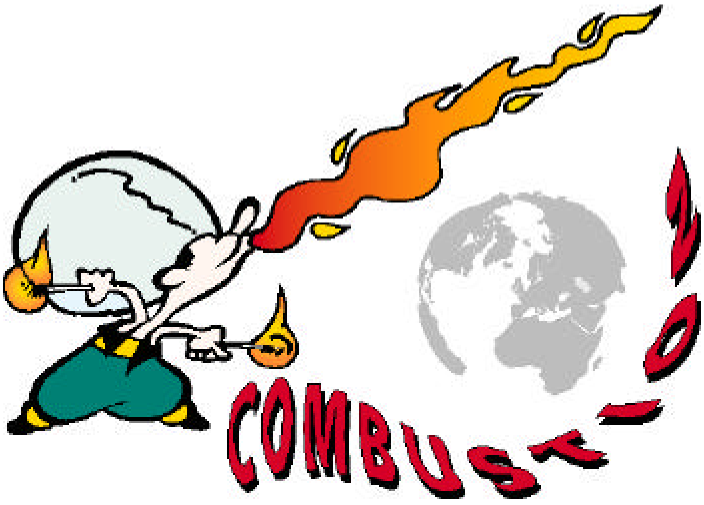
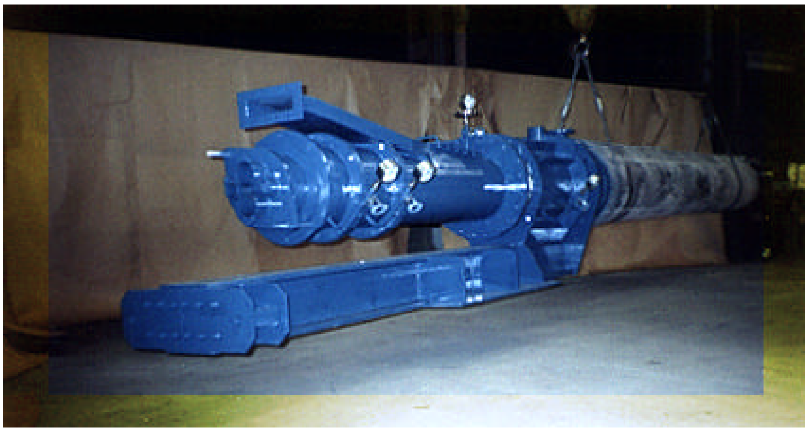


Combustion Manual



LAFARGE

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1. OBJECTIVES

Burning control is possible; some plants have proved it.
Means are available and easily accessible to any professional in good standing.

What are the means that must be used to control burning?

- a uniform raw mix,
- fuels well prepared (fineness) and well fed,
- a well centered and controlled flame.

Combustion control pays off. This has been observed in several plants.

What are the benefits of combustion control?

A better burning uniformity

A better burning uniformity means :

- stable burning without overburning,
- regular clinker quality,
- optimized operation of the cooler,
- a better refractory performance.

More flexibility in the selection of fuels

Taking all the opportunities to use less expensive fuels represents important economical savings. These fuels may be high-sulfur cokes, various residues, tyres, and sometimes we can get paid to burn them.

A better clinker reactivity

Burning control produces a shorter and hotter flame allowing the obtention of more reactive clinkers. They are easier to grind and can take higher volumes of additions leading to more or less important savings.

An easier compliance to environment regulations

A short and regular flame minimizes NOx emissions and reduces SO_2 emissions contributing to a better environment and to meeting the environment standards that become increasingly more demanding.

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2. MAINTAINING A UNIFORM RAW MIX

Maintaining a uniform raw mix is basic to any burning optimization. Its importance did not go unheeded since one of the themes of the first Technical Plan dealt with raw mix composition.

The importance of raw mix uniformity was emphasized in 1996 in the Technical Doctrines that included a theme on raw mix. It was written:
"Raw mix quality governs the technical and economical performances of the production process as well as the quality of the finished product".

Raw mix uniformity is a prerequisite to any burning optimization.

Three criteria govern raw mix control:

- **chemical composition**,
- **uniformity**,
- **fineness**.

2.1 Raw mix composition

Except in properly identified cases, aiming at least 60% C_3S (*) is necessary to obtain a reactive clinker. But it is not sufficient. The raw mix must also be adjusted to preferably obtain C_3A, which is more reactive, rather than C_4AF.

A silica modulus between 2.4 and 2.6 and a liquid phase between 22 and 24% (1450º C) make the raw mix easier to burn and contribute to burning stability.

Secondary raw materials (SRM) should be used as much for improving the chemistry as for economical balance.

2.2 Raw mix uniformity

The method used to measure raw mix uniformity is the KFUI measured in C_3S. Its value must be lower than 14.

Obtaining a KFUI lower than 14 (*) is a requirement but not sufficient to guarantee, in all cases, a uniform raw mix. In particular, the uniformity of the silica modulus (SM) and ferroalumina (F/A) must be controlled.
The conditions under which kiln dust returns to the feed can have a very important impact on uniformity, in particular in case of a shutdown of the raw mix mill.

(*) Calculated from the raw mix analysis brought to zero loss on ignition.

Changing the prehomo stockpile is an important factor regarding raw mix uniformity.

It is also necessary in order not to destabilize burning to insure the uniformity of:

- raw mix fineness,
- kiln feed flow.

2.3 Raw mix fineness

Raw mix rejects:

- **200 µm : < 1 %,**
- **100 µm : < 10 %,**

generally contribute to good burning quality.

2.4 Conclusions

Failure to meet these prerequisites leads to a loss of the expected profitability, increases risks on the refractory life and is harmful to the combustion optimization credibility.

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3. FUELS

The available fuels on the local market vary a great deal and are different from plant to plant. The behavior of the different fuels varies a great deal and the applicable rules for their use should be adapted case by case.

It is therefore necessary to have equipment that are as multi-fuel as possible with adjustments adapted to the fuel used (Lafarge burner pipe…).

Fuel constraints are related to :

Chlorine

Disturbances linked to chlorine volatilization are not presently controlled. Hence the amount of chlorine entering the kiln must be limited (fuel, raw mix). As soon as the chlorine content exceeds the equivalent of 300 g/t of clinker, a by-pass should be installed.

Sulfur

Sulfur is controllable. However when the sulfur alkali ratio exceeds 1.2, the following should be envisaged:
- use of special equipment (fuel feed and Lafarge burner pipe),
- adapting impulse and swirl,
- appropriate instrumentation,
- ...

Volatile materials

Solid fuel volatile materials vary in general from 10 to 45%.
Below 10%, additional combustion problems will have to be faced.
Above 25%, increased safety risks emerge.

LHV

Today there is general agreement that it is not possible to keep the nominal kiln flow if the burner pipe average LHV drops below 20,000 kJ/kg.

3.1 Solid fuels

There are two types of solid fuels :
- coal,
- petroleum coke.

3.1.1 Coal

Coal distribution in the world insures enough supply for a long time and a «coal crisis» should not be of concern.

There are several kinds of coal used in cement production:
- charcoal (moinha),
- lignites with volatile matter contents ranging from 25 to 45%,
- high quality coals (flaming…).

The coal Hardgrove hardness varies between 40 and 110 and the LHV between 23,000 and 29,000 kJ/kg based on the ash and volatile matter content.

3.1.2. Petroleum coke

Petroleum coke is a residue from the oil industry. Its cost is a function of its sulfur content.

There are:
- delayed coke, the most commonly used in cement production

Hardgrove index	*: 60 - 70 (less representative for coke than for coal)*
% ash	*: 0.5 to 1.5%*
VM	*: 8 to 15%*
LHV	*: 34,500 to 35,000 kJ/kg*
S	*: 2 to 8%*
Cl	*: 0.01 to 0.02%*

- Fluid coke, very hard and very little used in cement production,
- Shot coke, hard to grind, is found as impurity in delayed coke.

Sulfur contained in coke increases the kiln sulfur load. The volatilization control obtained by the Group should allow us to select everywhere less expensive high-sulfur coke.

3.2 Liquid fuels

On the market can be found:
- standard bunker oils,
- other heavy refinery by-products usually containing more sulfur (vacuum and visco-reduction residues).

Liquid fuels should be reheated and fed to the burner at such a temperature that their viscosity is not higher than 25 cSt. Pressure should be adapted to the type of pulverization.

It is necessary to correctly filter fuels to insure adequate pulverization (two or three-stage filtration at 500, 250 and then 125 μm).

3.3 Substitution fuels

Substitution fuels mean industrial domestic or miscellaneous wastes.

Except in special cases, waste combustion creates process disturbances because of:
- water content, chlorine content, poorly adapted viscosity,
- too coarse or badly controlled grading at the plant,
- irregular supplies both in quantity and quality.

Three types of waste can be distinguished:
- liquid waste: solvents, washing waste, drain oil, ...,
- solid waste: tyres, car residues, ...,
- pasty waste: various sludges (paints, …).

Cement kilns are well adapted for waste destruction because of the treatment duration at high temperature and the basic nature of the material in the kiln.

However, the combustion method is related to the type of waste:
- liquid wastes are often injected through the burner pipe after being properly prepared (homogenization, filtration),
- solid wastes are injected depending on the situations through the burner pipe or at the upstream end of the kiln,
- pasty wastes are presently introduced at the downstream end of the kiln by means of a special pump (concrete pump).

Introduction of tyres in the kiln

Liquid wastes contribute to limiting the kiln and clinker sulfur load. They can reduce NOx emissions owing to their water and volatile matter content.

The high variability of wastes requires supply, control and storage logistics. Moreover, specific safety problems must be taken into account.

3.4 Flexibility

Flexibility consists in accepting the constraints linked to the use of existing fuels available on the market.

