Example 1

Determine the stoichiometric air required for complete combustion of 1 kg n-heptane. What is the % analysis of the combustion products on a molar and mass basis?

$$C_7H_{16(l)} + 11(O_{2(g)} + 3.76 N_{2(g)}) \longrightarrow 7 CO_{2(g)} + 8 H_2O_{(g)} + 11(3.76) N_{2(g)}$$

$$\left(11 \frac{\text{kmol } O_2}{\text{kmol fuel}}\right) + \left(11 \frac{\text{kmol } O_2}{\text{kmol fuel}}\right)\left(3.76 \frac{\text{kmol } N_2}{\text{kmol } O_2}\right) \qquad 8 \frac{\text{kmol } H_2O}{\text{kmol fuel}}$$

$$\overline{A/F}^{\circ} = \frac{11(1+3.76)}{1} = 52.36 \frac{\text{kmol air}}{\text{kmol fuel}}$$

$$A/F^{\circ} = \overline{A/F}^{\circ} \cdot \frac{M_{air}}{M_{fuel}} = \left(52.36 \frac{\text{kmol air}}{\text{kmol fuel}}\right) \frac{(28.97 \text{ kg/kmol air})}{(100 \text{ kg/kmol fuel})} = 15.14 \frac{\text{kg air}}{\text{kg fuel}}$$

Products	molar basis				
CO_2	7	12.4%	7 × 44 =	308.1	19.13% kg CO_2/kg product
H_2O	8	14.2%	8 × 18 =	144.1	8.95%
N_2	41.36	73.4%	41.36 × 28 =	1158.6	71.92%
total	56.36	100%		1610.8	100%
	↑ kmol product / kmol fuel			↑ kg product / kmol fuel	

Alternative A/F calculation

$$A/F = \frac{(11 \text{ kmol } O_2/\text{kmol fuel})(32 \text{ kg/kmol } O_2) + (11 \cdot 3.76 \text{ kmol } N_2/\text{kmol fuel})(28 \text{ kg/kmol } N_2)}{(7 \text{ kmol C/kmol fuel})(12 \text{ kg/kmol C}) + (8 \text{ kmol } H_2/\text{kmol fuel})(2 \text{ kg/kmol } H_2)} = 15.1$$

Example 2

5 mols of propane, $C_3H_8(g)$, are completely burned at 1 atm with the theoretical amount of air. What is the volumetric analysis of the dry combustion products?

$$5\,C_3H_{8\,(g)} + 25\left(1\,O_{2\,(g)} + 3.76\,N_{2\,(g)}\right) \rightarrow 15\,CO_{2\,(g)} + 20\,H_2O_{(g)} + 94.0\,N_{2\,(g)}$$

25 mols of O_2, or 119 mols of air, are required for complete combustion

Treat the air as an ideal gas; (25°C, 1 atm)

$$V_{air} = \frac{nRT}{P} = \frac{(119\text{ mol})(8.3144\text{ J/mol k})(25+273.15\text{ k})}{(101.3\text{ kPa})} = 2.92\text{ m}^3$$

Dry Volumetric Analysis of Products

$$\frac{V_{CO_2}}{V_{CO_2}+V_{N_2}} = \frac{n_{CO_2}}{n_{CO_2}+n_{N_2}} = \frac{15}{15+94} = 13.76\%$$

$$\frac{V_{N_2}}{V_{CO_2}+V_{N_2}} = 86.24\%$$

Example 3

An analysis of coal gives the following % by mass:

carbon	80.7%
hydrogen	4.9%
oxygen	5.3%
nitrogen	1.1%
sulfer	1.8%
ash	balance

What is the air-to-fuel ratio if 20% excess air is used during combustion?

	mols per kg coal	stoichiometric kmols of O_2 per kg coal
C	$\frac{0.807}{12} = 0.0672$	0.0672
H_2	$\frac{0.049}{2} = 0.0245$	0.0123
S	$\frac{0.018}{32} = 5.625\cdot10^{-4}$	$5.625\cdot10^{-4}$
O_2	$\frac{0.053}{32} = 1.656\cdot10^{-3}$	0
N_2	$\frac{0.011}{28} = 3.929\cdot10^{-4}$	0

