# SPECIALIZED COAL AND PET-COKE FIRING PIPE DESIGN

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**Abstract**

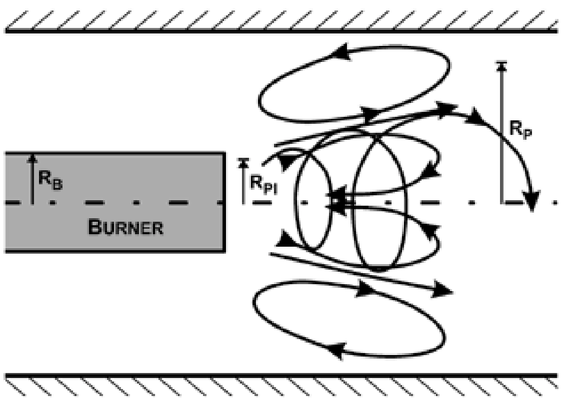
This paper discusses the specialized coal and pet-coke-firing viewing the design of customized combustion systems in order to meet client's specific requirements. This is an approach to combustion subject that is becoming well known and widely accepted all over the world, fitting particularly well when the combustion takes place inside a clinker rotary kiln. The best way to do this approach is by means of dimensionless indexes, which characterize macroscopically the result of a wide variety of simultaneous chemical reactions, and phenomena of heat, mass and momentum transfer. The most significant dimensionless indexes, which help tremendously in the combustion system design, are presented and discussed.

## Preliminary Comments

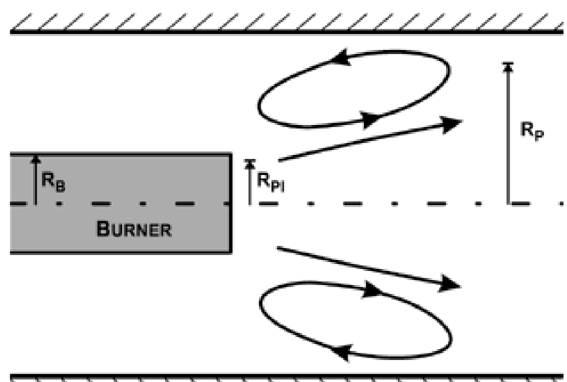
To talk about the customized design of combustion system for cement kilns, the characteristics of the flame that results from the injection of the fuel in a high-temperature chamber in the presence of preheated air should be analyzed and very well known. Some very important phenomena happen at that zone of the kiln and affect tremendously the characteristics of the clinker produced.

The injection of fuel and primary air at much higher velocities than the secondary air causes the formation of external re-circulations or vortices. The intensity of those re-circulations is very important because they interfere with the mixture rate of the fuel/primary airflows with the secondary air necessary to complete the combustion reactions. The primary air jet may act as an ejector, producing suction effects and accelerating the secondary air.

Some burners can produce internal re-circulations too. Those re-circulations occur internally to the flame and can be very important to accelerate the ignition of the fuel particle cloud. Depending on the intensity of the internal re-circulations, the first temperature peak of the flame can be brought closer to the burner, which may be important to the process. In some cases, it can occur also the generation of small-scale internal re-circulations, a very important phenomenon to the ignition of small particles and wastes.

