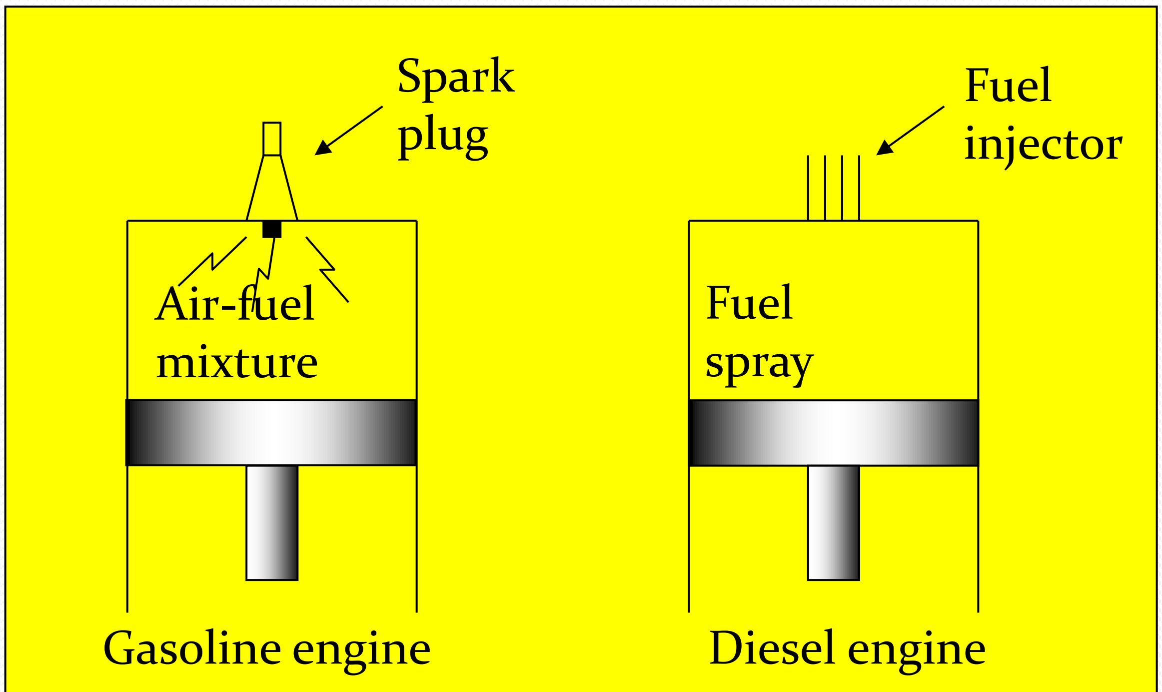
A. Diesel cycle : The ideal cycle for CI engines

- An CI power cycle useful in many forms of automotive transportation, railroad engines, and ship power plants
- Replace (the spark plug + carburetor) in SI by fuel injector in CI engines



A. Diesel cycle : The ideal cycle for CI engines

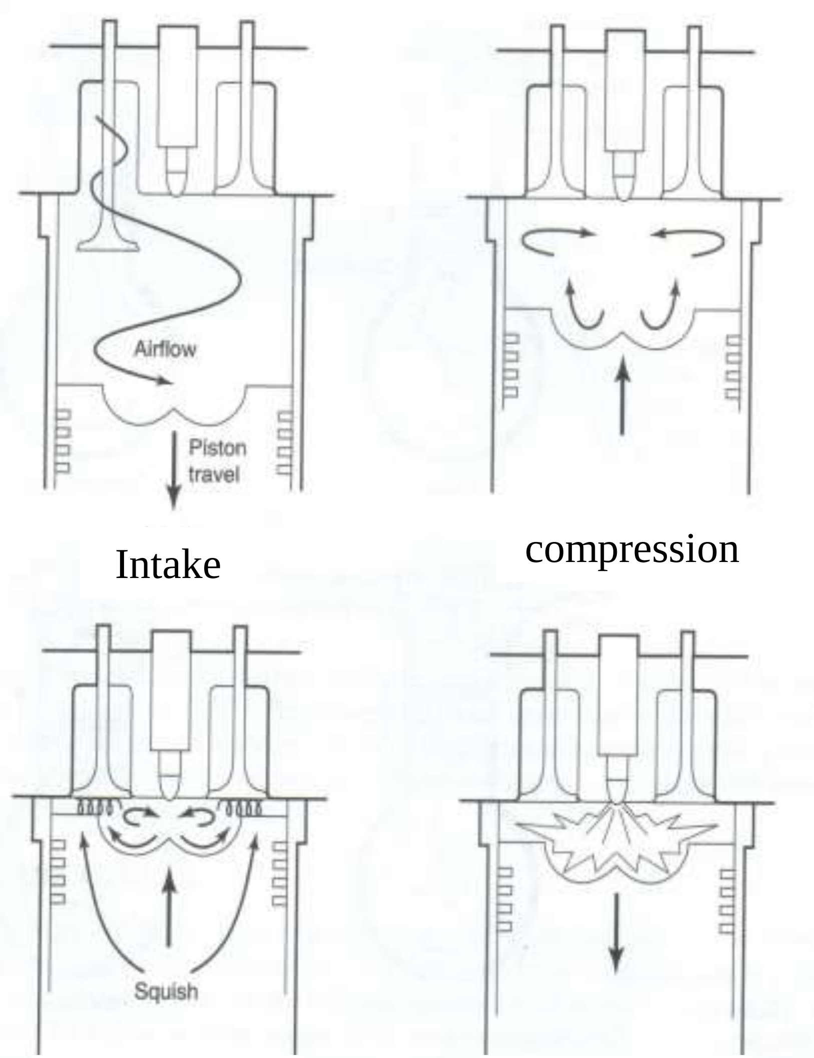
(1)

Inlet valve open and fresh air is drawn into the cylinder

(2)

Temperature rise about the auto-ignition temperature of the fuel.

