Answer Key

Ideal Gas Mixtures, Fuels and Combustion, Chimney and Machine Foundation

1

Fuel: C_5H_8 ; $e = 35\%$

$m_F = 0.20 kg$

Find: mass of air required:

$$1 mol\ C_5H_8 + a(1.35 mol)[1 mol\ O_2' + 3.76 N_{2air}'] \rightarrow bCO_2 + cH_2O_F + a(0.35 mol)O_{2excess} + a(1.35)(3.76 mol)N_{2air}'$$

For Carbon:

$(1)(5) = b(1)$

$b = 5$

For Hydrogen:

$(1)(8) = c(2)$

$c = 4$

For Oxygen;

$a(1.35)(1)(2) = b(2) + c(1) + a(0.35)(2)$

$a = 7$

Balanced actual equation:

$$C_5H_8 + 9.45 mol[1 mol\ O_2' + 3.76 N_{2air}'] \rightarrow 5 mol\ CO_2 + 4 mol\ H_2O_F + 2.45 mol\ O_{2excess} + 35.532 mol\ N_{2air}'$$

The actual air-fuel ratio

$A:F' = \frac{m_a'}{m_F}$; $m_a' = [(9.45)(16)(2) + (9.45)(3.76)(14)(2)] mol = 1297.296 kg_a'$

$m_F = [(1)(12)(5) + (1)(1)(8)] mol = 68 kg_F$

Subst;

$$A:F' = \frac{1297.296 kg_a'}{68 kg_F} = 19.0779 \frac{kg_a'}{kg_F}$$

The mass of air required:

$$m_a' = \left(19.0779 \frac{kg_a'}{kg_F}\right)(0.20 kg)$$

$$\boxed{m_a' = 3.8156\ kg_a}$$

$$aC_6H_{18} + bO_2 + cN_2 \longrightarrow 15CO_2 + 2CO + 3O_2 + 80N_2 + dH_2O$$

For Carbon

$$a(6) = (15)(1) + 2(1)$$
$$a = 2.833$$

For Hydrogen;

$$a(18) = d(2)$$
$$d = 25.497$$

For Nitrogen;

$$c(2) = 80(2)$$
$$c = 80$$

For Nitrogen – Oxygen ratio

$$\frac{c}{b} = 3.76$$
$$\frac{80}{b} = 3.76$$
$$b = 21.2766$$

BALANCED MOLAR EQUATION

$$2.833\,C_6H_{18} + 21.2766\,O_2 + 80N_2 \longrightarrow 15CO_2 + 2CO + 3O_2 + 80N_2 + 25.497H_2O$$

OR

$$C_6H_{18} + 7.5103\,O_2 + 28.2386\,N_2 \longrightarrow 5.2947\,CO_2 + 0.7060\,CO + 1.0589\,O_2 + 28.2386\,N_2 + 9H_2O$$

ACTUAL AIR-FUEL RATIO:

$$A{:}F' = \frac{m_a'}{m_F} \quad ; \quad m_a' = \left[(7.5103)(16)(2) + (28.2386)(14)(2)\right] kg = 1031.0104\ kg_a'$$

$$m_F = \left[(1)(12)(6) + (1)(1)(18)\right] kg_F = 90\ kg_F$$

$$A{:}F' = \frac{1031.0104\ kg_a'}{90\ kg_F}$$

$$\boxed{A{:}F' = 11.4557\ kg_a'/kg_F}$$

$C_{15}H_{30}$ with 20% excess air

Find: molal air-fuel ratio

$$1\,mol\ C_{15}H_{30} + a(1.20\,mol)\left[1\,mol\ O_2' + 3.76N_2'{}_{air}\right] \longrightarrow bCO_2 + cH_2O_F + a(0.20\,mol)O_{2\,excess} + a(1.20)(3.76\,mol)N_2'{}_{air}$$

For Carbon:

$$(1)(15) = b(2)$$
$$b = 7.5$$

For Hydrogen;

$$(1)(30) = c(2)$$
$$c = 15$$

For oxygen:

$$a(1.20)(2) = b(2) + c(1) + a(0.20)(2)$$
$$a = 15$$

Balanced molal equation:

$$C_{15}H_{30} + 18\,mol\left[1\,mol\ O_2' + 3.76N_{2\,air}'\right] \longrightarrow 7.5CO_2 + 15H_2O_F + 3O_{2\,excess} + 67.68N_2'{}_{air}$$

