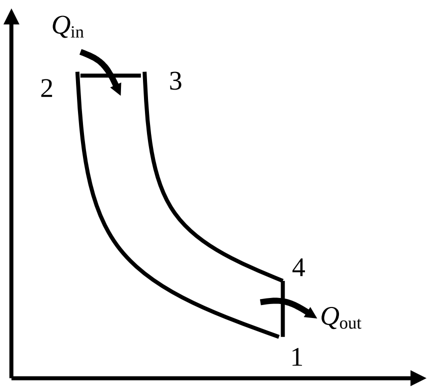
9-65 A six-cylinder compression ignition engine operates on the ideal Diesel cycle. The maximum temperature in the cycle, the cutoff ratio, the net work output per cycle, the thermal efficiency, the mean effective pressure, the net power output, and the specific fuel consumption are to be determined.

Assumptions **1** The air-standard assumptions are applicable. **2** Kinetic and potential energy changes are negligible. **3** Air is an ideal gas with constant specific heats.

Properties The properties of air at 850 K are c_p = 1.110 kJ/kg·K, c_v = 0.823 kJ/kg·K, R = 0.287 kJ/kg·K, and k = 1.349 (Table A-2b).

Analysis (*a*) Process 1-2: Isentropic compression



$$T_2 = T_1\left(\frac{v_1}{v_2}\right)^{k-1} = (340\text{ K})(19)^{1.349-1} = 950.1\text{ K}$$

$$P_2 = P_1\left(\frac{v_1}{v_2}\right)^{k} = (95\text{ kPa})(19)^{1.349} = 5044\text{ kPa}$$

The clearance volume and the total volume of the engine at the beginning of compression process (state 1) are

$$r = \frac{V_c + V_d}{V_c} \longrightarrow 19 = \frac{V_c + 0.0045\text{ m}^3}{V_c}$$

$$V_c = 0.0001778\text{ m}^3$$

$$V_1 = V_c + V_d = 0.0001778 + 0.0032 = 0.003378\text{ m}^3$$

The total mass contained in the cylinder is

$$m = \frac{P_1 V_1}{RT_1} = \frac{(95\text{ kPa})(0.003378\text{ m}^3)}{(0.287\text{ kPa}\cdot\text{m}^3/\text{kg}\cdot\text{K})(340\text{ K})} = 0.003288\text{ kg}$$

The mass of fuel burned during one cycle is

$$AF = \frac{m_a}{m_f} = \frac{m - m_f}{m_f} \longrightarrow 28 = \frac{(0.003288\text{ kg}) - m_f}{m_f} \longrightarrow m_f = 0.0001134\text{ kg}$$

Process 2-3: constant pressure heat addition

$$Q_{\text{in}} = m_f q_{\text{HV}} \eta_c = (0.0001134\text{ kg})(42{,}500\text{ kJ/kg})(0.98) = 4.723\text{ kJ}$$

$$Q_{\text{in}} = mc_v(T_3 - T_2) \longrightarrow 4.723\text{ kJ} = (0.003288\text{ kg})(0.823\text{ kJ/kg.K})(T_3 - 950.1)\text{K} \longrightarrow T_3 = \mathbf{2244\ K}$$

The cutoff ratio is

$$\beta = \frac{T_3}{T_2} = \frac{2244\text{ K}}{950.1\text{ K}} = \mathbf{2.362}$$

(*b*)

$$V_2 = \frac{V_1}{r} = \frac{0.003378\text{ m}^3}{19} = 0.0001778\text{ m}^3$$

$$V_3 = \beta V_2 = (2.362)(0.0001778\text{ m}^3) = 0.0004199\text{ m}^3$$

$$V_4 = V_1$$

$$P_3 = P_2$$

Process 3-4: isentropic expansion.

$$T_4 = T_3\left(\frac{\boldsymbol{v}_3}{\boldsymbol{v}_4}\right)^{k-1} = (2244\ \text{K})\left(\frac{0.0004199\ \text{m}^3}{0.003378\ \text{m}^3}\right)^{1.349\text{-}1} = 1084\ \text{K}$$

$$P_4 = P_3\left(\frac{\boldsymbol{v}_3}{\boldsymbol{v}_4}\right)^{k} = (5044\ \text{kPa})\left(\frac{0.0004199\ \text{m}^3}{0.003378\ \text{m}^3}\right)^{1.349} = 302.9\ \text{kPa}$$

Process 4-1: constant voume heat rejection.

$$Q_{\text{out}} = mc_{\boldsymbol{v}}(T_4 - T_1) = (0.003288\ \text{kg})(0.823\ \text{kJ/kg}\cdot\text{K})(1084 - 340)\text{K} = 2.013\ \text{kJ}$$

The net work output and the thermal efficiency are

$$W_{\text{net,out}} = Q_{\text{in}} - Q_{\text{out}} = 4.723 - 2.013 = \mathbf{2.710\ kJ}$$

$$\eta_{\text{th}} = \frac{W_{\text{net,out}}}{Q_{\text{in}}} = \frac{2.710\ \text{kJ}}{4.723\ \text{kJ}} = 0.5737 = \mathbf{57.4\%}$$

(*c*) The mean effective pressure is determined to be

$$\text{MEP} = \frac{W_{\text{net,out}}}{\boldsymbol{v}_1 - \boldsymbol{v}_2} = \frac{2.710\ \text{kJ}}{(0.003378 - 0.0001778)\text{m}^3}\left(\frac{\text{kPa}\cdot\text{m}^3}{\text{kJ}}\right) = \mathbf{847\ kPa}$$

(*d*) The power for engine speed of 1750 rpm is

$$\dot{W}_{\text{net}} = W_{\text{net}}\frac{\dot{n}}{2} = (2.710\ \text{kJ/cycle})\frac{1750\ (\text{rev/min})}{(2\ \text{rev/cycle})}\left(\frac{1\ \text{min}}{60\ \text{s}}\right) = \mathbf{39.5\ kW}$$

Note that there are two revolutions in one cycle in four-stroke engines.

(*e*) Finally, the specific fuel consumption is

$$\text{sfc} = \frac{m_f}{W_{\text{net}}} = \frac{0.0001134\ \text{kg}}{2.710\ \text{kJ/kg}}\left(\frac{1000\ \text{g}}{1\ \text{kg}}\right)\left(\frac{3600\ \text{kJ}}{1\ \text{kWh}}\right) = \mathbf{151\ g/kWh}$$