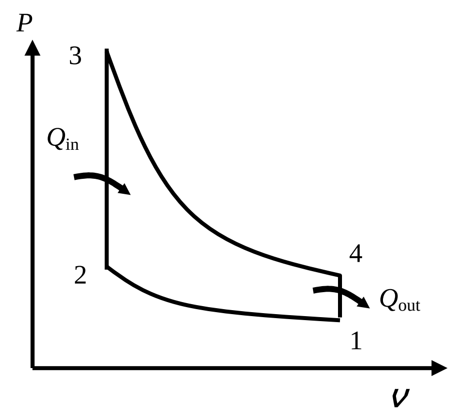
9-43 A gasoline engine operates on an Otto cycle. The compression and expansion processes are modeled as polytropic. The temperature at the end of expansion process, the net work output, the thermal efficiency, the mean effective pressure, the engine speed for a given net power, and the specific fuel 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: polytropic compression



$$T_2 = T_1\left(\frac{v_1}{v_2}\right)^{n-1} = (310\text{ K})(11)^{1.3-1} = 636.5\text{ K}$$

$$P_2 = P_1\left(\frac{v_1}{v_2}\right)^{n} = (100\text{ kPa})(11)^{1.3} = 2258\text{ kPa}$$

$$w_{12} = \frac{R(T_2 - T_1)}{1-n} = \frac{(0.287\text{ kJ/kg}\cdot\text{K})(636.5-310)\text{K}}{1-1.3} = -312.3\text{ kJ/kg}$$

Process 2-3: constant volume heat addition

$$T_3 = T_2\left(\frac{P_3}{P_2}\right) = (636.5\text{ K})\left(\frac{8000\text{ kPa}}{2258\text{ kPa}}\right) = 2255\text{ K}$$

$$q_{in} = u_3 - u_2 = c_v(T_3 - T_2)$$
$$= (0.823\text{ kJ/kg}\cdot\text{K})(2255-636.5)\text{K} = 1332\text{ kJ/kg}$$

Process 3-4: polytropic expansion.

$$T_4 = T_3\left(\frac{v_3}{v_4}\right)^{n-1} = (2255\text{ K})\left(\frac{1}{11}\right)^{1.3-1} = \mathbf{1098\text{ K}}$$

$$P_4 = P_3\left(\frac{v_2}{v_1}\right)^{n} = (8000\text{ kPa})\left(\frac{1}{11}\right)^{1.3} = 354.2\text{ kPa}$$

$$w_{34} = \frac{R(T_4 - T_3)}{1-n} = \frac{(0.287\text{ kJ/kg}\cdot\text{K})(1098-2255)\text{K}}{1-1.3} = 1106\text{ kJ/kg}$$

Process 4-1: constant volume heat rejection.

(*b*) The net work output and the thermal efficiency are

$$w_{net,out} = w_{34} - w_{12} = 1106 - 312.3 = \mathbf{794\text{ kJ/kg}}$$

$$\eta_{th} = \frac{w_{net,out}}{q_{in}} = \frac{794\text{ kJ/kg}}{1332\text{ kJ/kg}} = 0.596 = \mathbf{59.6\%}$$

(*c*) The mean effective pressure is determined as follows

$$v_1 = \frac{RT_1}{P_1} = \frac{(0.287\text{ kPa}\cdot\text{m}^3/\text{kg}\cdot\text{K})(310\text{ K})}{100\text{ kPa}} = 0.8897\text{ m}^3/\text{kg} = v_{max}$$

$$v_{min} = v_2 = \frac{v_{max}}{r}$$

$$\text{MEP} = \frac{w_{net,out}}{v_1 - v_2} = \frac{w_{net,out}}{v_1(1-1/r)} = \frac{794\text{ kJ/kg}}{(0.8897\text{ m}^3/\text{kg})(1-1/11)}\left(\frac{\text{kPa}\cdot\text{m}^3}{\text{kJ}}\right) = \mathbf{982\text{ kPa}}$$

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

$$r = \frac{V_c + V_d}{V_c} \longrightarrow 11 = \frac{V_c + 0.0016\,\mathrm{m}^3}{V_c} \longrightarrow V_c = 0.00016\,\mathrm{m}^3$$

$$V_1 = V_c + V_d = 0.00016 + 0.0016 = 0.00176\,\mathrm{m}^3$$

The total mass contained in the cylinder is

$$m_t = \frac{P_1 V_1}{RT_1} = \frac{(100\,\mathrm{kPa})/0.00176\,\mathrm{m}^3)}{(0.287\ \mathrm{kPa \cdot m^3/kg \cdot K})(310\ \mathrm{K})} = 0.001978\,\mathrm{kg}$$

The engine speed for a net power output of 50 kW is

$$\dot{n} = 2\frac{\dot{W}_{\mathrm{net}}}{m_t w_{\mathrm{net}}} = (2\,\mathrm{rev/cycle})\frac{50\,\mathrm{kJ/s}}{(0.001978\,\mathrm{kg})(794\,\mathrm{kJ/kg \cdot cycle})}\left(\frac{60\,\mathrm{s}}{1\,\mathrm{min}}\right) = \mathbf{3820\ rev/min}$$

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

(*e*) The mass of fuel burned during one cycle is

$$\mathrm{AF} = \frac{m_a}{m_f} = \frac{m_t - m_f}{m_f} \longrightarrow 16 = \frac{(0.001978\,\mathrm{kg}) - m_f}{m_f} \longrightarrow m_f = 0.0001164\,\mathrm{kg}$$

Finally, the specific fuel consumption is

$$\mathrm{sfc} = \frac{m_f}{m_t w_{\mathrm{net}}} = \frac{0.0001164\,\mathrm{kg}}{(0.001978\,\mathrm{kg})(794\,\mathrm{kJ/kg})}\left(\frac{1000\,\mathrm{g}}{1\,\mathrm{kg}}\right)\left(\frac{3600\,\mathrm{kJ}}{1\,\mathrm{kWh}}\right) = \mathbf{267\ g/kWh}$$