2020

RANK Improvement WORKBOOK

Answer key and Hint of
Objective & Conventional *Questions*

Mechanical Engineering

Internal Combustion Engine

MADE EASY Publications

1 Air Standard Cycles

LEVEL 1 Objective Questions

1.	(d)
2.	(a)
3.	(b)
4.	(c)
5.	(525)
6.	(a)
7.	(b)
8.	(d)
9.	(a)

LEVEL 2 Objective Questions

10.	(b)
11.	(a)
12.	(d)
13.	(c)
14.	(a)
15.	(d)
16.	(722)
17.	(d)
18.	(a)
19.	(b)

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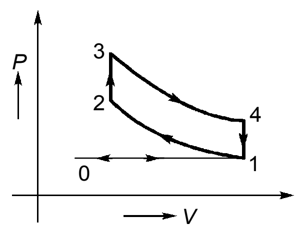
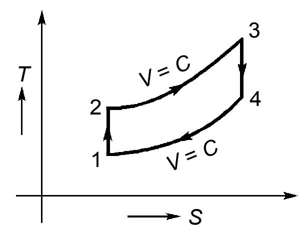
LEVEL 3 Conventional Questions

Solution : 20

Otto cycle:

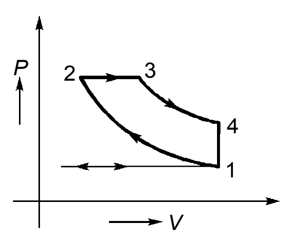


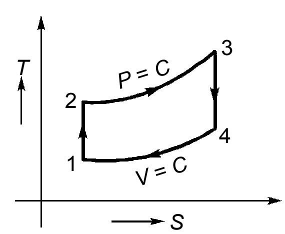


The processes:

1. 0 - 1 and 1 - 0 on the p-v diagram represents suction and exhaust processes and their effect is nullified.
2. 1 - 2 represents isentropic compression
3. 2 - 3 represents constant volume heat addition
4. 3 - 4 represents isentropic expression
5. 4 - 1 represents constant volume heat rejection

Diesel cycle:





1. 0–1 suction
2. 1 - 2 represents isentropic compression
3. 2 - 3 represents constant pressure heat addition
4. 3 - 4 represents isentropic expansion
5. 4 - 1 represents constant volume heat rejection
6. 1–0 exhaust

Given:
$$d = 20 \text{ cm},$$
$$L = 30 \text{ cm}$$
$$V_c = 0.10 \times V_s$$

r_c (cut-off) takes place at 10% of the stroke

$$V_s = \frac{\pi}{4} d^2 L$$

$$= \frac{\pi}{4}(0.20)^2 (0.30) = 9.42 \times 10^{-3} \text{ m}^3$$

$$r = \text{compression ratio} = \frac{V_c + V_s}{V_c} = 1 + \frac{V_s}{V_c}$$

$$r = 1 + \frac{V_s}{0.1 \times V_s} = 11$$

$$\text{Cut-off volume} = V_3 - V_2 = 0.10 \times V_s$$

$$V_3 - V_2 = 0.10 \times \left(\frac{V_c}{0.10}\right) = V_c = V_2$$

$$V_3 = 2\,V_2$$

$$r_c = \frac{V_3}{V_2} = 2$$

$$\eta = 1 - \frac{1}{r^{\gamma-1}} \frac{r_c^{\gamma} - 1}{\gamma(r_c - 1)}$$

$$\eta = 1 - \frac{1}{(11)^{0.4}} \times \frac{2^{1.4} - 1}{1.4(2-1)} = 55.135\%$$

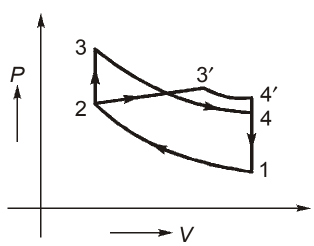
Solution : 21

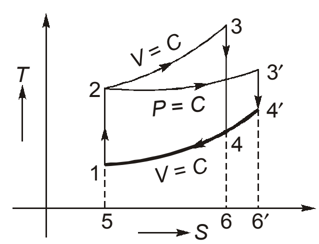
Same compression ratio and heat addition:

The otto cycle and diesel cycle are shown in the *P-V* and *T-S* diagram for the same compression ratio and heat input.

1 - 2 - 3 - 4 otto cycle

1 - 2′ - 3′ - 4′ diesel cycle

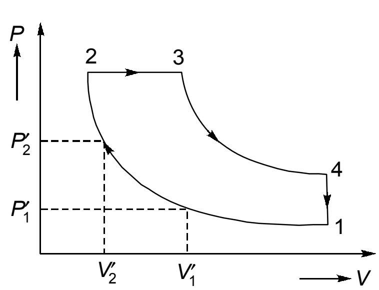




All the cycles start from the same initial state point 1 and the air is compressed from state 1 to state 2 as the compression ratio is same. From the T-s diagram, it can be seen that for the same heat input, heat rejection in diesel cycle (514′6′) is maximum and more than that in otto cycle (5146). Consequently, the otto cycle has the highest work output and efficiency.

