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Investigate the Effect Excess Oxygen on the Clinker Quality in the Rotary kiln

Mohammed Abdul Hameed Jassim Al-Kufi[1], Hassan Mohammed Jassim and Mohammed Mundher Neamah AL-Zajrawee[2]

[1]Department of Islamic Education, University of Kufa, 31001 Al-Najaf, Iraq /Chief Engineer Senior / Hassan Mohammed Jassim/ Bsc. in Engineering of Production and Minerals.

[2]Master of Mathematics/Ministry of Education.

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ABSTRACT

The purpose of this subject to know the quality of clinker which produce from the rotary kiln according to amount oxygen rate in the exhausted cases measured by or sat device in smoke chamber .the expert in quality control can be recognize the good clinker and bad clinker according to the condition of kilne to maintain the flame temperature in suitalele range that inverts relation with excess oxygen to protect the material temperature in in the burning zone . if the temperature of materials increased or decreased or decreased will be cause upset the kiln and the material feed become deeay so that the economy cost is rising.

Introduction

According to the principal production high quality cement at least fuel consumption to improve the environment, this studying demand the equations of combustion to measure the stoichiometric air excess air analysis the exhaust guses and arrangement it, flame tempera rue law, decomposition material feed to their compounds and reacts according to the temperatures in the kiln. the information available in the references the nao dynamic, cement data , cement engineering … etc .so that applying the equations to reach the target in high quality with low economy cost

Combustion

1-Combustion: Mean burning and a fuel is a substance , be it either solid , liquid or gas,which can be relatively easily obtained in abundant quantity,can be relatively easily handled and ,when burnt , it liberates a large quantity,of energy for a given bulk.the burning of the fuel must also be easily controllable.

The vast majority of fuels are found to be carbon or hydrogen or some combination of carbon and hydrogen, called hydrocarbons these fuels appear in the forms, solid, liquid and gas.

2-Exothermic and endothermic reactions

During many chemical reactions energy is liberated, which in others heat is absorbed. A chemical reaction in which energy is liberated is called an exothermic reaction. Thus,the burning of all fuels are exothermic reactions.

A chemical reaction in which energy is absorbed is called an endothermic reaction.

3- The molecule and relative molecular mass (molecular weight)

Some elements do not normal exist as structures of single atoms but form themselves into structures of minute particles containing two atoms. Examples of this are oxygen, hydrogen and nitrogen.

In a similar way,when compounds are formed ,they are again made up of minute particles, and each of these particles ,and each of these particles is made up of two or more atoms . for example, a particles of carbon dioxide is made up of one atom of carbon in chemical combination with two atom of oxygen .

Such minute particles as these, which contain more than one atom, are called molecules.

Since a molecule is made up of atoms, then its mass relative to the relative atomic mass scale can be established. the mass of a molecule so determined is commonly called its molecular weight. It is now recommended that it be called the relative molecular mass.

Reference ((**Basic engineering thermodynamic**)) **page571 Rayner Joel**

Table of relative atomic and molecular masses.

Substance	Symbol		Relative atomic mass	Relative molecular mass
Carbon	C	Elements	12	------
Hydrogen	H_2	Elements	1	2
Oxygen	O_2	Elements	16	32
Nitrogen	N_2	Elements	14	28
Sulphur	S	Elements	32	-----
Carbon monoxide	CO	Compounds	-----	28
Carbon dioxide	CO_2	Compounds	-----	44
Water	H_2O	Compounds	-----	18

Take the case of carbon dioxide.
Relative mass of one atom of carbon = 12
Relative mass of two atoms of oxygen = 2×16=32
Relative molecular mass of carbon dioxide = 12+32=44

It should be noted that molecules containing two atoms, such as oxygen,hydrogen and carbon monoxide, are called diatomics.

Tele:
E-mail address: mohammeda.alkufi@uokufa.edu.iq

Molecules containing three atoms , such as carbon dioxide and water are called tri atomics.Molecules containing more than three atoms are called poly atomics.

Reference ((Basic engineering thermodynamic)) page571 Rayner Joel

4-Air

During combustion, a fuel always reacts, as it is called, with oxygen and liberated energy. The necessary supply of oxygen is nearly always obtained from air. A knowledge of the constituents of air is therefore required in order that the amount of oxygen in a given bulk may be known.

Now air contains many gases as well as oxygen. Such gases as nitrogen, argon, helium, neon, krypton, xenon and carbon dioxide are also prent, together with some water vapour.of all these constituent, Oxygen and nitrogen make up the main bulk. So much so, in fact for most combustion purpose it is most usual to assume that air consists entirely of these two gases.

It has already been suggested that oxygen is the reating agent during the combustion of a fuel. This oxygen cannot be obtained without it being accompanied by nitrogen .Now nitrogen is an inert gas, meaning that it does not take part in the combustion reaction. On the other hand, the fact that it is there will produce the effect of slowing down the combustion reaction, since it will interfere with the necessary contact of the oxygen with the fuel.

Reference ((Basic engineering thermodynamic)) page571 Rayner Joel

Also, the nitrogen will absorb some of the energy liberated as a result of the combustion and will therefore be responsible for a lower combustion temperature. The effect of the nitrogen need not altogether be considered as being detrimental. combustion with pure oxygen would be very rapid and would produce extremely high temperatures. Very rapid combustion would probably produce control difficulties while too high combustion temperatures would produce damage to materials.

