Example (3.2) Determine the air–fuel ratio on both a molar and mass basis for the complete combustion of octane, C_8H_{18}, with (a) the theoretical amount of air, (b) 150% theoretical air (50% excess air).

Solution

(a) For complete combustion of C_8H_{18} with the theoretical amount of air, the products contain carbon dioxide, water, and nitrogen only. That is

$$C_8H_{18} + a(O_2 + 3.76N_2) \rightarrow bCO_2 + cH_2O + dN_2$$

Applying the conservation of mass principle to carbon, hydrogen, oxygen, and nitrogen:

C: $b = 8$

H: $2c = 18 \rightarrow c = 9$

O: $2b + c = 2a \rightarrow a = 12.5$

N: $d = 3.76a \rightarrow d = 47$

Then the balanced chemical equation is:

$$C_8H_{18} + 12.5(O_2 + 3.76N_2) \rightarrow 8CO_2 + 9H_2O + 47N_2$$

The air-fuel ratio on molar basis is;

$$\overline{AF} = \frac{12.5(1+3.76)}{1} = 59.5 \ kmol\ air/kmol\ fuel$$

The air-fuel ratio on mass basis is;

$$AF = \frac{m_{air}}{m_{fuel}} = \frac{(NM)_{air}}{(NM)_{fuel}} = \frac{(NM)_{air}}{(NM)_C + (NM)_{H2}}$$

$$AF = \frac{(12.5 \times 4.76kmol) \times (29\ kg/kmol)}{(8kmol) \times (12\ kg/kmol) + (9kmol) \times (2\ kg/kmol)}$$

$$AF = 15.1 \ kg\ air/kg\ fuel$$

(b) For 150% theoretical air,

$$\overline{AF}_{150\%} = 1.5 \times 59.5 = 89.25 \ kmol\ air/kmol\ fuel$$

$$AF_{150\%} = 1.5 \times 15.1 = 22.65 \ kg\ air/kg\ fuel$$

OR,

the chemical equation for combustion takes the form;

$$C_8H_{18} + 1.5 \times [12.5(O_2 + 3.76N_2)] \rightarrow aCO_2 + bH_2O + cN_2 + dO_2$$

Applying the conservation of mass;

C: $a = 8$

H: $2b = 18 \rightarrow b = 9$

O: $2a + b + 2d = 1.5 \times 12.5 \times 2 \rightarrow d = 6.25$

N: $c = 1.5 \times 12.5 \times 3.76 \rightarrow c = 70.5$

Then the balanced chemical equation for 150% theoretical air is:

$$C_8H_{18} + 18.75(O_2 + 3.76N_2) \rightarrow 8CO_2 + 9H_2O + 70.5N_2 + 62.5O_2$$

The air-fuel ratio on molar basis is;

$$\overline{AF}_{150\%} = \frac{18.75(1+3.76)}{1} = 89.25 \ kmol\ air/kmol\ fuel$$

The air-fuel ratio on mass basis is;

$$AF_{150\%} = \frac{m_{air}}{m_{fuel}} = \frac{(NM)_{air}}{(NM)_{fuel}} = \frac{(NM)_{air}}{(NM)_C + (NM)_{H2}}$$

$$AF_{150\%} = \frac{(18.75 \times 4.76kmol) \times (29\, kg/kmol)}{(8kmol) \times (12\, kg/kmol) + (9kmol) \times (2\, kg/kmol)}$$

$$AF_{150\%} = 22.7 \;\; kg\ air/kg\ fuel$$

Example (3.3) Propal alcohol (C_3H_7OH) is burned with 50 percent excess air. Write the balanced reaction equation for complete combustion and determine the air-to-fuel ratio.