At $\left(\frac{1}{8}\right)^{th}$ stroke, $P_1' = 1.4$ bar

At $\left(\frac{7}{8}\right)^{th}$ stroke, $P_2' = 14$ bar



$$\text{Stroke} = V_1 - V_2$$

$$\text{Volume } V_1' \text{ at } \left(\frac{1}{8}\right)^{\text{th}} \text{ stroke} = V_1 - \frac{1}{8}(V_1 - V_2) \quad V = \frac{V_1}{V_2} \text{ (compression ratio)}$$

$$= \frac{8V_1 - V_1 + V_2}{8} = \frac{7V_1}{8} + \frac{V_2}{7}$$

$$V_1' = \frac{V_2}{8}\left(1 + 7\frac{V_1}{V_2}\right) = \frac{V_2}{8}(1 + 7r)$$

V_2' at $\frac{7}{8}^{\text{th}}$ of stroke

$$V_2' = V_1 - \frac{7}{8}(V_1 - V_2)$$

$$= \frac{8V_1 - 7V_1 + 7V_2}{8} = \frac{V_1}{8} + \frac{7V_2}{8} = \frac{V_2}{8}(7 + r)$$

Now, applying the equation

$$P_1' V_1'^{\,n} = P_2' V_2'^{\,b}$$

$$\frac{V_1'}{V_2'} = \left(\frac{P_2'}{P_1'}\right)^{\frac{1}{2}} = \left(\frac{14}{1.4}\right)^{\frac{1}{1.41}} = 5.12$$

$$r = 19.373$$

As cut off occurs at $\left(\frac{1}{15}\right)^{\text{th}}$ of stroke

So,

$$V_3 - V_2 = \frac{1}{15}(V_1 - V_2)$$

$$\frac{V_3}{V_2} = 1 + \frac{1}{15}\left(\frac{V_1}{V_2} - 1\right)$$

$$\frac{V_3}{V_2} = 2.22486 = r_c$$

$$\eta_{\text{diesel}} = 1 - \frac{1}{(r)^{\gamma-1}} \frac{r_c^{\gamma} - 1}{\gamma(r_c - 1)}$$

$$= \frac{1}{(19.373)^{0.41}} \times \frac{2.22486^{1.41} - 1}{1.41(2.22486 - 1)}$$

$$\eta_{\text{diesel}} = 64.132\%$$

$$\eta_{\text{ith}} = 0.5\,5\,\eta_{\text{diesel}} = 32\%$$

$$= \frac{IP}{\dot{m}_f \times C_V} = \frac{(BP)/\eta_{\text{mech}}}{\dot{m}_f \times C_V} = \frac{(BP)/0.8}{\dot{m}_f \times 41900}$$

$$\dot{m}_f = \frac{1/0.8}{41900 \times 0.32} = 9.322792 \times 10^{-5} \text{ kg/s kW}$$

$$\text{SFC} = 0.3356 \text{ kg/kW-hr}$$

Solution : 22

Given:

$$r = 8,$$
$$P_1 = 1 \text{ bar}$$
$$T_1 = 300 \text{ K},$$
$$Q_1 = \text{Heat transfer} = 1900 \text{ kJ/kg of air per cycle}$$

$$\eta_{\text{air-std}} = 1 - \frac{1}{r^{\gamma-1}} = 1 - \frac{1}{(8)^{0.4}} = 56.47\%$$

$$\text{work done} = \eta \times Q_1$$
$$= 0.5647 \times 1900 = 1072.97 \text{ kJ/kg}$$

$$P_m = \frac{\text{work done}}{\text{swept volume}}$$

$$v_1 = \frac{RT_1}{P_1} = \frac{287 \times 300}{1 \times 10^5} = 0.861 \text{ m}^3/\text{kg}$$

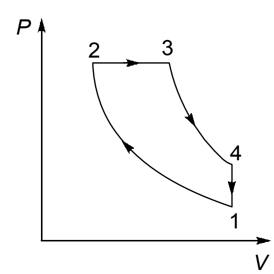
$$r = \frac{v_1}{v_2} = 8$$

$$v_2 = \frac{v_1}{8} = 0.1076 \text{ m}^3/\text{kg}$$

$$\text{swept volume} = v_1 - v_2 = 0.861 - 0.1076 = 0.75233 \text{ m}^3/\text{kg}$$

$$P_m = \frac{1072.97 \times 10^3}{0.7533} = 14.24 \text{ bar}$$

Solution : 23



$$\text{Work output} = p_{mep} \times V_s = \text{Area } 1234$$
$$= \text{Area under 2–3 + Area under 3-4 – Area under 2-1}$$
$$= p_2(V_3 - V_2) + \frac{p_3V_3 - p_4V_4}{\gamma - 1} - \frac{p_2V_2 - p_1V_1}{\gamma - 1}$$

$$r = \frac{V_1}{V_2} = 1 + \frac{V_s}{V_c} = 12 \Rightarrow V_s = 11\,V_c$$

$$V_2 = V_c$$
$$\Rightarrow \quad V_1 = V_4 = 11\,V_c + V_c = 12\,V_c$$
$$V_3 = \rho V_2 = \rho V_c \qquad (\rho = \text{cutoff ratio})$$
$$\frac{P_2}{P_1} = r^{\gamma} = 12^{1.4} = 32.42$$

$$P_2 = 32.42 \times 1.03 \times 10^5 = 33.39 \times 10^5 \text{ N/m}^2 = p_3$$

$$\frac{P_3}{P_4} = \left(\frac{r}{\rho}\right)^{1.4} = \frac{12^{1.4}}{\rho^{1.4}} = \frac{32.42}{\rho^{1.4}}$$

$$P_4 = \frac{P_3}{32.42} \times \rho^{1.4} = \frac{33.39 \times 10^5}{32.42} \times \rho^{1.4} = 1.03\rho^{1.4} \times 10^5$$

$$\text{Area } 1234 = \begin{Bmatrix} 33.39(\rho V_c - V_c) + \dfrac{33.39 \times \rho V_c - 1.03\rho^{1.4} \times 12 V_c}{0.4} \\ -\dfrac{33.39 \times V_c - 1.03 \times 12 V_c}{0.4} \end{Bmatrix} \times 10^5 \quad ...(1)$$

$$V_s = 11\, V_c$$

$$p_{mep} \times V_s = 8 \times 11\, V_c \times 10^5 \quad ...(2)$$

$$\text{Area } 1234 = p_{mep} \times V_s$$

Using (1) and (2) $\Rightarrow 0.672\,\rho - 0.178\,\rho^{1.4} = 1$

Solving by iteration, $\rho = 2.38$

$$\eta = 1 - \frac{1}{r^{\gamma-1}} \frac{(\rho^\gamma - 1)}{\gamma(\rho - 1)} = 1 - \frac{1}{12^{0.4}} \frac{(2.38^{1.4} - 1)}{1.4(2.38 - 1)} = 0.5466 = 54.66\%$$

