Thermodynamics #6

Heat engine

cyclic process converting $Q_+$ to $W$.

$\Delta U = 0$

$e = \frac{W}{Q_+}$

idealized as reversible process of ideal gas

Note: friction is an irreversible process

reversible refers to direction of time

$W = (P_2 - P_1)(V_2 - V_1)$

$Q = nC_p(T_4 - T_3) - nC_v(T_4 - T_2)$

$\quad - nC_p(T_2 - T_1) + nC_v(T_2 - T_1)$
gasoline engine (Otto cycle)

Steps 1, 3 are adiabatic ($Q = 0$)
Steps 2, 3 are $W = 0$

$$Q_1 - W_2 + Q_c - W_3 = \Delta U = 0$$

Here $W_2 < 0$, $Q_c < 0$

$$e = \frac{Q_1 - |Q_c|}{Q_1} = 1 - \frac{|Q_c|}{Q_1}$$

$$\frac{|Q_c|}{Q_1} = \frac{nC_v(T_d - T_a)}{nC_v(T_c - T_b)} = \frac{T_d - T_a}{T_c - T_b}$$

Introduce compression ratio $r = \frac{V_f}{V_i}$

For adiabatic (1)

$$\frac{T_a V_f^{\gamma - 1}}{T_b V_i^{\gamma - 1}} = \frac{T_a}{T_b} r^{\gamma - 1} = 1$$

Pronounced:

$$\frac{T_d}{T_c} r^{\gamma - 1} = 1$$
\[ \frac{Q_d}{Q^*} = \frac{T_d - T_a}{k^* - 1 (T_d - T_a)} \]

giving \( e = 1 - T^{-1} \) idealized Otto

for air \((\gamma = 1.4)\) and \( r = 10 \)

\[ e = 1 - 10^{-1.4} = 60\% \]

not also:

\[ r^{* - 1} = \frac{T_0}{T_a} = \frac{T_e}{T_a} \]

\[ S \ e = 1 - \frac{T_a}{T_0} = 1 - \frac{T_e}{T_a} \]

Since engine is idealized, this is the best you can do.

This is the second law.
Stirling engine

\[ W = Q_H - |Q_C| = nR(T_H - T_C) \ln r \]

\[ \frac{|Q_C|}{Q_H} = \frac{nRT_C \ln r}{nRT_H \ln r} = \frac{T_C}{T_H} \]

\[ \varepsilon = 1 - \frac{T_C}{T_H} \]

Carnot engine

Steps:
2.4 are adiabatic

\[ W_2 = -\Delta U = -nC_v(T_H - T_C) \]
\[ W_4 = -\Delta U = +nC_v(T_H - T_C) \]

\[ W_2 + W_4 = 0 \]
\[ W = \frac{Q_c}{T_c} - (P_c) \]
\[ e = 1 - \frac{Q_c}{Q_H} \]

\[ |Q_c| = nRT_c \ln \left( \frac{V_a}{V_b} \right) \]

\[ Q_H = nRT_H \ln \left( \frac{V_d}{V_e} \right) \]

but since 2, 4 are adiabatic:

\[ \frac{T_H V_d^{-1}}{T_H V_c^{-1}} = \frac{T_c V_a}{T_c V_b} \]

\[ \frac{V_d}{V_e} = \frac{V_a}{V_b} \]

\[ \frac{|Q_c|}{Q_H} = \frac{T_c}{T_H} \]

adiabatic process

\[ e = 1 - \frac{T_c}{T_H} \]

idealized

Cannot super
The Entropy

\[ T_1, T_2 \text{ are constant entropy curves} \]

\[ \Delta Q_{ab} \text{ depends on the thermodynamic path} \]

However, adiabatic paths \( T_i V_i = \sigma_i \) are unique so

\[ \Delta Q_{ab} = nRT_2 \ln \left( \frac{V_b}{V_c} \right) \]

\[ = nRT_2 \ln \left( \frac{T_2^0 S_2}{T_2^0 S_1^{1/4}} \right) \]

\[ \Delta Q_{ab} \frac{T_2}{T_2} = \left[ \frac{nRT_2}{J-1} \right] (\ln T_2 - \ln \sigma_1) = \Delta S_{12} \]

\( \Delta S_{12} \) is path independent.

\[ dS = \frac{dQ}{T} \text{ is path independent} \]