Clinker quality dramatically improved, while reducing fuel use

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Fire and the heat from it drives the cement making process, initiating the clinker producing reactions, and a large proportion of cement making costs (fuel cost, refractories, maintenance) are linked to combustion.

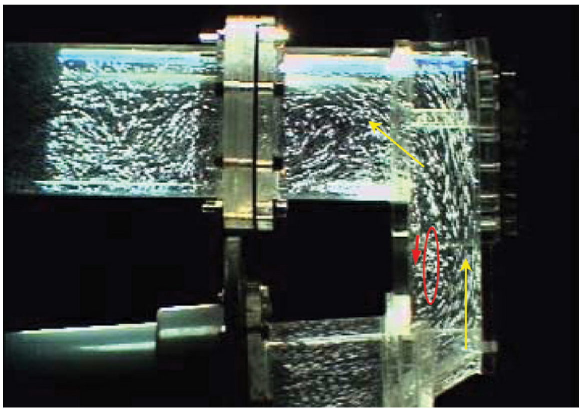
These are the obvious connections. Indirectly though, the combustion system also largely determines clinker quality and the grindability of clinker thus affecting the cement mill power consumption and output as well. In some cases, emissions restrict production, and combustion is a major factor in this too.

Delivering benefits through optimizing combustion is the business of FCT Combustion Pty Ltd. Scientifically based techniques developed by FCT and validated over the past 20 years have been proven to deliver large benefits to customers.

The effect of different burner design

All burner systems are not created equal - the nature of flames and heat transfer to the process certainly depends on the burner design, but just as much on the aerodynamics of the combustion environment. It is the combination, therefore, of a burner design and airflow patterns around it that determine the nature of the flame produced and the way the heat is transferred to the material. A burner design developed in isolation without reference to aerodynamics will behave differently in different kilns and is not an engineering solution.

In cement kiln projects, the difference between burners can be surprising. If benefits such as a 7% reduction in specific fuel consumption, 8% increase in production, 7% increase in cement strength, and significant increases in refractory life could be achieved, alongside higher percentages of much cheaper fuels such as petcoke being used, great results could be attained. In the case of a 1 million tpa cement plant, such benefits could run into several million dollars extra profit annually. Yet such benefits have been documented where kiln and calciner burners have been replaced by optimized equipment.



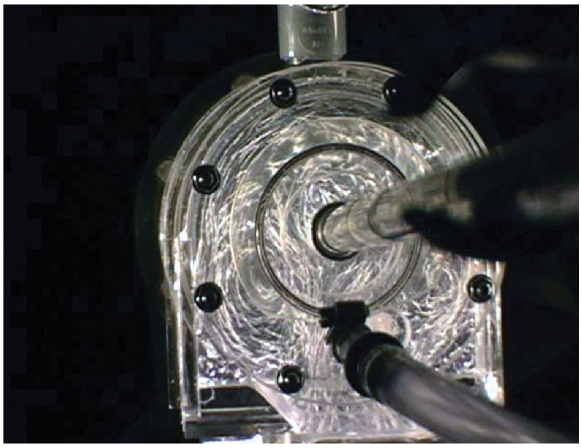


Figure 1. Examples of water bead modeling of kiln hoods.

Combustion equipment typically represents a small percentage of total plant capital, but its performance strongly influences the return on investment from that plant. It is, therefore, false economy to buy burners on price alone, as a non-optimized burner could cost a plant each year much more than the purchase cost of an optimized burner.

Combustion zone aerodynamics

The mass of combustion air, be it primary, secondary or tertiary in a cement kiln or calciner, is approximately an order of magnitude more than the fuel. The velocity and direction of this air is a major influence on the nature of the flame (size, shape, length, stability), as it is the interaction between this combustion air and the fuel coming from the burner that defines the flame.

The secondary air from the cooler undergoes several changes in direction before it enters the kiln, leaving potential for poor combustion aerodynamics in the region of the kiln burner. Likewise the calciner tertiary air inlets often produce stratification and recirculation in the calciner vessel, leading to poor fuel/air mixing.

Small differences in cooler throat, cooler bull nose, kiln hood, tertiary air off-takes, secondary air temperature/velocity and air leakage points to name a few, can have an enormous effect on the air flow patterns in the combustion environment of the rotary kiln. Tertiary air inlet design and location as well as tertiary air temperature and velocity will likewise determine the airflow patterns in a flash calciner.

