APCAC XVII TECHNICAL CONFERENCE

FUEL CHANGES IN CEMENT KILN APPLICATIONS

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1. Abstract

Due to the increasing costs of liquid and gaseous fuels, many cement plants burning these fuels are converting to solid fuels such as coal and petroleum coke as their main fuel to reduce operating costs. This paper discusses various topics that are important when considering fuel changes. Subjects discussed are: the chemical and physical properties of solid fuels, the impact of solid fuels on kiln operation, the selection of appropriate equipment for grinding and firing the solid fuels, and safety considerations. The importance of following good engineering practice are emphasized to achieve projected results.

2. Introduction

Cement plant owners, managers and technical personnel are constantly searching for ways to reduce operating costs at their plants. One potential method of reducing operating costs is to change the current fuel to another that is less expensive. In some occasions, coal, petroleum coke or combinations of both replace gaseous or liquid fuels. In other occasions, 100 percent petroleum coke or combinations of coal and petroleum coke replace coal. In other occasions, other combustible materials such as tires, rice husks, liquid or solid waste fuels replace or partially replace the main fuels as well. This paper focuses only on fuel changes to coal, petroleum coke and combinations of both.

3. Fuel Properties and Characteristics

Fuel properties and characteristics have significant impacts on cement quality, on kiln system operation and design, on emissions from the cement kiln system, and on the fuel preparation system. This section provides general fuel properties and characteristics of the different fuels.

3.1. Gaseous Fuels

The gaseous fuel used in cement plants is typically natural gas. Natural gas is composed mainly of methane, CH_4. Other components found in smaller proportions are ethane (C_2H_6), propane (C_3H_8), butane (C_4H_{10}), pentane (C_5H_{12}), carbon dioxide (CO_2), and nitrogen (N_2). Table 1, Typical Natural Gas Composition, provides typical chemical analysis ranges of natural gas. Gaseous fuels have several advantages as compared to liquid and solid fuels, such as not requiring preheating, drying or grinding and the primary air for firing into the kiln system can be lower.

Table 1, Typical Natural Gas Composition

Compound	Natural Gas Composition[1], volume %
Methane, CH_4	86.3 to 95.2
Ethane, C_2H_6	2.5 to 8.1
Propane, C_3H_8	0.6 to 2.8
Butane, C_4H_{10}	0.13 to 0.66
Pentane, C_5H_{12}	0 to 0.44
Carbon Dioxide, CO_2	0 to 1.1
Nitrogen, N_2	0.31 to 2.47

3.2. Fuel Oils

Fuel oils are comprised mainly of complex mixtures of hydrocarbons with small amounts of nitrogen, oxygen and sulfur. However, the elemental composition does not vary substantially. Table 2, Fuel Oils, provides the typical chemical composition range of fuel oils. Several different fuel oils are used in cement plants; generally, they are the heavier grades such as No. 6 fuel oil which require preheating before they can be pumped and atomized. In cement kiln systems, liquid fuels are atomized to obtain optimized combustion characteristics. Liquid fuels, during combustion, evaporate and the resulting combustible vapors then burn as gases. Atomization of liquid fuels increases the evaporation rate by producing a large number of small liquid particles, which creates a large surface area to volume ratio.[2]

Table 2, Fuel Oils

Element or compound	Fuel Oil Composition range[3], % mass
Carbon, C	83 to 87
Hydrogen, H_2	10 to 14
Nitrogen, N_2	0.1 to 1.5
Oxygen, O_2	0.1 to 1.5
Sulfur, S	0.1 to 5.0

3.3.   Coal

Coal is classified by rank into four major groups: anthracite, bituminous, sub-bituminous, and lignite. Table 3, Coal Classification, provides the coal classification according to the various ranks. Generally, coals used in cement plants are bituminous and sub-bituminous. Normally, in cement kiln systems, coal has to be dried and ground before firing. During combustion, volatile matter in coal evaporates and combusts as in the case of liquid fuels. However, the fixed carbon does not evaporate. Instead, oxygen has to react with carbon on the surface of the coal particles. [4] Evaporation of the volatile matter also increases the surface area available for reaction with oxygen.