Solution:

For complete combustion of C_8H_{18} with the theoretical amount of air, the products contain carbon dioxide, water, and nitrogen only. That is

$$C_3H_7OH + a(O_2 + 3.76N_2) \rightarrow bCO_2 + cH_2O + a \times 3.76 \times N_2$$

Applying the conservation of mass;

C: $3 = b$

H: $8 = 2c \rightarrow c = 4$

O: $1 + 2a = 2b + c = 6 + 4 = 10 \rightarrow a = \frac{9}{2} = 4.5$

Then the balanced chemical equation for 150% theoretical air is:

$$C_3H_7OH + 4.5(O_2 + 3.76N_2) \rightarrow 3CO_2 + 4H_2O + 4.5 \times 3.76 \times N_2$$

$$AF = \frac{m_{air}}{m_{fuel}} = \frac{(NM)_{air}}{(NM)_{fuel}} = \frac{(NM)_{air}}{(NM)_C + (NM)_{H2} + (NM)_{O2}}$$

$$AF = \frac{(4.5 \times 4.76kmol) \times (29kg/kmol)}{(3kmol) \times (12kg/kmol) + (8kmol) \times (1kg/kmol) + (1kmol) \times (16kg/kmol)}$$

$$AF = \frac{621.18}{60} = 10.353 \;\; kg\ air/kg\ fuel$$

Then the balanced chemical equation for 150% theoretical air is:

$$C_3H_7OH + 1.5 \times 4.5(O_2 + 3.76N_2) \rightarrow 3CO_2 + 4H_2O + 25.38N_2 + 2.25O_2$$

$$AF_{150\%} = \frac{(6.75 \times 4.76kmol) \times (29kg/kmol)}{(3kmol) \times (12kg/kmol) + (8kmol) \times (1kg/kmol) + (1kmol) \times (16kg/kmol)}$$

$$AF_{150\%} = \frac{931.77}{60} = 15.53 \;\; kg\ air/kg\ fuel$$

Or $AF_{150\%} = 1.5 \times 10.353 = 15.53 \;\; kg\ air/kg\ fuel$

Example (3.4) Propane (C_3H_8) is burned with 75 % excess air during a combustion process. Assuming complete combustion, determine the air–fuel ratio.

Solution:

For complete combustion of C_3H_8 with the theoretical amount of air, the products contain carbon dioxide, water, and nitrogen only, that is:

$$C_3H_8 + a(O_2 + 3.76N_2) \rightarrow bCO_2 + cH_2O + a \times 3.76 \times N_2$$

Applying the conservation of mass;

C: $3 = b$

H: $8 = 2c \rightarrow c = 4$

O: $2a = 2b + c = 6 + 4 = 10 \rightarrow a = \frac{10}{2} = 5$

Then the balanced chemical equation for 100% theoretical air is:

$$C_3H_8 + 5(O_2 + 3.76N_2) \rightarrow 3CO_2 + 4H_2O + 18.8N_2$$

$$AF_{100\%} = \frac{m_{air}}{m_{fuel}} = \frac{(NM)_{air}}{(NM)_{fuel}} = \frac{(NM)_{air}}{(NM)_C + (NM)_{H2}}$$

$$AF_{100\%} = \frac{(5 \times 4.76 kmol) \times (29 kg/kmol)}{(3kmol) \times (12kg/kmol) + (8kmol) \times (1kg/kmol)}$$

$$AF_{100\%} = \frac{690.2}{44} = 15.69 \; kg\ air/kg\ fuel$$

$$AF_{175\%} = 1.75 \times 15.69 = 27.46 \; kg\ air/kg\ fuel$$

Example (5.5) A certain fuel oil has the composition $C_{10}H_{22}$. If this fuel is burned with 150% theoretical air, what is the composition of the products of combustion?

Solution:

For complete combustion of $C_{10}H_{22}$ with the theoretical amount of air, the products contain carbon dioxide, water, and nitrogen only. That is

$$C_{10}H_{22} + a(O_2 + 3.76N_2) \rightarrow bCO_2 + cH_2O + a \times 3.76 \times N_2$$

Applying the conservation of mass;

C: $10 = b$

H: $22 = 2c \rightarrow c = 11$

O: $2a = 2b + c = 20 + 11 = 31 \rightarrow a = \frac{31}{2} = 15.5$

$$C_{10}H_{22} + 15.5(O_2 + 3.76N_2) \rightarrow 10CO_2 + 11H_2O + 58.28N_2$$

Then the balanced chemical equation for 150% theoretical air is:

$$C_{10}H_{22} + 1.5 \times 15.5(O_2 + 3.76N_2) \rightarrow 10CO_2 + 11H_2O + 1.5 \times 58.28N_2 + 7.75O_2$$

Or

$$C_{10}H_{22} + 23.25(O_2 + 3.76N_2) \rightarrow 10CO_2 + 11H_2O + 1.5 \times 87.42N_2 + 7.75O_2$$