Now a gas has both mass and volume .The constituents of air are therefore given as percentage composition by mass and by volume .Neglecting all other gases but oxygen and nitrogen, the composition is given as:

	By mass	By volume
Oxygen	23.2 %	21%
Nitrogen	76.8%	79%

It is very common in problem work, however, to be given a mass analysis of

Oxygen 23%, Nitrogen 77%

Reference ((Basic engineering thermodynamic)) page571 Rayner Joel

5- Combustion equations – stoichiometry

The chemical process of combustion is written out in the form of equations.

Take the case of the combustion of carbon C, with oxygen $\boldsymbol{O_2}$, which results in the production of carbon dioxide, $\boldsymbol{CO_2}$, if the combustion is complete .

$$C + O_2 = CO_2$$

There is one atom of carbon on each side and two atoms of oxygen on each side. this equation balances and hence this is the complete equation for the combustion of carbon with oxygen to form carbon dioxide.

This balance chemical equation is called the Stoichiometric equation since it represents the correct balance between the amount of fuel provided and the amount of oxygen supplied .later, nitrogen will also appear in the stoichiometric equation when the combustion of a fuel in air is considered.

6-Complete combustion of carbon to carbon dioxide by mass:

$\mathrm{C} + \mathrm{O_2} = \mathrm{CO_2}$ combustion equation .

$12 + (2 * 16) = \{12 + (2 * 16)\}$ proportion by mass .

$12 + 32 = 44$

$1 + 2.66 = 3.66$ Divided through by 12 .

$1\mathrm{Kg\ C} + 2.66\mathrm{Kg\ O_2} = 3.66\ \mathrm{Kg\ CO_2}$

Hence $2.66\ \mathrm{Kg\ O_2}$ = Stoichiometric mass of $\mathrm{O_2}$.

Now $2.66\ \mathrm{Kg\ O_2}$ are contained in

$$\frac{2.66\ \mathrm{Kg\ O_2}}{0.23\ \mathrm{Kg}\ \frac{\mathrm{O_2}}{\mathrm{Kg\ air}}} = 11.5\ \mathrm{Kg\ air}$$

= stoichiometric mass of air

This air will contain

$11.5 - 2.66 = 8.84\mathrm{Kg\ N_2}$

Hence.

$1\ \mathrm{Kg\ C} + 11.5\ \mathrm{Kg\ air} = 3.66\ \mathrm{Kg\ CO_2} + 8.84\mathrm{Kg\ N_2}$

7- Combustion of Hydrogen, H_2 with Oxygen, O_2 to form water, H_2O .

$2\mathrm{H_2} + \mathrm{O_2} = 2\mathrm{H_2O}$

$2 * 2 + 2 * 16 = 2 * (2 + 16)$

Thus it appears that,

4 masses $\mathbf{H_2}$ combined with 32 masses $\mathbf{O_2}$ = 36masses$\mathbf{H_2O}$.

Dividing throughout by 4, then

1 mass $\mathbf{H_2}$ +8 masses $\mathbf{O_2}$ = 9 masses $\mathbf{H_2O}$

Now the mass chosen can be on any mass scale .Assume the mass to be in kilograms, then:

1Kg $\mathbf{H_2}$ +8 Kg $\mathbf{O_2}$ = 9 Kg $\mathbf{H_2O}$

Hence mass of air required to completely burn 1 Kg $\mathbf{H_2}$ = $\frac{\mathbf{8}}{\mathbf{0.23}}$ = 34.5 Kg

Of this 34.5 kg, there are 8kg$\mathbf{O_2}$. Hence, the nitrogen, $\mathbf{N_2}$present = 34.5 -8=26.5 kg.

Now, as already stated , this N2 does not take any part in the combustion process itself. Hence there is as much $\mathbf{N_2}$ after combustion as there was before.

$1\ \mathrm{kg\ H_2} + 34.5\ \mathrm{kg\ air} = 9\mathrm{kg\ H_2O} + 26.5\ \mathrm{kg\ N_2}$.

8- Complete combustion of methane by mass

Combustion equation: $\mathbf{CH_4 + 2O_2 = CO_2 + 2H_2O}$

Proportion by mass:

$$(12 + 4) + 2(2 * 16) = (12 + 32) + 2(2 + 16)$$

$$16 + 64 = 44 + 36$$

Divide through by 16: $1 + 4 = 2.75 + 2.25$

$1\ \mathrm{Kg\ CH_4} + 4\ \mathrm{Kg\ O_2} = 2.75\ \mathrm{kg\ CO_2} + 2.25\ \mathrm{kg\ H_2O}$

Stoichiometric mass of air $= 4/0.23 = 17.39$ kg .

This air will contain $17.39 - 4 = 13.39\ \mathrm{Kg\ N_2}$

Hence $1\ \mathrm{Kg\ CH_4} + 17.39\ \mathrm{kg\ air} = 2.75\ \mathrm{Kg\ CO_2} + 2.25\ \mathrm{kg\ H_2O} + 13.39\ \mathrm{N_2}$

9- Complete combustion of sulphur to sulphur dioxide

$\mathrm{S} + \mathrm{O_2} = \mathrm{SO_2}$

$32 + 32 = 64$

Divide through by 32

$1 + 1 = 2$

$1\ \mathrm{Kg\ S} + 1\ \mathrm{Kg\ O_2} = 2\ \mathrm{Kg\ SO_2}$

Stoichiometric mass of air $= 1/0.23 = 4.3$ Kg.

$\mathrm{N_2} = 4.3 - 1 = 3.3$ Kg .