Sometimes there is an opportunity to obtain low-cost but hard-to-use fuels. In such a case, the installations must be adapted to correctly burn this type of products:

- grinding adaptation,
- multi-fuel burner pipe,
- controlled fuel preparation (tyres),
- suitable storage,
- adapted safety measures.

4. SOLID FUEL PREPARATION

The objective of solid fuel preparation is:

- to mix the different fuels in order to obtain a uniform mixture,
- to bring them to a sufficient fineness to insure a rapid and complete combustion in the burner pipe.

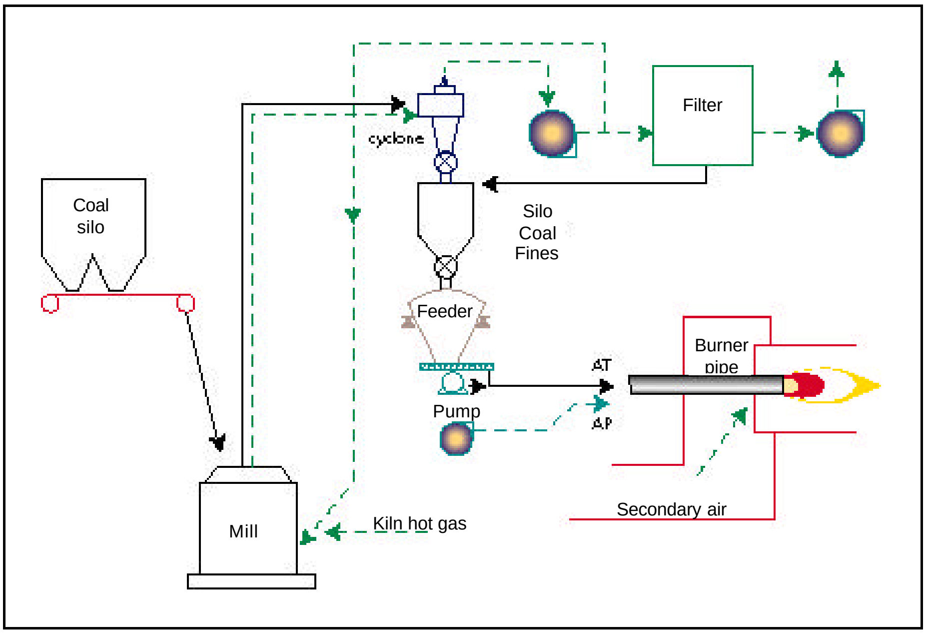
They should be dried simultaneously (at ± 1% moisture) and ground to a fineness consistent with the sulfur/alkali molar ratio (S/A) as shown in the following Table:

		S/A < 1.2	S/A > 1.2
Uniformity of coal/coke mixture		Feed essential, special hoppers and feeders	
Fineness	Passing 70 #	>99%	>99.9%
	Passing 200 #	98 - 0.7% VM	98 - 0.6% VM
Dynamic separator		-	recommended

Note : When the passing 70 mesh are met, the second rule is also usually met.

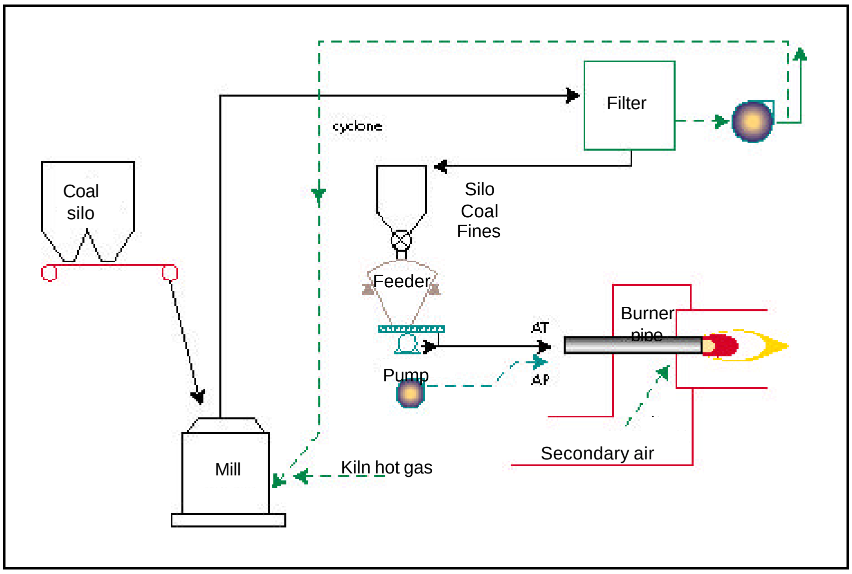
In the case of a precalciner kiln without a separate furnace, the fuel needs sometimes to be ground finer for the precalciner than for the burner pipe to take into account the treatment duration and the temperature which is lower in the burner pipe.

No matter the S/A ratio, the recommended grinding shop is the indirect-firing system.



Indirect firing system

The present trend is to eliminate the intermediate cyclone and to recirculate the gases after filtration.



Indirect system evolution

The indirect-firing system is characterized by the grinding and mill ventilation which are independent from the kiln feed or precalciner owing to:

- an intermediate stockpile of the pulverized fuel,
- the exit to the atmosphere of the clean ventilation and drying (thus avoiding the introduction in the kiln of a large amount of low-temperature primary air).

Some plants are equipped with different systems:

Direct firing

All the gases (or air) for drying and mill ventilation insure the pneumatic conveying of the pulverized fuel, i.e., 20 to 35% of cold primary air.

Semi-direct or semi-indirect firing

Installations corresponding to intermediate systems between direct heating and indirect heating (stockpiling and coal feed using mill gases, or independent primary air, without stockpiling nor fuel feed…).

These heating systems do not allow controlling combustion in a satisfactory manner.

Concerning these more or less outdated systems, the indirect-firing system offers the following advantages:

Possibility of adjusting the combustion with an efficient burner pipe for:

- controlling volatilization phenomena linked to the use of high-sulfur fuels (petroleum coke with 6% sulfur),
- shortening the burning zone which is favorable for a better combustion and the production of more reactive clinkers,
- reducing the heat consumption estimated at 100 to 150 kJ/kg depending on the type of kiln.

5. FUEL FEED

5.1 Solid fuels

To ensure stable and regular burning, a stable coal flow in the burner pipe as well as in the precalciner is essential. The target flow must be stable within ± 1%. The actual flow must be known and in new installations or extensive renovations, the actual flow should be measured.

5.2 Fuel feed

Three feed systems are used in the Group's plants:
- Pfister,
- Schenck,
- Pillard.

The Table below provides a comparison between the different systems:

	PFISTER	SCHENCK	PILLARD
Anti-bridging silo	No	No	Yes
Extraction aid	Fluid air	Clod breaker + air	Rotary arm
Intermediate weigh hopper	Required to regulate the feed and calibrate the electronics	No, weigh hopper Risk sometimes of lack of control of extraction uniformity	Yes, the weight loss reliability for calibration is in the process of being determined
Flow adjustment mechanism	Rotary air lock integrated at the base of the silo	Large-size rotary air lock	High-speed screw (400 – 450 t/min.)
Flow meter	Permanent air lock weighing with electronic adjustment of air lock velocity	Coriolis effect	Weight-loss calibration of a Coriolis (*) - effect flow meter
Electronics	Supplier (black box)	Supplier (black box)	Commercial
Wear	Sensitive issue, maintenance requires an excellent tooling precision	Coriolis: very tough air lock: yet to be observed	The past performance of the high-speed screw is reassuring; easy maintenance

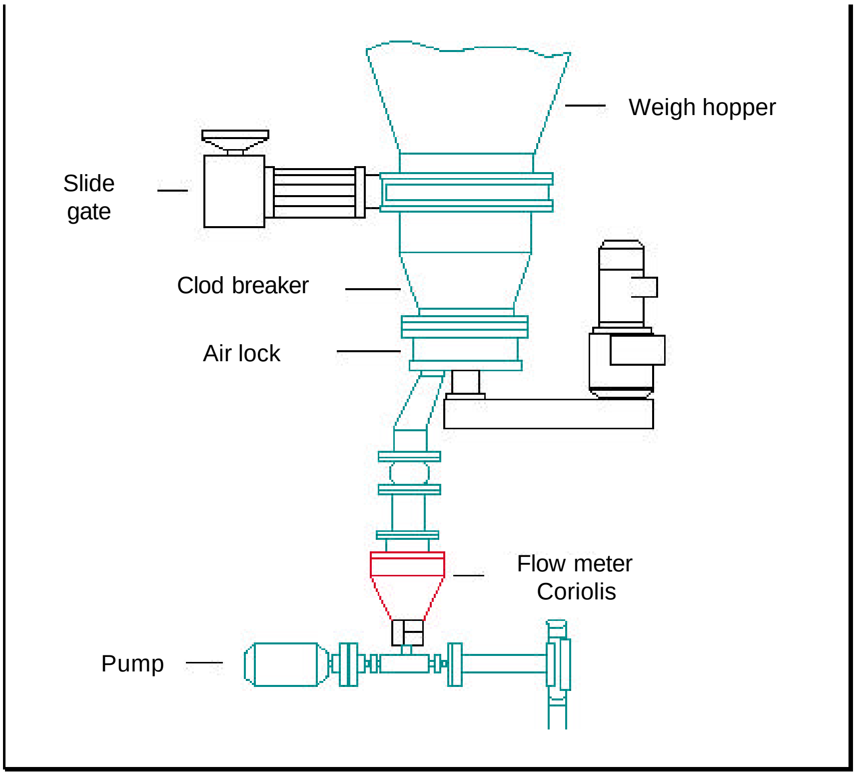
Comparison of different systems

** At Darica, the pneumatic conveying of the coal is by pump with a significant DP, over a distance of 80 m and it has been possible to calibrate the conveying pressure but this method requires frequent calibrations.*

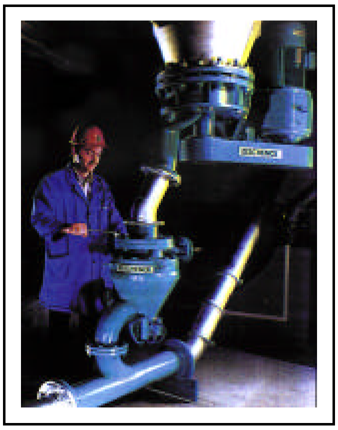
Schenck System

The system consists of:
- weigh hopper,
- air lock at the base of the silo above a clod breaker,
- Coriolis-effect flow meter.