$0.0672\,C_{(s)} + 0.0672\,O_{2(g)} \rightarrow 0.0672\,CO_{2(g)}$

$0.0243\,H_{2(g)} + 0.0123\,O_{2(g)} \rightarrow 0.0243\,H_2O_{(g)}$

$5.625\cdot10^{-4}\,S_{(s)} + 5.625\cdot10^{-4}\,O_{2(g)} \rightarrow 5.625\cdot10^{-4}\,SO_{2(g)}$

0.0801 kmols O_2 required

$-1.656\cdot10^{-3}$ kmols O_2 in coal

0.0784 kmols of O_2 per kg coal

Stoichiometric:

$$A/F^{\circ} = \left(\frac{0.0784\text{ kmol }O_2}{\text{kg coal}}\right)\left(\frac{1\text{ kmol air}}{0.2099\text{ kmol }O_2}\right)\left(28.97\,\frac{\text{kg}}{\text{kmol}}\text{ air}\right) = 10.82\,\frac{\text{kg air}}{\text{kg coal}}$$

20% excess air:

$$A/F\big|_{20\%\text{ excess}} = 1.2\,A/F^{\circ} = 13\,\frac{\text{kg air}}{\text{kg coal}}$$

Example 4

Volumetric analysis of dry combustion products of a hydrocarbon fuel combusted in air at 1 atm, 60°F, and 60% RH shows:

	%V
CO_2	10.00
O_2	2.37
CO	0.53
N_2	87.10 (by difference)
	100.00

(a) What is the mass ratio of hydrogen to carbon in the fuel?

(b) What is the air-to-fuel ratio (by mass) of combustion?

	mols per dry product	C	O	N
CO_2	0.10	0.10	0.20	
O_2	0.0237		0.0474	
CO	0.0053	0.0053	0.0053	
N_2	0.871			1.742
Total	1	0.1053	0.2527	1.742

We can safely assume that all hydrogen is fully combusted into H_2O and that all product N_2 was originally from the air used for combustion.

The number of mols of O_2 associated with 0.871 mols of N_2 in air is:

$$\frac{0.871 \frac{\text{mol } N_2}{\text{mol product}}}{3.76 \frac{\text{mol } N_2}{\text{mol } O_2}} = 0.2316 \frac{\text{mol } O_2}{\text{mol product}} \longleftarrow \text{from air used for combustion}$$

The number of mols of O_2 used in combustion of carbon is $0.1264 \frac{\text{mol } O_2}{\text{mol product}}$.

The difference, $0.1053 \frac{\text{mol } O_2}{\text{mol prod.}}$, was used in combustion of hydrogen.

therefore, $0.2105\ H_{2(g)} + 0.1053\ O_{2(g)} \longrightarrow 0.2105\ H_2O_{(g)}$

(a) Hydrogen-to-carbon ratio

$$\frac{n_H}{n_C} = \frac{2(0.2105)}{0.1053} = 4 \frac{\text{mols } H}{\text{mols } C} \qquad \frac{m_H}{m_C} = \frac{2(0.2105)(1)}{(0.1053)(12)} = 0.333 \frac{\text{kg } H}{\text{kg } C}$$

(b) air-to-fuel ratio

$$A/F = \frac{\left(0.871 \frac{\text{kmol } N_2}{\text{kmol prod.}}\right)\left(\frac{1 \text{ kmol air}}{0.79 \text{ kmol } N_2}\right)\left(28.97 \frac{\text{kg}}{\text{kmol}} \text{ air}\right)}{\left(0.1053 \frac{\text{kmol } C}{\text{kmol prod.}}\right)\left(12 \frac{\text{kg } C}{\text{kmol}}\ C\right) + \left(0.2105 \frac{\text{kmol } H_2}{\text{kmol prod.}}\right)\left(2 \frac{\text{kg}}{\text{kmol}}\ H\right)} = 18.96 \frac{\text{kg air}}{\text{kg fuel}}$$