P1.

$$0.8\,CH_4 + 0.2\,C_2H_6 + 1.5\,(0.8\times2 + 0.2\times3.5)(O_2 + 3.76N_2)$$
$$\rightarrow 1.2\,CO_2 + 2.2\,H_2O + 1.15\,O_2 + 12.972\,N_2$$

$$\Rightarrow 0.8\,CH_4 + 0.2\,C_2H_6 + 3.45\,(O_2 + 3.76N_2)$$
$$\rightarrow 1.2\,CO_2 + 2.2\,H_2O + 1.15\,O_2 + 12.972\,N_2$$

$$H_{reac} = \sum_R n_i \bar{h}_i = 0.8\times(-74850) + 0.2(-84680)$$
$$+ 3.45\{0 + 3031\} + 12.972\{0 + 2973\}$$
$$= -27793.3 \text{ kJ}$$

$$H_{prod} = \sum_P n_i \bar{h}_i = 1.2\{-393520 + 22810\} + 2.2\{-241820 + 18005\}$$
$$+ 1.15\{0 + 15838\} + 12.972\{0 + 15046\}$$
$$= -723854.6 \text{ kJ}$$

$$H_{reac} + Q = H_{prod}$$
$$\Rightarrow Q = -723854.6 - (-27793.3) = -696061.3 \ \frac{\text{kJ}}{\text{kmol}_{fuel}}$$

$$\Rightarrow Q = -\frac{696061.3}{MW_{Fuel}}$$
$$= -37024.5 \ \frac{\text{kJ}}{\text{kg fuel}}$$

$$MW_{Fuel} = 0.8\times16 + 0.2\times30$$
$$= 18.8$$

b) Let n_v be the number of mole of water vapor.

$$\frac{P_v}{P_{tot}} = \frac{n_v}{n_{tot}} = \frac{n_v}{1.2 + n_v + 1.15 + 12.972} = \frac{3.169\times10^3}{101325}$$

$$\Rightarrow n_v = 0.495 \text{ kmol}$$

No. of mole of liquid water $= 2.2 - 0.495$
$$= 1.705 \ \frac{\text{kmol}}{\text{kmol fuel}}$$
$$= \frac{1.705\times18}{18.8} \ \frac{\text{kg}}{\text{kg fuel}} = 1.632 \ \frac{\text{kg}}{\text{kg fuel}}$$

P2

$$CO + \frac{3}{4} O_2 \rightarrow aCO_2 + \frac{1}{4} O_2 + b\,CO$$

(a)

Given, $\frac{b}{a} = \frac{3}{4} = \frac{X_{CO}}{X_{CO_2}}$ — (1)

$$K_p = \frac{P_{CO_2}/p^o}{\left(\frac{P_{CO}}{p^o}\right)\left(\frac{P_{O_2}}{p^o}\right)^{1/2}} = \frac{X_{CO_2}}{X_{CO} X_{O_2}^{1/2}} \left(\frac{P}{p^o}\right)^{-1/2} = \frac{X_{CO_2}}{X_{CO} X_{O_2}^{1/2}}$$

$$\Rightarrow \frac{\#C}{\#O} = \frac{1}{\left(1+\frac{3}{4}\cdot 2\right)} = \frac{2}{5} = \frac{X_{CO_2} + X_{CO}}{2X_{CO_2} + X_{CO} + 2X_{O_2}} \quad \text{— (2)}$$

$$X_{CO} + X_{CO_2} + X_{O_2} = 1 \quad \text{— (3)}$$

Using (1), (3) becomes $X_{CO_2}\left[1+\frac{3}{4}\right] + X_{O_2} = 1$

$$\Rightarrow X_{O_2} = 1 - \frac{7}{4} X_{CO_2}$$

(2) become

$$5(X_{CO_2} + X_{CO}) = 4X_{CO_2} + 4X_{O_2} + 2X_{CO}$$

$$\Rightarrow X_{CO_2} + 3X_{CO} = 4\left[1 - \frac{7}{4} X_{CO_2}\right]$$

$$\Rightarrow X_{CO_2} + 3\,\frac{3}{4} X_{CO_2} = 4 - 7X_{CO_2}$$

$$\Rightarrow X_{CO_2}\left[1 + \frac{9}{4} + 7\right] = 4 \Rightarrow X_{CO_2} = \frac{16}{41}$$

$$X_{CO} = \frac{12}{41}, \quad X_{O_2} = \frac{13}{41}$$

$$K_p = \frac{(16/41)}{\left(\frac{12}{41}\right)\left(\frac{13}{41}\right)^{1/2}} = 2.37$$