Table 3, Coal Classification

Class	Fixed carbon limits, % (dry ash free basis)	Volatile-matter limits, % (dry ash free basis)	Higher Calorific value limits, kcal/kg (moist, ash free basis)
Anthracite	86 to 98	0 to 14	
Bituminous	69 to 86	14 or greater	Greater than 5,833
Sub-bituminous			4,611 to 6,389
Lignite			Less than 4,611

3.4. Petroleum Coke

Petroleum coke is a byproduct from oil refining industry and exists in four basic forms, delayed coke (green coke), calcined coke, fluid coke and flexicoke. Delayed coke is a byproduct of the delayed coker process. Calcined coke is delayed coke that has been pyrolized above 1400°C to remove the volatile part and is usually used in the production of carbon electrodes for metallurgical applications. Fluid coke is produced in a fluid bed coking process. Flexicoke is produced using a fluid bed coking process with a gasification step added. In most cement kiln applications, petroleum coke also has to be dried and ground before firing. During combustion, the volatile matter in petroleum coke also evaporates, and combusts as in the case of liquid fuels. However, the fixed carbon does not evaporate. Instead, oxygen has to react with carbon on the surface of the petroleum coke particles. [5]

3.5.   Summary of Fuels

Table 4, Fuel Properties, summarizes some of the properties of fuels. From this table, it is apparent that coal typically will have more ash than the other fuels listed while petroleum coke typically will have more sulfur than the other fuels listed. Also, from this table, it is apparent that fluid coke typically will have the lowest hardgrove grindability index (HGI) which makes it the most difficult to grind as compared with the other fuels.

Table 4, Fuel Properties

Description	Natural gas	Fuel oil	Coal	Delayed coke, % mass	Fluid Coke, % mass
Ash	0	0.01 to 0.5[6]	4 to 15	0.2 to 1.0	0.2 to 0.5
Volatile matter	Not applicable	high	30 to 40	8 to 16	2.0 to 6.5
Sulfur	Traces	0.1-5.0	0.6 to 3.0	2.0 to 7.5	3.5 to 6.5
Hardgrove Grindability index (HGI)	Not applicable	Not applicable	30 to 60	50 to 90	<30

Table 5, Solid Fuel Properties, provides some typical values for the listed variables that are used to predict the effect of the deflagration of the solid fuels.[7] These values provide an indication of the fuel burning characteristics, for example, the rate of pressure rise, K_{St}, provides an indication of the speed of combustion. The values of K_{St} are sample specific and are dependent on several parameters including the fuel fineness. K_{St} increases when the size of the fuel particle decreases.

Table 5, Solid Fuel Properties

Material	Mass median diameter µm	Minimum flame concentration g/m^3	K_{st} bar-m/sec
Lignite	32	60	151
Bituminous Coal	24	60	129
Petroleum coke	15	125	47

4. Fuel Change Impacts On Cement Quality

This section discusses some of the fuel change impacts on cement quality. These impacts on cement are caused by the change of clinker chemistry due to a change of the fuel chemical properties.

4.1. Ash Effects

Fuel ash changes caused by a fuel change will have an effect on the potential clinker mineral phases, tricalcium silicate (C_3S), dicalcium silicate (C_2S), calcium aluminate (C_3A) and tetracalcium aluminoferrite (C_4AF). The percentage of each of these mineral phases provide an indication of the potential properties of the cement made from the clinker, such as the cement strength development, workability and color. A change to any of these mineral phases will modify the cement properties; therefore, to maintain similar cement properties, it is important to maintain similar mineral phases in the cement.

This section presents an example of the effect of a fuel change on the clinker mineral phases caused by a fuel change from natural gas to coal. However, any fuel change that modifies the ash chemistry or ash input to the cement kiln system will have an effect on the clinker compounds unless corrections are made. Table 6, Typical Coal Ash Chemistry Range, provides the range of coal ash elements or compounds that will be found in coal.

Table 6, Typical Coal Ash Chemistry Range

Element	Typical Chemical Analysis range, % mass[8]
SiO_2	20 to 60
Al_2O_3	10 to 35
Fe_2O_3	5 to 35
CaO	1 to 20
MgO	0.3 to 4
TiO_3	0.5 to 2.5
Na_2O and K_2O	1 to 4
SO_3	0.1 to 12

Table 7, Raw Material Compositions, shows the chemical compositions of the limestone, clay and fuel ash that are used in this example. Table 8, Preheater Kiln System Clinker Composition, shows the effect on clinker composition after the main fuel has been changed in a preheater kiln system. Table 9, Wet Process System Clinker Composition, shows the effect on clinker composition after the main fuel has been changed in a wet process system.