Diesel fuel is sprayed into the combustion chamber.



Intake

compression

Combustion

Exhaust

(3)

Evaporation, mixing, ignition and combustion of diesel fuel.

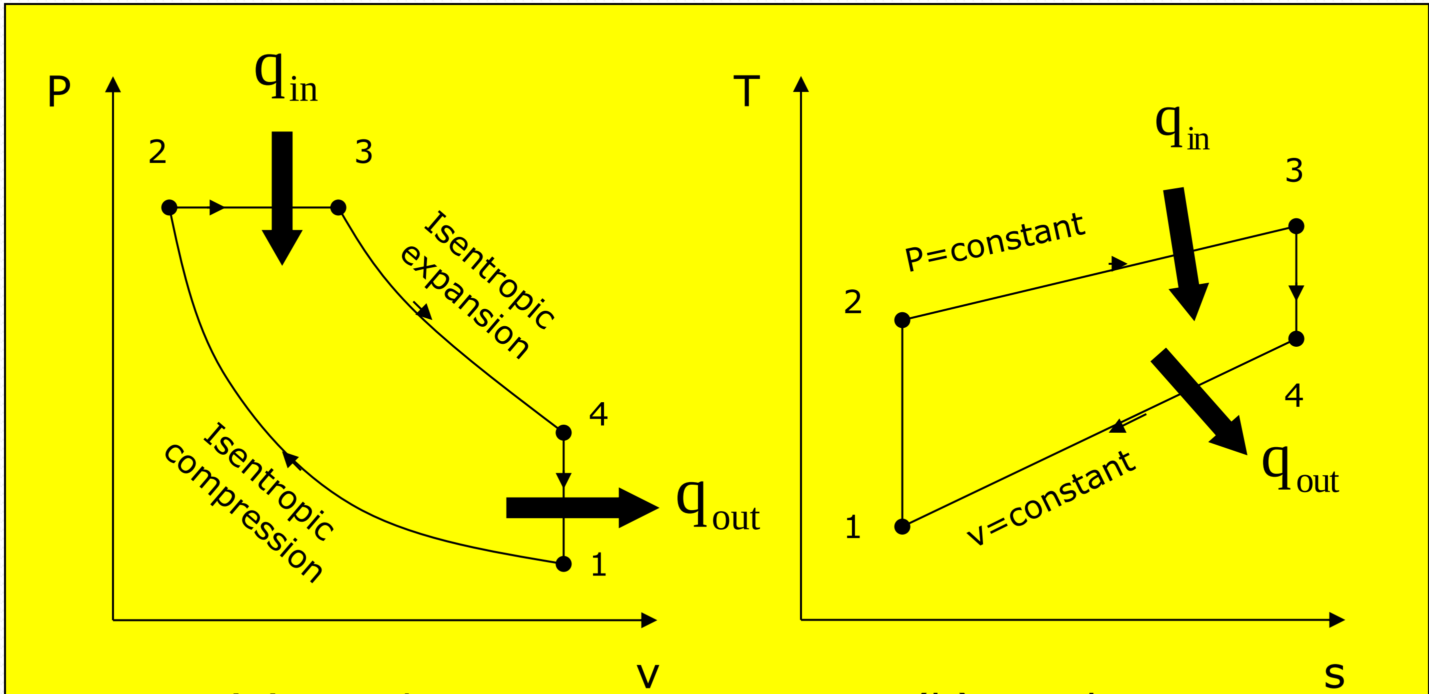
In the later stages, expansion process occur.

(4)

Burned gases is pushed out to the exhaust valve

A Diesel cycle : The ideal cycle for CI engines

Processes:
1-2 Compression
(s = Const)
2-3 Combustion
(P = Const.)
3-4 Expansion
(s = Const)
4-1 Exhaust
(V = Const)



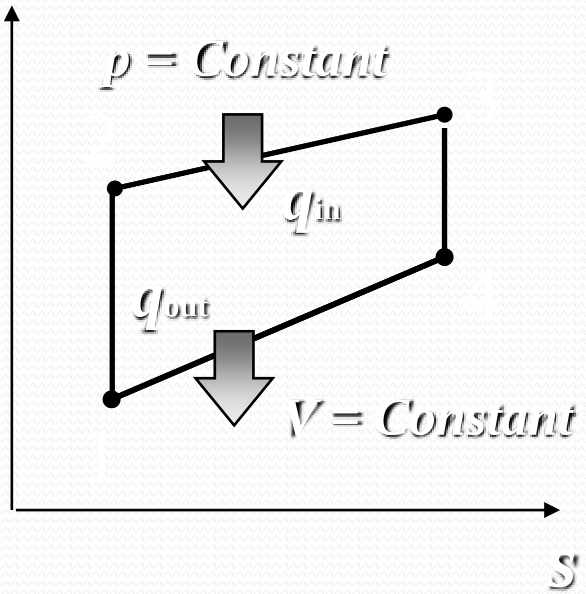
(a) P-v diagram (b) T-s diagram

- Eliminates **pre-ignition** of the fuel-air mixture when compression ratio is high.
- The combustion process in CI engines takes place over a **longer interval** and is approximated as constant-pressure heat addition process.