2 (b)

$$CO + 1.8 \times \frac{1}{2} O_2 \rightarrow a\,CO_2 + b\,CO + 0.4\,O_2$$

$$\frac{\#C}{\#O} = \frac{1}{1+1.8} = \frac{5}{14} = \frac{X_{CO_2} + X_{CO}}{2X_{CO_2} + X_{CO} + 2X_{O_2}} \quad -(1)$$

$$X_{CO_2} + X_{CO} + X_{O_2} = 1 \quad -(2)$$

$$\frac{X_{CO_2}}{X_{CO}\, X_{O_2}^{1/2}} = K_p = 2.37 \quad -(3)$$

Solving, $X_{CO_2} = 0.369$, $X_{CO} = 0.254$, $X_{O_2} = 0.377$

$$\therefore \frac{X_{CO}}{X_{CO_2}} = \frac{0.254}{0.369} = 0.69 \quad \text{(Ans).}$$

P4

$$B.P. = \frac{2\pi N T}{60 . 1000} = \frac{2\pi \; 1440 . 100}{60 . 1000} = 15.086 \text{ KW} \quad (2P)$$

(i) $$\eta_{bth} = \frac{\cancel{15.086} \; \cancel{\times} \; BP}{\dot{m}_f \times CV} = \frac{15.086}{\frac{5}{3600} \times 42000} = 25.86\% \quad (2P)$$

$$\dot{m}_f = 5 \text{ kg/hr} = \frac{5}{3600} \frac{kg}{s}$$

$$CV = 42 \text{ MJ/kg}$$

(ii) $$BMEP = \frac{BP \times 60 \times 1000}{L A n K}$$

$$= \frac{15.086 \times 60000}{0.12 \times 7.857 \times 10^{-3} . (720) . 4}$$

$$= 3.33 \times 10^{5} \text{ N/m}^2$$

$$= 3.33 \text{ bar} \quad (4P)$$

$K =$ No. of cyl $= 4$

$n = \frac{N}{2}$ (four-stroke)

$\Rightarrow n = \frac{1440}{2} = 720$

$L = 0.12 \, m$

$$A = \frac{\pi}{4} D^2 = \frac{\pi}{4} (0.1)^2 = 7.857 \times 10^{-3} \, m^2$$

(iii) $$\dot{V}_a = C_d \, A_{orifice} \sqrt{2g \, \Delta h_w \frac{\rho_w}{\rho_a}}$$

$$= 0.62 \times 1.9643 \times 10^{-3} \sqrt{2g \; 4.6 \times 10^{-2} . \frac{1000}{1.16}}$$

$$= 0.0339 \frac{m^3}{s} = 2.036 \frac{m^3}{min}$$

$\Delta h_w = 4.6 \text{ cm} = 4.6 \times 10^{-2} \, m$

$$A_{orifice} = \frac{\pi}{4} D^2 = \frac{\pi}{4} (0.05)^2 = 1.9643 \times 10^{-3} \, m^2$$

$C_d = 0.62$

$$\rho_a = \frac{p}{R_{air} T} = \frac{10^5}{287 \times 300} = 1.16 \frac{kg}{m^3}$$

$$V_s = \frac{\pi}{4} D^2 L n K$$

$$= \cancel{\frac{\pi}{4}} \; 7.857 \times 10^{-3} . 0.12 . 720 . 4$$

$$= 2.715 \, m^3/min$$

$$\eta_v = \frac{\dot{V}_a}{V_s} = \frac{2.036}{2.715} = 75\% \quad (4P)$$

P.5

$$0.65CH_4 + 0.02H_2 + 0.02N_2 + 0.031CO_2 + a(O_2 + 3.76N_2)$$
$$\rightarrow bCO_2 + cH_2O + dCO + eO_2 + fN_2$$

