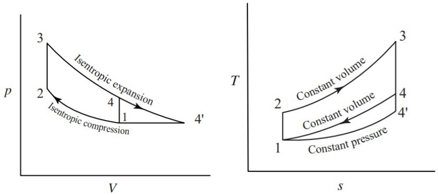


The Atkinson Cycle

- For temperature relations:

$$\frac{T_3}{T_2} = \frac{e^\gamma}{r^\gamma}$$

$$T_3 = T_2 \frac{e^\gamma}{r^\gamma} = T_1 r^{\gamma-1} \frac{e^\gamma}{r^\gamma}$$



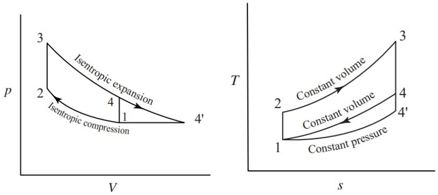
The Atkinson Cycle

- For temperature relations:

$$\frac{T_{4'}}{T_3} = \left(\frac{V_3}{V_{4'}}\right)^{(\gamma-1)} = \frac{1}{e^{(\gamma-1)}}$$

$$T_{4'} = T_3 \frac{1}{e^{(\gamma-1)}} = T_1 r^{\gamma-1} \frac{e^{\gamma}}{r^{\gamma}} \frac{1}{e^{(\gamma-1)}}$$

$$T_{4'} = T_1 \frac{e}{r}$$

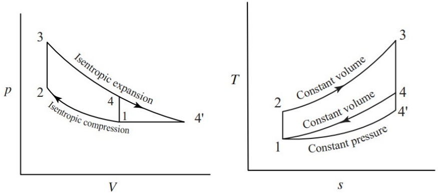


The Atkinson Cycle

- Substituting the temperature relations:

$$\eta_{\text{Atkinson}} = 1 - \gamma \frac{e - r}{e^{\gamma} - r^{\gamma}}$$

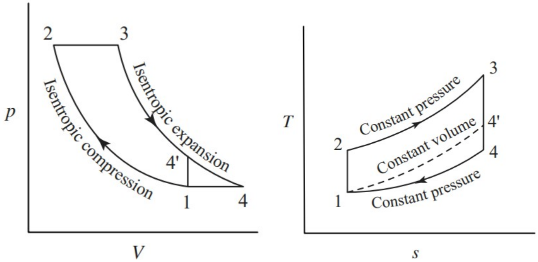
- The final expression shows that efficiency depends on the compression ratio r, expansion ratio e, and the specific heat ratio γ.



The Brayton Cycle

The Brayton Cycle

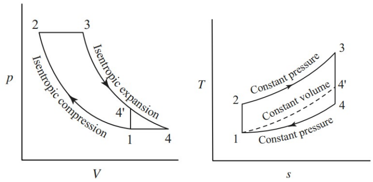
- Brayton cycle is a theoretical cycle for gas turbines.
- Consists of two reversible adiabatic (isentropic) processes and two constant pressure processes.
- Similar to Diesel cycle in compression and heat addition.
- Extended isentropic expansion followed by constant pressure heat rejection.



Efficiency of Brayton Cycle

$$\eta_{Brayton} = \frac{Q_S - Q_R}{Q_S} = \frac{mC_p(T_3 - T_2) - mC_p(T_4 - T_1)}{mC_p(T_3 - T_2)}$$

$$\eta_{Brayton} = 1 - \frac{T_4 - T_1}{T_3 - T_2}$$

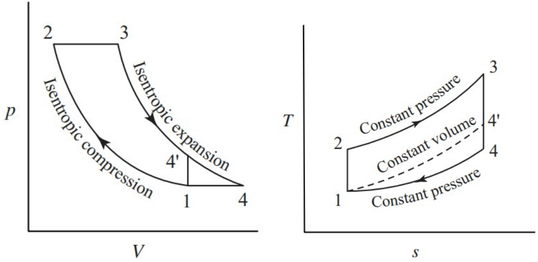


Efficiency of Brayton Cycle

- Compression ratio: $r = \frac{V_1}{V_2}$
- Pressure ratio: $r_p = \frac{p_2}{p_1}$
- For the Brayton cycle:

$$\frac{T_3}{T_4} = \left(\frac{p_3}{p_4}\right)^{\frac{\gamma-1}{\gamma}} = \left(\frac{p_2}{p_1}\right)^{\frac{\gamma-1}{\gamma}}$$