The fuel is conveyed to the burner pipe:
- either by an ejector,
- or a coal pump.



Schenck system



Coriolis

Pfister system

It is a feed system consisting essentially of:
- weigh hopper silo,
- coal (or coke) chute feeding the air lock cavities,
- large-diameter vertical axis rotary air lock with adjustable speed,
- coal ejection from the cavities after an approximate 270° rotation,
- *the air lock is scale-mounted, the weight is representative of the filling rate of the cavities,*

- flow regulator (black-box type) permanently adjusting the air lock speed based on its weight.

Intermediate hopper

The installation of an intermediate hopper between the silo and the feed system is strongly recommended for the two systems (Schenck and Pfister) to:

- regulate the feeder,

calibrate the electronics governing the rotating speed of the feeder.

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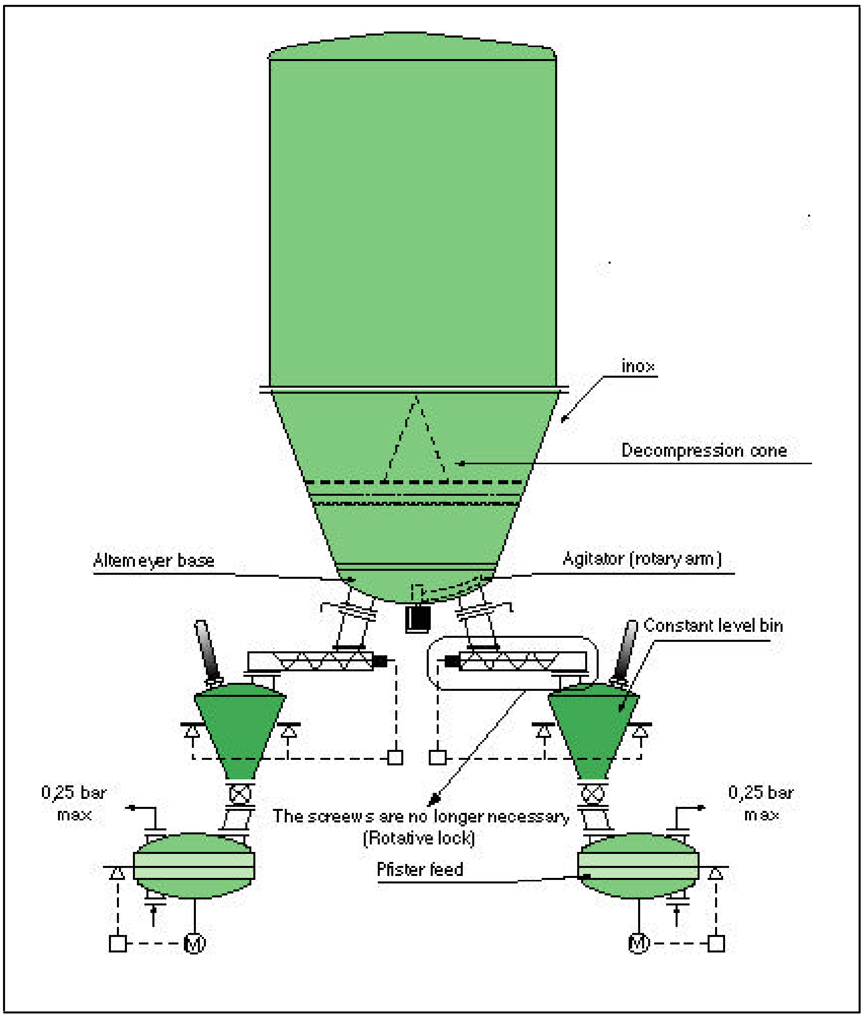
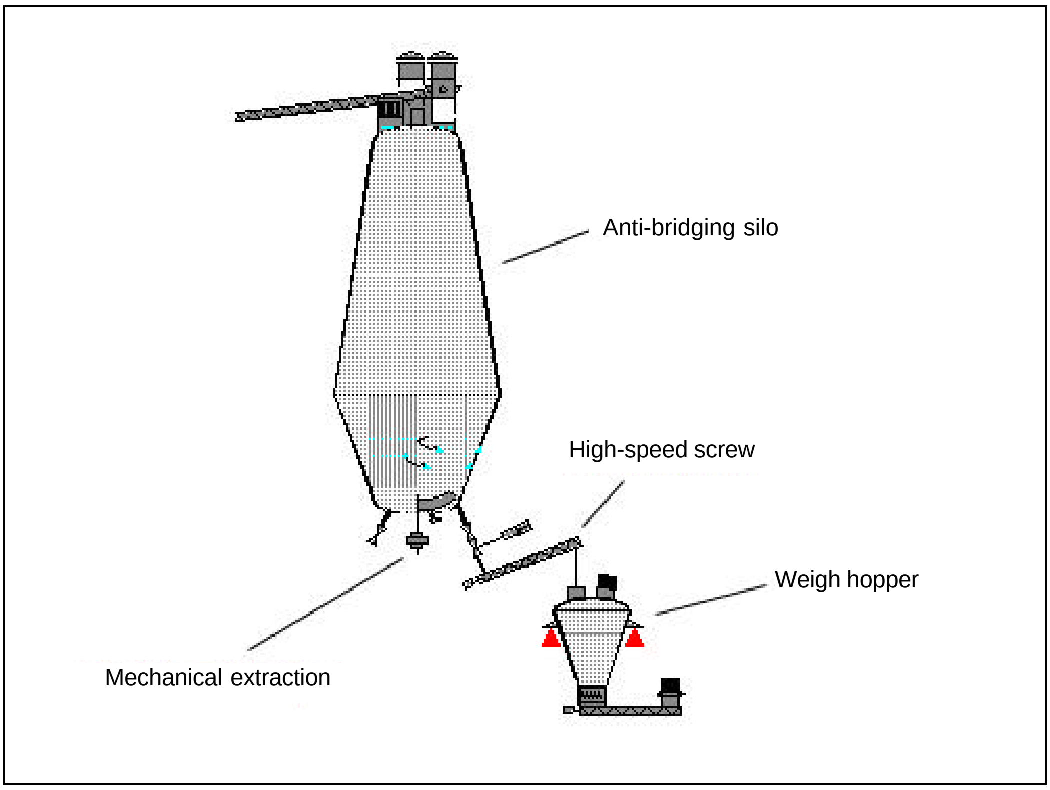


Pfister system

Pillard system

The Pillard system consists of:

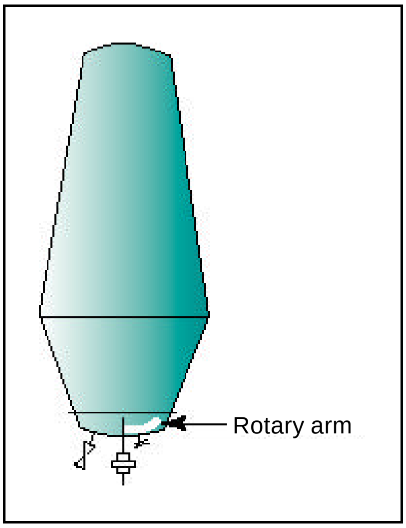
- «anti-bridging» silo avoiding extraction difficulties when moisture is not perfectly controlled,
- intermediate constant-level hopper between silo and feed to regulate the feed system flow (PID control),
- high-speed screws avoiding any flushing phenomenon and used as flow adjustment mechanism instead of air locks to limit flushing risks linked to a premature wear of the air lock rotors.



Lafarge Feed System

Fuel stockpiling

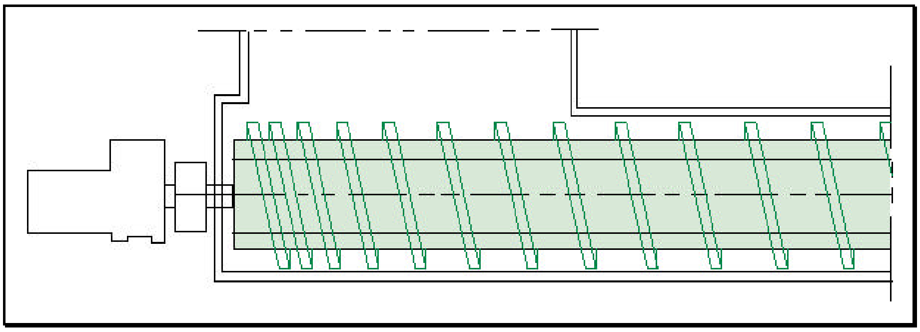
The regular outflow of the pulverized-coal silo governs the feed accuracy. The Matozinhos experiment tends to favor the anti-bridging silo. The latter consists of two frustrums with the lower part made of inox steel or ordinary steel covered with a teflon epoxy paint.



anti-bridging silo

A mechanical agitation (rotary arm) at the base of the silo facilitates the extraction; fluidization is not recommended to prevent safety problems.