$1\ \mathrm{Kg\ S} + 4.3\ \mathrm{Kg\ air} = 2\ \mathrm{Kg\ SO_2} + 3.3\ \mathrm{Kg\ N_2}$.

10-Stoichiometric mass of air for the complete combustion of fuel.

If the analysis of a fuel is given by mass, then proceed as follows:

1-Determine the mass of Oxygen required for each constituent. From this, Find the total mass of Oxygen by adding all the separate masses required.

2-Subtract any Oxygen which may be in the fuel since this does not have to be supplied.

3-Stoichiometric mass of air $= \mathbf{O_2}\ \boldsymbol{required}\ /\mathbf{0.23}$.

Example 1:

A fuel consists of 72% carbon, 20% hydrogen and 8 % Oxygen by mass. Determine the stoichiometric mass of air required to completely burn 1 Kg of this fuel.

A convenient form of solution here is to tabulate results.

Constituent	Mass of consist Kg/Kg fuel	$\mathbf{O_2}$ required Kg/Kg consist	$\mathbf{O_2}$ required Kg/Kg fuel
C	**0.72**	**2.66**	**0.72*2.66= 1.92**
$\mathbf{H_2}$	**0.2**	**8**	**0.2*8=1.6**
$\mathbf{O_2}$	**0.08**	**----**	**-0.08**

O_2 required $= 1.92 + 1.6 - 0.08$

$= 3.44$ Kg/Kg $_{fuel}$.

Stoichiometric air required

$= 3.44 / 0.23 = 14.8$ Kg/Kg $_{fuel}$.

Reference ((Basic engineering thermodynamic)) page 583 Rayner Joel

11- The products of combustion by mass:

Example 2:

A fuel oil consists of the following percentage analysis by:

$82\ \%\ C$, $12\ \%\ H_2$, $2\%\ O_2$, $1\%\ S$, $3\ \%\ N_2$

Determine the stoichiometric mass of air required to completely burn $\mathbf{1}\boldsymbol{Kg}$ of this fuel and also determine the products of combustion both by mass and as a percentage.

Constituent	Mass consist **Kg/Kg** $_{\text{fuel}}$	$\mathbf{O_2}$ required **Kg/Kg** $_{\text{fuel}}$	Products of combustion **Kg/Kg** $_{\text{fuel}}$			
			$\mathbf{CO_2}$	$\mathbf{H_2O}$	$\mathbf{SO_2}$	$\mathbf{N_2}$
$\boldsymbol{C}$	0.82	0.82*2.66=2.19	0.82*3.66=3.01	-----	----	0.82*8.84=7.25
$\boldsymbol{H_2}$	0.12	0.12*8= 0.96	-------	0.12*9=1.08	----	0.12*26.5=3.18
$\boldsymbol{S}$	0.01	0.01 *1 =0.01	-------	------	0.01*2=0.02	0.01*3.3=0.033
$\boldsymbol{O_2}$	0.02	-0.02	-------	-----	------	0.02/0.23*0.77 = -0.066
$\boldsymbol{N_2}$	0.03	-----	------	------	------	0.03
			3.01	1.08	0.02	10.427

Total O2 required = 2.19 +0.96 +0.01 -0.02 =3.14 Kg/Kg $_{fuel}$.

Stoichiometric air = 3.14 / 0.23 = 13.54Kg/Kg $_{fuel}$.

Total products of combustion/

Kg $_{fuel}$ $= 3.01 + 1.08 + 0.02 + 10.427 = 14.537\ Kg$. $CO_2 = 3.01/ 14.537 * 100 = 20.7\ \%$.

$H_2O = 1.08/14.537 * 100 = 7.43\ \%$.

$SO_2 = 0.02/14.537 * 100 = 0.14\ \%$.

$N_2 = 10.427/14.537 * 100 = 71.73\ \%$.

12- Conversion of volumetric to mass or gravimetric analysis

By Avogadro´s Hypothesis, proportions by molecules are also proportions by volume.

Avogadro´s Hypothesis .This hypothesis states that equal volumes of different gases at the same pressure and temperature contain the same number of molecules.

Then the mass of equal volumes will be proportional to the relative molecular masses of the gases.

Hence it follows that , for a gas ,

Proportion by mass = Proportion by volume * Relative molecular mass.

Constituent	% by volume	Product % by vol. * relative molecular mass	% by mass
$\mathbf{CO_2}$	20	20*44= 880	880/3160 *100=27.9
$\boldsymbol{N_2}$	70	70*28=1960	1960/3160 *100= 62
$\boldsymbol{O_2}$	10	10*32=320	320/3160*100= 10.1
Total	100	3160	100

Example 3: A gas consists of 20 % $\mathbf{CO_2}$, 70 % $\boldsymbol{N_2}$ and 10% $\boldsymbol{O_2}$ by volume. Determine the percentage analysis of the gas by mass

Reference ((Basic engineering thermodynamic)) page 592 Rayner Joel

13- Conversion of mass to volumetric analysis

Hence, to convert mass to volumetric analysis. divide the percentage mass by the relative molecular mass, sum the quotients, and hence obtain the percentage by volume.

Example 4: A gas consists of the following percentage analysis by mass:

$30\%\ CO$, $20\ \%\ N_2$, $15\ \%\ CH_4$, $25\%\ H_2$, $10\ \%\ O_2$.

Determine the percentage composition of the gas by volume.