In these examples, the specific fuel consumption of the preheater kiln system is 750 kcal/kg of clinker and 1500 kcal/kg of clinker for the wet process system. The fuel net heating value is 7400 kcal/kg coal and the ash content is 9.3 percent. The column titled "Natural Gas Fired" provides the clinker compounds prior to the fuel change. The column titled

"Coal Fired (Uncorrected)" provides the potential clinker compounds if the kiln feed chemistry was not corrected. The column titled "Coal Fired (corrected)" provides the potential clinker compounds if the kiln feed chemistry is corrected.

Table 7, Raw Material Compositions

Compound	Limestone (% mass)	Clay (% mass)	Fuel Ash (% mass)
SiO_2	3.89	70.03	51.32
Al_2O_3	1.93	17.17	10.19
Fe_2O_3	0.93	5.00	16.11
CaO	91.19	4.25	10.30
Other	2.06	3.55	12.08

Table 8, Preheater Kiln System Clinker Composition

Clinker Component	Natural Gas Fired	Coal Fired (uncorrected)	Coal Fired (Corrected)
Limestone (% mass)	72.3	71.6	72.1
Clay (% mass)	27.7	27.5	27.0
Fuel Ash (% mass)	0	0.9	0.9
C_3S (% mass)	60	55.3	60.0
C_2S (% mass)	18.4	22.8	18.3
C_3A (% mass)	12.8	12.7	12.5
C_4AF (% mass)	6.3	6.7	6.6
Silica ratio	2.71	2.68	2.68

Table 9, Wet Process System Clinker Composition

Clinker Component	Natural Gas Fired	Coal Fired (uncorrected)	Coal Fired (Corrected)
Limestone (% mass)	72.3	70.9	71.9
Clay (% mass)	27.7	27.2	26.2
Fuel Ash (% mass)	0	1.9	1.9
C_3S (% mass)	60.0	50.6	60.0
C_2S (% mass)	18.4	27.1	18.2
C_3A (% mass)	12.8	12.6	12.3
C_4AF (% mass)	6.3	7.1	7.0
Silica ratio	2.71	2.66	2.64

4.2. Sulfur Effects

The behavior of sulfur in a cement kiln system is an important subject when considering a fuel change that will change the sulfur input to the cement kiln system.

Before discussing the effects of changing the sulfur input to the cement kiln system, it is helpful to describe the sources of sulfur and their typical behavior in cement kiln systems.

Sulfur enters the cement kiln system in the kiln feed and in the fuel. Kiln feed and fuel sulfur may be in the form of elemental sulfur, organic sulfur compounds, sulfides (either simple sulfides such as pyrites or polysulfides), or sulfates.[9]

The reactions involving sulfur in a cement kiln are complex and are influenced by many variables such as the sulfur compound forms, retention times at various temperatures, availability of other compounds such as $CaCO_3$, CaO, K_2O, Na_2O, O_2 and others.

Depending on the sulfur compound and its location in a cement kiln system, sulfur may exit the kiln system as gaseous sulfur dioxide (SO_2) or as sodium sulfate (Na_2SO_4), potassium sulfate (K_2SO_4), and calcium sulfate ($CaSO_4$). The sulfur dioxide gases are emitted to the atmosphere with the other kiln system vent gases. The sulfate compounds exit the kiln in the clinker product or in the kiln system vent dust.

Fuel sulfur entering preheater kiln systems usually exits the kiln as sulfates in the clinker and in the preheater bypass dust (of kiln systems equipped with a preheater bypass). Fuel

sulfur usually has little effect on the SO_2 emissions from preheater kiln systems. Fuel sulfur entering wet process kilns and dry process long kilns usually exits the kiln as sulfates in the clinker with a portion exiting as SO_2 in the kiln vent gases, provided an oxidizing atmosphere is maintained in the kiln.

Two examples to show the potential magnitude of sulfur increase caused by a fuel change are shown. These examples show the effects of changing from 100 percent natural gas to 100 percent petroleum coke in a wet process system and a preheater kiln system. Table 10, Sulfur Increase, shows the increased input of sulfur to the example kiln systems.