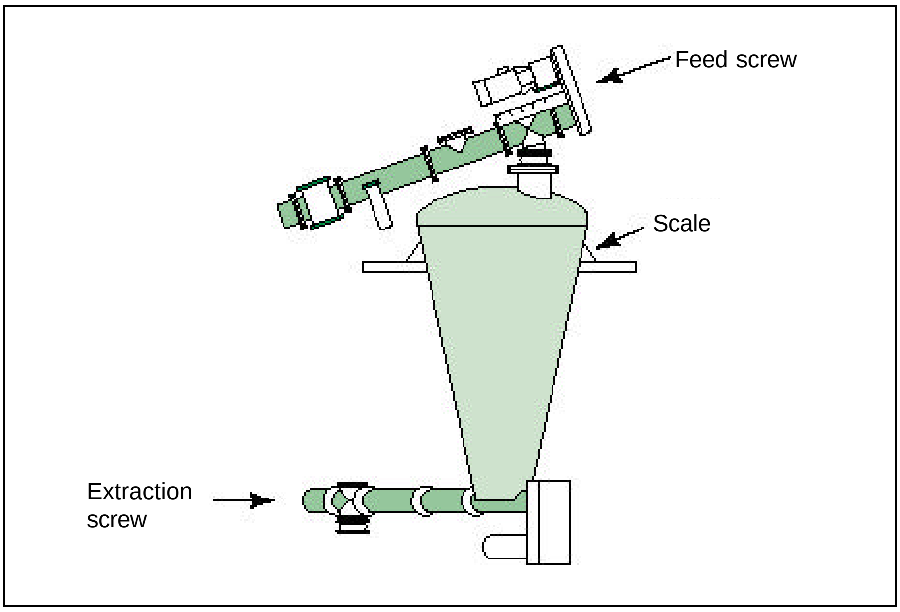
Extraction with a Bremer-type high-speed screw which prevents flushing is advised, however, a rotary air lock may be considered.



high-speed screw

Weigh hopper and feed

The intermediate hopper downstream from the silo insures the flow uniformity owing to its reduced volume and its elaborate extraction system (progressive control of the fuel).



weigh hopper

It is fed by a high-speed screw (Bremer-type) but a good quality air lock is also possible; the screw speed is submitted to the hopper weight (PID).

The hopper is designed to avoid any fuel sticking to the walls (interior teflon epoxy-based paint).

At the base of the hopper there is:
- a clod breaker insuring homogeneity of the feed screw,
- a high-speed feed screw to regulate flow (Bremer type screw).

Flow measurement

Several instantaneous flow measuring systems are in competition nowadays:

- Coriolis-effect (Schenck) flow meter	:	validated,
- Feed pressure measurement	:	must be calibrated several times daily,
- Impact plate	:	not recommended,
- Granucor feeder (capacitive)	:	to be proscribed.

All instantaneous flow sensors must be calibrated. The intermediate hopper weight loss presently constitutes the best solution for the calibration.

Fuel conveying

The fuel velocity should be:
- sufficient to prevent deposits and pulsations causing CO peaks,
- but not too high to limit abrasion, in particular in elbows and the burner pipe inlet.

The distances between the feeder and the burner pipe should be reduced, the number of elbows limited and ascending non-vertical parts should be avoided.

The fuel concentration in the conveying air should be the highest possible (NOx limitation). It should be adapted to the existing systems.

With a pump, a coal concentration of 7 kg/m^3 is foreseeable.

With the Pfister system, the conveying line pressure drop limits the coal concentration.

Velocities currently used at the burner pipe tip:
- above 25 m/s for lines less than 50 m and for conveying concentrations lower than 3 kg/m^3,
- above 30 m/s beyond 3 kg/m^3.

The start-up velocity of the conveying line should never be less than 20 m/s and should be increasing up to the burner pipe tip.

5.3 Liquid fuels

The pulverization quality governs good fuel combustion. The optimum combustion factors are:
- viscosity (25 cSt for standard injectors),
- suitable filtration,
- type of pulverizer used.

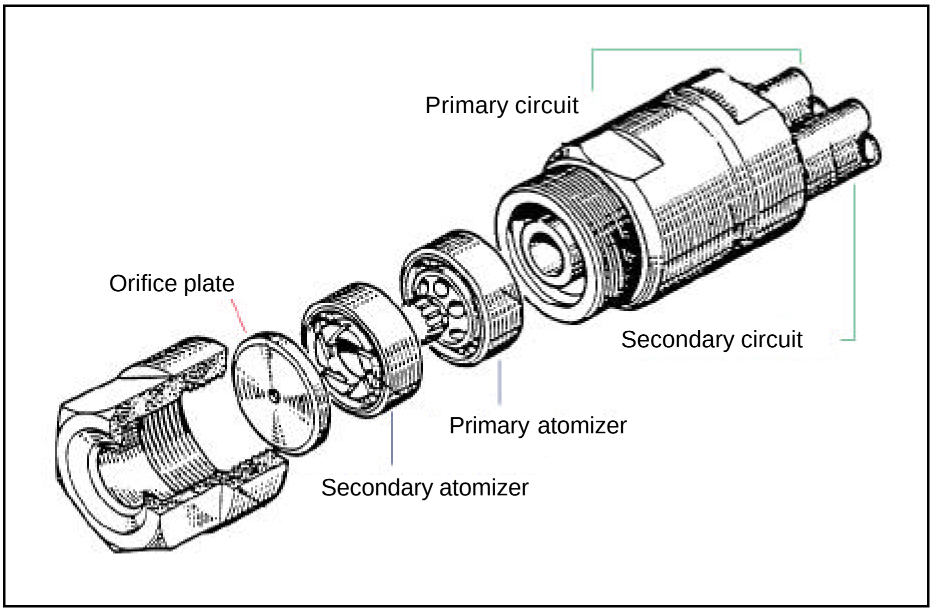
Injectors used should be capable of thoroughly mixing the fuel to the primary air. The pulverized bunket oil jet stream must produce a hollow cone with a divergence adapted to the primary air flow.

Two types of pulverizers are used:
- pressure pulverizers,
- vapor or air-assisted pulverizers.

Pressure pulverizer

For example, the Pillard MY is normally well suited. The flow is adjusted by the fuel pressure and operates adequately for a flow ranging between 80 and 100% of the fuel scale.

If the flow differs, the orifice plate and atomizer should be changed.
The primary / secondary pressure differential allows the adjustment of the divergence angle of the streams jet (optimization).

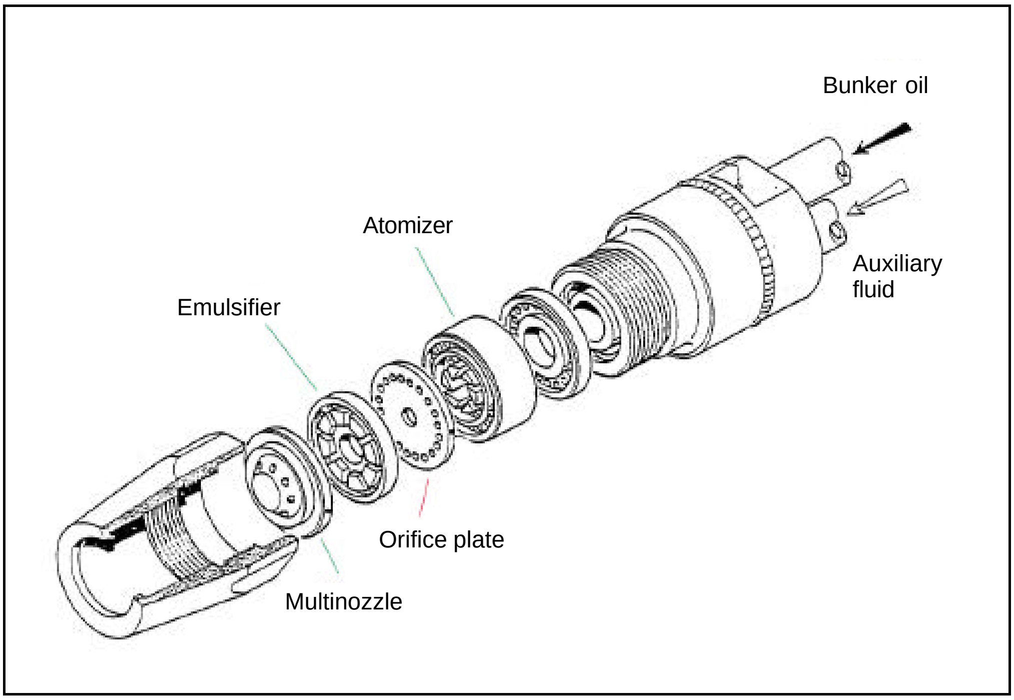


Type MY pressure pulverizer

Assisted pulverizer

Pulverization is assisted either by air or vapor. The possible flow variation is large (1 to 8). Example: Pillard ZV2.

This pulverizer is well adapted to wastes because it allows the instantaneous reestablishment of the desired flow in case of a sudden stop of the waste injection.



Type ZV2 assisted pulverizer

6. COMBUSTION

Combustion optimization usually consists in looking for a short and oxidizing flame well hooked to the burner pipe in order to obtain a clinker which is uniform (sulfate cycle control) and reactive (short burning zone).

