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Determination of the Percentage of Theoretical Air Used in the Combustion of Propane

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ABSTRACT

Stoichiometric theoretical air is defined as the exact quantity of air required to provide exact quantity of oxygen for complete combustion. The quantity of air needed for stoichiometric combustion is fairly constant on the air/gas ratio with 16 as the approximate value. Under stoichiometric conditions, more than ten (10) volumes of air is required to burn completely, one (1) volume of a natural gas that is normally flared during a drilling operation. For complete combustion to occur, all the carbon in the fuel (propane) must burn to carbon dioxide and all the hydrogen converted to water, and all the sulphur in the fuel must produce sulphur dioxide.

1. Introduction

The stoichiometric combustion could be construed as that where enough air is available for the complete or near-complete combustion of a given quantity or percentage of fuel. Stoichiometric air or theoretical air is the exact amount of air required to provide the right amount of oxygen for complete combustion. The amount of air required for complete combustion is fairly constant on the air/gas weight ratio, with an approximate value of 16 [**1-6**]. However, due to the deficiencies of furnace mixing, an excess quantity of air is needed to maintain an adequate quantity of oxygen until the end of the burning. One way of indicating the air/fuel ratio is the excess air coefficient, which is the ratio of the total quantity of air used in the combustion to the quantity of stoichiometric air. The volume and enthalpy of the flue gases are controlled by the excess air which is determinant for the efficiency of the boiler. A large excess of air is unacceptable because it reduces the flame temperature and raises heat losses by enthalpy of the dry gas [**1, 7**]. Conversely, a small air can result in incomplete combustion and formation of CO, soot and of course, smoke of unburnt fuel, that causes risk of explosion. Therefore, an optimum surplus air coefficient is needed to reduce both losses. In the design of boiler, a curve is defined by the manufacturer known as the air/fuel curve. The curve connects the air inlet as a function of the fuel through pot; and focuses to maintain the surplus air coefficient within the expected range for each type of boiler [**8-12**]. Nevertheless, variations in fuel composition cause derivations from this curve and inhibit the boiler's operation efficiency.

2. Methodology

2.1 Determination of the Percentage of Theoretical Air used in the Combustion of Propane

2.1.1 Problematic

Assuming liquid propane is burned with dry air. A volumetric analysis of the products of combustion yields the following volume percent composition on a dry basis: 8.6% CO_2, 0.6%CO, 72% O_z and 83.6% N_2 (as assumed). Determine the percentage of theoretical air used in this combustion process.

2.1.2 Analysis

The reaction equation per 100mole of dry products can take the next form.

$$x\, C_3H_8 + aO_2 + bN_2 \longrightarrow 8.6CO_2 + 0.6CO + CH_2O + 7.2\, O_2 + 83.6N_2$$

Applying the atomic balance we have,

$$C \longrightarrow x = (8.6 + 0.6)/3 = 3.067$$

$$H \longrightarrow c = 3.067x8/2 = 12.268$$

$$O \longrightarrow a = (8.6x2+0.6+12.268+7.2x2)/2 = 22.234$$

$$N \longrightarrow b = 83.6$$

Hence, the actual reaction equation:

$$3.067C_3H_8 + 22.234O_2 + 83.6N_2 \longrightarrow 8.6CO_2 + 0.6CO + 12.268\, H_2O + 7.2O_2 + 83.6N_2$$

Therefore, the actual air/fuel ratio is

$$AF = \frac{n_{air}}{n_{fuel}} = \frac{22.234+83.6}{3.067} = 34.5Kmol_{air}/Kmol_{fuel}$$

And the theoretical reaction equation:

$$C_3H_8 + 5(O_2+3.76N_2) \longrightarrow 3CO_2 + 4H_2O + 18.8N_2$$

Therefore the theoretical air-fuel ratio

$AF_{th} = \frac{5 \times 4.76}{1}$ = 23.8Kmol$_{air}$/Kmol$_{fuel}$

Hence, the percentage theoretical air,

%theoretical air = $\frac{AF}{AF_{air}} \times 100$

$\frac{34.5}{23.8}$ x 100 = 14.5%

3. Results and Discussion

3.1 Stoichiometric Air-fuel Ratio

The stoichiometric air-fuel ratio can be defined as ratio of quantity of air needed for complete combustion of 1Kg of fuel. If the combustion is complete, then only maximum heat is available from a given fuel. The theoretically exact quantity of oxygen needed can be calculated with the help of equations or with the help of the formula derived from above equations and it will fine us directly the theoretically needed oxygen if we know the ultimate analysis of the fuel.