Table 10, Sulfur Increase

Description	Wet process kiln system	Preheater-calciner kiln system
Fuel consumption (kcal/kg clinker)	1500	750
Fuel heating value (kcal/kg petroleum coke)	8400	8400
Sulfur content (%)	6.0	6.0
S increase (kg S/kg clinker)	1.1%	0.5%
SO_2 equivalent increase (kg SO_2/kg clinker)	2.1%	1.1%
SO_3 equivalent increase (kg SO_3/kg clinker)	2.7%	1.3%

Most standards on cement quality have limits on the SO_3 content. The reason for these limits is to prevent long-term expansion characteristics.[10] The Standard Specification for Portland Cement[11] in the United States limits the SO_3 to 2.3 to 4.5 percent depending on

the type of cement and the tricalcium aluminate (C_3A) content. These limits are on the total SO_3 content of cement, which includes SO_3 derived from clinker as well as from gypsum ($CaSO_4 \bullet 2H_2O$). There are cases where the cement properties can be improved by exceeding the SO_3 limits. In these cases, it is permissible to exceed the limits provided it has been demonstrated that cement with the increased SO_3 content will not develop expansion in water exceeding 0.020 percent at 14 days. Table 11, Portland Cement Standards, lists the current sulfate content limits in the United States.

Table 11, Portland Cement Standards

Description	Type I and IA	Type II and IIA	Type III and IIIA	Type IV and V
SO_3 maximum				
C_3A is 8% or less	3.0	3.0	3.5	2.3
C_3A is more than 8%	3.5	not applicable	4.5	not applicable

The total sulfate content and the form that the sulfate exists in the cement effect the setting properties of the cement. The dissolution rate of $CaSO_4$ into Ca^{2+} and SO_4^{2-} must be adjusted to the rate of which Al^{3+} ions from the C_3A enter the liquid phase during the initial phases of cement hydration. Since the dissolution rate of anhydrite ($CaSO_4$) is slower than gypsum ($CaSO_4 \bullet 2H_2O$) and hemihydrate ($CaSO_4 \bullet \frac{1}{2}H_2O$), it is important to have the different sulfates in the appropriate ratio. If the dissolution of calcium sulfate is too low, then a flash set may occur.[12]

In general, experience has shown that the sulfate content, as SO_3, in clinker should not exceed about 1.5 to 2.0 percent; otherwise, cement-setting problems may occur.

Preheater kiln systems may require a preheater bypass system to lower the calcium sulfate in the clinker to an acceptable level to maintain good quality cement. When a bypass system is used, some of the sulfur will exit as gaseous SO_2 in the bypass gases and as sulfates in the bypass dust.

Wet process kiln systems and long dry kiln systems typically have limited control on the sulfates content in clinker. By increasing the burning zone temperature and lowering the kiln exit gas oxygen content it may be possible to lower the sulfates content in the clinker by increasing the SO_2 emissions from the kiln. This is usually not acceptable because of environmental concerns.

5. Fuel Change Impacts on the Cement Kiln System

This section discusses some of the fuel change impacts on the cement kiln system caused by a change of the fuel chemical properties and burning characteristics.

5.1. Optimum Combustion Characteristics

When considering a fuel change, it is important to take steps to maintain optimum combustion characteristics and good fuel burnout in the kiln and calciner. Optimum combustion characteristics in a cement kiln system provide the lowest specific fuel consumption and highest production which occur with the hottest flame possible while maintaining good refractory life and acceptable emission rates. Good fuel burnout is required to maintain low emission levels of carbon monoxide (CO) and to avoid carbon in the fuel from entering the kiln charge and creating local reducing conditions.

Optimum combustion characteristics and a high level of fuel burnout is typically ensured in the design of a system by the appropriate selection of fuel fineness, burner design and the calciner design of precalciner kiln systems. In the operation, the combustion characteristics can be improved by an increase in the oxygen concentration in the combustion zone.

5.2. Fuel Fineness

Determining the appropriate fuel fineness during the design phase is important since it affects the grinding system design and capacity. Fuel fineness influences the rate at which the fuel particles are exposed to oxygen. Finer fuel particles increase the surface area available for reaction with oxygen, which increase the reaction speed and hence, the combustion rate.

Experience shows that the recommended fineness of coal for firing in cement kiln systems is related to the volatile content of the coal. The lower the volatile content, the finer the solid fuel has to be ground. Table 12, Solid Fuel Fineness, provides typically recommended fineness for burning coal and petroleum coke in cement kilns and calciners. During actual operation, the kiln operator can adjust the fuel fineness to optimize the combustion.