Total system design considerations

With the complexities of the cement process, changes and solutions need to be implemented with a broad perspective in mind. In combustion systems especially, it is important to know and understand the implications of a new burner or fuel change on fuel efficiency, production rate, product quality, refractory life, emissions and operating stability for example. Without such proper investigation prior to a change, optimal outcomes are not possible, and disappointments are common.

In order to ensure that all relevant factors are taken into account in combustion system design, process parameters and kiln system design must be considered when devising a burner for a given application. FCT employs experienced cement and lime process experts and skilled combustion engineers to evaluate the whole system.

Part of the FCT design process includes the use of proprietary modeling techniques developed by the company and used since 1984. These techniques for analyzing the fuel/air interaction in combustion environments and for predicting heat release and heat flux profiles provide vital information and design parameters used in FCT burner designs. Both physical and mathematical modeling techniques are used in combination to arrive at the best solution or burner design.

Water bead modeling

Water bead modeling is used to examine the flow patterns inside a vessel such as a kiln or calciner. A model of the internal dimensions of a kiln, cooler, calciner or duct, for example, is drawn up from plant drawings and built using clear plastic material. Water, containing polystyrene beads with the same density as water, is passed through it under fluid dynamic conditions representative of the plant, and the resulting flow patterns observed with the aid of photography. Water flow patterns will be identical to those which air will follow in the plant, but more easily observable in the model. The process indicates potential problems such as unstable or reverse flow, high and low velocity areas and the cause of any undesirable flow patterns.

Acid alkali modeling

All combustion takes place in the following sequence:

- Mixing
- Ignition
- Chemical Reaction
- Dispersion of Combustion Products

Generally, ignition and chemical reaction (combustion) occur virtually instantaneously compared to mixing, so that the combustion process is controlled by the rate of fuel/air mixing. Hence the often heard phrase: "If it's mixed, it's burnt".

Acid alkali modeling is used to examine the fuel/air interaction in a given combustion environment. A physical model is designed and built in the same way as for water bead modeling, but burners are included. The model is designed, built and operated observing fluid dynamic similarity with the real plant in preference to geometric similarity.

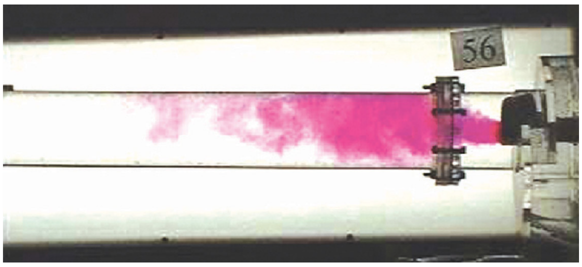


Figure 2. Modeling of a kiln burner.

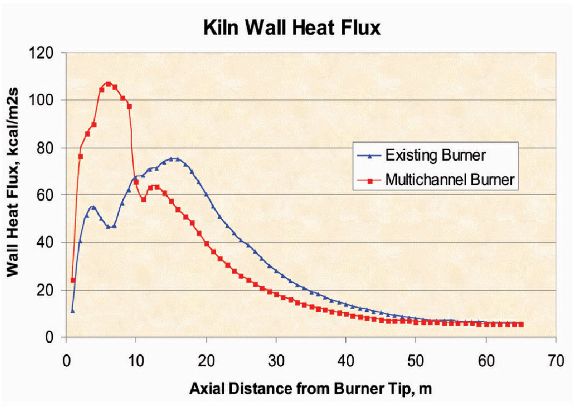


Figure 3. Heat flux profiles determined from mathematical modeling.

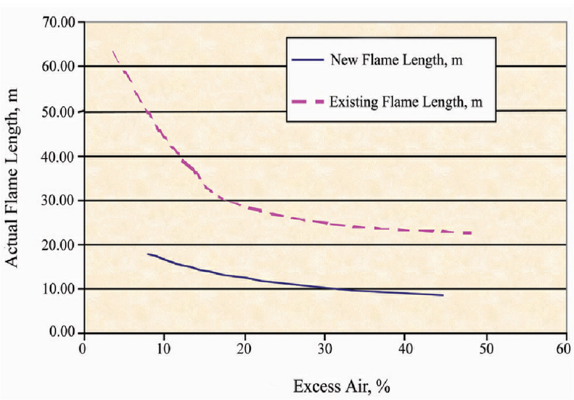


Figure 4. Flame length determinations from physical modeling.