- Energy balance for closed system:

$$q_{in} - w_{b\,out} = \Delta u_{3-2}$$

$$q_{in} = q_{23} = w_{23} + (u_3 - u_2) = P_2(v_3 - v_2) + (u_3 - u_2) = (h_3 - h_2) = c_p(T_3 - T_2)$$



$$-q_{out} = q_{41} = w + \Delta u_{41}$$

$$q_{out} = (u_4 - u_1)$$

$$\therefore \quad q_{out} = (u_4 - u_1) = c_v(T_4 - T_1)$$

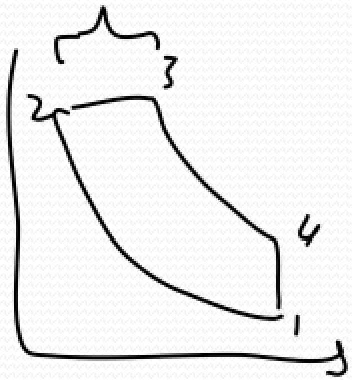
$$\eta_{th,diesel} = \frac{w_{net}}{q_{in}} = 1 - \frac{q_{out}}{q_{in}} = 1 - \frac{T_4 - T_1}{K(T_3 - T_2)} = 1 - \frac{T_1(T_4/T_1 - 1)}{kT_2(T_3/T_2 - 1)}$$

A. Diesel cycle : The ideal cycle for CI engines

- Define a new quantity

$$r_c \equiv \text{cutoff ratio}$$

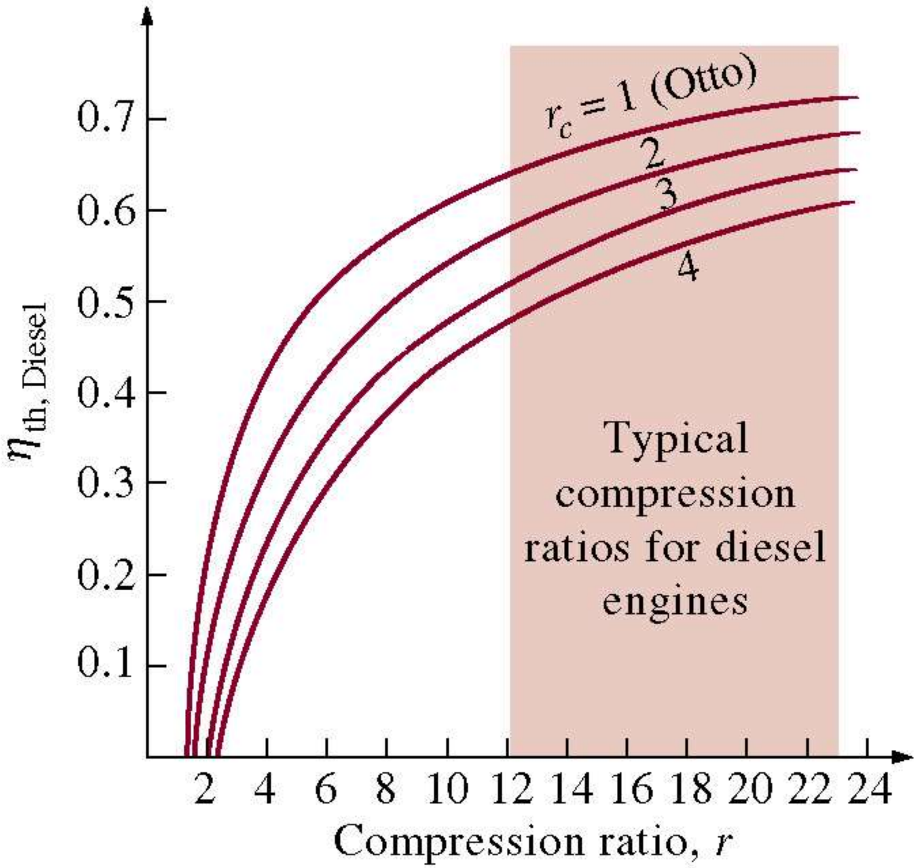
$$r_c \equiv \frac{V_{\text{cylinder after combustion}}}{V_{\text{cylinder before combustion}}} = \frac{V_3}{V_2} = \frac{v_3}{v_2}$$



$$\eta_{\text{th,diesel}} = 1 - \frac{1}{r^{k-1}}\left[\frac{r_c^k - 1}{k(r_c - 1)}\right] \quad \text{where } r = \frac{v_1}{v_2}$$

$$\left[\frac{r_c^k - 1}{k(r_c - 1)}\right] > 1 \Rightarrow \eta_{\text{th,otto}} > \eta_{\text{th,Diesel}}$$

A. Diesel cycle : The ideal cycle for CI engines



- As the cut off ratio decreases, η_{th} reases
- esel engines operate at much higher r and usually more efficient than spark-ignition engines.
- The diesel engines also burn the fuel more completely since they usually operate at lower rpm than SI engines.
- CI engines operate on lower fuel costs.

- At $r_c = 1$, the Diesel and Otto cycles have the same efficiency.
  - Physical implication for the Diesel cycle: No change in volume when heat is supplied.
  - A high value of k compensates for this.
- For $r_c > 1$, the Diesel cycle is less efficient than the Otto cycle.

