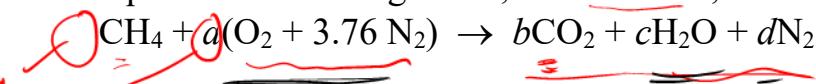


Today, we will:

- 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,



Notation:

- $a = \text{actual}$  molar coefficient: molar coefficient  $a$  in the combustion chemical equation ( $a$  is not necessarily the *stoichiometric* value – can be smaller or larger than  $a_{\text{stoich}}$ ).
- $a_{\text{stoich}} = \text{stoichiometric}$  molar coefficient: molar coefficient  $a$  in the combustion 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).
- $(F/A)_n = \text{molar fuel-to-air ratio} = (\# \text{ mols of fuel}) / (\# \text{ mols of air}) = 1/a$ .
- $(F/A)_n = \text{actual}$  molar fuel-to-air ratio  $= 1/a$ .
- $(F/A)_{n, \text{stoich}} = \text{stoichiometric}$  molar fuel-to-air ratio  $= 1/a_{\text{stoich}}$ .

**Equivalence ratio  $\Phi$**  is defined as the ratio of the *actual* fuel/air ratio to the *stoichiometric*

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

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

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

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  $\text{CO, NO}_x, \text{soot, alcohol,}$

- 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.

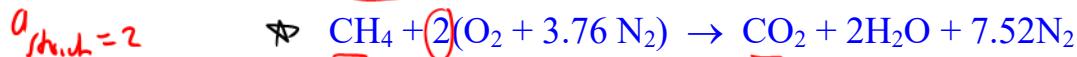
$\text{CO, NO}_x, \text{soot, alcohol, unburned fuel, other hydrocarbons, etc.}$

## 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,



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



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<sub>2</sub>, and only trace amounts of other nasty air pollutants. The general equation is



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

**Solution:**

$$\begin{aligned} \text{C: } 1 &= b + e \rightarrow e = 1 - b & (1) \\ \text{H: } 4 &= 2c \rightarrow c = 2 \\ \text{N: } 2(3.76a) &= 2d \rightarrow d = 3.76a = 8.836 = d \end{aligned}$$

$$\text{O: } 2a = 2b + c + e + 2f \quad (2)$$

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

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

$$\begin{aligned} b &= 1.7 - 2f \\ e &= 1 - b \end{aligned} \quad \text{for a given } f$$

To  $f = 0$       No O<sub>2</sub> passing through (in the comb. products)

$$b = 1.7 - 2f = 1.7$$

$$e = 1 - b = 1 - 1.7 = -0.7 \quad \text{X IMPossible!}$$

Try  $f=1$

Some  $O_2$  in the comb. products

$$b = 1.7 - 2f = -0.3 \quad \text{X}$$

$$e = 1 - b = 1.3$$

IMPOSSIBLE

Try  $f=0.5$

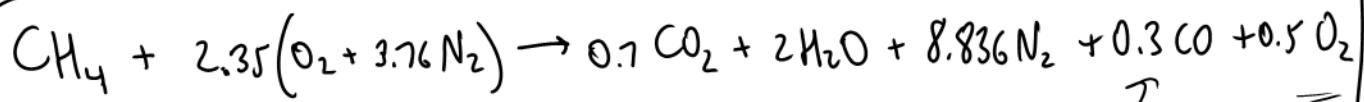
Some  $O_2$  in combustion products

$$b = 1.7 - 2f = 0.7$$

$$e = 1 - 0.7 = 0.3$$



FINAL CHEM. EQ.



Air pollutant