The pink color of the alkali solution fades on reaction with the acid, leaving a trail of pink where there is un-reacted alkali, representing the kiln flame in the plant.

Air flow (represented by an acid solution) and fuel (represented by a phenolphthalein doped alkali solution), are introduced into the model kiln at rates, concentrations, velocities and positions representative of the actual plant conditions.

The resulting reaction between the acid (air) and alkali (fuel) is representative of the combustion reaction. The model allows solutions to be developed and tested to ensure optimized combustion prior to installing and commissioning a new burner on a specific kiln. Variables such as primary air quantity and momentum, burner position and insertion distance, excess air requirements and fuel injection velocities, can all be determined from the model so that trial and error after installation is eliminated. In cases where the kiln aerodynamics are not good for combustion, physical changes to hood, cooler throat, off-take ducts, and the like, can be modeled and the most cost effective design solution determined. In existing plants improvements have often been made with simple changes to refractory profiles.

Mathematical modeling

Results from physical modeling are corrected with mathematical models that take into account the kiln or calciner temperature (physical models are run iso-thermally) and the fuel properties. With some fuels, such as petcoke, the slow chemical reaction (combustion) may be significant and burn rates of these fuels must be considered in flame length determinations.

Modeling validation

Initial validation of FCT modeling techniques was carried out on a full size coal fired cement kiln in the late 1970s. Since that time, the company has conducted over two hundred model studies on operating plants, with the implementation of model results proving the methods used. The physical and mathematical modeling techniques used by FCT have been validated many times over, allowing their use with confidence in design or diagnostic applications.

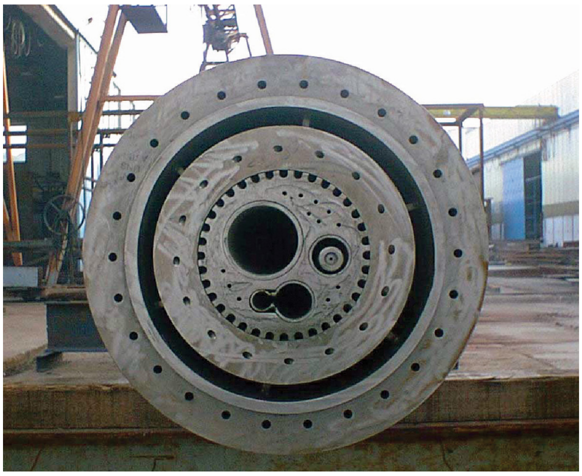


Figure 5. FCT burners are designed from a total system perspective.

Burner design

Designing kiln burners, therefore, is more than ensuring they will be able to deliver the correct fuel rate. Process operation, fuel properties, heat flux requirements, and kiln system aerodynamics evaluations should form part of the design process.

The most important factor is to match the momentum of the fuel and primary air coming from the burner with the momentum of the secondary air or tertiary air to achieve complete combustion within the limits of the kiln or calciner. At the same time, flame impingement on refractory or kiln materials is to be avoided, while heat flux must be tolerable for the refractory materials.

Cement kiln burners (except for Gyro-Therm burners) are turbulent jet diffusion burners that rely on friction between the burner jets (fuel and primary air) and the surrounding air to entrain secondary air into the fuel jet causing it to expand.

The relative momentum between burner and surrounding air is one of the key factors in designing a burner with the correct flame length and shape. The Craya-Curtet parameter indicates burner design parameters required for a given kiln system and operating conditions for adequate secondary air entrainment and hence fuel/air mixing Inadequate secondary air entrainment gives long lazy flames, high CO levels and can lead to kiln instability and build up problems.

Excessive burner momentum on the other hand can give a very aggressive flame with refractory problems and poor thermal efficiency due to high primary air levels.

The physical modeling may also indicate some aerodynamic issues that require correction through modifications to vessels/ducts, or a burner design/ location to counteract them.