Constituent	**% by mass**	**% by mass Relative molecular mass**	**% by volume**
$\boldsymbol{CO}$	30	30/28 = 1.071	1.071 /15.535*100 = 6.9
$\boldsymbol{N_2}$	20	20/28 = 0.0715	0.0715/15.535*100 = 4.6
$\boldsymbol{CH_4}$	15	15/16 = 0.937	0.937/15.513*100 = 6.03
$\boldsymbol{H_2}$	25	25/2 = 12.5	12.5/15.535*100 = 80.5
$\boldsymbol{O_2}$	10	10/32 = 0.312	0.312/15.535*100 = 1.98
Totals	100	15.535	100

14- Excess air

If O_2 appear in a dry flue gas analysis , then it means that excess air has been supplied to the fuel over that required for complete combustion .

15-Determining Excess or Deficiency of air

To assist the operator, analyzing apparatus is available that continuously determines the amount of oxygen, and combustibles (carbon monoxide) in the kiln exit gases. Other analyzers, less frequently used for making periodical analyses of gas samples to determine oxygen, carbon monoxide and carbon dioxide content .

The percent oxygen contained in the kiln gases gives the best indication of the combustion condition in the kiln because this oxygen is directly related to the amount of air introduced and the amount air contains 21% oxygen by volume. If there were no combustion reaction in the kiln.However, because combustion reactions do take place in the kiln, most of the oxygen reacts with carbon, hydrogen and sulphur to form the combustion products, CO_2, H_2O and SO_2.

Thus no free oxygen can be found in the kiln exit gases no excess air has been introduced into the kiln.

Many viewpoints and opinions, some error, have been advanced, so it is well at this point to review the theory of perfect combustion.

First, most efficient combustion takes place when there is neither carbon monoxide nor excess air present in the kiln exit gases, that is, the oxygen and the combustibles recorders should both have a reading of zero.

Reference ((Rotary cement kiln)) By Kure E. Peray page 33

Second, with any increase of either carbon monoxide or excess air, valuable heat is lost.

Through experience it has been found that a rotary kiln operates best when the kiln exit gases have an oxygen content of not less than 0.7% and not more than 3.5 % under stable operating conditions.

The optimum meet point is between 1 and 1.5% oxygen.

Proper combustion requires that the kiln be operated in such a manner that :

1-The kiln exit gases have an oxygen content of not less than

2-0.7% nor more than 3.5% under normal operating conditions.

3-The kiln exit gas contain no carbon monoxide.

4-The kiln exit gas contain the maximum percentage of carbon dioxide.

5-Strive for optimum combustion conditions at all times by stabilizing kiln gas oxygen content between 1% and 1.5%.

Take immediate steps to eliminate combustibles in the exit gases whenever any carbon monoxide is detected therein.

All the above paragraphs to maintain the flame temperature in the range > 2000 C , to protect the gases temperature in the burning zone and the refractory temperature 1590C.

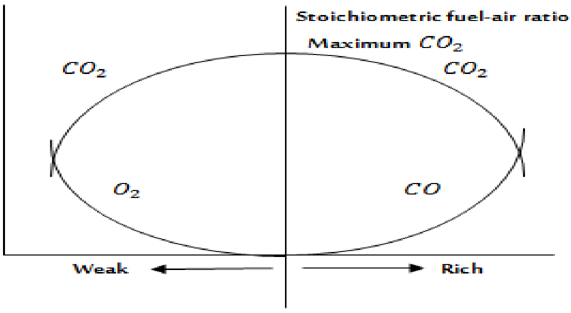

Figure 1.Fuel – air ratio Basic Engineering Thermodynamic Joel.

Hence can determine the excess air according to the analysis by the orsat apparatus for combustion products with the mole method.

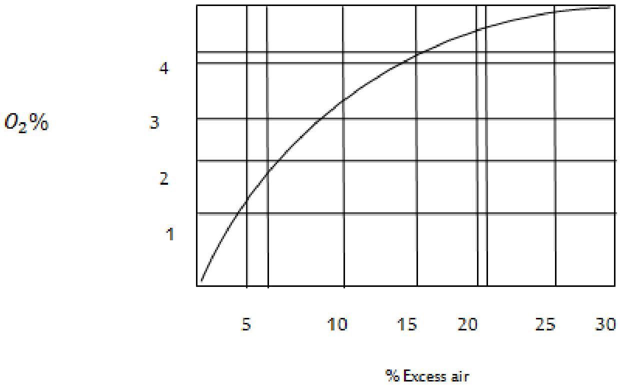

Figure 2. Ideal operating conditions in the kiln occur when the kiln exit gas contains between 0.7 and 3.5% oxygen.

$$\text{Excess air} = \frac{100\ O_2 * 0.95}{21 - O_2}$$

Zone A indicates an excess of air, resulting in excessive heat loss:

Zone B indicates a deficiency of air resulting in the formation of carbon monoxide.

Reference: Rotary cement kiln By: Kurt Peray and Joseph J.Waddell page 34

16- The mole (symbol (mol))

A mole of substance is defined as the mass of the substance equal to its relative molecular mass .

If the unit of mass is taken as the mass of the substance equal to its relative molecular mass.

If the unit of mass is taken as the kilogram, then:

$1 \text{ mole } O_2 = 32 \text{ kg } O_2$ mole C $=$ 12 kg C. $1\ mole\ H_2 = 2\ kg\ H_2$ $1\ mole\ S =$ $32\ kg\ S$. $1\ mole\ CO_2 = 44Kg\ CO_2$

Since the kilogram mass had been used, the mole is referred to as the ((kilogram mole)) written kg mole, and in the case of O_2 , it would have been 32 kilograms of O_2.