Hence;

$$A:F = \frac{n_a'}{n_F} = \frac{[18 + (18)(3.76)]\,mol_a'}{1\,mol_F'}$$

$$\boxed{A:F = 85.68\,\frac{mol_a'}{mol_F}}$$

4

$$A:F = 11.5(\% G_{CF}) + 34.5\left[\% G_{H_2F} - \frac{\% G_{O_2F}}{8}\right] + 4.3(\% G_{SF})$$

$$A:F = 11.5(0.685) + 34.5\left[0.03 - \frac{0.04}{8}\right] + 4.3(0.08)$$

$$A:F = 9.084 \frac{kg_a}{kg_F}$$

For actual Air-Fuel ratio w/ 30% excess air

$$A:F' = A:F(1+e)$$

$$A:F' = \left(9.084 \frac{kg_a}{kg_F}\right)(1+0.30)$$

$$\boxed{A:F = 11.8092 \frac{kg_a'}{kg_F}}$$

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$$HHV = 14600(\%G_{CF}) + 62000\left[\%G_{H_2F} - \frac{\%G_{O_2F}}{8}\right] + 4050(\%G_{SF})$$

$$HHV = 14600(0.72) + 62000\left[0.03 - \frac{0.035}{8}\right] + 4050(0.065)$$

$$\boxed{HHV = 12364 \ Btu/lb_F}$$

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PARTIAL pressure of WATER VAPOR

$$P_{H_2O_F} = \left(\frac{n_{H_2O\,F}}{n_T}\right) P_T$$

$$70\,CH_4 + a(1.20\,mn)\left[1\,mn\,O_2' + 3.76\,N_2'{}_{air}\right] \longrightarrow b\,CO_2 + c\,H_2O_F + a(0.20\,mn)\,O_{2\,excess} + a(1.20)(3.76\,mn)\,N_2'{}_{air}$$

for carbon:

$$(70)(1) = b(1)$$
$$b = 70$$

For Hydrogen

$$(70)(4) = c(2)$$
$$c = 140$$

for oxygen;

$$a(1.20)(2) = b(2) + c(1) + a(0.20)(2)$$
$$a = 140$$

Balanced molal equation

$$70\,CH_4 + 168\,mn\left[1\,mn\,O_2' + 3.76\,N_2'{}_{air}\right] \longrightarrow 70\,CO_2 + 140\,H_2O_F + 28\,O_{2\,excess} + 631.68\,N_2'{}_{air}$$

$$30\,C_2H_6 + a(1.20\,mn)\left[1\,mn\,O_2' + 3.76\,N_2'{}_{air}\right] \longrightarrow b\,CO_2 + c\,H_2O_F + a(0.20\,mn)\,O_{2\,excess} + a(1.20)(3.76\,mn)\,N_2'{}_{air}$$

For Carbon:

$$(30)(2) = b(1)$$
$$b = 60$$

For Hydrogen

$$(30)(6) = c(2)$$
$$c = 90$$

For Oxygen:

$$a(1.20)(2) = b(2) + c(1) + a(0.20)(2)$$
$$a = 105$$

Balanced molal equation:

$$30\,C_2H_6 + 126\,mn\left[1\,mn\,O_2' + 3.76\,N_2'{}_{air}\right] \longrightarrow 60\,CO_2 + 90\,H_2O_F + 21\,O_{2\,excess} + 473.76\,N_2'{}_{air}$$

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For n_T of CH_4 & C_2H_6

$$n_T = [70 + 140 + 28 + 631.68] + [60 + 90 + 21 + 473.76]$$

$$n_T = 1514.44 \text{ mol}$$

For $n_{H_2O_F}$;

$$n_{H_2O} = (140 + 90)$$

$$n_{H_2O} = 230 \text{ mol } H_2O$$

Hence;

$$P_{H_2O_F} = \left(\frac{n_{H_2O}}{n_T}\right) P_T = \left(\frac{230 \text{ mol } H_2O}{1514.44 \text{ mol}}\right)(100 \text{ kPa})$$

$$\boxed{P_{H_2O_F} = 15.1871 \text{ kPa}}$$

$m_g = 20\ kg$

$m_F = 1\ kg_F$

Fuel: $C_{12}H_{26}$

$m_a' + m_F = m_g$

$m_a' + 1\ kg_F = 20\ kg$

$m_a' = 19\ kg_a'$

$A{:}F' = \frac{26\ kg_a'}{1\ kg_F} = 19\ \frac{kg_a'}{kg_F}$

$A{:}F' = A{:}F(1+e)$

Solving for the theoretical Air-fuel ratio

$$C_{12}H_{26} + a[1\ mol\ O_2 + 3.76\ N_{2\,air}] \longrightarrow bCO_2 + cH_2O_F + a(3.76)N_{2\,air}$$

For Carbon;

$(1)(12) = b(1)$

$b = 12$

For Hydrogen;

$(1)(26) = c(2)$

$c = 13$

For oxygen;

$a(2) = b(2) + c(1)$

$a = 18.5$

For the mass of fuel

$m_F = (1)(12)(12) + (1)(1)(26) = 170\ kg_F$

For the mass of air;

$m_a = (18.5)(16)(2) + (18.5)(3.76)(14)(2) = 2539.68\ kg_a$

$A{:}F = \frac{2539.68\ kg_a}{170\ kg_F} = 14.939\ \frac{kg_a}{kg_F}$

Hence;