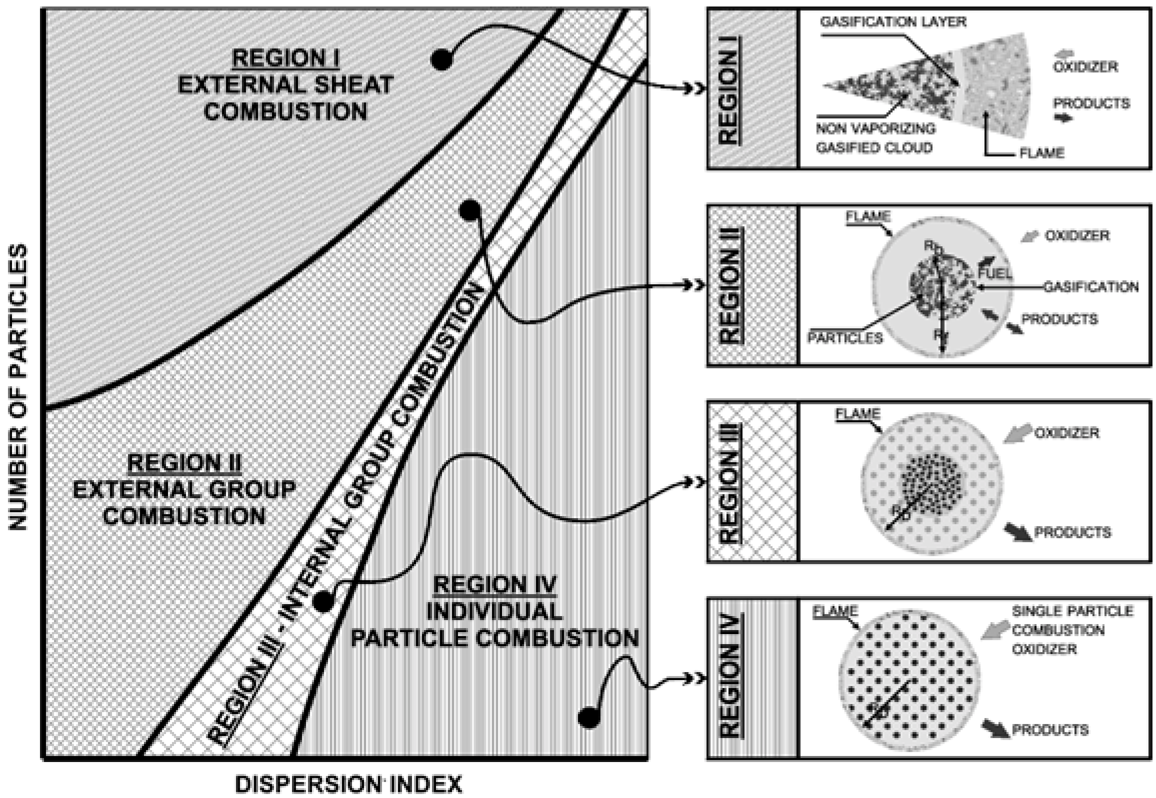



EXTERNAL AND INTERNAL RE-CIRCULATION




EXTERNAL RE-CIRCULATION

Many chemical reactions take place in the flame and these reactions strongly depend on the mixture of the reactants. As the mixture happens progressively and far from the tip, the burner must provide the adequate propagation of the effects of kinetic energy. Turbulence is generated as a function of the kinetic energy of the jets, mainly of cloud presented by H.H. Chiu et al at the 19th Combustion Symposium, in 1982, and they can be visualized in the graph prepared by those authors and reproduced in this paper. Therefore, the control of fuel cloud dispersion is very important to define the characteristics of the flame and the thermal profile of the kiln.




CLOUD COMBUSTION MECHANISMS

primary air and fuel flows. So, the characteristics of a flame are strongly related to the kinetic energy of all the flows at the burning zone.

The last aspect of this field of combustion to be pointed out refers to the dispersion of the cloud of pulverized fuel. In a clinker kiln, the fuel particles usually do not burn individually – they burn in a cloud. The mechanisms of combustion of a cloud of particles depend on its dispersion. So, poorly dispersed clouds will present basically “external sheath combustion” and “external group combustion”, as observed very close to the tip of most burners. On the other hand, well-dispersed clouds may present “internal group combustion” and “individual particle combustion”, as observed far from the burner tip. Those outcomes agree with the model for the combustion mechanism of a

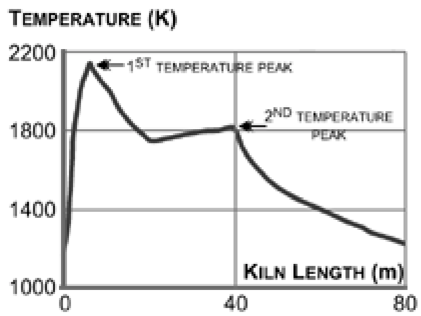
## Application

Usually, a company needs a customized combustion system when either:

- It is installing a new kiln;
- It is substituting a fuel for another;
- It is facing a new environmental situation;
- It is having the opportunity to use a technologically updated equipment;
- The combustion system of an existing kiln is not able to allow operators to run the equipment at desired conditions.

Operating problems in existing kilns may be related to one or more of the following aspects:

Clinker quality: improving of clinker quality through adequate heating and cooling rates inside the kiln is a major concern at cement plants. These parameters may affect significantly C3S and C2S contents in the clinker, as well as the size and morphological characteristics of the crystals. Flame shape is one of the very important




**TYPICAL TEMPERATURE PROFILE ALONG KILN LENGTH**

factors to determine those quality parameters. Position and intensity of the two temperature peaks frequently observed along the length of clinker kilns – as shown in the figure – affect those rates. The occurrence of the two temperature peaks, it should be pointed out, can be:

- Predicted by mathematical modeling through the use of CFD (Computational Fluid Dynamics);
- Checked by experimental tests.

