ESO 201A: Thermodynamics

2016-2017-I semester

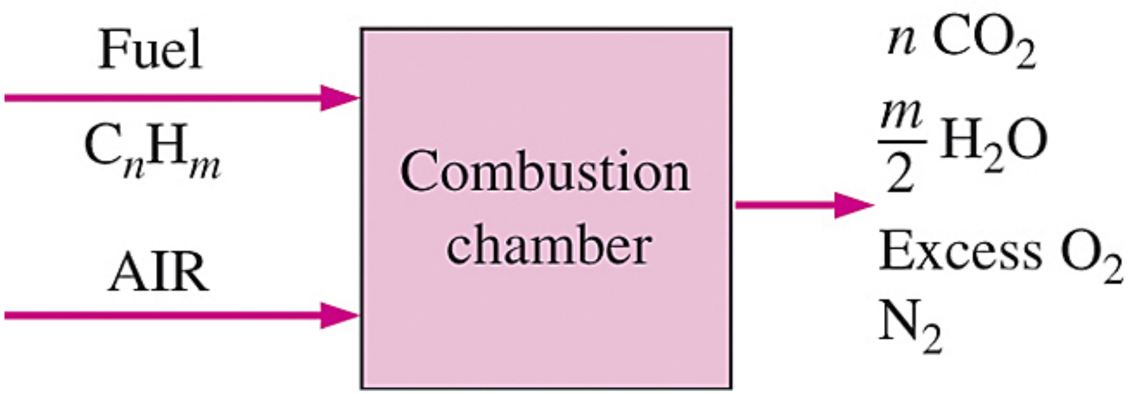
Chemical Reaction: part 2

Dr. Jayant K. Singh
Department of Chemical Engineering
Faculty Building 469,
Telephone: 512-259-6141
E-Mail: jayantks@iitk.ac.in
home.iitk.ac.in/~jayantks/ESO201/index.html

Learning Objectives

- Give an overview of fuels and combustion.
- Apply the conservation of mass to reacting systems to determine balanced reaction equations.
- Define the parameters used in combustion analysis, such as air–fuel ratio, percent theoretical air
- Apply energy balances to reacting systems for both steady-flow control volumes and fixed mass systems.
- Calculate the enthalpy of reaction, enthalpy of combustion, and the heating values of fuels.
- Determine the adiabatic flame temperature for reacting mixtures.

Theoretical and Actual Combustion Processes



A combustion process is complete if all the combustible components of the fuel are burned to completion.

Oxygen has a much greater tendency to combine with hydrogen than it does with carbon. Therefore, the hydrogen in the fuel normally burns to completion, forming H_2O.

Complete combustion: If all the carbon in the fuel burns to CO_2, all the hydrogen burns to H_2O, and all the sulfur (if any) burns to SO_2.

Incomplete combustion: If the combustion products contain any unburned fuel or components such as C, H_2, CO, or OH.

Reasons for incomplete combustion:

1 ***Insufficient oxygen***,

2 ***insufficient mixing*** in the combustion chamber during the limited time that the fuel and the oxygen are in contact, and

3 ***dissociation*** (at high temperatures).

Energy content

Stoichiometric or **theoretical air:** The minimum amount of air needed for the complete combustion of a fuel. Also referred to as the *chemically correct amount of air,* or *100% theoretical air.*

Stoichiometric or **theoretical combustion:** The ideal combustion process during which a fuel is burned completely with theoretical air.

For example, the theoretical combustion of methane is

$$CH_4 + 2(O_2 + 3.76N_2) \rightarrow CO_2 + 2H_2O + 7.52N_2$$

The complete combustion process with no free oxygen in the products is called theoretical combustion.

Combustion

Excess air: The amount of air in excess of the stoichiometric amount. Usually expressed in terms of the stoichiometric air as *percent excess air* or *percent theoretical air*.

Deficiency of air: Amounts of air less than the stoichiometric amount. Often expressed as *percent deficiency of air*.

Equivalence ratio: The ratio of the actual fuel–air ratio to the stoichiometric fuel–air ratio.

50% excess air = 150% theoretical air
200% excess air = 300% theoretical air.
90% theoretical air = 10% deficiency of air

Gas analyzer

Predicting the composition of the products is relatively easy when the combustion process is assumed to be complete.

With actual combustion processes, it is impossible to predict the composition of the products on the basis of the mass balance alone.

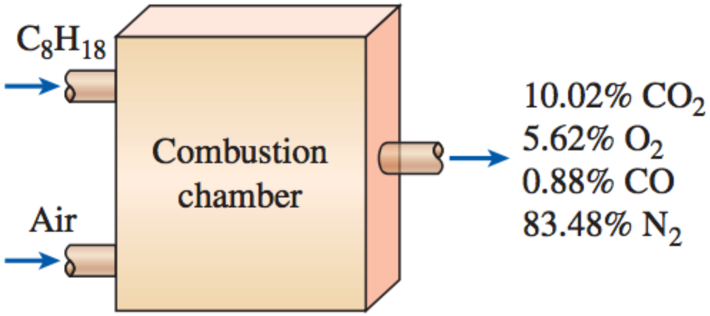
Then the only alternative we have is to measure the amount of each component in the products directly.

A commonly used device to analyze the composition of combustion gases is the **Orsat gas analyzer**.

The results are reported on a dry basis.

Example

Octane (C_8H_{18}) is burned with dry air. The volumetric analysis of the products on a dry basis is shown in the figure.



Determine (a) the air–fuel ratio, (b) the percentage of theoretical air used.

Considering 100 kmol of dry products for convenience, the combustion equation can be written a

Example

$$xC_8H_{18} + a(O_2 + 3.76N_2) \rightarrow 10.02CO_2 + 0.88CO + 5.62O_2 + 83.48N_2 + bH_2O$$

Example

$$AF = \frac{m_{air}}{m_{fuel}} = \frac{(16.32 \times 4.76 \text{ kmol})(29 \text{ kg/kmol})}{(8 \text{ kmol})(12 \text{ kg/kmol}) + (9 \text{ kmol})(2 \text{ kg/kmol})}$$

$$= \mathbf{19.76 \text{ kg air/kg fuel}}$$

To find the percentage of theoretical air used

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

O_2: $$a_{th} = 8 + 4.5 \rightarrow a_{th} = 12.5$$

$$\text{Percentage of theoretical air} = \frac{m_{air,act}}{m_{air,th}} = \frac{N_{air,act}}{N_{air,th}}$$

$$= \frac{(16.32)(4.76) \text{ kmol}}{(12.50)(4.76) \text{ kmol}}$$

$$= \mathbf{131\%}$$

Next lecture

- Give an overview of fuels and combustion.
- Apply the conservation of mass to reacting systems to determine balanced reaction equations.
- Define the parameters used in combustion analysis, such as air–fuel ratio, percent theoretical air
- Apply energy balances to reacting systems for both steady-flow control volumes and fixed mass systems.
- Calculate the enthalpy of reaction, enthalpy of combustion, and the heating values of fuels.
- Determine the adiabatic flame temperature for reacting mixtures.