Most burners have some degree of adjustability, but this is of limited help for optimization. Given the huge number of variables that exist and the relatively slow response time of the kiln to changes, optimization 'on the run' can be a time consuming and expensive business. In fact, the majority of burners adapted whilst in operation will never be truly optimized, as the inherent burner design will limit the true potential.

Changes in product quality, fuel efficiency, refractory life, etc, from a change in the burner setup can take weeks, months or even years to evaluate. There are always complicating factors in cement plants making it difficult to draw conclusions quickly. The value of modeling is in establishing optimum conditions on the model, and then applying this to the plant with minimal risk and disruption.

Kiln burner case study

General

Akcansa Cimento has a plant in Buyukcekmece with three kiln lines producing 1.85 million tpa of clinker. Kiln 3 is a preheater kiln producing 1650 tpd. The kiln uses solid fuel, with oil and gas as back up and warm up fuel. Akcansa Cimento was using a combination of imported and local coal with up to 30% petcoke, but was keen to use more petcoke since it is a cheaper fuel.

The main issues with the kiln system were that high levels of CO were observed at the kiln inlet that became worse with petcoke firing. Large build ups in the riser duct and kiln rings were also causing operational instability and became unacceptable if the percentage of petcoke increased above 30%.

Technical evaluations and modeling phase

FCT began the project with a site visit by two engineers to take plant measurements and gather operating data and plant drawings. This information was evaluated and a model of the kiln was designed and built to simulate kiln 3 operations.

Operating the model in the laboratory under simulated plant conditions revealed the cause of the problem. The kiln burner was not correctly designed for the kiln geometry and its operating conditions. The burner fuel was not mixing properly with the primary and secondary air, and a long lazy flame was produced in the kiln.

The flame was impinging on the clinker in the kiln, and when this occurs the sulphur in the clinker is readily converted to SO2 and carries through to the back of the kiln where it combines with lime and other minerals to produce build up that affects kiln operation. As the alkali content of the feed material was sufficient to combine with the sulphur introduced into the kiln system, it was concluded that the main reason for the sulphur volatilization was the flame impingement. The original burner was also tested at varying excess air levels, as sometimes a flame can be significantly improved if a little more excess air is present. In this case, however, the flame was very poor even at high excess air up to 30%.

The model clearly showed that the existing burner design was producing a flame that was too long and lazy for good kiln operation, and that impingement of the flame on the clinker was undoubtedly driving sulphur out of the clinker even at high excess air levels.

Following the technical investigations, the conclusions reached were that:

- The extant burner provides insufficient momentum to entrain the combustion air.
- The burner position and angle in the kiln causes flame impingement.
- The kiln is operated with too little excess air.
- Flame length is excessive at all reasonable excess air levels.

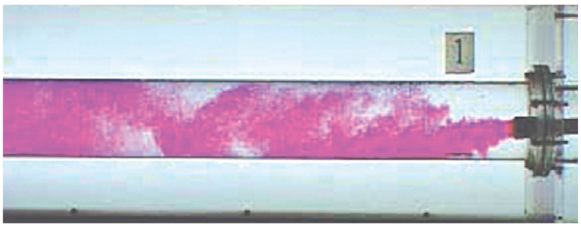


Figure 6. Model showing original flame in Akcansa kiln 3. Note poor fuel/air mixing, long flame and impingement on clinker charge in kiln.

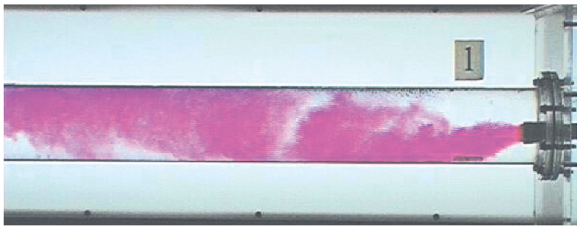


Figure 7. Kiln 3 original burner operating at 5% excess air.

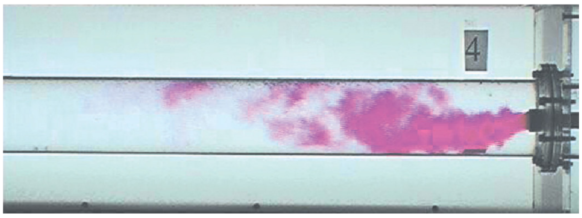


Figure 8. Kiln 3 original burner operating at 30% excess air.