Example

An air standard Diesel cycle has a compression ratio of 16 and cut off ratio of 2. At beginning of the compression process, air is at 95kPa and 27^{o}C. Accounting for the variation of specific heat with temperature, determine

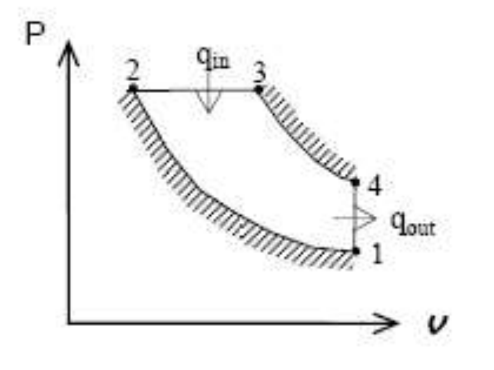
a) Temperature after the heat additional process.

b) Thermal efficiency

c) The mean effective pressure

Solution :

Solution :



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

Properties The gas constant of air is R = 0.287 kJ/kg.K.
The properties of air are given in Table A-17.

Analysis (*a*) Process 1–2: isentropic compression.

$$T_1 = 300\text{K} \longrightarrow \begin{array}{l} u_1 = 214.07\text{kJ/kg} \\ v_{r_1} = 621.2 \end{array}$$

$$v_{r_2} = \frac{v_2}{v_1} v_{r_1} = \frac{1}{r} v_{r_1} = \frac{1}{16}(621.2) = 38.825 \longrightarrow \begin{array}{l} T_2 = 862.4\text{ K} \\ h_2 = 890.9\text{ kJ/kg} \end{array}$$

Process 2–3: P = constant heat addition.

$$\frac{P_3 v_3}{T_3} = \frac{P_2 v_2}{T_2} \longrightarrow T_3 = \frac{v_3}{v_2} T_2 = 2T_2 = (2)(862.4\text{ K}) = \mathbf{1724.8\text{ K}} \longrightarrow \begin{array}{l} h_3 = 1910.6\text{ kJ/kg} \\ v_{r_3} = 4.546 \end{array}$$

(*b*) $q_{in} = h_3 - h_2 = 1910.6 - 890.9 = 1019.7\text{kJ/kg}$

Process 3–4: isentropic expansion.

$$\upsilon_{r_4} = \frac{\upsilon_4}{\upsilon_3}\upsilon_{r_3} = \frac{\upsilon_4}{2\upsilon_2}\upsilon_{r_3} = \frac{r}{2}\upsilon_{r_3} = \frac{16}{2}(4.546) = 36.37 \longrightarrow u_4 = 659.7\text{kJ/kg}$$

Process 4–1: υ = constant heat rejection.

$$q_{out} = u_4 - u_1 = 659.7 - 214.07 = 445.63 \text{ kJ/kg}$$

$$\eta_{th} = 1 - \frac{q_{out}}{q_{in}} = 1 - \frac{445.63 \text{ kJ/kg}}{1019.7 \text{ kJ/kg}} = \mathbf{56.3\%}$$

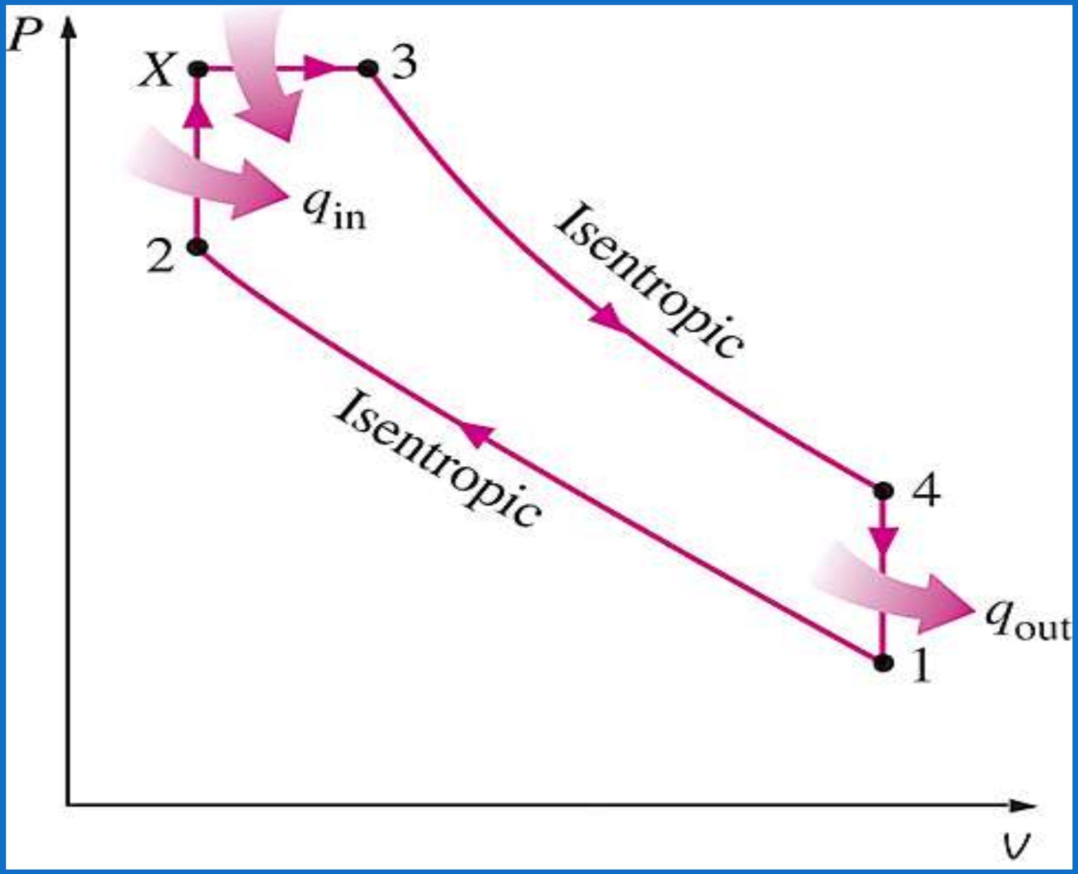
(*c*) $w_{net,out} = q_{in} - q_{out} = 1019.7 - 445.63 = 574.07 \text{ kJ/kg}$