$A{:}F' = A{:}F(1+e)$

$19\ \frac{kg_a'}{kg_F} = 14.939\ \frac{kg_a}{kg_F}(1+e)$

$\boxed{e = 27.18\ \%}$

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By mass balance in the Furnace

$$m_a + m_c = m_{gas} + m_{ash}$$

$$\left(18\ \frac{kg}{kg_{coal}}\right)\left(2500\ \frac{kg_{coal}}{hr}\right) + \left(2500\ \frac{kg_{coal}}{hr}\right) = m_g + (0.12)\left(2500\ \frac{kg_{coal}}{hr}\right)$$

$$\boxed{m_g = 47200\ \frac{kg}{hr}}$$

$$h_s = \frac{\gamma_w h_w}{\gamma_a - \gamma_g} = \frac{0.32\ kPa}{(1.18 - 0.80)\ kg/m^3 \left(\frac{9.81\ m/s^2}{1000\ \frac{kg\text{-}m}{kN\text{-}s^2}}\right)}$$

$$\boxed{h_s = 85.8415\ m}$$

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$$\dot{V}_g = \frac{m_g R_g T_g}{P} = \frac{\left(\frac{54000}{3600}\ \frac{kg}{s}\right)\left(0.288\ kJ/kg\text{-}K\right)\left(28+273\right)K}{98\ kPa}$$

$$\dot{V}_g = 13.2686\ m^3/s$$

then;

$$\dot{V}_g = A v$$

$$13.2686\ m^3/s = \frac{\pi D^2}{4}\left(6\ m/s\right)$$

$$\boxed{D = 1.6780\ m}$$

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$m_a + m_c = m_g + m_{ASH}$

$$\left(16.2\ \frac{kg}{kg_{coal}}\right)\left(3200\ kg_{coal}/hr\right) + \left(3200\ kg_{coal}/hr\right) = m_g + (0.10)\left(3200\ kg_{coal}/hr\right)$$

$$m_g = 54720\ kg/hr$$

$$\dot{V}_g = \frac{m_g R_g T_g}{P} \quad ; \quad R_g = \frac{\bar{R}}{MW} = \frac{8.314\ kJ/kg\text{-}k}{31\ kg/kg}$$

$$R_g = 0.2682\ kJ/kg\text{-}k$$

$$\dot{V}_g = \frac{\left(\frac{54720}{3600}\ \frac{kg}{s}\right)\left(0.2682\ kJ/kg\text{-}k\right)(290+273)k}{98\ kPa}$$

$$\dot{V}_g = 23.4199\ m^3/s$$

then;

$$\dot{V}_g = Av$$

$$23.4199\ m^3/s = \frac{\pi D^2}{4}\left(8.8\ m/s\right)$$

$$\boxed{D = 1.8408\ m}$$

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$$h_s = \frac{\gamma_w h_w}{\gamma_a - \gamma_g} = \frac{\rho_w h_w}{\rho_a - \rho_g}$$

$$\rho_a = \frac{P}{RT} = \frac{100\ kPa}{(0.287\ kJ/kg\text{-}K)(28+273)K} = 1.1576\ kg/m^3$$

$$\rho_g = \frac{P}{RT} = \frac{100\ kPa}{(0.280\ kJ/kg\text{-}K)(188+273)K} = 0.7747\ kg/m^3$$

subst;

$$h_s = \frac{(1000\ kg/m^3)(0.232\ m)}{(1.1576 - 0.7747)\ kg/m^3}$$

$$\boxed{h_s = 605.9023\ m}$$

Exponential LEAP ONLINE REVIEW

Gravemetric Analysis of Gas

CO_2	20%	$0.20/44$	$= 0.004545$
O_2	8%	$0.07/32$	$= 0.002188$
N_2	72%	$0.72/28$	$= 0.02571$
			0.03244 mol

$$MW = \frac{m}{n} = \frac{1\ kg}{0.03244} = 30.8233\ kg/kg_{mol}$$

$$R = \frac{\bar{R}}{MW} = \frac{8.314\ kJ/kg\text{-}K}{30.8233\ kg/kg_{mol}} = 0.2697\ kJ/kg\text{-}K$$

and;

$$h_s = \frac{\gamma_w h_w}{\gamma_a - \gamma_g}$$

$$;\ \rho_a = \frac{P}{RT} = \frac{95\ kPa}{(0.287\ kJ/kg\text{-}K)(23+273)K}$$

$$\rho_a = 1.118\ kg/m^3$$

$$\rho_g = \frac{P}{RT}$$

$$t = \frac{t_2 + t_1}{2} = \frac{(198+162)°C}{2} = 180°C$$

$$\rho_g = \frac{95\ kPa}{(0.2697\ kJ/kg\text{-}K)(180+273)K}$$

$$\rho_g = 0.7776\ kg/m^3$$

Hence;

$$h_s = \frac{0.18\ kPa}{(1.118 - 0.7776)\frac{kg}{m^3}\left(\frac{9.81\ m/s^2}{1000\ \frac{kg\text{-}m}{kN\text{-}s^2}}\right)}$$

$$\boxed{h_s = 53.9031\ m}$$