The oxygen for the combustion of a fuel is to be gotten from the atmospheric air, although in some cases, a certain quantity of oxygen in a constituent of the fuel. Air is a mixture of oxygen, nitrogen, a small quantity of carbon dioxide and small traces of rare gases such as neon, argon, krypton, etc [13-17]. For all practical purpose, it is assumed that air consists of 23% by weight of oxygen, the remaining 77% being nitrogen. If it is considered by volume, air consists of 21% of oxygen and 79% of Nitrogen. If the quantity of oxygen necessary for the combustion of a fuel is known, then we can determine the quantity of air necessary for the complete combustion of 1kg of fuel.

Let us consider 1kg of a fuel, the ultimate analysis shows carbon is C kg, hydrogen is H kg, Oxygen is O kg and sulphur is S kg.

1kg of carbon requires 8/3kg of oxygen for its compete combustion, Hence, C kg of carbon will require Cx8/3kg of oxygen which is equivalent to 2.66Ckg of oxygen considering up to two places of decimal.

1kg of hydrogen needs 8kg of oxygen; hence H kg of hydrogen needs 8kg of oxygen.

Therefore, the amount of oxygen needed for combustion of 1kg of the fuel is: (2.66C + 8H + S)kg

If the fuel contains O kg of oxygen; then it can be taken into account.

:. Oxygen needed from air for the complete combustion of fuel will be (2.66C + 8H + S-O) which is written as 2.66C + 8(H-O/8) + S, the term in the bracket being known as the available hydrogen. Thus, we have the formula for determination of minimum quantity of oxygen for complete combustion of a solid or liquid fuel whose ultimate analysis is known.

The formula can be written thus,

Minimum quantity of oxygen needed for complete combustion of a fuel

$\frac{M_O}{M_f} = 2.66+8(H-\frac{O}{8}) + S$ kg

Where M_o = mass of oxygen

M_f = mass of fuel

Since air contains 23% by weight of oxygen, 1kg of oxygen contained in $\frac{100}{23}$ = 4.35kg of air and thus, the minimum quantity of air needed for complete combustion of 1kg of fuel is $(\frac{A}{F})_c = (\frac{M_O}{M_f})_c = [2.68C + 8(H - \frac{O}{8}) + S]$kg

Where ma = mass of air

Simplifying we have the quantity of air needed for complete combustion of 1kg of a fuel and it will be

$(\frac{A}{F})_c = 11.6C + 34.8 (H- \frac{O}{8}) + 4.35$kg

3.2 Determination of Excess Air

We have calculated the minimum quantity of air needed for complete combustion of 1kg of fuel. In actual practice, we supply air more than the theoretical minimum quantity in order to ensure the complete combustion of the fuel because all of the air supplied does not come into close contact with the particles of the fuel.

A large quantity of excess air has a cooling effect on the process of combustion and represents a loss; and to avoid the cooling effect, air is pre-heated before it enters the furnace of a boiler [18-25].

The excess air is more in combustion with the artificial draught system as against the natural draught system. The total quantity of air supplied varies with the quantity of the fuel, combustion rate, system of firing and draught intensity. The excess air may approach 100% but the modern practice is to use 25 to 50%. The excess air is shown by CO_2% in flue gases. When the boiler plant of Lancashire boiler type employs hand- firing with natural draught system, 10% to 12% CO_2 in flue gases would definitely be considered as a good practice. With mechanical strokers and artificial draught it would be responsible to expect 12% to 15% CO_2.

All this air taken in during suction stroke in case of internal combustion engine will not come in contact with the fuel particles; as a result excess air is supplied and it should be reduced to minimum to have more specific output. If air supply to an engine cylinder is less than 15% excess, the mixture of air and fuel in the cylinder is known rich. If air supply is more than 30% in excess of the theoretical minimum, the mixture is called a weak mixture.

3.3 Projection

Determination of air supplied from volumetric Analysis of Fluid Gases.

The amount of air supplied to a boiler furnace is very great and so it cannot be measured directly. Its indirect measurement can be done if we know the volumetric analysis of dry flue gas. Considering the volumetric analysis of gas, we consider carbon monoxide, carbon dioxide, nitrogen and oxygen. Because the quantity of sulphurdioxide is very small, water vapour is considered.

Let us consider the fuel which contains C% by weight of carbon. Analysis of dry flue gas of the combustion of this fuel shown below:

Constituent	%
CO_2	C_2
CO	C_1
O_2	O
N_2	N

Of course, the molecular weights of gases are the relative weight of equal volumes of the given relative volume of gases as shown below:

Constituents	% of volume	Molecular mass	Relative mass
CO_2	C_2	44	44 C_2
CO	C_1	28	28 C_1
O_2	O	32	32 O
N_2	N	28	28 N

When 12kg of carbon dioxide is burnt gives 44kg of carbon dioxide.