The occurrence of the two temperature peaks is a very complex phenomenon influenced by three-dimensional multi-phase flows with mass, heat (conduction, convection and radiation) and momentum exchanges with simultaneous chemical reactions. It is a very hard task to understand this phenomenon and to manage it in order to get specific results. In short, the occurrence of two clearly defined peaks separated by a large lower temperature zone indicates the tendency for obtaining less C3S and large crystals. On the other hand, the occurrence of two peaks almost coincident and close to burner tip indicates that the possibility of obtaining high C3S clinker with smaller crystals is considerable.

Clinker grain size: another concern is to improve clinker grain size distribution. This factor may have influence in both kiln and cooler operation, depending on how much dust is generated in the process. Additionally, plant operation teams usually search for convenient clinker grain size, in order to decrease electric power consumption at the cement mills and eventually getting grinding plant capacity enhancement. Once again, flame shaping may help to optimize this aspect of plant operation.

Coating: control of coating formation reflects in the kiln operation and its stability influences refractory life, also. Although raw material feed to the kiln and refractories used in its lining are of utmost importance, thermal distribution is a major factor to define coating characteristics. The adjustment of the intensity and position of the two temperature peaks, once again, can help to form a thick and stable coating. In other words, that adjustment may allow the protection of the basic bricks at the most critical sections of the kiln and obtaining a time-extended refractory service life.

Emissions: the control of gaseous emissions, particularly of THC (total hydrocarbons), $NO_X$ (Nitrogen oxides) and CO (carbon monoxide) is becoming one of the most important concerns to plant managers, as environmental regulations may impose serious restraints to the operation of many kilns. Conciliating the complete combustion of the fuels (i.e. low CO and THC emissions) with adequate temperature, fuel and oxidant distributions (i.e. low $NO_X$ emission) is the task in this case. One should notice that sometimes the objective of low $NO_X$ emissions conflicts with the objective of high quality clinker production. A customized combustion system is a must when the plant faces a conciliation problem of this kind and an equilibrium point has to be found by operation personnel. $SO_X$ emissions, it should be pointed out, are much more related to other process conditions than to combustion.

Sulfur purge: purge of sulfur from the kiln interior through the clinker produced, especially when burning high-sulfur fuels as pet-coke, may request special temperature profile along the kiln length to avoid excessive recycling of sulfur compounds and ring formation on kiln internal walls and/or build-ups on pre-heaters. Normally, a short sintering zone would be needed to meet sulfur purge requirements. Adequate pet-coke grinding, turbulence at convenient levels and controlled conditions for the fuel cloud dispersion are the minimum requirements to get that short sintering zone. Additionally, one should pay attention to the occurrence of reducing zones in the kiln's internal atmosphere, which makes more difficult the sulfur purge.

Specific consumption: decrease of specific heat consumption of the kiln may arise as a necessity to cut costs and increase market competitiveness. This improvement may be obtained through exhaust gas temperature drop as consequence of a shortened flame and/or a total excess air limitation, which should be attained only through the proper design of a combustion system. Some combustion systems allow significantly reduction of primary air rate, which is also a way of reducing, although in small percentage kiln specific consumption.

Waste fuel burning: the use of alternative fuels, either solid or liquid, may lead to operational problems, emission problems and clinker quality problems. Due to the wide variety of wastes that might be consumed, depending on the cement plant location, the problems may vary from kiln to kiln, as the interactions between raw materials, conventional fuels, alternative fuels, refractories, etc. are different.

## Design Considerations

It is unlikely, if not impossible, that a standard combustion system, including the so-called “shelf burners”, would be able to satisfy any of the client’s needs.

The combustion system design must be oriented towards the right direction, so one should develop the design with the aim of reaching clearly defined objectives.

Naturally, every combustion system design should start with the knowledge of the process to be carried out in the cement kiln. This involves an extensive data-gathering phase.

If the system will be installed in a new kiln, the main data to be collected should include the following topics:

- Process data: type (wet, dry, semi-dry, …), product output, thermal consumption, etc.;
- Available raw material data: chemical analyses, fineness, moisture, expected quality fluctuations, etc.;
- Kiln project documentation: drawings and technical specifications;
- Type of clinker to be obtained and its required characteristics;
- Fuels to be used: analyses, supply conditions (fineness, moisture, …), etc.

