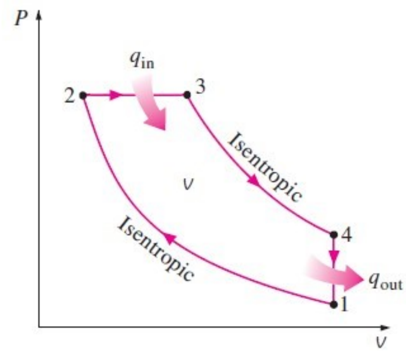
these engines takes place over a longer interval. Because of this longer duration, the combustion process in the ideal Diesel cycle is approximated as a constant-pressure heat-addition process. In fact, this is the only process where the Otto and the Diesel cycles differ. The remaining three processes are the same for both ideal cycles. The four processes comprising the cycle are shown on the (P-V) diagram:

1-2 Isentropic compression
2-3 Constant-pressure heat addition
3-4 Isentropic expansion
4-1 Constant-volume heat rejection



Noting that the Diesel cycle is executed in a piston-cylinder device, which forms a closed system, the amount of heat transferred to the working fluid at constant pressure and rejected from it at constant volume can be expressed as:

$$q_{in} = h_3 - h_2 = C_p(T_3 - T_2) \qquad \ldots\ldots\ldots\ldots\ldots\ldots (8.10)$$

$$q_{out} = u_4 - u_1 = C_v(T_4 - T_1) \qquad \ldots\ldots\ldots\ldots\ldots\ldots (8.11)$$

Then the thermal efficiency of the ideal Diesel cycle under the cold-air-standard assumptions is expressed as:

$$\eta_{th} = \frac{w_{net}}{q_{in}} = 1 - \frac{q_{out}}{q_{in}} = \frac{C_v(T_4 - T_1)}{C_p(T_3 - T_2)} = \frac{(T_4 - T_1)}{\gamma(T_3 - T_2)} = \frac{T_1(T_4/T_1 - 1)}{\gamma T_2(T_3/T_2 - 1)}$$

We now define a new quantity, the **cutoff ratio** r_c as the ratio of the cylinder volumes after and before the combustion process:

$$r_c = \frac{V_3}{V_2} = \frac{v_3}{v_2} \qquad \ldots\ldots\ldots\ldots\ldots\ldots (8.12)$$

Utilizing this definition and the isentropic ideal-gas relations for processes 1-2 and 3-4, we see that the thermal efficiency relation reduces to:

$$\eta_{th} = 1 - \frac{1}{r^{\gamma-1}}\left[\frac{r_c^{\gamma} - 1}{\gamma(r_c - 1)}\right] \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ldots (8.13)$$

where r is the compression ratio defined by equation (8.9). Looking at equation (8.13) carefully, one would notice that under the cold-air-standard assumptions, the efficiency of a Diesel cycle differs from the efficiency of an Otto cycle by the quantity in the brackets. This quantity is always greater than 1. Therefore:

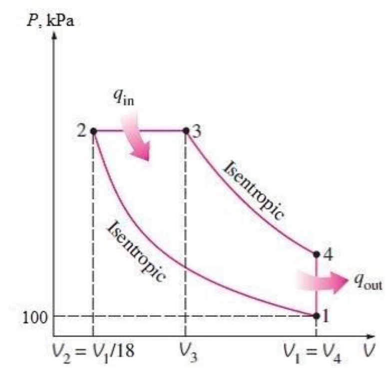
$$\eta_{th.Otto} > \eta_{th,Diesel} \qquad \ldots\ldots\ldots\ldots\ldots\ldots (8.14)$$

Example (8.2): An air-standard Diesel cycle has a compression ratio of 18, and the heat transferred to the working fluid per cycle is 1800 kJ/kg. At the beginning of the compression process, the pressure is 0.1 MPa and the temperature is 15°C. Draw the (*P-V*) diagram of the cycle and determine:

1) The pressure and temperature at the end of each process of the cycle.
2) The thermal efficiency of the cycle.
3) The mean effective pressure.

Solution:

1) The compression ratio $r = \frac{v_1}{v_2} = 18$



$$P_1 v_1 = RT_1 \rightarrow v_1 = \frac{RT_1}{P_1} = \frac{0.287 \times 288}{0.1 \times 10^3} = 0.827 \text{ m}^3/\text{kg}$$

$$v_4 = v_1 = 0.827 \text{ m}^3/\text{kg}$$

$$r = \frac{v_1}{v_2} \rightarrow v_2 = \frac{0.827}{18} = 0.0459 \text{ m}^3/\text{kg}$$

Process 1-2 (isentropic compression):

$$\frac{T_2}{T_1} = \left(\frac{V_1}{V_2}\right)^{\gamma-1} = r^{\gamma-1} \rightarrow T_2 = (15 + 273) \times (18)^{1.4-1}$$