Table 12, Solid Fuel Fineness

| Description	Coal	Petroleum Coke
Volatile content % mass (dry, ash free)	30	12
Kiln burner fuel fineness (% retained 90 micron)	20	5 to 7[13,14]
Calciner burner fuel fineness (% retained on 90 micron)	10	3 to 5[15,16]

5.3.   Burner Design

Determining the appropriate burner design for the new fuel is important to ensure good fuel and oxygen mixing which is required for good combustion. In cement kilns, the preferred burner has flame-shaping capabilities that provide the ability to control the fuel and air mixing and has the ability to minimize primary air. Typically, minimizing primary air will improve the fuel efficiency of the cement kiln system by replacing the primary air with hot secondary air. Typically, these burners require an indirect solid fuel firing system.

5.4.   Calciner Design and Modification

Before discussing steps to control combustion in calciners, it is appropriate to review the three basic types of calciners that exist, the "total flow" calciner, the "tertiary air flow" calciner and the "hybrid" calciner. Figure 1, Calciners, provides typical layouts of these calciners.

Figure 1, Calciners
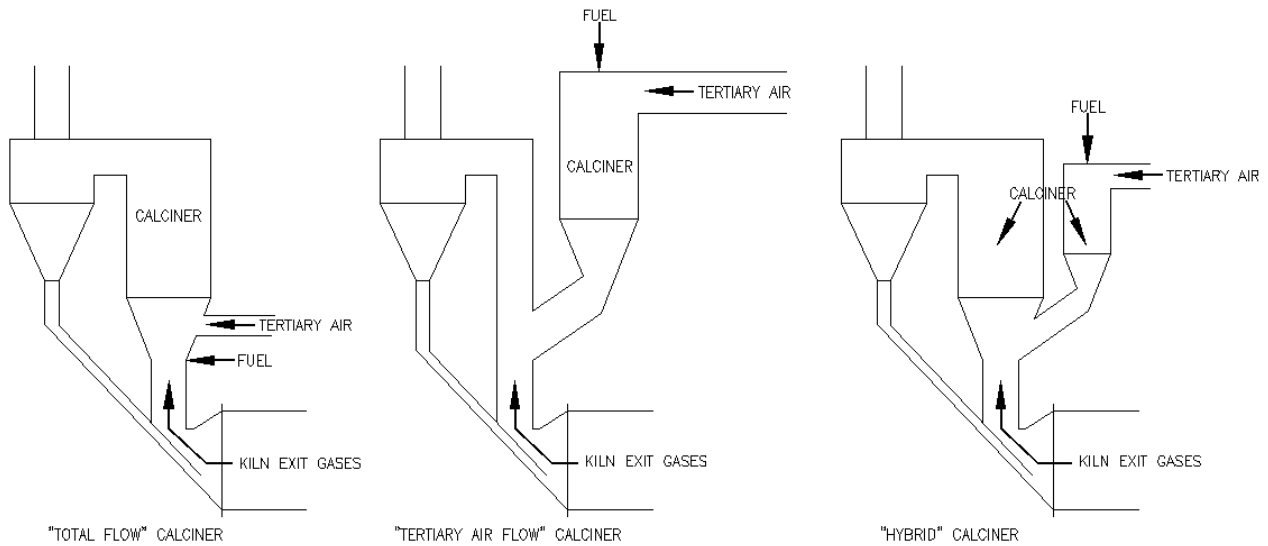
In total flow calciners, combustion takes place in a mixture of kiln exit gases and tertiary air. Combustion therefore starts in gases with about 10 to 14 percent oxygen and ends in about 1 to 3 percent oxygen. Although not shown in figure 1, raw meal from the preheater 2nd lowest stage is fed into the bottom of the calciner and is conveyed through the calciner to the lowest stage cyclone by the calciner gases. During this time, fuel combustion is occurring and transferring heat to the raw meal causing calcination.

In tertiary air flow calciners, combustion takes place in air. Combustion therefore starts in gases with 21 percent oxygen and ends in about 1 to 3 percent oxygen. Although not shown in figure 1, raw meal from the preheater 2nd lowest stage is fed into the calciner at the fuel burner end. The raw meal is conveyed through the calciner to the bottom stage cyclone by the calciner gases. During this time, fuel combustion is occurring and transferring heat to the raw meal causing calcination.

