Today, we will:

- Discuss **Non-Stoichiometric Combustion** and **Equivalence Ratio**
- Do an example problem

Non-Stoichiometric Combustion and Equivalence Ratio:

Consider the chemical equation for burning a fuel, like methane,

$$CH_4 + a(O_2 + 3.76\ N_2) \rightarrow bCO_2 + cH_2O + dN_2$$

Notation:

- a = ***actual* molar coefficient**: molar coefficient a in the cumbustion chemical equation (a is not necessarily the *stoichiometric* value – can be smaller or larger than a_{stoich}).
- a_{stoich} = ***stoichiometric* molar coefficient**: molar coefficient a in the cumbustion chemical equation that leads to exact stoichiometric balance, or ***ideal combustion***. Again, this means that ***all*** the carbon in the fuel gets converted to carbon dioxide in the combustion gases (exhaust gases).
- $(F/A)_n$ = molar fuel-to-air ratio = (# mols of fuel) / (# mols of air) = $1/a$.
  - $(F/A)_n$ = ***actual*** molar fuel-to-air ratio = $1/a$.
  - $(F/A)_{n,\text{ stoich}}$ = ***stoichiometric*** molar fuel-to-air ratio = $1/a_{\text{stoich}}$.

molar

Equivalence ratio Φ is defined as the ratio of the *actual* fuel/air ratio to the *stoichiometric* fuel/air ratio.

$$\text{Equivalence ratio} = \Phi = \frac{(F/A)_n}{(F/A)_{n,\text{ stoich}}} = \frac{1/a}{1/a_{\text{stoich}}} = \frac{a_{\text{stoich}}}{a}$$

- If $\Phi = 1$, the combustion is ***stoichiometric***.

  $a = a_{\text{stoich}}$ $(F/A)_n = (F/A)_{n,\text{stoich}}$ → ideal comb.

  no additional comb. products

- If $\Phi < 1$, the combustion is ***fuel-lean*** (excess air).

  $a > a_{\text{stoich}}$ $(F/A)_n < (F/A)_{n,\text{stoich}}$

  not ideal – Get extra comb. products CO, NO_x, soot, alcohol,

- If $\Phi > 1$, the combustion is ***fuel-rich*** (too little air, and incomplete combustion).

  $a < a_{\text{stoich}}$ $(F/A)_n > (F/A)_{n,\text{stoich}}$

  not ideal – Get extra combustion products on right side of eq.

  CO, NO_x, soot, alcohols, unburned fuel, other hydrocarbons, etc.

Example: Non-Ideal Combustion of Methane

Given: Methane is burned with simple dry air. In a previous lecture we worked out the stoichiometric case. Starting with this equation with variable molar coefficients,

$$CH_4 + a(O_2 + 3.76\ N_2) \rightarrow bCO_2 + cH_2O + dN_2$$

we calculated the coefficients and came up with this final chemical equation for stoichiometric combustion of methane and simple dry air:

$a_{stoich} = 2$

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

Notice that *all* the carbon in the fuel is converted to carbon dioxide in the products.

To do: Now consider the non-stoichiometric case. There can be many nasty products of combustion when a fuel combusts with either too much air or too little air. Here we consider a rather simple case where the "extra" products of combustion are CO, O_2, and only trace amounts of other nasty air pollutants. The general equation is

$$CH_4 + a(O_2 + 3.76\ N_2) \rightarrow bCO_2 + cH_2O + dN_2 + eCO + fO_2 + \text{trace}$$

Now consider a case that is fuel-lean ($a > a_{stoich}$), namely $a = 2.35$. Determine the remaining molar coefficients.

Solution:

C: $1 = b + e \rightarrow e = 1 - b$ (1)

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

N: $2(3.76a) = 2d \rightarrow d = 3.76a = 8.836 = d$

O: $2a = 2b + c + e + 2f$ (2)

3 unk. b, e, f
2 eq. } specify or measure f

Solve (1) & (2) simult. for e & b

$b = 1.7 - 2f$ $e = 1 - b$ for a given f

Try $f = 0$ No O_2 passing through (in the comb. products)

$b = 1.7 - 2f = 1.7$

$e = 1 - b = 1 - 1.7 = -0.7$ X IMPOSSIBLE!

Try $f=1$ Some O_2 in the comb. products

$b = 1.7 - 2f = -0.3$ ✗ IMPOSSIBLE

$e = 1 - b = 1.3$

Try $f = 0.5$ Some O_2 in combustion products

$b = 1.7 - 2f = 0.7$

$e = 1 - 0.7 = 0.3$

☺

FINAL CHEM. EQ.

$$CH_4 + 2.35(O_2 + 3.76 N_2) \rightarrow 0.7\,CO_2 + 2H_2O + 8.836\,N_2 + 0.3\,CO + 0.5\,O_2$$

+ trace

air pollutant