Solution : 24

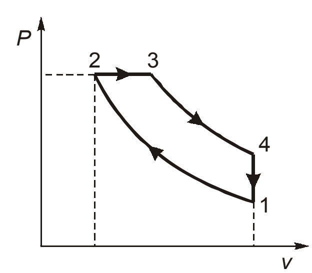
Diesel cycle

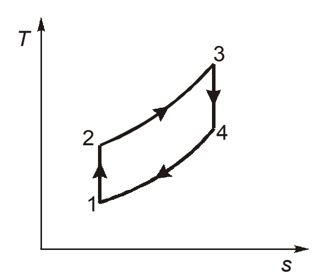
$$\eta = 1 - \frac{1}{(r_c)^{\gamma-1}} \frac{[\rho^\gamma - 1]}{[\gamma(\rho - 1)]}$$

where r_c = Compression ratio = $\dfrac{V_1}{V_2}$

ρ = Cut of ratio = $\dfrac{V_3}{V_2}$

$\gamma = \dfrac{c_P}{c_V}$





Given:

c_v = 0.717 kJ/kgK

γ = 1.4

c_p = 1.0038 kJ/kgK

∴ $R = c_p - c_v$ = 0.2868 kJ/kgK

∴ $$(\eta_t)_{\text{Diesel}} = 1 - \frac{1}{(16)^{0.4}} \frac{[\rho^{1.4} - 1]}{1.4(\rho - 1)}$$

where ρ = Cut off ratio = $\dfrac{V_3}{V_2}$

$$V_3 - V_2 = 0.10(V_1 - V_2)$$

$$\left(\frac{V_3}{V_2} - 1\right) = 0.10\left(\frac{V_1}{V_2} - 1\right)$$

$$(\rho - 1) = 0.10\,(16 - 1)$$

$$\rho = 2.5$$

$$\therefore \quad (\eta_I)_{Diesel} = 1-\frac{1}{(16)^{0.4}}\left[\frac{(2.5)^{1.4}-1}{1.4(2.5-1)}\right] = \mathbf{0.5905 = 59.05\%}$$

Case-II

When c_v is decreases by 2%

i.e. $c_v' = 0.70266$ kJ/kgK

$$R = 0.2868 = c_p' - c_v'$$

$$c_p' = 0.98946 \text{ kJ/kgK}$$

$$\therefore \quad \gamma' = \frac{c_p'}{c_v'} = 1.4081$$

$$\therefore \quad (\eta_{II})_{Diesel} = 1-\frac{1}{(16)^{0.4081}}\frac{\left[(2.5)^{1.4081}-1\right]}{\left[(1.4081)(2.5-1)\right]} = \mathbf{0.5978}$$

$\therefore$ % increase in efficiency of diesel cycle

$$= \frac{0.5978-0.5905}{0.5905} = \mathbf{1.236\%}$$

Solution : 25

$$P_1 = 1 \text{ bar}$$

$$T_1 = 273 + 90 = 363 \text{ K}$$

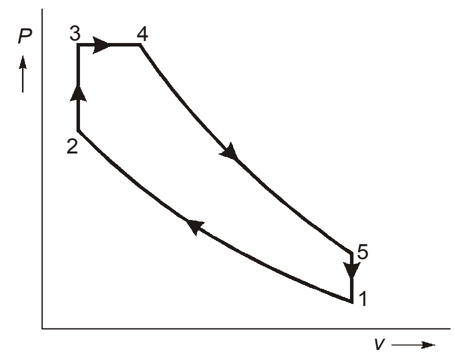
$$r = \frac{V_1}{V_2} = 13$$

$$Q_S = 1675 \text{ kJ/kg}$$

$$\gamma = 1.4$$

$$R = 0.287 \text{ kJ/kgK}$$

$$C_v = 0.71 + 20 \times 10^{-5}\, T$$



For the process 1-2 $\quad P_2V_2^{\gamma} = P_1V_1^{\gamma}$

$$\therefore \quad P_2 = P_1\left(\frac{V_1}{V_2}\right)^{\gamma} = 1\times 13^{1.4} = 36.27 \text{ bar}$$

$$T_2 = T_1 r^{\gamma-1} = 363(13)^{0.4} = 1012.7 \text{ K}$$

$$Q_{2-3} = \frac{1675}{2} = 837.5 \text{ kJ/kg} = \int_2^3 C_v dT = \int_2^3 (0.71+20\times10^{-5}T)\,dT$$

$$Q_{2-3} = 0.71\times(T_3-T_2)+20\times10^{-5}\left(\frac{T_3^2-T_2^2}{2}\right)$$

$$Q_{2-3} = 0.71(T_3-1012.7) + 10\times10^{-5}(T_3^2 - 10.25\times10^5)$$

$$\therefore \quad 837.5 = 0.71\,T_3 - 719 + 10\times10^{-5}\,T_3^2 - 102.5$$

or $\quad 10\times10^{-5}\,T_3^2 + 0.71\,T_3 - 1659 = 0$

or $\quad T_3^2 + 0.71\times10^4\,T_3 - 1659\times10^4 = 0$

$$\therefore \quad T_3 = \frac{-0.71\times10^4 \pm\sqrt{(0.71\times10^4)^2+4\times1659\times10^4}}{2}$$

$$= 1853 \text{ K (–ve value discarded)}$$

For the constant volume process 2-3

$$\frac{P_2}{T_2} = \frac{P_3}{T_3}$$

(i) $$P_3 = \frac{T_3}{T_2},\ P_2 = \frac{1853}{1012.7} \times 36.27 = 66.365 \text{ bar}$$