Carbon in $44C_2$kg will be

$$\frac{44C_{2}\,x\,12}{44} = 12C_2\text{kg}$$

When 12 kg of carbon is burnt with 16kg of oxygen, it will give rise to 28kg of carbon monoxide $28C_1$kg of carbon monoxide will be produce by the combustion of $\frac{28C1\,x\,12}{28}$ $=12C_1$kg

:. We have $\frac{mass\ of\ nitrogen\ in\ flue\ gases}{mass\ of\ carbon\ influe\ gases}$

$$=\frac{28N}{12(C1+C2)}$$

If nitrogen in the fuel is neglected, the ratio above is the ratio of the weight of nitrogen in the air supplied per kg of fuel to the weight of carbon in 1kg of fuel. Mass of carbon in 1kg fuel = $\frac{C}{100}$kg

:. We have, mass of nitrogen in the air supplied per kg of fuel

$$= \frac{28N}{12(C1+C2)} \text{ x } \frac{C}{100}$$

Mass of nitrogen is the air supplied per kg of fuel

$$=\frac{28NC}{100x12(C1+C2)}$$

The air contains 77% by mass of nitrogen.

If Ma is the quantity of air supplied per kg of fuel then nitrogen will be

$$\text{Ma x } \frac{77}{100}$$

:. We have $\text{Ma } \frac{77}{100} = \frac{28NC}{100\,x\,12(C1+C2)}$

$$\text{Wa} = \frac{NC}{33\,(C1+C2)}\text{kg/kg of fuel}$$

All the letters show the percentage of the respective constituents by volume. The excess air supplied is determined from the percentage of oxygen in dry flue gas analysis. When 0% of oxygen is the excess air, the quantity of nitrogen associated with this oxygen is 0 x $\frac{77}{21}$kg

:. The ratio of excess air to the total air is $\frac{O\,x79}{21\,x\,N} = \frac{excess\ air}{total\ air}$

But total air = $\frac{NC}{33(C1+C2)}$

:. Excess air = O x $\frac{79}{21}$ x $\frac{C}{33(C1+C2)}$kg

= $\frac{79OC}{21X33(C1+C2)}$ kg

3.4 Determination of the quantity of air supplied per kg of fuel.

Determination of the quantity of air supplied per kg of fuel from the analysis of flue gases when given by mass:
Let C be the % of combustion in 1kg of fuel and the gas by weight is given below:

Constituent	%
CO_2	C_2
CO	C_1
O_2	O
N_2	N

Mass of carbon in C^1kg of carbon monoxide is $\frac{12}{28}C^1{}_1$

Mass of carbon dioxide in $C^1{}_2$kg of carbon dioxide in $\frac{12}{44}C^1{}_2$

:. We have mass of nitrogen in

$$\frac{flue\ gas}{mass\ of\ carborn\ in\ flue\ gas}$$

$$= \frac{N^1}{\frac{12}{28}C^1 1+\frac{12}{28}\ C^1 2}$$

If we neglect the nitrogen in the fuel, above ratio is the ratio of the weight of nitrogen in the air supplied per kg of fuel to the weight of carbon in 1kg of the fuel.

The mass of 1 kg of carbon in fuel is $\frac{C}{100}$kg

$$:.\ \frac{\text{mass of nitrogen in the air supplied per kg}}{\frac{C}{100}}$$

$$= \frac{N^1}{\frac{12}{28}C^1 1+\frac{12}{44}\ C^1 2}$$

Mass of nitrogen in the air supplied per kg

$$= \frac{N^1 C}{100\ (\frac{12}{28}C^1 1+\frac{12}{44}C^1 2)}$$

The air contains 77% by mass of nitrogen. If Wa is the quantity of air supplied per kg of fuel then nitrogen will be

$$\frac{77}{100} \text{ x } W^1a = \frac{N^1 C}{\frac{12}{28}\ C^1 1+\frac{22}{44}\ C^1 2}$$

$$W^1a = \frac{N^1 C}{77\left(\frac{12}{28}\ C1+\frac{12}{44}\ C2\right)}$$

$$= \frac{N^1 C}{(33C^1 1+21\ C^1 2)} \text{kg/kg of fuel}$$

4. Conclusion

The minimum amount of air which will allow the complete combustion of propane called the theoretical air and it is also known as stoichiometric air. For complete combustion to occur, all the carbon in the fuel (propane) must burn to carbon dioxide and all the hydrogen converted to water, and all the sulphur in the fuel must produce sulphur dioxide.

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