To determine the number of moles of gas for example it is necessary to divide the mass of gas by its relative molecular mass. Thus,

$n = \frac{m}{M}$ ……… 1

Where, $n =$ number of moles.

$m =$ mass of gass.

$M =$ relative molecular mass of gass.

From 1 $m = n M$ …….. 2

Example 4: The percentage composition of sample of liquid fuel by weight is, $C = 84.8$ percent, and $H_2 = 15.2$ percent.Calculate the weight of air needed for the combustion of $1Kg\ fuel$, When the Orsat apparatus reading excess O_2 is 2.89%.

Solution:

Minimum O_2 required(StoichiometricO_2) $= 0.848 * 2.66 + 0.152 * 8 = 3.47 \frac{Kg}{Kg_{fuel}}$.

Minimum air required (stoichiometric air)

$$= \frac{3.47\, Kg/Kg\ fuel}{0.23\, Kg/Kg\ air} = 15 \frac{Kg_{air}}{Kg_{fuel}}.$$

When $O_2 = 2.89\ \%$ in exhaust, used the mole method to determine total air (Stoichiometric air + excess air).

$$\frac{0.848}{12}(C) + \frac{15.2}{2}(H2) + a(O2) + \frac{79}{21}a(N2) = b(CO_2) + C(H2O) + e(O_2) + f(N_2)$$

Balancing C: $b = \frac{84.8}{12} = 7.03\, moles.$

Balancing $H_2 : C = \frac{15.2}{2} = 7.6\, moles$

Balancing $O_2 : 2a = 2b + c + 2e.$

$a = b + \frac{c}{2} + e.$

$a = 7.03 + \frac{7.6}{2} + e.$

$a = 10.83 + e$ ……………... (1)

$N_2 : f = 3.76\, a$

Excess O_2 :

$$\frac{e}{B + c + e + f} = 0.0289$$

$$\frac{e}{7.03 + 7.6 + e + 3.76\, a} = 0.0289 \quad \text{…………} \quad (2)$$

$$\frac{e}{14.63 + e + 3.76\,(10.83 + e)} = 0.0289$$

$$\frac{e}{14.63 + e + 40.72 + 3.76\, e} = 0.0289$$

$$\frac{e}{55.35 + 4.76\, e} = 0.0289$$

$34.6\, e = 55.35 + 4.76\, e \longrightarrow 29.84\, e = 55.35 \longrightarrow e = 1.85$

Substitute e in equation (1).

$a = 10.83 + 1.85 = 12.68\, moles$

left side from equation :

$(84.8/12) * 12\,(E) + (15.2/2) * 2(H_2) + 12.68 * 32\,(O_2) + 3.76 * 12.68 * 28\,(N_2$

$= \overbrace{84.8\,(C) + 15.2\,(H_2)}^{fuel}$

$+ \overbrace{405.76\,(O_2) + 1334.95\,(N_2)}^{air}$

= 100 Kg ((fuel)) , 1740.71 Kg ((Air))

Total air = 1740.71 / 100 = 17.4 Kg air / Kg_{fuel}

Excess air = Total air – Stoichiometric air.

Excess air = 17.4 – 15 = 2.4 Kg/Kg_{fuel}.

17-Chemical transformations in the thermal treatment of Portland cement raw meal (principal reactions in clinker burning).

Temperature	Process	Chemical transformation
< 200	Escape of free water	
100- 400	Escape of absorbed water	
400- 750	$AL_4(OH)_8\,(Si)_4\,O_{10} \longrightarrow 2(AL_2O_3\,2SiO) + 4H_2O$	
600- 900	$(AL_2O_3)(2SiO_2) \longrightarrow AL_2O_3 + 2SiO_2$	
600-1000	$Ca\,CO_3 \longrightarrow Ca\,O + CO_2$	
	$AL_2O_3 + 2SiO_2 + 3CaO \longrightarrow (CaO)(AL_2O_3) + 2(CaO)(SiO_2)$	
800 – 1300	$(CaO)(SiO_2) + CaO \longrightarrow (2CaO)(SiO_2)$	
	$2CaO + SiO_2 \longrightarrow (2CaO)(SiO_2)$	
	$CaOAL_2O_3 + 2CaO \longrightarrow (3CaO)AL_2O_3$	
	$CaOAL_2O_3 + 3CaO + Fe_2O_3 \longrightarrow 4CaO\,AL_2O_3\,Fe_2O_3$	
1300-1450	$2CaO\,SiO_2 + CaO \longrightarrow (3CaO)(SiO_2)$	

18-Reactions in the presence of liquid phase (clinkering).

The first formation of liquid (melt) marking the start of what is known ((sintering)) or ((clinkering)), occurs at a temperature of between about 1260 Cº and 1310 Cº .With further rise in temperature the proportion of liquid phase increases to around 20-30% (by weight) at 1450 Cº .At these temperatures the main component of Portland cement clinker is formed, namely tri calcium silicate (C_3S) , known as a lite.

At the start of clinkering the material still contains substantial amounts of uncombined **CaO** as well as dicalicium silicate (C_2S).

In the presence of the liquid phase these compounds pass into solution, the diffusion of the reactants is greatly facilifated in the liquid (as opposed to the solid state), tricalicium silicate (C_3S) is formed accordance with the following reaction and crystallizes.

