

Air Standard Otto Cycle

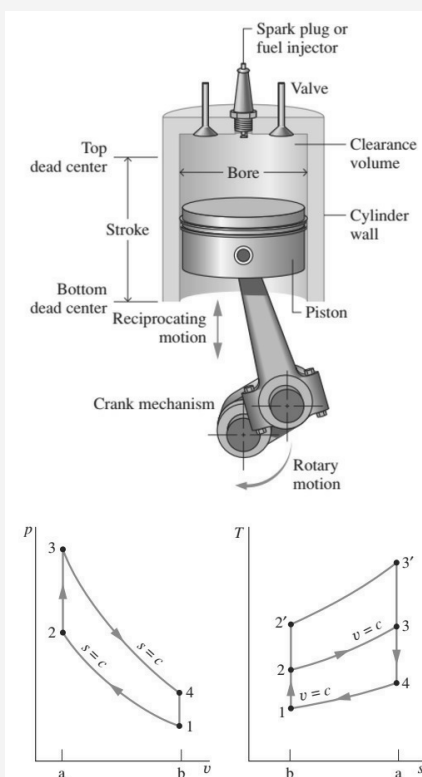
Process 1–2: An isentropic compression of the air as the piston moves from bottom dead center to top dead center.

Process 2–3: A constant-volume heat transfer to the air from an external source while the piston is at top dead center. This process is intended to represent the ignition of the fuel–air mixture and the subsequent rapid burning.

Process 3–4: An isentropic expansion (power stroke).

Process 4–1: Completes the cycle by a constant-volume process in which heat is rejected from the air while the piston is at bottom dead center.

Air Standard Otto Cycle Diagram and Schematic



$$\eta = \frac{(u_3 - u_2) - (u_4 - u_1)}{u_3 - u_2} = 1 - \frac{u_4 - u_1}{u_3 - u_2}$$

$$\eta = 1 - \frac{1}{r^{k-1}} \quad (\text{cold air-standard basis})$$

Second Law

Second Law of Thermodynamics

$$\oint \left(\frac{\delta Q}{T} \right)_b = -\sigma_{cycle}$$

$$\frac{dS}{dt} = \frac{\dot{Q}}{T} + \sum \dot{m}_i s_i - \sum \dot{m}_e s_e + \dot{\sigma}$$

$$S_2 - S_1 = \int_1^2 \left(\frac{\delta Q}{T} \right)_b + \sigma$$

Efficiencies

$$\text{Power} = 1 - Q_C / Q_H$$

$$\text{Turbine} = W_{ACTUAL} / W_{IDEAL}$$

$$\text{Refrigeration} = Q_C / Q_H - Q_C$$

$$\text{Comp or Pump} = W_{IDEAL} / W_{ACTUAL}$$

$$\text{Heat} = Q_H / Q_H - Q_C$$

$$\text{Regenerator} = Q_{ACTUAL} / Q_{IDEAL}$$

Ideal Gases

$$pV = RT$$

$$pV = mRT$$

$$C_P = C_V + R$$

$$\text{Polytropic Process:}$$

$$k = C_P / C_V$$

$$P_R = P / P_C$$

$$T_R = T / T_C$$

$$pV^n = \text{constant}$$

Exact Analysis of Isentropic Process for Ideal Air

$$P_{R2} / P_{R1} = P_1 / P_2$$

$$V_{R2} / V_{R1} = V_2 / V_1$$

$$\text{Pressure ratio} = P_2 / P_1$$

Exact Analysis of Entropy Change in Ideal Gases

$$\Delta s = \int_{T_1}^{T_2} \frac{C_P}{T} dT - R \ln(p_2/p_1) = s_2^* - s_1^* - R \ln(p_2/p_1) = \int_{T_1}^{T_2} \frac{C_P}{T} dT + R \ln(v_2/v_1) \quad \Delta h = \int_{T_1}^{T_2} C_P dT$$

Air Standard Diesel Cycle

The air-standard Diesel cycle is an ideal cycle that assumes heat addition occurs during a constant-pressure process that starts with the piston at top dead center. The cycle consists of four internally reversible processes in series.

Process 1-2 is the same as in the Otto cycle: an isentropic compression. Heat is not transferred to the working fluid at constant volume as in the Otto cycle, however. **In the Diesel cycle, heat is transferred to the working fluid at constant pressure.**

Process 2-3 also makes up the first part of the power stroke.

Process 3-4 is an isentropic expansion and is the remainder of the power stroke.

Process 4-1 As in the Otto cycle, the cycle is completed by a constant-volume process in which heat is rejected from the air while the piston is at bottom dead center. This process replaces the exhaust and intake processes of the actual engine.

Miscellaneous

$$Tds = du + pdv$$

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$$x = M_{\text{VAPOR}} / M_{\text{TOTAL}}$$

$$S = S_f + (x)S_{fg} = S_f(1 - x) + S_g$$

$$\text{Expansion valve: } \Delta h = 0$$

$$\text{Condensor: } Q_{\text{OUT}}$$

$$\text{Evaporator: } Q_{\text{IN}}$$

$$\text{First law: } E_{\text{IN}} - E_{\text{OUT}} = \Delta E_{\text{SYSTEM}}$$

$$h = u + pv$$

$$W = VI \text{ (electrical)}$$

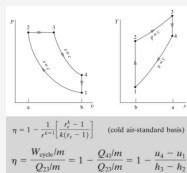
Specific Heat

Isentropic Relationships for gases with constant specific heat
 $P_2/P_1 = (v_2/v_1)^{\gamma}$; $T_2/T_1 = (P_2/P_1)^{(\gamma-1)/\gamma} = (v_2/v_1)^{\gamma-1}$

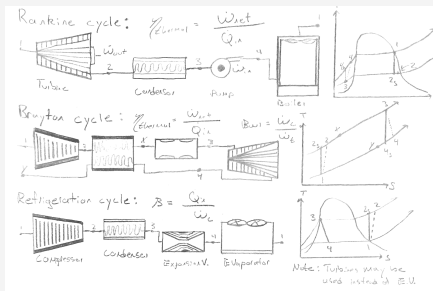
Solid / Liquid Relationships
 $\Delta u = \Delta h = c \Delta T$; $\Delta s = c \ln \left(\frac{T_2}{T_1} \right)$
 $\Delta u = c_v \Delta T$; $\Delta h = c_p \Delta T$
 $\Delta s = c_p \ln \frac{T_2}{T_1} + R \ln \frac{P_2}{P_1} = c_p \ln \frac{T_2}{T_1} - R \ln \frac{P_2}{P_1}$

Heat Transfer Relationships
 • Conduction: $\dot{Q}_c = -kA \frac{dT}{dx}$
 Convection: $\dot{Q}_c = hA(T_b - T_f)$
 Radiation: $\dot{Q}_c = \epsilon \sigma A(T_b^4 - T_s^4)$

Air Standard Diesel Cycle Diagram and Schematic



Cycles



Work

Flow Relationships
 $\dot{m} = \frac{dV}{dt}$; $\dot{V} = A V_c / \rho$; $\dot{Q} = \dot{m} h$

Boundary Work
 $W = \int P dV$; $W = P(P_2 - P_1)$ (Constant Pressure)
 $W = \frac{P_2 V_2 - P_1 V_1}{1 - n}$ (Polytropic Process) = $P_1 V_1 \ln \frac{P_2}{P_1}$ (Polytropic Process, $n=1$)

Flow Work
 $w = \int_1^2 v dp$; $W = \dot{m} \int_1^2 v dp$