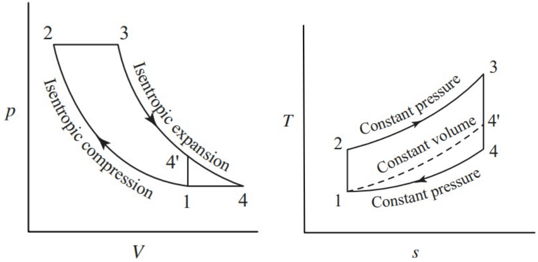
$$\frac{T_3}{T_4} = \left(\frac{V_1}{V_2}\right)^{\gamma-1} = r^{\gamma-1}$$



Efficiency of Brayton Cycle

$$T_4 = \frac{T_3}{r^{\gamma-1}}$$

$$T_1 = \frac{T_2}{r^{\gamma-1}}$$

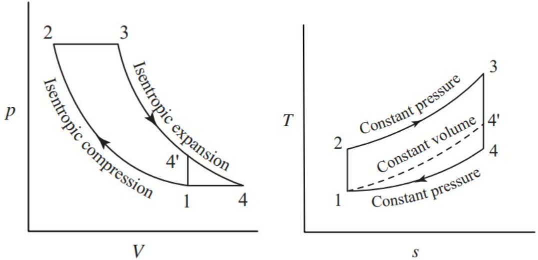


Efficiency of Brayton Cycle

$$\eta_{Brayton} = 1 - \frac{1}{r^{\gamma-1}}$$

$$r = \frac{V_1}{V_2} = \left(\frac{p_2}{p_1}\right)^{\frac{1}{\gamma}} = r_p^{\frac{1}{\gamma}}$$

$$\eta_{Brayton} = 1 - \frac{1}{\left(r_p^{\frac{1}{\gamma}}\right)^{\gamma-1}} = 1 - \frac{1}{(r_p)^{\frac{\gamma-1}{\gamma}}}$$



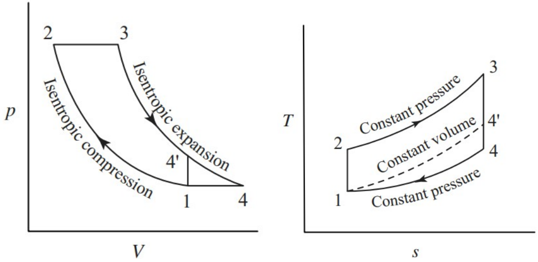
- Efficiency depends on the pressure ratio r_p and specific heat ratio γ.

Work Output of Brayton Cycle

- Network output = Expansion work - Compression work
- Network output = $C_p(T_3 - T_4) - C_p(T_2 - T_1)$

$$W = C_p T_1 \left(\frac{T_3}{T_1} - \frac{T_4}{T_1} - \frac{T_2}{T_1} + 1 \right)$$

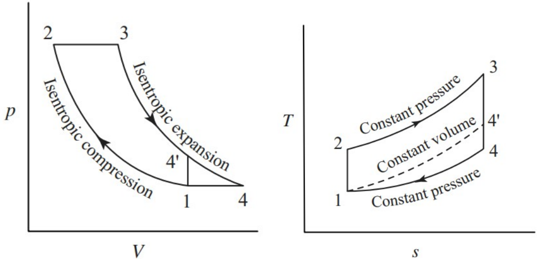
$$\frac{W}{C_p T_1} = \left(\frac{T_3}{T_1} - \frac{T_4}{T_1} - \frac{T_2}{T_1} + 1 \right)$$



Work Output of Brayton Cycle

$$\frac{W}{C_p T_1} = \left(\frac{T_3}{T_1} - \frac{T_4}{T_1} - \frac{T_2}{T_1} + 1\right)$$

- Work output depends on:
    - Initial temperature T_1
    - Ratio $\frac{T_3}{T_1}$
    - Pressure ratio r_p
    - Specific heat ratio γ



End of Lecture 15