Hybrid calciners are essentially a combination of the total flow calciner and the tertiary air flow calciner. In hybrid calciners, combustion starts in tertiary air similar to tertiary air flow calciners and is completed in a mixture of kiln vent gases and tertiary air similar to total flow calciners. Combustion therefore starts in gases with 21 percent oxygen and ends in about 1 to 3 percent oxygen. Although not shown in figure 1, raw meal from the preheater 2nd lowest stage is fed into the calciner at the fuel burner end and into the kiln riser duct. The raw meal is conveyed through the calciner and riser duct to the bottom stage cyclone by the calciner gases and kiln vent gases, respectively. During this time, fuel combustion is occurring in the calciner and transferring heat to the raw meal causing calcination.

The gas temperature at the exit of the three types of calciners is kept around 870 to 900°C which is required for calcination of limestone (decarbonization of $CaCO_3$ to CaO and CO2) and yet low enough to avoid forming clinker in the calciner.

Total flow calciners and hybrid calciners have an advantage that they can create a reducing zone in the kiln vent gases which reduces nitrogen oxides, NOx, generated in the cement kiln. Tertiary air flow calciners and hybrid calciner have an advantage that combustion starts in an atmosphere with 21 percent oxygen, which is favorable for hard-to-burn fuels. In addition, tertiary air flow calciners and hybrid calciners can operate with an increased temperature in the combustion zone of the calciner, which is also favorable for hard-to-burn fuels. The required calciner volume of tertiary air flow calciners for a particular application is less than the volume required for total flow calciner and hybrid calciners. This is due to several reasons, including the reason that the kiln vent gases do not pass through the calciner.

Table 13, Calciners, summaries the some of design features of the three basic types of calciners.

Table 13, Calciners

Total Flow Calciner	Tertiary Air Flow Calciner	Hybrid Calciner
• Combustion occurs in kiln vent gases mixed with tertiary air (10 to 14% O_2) • Combusion gas temperatures of 870°C to 900°C	• Combustion starts in tertiary air (21% O_2) • Combustion gas temperatures of 870°C to 1100°C	• Combustion starts in tertiary air (21% O_2) and then mixes with kiln vent gases • Combustion gas temperatures of 870°C to 1500°C (localized)
• Low NOx arrangement available	• Smallest calciner vessel • Best suited for hard-to-burn fuels	• Low NOx arrangement available • 2nd smallest calciner vessel • Better suited for hard-to burn fuels

In general, a fuel change from one fuel to a harder-to-burn fuel will require modifications to the calciner operation and design. This following section describes some potential modifications as they relate to existing calciners.

5.4.1. Situation 1

Situation 1 occurs when the existing plant has a total flow calciner.

Option 1a is to increase the retention time of the total flow calciner by increasing the volume of the calciner vessel. Increased retention time provides additional time that is essential for fuel burn out.

Option 1b is to convert the existing calciner to a hybrid calciner, and in some cases, lengthening the existing total flow calciner also. This option has the advantage that it provides the ability to increase the temperature of combustion in the "tertiary air flow" section of the calciner. The increased temperature of combustion will increase the combustion rate of slower burning fuels. The increased combustion rate will reduce the required retention time for combustion. For example, the typically recommend retention time for petroleum coke in a total flow calciner is about 7 seconds while in a hybrid calciner it is about 4.5 seconds.

5.4.2. Situation 2

Situation 2 occurs when the existing kiln system has a tertiary air flow calciner.

Option 2a is to increase the retention time of the total flow calciner by increasing the volume of the calciner vessel. Increased retention time provides additional time that is essential for fuel burn out.

Option 2b is to increase the combustion temperature in the tertiary air flow calciner. This can be done by directing some of the raw meal that normally enters the tertiary air flow calciner near the burners to the kiln riser duct or to a location near the exit of the calciner. This option, in some cases, is an operational change of the existing calciner only. This option provides limited improvement of combustion, however, in some cases, it may be sufficient to satisfy the plant's requirements.

5.4.3. Situation 3

Situation 3 occurs when the existing kiln system has a hybrid calciner.

Option 3a is to increase the retention time of the hybrid calciner by increasing the volume of the calciner vessel. Increased retention time provides additional time that is essential for fuel burn out.