$\boldsymbol{T_2} = \mathbf{915\ K}$ **Ans.**

$$\frac{P_2}{P_1} = \left(\frac{V_1}{V_2}\right)^{\gamma} = r^{\gamma} \rightarrow P_2 = 0.1 \times 10^3 \times (18)^{1.4}$$

$\boldsymbol{P_2} = \mathbf{5720\ kPa}$ **Ans.**

Process 2-3 (constant-pressure heat addition):

$\boldsymbol{P_3 = P_2} = \mathbf{5720\ kPa}$ **Ans.**

$$q_{in} = C_p(T_3 - T_2) \rightarrow 1800 = 1.005 \times (T_3 - 915)$$

$\boldsymbol{T_3} = \mathbf{2706\ K}$ **Ans.**

$$\frac{v_3}{v_2} = \frac{T_3}{T_2} \rightarrow v_3 = 0.0459 \times \frac{2706}{915} = 0.1357 \text{ m}^3/\text{kg}$$

Process 3-4 (isentropic expansion):

$$\frac{T_3}{T_4} = \left(\frac{V_4}{V_3}\right)^{\gamma-1} \rightarrow T_4 = \frac{2706}{(0.827/0.1357)^{1.4-1}}$$

$\boldsymbol{T_4} = \mathbf{1313\ K}$ **Ans.**

$$\frac{P_3}{P_4} = \left(\frac{V_4}{V_3}\right)^{\gamma} \rightarrow P_4 = \frac{5720}{(0.827/0.1357)^{1.4}}$$

$\boldsymbol{P_4 = 456}$ **kPa** **Ans.**

2) $q_{out} = C_v(T_4 - T_1) = 0.718 \times (1313 - 288) = 736$ kJ/kg

$w_{net} = q_{in} - q_{out} = 1800 - 736 = 1064$ kJ/kg

The thermal efficiency of the cycle:

$$\eta_{th} = \frac{w_{net}}{q_{in}} = \frac{1064}{1800}$$

$\boldsymbol{\eta_{th} = 59}$% **Ans.**

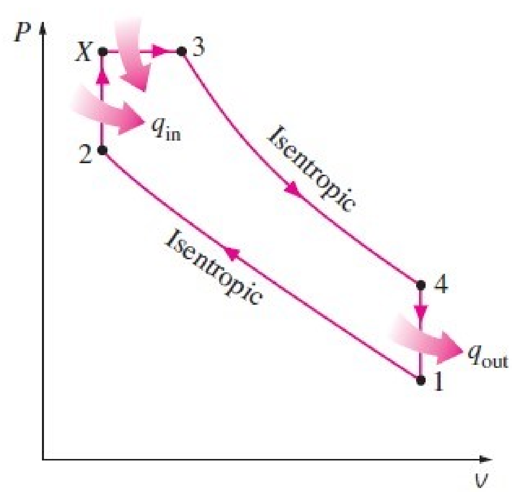
3) The mean effective pressure:

$$MEP = \frac{w_{net}}{v_1 - v_2} = \frac{1064}{0.827 - 0.0459}$$

$\boldsymbol{MEP = 1362}$ **kPa** **Ans.**

Dual Cycle

Approximating the combustion process in internal combustion engines as a constant-volume or a constant-pressure heat-addition process is overly simplistic and not quite realistic. Probably a better (but slightly more complex) approach would be to model the combustion process in both gasoline and diesel engines as a combination of two heat-transfer processes, one at constant volume and the other at constant pressure. The ideal cycle based on this concept is called the **dual cycle,** and a (*P*-*V*) diagram for it is shown below. The relative amounts of heat transferred during each process can be adjusted to approximate the actual cycle more closely. Note that both the Otto and the Diesel cycles can be obtained as special cases of the dual cycle.



Exercises

Problem (8.1): The compression ratio of an air-standard Otto cycle is 9.5. Prior to the isentropic compression process, the air is at 100 kPa, 35°C and 600 cm^3. The temperature at the end of the isentropic expansion process is 800 K. Determine (a) the highest temperature in the cycle (b) the highest pressure in the cycle (c) the amount of heat transferred in (d) the thermal efficiency (e) the mean effective pressure.

Ans. (1969 K, 6072 kPa, 0.59 kJ, 59.4%, 652 kPa)

Problem (8.2): An ideal diesel engine has a compression ratio of 20 and uses air as the working fluid. The state of air at the beginning of the compression process is 95 kPa and 20°C. If the maximum temperature in the cycle is not to exceed 2200 K, determine (a) the thermal efficiency (b) the mean effective pressure.

Ans. (63.5%, 933 kPa)