$$\upsilon_1 = \frac{RT_1}{P_1} = \frac{(0.287 \text{ kPa}\cdot\text{m}^3/\text{kg}\cdot\text{K})(300 \text{ K})}{95 \text{ kPa}} = 0.906 \text{ m}^3/\text{kg} = \upsilon_{max}$$

$$\upsilon_{min} = \upsilon_2 = \frac{\upsilon_{max}}{r}$$

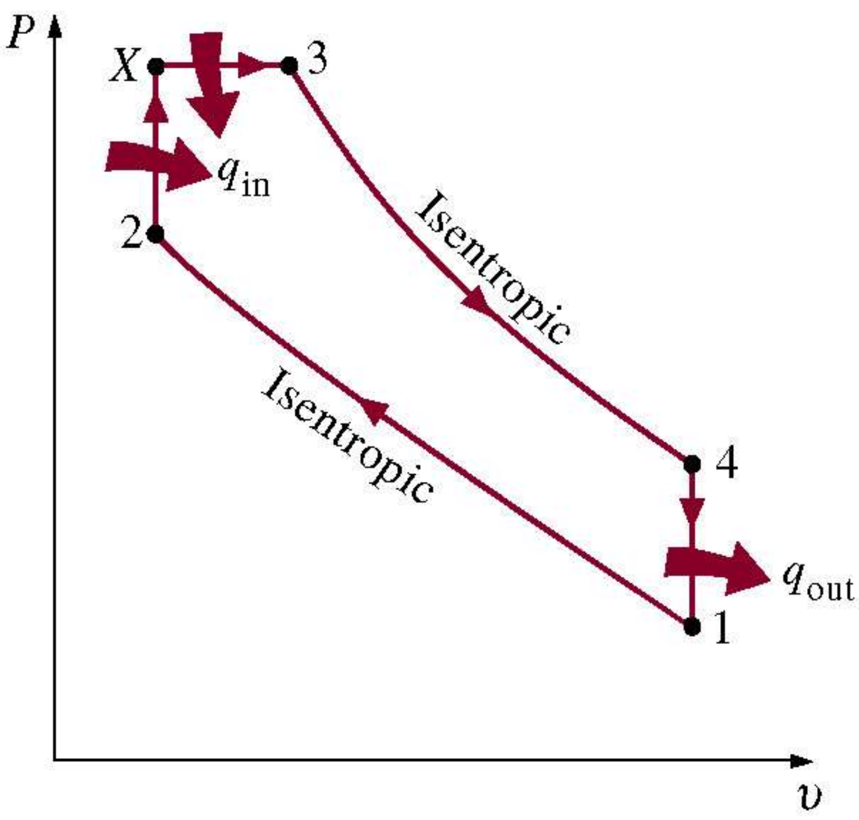
$$\text{MEP} = \frac{w_{net,out}}{\upsilon_1 - \upsilon_2} = \frac{w_{net,out}}{\upsilon_1(1 - 1/r)} = \frac{574.07 \text{ kJ/kg}}{(0.906 \text{ m}^3/\text{kg})(1 - 1/16)}\left(\frac{\text{kPa}\cdot\text{m}^3}{\text{kJ}}\right) = \mathbf{675.9 \text{ kPa}}$$

Dual cycle: A more realistic ideal cycle model for modern, high-speed compression ignition engine.