<u>Option 3b</u> is to increase the combustion temperature in the hybrid calciner. This can be done by directing some of the raw meal that normally enters the calciner near the burners to the kiln riser duct or to a location near the exit of the calciner. This option is an operational change of the existing calciner only. This option provides limited improvement of combustion, however, in some cases, it may be sufficient to satisfy the plant's requirements.

5.5.   Increase Oxygen Concentration In The Combustion Zone

Combustion characteristics can be improved by an increase in the oxygen concentration in the combustion zone, which will increase the combustion speed. Oxygen concentration in the combustion zone of the kiln and calciner can be increased to a limited extent by increasing the excess air percentage, for example, from 10 to 15 percent excess air.

Another possible method is to use oxygen enrichment in the kiln or calciner. Oxygen enrichment is achieved by introducing oxygen into the kiln or calciner with a lance. Oxygen enrichment will have other positive effects such as increased clinker production. In the past, the main reason to use oxygen enrichment was to increase capacity of the kiln system.[17]

The impact of increased oxygen can be substantial; for example, methane has a fundamental burning velocity of 45 cm/sec in air and 450 cm/sec in oxygen.[18]

5.6.   Material Build-up in Preheater Kiln Systems

When considering a fuel change in preheater kiln systems, it is important to consider the potential effects of the fuel chemical composition on material build-ups in the kiln system. The main chemical elements that cause material build-up in cement kiln systems are chlorine, sodium, potassium and sulfur. These components evaporate in the hotter areas such as the burning zone and condense in the cooler areas of the cement kiln system such as the walls in the preheater tower and kiln feed end. These condensed components generate material build-ups that cause increased pressure drops in the preheater tower and material blockages.

Typically, the material build-ups are more pronounced when the molar ratio of sulfur-to-alkali is not balanced in the kiln feed end area. Alkali referred to in this ratio is the alkali that is available to react with sulfur. High sulfur-to-alkali molar ratios tend to generate sulfate buildups in the kiln feed end area. Low sulfur-to-alkali molar ratios tend to generate alkali buildups in the kiln feed end area.

Adding a raw meal "curtain" near the kiln feed end can reduce material build-ups in preheater kiln systems. Feeding a portion of the raw meal from the second lowest cyclone to the feed end housing produces the raw meal curtain. The raw meal curtain quenches the kiln vent gases, hence the volatile elements, by absorbing heat from the kiln vent gases to calcine the raw meal curtain.[19]

Figure 2, Raw Meal "Curtain"
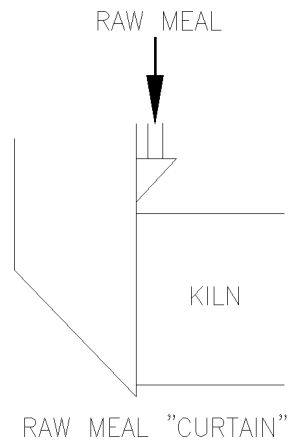
Another possible measure to reduce the material build-up problems is to install air cannons in the affected areas of the kiln system such as the kiln feed end housing.

These measures, when taken, will allow more of the negative contributor such as high sulfur petroleum coke to be burned. Petroleum coke, with a high sulfur content, typically will contribute to a high sulfur-to-alkali ratio that may cause sulfur buildups.

6. Fuel Change Impacts on the Fuel Preparation Equipment

This section describes some options for the fuel preparation system that will allow a plant to fire new fuels. Depending on the type and extent of the fuel change, several options exist for the fuel preparation equipment that may be economically justifiable.

Before discussing options for the fuel preparation system, it is worthwhile to review the different types of mills available.

6.1. Mills

Several different types of mills are used to grind coal and petroleum coke; however, the most commonly used in the cement industry are vertical roller mills and ball mills. Table 14, Vertical Roller Mills Versus Ball Mills, provides a list of commonly accepted advantages and disadvantages of vertical roller mills as compared with ball mills.