$CaO + 2CaO \longrightarrow 3CaO\,SiO_2\ C_3S$

With this the main object of the clinkering process , i.e., the formation of the valuable compounds C_3S , has been a achieved and it is this that requires and justifies the effort and cost of heating the raw materials to the high clinkering temperature , which gas temperature 1790 Cº , feed materials 1450 Cº and refractory 1550 Cº depending on the flame temperature not less than 1900 Cº .

If the flame temperature is decreased below 1850 Cº that caused decrease in gases temperature and material temperature below 1400 Cº, that result in the liquid phase is not created (not formation the alite C_3S). The quality of cement had become bad quality, with worthy mentioning the alite in clinker phase ≥ 40 represent the majority phase in the clinker.

Reference: ((Cement Engineering Handbook)) KHD HUMBOLDT WEDAG

19-Flame temperature

The theoretical flame temperature from the combustion of fuel oil can be derived from the following formula :

$T_F = \frac{Q}{V_G} * C_P$

T_F =Flame temperature.

Q = Heating value of fuel.Kcal/Kg.

V_G = Volume of combustiongases, Nm3/Kg.

C_P = specific heat of combustion gases .

Reference ((Cement- data – book))

For Example:Fuel oil

Q =9750Kcal/Kg fuel.

V_G = 11.3 m^3 /Kg fuel.

C_P = 0.4 K cal/m^3 .Cº.

T_F = 9750 / 11.3 *0.4 = 2157 Cº.

When the flame temperatures of a fuel are plotted versus the rate of excess air that inversely proportion as shown in fig 3 .

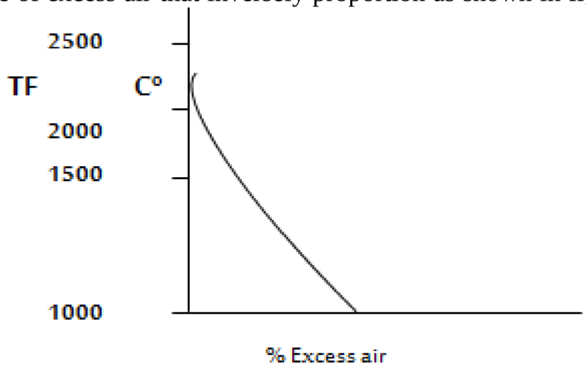

Figure 3

((Cement –Data – Book page 313))

20- Portland cement clinker

Portland cement clinker consists substantially of the four crystalline clinker phase alite (C_3S), belite (C_2S), calcium aluminate (C_3A) and calcium – alumino ferrite (C_4AF).

21- Alile (tricalcium silicate)

Chemically pure tricalciam silicate (C_3S= 3CaO.SiO_2) is created in the burning zone of the kiln depend upon the 1450C for materials in the burning. Quantitatively and also with regard to the properties of the cement (more particularly its strength development), tricalcium silicate is the most important constituent of cement.

For this compound to form in the burning process, it is essential that sintering should occur. Minimum rate in cement clinker is 40 percent. If the temperature of materials in the burning zone does not reach to 1450 C because upset in the kiln process (increased in excess air) results in the flame temperature is decreased and this compound is not create and the cement production is not have strength development, the final production is bad quality. The compared strength development to the four cement clinker phase are illustrated in the Fig4.

Reference ((Cement Engineers Handbook. HUMBOLDT WEDAG)) page 128

22- Rotary kiln in cement plant Kufa.

Dimensions = 5.25m* 5.75m * 175 m.

Kiln capacity maximum = 1500 t/day .wet process.

Fuel type: heavy fuel oil.

$C = 86\%$, $H_2 = 11.7\%$, $S = 1.5\%$, $O_2 = 0.6\%$, $N_2 = 0.2\%$.

Lower calorific value $Q = 9510$ Kcal/kg $_{fuel}$.

Fuel consumption per ton clinker = 180 liter / ton $_{clinker}$

= 165 kg fuel /ton $_{clinker}$

23- Determining stoichiometric air consumption for the heavy fuel in kiln and calculate the flame temperature.

Constitution.	Mass constitution Kg /Kg $_{Fuel}$	O_2 required kg/kg $_{constitution}$	O_2 required kg/kg $_{fuel}$
C	0.86	2.666	0.86*2.666=2.292
H_2	0.117	8	0.117 * 8=0.936
S	0.015	1	0.015*1=0.015
O_2	-0.006	-----	-0.006
N_2	0.002	-----	------

Total$O_2 = \mathbf{2.292 + 0.936 + 0.015 - 0.015 - 0.006 = 3.237}$ Kg/Kg $_{fuel}$

Stoich. Air $= \frac{3.237}{0.23} = 14.07$ Kg air/Kg $_{fuel}$.

$V_g = \frac{mass}{Density\ of\ air} = \frac{14.07}{1.2928} = 10.88\ m^3/kg_{fuel}$

Refer to the formula $T_F = \frac{Q}{V_g\ C_P}$ in page 18

$T_F = \frac{9510}{10.88 * 0.4} = 2185$ Cº

This is ideal case that in exhaust gas has noO_2 and CO in the products of combustion.

24- Determining the excess air consumption and flame temperature when the Orsat apparatus is reading $O_2 = 1\%$.

Solution:

Refer to the formula (Excess air % $= \frac{100*0.95\ O_2}{21-O_2}$) in page 14

Excess air % $= \frac{100*0.95*1}{21-1} = \frac{95}{20} = 4.75\%$

Excess air amount $= 0.0475 * 10.88 = 0.5168\ m^3/kg_{fuel}$.