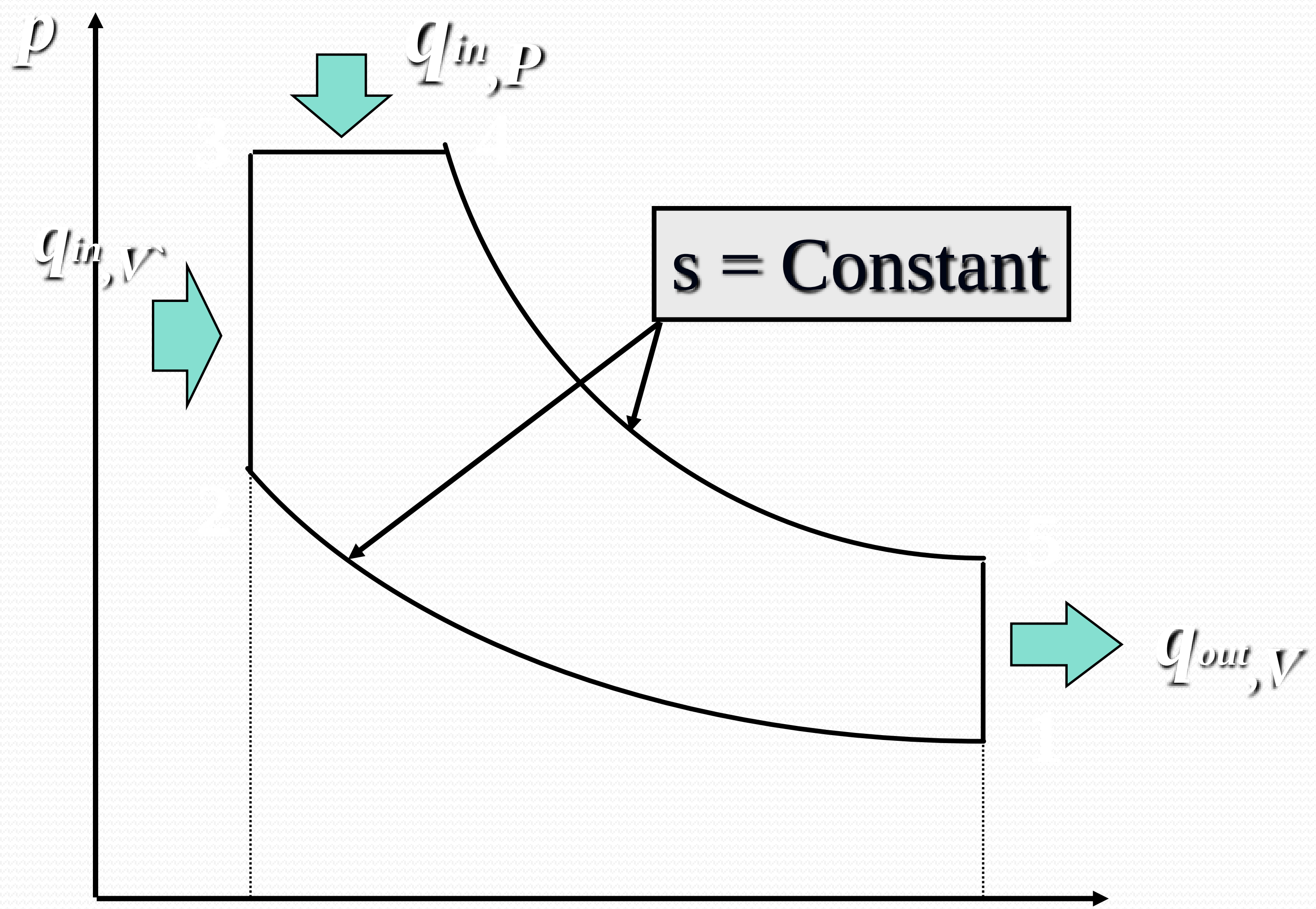
P-v diagram of an ideal dual cycle.

The ideal Dual cycle



- The dual cycle is designed to capture some of the advantages of both the Otto and Diesel cycles.
- It it is a better approximation to the actual operation of the compression ignition engine.

The ideal Dual cycle



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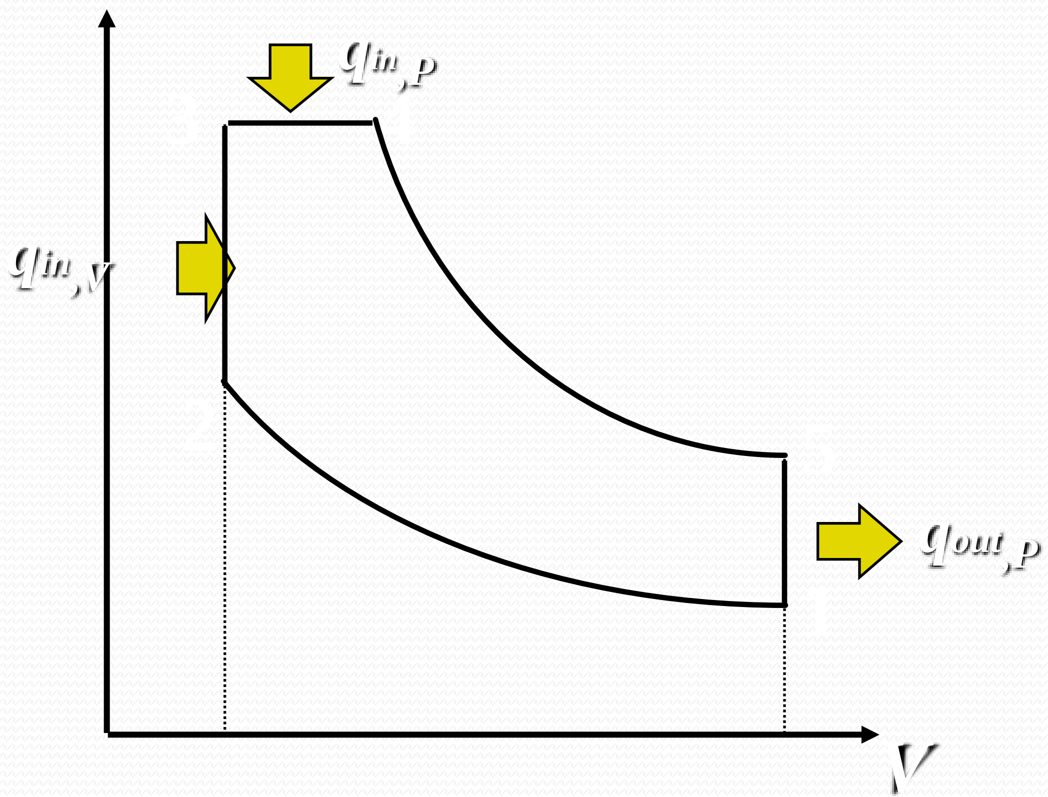
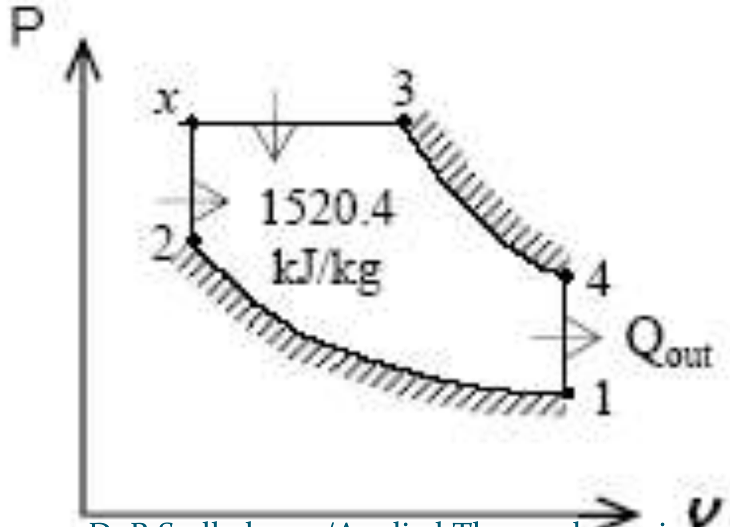