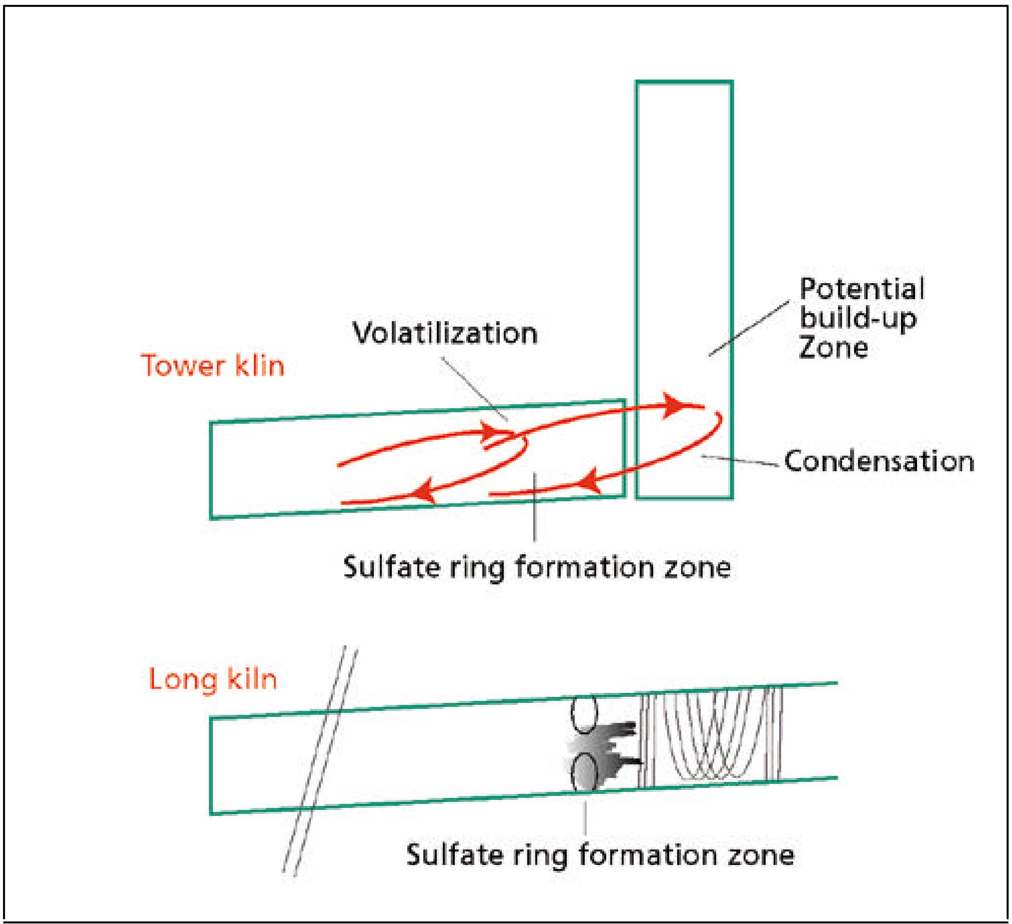
Combustion optimization is a must when using high-sulfur fuels.

Success in a combustion optimization project implies the combination of a number of conditions:
- will-power attitude shared by others,
- defining the objectives, obtaining the means, checking the progress of the work regularly,
- availability of recognized indicators (KSUI, ...),
- control of the prerequisites (raw mix uniformity, …),
- assembling a competent team available for site involvement 24h/24.

Adherence to fuel preparation and feed requirements and the installation of a suitable burner pipe will be conducive to combustion optimization without risks to the refractory or the mechanical performance of the kiln to the extent that the operating staff has been well trained.

The Group's experience has made possible the definition of a number of guide values on impulse, swirl and kiln outlet oxygen. These values should be optimized based on the combustion quality.

6.1 Volatilization problems



Volatilization diagram

Raw mix and fuel carry minor elements (sulfur, alkalies and chlorine) which volatilize in the kiln, condensate on cold areas, thus creating a circulating load of chlorides and sulfates combined to alkalies and eventually to lime forming build-ups that must be destroyed.

Chlorine volatilizes almost entirely (volatilization coefficient > 99%), and condensates in the upper cyclones introducing large material flow disturbances (by promoting the emergence of a liquid phase at low temperature). Combustion optimization has no effect on its behaviour and the induced effects.
As chlorine intakes reach the 300 g/t of clinker level, the installation of a gas by-pass is indispensable for tower kilns.

Sulfur has a volatilization coefficient varying with the nature of the formed salts, the atmosphere and burning temperature.

The principal reactions involving sulfur, alkalis and limestone:

- $K_2O + SO_2 + 1/2O_2 \iff K_2SO_4$,
- $Na_2O + SO_2 + 1/2O_2 \iff Na_2SO_4$
- $CaO + SO_2 + 1/2O_2 \iff CaSO_4$.

The lime reaction with sulfur is produced in a significant way when the S/A molar ratio < 1.

$CaSO_4$ is much more unstable under burning atmosphere and temperature than K_2SO_4 and Na_2SO_4, wherefrom the different plant sensitiveness to volatilization problems based on the S/A molar ratio:

- S/A < 1.2, very few volatilization problems,
- S/A > 1.2, potential volatilization problems if combustion is out of control.

The literature abounds of volatile element balances, modelization and the interested reader can refer to the bibliography.

6.2 Burner pipes

The purpose of the burner pipe is to inject the fuel in the kiln, insure mixing with secondary air and define the flame shape.

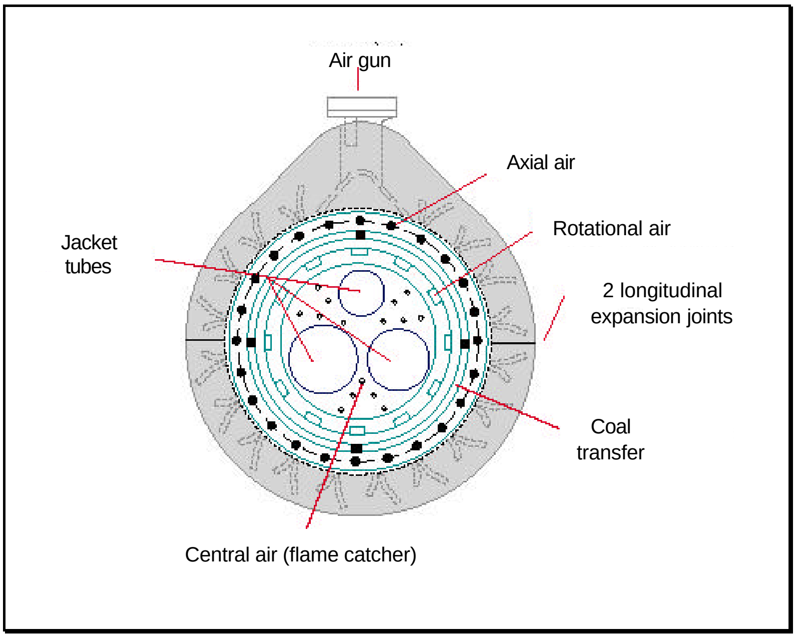
6.2.1 Flame position and shape

The flame must be centered along the kiln axis. Flame centering is obtained by adjusting the burner pipe with respect to the carriage.

This is to prevent the flame from licking the material load and causing over volatilization of the sulfur and alkalies bound to unburnt coal particles, locally producing a reducing atmosphere.
It has been shown that volatilization is highly dependent upon the material/fuel solid particle contact.

The shape of the flame should be narrow in order to protect the refractory.

6.2.2 Design of the Lafarge burner pipe for solid and liquid fuels



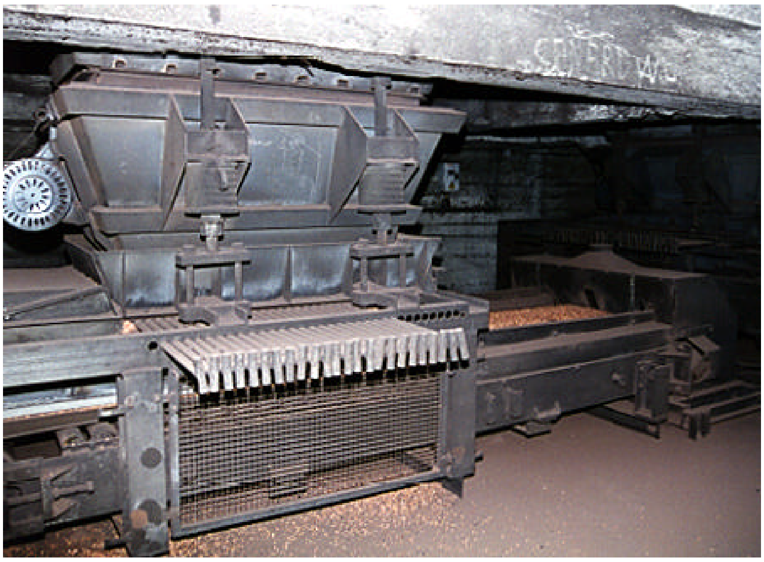
Burner pipe - tip

The Lafarge burner pipe is what is needed when it is desired to optimize the combustion and use high-sulfur fuels (S/A > 1.2).

It is made up of several concentric circuits. From outside to inside can be found:
- axial air circuit terminated by a set of circular holes to provide a good peripheral air distribution. The circuit should be fed by a pressure booster designed for a 70 kPa pressure,
- annular solid fuel circuit in which the air conveying flow provides a tip velocity of about 25 to 32 m/s,
- rotational air circuit fed by a high-pressure (17 kPa) fan and fitted with a swirler usually inclined at 35° and designed to rotate the air.

Also in the center is a relatively large-diameter «hub» ("bluff-body") that catches the flame while creating a dead recirculation zone. It is cooled by by-passing a small fraction of the rotational air.

In the center of the burner pipe can be found several jacket tubes to receive the liquid injection rods (bunker oils, liquid wastes, water, ...).



Waste feed (corn)

Particulars

Feed design: The burner pipe inlet coal feed circuit should be looked after to minimize wear (the injection tube inclination with respect to the burner pipe should be 12° max.).

Suitable coal feed

Air gun

An air gun can be installed above the burner pipe, its function being to destroy the material build-ups.

6.2.3 Other burner pipes

Other types of burner pipes can be found within the Group.

Rotaflam burner pipe

The axial and rotational circuits are outside the coal circuit. Outlet sections of axial and rotational circuits are adjustable by sliding. The functional clearance can create high excentrations at high temperature which adversely affect the refractory life.

Unitherm burner pipe

It looks similar in design to the Rotaflam burner pipe; the presence of nozzles that can be directed tangentially by mechanical control suppresses the two circuits (axial and rotational) of the Rotaflam burner pipe.