(ii) For the process 3-4, $Q_{3-4} = 837.5$ kJ/kg

$$C_p = R + C_v$$

$$Q_{3-4} = \int_3^4 C_p dT = \int_4^3 (R + C_v) dT = \int_3^4 \left(0.287 + 0.71 + 20 \times 10^{-5} T\right) dT$$

$$= \int_3^4 \left(0.997 + 20 \times 10^{-5} T\right) dT$$

$\therefore$ $$837.5 = 0.997(T_4 - 1853) + 20 \times 10^{-5}\left(\frac{T_4^2 - 1853^2}{2}\right)$$

or $$837.5 = 0.997\ T_4 - 1847.44 + 10 \times 10^{-5}\ T_4^{\ 2} - 343.36$$

$$T_4 = \frac{-997 \pm \sqrt{0.997^2 + 4 \times 3028.3 \times 10^{-4}}}{2 \times 10^{-4}}$$

$$= 2440.17 \text{ K (–ve discarded)}$$

For constant pressure process, $$V_4 = \frac{T_4}{T_3} \times V_3 = \frac{2440.17}{1853} \times V_3 = 1.3168 V_3$$

$$\text{Percentage cut-off} = \frac{V_4 - V_3}{V_1 - V_3} = \frac{(1.3168 - 1)}{(13 - 1)} \times 100 = 2.64\%$$

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2 Combustion & Knocking in SI and CI Engines

LEVEL 1 Objective Questions

1.	(c)
2.	(c)
3.	(c)
4.	(d)
5.	(c)
6.	(d)
7.	(a)

LEVEL 2 Objective Questions

8.	(a)
9.	(d)
10.	(c)
11.	(d)
12.	(c)
13.	(a)
14.	(d)
15.	(b)
16.	(b)

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3 Analysis and Injection of Fuel and Fuel Emissions

LEVEL 1 Objective Questions

1.	(c)
2.	(d)
3.	(c)
4.	(c)
5.	(d)
6.	(a)
7.	(a)
8.	(d)
9.	(c)
10.	(b)

LEVEL 2 Objective Questions

11.	(d)
12.	(a)
13.	(a)
14.	(d)
15.	(b)
16.	(d)
17.	(b)
18.	(b)
19.	(d)
20.	(c)
21.	(b)
22.	(b)
23.	(b)
24.	(d)
25.	(a)
26.	(b)
27.	(d)

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LEVEL 3 Conventional Questions

Solution : 28

Fuel injection rate (permit) per cylinder

$$= \frac{0.2 \times 180}{4 \times 60} = 0.15 \text{ kg/min}$$

$$\text{Fuel injected per injection} = \frac{0.15}{\left(\frac{1500}{2}\right)} = 2 \times 10^{-4} \text{ kg/injection}$$

$$\text{Time of injection, } t = \frac{\theta}{\omega} = \frac{15 \times (\pi / 180)}{2\pi N / 60} = 1.667 \times 10^{-3} \text{ sec}$$

$$\text{Fuel injection rate, } \dot{m}_f = \frac{2 \times 10^{-4}}{1.667 \times 10^{-3}} = 0.12 \text{ kg/sec}$$

Average pressure difference across orifice during injection

$$\Delta P = \frac{(200 + 500)}{2} - \frac{(30 + 50)}{2} = 310 \text{ bar}$$

$$\text{Velocity of fuel jet, } V_j = \sqrt{\frac{2\,\Delta P}{\rho_f}} = 262.467 \text{ m/sec}$$

Rate of fuel injection is also given by

$$\dot{m}_f = C_d \cdot A \cdot V_j \cdot \rho_f$$

$$A = \frac{\dot{m}_f}{C_d . V_j . \rho_f} = \frac{0.12}{0.7 \times 262.467 \times 900}$$

$$= \frac{6.5314 \times 10^{-4}}{900} \text{ m}^2 = 7.257 \times 10^{-7} \text{ m}^2$$

$$\therefore \quad d = \sqrt{\frac{4\,A}{\pi}} = 9.612 \times 10^{-4} \text{ m} = 0.9612 \text{ mm}$$

Solution : 29

Given:

V_s = 3.2 litre = 3.2×10^{-3} m^3

n = 5 cylinder

N = 2400 rpm

(Since, fuel injection occurs from 20° *b* TDC to 5° *a* TDC, so crank travels through $\theta = 20 + 5 = 25°$)

η_V = 0.95

equivalence ratio (ϕ) = 0.80

(A/F)stoichiometric = 14.5

$$\text{Time for injection} = \frac{\theta}{360 \times \left(\frac{N}{60}\right)} = \frac{25}{360 \times \left(\frac{2400}{60}\right)} = 1.736 \times 10^{-3}$$

$$\phi = \frac{\text{Actual fuel-air ratio}}{\text{Stoichimetric fuel-air ratio}}$$

$$(A/F)_{actual} = 0.80 \times 14.5 = 11.6$$

$$\text{Swept volume/cylinder} = \frac{3.2}{5} = 0.64 \text{ litres}$$

$$= 0.64 \times 10^{-3} \text{ m}^3$$

$$\text{Rate of swept volume/cylinder} = \left(\frac{0.64 \times 10^{-3} \times 2400}{2 \times 60}\right) = 0.0128 \text{ m}^3/\text{sec}$$

$$\eta_v = 0.95 = \frac{\dot{V}_a}{\dot{V}_s}$$

$$\dot{V}_a/\text{cylinder} = 0.95 \times 0.0128 = 0.01216 \text{ m}^3/\text{sec}$$

$$(A/F)_{ratio} = 11.6$$

$$\dot{V}_F, \text{ fuel flow rate/cylinder} = \frac{0.01216}{11.6} = 1.0482 \times 10^{-3} \text{ m}^3/\text{sec}$$

$$\text{Fuel flow rate/cylinder/cycle} = 1.0482 \times 10^{-3} \times \frac{1}{\left(\frac{2400}{2 \times 60}\right)} = 5.241 \times 10^{-5} \text{ m}^3/\text{cycle}$$