Normally the design of a combustion system for a new kiln has more uncertainty on data concerning raw materials and fuels. The result of the interaction between raw meal, fuels and refractories eventually is a little different than predicted in the plant project. Consequently, it is recommended that the design of the customized combustion system for a new kiln consider wider ranges for operational parameters.

On the other hand, the design of a customized combustion system that will fit an existent kiln requires the previous knowledge of the following data:

- Process data: type (wet, dry, semi-dry, etc.), actual product output, actual thermal consumption, etc.;
- Actual raw material data: chemical analyses, fineness, moisture, actual quality fluctuations, etc., remarking that:
- Fluctuations on raw material composition is a very common cause of kiln instability and may explain “poor performance” of both refractory bricks and burner pipe;
- Kiln project documentation: drawings and technical specifications, remarking that:
  - It must be checked if the available documentation actually correspond to the equipment working at the field;
- Existent firing system project data;
- Clinker characteristics data: chemical analyses, crystallographic analyses, physical properties, etc., remarking that:
  - It is very important to discern from target values and actual values;
  - In case of significant discrepancies between target and actual values, a doubtless diagnosis on the causes of those differences should be made;
- Fuels actually used data: proximate and elementary analyses and conditions of supply (fineness, moisture, etc.), remarking that:
  - During its service life, almost all the cement plants experienced fuel changes and, by that reason, the knowledge of actual characteristics of the fuels being used is fundamental.
  - Particle size distribution and moisture can affect significantly the combustion conditions, especially the ignition of the particle cloud;
- Kiln operational parameters: production rate, fuel consumption, product/raw material rate, specific exhaust gas flow, specific cooling air flow, primary air rate, etc., remarking that:
  - It is useful to check what is the factor that limits kiln output, for example: kiln exhaust gases capacity, clinker cooler capacity, kiln drive power, kiln shell temperature, raw meal

grinding/feeding, fuel grinding/drying or others.
- Field measurements: mass flows of raw materials, cooling air, fuels, primary air, product, exhaust gases, composition, temperature and pressure of gaseous streams, etc.

Field measurement is one of the most important phases of a data-gathering process. The measurements often show that the kiln is not running as considered during its project. Frequently those measurements allow discovering causes not suspected for an unsatisfactory performance of a cement kiln, sometimes unfairly claimed as a combustion system fault. Solving that type of problems may bring better operating conditions and make easier any improvements to combustion system. For example, it can be presented the case of a kiln that had a very long sintering zone and was producing poor quality clinker. Despite the burning system of the kiln was not a very advanced one, the main reason for the long flame was lack of oxygen inside the kiln. Exhaust gas analysis at smoke chamber showed oxygen availability, but in fact the probe was taking samples under influence of false air infiltration through the kiln inlet seal and there was not enough oxygen inside the kiln to complete the combustion.

After acquiring the maximum of useful information, one can proceed to establish the basis for the design. Fundamentally, it comprises the thermal capacity of the system (as a function of kiln maximum production, specific heat consumption and thermal "split" between pre-calciner and main burner, if applicable). Nevertheless, additional information must be taken in account to the proper design, as follows:

- The target product: the clinker characteristics that must be obtained normally and continuously from the kiln;
- Raw materials available or obtainable: chemical composition, moisture, fineness, stability of feeding conditions, etc.;
- Available equipment: the kiln itself (capacity, dimensions, heat consumption, refractory lining types and distribution), existing combustion system (direct, semi-direct, indirect, etc.), existing coal/coke grinding plant characteristics (mill type, fan type, mill capacity and limitations, drying limitations, particle size distribution obtained versus desired/necessary) and primary air supply conditions (type of blower, flow and pressure characteristics and limitations);
- Available fuels: coal and or petroleum coke – heating values, volatile matter content, fixed carbon, moisture, ash content, sulfur content, Hard Grove Index (HGI), etc., remarking that:
  - Concerning pet-coke, the HGI may vary considerably depending mainly on the origin of the fuel.
  - Fluid coke is normally very hard (HGI < 30), present low volatile matter content and has low permeability.
  - Green delayed cokes present higher permeability and may present HGI between 45 and 55, or even more.
  - Usually, high-HGI cokes present lighter volatile matter.
  - Low-HGI cokes, even with the same total volatile matter content of high-HGI cokes, normally present heavier volatile matter.
  - High-sulfur pet-cokes usually are harder, have heavier volatile matter and present higher nitrogen content, which affects significantly $NO_X$ generation;
- Required thermal profile, remarking that:
  - It must be defined if the combustion system design will aim at hard, short and very radiant flames, for instance, to maximize clinker quality or, on the other hand, aim at softer and narrower flames, for example to get the maximum life for refractory bricks;
  - Considerations on the desirable temperature peaks intensity and position should be made at this point.
- Coating characteristics preview according to raw materials and refractory lining project;

