Lecture Six

Fuels and Combustion

Any material that can be burned to release thermal energy is called a **fuel**. Most familiar fuels consist primarily of hydrogen and carbon. They are called **hydrocarbon fuels** and are denoted by the general formula C_nH_m. Hydrocarbon fuels exist in all phases, some examples being coal, gasoline, and natural gas. A chemical reaction during which a fuel is oxidized and a large quantity of energy is released is called **combustion**. The oxidizer most often used in combustion processes is air, for the obvious reasons that it is free and readily available. Pure oxygen O_2 is used as an oxidizer only in some specialized applications, such as cutting and welding, where air cannot be used. During a combustion process, the components that exist before the reaction are called **reactants** and the components that exist after the reaction are called **products**. Consider, for example, the combustion of 1 kmol of carbon with 1 kmol of pure oxygen, forming carbon dioxide as follows:

$$C + O_2 \rightarrow CO_2$$

Here C and O_2 are the reactants since they exist before combustion, and CO_2 is the product since it exists after combustion. Note that a reactant does not have to react chemically in the combustion chamber. For example, if carbon is burned with air instead of pure oxygen, both sides of the combustion equation will include N_2. That is, the N_2 will appear both as a reactant and as a product. We should also mention that bringing a fuel into intimate contact with oxygen is not sufficient to start a combustion process. The fuel must be brought above its **ignition temperature** to start the combustion.

Chemical equations are balanced on the basis of the **conservation of mass principle** (or the **mass balance**), which can be stated as follows: **The total mass of each element is conserved during a chemical reaction**. That is, the total mass of each element on the right-hand side of the reaction equation (the products) must be equal to the total mass of that element on the left-hand side (the reactants) even though the elements exist in different chemical compounds in the reactants and products. Also, the total number of atoms of each element is conserved during a chemical reaction since the total number of atoms is equal to the total mass of the element divided by its atomic mass.

A frequently used quantity in the analysis of combustion processes to quantify the amounts of fuel and air is the **air-fuel ratio** (*AF*). It is usually expressed on a mass basis and is defined as the ratio of the mass of air to the mass of fuel for a combustion process. That is:

$$AF = \frac{m_{\text{air}}}{m_{\text{fuel}}} \qquad \dots\dots\dots\dots\dots\dots\dots (7.22)$$

The reciprocal of air–fuel ratio is called the **fuel-air ratio** (FA). The air-fuel ratio can also be expressed on a mole basis as the ratio of the mole numbers of air to the mole numbers of fuel:

$$AF = \frac{N_{\text{air}}}{N_{\text{fuel}}} \qquad \dots\dots\dots\dots\dots\dots\dots (7.23)$$

The dry air can be approximated as 21 percent oxygen and 79 percent nitrogen by mole numbers. Therefore, each mole of oxygen entering a combustion chamber is accompanied by 0.79/0.21 = 3.76 mole of nitrogen.

Example (7.5): Calculate the theoretical air-fuel ratio on mole basis for the combustion of octane, C_8H_{18}.

Solution:

The chemical reaction of methane with air is:

$$C_8H_{18} + xO_2 + 3.76xN_2 \rightarrow yCO_2 + zH_2O + 3.76xN_2$$

Balancing the two sides of the equation:

Carbon (C): $8 = y$

Hydrogen (H_2): $18 = 2z \rightarrow z = 9$

Oxygen (O_2): $2x = 2y + z \rightarrow 2x = 2 \times 8 + 9 \rightarrow x = 12.5$

Then, the reaction equation becomes:

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

The air-fuel ratio on a mole basis is:

$$AF = \frac{N_{\text{air}}}{N_{\text{fuel}}} = \frac{12.5 + 47}{1} = 59.5 \text{ kmol air/kmol fuel}$$