Solution : 30

Given: $n = 6$; B.P. = 125 B.P. = 125 kW; N = 3000 r.p.m. ; b.s.f.c. = 200 g/kWh; Sp.Gr. of fuel = 0.85.

$$\text{Fuel consumption per hour} = \text{b.s.f.c.} \times \text{B.P.}$$

$$= \frac{200}{1000} \times 125 = 25 \text{ kg}$$

$$\therefore \quad \text{Fuel consumption per cylinder} = \frac{25}{n} = \frac{25}{6} = 4.167 \text{ kg/h}$$

$$\text{Fuel consumption per cycle} = \frac{\text{Fuel consumption per cylinder per min.}}{\text{No. of cycles per min.}}$$

$$= \frac{(4.167/60)}{(3000/2)} = 4.63 \times 10^{-5} \text{ kg} = 0.0463 \text{ g}$$

$$\therefore \quad \text{Volume of fuel injected per cycle} = \frac{\text{Fuel consumption per cycle}}{\text{Specific gravity of fuel}}$$

$$= \frac{0.0463}{0.85} = 0.05447 \text{ c.c.}$$

Solution : 31

Given: $n = n_0 = 6$; $N = 1500$ r.p.m. ; B.P. = 220 kW, b.s.f.c. = 0.273 kg/kWh

$\theta = 30°$, Sp. Gr. of oil = 0.85, $C_f = 0.9$, $\Delta p = p_1 - p_2 = 160 - 40 = 120$ bar

Diameter of the nozzle orifice, d_0:

We know that, actual fuel velocity of injection,

$$V_f = C_f\sqrt{\frac{2(p_1 - p_2)}{\rho_f}} = C_f\sqrt{\frac{2\Delta p}{\rho_f}}$$

$$= 0.9 \times \sqrt{\frac{2 \times 120 \times 10^5}{(0.85 \times 1000)}} = 151.23 \text{ m/s}$$

Volume of fuel injected per second, $Q_f = \frac{0.273 \times 220}{(0.85 \times 1000) \times 3600} = 1.963 \times 10^{-5} \text{ m}^3/\text{s}$

Also, volume of fuel injected per second,

$$Q_f = \left[\frac{\pi}{4} d_0^2 \times n_0\right] \times V_f \times \left[\frac{\theta}{360} \times \frac{60}{N}\right] \times \frac{N_i}{60}$$

(where N_i = No. of injection/min. = $\frac{1500}{2} = 750$)

$$1.963 \times 10^{-5} = \left[\frac{\pi}{4} d_0^2 \times 6\right] \times 151.23 \times \left[\frac{30}{360} \times \frac{60}{1500}\right] \times \frac{750}{60} = 29.694\, d_0^2$$

$$\therefore \quad d_0 = \left(\frac{1.963 \times 10^{-5}}{29.694}\right)^{1/2} = 8.13 \times 10^{-4} \text{ m or } 0.813 \text{ mm}$$

Solution : 32

Given: Power developed = 11 kW; N = 1800 rpm., θ = 32° of crank travel; d_0 = 0.47 mm; C_f = 0.9; $\Delta_p = p_1 - p_2 = 118.2 - 31.38 = 86.82$ bar

$$\text{Sp.gr.} = \frac{141.5}{131.5 + °API} = \frac{141.5}{131.5 + 32} = 0.8654$$

Actual fuel velocity of injection, $V_f = C_f\sqrt{\frac{2\Delta p}{\rho_f}} = 0.9\sqrt{\frac{2 \times 86.82 \times 10^5}{(0.8654 \times 1000)}} = 127.48 \text{ m/s}$

Now, $m_f = A_0 \times V_f \times \rho_f$

$$= \frac{\pi}{4} d_0^2 \times V_f \times \rho_f$$

$$= \frac{\pi}{4} \times \left(\frac{0.47}{1000}\right)^2 \times 127.48 \times (0.8654 \times 1000)$$

$$= 0.01914 \text{ kg/s}$$

Time for fuel injection per cycle $= \frac{\theta}{360} \times \frac{60}{N} = \frac{32}{360} \times \frac{60}{1800} = 2.963 \times 10^{-3} \text{ s}$

Mass of fuel injected per cycle $= 0.01914 \times 2.963 \times 10^{-3} = 5.671 \times 10^{-5}$ kg/cycle

Total number of cycles per hour $= \frac{1800}{2} \times 60 = 54000$

$\therefore$ Fuel consumption in kg/kWh $= 5.671 \times 10^{-5} \times 54000 \times \frac{1}{11} = 0.278$ kg/kWh

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4 Testing and Performance of I.C. Engine

LEVEL 1 Objective Questions

1.	(b)
2.	(a)
3.	(c)
4.	(a)
5.	(b)
6.	(a)
7.	(d)
8.	(c)
9.	(a)
10.	(b)