V_g = total air = stoichiometric air + Excess air amount.

$V_g = 10.88 + 0.516 = 11.396$ m^3/Kg $_{fuel}$.

$T_F = Q/\ V_g\ C_P = 9510/\ 11.396 * 0.4 = 2086\ C^{o}$.

Mass of air excess $= 0.5168 * density\ of\ air$.

$= 0.5168 * 1.2928 = 0.668\ kg\ air\ /kg_{fuel}$.

Mass of excess air per ton clinker = $0.668\ Kg_{air}/kg_{fuel} * 165\ kg_{fuel}\ /ton_{clinker}$.

$Mg = 110.22\ Kg_{air}\ /ton_{clinker}$.

Heat lost = mg CPΔT

CP= 0.26 Kcal/Kg air Cº.

$= 110.22 * 0.26(1790 - 40)$.

$\Delta T = T2 - T1$

= 50.150 Kcal $/ton_{clinker}$.

$T_2 = 1790$Cº.

$T_1 = 40$Cº.

Mg= mass of excess air.

Fuel loss $= 50150/9510 = 5.27\ Kg/ton_{clinker}$.

Volume of fuel loss

$= 5.27/920 = 0.0057 m^3{}_{fuel\ /ton_{clinker}}$

$= 5.7\ liter_{fuel\ /ton_{clinker}}$

Fuel loss per hr= $5.7\ liter\ /ton_{clinker}$

$* 60\ ton_{clinker\ /hr}$

$= 343\ liter\ /hr$

25-Determining the excess air consumption and flame temperature when the Orsat apparatus is reading O2= 1.5%.

Solution:

Excess air $= \frac{100 * 0.95\ O_2}{21-O_2} = \frac{100 * 0.95*1.5}{21-1.5} = \frac{95*1.5}{19.5} = 7.3\%$

Excess air amoun$t = 0.073 * 10.88 = 0.794\ m^3/Kg_{fuel}$

V_g = Total air $= 0.794 + 10.88 = 11.674\ m^3/Kg_{fuel}$

$T_F = \frac{Q}{V_g\ C_P} = 9510\ /\ 11.674 * 0.4 = 2036\ C^{o}$.

Mass of excess air $= 0.5168 * density\ of\ air$.

$= 0.5168 * 1.2928 = 0.668\ kg\ air\ /kg_{fuel}$.

Mass of excess air per ton clinker $= 1.0264\ Kg_{air}\ / Kg_{fuel} * 165\ Kg_{air}/Kg_{fuel}$.

$Mg = 169.356\ Kg_{air}\ /ton_{clinker}$.

Heat lost = $mg\ CP\Delta T$

= 169.356 *0.26 *1750 = 77056.98 K_{cal} /$ton_{clinker}$.

Fuel Loss = (77056.98 K_{cal}/$ton_{clinker}$) /9510 = 8.1 Kg_{fuel}/$ton_{clinker}$

Volume of fuel loss $= 8.1 / 920 = 0.0088\, m^3{}_{fuel} / ton_{clinker}$.
$= 8.8\, liter / ton_{clinker}$.
Fuel loss per hr= $8.8\, liter / ton_{clinker} * 60\, ton_{clinker} / hr$
$= 528\, liter / hr$.

26- Determining the excess air consumption and flame temperature when the Orsat apparatus is reading $O_2 = 2$%.

Solution:

Excess air % $= \frac{100 * 0.95\, O_2}{21 - O_2} = \frac{100 * 0.95*2}{21-2} = \frac{95*2}{19} = 10\%$

Excess air amount $= 0.1 * 10.88 = 1.088\, m^3/Kg_{fuel}$

$V_g =$ Total air $= 1.088 + 10.88 = 11.968\, m^3/Kg_{fuel}$

$T_F = \frac{Q}{V_g\, C_P} = 9510 / 11.968 * 0.4 = 1986\, C^º$.

Mass of excess air $= 1.088\, m^3/Kg_{fuel} * 1.2928\, Kg_{air}/m^3 = 1.406\, Kg_{air} /Kg_{fuel}$. Mass of excess air per ton clinker $= 1.406\, Kg_{air} /Kg_{fuel} * 165\, Kg_{air}/Kg_{fuel}$.

$Mg = 232\, Kg_{\text{excess air}} /ton_{clinker}$.

Heat lost = $mg\, C_P \Delta T$
$= 232 * 0.26 * 1750 = 105598\, K_{cal} /ton_{clinker}$.

Fuel $Loss = (105598\, K_{cal}/ton_{clinker}) /9510 = 11.1\, Kg_{fuel}/ ton_{clinker}$ Volume of fuel loss
$= 11.1 / 920 = 0.012\, m^3{}_{fuel} / ton_{clinker}$.
$= 12\, liter / ton_{clinker}$.

Fuel loss per hr
$= 12\, liter / ton_{clinker} * 60\, ton_{clinker} / hr$
$= 720\, liter / hr$.

27- Determining the excess air consumption and flame temperature when the Orsat apparatuse is reading $O_2 = 3$ %.

