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Welcome to

EEN-E2002 Combustion Technology

Lecture on 27 Feb 2019

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Today's topics

Mass balance in combustion.

Energy balance in combustion; especially the role of energy feedback from the flame.

Fuel, air, flue gas and ash flows and their arrangement in practical systems.

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Combustion reactions

Combustion reaction (in general):

Stoichiometric coefficients

$$C_aH_bO_c + d \cdot O_2 \rightarrow e \cdot CO_2 + f \cdot H_2O + g \cdot O_2$$

theoretical oxygen requirement for complete combustion:
$d_{theor} = a + b/4 - c/2$

Element balance

Element	Left-hand side	Right-hand side	
C	a	e	=> e = a
H	b	2f	=> f = b/2
O	c + 2d	2e + f + 2g	=> g = d – (a+b/4-c/2)

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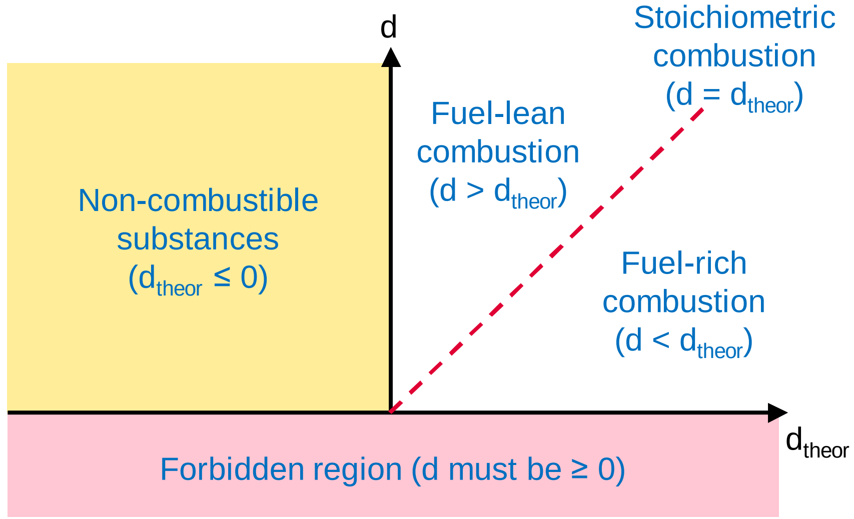
Mapping of d and d_{theor}



Notes

- More reading: Borman & Ragland Section 3.3 (however, note that there is an error in Eq. (3.28) on p. 67).
- In the region of fuel-rich combustion, the products cannot consist only of CO_2 and H_2O; there is not enough oxygen available for that. The products are a more complex mixture of compounds, typically including CO, CO_2, H_2, H_2O, and possibly other compounds, e.g., CH_4, tar-like liquid-phase compounds, and soot and char and other solid compounds.
- *Gasification* can be regarded as a special class of fuel-rich combustion. To obtain a product gas with high energy content, the oxygen input is usually kept very small.
- The case d = 0 is nowadays often called *pyrolysis*. This is a process consisting of thermal decomposition without oxygen.

Equivalence ratio

Define equivalence ratio as

$$F = \frac{d_{theor}}{d}$$

F = 1: stoichiometric combustion

F < 1: fuel-lean combustion

F > 1: fuel-rich combustion

(ϕ is also used as a symbol for equivalence ratio)

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Air factor and excess air

Define air factor as

$$\lambda = \frac{d}{d_{theor}} = \frac{1}{F}$$

$\lambda = 1$: stoichiometric combustion

$\lambda > 1$: fuel-lean combustion

$\lambda < 1$: fuel-rich combustion

Excess air = $\lambda - 1$

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Notes

- The names “air factor” and “excess air” indicate that the fuel is burned in air (not, e.g., in pure oxygen, etc.). This needs not be taken too seriously.
- In the English-language literature, the term “air factor” seems to be practically unknown and only the term “excess air” is used.
- The term “air factor” seems to be of German origin (Luftzahl, Luftverhältnis).

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Generalizations – 1

What if the fuel also contains sulfur and/or nitrogen?

- Sulfur is normally assumed to form SO_2.
- Nitrogen is normally assumed to form N_2.

This is a simplification, since sulfur also forms some SO_3 and nitrogen forms some nitrogen oxides (NO_x = NO, NO_2, etc.). However, the effect of these reactions on stoichiometry is usually very small.

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Generalizations – 2

What if we do not know the chemical formula of the fuel?

Normally, the composition of the fuel is given as mass percentages of major elements:

carbon	C
hydrogen	H
sulfur	S
nitrogen	N
oxygen	O

This is the <u>ultimate analysis</u> of the fuel. The mass percentages can then be used for air and flue gas calculations (see, e.g., Borman & Ragland Ex. 3.4).

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Notes

- The elements C, H, S, N and O are the combustible part of the fuel (the dry, ash-free substance); in addition to them, the fuel normally also contains some moisture and some ash.
- There are laboratory procedures for determining the amounts of C, H, S and N in the fuel. Everything else is usually assumed to be oxygen; that's why it is often mentioned in laboratory analysis reports as “oxygen (by difference)”. In some cases, it is important to determine the amount of some other element in the fuel, e.g., Cl.
- Want to know more? See “Analysis and testing of solid fuels” in the end of Section 2.3 of Borman & Ragland.

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Practical perspective

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The big picture of everything