LEVEL 2 Objective Questions

11.	(d)
12.	(d)
13.	(a)
14.	(b)
15.	(c)
16.	(c)
17.	(a)
18.	(c)
19.	(c)
20.	(a)
21.	(a)

■■■■

LEVEL 3 **Conventional Questions**

Solution : 22

Given: $\eta_{bt} = 35\% = 0.35$; $\frac{\dot{m}_a}{\dot{m}_f} = 25$; $CV = 42000$ kJ/kg; $T = 15 + 273 = 288$K; $p_{b\,mep} = ?$

$$\therefore \quad \eta_{bt} = \frac{\text{Brake Power (B.P.)}}{\dot{m}_f \times CV}$$

$$0.35 = \frac{BP}{\frac{\dot{m}_a}{25} \times 42000}$$

$$\dot{m}_a = \frac{BP}{588} \text{ kg/sec}$$

[Unit of Brake Power, BP is in kW]

As we know, $\quad pV_s = m_a RT \quad$ (V_s = stroke volume)

$$0.760 \times 13600 \times 9.81 \times V_s = \frac{BP}{588} \times 287 \times 288$$

$$\frac{BP}{V_s} = 721.314 \text{ kN/m}^2$$

$$\text{Brake mean effective pressure, } p_{bmep} = \frac{BP}{V_s} = 721.314 \text{ kN/m}^2 = 7.21 \text{ bar}$$

Solution : 23

$$\text{Brake power, BP} = \frac{2\pi N}{60}.T = \frac{2\pi \times 1200 \times 120}{60} = 15.079 \text{ kW}$$

$$\text{Thermal power, TP} = \dot{m}_f .\text{CV} = \frac{5}{3600} \times 42000 = 58.33 \text{ kW}$$

(i) Brake thermal efficiency,

$$\eta_{th} = \frac{B.P.}{T.P.} \times 100 = \frac{15.079}{58.33} \times 100 = 25.85\%$$

(ii) Brake mean effective pressure

$$\therefore \quad \text{B.P.} = P_{bmep} \times \frac{\pi}{4}.\text{B}^2.\text{S}.\frac{N}{60} \times \frac{1}{2} \times x$$

$$15079 = P_{bmep} \times \frac{\pi}{4} \times (0.1)^2 \times 0.12 \times \frac{1200}{60} \times \frac{1}{2} \times 4$$

$$15079 = P_{bmep} \times 0.0377$$

$$P_{bmep} = 4 \text{ bar}$$

(iii) Volume flow rate $\quad \dot{V}_a = C_d \times A \times \sqrt{2gh\left(\frac{\rho_w}{\rho_a}\right)}$

$$\rho_a = \frac{P_a}{RT_a} = \frac{1\times10^5}{287\times290} = 1.2 \text{ kg/m}^3$$

$$\therefore \quad \dot{V}_a = 0.6\times\frac{\pi}{4}(0.05)^2\times\sqrt{2\times9.81\times0.046\times\frac{1000}{1.2}}$$

$$= 0.0323 \text{ m}^3\text{/sec}$$

$$\text{Swept volume, } \dot{V}_s = \frac{\pi}{4}.B^2.S.\frac{N}{2\times60}\times 4 = 0.0377 \text{ m}^3\text{/sec}$$

$$\text{Volumetric efficiency, } \eta_V = \frac{\dot{V}_a\times100}{\dot{V}_s} = \frac{0.0323}{0.0377}\times100 = 85.68\%$$

Solution : 24

$$\text{Mechanical efficiency at full load} = \frac{bp}{bp+fp} = \frac{55}{55+9} = \frac{55}{64} = 0.8594 \text{ or } 85.94\%$$

$$\text{Mechanical efficiency at half load} = \frac{27.5}{27.5+9} = 0.7534 \text{ or } 75.34\%$$

$$\text{Mechanical efficiency at quarter load} = \frac{13.75}{13.75+9} = 0.6044 \text{ or } 60.44\%$$

$$\text{Mass of fuel/s, } \dot{m}_f = \frac{bp}{\eta_{bth}\times CV} = \frac{55}{0.25\times42\times10^3} = 5.238\times10^{-3} \text{ kg/s}$$

$$\text{Volume flow rate of fuel} = \frac{5.238\times10^{-3}}{0.75\times1000} = 6.984\times10^{-6} \text{ m}^3\text{/s}$$

Indicated thermal efficiency at full load,

$$\eta_{ith} = \frac{\eta_{bth}}{\eta_m} = \frac{0.25}{0.8594} = 0.2909 \text{ or } 29.09\%$$

Solution: 25

Friction power = 2.5 kW, as reading during motoring.

$$\text{Brake power} = \frac{2\pi NT}{60{,}000} = \frac{2\pi\times600\times200}{60{,}000} = 12.57 \text{ kW}$$

Indicated power, IP = B.P + F.P = 12.57 + 2.5 = 15.07 kW

$$\text{Mechanical, } \eta_m = \frac{B\cdot P}{IP} = \frac{12.57}{15.07} = 83.41\%$$

$$\text{Indicated thermal efficiency, } \eta_{i,th} = \frac{I\cdot P}{\text{Heat supplied}} = \frac{15.07\times3600}{2.5\times40.5\times10^3} = 53.58\%$$

Heat balance for the engine in kW basis

1. $$\text{Energy supplied} = \frac{2.5\times40.5\times10^3}{3600} = 28.125 \text{ kW}$$

2. Heat expenditure or energy distribution

(a) Heat in B.P = 12.57 kW

(b) Heat carried away by cooling water $= m c_p \Delta T = \dfrac{800 \times 4.2 \times 8}{3600} = 7.46$ kW

(c) Heat carried away by exhaust gases $= m_g c_{pg} \Delta T$

$$= \frac{(30 \times 2.5 + 2.5) \times 1.05 \times (320 - 30)}{3600} = 6.55 \text{ kW}$$