$$r = \frac{V_1}{V_2}$$

$$r_c = \frac{V_4}{V_3}$$

Example

The compression cycle of an ideal dual cycle is 14. Air is at 100kPa and 300K at beginning of the compression process and at 2,200K at the end of heat addition process. Heat transfer process to air is take place partly at constant volume and partly at constant pressure and its amount to 1,520.4 kJ/kg. Assume variable specific heat for air, determine the thermal efficiency of the cycle.



Solution

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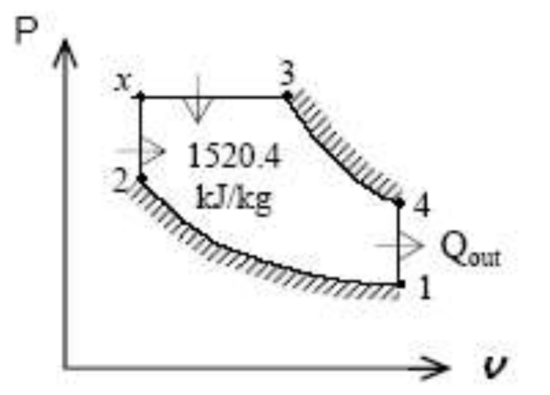

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$$v_{r_2} = \frac{v_2}{v_1} v_{r_1} = \frac{1}{r} v_{r_1} = \frac{1}{14}(621.2) = 44.37 \longrightarrow \begin{array}{l} T_2 = 823.1\text{ K} \\ u_2 = 611.2\text{ kJ/kg} \end{array}$$

Process 2–x, x–3: heat addition,

$$T_3 = 2200\ \text{K} \longrightarrow \begin{array}{l} h_3 = 2503.2\ \text{kJ/kg} \\ \upsilon_{r_3} = 2.012 \end{array}$$

$$q_{in} = q_{x-2,in} + q_{3-x,in} = (u_x - u_2) + (h_3 - h_x)$$
$$1520.4 = (u_x - 611.2) + (2503.2 - h_x)$$

By trial and error, we get $T_x = 1300$ K and $h_x = 1395.97$, $u_x = 1022.82$ kJ /kg.

Thus,

$$q_{2-x,in} = u_x - u_2 = 1022.82 - 611.2 = 411.62\ \text{kJ/kg}$$

and

$$\text{ratio} = \frac{q_{2-x,in}}{q_{in}} = \frac{411.62\ \text{kJ/kg}}{1520.4\ \text{kJ/kg}} = \mathbf{27.1\%}$$

$$\frac{P_3\upsilon_3}{T_3} = \frac{P_x\upsilon_x}{T_x} \longrightarrow \frac{\upsilon_3}{\upsilon_x} = \frac{T_3}{T_x} = \frac{2200\ \text{K}}{1300\ \text{K}} = 1.692 = r_c$$

$$\upsilon_{r_4} = \frac{\upsilon_4}{\upsilon_3}\upsilon_{r_3} = \frac{\upsilon_4}{1.692\upsilon_2}\upsilon_{r_3} = \frac{r}{1.692}\upsilon_{r_3} = \frac{14}{1.692}(2.012) = 16.648 \longrightarrow u_4 = 886.3\ \text{kJ/kg}$$

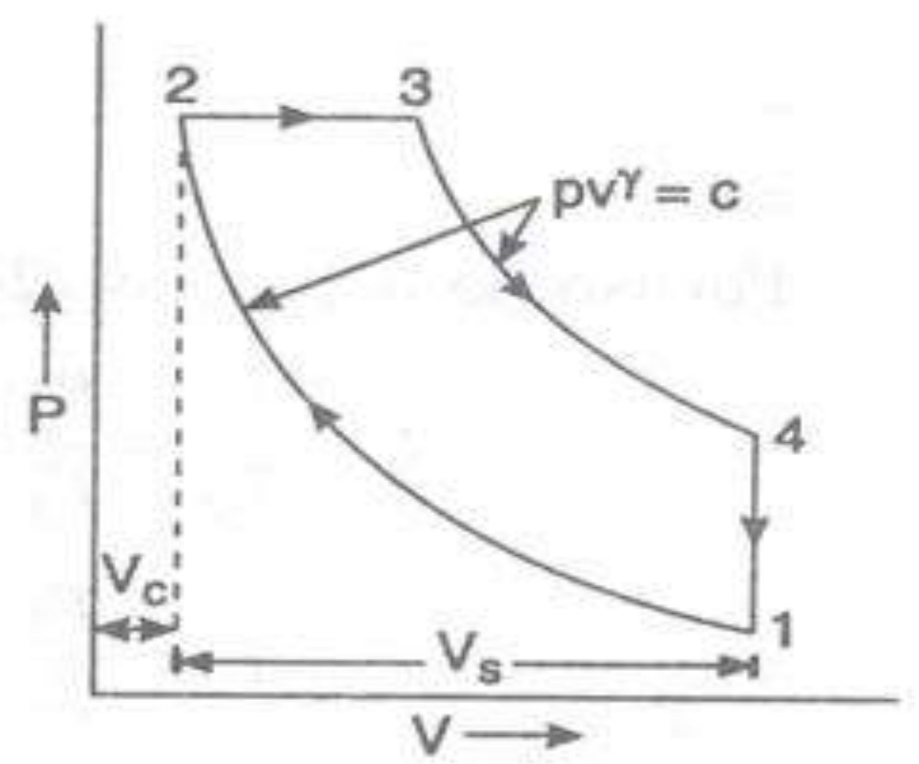
Process 4-1: v = constant heat rejection.