Solution :

Excess air % $= \frac{100 * 0.95\, O_2}{21 - O_2} = \frac{100 * 0.95*3}{21-3} = \frac{95*3}{18} = 15.833\%$

Excess air amount $= 0.1583 * 10.88 = 1.72\ m^3/ Kg_{fuel}$

$V_g =$ Total air $= 1.72 + 10.88 = 12.60\, m^3/Kg_{fuel}$

$T_F = \frac{Q}{V_g\, C_P} = 9510 / 12.6 * 0.4 = 1886\, C^º$.

Mass of excess air $= 1.72\ m^3/Kg_{fuel} * 1.2928\ Kg_{air}/m^3 = 2.223\ Kg_{air} /Kg_{fuel}$.

Mass of excess air per ton clinker $= 2.223\, Kg_{air} /Kg_{fuel} * 165\, Kg_{air}/Kg_{fuel}$.

$Mg = 366\, Kg_{\text{excess air}} /ton_{clinker}$.

Heat lost = $mg\, C_P \Delta T$
$= 366 * 0.26 * 1750 = 166937\, K_{cal} /ton_{clinker}$.

Fuel $Loss = (166937\, K_{cal}/ton_{clinker}) /9510 = 17.55\, Kg_{fuel}/ ton_{clinker}$ Volume of fuel loss
$= 17.55 / 920 = 0.019\, m^3{}_{fuel} / ton_{clinker}$.
$= 19\, liter / ton_{clinker}$.

Fuel loss per hr
$= 19\, liter / ton_{clinker} * 60\, ton_{clinker} / hr$
$= 1140\, liter / hr$.

28-Determining the excess air consumption and flame temperature when the Orsat apparatus is reading $O_2 = 3.5$ %.

Solution :

Excess air % $= \frac{100 * 0.95\, O_2}{21 - O_2} = \frac{100 * 0.95*3.5}{21-3.5} = \frac{95*3.5}{17.5} = 19\%$

Excess air amount $= 0.19 * 10.88 = 2.067\ m^3/ Kg_{fuel}$

$V_g =$ Total air $= 2.067 + 10.88 = 12.947\, m^3/Kg_{fuel}$

$T_F = \frac{Q}{V_g\, C_P} = 9510 / 12.947 * 0.4 = 1836\, C^º$.

Mass of excess air $= 2.067\, m^3/Kg_{fuel} * 1.2928\, Kg_{air}/m^3 = 2.672\, Kg_{air} /Kg_{fuel}$. Mass of excess air per ton clinker
$= 2.672\, Kg_{air} /Kg_{fuel} * 165\, Kg_{air}/Kg_{fuel}$.

$Mg = 440.91\, Kg_{\text{excess air}} /ton_{clinker}$.

Heat lost = $mg\, C_P \Delta T$
$= 440.91 * 0.26 * 1750 = 2006167\, K_{cal} /ton_{clinker}$. Fuel $Loss = (2006167\, K_{cal}/ton_{clinker}) /9510 = 21.09\, Kg_{fuel}/ ton_{clinker}$ Volume of fuel loss
$= 21.09 / 920 = 0.0229\, m^3{}_{fuel} / ton_{clinker}$.
$= 22.9\, liter / ton_{clinker}$.

Fuel loss per hr
$= 22.9\, liter / ton_{clinker} * 60\, ton_{clinker} / hr$
$= 1375.5\, liter/hr$.

29 - Determining the excess air consumption and flame temperature when the Orsat apparatus is reading $O_2 = 4$ %.

Solution:

Excess air % $= \frac{100 * 0.95\, O_2}{21 - O_2} = \frac{100 * 0.95*4}{21-4} = \frac{95*4}{17} = 22.35\%$

Excess air amount $= 0.2235 * 10.88 = 2.431\ m^3/Kg_{fuel}$

$V_g =$ Total air $= 2.431 + 10.88 = 13.311\, m^3/Kg_{fuel}$

$T_F = \frac{Q}{V_g\, C_P} = 9510 / 13.311 * 0.4 = 1786\, C^º$.

Mass of excess air $= 2.431\, m^3/Kg_{fuel} * 1.2928\, Kg_{air}/m^3 = 3.143\, Kg_{air} /Kg_{fuel}$. Mass of excess air per ton clinker $= 3.143\, Kg_{air} /Kg_{fuel} * 165\, Kg_{air}/Kg_{fuel}$.

$Mg = 518.56\, Kg_{\text{excess air}} /ton_{clinker}$.

Heat lost = $mg\, C_P \Delta T$
$= 518.56 * 0.26 * 1750 = 235945.5\, K_{cal} /ton_{clinker}$. Fuel $Loss = (235945.5\, K_{cal}/ton_{clinker}) /9510 = 24.81\, Kg_{fuel}/ ton_{clinker}$ Volume of fuel loss
$= 24.81 / 920 = 0.027\, m^3{}_{fuel} / ton_{clinker}$.
$= 27\, liter / ton_{clinker}$.

Fuel loss per hr
$27\, liter / ton_{clinker} * 60\, ton_{clinker} / hr$
$= 1620\, liter/hr$.

Reference

[1] Cement Engineers Handbook- by otto Labahn/ Koh/ has 1954 KHD .
[2] Cement data book by Dipl-Ing. Watter H.Duda.
[3] Rotary Cement Kiln by Kurt E.Peray and Joseph J. Waddell New York 1972.
[4] Mechanics of Materials by Ferdinand P. Beer E. Russell Johnston. Jr.
[5] Engineering Thermodynamics Er.R.K Raj put.
[6] Strength of Materials R.S. KHRMI.
[7] Strenhth of Materials by singer.
[8] Internal Combustion Engine- Prof.P.L. Ballaney.