(d) Heat lost by radiation or unaccounted losses

$$= 28.125 - (12.57 + 7.46 + 6.55) = 1.545 \text{ kW}$$

Heat input	kW	%	Heat Expenditure	kW	%
Heat supplied by fuel	28.125	100	1. B.P. 2. cooling water 3. exhaust gas 4. unaccounted losses	12.57 7.46 6.55 1.545	44.7 26.52 23.29 5.49
			Total	28.125	100%

Heat Balance Sheet

Solution : 26

(i) Brake power, $bp = \dfrac{2\pi NT}{60} = \dfrac{2\pi \times 2000 \times 300}{60} = 62.83 \times 10^3$ W $= 62.83$ kW

(ii) Indicated power, $ip = \dfrac{bp}{\eta_m} = \dfrac{62.83}{0.85} = 73.92$ kW

(iii) $$bp = \frac{p_{m_b} LANn}{120}$$

$$p_{mb} = \frac{120 \times bp}{LAN n} = \frac{120 \times 62.83 \times 10^3}{0.12 \times \frac{\pi}{4}(0.10)^2 \times 2000 \times 6} = 6.67 \text{ bar}$$

(iv) Friction power, $fp = ip - bp$

$= 73.92 - 62.83 = 11.09$ kW

(v) Brake work from one cylinder in one cycle,

$$W_b = p_{mb} \cdot V_s = p_{m_b} \frac{\pi}{4} d^2 L = 6.67 \times 10^5 \times \frac{\pi}{4}(0.10)^2 \times 0.12 = 0.629 \times 10^3 \text{ J} = 0.629 \text{ kJ}$$

Swept volume, $V_s = \dfrac{\pi}{4} d^2 L = \dfrac{\pi}{4}(0.10)^2 \times (0.12) = 0.9425 \times 10^{-3}$ m^3

Clearance volume, $V_c = \dfrac{V_s}{(r-1)} = \dfrac{0.9425 \times 10^{-3}}{(18-1)} = 0.0554 \times 10^{-3}$ m^3

V_{BDC} = total cylinder volume $= V_s + V_c$

$= (0.9425 + 0.0554) \times 10^{-3} = 0.9979 \times 10^{-3}$ m^3

Mass of air in one cylinder per cycle,

$$m_a = \frac{pV_{BDC}}{RT} = \frac{0.9\times10^5 \times 0.9979\times10^{-3}}{287\times(39+273)} = 1.002 \times 10^{-3}\text{ kg}$$

Brake specific work per unit mass of air,

$$w_b = \frac{W_b}{m_a} = \frac{0.629}{1.002\times10^{-3}} = 628\text{ kJ/kg}$$

(vi) $$\frac{m_a}{m_f} = 20$$

$\therefore$ mass of fuel in one cylinder for one cycle, $m_f = \frac{m_a}{20}$

$$= \frac{1.002}{20}\times10^{-3} = 0.0501 \times 10^{-3}\text{ kg}$$

$$\dot{m}_f = m_f \times \frac{N}{120}\times n = 0.0501\times10^{-3}\times\frac{2000}{120}\times 6 = 0.00501\text{ kg/s}$$

(vii) Brake thermal efficiency

$$\eta_b = \frac{bp}{\dot{m}_f \times CV \times \eta_c} = \frac{62.83}{0.00501\times42000\times0.98} = 0.305 = 30.5\%$$

(viii) Volumetric efficiency,

$$\eta_v = \frac{m_a}{\rho_a \cdot V_s}$$

ρ_a is the standard air density which is equal to 1.181 kg/m^3.

$$\eta_v = \frac{1.002\times10^{-3}}{1.181\times0.9425\times10^{-3}} = 0.9 = 90\%$$

(ix) Brake specific fuel consumption

$$bsfc = \frac{\dot{m}_f}{bp} = \frac{0.00501\times3600}{62.83} = 0.287\text{ kg/kWh}$$

Solution : 27

Given: d = 35 cm, n = 4 cylinders, l = 40 cm, N = 315 rpm, P_{im} = 7 bar, BP = 260 kW, $\dot{m}_F$ = 80 kg/hr, CV =43000 kJ/kg, H_2 content = 13%, $\dot{m}_a$ =30 kg/min, $\dot{m}_w$ = 90 kg/min, $(\Delta T)_w$ = 38°C, $\dot{m}_{oil}$ = 45 kg/min, $(c_p)_{oil}$ = 2.3 kJ/kg-K, T_{exh}=322°C, T_0 = 22°C, $(c_p)_{exh}$ = 1.1 kJ/kg-K, $(c_p)_{steam}$ = 2 kJ/kg-K

Latent heat of steam = 2520 kJ/kg

$$\text{Total swept volume } (V_s) = \frac{\pi}{4}d^2 \times l \times n$$

$$= \frac{\pi}{4}(0.35)^2 \times 0.40 \times 4 = 0.15386\text{ m}^3$$

$$\dot{V}_s = (V_s) \times \frac{N}{2 \times 60}$$

$$= 0.15386 \times \frac{315}{2 \times 60} = 0.4038 \text{ m}^3\text{/sec.}$$

$$\text{Indicated power } (IP) = P_{im} \times \dot{V}_s = 7 \times 10^5 \times 0.4038 = 282.72 \text{ kW}$$

$$\eta_m = \frac{BP}{IP} = \frac{260}{282.72} = 91.96\%$$

$$\text{Heat input} = \dot{m}_F \times CV$$

$$= \frac{80}{60} \times 43000 = 57333.33 \text{ kJ/min}$$

$$\eta_{ith} = \frac{IP}{\text{Heat input}} = \frac{282.72 \times 60}{57333.33} = 29.58\%$$

$$\text{Heat equivalent to } BP = 260 \times 60 = 15600 \text{ kJ/min}$$

$$\text{Heat lost to cooling water} = \dot{m}_w c_{pw} (\Delta T)_w = 90 \times 4.18 \times 38 = 14295.6 \text{ kJ/min}$$

$$\text{Heat lost to cooling oil} = \dot{m}_{\text{oil}} (c_p)_{\text{oil}} (\Delta T)_{\text{oil}} = 45 \times 2.3 \times 23 = 2380.5 \text{ kJ/min}$$

As 1 kg of H_2 produces 9 kg of H_2O.