KHD Pyrojet burner pipe

Its design is similar to that of the Lafarge burner pipe. On the other hand, for S/A > 1.2, the impulse and swirl levels must be adapted which amounts to doubling the primary air rate with respect to the KHD standards.

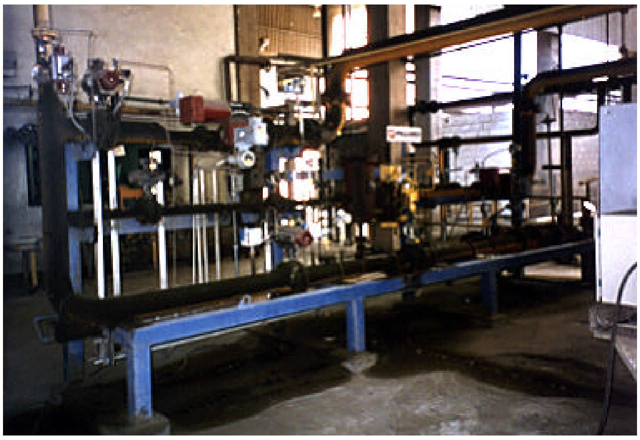
6.2.4 Liquid fuel burner pipe

The liquid fuel burner pipe is identical to the Lafarge burner pipe, only the coal circuit is eliminated.

In that case, the impulse level being relatively low, the two primary air circuits are usually fed by a simple high-pressure fan common to both circuits.

The ventilation characteristics should be defined on the basis of the required impulse and swirl levels.

6.2.5 Gas burner pipe



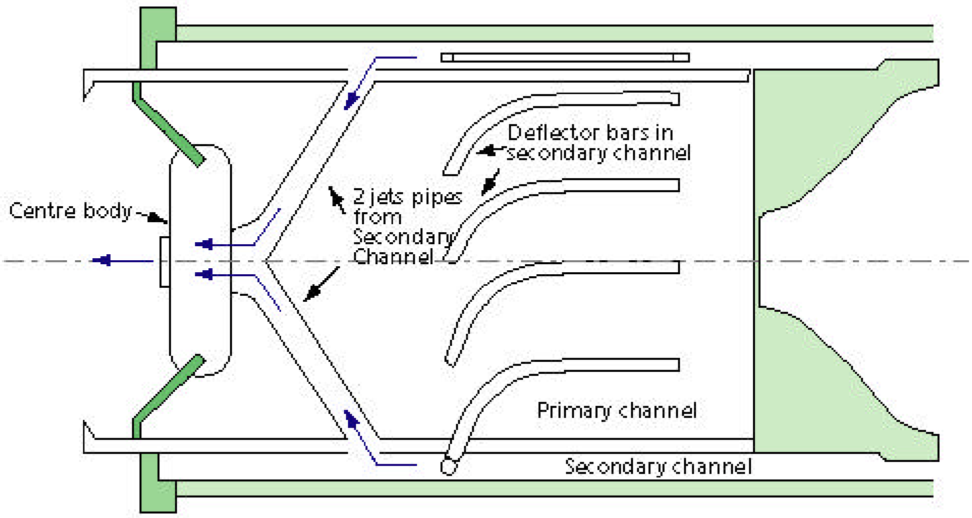
Gas feed bent

«Adelaïde Cement» burner pipe

This burner pipe uses a precession movement produced by the gas release in a specifically designed room to obtain an injection in the furnace like a revolving concentrated jet stream.

The injection cone, as defined by the revolving jet stream envelope, is therefore alternatively rich and poor in fuel, attenuating the formation of thermal NOx (from 1700 down to 1450 ppm) at the Richmond kiln outlet.

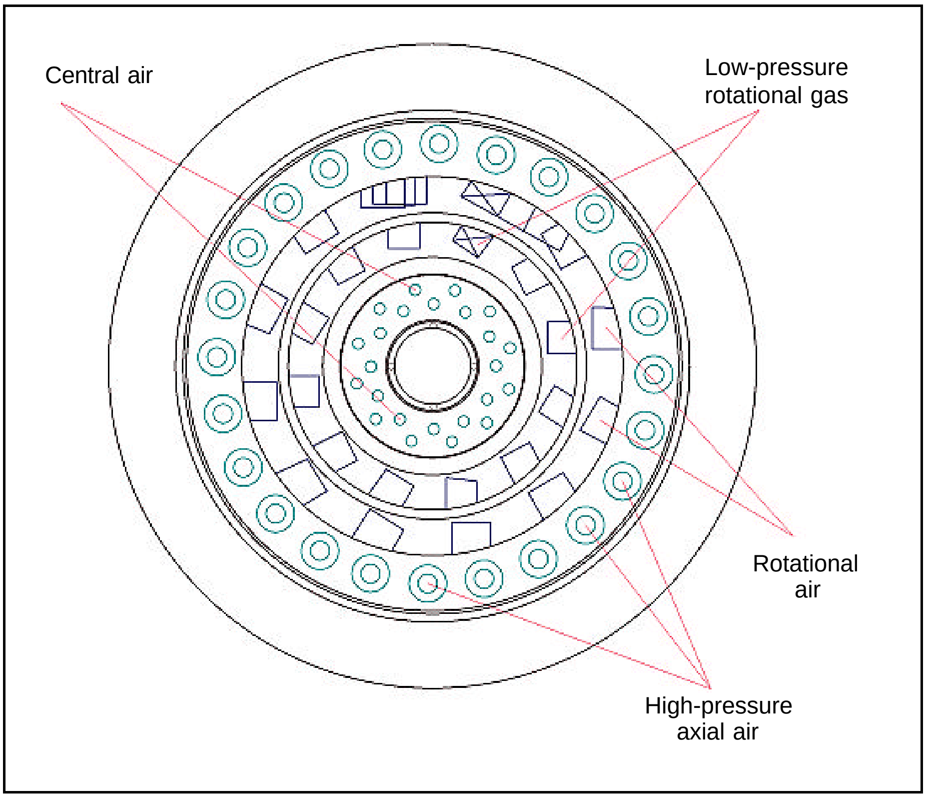
The test conducted on this burner pipe at the Richmond plant of Lafarge Corp. has highlighted the poor performance of the bluff-body support and the big problems that can result from its deformations: asymmetrical flame and brickwork destruction.



Adelaïde Cement burner pipe

Pillard ROTAGAZ burner pipe

The design represents an evolution of the burner pipe developed in the past by GDF (Gaz de France). The alternating gas and primary air circuits (at a limited rate of about 5% of the stoechiometric air) should aeraulically provide the adjustment flexibility of the desired shape of the flame. It is being fine tuned at the Ocumare plant of F.N.C.



Pillard Rotaflam burner pipe

6.2.6 Burner pipe recommendations

When S/A > 1.2, the combustion optimization is a must.
Other types of burner pipes are suitable when S/A < 1.2.

A short narrow flame is not possible with ROTAFLAM and UNITHERM; burning is not as rapid, the clinker reactivity not optimum.

	S/A < 1.2	S/A > 1.2
Flame	Centered in the kiln	
Lafarge burner pipe	yes	yes
KHD burner pipe	yes	yes (but with adapted primary air)
Rotaflam burner pipe	possible	no
Unitherm burner pipe	possible	no

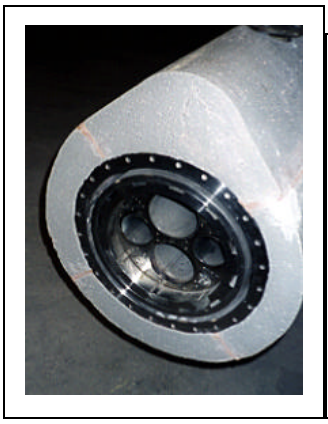
6.2.7 Comparison between different types of burner pipes

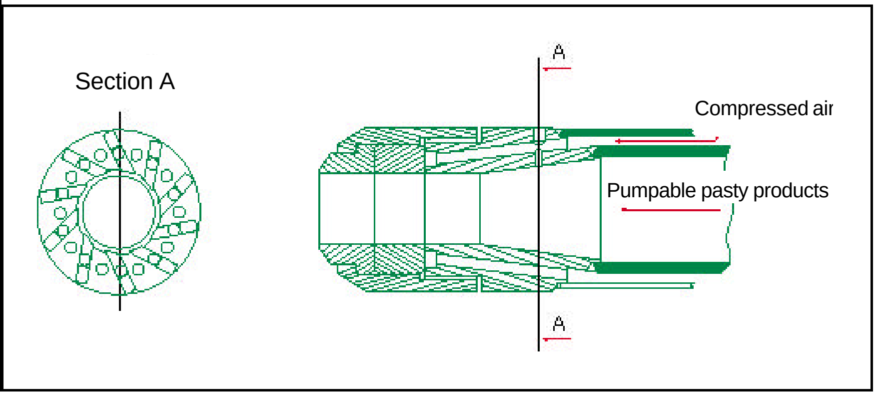
	PILLARD (ROTAFLAM)	KHD (or similar)	LAFARGE
Number of circuits	3		
Position of primary air circuits with respect to coal circuit	Both rotational and axial air circuits are external to the coal circuit	The coal circuit is placed between the rotational circuit and the axial circuit	
Influence of the «swirl» circuit	«inhale» outside the fine coal particles	The rotational air «push» the coal streak outside	
Central hub (creates a recirculation of the burnt hot gases toward the center, facilitating the combustion ignition)	Large hub diameter (internal part of the traditional primary air circuits); excellent firing speed results	Small diameter	Large diameter, excellent result
Primary air rate based on fuels	Constant and low (about 5 %)		Higher, varies with fuels
Flame length	Long	More or less long	Shorter but narrow, adjustable with primary air flow
Flame diameter	Small, if not flared flame independent from the main central flame (double flame)	Average	Average, adjustable
Possibilities to operate with SO3/Alcali > 1.2	No	No (*)	Yes
• NOx	Similar emission level for identical burning conditions		

(*) Except when adherence to impulse and swirl levels discussed in this document is required.