Dry exhaust gas analysis

$\# C : \quad 0.65 + 0.31 = b + d \quad — ①$

$\# H : \quad 0.65 \times 4 + 0.04 = 2c \quad \Rightarrow c = 1.32$

$\# O : \quad 0.31 \times 2 + 2a = 2b + c + d + 2e \quad — ②$

$\# N : \quad 0.04 + 7.52a = 2f \quad — ③$

From Dry gas analysis

$$\frac{11.4}{83} = \frac{b}{f}, \quad \frac{5.3}{83} = \frac{e}{f}$$

$$\frac{0.3}{83} = \frac{d}{f},$$

$\Rightarrow b = 0.137f, \quad e = 0.0639f,$

$d = 3.615 \times 10^{-3} f$

Using these expⁿ in Eq ②, we get

$0.4054f + 1.32 = 0.62 + 2a$

$\Rightarrow f = 4.93a - 1.727 \quad — ⑤$

Solving ③ & ⑤, $a = 1.493$, $f = 5.634$

$b = 0.772$, $e = 0.36$, $d = 0.02$, $c = 1.32$

$$\left(\frac{A}{F}\right)_{act} = \frac{1.493(32 + 3.76 \times 28)}{0.65 \times 16 + 0.02 \times 2 + 0.02 \times 28 + 0.31 \times 44} = 8.32$$

~~% excess air~~

Stoic. eq^n:

$$0.65\,CH_4 + 0.02H_2 + 0.02N_2 + 0.31\,CO_2 + 1.31(O_2 + 3.76N_2).$$

$$\rightarrow 0.65CO_2 + 1.32\,H_2O + 4.93\,N_2$$

$$+ 0.31CO_2 + 0.02N_2$$

$$\rightarrow \cancel{0.65CO_2+}\ 0.96\,CO_2 + 1.32H_2O + 4.95N_2$$

$$\left(\frac{A}{F}\right)_{st} = \frac{1.31(32 + 3.76\times 28)}{0.65\times 16 + 0.02\times 2 + 0.02\times 28 + 0.31\times 44} = 7.3$$

$$\%\ \text{excess air} = \frac{8.32 - 7.3}{7.3}\times 100 = 14\%$$

P3

a) $\frac{d[N]}{dt} = k_{1f}[O][N_2] - k_{2f}[N][O_2] = 0$ (at steady state)

$\Rightarrow [N]_{ss} = \frac{k_{1f}[O][N_2]}{[O_2]}$

$\frac{d}{dt}[NO] = k_{1f}[O][N_2] + k_{2f}[N][O_2] = 2k_{1f}[O][N_2]$

b) $X_O = 8.036 \times 10^{-5} \Rightarrow [O] = \frac{X_O P}{R_u T} = \frac{8.036 \times 10^{-5} \times 101325}{8314 \times 2400}$

$= 4.08 \times 10^{-7} \frac{kmol}{m^3}$

$[O] = 4.08 \times 10^{-10} \frac{gmol}{cm^3}$

$X_{N_2} = 0.735 \Rightarrow [N_2] = \frac{0.735 \times 101325}{8314 \times 2400} = 3.73 \times 10^{-3} \frac{kmol}{m^3}$

$[N_2] = 3.73 \times 10^{-6} \frac{gmol}{cm^3}$

$k_{1f} = 1.82 \times 10^{14} \exp\left(\frac{-38370}{T}\right) = 2.0739 \times 10^{7} \frac{cm^3}{gmol\text{-}s}$

$\frac{d}{dt}[NO] = 2k_{1f}[O][N_2] = 63.12 \times 10^{-9}$

$\Rightarrow [NO]_f - 0 = 63.12 \times 10^{-9}\, t$

$\Rightarrow t = \frac{3.66 \times 10^{-7}}{63.12 \times 10^{-9}} = 5.8$ sec

$[NO]_f = 3.66 \times 10^{-4} \frac{kmol}{m^3}$

$= 3.66 \times 10^{-7} \frac{gmol}{cm^3}$