$$q_{\text{out}} = u_4 - u_1 = 886.3 - 214.07 = 672.23 \text{ kJ/kg}$$

$$\eta_{\text{th}} = 1 - \frac{q_{\text{out}}}{q_{\text{in}}} = 1 - \frac{672.23 \text{ kJ/kg}}{1520.4 \text{ kJ/kg}} = \mathbf{55.8\%}$$

Example: An ideal Diesel engine has a diameter of 15 cm and stroke 20 cm. The clearance volume is 10 percent of swept volume. Determine the compression ratio and the air standard efficiently of engine if the cut off takes place at 6 percent of the stroke.

Solution: Given that:



Swept volume $V_s = \pi/4\ d^2 . L = \pi/4\ (15)^2 \ X\ 20$

$= 3540\ cm^3$

Clearance volume $V_c = 0.1\ V_s = 354\ cm^3$

Total volume $V_1 = V_c + V_s = (354 + 3540)\ cm^3$

$\Rightarrow V_1 = 3894\ cm^3$

Compression ratio, $r = V_1/V_2 = V_1/V_c = 3894 / 354 = 1$

Cut off ratio; $ß = V_3 / V_2 = V_2 + (V_3 - V_2) / V_2$

$= 354 + 3540\ X\ 0.06 / 354 = 1.6$

Air standard efficiency of the cycle:

$\prod_{diesel} = 1 - 1/r^{\prod-1}\ [ß^{\prod-1} / \prod(ß-1)] = 1 - 1/(11)0.4\ [(1.6)1.4 - 1 / 1.4\ (1.6 - 1)]$

$= 0.5753$ (or 57.53 percent)

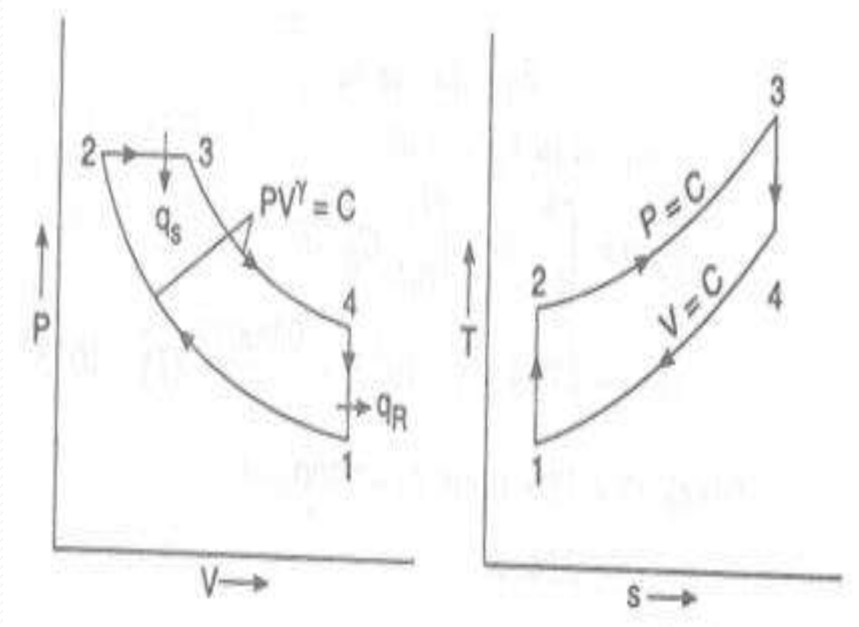
Example: A diesel engine receives air at 0.1 MPa and 300^0 K in the beginning of compression stroke. The compression ratio is 16. Heat added per kg of air is 1506 kJ/kg. Determine fuel cut off ratio and cycle thermal efficiency.

Assume $C_p = 1.0$ kJ / kg K, $R = 0.286$ kJ/kg K

Solution: For process (1-2) $T_2 / T_1 = r^{\prod-1}$

$\prod = C_p / C_v = 1.0 / 0.714 = 1.4$ ($C_v = C_p - R = 1.0 - 0.286 = 0.714$ kJ/kg K)

$T_2 = T_1.(16)^{1.4-1} = 300\ (16)^{(1.4-1)} = 909.43$ K



For Process (2-3) $T_3 / T_2 = v_3 / v_2 = \prod$

Heat added = $C_p\ (T_3 - T_2)$

$1500 = 1\ (T_3 - 909.43)$

$\Rightarrow T_3 = 2409.43$ K

$\therefore T_3 / T_2 = 2409.43 / 909.43 = 2.65$

Fuel cut off ratio, $\prod = T_3 / T_2 = 2.65$

$\therefore\ \prod_{cycle} = 1 - 1/r^{\prod-1} [\prod^{\prod}-1 / \prod (\prod-1)] = 1 - 1 / 16^{0.4} (2.65^{1.4} - 1 / 1.4(2.65 - 1))$

$= 1 - 0.32987\ (1.26117) = 0.5839 = 58.39\%$