Therefore, H_2O produced $= 9 \times \% H_2 \times$ mass of fuel/min

$$= 9 \times 0.13 \times \frac{80}{60}$$

$$\dot{m}_s = 1.56 \text{ kg/min}$$

$$\text{Mass of wet exhaust gases/min } (m_T) = \dot{m}_a + \dot{m}_F$$

$$\dot{m}_T = 30 + \frac{80}{60} = 31.33 \text{ kg/min}$$

$$\text{Mass of dry exhaust gases/min} = 31.33 - 1.56 = 29.77 \text{ kg/min}$$

$$\text{Heat lost to dry exhaust gases/minute} = 29.77 \times 1.1 \times (322 - 22) = 9824.1 \text{ kJ/min}$$

Now, assuming the steam in the exhaust exists as superheated steam at exhaust gas temperature, its enthalpy 'h' is given by:

$$h = 4.18 \times 100 + 2520 + 2\,(322 - 100) = 3382 \text{ kJ/kg}$$

Now heat carried away by steam in the exhaust gas

$= \dot{m}_s (h - h')$ sensible heat of water at thed room temperature

$= 1.56 \times (3382 - 4.18 \times 22)$

$= 5132$ kJ/min

Unaccounted heat loss $= 57333.33 - [15600 + 14295.6 + 2380.5 + 9824.1 + 5132]$

$= 10101.13$ kJ/min

Heat input (per minute)	(kJ)	Heat expenditure (per minute)	(kJ)	%age contr.
Heat supplied by fuel	57333.33	1. Heat equivalent to BP	15600	27.2
		2. Heat lost to cooling medium	14295.6	24.934
		3. Heat lost to cooling oil	2380.5	4.152
		4. Heat carried away by steam	5132	8.95
		5. Heat lost in dry exhaust	9824.1	17.135
		6. Unaccounted losses	10101.13	17.618
		Total	57333.33	100

Solution : 28

Given data: Diameter of orifice =3.8 cm, Coefficient of discharge = 0.6, Pressure drop =145 mm of water = 1,422.45 N/m^2, Barometer reading =75.5 cm of Hg = 1,00, 729.08 N/m^2 , Compression ratio = 6, Stroke volume = 2000 cm^3 , Temperature of air = 299 K, *BP* = 29.5 kW at 2600 rpm, *FC* = 0.14 kg/min, *CV* = 43960 kJ/kg

1. Volumetric efficiency

$$\eta_v = \frac{\text{Actual volume inhaled/cycle}}{\text{swept volume}},$$

$$\rho_{air} = \frac{1.00729 \times 10^5}{287 \times 299} = 1.1738 \text{ kg/m}^3$$

Now in orifice meter air inhaled per second

$$= C_{d\,orifice}\sqrt{2\Delta P \rho_{air}}$$

$$= 0.6 \times \left(\frac{\pi}{4} \times 0.038^2\right) \times \sqrt{2 \times 1422.45 \times 1.173}$$

$$= 0.03932 \text{ kg/s}$$

$$\text{Swept volume} = 2000 \times 10^{-6} \times \frac{2600}{2 \times 60} = 0.0433 \text{ m}^3\text{/rev}$$

$$\text{Actual mass inhaled/s} = 0.03932 \text{ kg/s}$$

$$\text{Actual volume inhaled/s} = \frac{0.03932}{1.1738} = 0.03349 \text{ m}^3\text{/s}$$

$$\eta_v = \frac{0.03349}{0.0433} = 0.7736 = 77.36\%$$

2. Air-fuel ratio

$$m_a = 0.03932 \text{ kg/s}$$

$$SFC = m_f = 0.14 \text{ kg/min} = \frac{0.14}{60} \text{ kg/s} = 2.33 \times 10^{-3} \text{ kg/s}$$

$$\left(\frac{A}{F}\right) = \frac{0.03932}{2.33 \times 10^{-3}} = 16.85$$

3. Brake means effective pressure

$$BP = \frac{P_{me}LA}{60}\left(\frac{N}{2}\right)$$

$$\Rightarrow \quad P_{me} = \frac{60 \times 2 \times 29.5 \times 10^3}{2000 \times 10^{-6} \times 2600} = 6.81 \text{ bar}$$

4. Brake thermal efficiency

$$\eta_{Bth} = \frac{B.P}{m_f \times CV} = \frac{29.5 \times 10^3}{2.33 \times 10^{-3} \times 43960 \times 10^3}$$

$$= \frac{29.5 \times 10^3 \times 100}{102.4 \times 10^3} = 28.80\%$$

5. Relative efficiency

$$\eta_{Re} = \frac{\text{Actual thermal efficiency}}{\text{Air standard efficiency}}$$

$$\text{Air standard efficiency } \eta = 1 - \frac{1}{r^{\gamma-1}}$$

$$r = 6, \gamma = 1.4 \qquad \text{(for air)}$$

$$\eta_{air} = 1 - \frac{1}{6^{0.4}} = 0.5116 = 51.16\%$$

$$\eta_{relative} = \frac{28.8}{51.16} = 0.5628 = 56.28\%$$

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