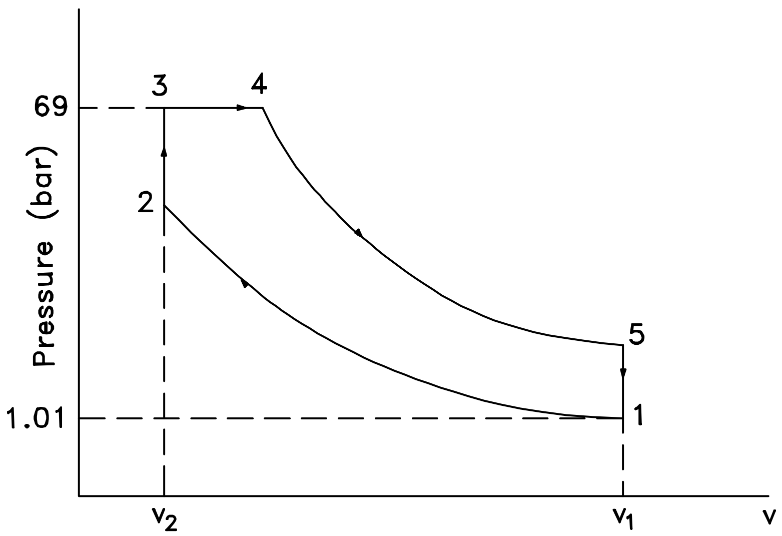
Problem: 6-3



Given: A oil engine takes in air at 1.01 bar, 20 $°C$ and the maximum pressure is 69 bar. The compressor ratio is 18:1

Find: Calculate the air standard thermal efficiency based on the dual-combustion cycle.

Assume: The heat added at constant volume is equal to the heat added at constant pressure.

For a perfect gas

$$\frac{T_2}{T_1} = \left(\frac{v_1}{v_2}\right)^{k-1} = 18^{0.4} = 3.18$$

or

$$T_2 = 3.18 \times T_1 = 3.18 \times 293 = 931\ K$$

where $T_1 = 20 + 273 = 293\ K$.
From $2 \rightarrow 3$ the process is at constant volume, hence

$$\frac{P_3}{P_2} = \frac{T_3}{T_2} \quad \text{since} \quad \frac{P_3 v_3}{T_3} = \frac{P_2 v_2}{T_2} \quad \text{and} \quad v_3 = v_2$$

therefore

$$T_3 = \frac{P_3}{P_2} \times T_2 = \frac{69 \times 931}{P_2}$$

To find P_2,

$$\frac{p_2}{p_1} = \left(\frac{v_1}{v_2}\right)^k = 18^{1.4} = 57.2$$

therefore

$$P_2 = 57.2 \times 1.01 = 57.8 \ bar$$

Then substituting

$$T_3 = \frac{69 \times 931}{57.8} = 1112 \ K$$

The heat added at constant volume is equal to the heat added at constant pressure in this example, therefore

$$\begin{aligned} c_v(T_3 - T_2) &= c_p(T_4 - T_3) \\ 0.718(1112 - 931) &= 1.005(T_4 - 1112) \end{aligned}$$

and

$$\begin{aligned} T_4 &= \frac{0.718 \times 181}{1.005} + 1112 \\ &= 1241.4 \ K \end{aligned}$$

To find T_5 it is necessary to know the value of the volume ratio, $r_v = v_4/v_3$. At constant pressure from $3 \to 4$

$$\frac{v_4}{v_3} = \frac{T_4}{T_3} = \frac{1241.4}{1112} = 1.116$$

Therefore

$$\frac{v_5}{v_4} = \frac{v_1}{v_4} = \frac{v_1 v_3}{v_2 v_4} = 18 \times \frac{1}{1.116} = 16.14$$

and

$$\frac{T_4}{T_5} = \left(\frac{v_5}{v_4}\right)^{k-1} = 16.14^{0/4} = 3.04$$

which leads to

$$T_5 = \frac{1241.4}{3.04} = 408 \ K$$

The heat supplied, Q_1 is given by

$$\begin{aligned} Q_1 &= c_v(T_3 - T_2) + c_p(T_4 - T_3) \\ &= 2c_v(T_3 - T_2) \end{aligned}$$

Since in this case, the heat added at constant volume is equal to the heat added at constant pressure

$$Q_1 = 2 \times 0.718 \times (1112 - 931) = 260\ kJ/kg$$

The heat rejected is given by

$$c_v(T_5 - T_1) = 0.718(408 - 293) = 82.6\ kJ/kg$$

The efficiency is

$$\begin{aligned} \eta &= \frac{\sum Q}{Q_1} = \frac{260 - 82.6}{260} = 1 - 0.318 = 0.682 \\ &= 68.2\% \end{aligned}$$