Table 14, Vertical Roller Mills Versus Ball Mills

Advantages Of A Roller Mill Versus A Ball Mill	Disadvantages Of A Roller Mill Versus A Ball Mill
• Lower energy consumption • Higher drying capacity • Wider range of output capacity • Faster feed-output changes • Accepts larger feed sizes • Lower noise level • Requires less space for installation	• Less suitable for abrasive feeds (Wear parts are expensive and replacement causes downtime) • Sensitive to variations in feed rate and feed quality • Higher maintenance costs

Based on table 15, the vertical roller mill is the preferred mill for most applications; however, some precautions are necessary when selecting a mill. Experience has shown that the best way to select a vertical mill for grinding petroleum coke is to perform tests on the petroleum coke in a vertical mill. The Hardgrove Index, which is commonly used to describe the grindability of coal, does not provide sufficient data for sizing a vertical mill for grinding petroleum coke.[20] Another precaution is to determine whether a vertical roller mill is the best application for the new fuel. Some vertical roller mills may not be suitable for grinding some petroleum cokes, for example, fluid coke and flexicoke, which typically has a ball-shaped form with about 93 percent smaller than 2380 μm (8 mesh). These types of petroleum coke are not typically suitable for grinding in some vertical roller mills since they tend to make the mill operation rough.

6.2. Fuel Preparation System Options

Numerous options for the fuel preparation system exist when considering a fuel change. The preferred option for a plant will depend on many factors such as the extent and type of fuel change and whether or not a grinding system exists. This section presents some situations and options that are available to the plant when considering a fuel change.

6.2.1. Situation 1

Situation 1 occurs when a plant has an existing coal grinding and firing system and would like to supplement coal with petroleum coke. The intent is to grind the mixture of coal and petroleum coke in the existing solid fuel grinding system without adding a new grinding system or firing system. This situation has several potential options.

Option 1a is to blend coal with petroleum coke before feeding the existing coal grinding system. This alternative has the lowest capital cost expenditure associated with it among all options. Typically, coal and petroleum coke are intermixed by storing the two fuels in separate storage piles, reclaiming them in a predetermined ratio, and storing them in a small pile. The mixed fuel pile is then fed into the existing dump hopper feeding the existing coal mill system.

One of the disadvantages of this option is that it is limited by the existing grinding system capacity. Another disadvantage is that the fuel mixture is seldom mixed properly resulting in the undesirable effect of varying the heat, sulfur and ash inputs into the kiln system. The

varying heat input to the kiln will result in a higher heat consumption, reduced refractory life, and increased downtime.

Option 1b is the same as option 1a with the addition that it considers a replacement of an existing static classifier with a dynamic classifier, which will increase the grinding capacity of the system. This change usually results in about 10 to 15 percent more capacity at the same fineness or the ability to grind the fuels finer.

Option 1c is the same as option 1a with the addition of a separate petroleum coke feed bin and weigh feeder to meter the petroleum coke along with metered coal into the mill. This will reduce the heat, sulfur and ash input variation to the kiln.

Option 1d is the same as option 1a with the addition that it includes the modifications of option 1b and 1c.

6.2.2. Situation 2

Situation 2 occurs when a plant has an existing coal grinding and firing system and would like to supplement coal with petroleum coke. However, unlike situation 1, the intent is to supplement the existing grinding capacity with a new grinding system.

Option 2a is to install a new grinding system with the grinding capacity to burn 100 percent petroleum coke in the kiln burner. This situation offers the advantage of burning different

mixtures of fuels in the kiln and calciner, which provides the ability to maximize the petroleum coke consumption without necessarily modifying the calciner.

6.2.3.   Situation 3

Situation 3 occurs when the existing plant does not have a solid fuel grinding system and would like to supplement or replace the existing fuel with either coal, petroleum or a mixture of both. In this case, a new grinding system is required.

Option 3a is to install a new grinding and firing system with the capacity designed to meet the plant desired solid fuel grinding rate, which may be 100 percent of the heat requirements of the kiln system. This option has the highest capital cost expenditure associated with it among all options.

7. Safety Considerations

When considering a fuel change, it is advisable to consider the safety aspects and requirements of the new fuel. Coal is significantly more dangerous to handle than the other fuels including petroleum coke because of its low ignition temperature and its auto-ignition potential while stored. Several good references and guidelines are available for design solid fuel preparation and firing systems such as the U.S. National Fire Protection Agency (NFPA) codes and the U.S. Portland Cement Association publication "Recommendation Guidelines for Coal System Safety."

8. Summary

This paper has shown several considerations that are important when considering a fuel change including the potential impacts on cement quality, on kiln design and operation, and on the grinding and firing system. Some of these impacts may limit the extent of the fuel change. The economic feasibility of a fuel change varies from one plant to the other; therefore, the economic feasibility of a fuel change must be evaluated separately for each plant.

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