No single burner pipe presently can meet the 800 mg level of NO_2/Nm^3 at 10 % oxygen under oxidizing burning conditions.

The KHD burner pipe is equivalent to the Lafarge burner pipe for equivalent air flow conditions.





multi-fuel burner pipe

Pasty product injector

As seen previously, the new potential fuels are often wastes and it is sometimes difficult to adapt the installations. Having optimized the combustion of the main fuel allows a greater margin to absorb the impurities contained in the wastes

The economical consequences can be very important.

6.3 Momentum and swirl

The flame is characterized by two parameters:
- specific momentum,
- swirl.

These parameters originate from theoretical studies for which references can be found in the Combustion Guide (see bibliography).

6.3.1 Momentum calculation

Impulse is the amount of axial movement produced by primary air.

$I = m \times V$

I : Momentum, N

m : primary air mass flow, kg/s

V : primary air velocity, m/s

The primary air (and the conveyed fuel) and secondary air mix is so much more rapid that the ratio of the amount of primary air movement to the amount of secondary air movement is high.

The burner pipe impulse is the sum of the axial impulse of each circuit.

$Ix = \sum Ix_i$

Ix_i = Momentum along the i circuit kiln axis

It has been agreed to ignore, except for gas, the amount of movement produced by the fuel itself (but the conveying air is considered).

Specific momentum

To express an momentum criterion independently of the kiln heat power, the specific momentum is defined as being the ratio:

$Is = Ix / Q$

Is : is expressed in $N.h.GJ^{-1}$

Q : kiln heat power (kilns without precal.)
Kiln heat power outside precal if AS precal
Total heat power (including precal) if AT precal.

Since the kiln heat power is almost proportional to the kiln air intake flow, the ratio of the amount of primary air movement to that of the secondary air is therefore well translated.

Note

The combustion air flow is relatively independent of the type of fuel. For a AT precal, the total heat power should be considered since the total combustion air travels the length of the kiln(assuming the back-end seal is relatively tight).

6.3.2 Swirl calculation

The swirl is the ratio of the rotational moment to the primary air axial moment. It is expressed by the equation:

$$Sw = \frac{I_{qr} * r_g}{Ix * De}$$

Where:

I_{qr} : the tangential impulse of the rotational circuit

with :

I_{qr} : I_{xr} tg a

$I_{\theta r}$: tangential momentum of the rotational air

I_{xr} : axial momentum of the rotational air

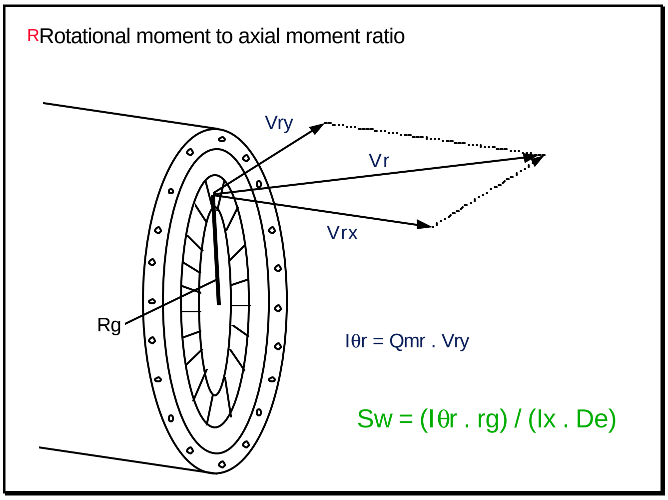
α : swirler angle

The radius of gyration is defined as a function of the respective radius of the rotational circuit at the burner pipe tip.

$r_g = 2/3\ (re^3 - ri^3) / (re^2 - ri^2)$

re : external radius

ri : internal radius



swirl

Ix is the axial momentum already calculated ($Ix = \Sigma_I x_i$).

De is the equivalent diameter of the fluid flow calculated as the diameter of the cylindrical opening through which would circulate the total primary air flow at such a velocity to produce the impulse Ix.

Hence a configuration goes from n circuits to a mono-circuit. Swirl is a dimensionless number that allows a comparison to be made between flames of different heat powers.

6.3.3 Effect of momentum and swirl on the flame

Specific momentum

The higher the specific momentum the shorter and hotter the flame.

Specific momentum values retained

Bunker oil	: 1.2 N. h.GJ^{-1}
Coal	: 1.5 N. h.GJ^{-1}
Coke	: 1.8 N. h.GJ^{-1}
Gas	: 1.8 N. h.GJ^{-1}

Swirl

The higher the swirl number the wider the flame diameter.

Swirl values retained

The design value is identical for all fuels (0.15) except for gas (0.05).

The swirl level is often lower.

It is helpful to adapt both swirl and momentum to insure the protection of the refractory (temperature monitoring with scanner).

Notes:

The values given for impulse and swirl and the monitoring are indicative and do not constitute targets to be attained. These are guide values useful for proceeding towards combustion optimization.

In practice, for the calculation of the specific impulse and swirl, it is necessary to have Tables (established during the operation of the circuits after calibration) giving, for the respective pressures of the 2 circuits, the corresponding impulse and swirl levels.

From time to time the Tables should be checked by measuring the fan and blower intake flow, a wide scatter reflecting a degradation of the burner pipe.

An Excel program available in the Technical Centers can also be used.

6.3.4 Influence of axial and rotational air on the flame

Rotational air	Axial air ↘	Axial air =	Axial air ↗	
↘	−−	−	+ (1)	Momentum
↘	= (1)	−	−−	Swirl
↘	++	+	−	Flame length
↘	−	−	−	Diameter
=	−	=	+	Momentum
=	+	=	−	Swirl
=	+	=	−	Flame length
=	+	=	−	Diameter
↗	= (1)	+	++	Momentum
↗	++	+	= (1)	Swirl
↗	+	−	−−	Flame length
↗	++	+	+	Diameter

(1) Results are a function of the relative importance of the two actions.

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7. AUXILIARY EQUIPMENTS

It is important:
- to have suitable instrumentation for controlling combustion quality,
- to know the shell temperature for detecting variations of the thermal conditions of the kiln,
- to have shell cooling fans for coating formation and protecting the shell.

7.1 Gas analysis

The proper adjustment of excess air cannot be done without a sensor for continuous sampling of the kiln outlet gases. It should not be influenced by the air intakes at the back-end seal, it must penetrate the kiln at least 200 mm. This sensor should at least be provided with:

- O_2 0 - 5 and 0 - 10 % scale
- CO 0 - 3000 ppm scale
- NO 0 - 2000 ppm scale

It is also becoming necessary to measure SO_2 in particular (0-15,000 ppm scale), when the S/A ratio is higher than 1.2. The kiln outlet SO_2 variations reflect those of the volatilization. An increase in SO_2 corresponds to an increase in volatilization, hence to an increase in the build-up risks.

SO_2 is more sensitive than CO for characterizing the burning atmosphere.

Gas sampling cabinet

O2 CO,NO,SO2 analysis cabinet

7.2 Scanner

Combustion and burning optimization results in hot flames, hence the need to permanently control the shell temperature. The installation of a scanner meets this requirement.

The scanner helps to control the flame temperature profile and allows steps to be taken to protect the refractory in case of local overheating.

Based on the temperature reading on the scanner the following may be done if need be:
- modify the swirl,
- modify the momentum,
- turn on or turn off some cooling ventilators.

7.3 Shell cooling fans

Shell cooling fans have a twofold objective:
- shell and refractory protection,
- coating stability.

Shell cooling fans should be installed at least as far as the second downstream lining. The installation of fans upstream from the second downstream lining stabilizes the upstream zone ring.

Zone ventilator

8. OPERATION

Combustion optimization requires:
- uniform raw mix,
- suitable fuel fineness,
- feed within ± 1% of the fuel flow,
- Lafarge burner pipe type required when S/A > 1.2,
- optimized values for specific impulse and swirl,
- central flame (burner pipe along the kiln axis if impulse is high).

8.1 Locally-reducing combustion

A certain kiln operation stability may be obtained despite a less than perfect combustion when the clinker SO_3 / alkali ratio does not exceed 1.2.

Beyond that a locally-reducing burning atmosphere promotes an excessive sulfur volatilization, incompatible with the process stability and huge build-ups may rapidly clog the kiln.

It seems that locally-reducing burning is essentially due to contact between the load material and the solid unburnts.

It is therefore necessary to adapt the excess air level in order to maintain an oxidizing atmosphere.

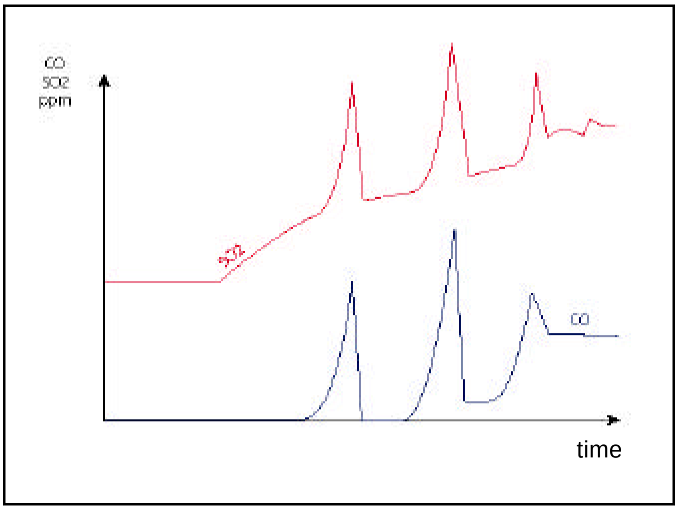
S/A ratio > 1.2

The SO_2 values usually recognized as maximum thresholds are:
- 4,000 to 5,000 ppm for tower kiln,
- 2,500 to 4,000 ppm for grate tower.

