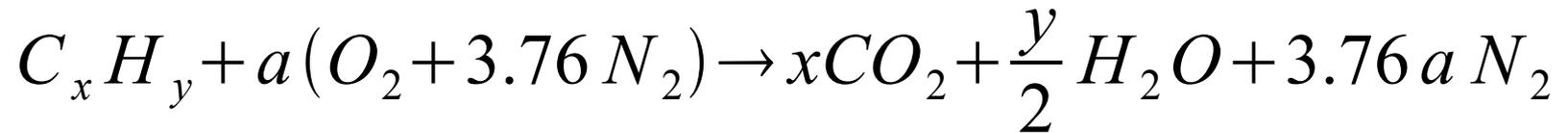


Reactant & Product Mixtures

- **Stoichiometry** – Mixture of oxidizer & fuel that contains *just enough* oxidizer for complete combustion of the fuel
- **Lean** – excess of air (more air than needed by fuel)
- **Rich** – excess of fuel (less air than needed by fuel)

Stoichiometric relation

- For hydrocarbon (C_xH_y) in air (21% O_2 , 79% N_2)



$$a = x + \frac{y}{4}$$

Air-Fuel Ratio

- Stoichiometric A/F ratio

$$\left(\frac{A}{F}\right)_{stoic} = \left(\frac{m_{air}}{m_{fuel}}\right)_{stoic} = \frac{4.76a}{1} \frac{M_{air}}{M_{fuel}}$$

- Equivalence Ratio Φ

$$\Phi = \frac{(A/F)_{stoic}}{(A/F)} = \frac{(F/A)}{(F/A)_{stoic}}$$

$\Phi = 1$ *stoichiometric*

$\Phi < 1$ *lean*

$\Phi > 1$ *rich*

Air-Fuel Ratio

- Relative air-fuel ratio λ

$$\lambda = \phi^{-1}$$

$\lambda = 1$ *stoichiometric*

$\lambda < 1$ *rich*

$\lambda > 1$ *lean*

- Percent stoichiometric air

$$x\% = \frac{100\%}{\phi}$$

- Percent excess air

$$x\% \text{ excess air} = \frac{(1 - \phi)}{\phi} 100\%$$

Example 2.1

A small, low-emission, stationary gas-turbine engine (see Fig. 2.4) operates at full load (3950 kW) at an equivalence ratio of 0.286 with an air flowrate of 15.9 kg/s. The equivalent composition of the fuel (natural gas) is $C_{1.16}H_{4.32}$. Determine the fuel mass flowrate and the operating air–fuel ratio for the engine.

Solution

$$\begin{aligned} \text{Given:} \quad & \Phi = 0.286, & MW_{\text{air}} &= 28.85, \\ & \dot{m}_{\text{air}} = 15.9 \text{ kg/s}, & MW_{\text{fuel}} &= 1.16(12.01) + 4.32(1.008) = 18.286 \\ \text{Find:} \quad & \dot{m}_{\text{fuel}} \text{ and } (A/F). \end{aligned}$$

We will proceed by first finding (A/F) and then \dot{m}_{fuel} . The solution requires only the application of definitions expressed in Eqns. 2.32 and 2.33, i.e.,

$$(A/F)_{\text{stoic}} = 4.76a \frac{MW_{\text{air}}}{MW_{\text{fuel}}},$$

where $a = x + y/4 = 1.16 + 4.32/4 = 2.24$. Thus,

$$(A/F)_{\text{stoic}} = 4.76(2.24) \frac{28.85}{18.286} = 16.82,$$

and, from Eqn. 2.33,

$$\boxed{(A/F)} = \frac{(A/F)_{\text{stoic}}}{\Phi} = \frac{16.82}{0.286} = \boxed{58.8}$$

Since (A/F) is the ratio of the air flowrate to the fuel flowrate,

$$\boxed{\dot{m}_{\text{fuel}}} = \frac{\dot{m}_{\text{air}}}{(A/F)} = \frac{15.9 \text{ kg/s}}{58.8} = \boxed{0.270 \text{ kg/s}}$$

Comment

Note that even at full power, a large quantity of excess air is supplied to the engine.

Example 2.2

A natural gas-fired industrial boiler (see Fig. 2.5) operates with an oxygen concentration of 3 mole percent in the flue gases. Determine the operating air–fuel ratio and the equivalence ratio. Treat the natural gas as methane.

Solution

$$\text{Given: } \chi_{\text{O}_2} = 0.03, \quad MW_{\text{fuel}} = 16.04, \\ MW_{\text{air}} = 28.85.$$

$$\text{Find: } (A/F) \text{ and } \Phi.$$

We can use the given O_2 mole fraction to find the air–fuel ratio by writing an overall combustion equation assuming “complete combustion,” i.e., no dissociation (all fuel C is found in CO_2 and all fuel H is found in H_2O):



where a and b are related from conservation of O atoms,

$$2a = 2 + 2 + 2b$$

or

$$b = a - 2.$$

From the definition of a mole fraction (Eqn. 2.8),

$$\chi_{\text{O}_2} = \frac{N_{\text{O}_2}}{N_{\text{mix}}} = \frac{b}{1 + 2 + b + 3.76a} = \frac{a - 2}{1 + 4.76a}.$$

Substituting the known value of χ_{O_2} ($= 0.03$) and then solving for a yields

$$0.03 = \frac{a - 2}{1 + 4.76a}$$

or

$$a = 2.368.$$

The mass air–fuel ratio, in general, is expressed as

$$(A/F) = \frac{N_{\text{air}}}{N_{\text{fuel}}} \frac{MW_{\text{air}}}{MW_{\text{fuel}}},$$

so

$$(A/F) = \frac{4.76a}{1} \frac{MW_{\text{air}}}{MW_{\text{fuel}}}$$

$$\boxed{(A/F)} = \frac{4.76(2.368)(28.85)}{16.04} = \boxed{20.3}$$

To find Φ , we need to determine $(A/F)_{\text{stoic}}$. From Eq. 2.31, $a = 2$; hence,

$$(A/F)_{\text{stoic}} = \frac{4.76(2)28.85}{16.04} = 17.1$$

Applying the definition of Φ (Eqn. 2.33),

$$\boxed{\Phi} = \frac{(A/F)_{\text{stoic}}}{(A/F)} = \frac{17.1}{20.3} = \boxed{0.84}$$