An example can enlighten in a very clear way about choosing the thermal profile in the design of a combustion system. It is a situation in which previous data indicate the presence of fluorine in the raw meal of a pre-calciner dry-process kiln that will burn 100% high-sulfur petroleum coke through indirect systems (both main and secondary). In this case, the kiln main burner should be able to produce a narrow and soft flame, in order to protect refractory lining from possible liquid phase wash out, but not a too long flame that would extend sintering zone. This extension would lead to an increase of sulfur compounds volatilization rates and problems with ring formation and pre-calciner build-ups. A very flexible main burning system would be required to allow operators to find the best adjustment in this case.

Another example refers to a coal-fired long dry-process kiln, which production rate was limited by unstable operation caused by periodical formation and fall of rings. In this case, a "double cooking" phenomenon was verified with two clearly separated temperature peaks. To solve the problem, not a new customized system was needed, but only a "customized modification". The indirect system primary air rate was adjusted and the air injection velocities were changed through modifications of the burner tip.

To go on with the design of a customized combustion system it is necessary to set the ranges of variation of the Dimensionless Indexes that will be used in the burner design. Some of those indexes are mentioned bellow. Several other indexes can be considered during burner design, depending on the objectives defined previously.

Axial index: this index refers to the generation of gaseous re-circulations externally to the flame. It is directly related to the aspiration and mixing of secondary air by both primary air and fuel/conveying air streams. The axial index also has some relation to dust re-circulation at the kiln outlet area and the formation of build-ups at the nose-ring, including the so-called "shark teeth".

Tangential index: this index refers to re-circulations internally to the flame, which has influence in the ignition of the particles and flame spread. The tangential index has close relationship with the position and intensity of the first temperature peak in the kiln. Usually, during the burner design the dimensions of the nozzles at the tip are calculated in order to allow the variation of this index inside a predetermined range, depending on the adjustment of the primary air components. So, if the basis of design indicates narrower flames, the burner designer should calculate the tip dimensions to get lower values of tangential index in the burner operational range. On the other hand, if the basis of project indicates that the process would require wide and short flames, then the designer should calculate the burner operational range to present higher tangential indexes.

Turbulence index: this index refers to the position of both temperature peaks in the kiln. During the calculation of the burner tip dimensions the turbulence index is checked to be above a minimum value all over the range of adjustment of the burner. Usually this minimum value is calculated as a function of fuel type, fuel preparation (moisture and fineness), secondary air temperature and kiln dimensions. With relationship to that minimum value of the turbulence index it should be pointed out that:

- Bituminous coal finely ground (90%<#170) would require lower turbulence indexes than petroleum coke ground to the same fineness;
- One system operating with 100% petroleum coke ground to 95%<#170 would require higher turbulence index than another system operating with the same coke ground to 99%<#170.

Dispersion index: this index refers to the conditions of dispersion of the pulverized fuel cloud in the primary and secondary air streams. The dispersion index is related to the intensity of both temperature peaks and, as consequence, plays a major role in the study of the "thermal $NO_X$" generation.

Some additional factors, not directly related to characteristic dimensionless indexes must be considered during the burner design. The first one refers to the secondary air conditions (temperature, velocity distribution, dust content, etc.). The second factor is the burner pipe penetration into the kiln cylinder in view that the length of this penetration has proved to interfere in both kiln performance and clinker quality. Finally, the firing hood geometry has some influence in the flame characteristics as it interferes with secondary airflow pattern.

Someone could ask how to know in advance the proper ranges of the dimensionless indexes for a certain application. The answer can be finding searching an extensive database with construction and operational details of more than 200 kilns worldwide.

Another question that may arise is how to "customize" a conventional coal direct-fired system, as this type of configuration normally does not offer too many resources to process control. The answer is a hybrid system, a configuration that brings additional flame shaping primary air components to an existing single channel pipe and uses the lowest possible conveying airflow. The hybrid system is a concept, not a standard product. The possibility of its use should be carefully studied to check the benefits that could be expected, for each particular case.

## Conclusion

After taking account of all considerations above, it is possible to conclude that the combustion plays a major role in the rotary kiln operation, but any improvement in this area should be faced, first of all, as a "cooking" problem and not merely as a "firing" problem. It must be considered all the predominant variables of the process and not only those related to the oxidation of a fuel.