Failing to have a SO_2 analyzer available, the CO emergence threshold should be used to set-up a slightly higher oxygen value. Attempt should be made to maintain CO to a value lower than 100 ppm (1).

(1) This value should be raised if coarse fuels are introduced in the smoke box (tyres, non-hazardous industrial waste).

The kiln (tower kiln) inlet material SO_3 content can be usefully controlled at a value lower than 2.5 times the average clinker SO_3.



Comparative CO, SO2 evolution

S/A ratio < 1.2

In the absence of NOx emission constraints, an excess of oxygen should be used in order to operate without CO.

If the NOx emissions have to be limited, it should be possible to operate on a «specified» CO. Meeting the established rules concerning fuel fineness and feed becomes critical.

8.2 Kiln outlet oxygen

After fulfilling the required prerequisites for an adequate combustion, the oxygen should be adapted to minimize volatilization.

In general, the amount of kiln outlet oxygen to aim at is:
- 1.2 to 1.5 % for an installation operating with a S/A ratio < 1.2,
- 3.0 to 3.5 % for S/A > 1.2.

In any event, as mentioned previously, these values should be adapted to avoid the presence of CO and limit the kiln outlet SO_2 level.

8.3 Cooler adjustment

Both the secondary air temperature and uniformity have an effect on combustion.

Secondary air below 800° C slows down the flame firing process, resulting in a high increase of the firing distance (plume) and accrued risks of unburnt solids falling on the load and producing a reducing atmosphere with its aftermath (volatilization).

Conversely, secondary air exceeding 1000° C appreciably increases the formation of thermal NOx.

The compromise with highly efficient boilers and SA precalciner kilns is to give preference to a high tertiary air temperature; in order to minimize kiln and precalciner NOx formation, the installation of a take-off on the kiln hood is therefore advised.

8.4 Lafarge performance index

Raw mix uniformity, combustion optimization and clinker uniformity can be controlled from the criteria agreed to in the Technical Plans.

- KFUI : < 14
- KSUI : < 10
- Free lime : > 0.5 - 0.7 depending on process
- free lime σ : < 0.2x m' + 0.1
- KK (C_3S) σ'^2 : < 16

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9. PRECALCINATION KILNS

9.1 The «5T»* rule

For a good combustion in the precalciner, the «5T» rules should be adhered to.

Temperature in the precalciner

A high temperature improves combustion and significantly reduces NOx emissions (hot-core precalciner); it is governed by:

- tertiary air temperature which should be maximized,
- precalciner design,
- kiln feed and fuel distribution.

Time of combustion

A long time process improves combustion performance.

* The oxygen content

Combustion should preferably be ignited in tertiary air before it is mixed with the kiln smoke and a sufficient air excess should be used for good combustion.

However, for reducing the NOx emission level stage combustion should be initially without air and then terminated upstream from the lower cyclone with excess air.

Turbulence

To improve the combustion kinetics, it is necessary, as for the main burner pipe, to insure rapid mixing of fuel and combustion agent.

Tenuity

The fuel should be well prepared and of the proper fineness, sometimes better than for the main burner pipe. If fineness is not sufficient, solid unburnts in the kiln inlet material increase the risks of volatilization in the kiln.

The combustion quality in the precalciner is important on account of :

- volatilization risks associated with the presence of solid unburnts,
- heat losses from gaseous unburnts,
- possible reduction of NOx emissions.

* The best English adaptation from French that could be made!

9.2 Formation of solid unburnts

Poor combustion in the precalciner causes the persistent presence of solid-carbon particles within the kiln inlet material.

This carbon promotes volatilization phenomena similar to those described for the rotary kiln.

Gaseous unburnts

Poor combustion in the precalciner promotes CO at the precalciner outlet which:

- either burns too late to participate to the heat exchanges and uselessly increases the smoke temperature,
- or is emitted in the atmosphere.

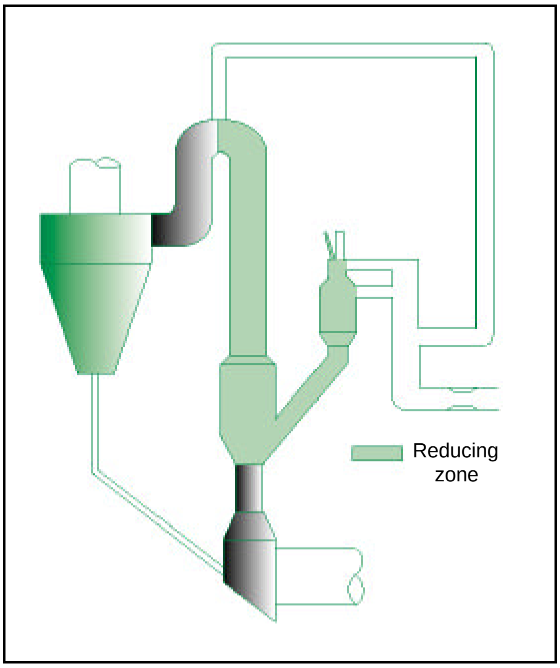
In all cases it is a heat loss.

9.3 NOx control

The temperatures reached in the precalciner do not allow an extensive formation of thermal NOx. However, nitrogen present in the fuel leads to the formation of combustible NOx.

This formation is limited when the temperature within the precalciner is very high (1200 °C).

To meet local regulations which will become increasingly more severe, some suppliers are proposing adaptations to existing precalciners. They are the low-NOx precal.



Low-NOx precalciner

With this type of precalciner stage combustion takes place. Part of the tertiary air is by-passed toward the precalciner outlet so that combustion develops as much as possible in a reducing atmosphere in order to :

- reduce the formation of combustible NOx in the precal,
- reduce the NOx contained in the kiln gases.

It is then possible to obtain a reduction of about 50% of nitrogen emissions.

Within the Group, a low-NOx precalciner will be installed soon at Port-La-Nouvelle.

10. WHERE TO START FROM?

As discussed, combustion optimization depends on prerequisites such as raw mix uniformity or adequate fuel preparation.

Achieving a uniform and suitable raw mix is a long operation requiring a lot of effort but one should not wait for perfection before getting started on combustion optimization.

A combustion project should start with an analysis of what differentiates the present situation from the Lafarge Standards.

It is the purpose of the Combustion Audit.

The combustion audit must cover the following areas:
- inspection of the materials (raw mix, clinker, fuels),
- shop description,
- operation,
- study of instabilities and operation problems,
- measurements,
- audit report.

The combustion audit must open to an action plan.

The plant should appropriate the audit conclusions and get organized by appointing a leader, drafting objectives, means, regular follow-ups on the actions and results.

11. CONCLUSIONS

11.1 Burning control

Burning control involves:
- raw mix uniformity,
- combustion optimization including:
  - adequate fuel preparation,
  - suitable burner pipe,
  - proper instrumentation,
  - optimized operation by trained personnel.

In this document, it has been shown that it is possible to burn high-sulfur fuels leading to S/A molar ratios of the clinker largely above 1.2 (up to 5 to-day).

The conduct of a combustion project requires at the onset a combustion audit. It is a professional task.

It is therefore possible to burn high-sulfur fuels!
Combustion optimization improves clinker reactivity!
It is possible if it is wanted! And it is economically profitable!

11.2 Flexibility

Burning optimization allows the use of high-sulfur fuels available on the local market and their cost may prove advantageous.

On the other hand, it is not yet possible to control chlorine intakes exceeding 300 g/t, this requiring the installation of a by-pass (tower kilns).

Residual fuels, when properly prepared and injected, do not or little disturb the process and their cost is sometimes very low. Sometimes the use of solvents at the burner pipe facilitates coke combustion and a reduction of S/A ratio.

Substitution raw materials (SRM), i.e. aluminum production wastes, may make the raw mix reactive and lower the raw material cost.

Flexibility requires an open and determined attitude. All the opportunities that are made available should be exploited.

11.3 Clinker reactivity

Improving clinker reactivity means producing strengths at the lowest energy cost. In other words, it means obtaining the same strength level at a lower fineness or with more additions.

It is therefore a source of potential gains.

Clinker reactivity is closely related to raw mix chemistry. It should be remembered that the objective is:
- high C_3S (60 % and more),
- good burning properties,
- reasonable silica modulus (2.4 - 2.6),
- formation of C_3A (reactive) rather than C_4AF.

Clinker reactivity relies also on the burning conditions; burning can be enhanced by the size of the alite and belite crystals which should be as small as possible.

11.4 Profitability of combustion investments

The combustion control quickly becomes profitable:

Examples Lafarge Ciments invested, between 1990 and 1995, US$ 35.5 with an annual average production of 6,870 kt ck/year, that is to say US$ 5/t ck/an and it obtained (fuel and power cost) savings of US$ 3/t ck ; the return time calculated, suppose that any investment should have be done at the same time, is under 2 years.

The Yozgat plant in Turkey could:
- reduce the heat consumption from 860 to 810 kcal/kg ck,
- increase the production of 5 to 7%,
- improve the clinker reactivity (additive rate raised from 1.4 to 1.55),
- use pet-coke in high proportion,
- improve the brickwork life time,

either a 1.5 year return time with 100% coke or 2.6 year with a 50/50 coke and local lignite blending.

11.5 SO_2-NOx-Environment

Sulfur volatilization control helps to meet the present SO_2 emission standards.

On the other hand, CEE NOx standards cannot be met under oxidizing combustion. Additional means for NOx reduction might become widespread.

Note
Good burning properties improve burning conditions and reduce kiln NOx.

NOx after-treatment is in some cases obviously necessary as for instance the installation of a low-NOx precalciner.

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