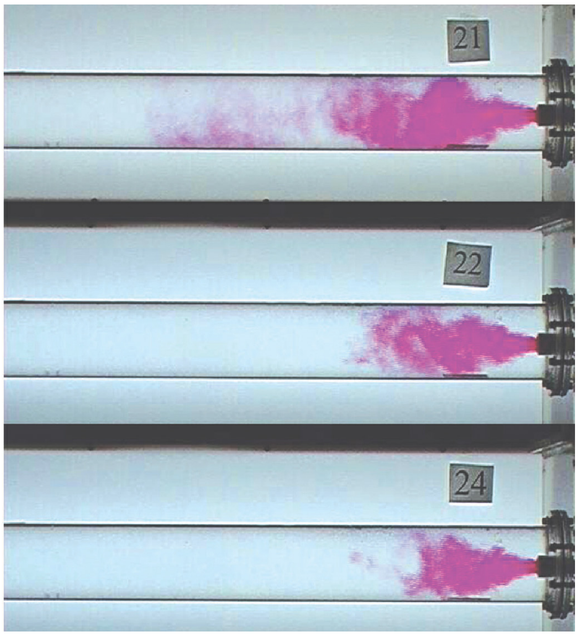


Figure 9. New kiln 3 burner showing flame length at 5, 10 and 30% excess air levels. Recommended condition to operate kiln with 10 - 15% excess air.

New burner design

Following the revelations of the modeling work, a new FCT burner was designed according to the FCT design parameters for momentum of the various burner jets in comparison to the secondary air momentum, and the new design was again tested in the model. The results were obvious, as shown in Figure 9.

The new burner design was further tested to find the optimal burner insertion distance/angle and swirl to axial momentum ratio.

The results from modeling the new burner were:

- The new burner provides substantially shorter flame length at all excess air levels.
- Satisfactory flame length and shape can be achieved at excess air levels of 10%.
- The burner performed best when aligned with the kiln axis.
- Correct burner momentum gives a shorter flame than the original burner.
- The burner performance was not particularly sensitive to insertion distance.
- Swirl must be below a critical level determined by the modeling or flame impingement would again be prevalent.

Project implementation

Following the modeling and technical evaluations, the results were translated into burner design parameters, and a new burner for kiln 3 was designed, manufactured and delivered to Akcansa. The burner was installed and commissioned in December 2002, and has operated extremely well since then, truly reflecting the expectations from the modeling work.

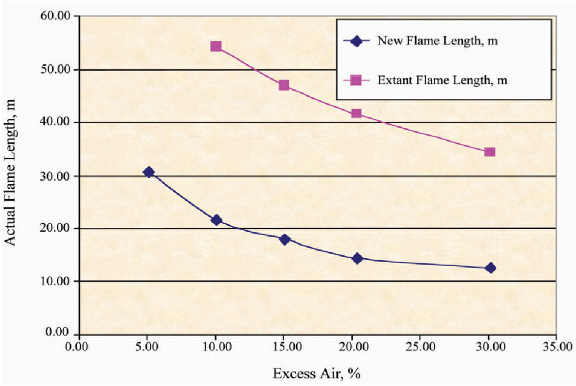


Figure 10. Flame length against excess air levels for original and new kiln 3 burner.

Figure 11. Modeling new burner with different swirl to axial momentum ratios.

Figure 12. Modeling new burner at different burner angles - performance is best with burner aligned with kiln axis.

The highlights from the installation have been:

- Petcoke usage has now increased to 100%; previously 30%.
- Clinker quality has improved dramatically, with 28 D strengths increasing by 10%.
- Almost no build up has been experienced in the kiln and riser, where previously build up was restricting kiln performance even with 30% petcoke.
- A fuel saving of about 45 kcal/kg was seen by the plant, partly attributable to a change in the coal dosing system and partly to the new burner.

The kiln is now operating in a very stable condition, producing excellent clinker more efficiently than before, giving an excellent payback on the burner investment. Following the success of this burner installation, Akcansa have also replaced the burners on the remaining two kilns from the Buyukcekmece site with FCT burners.

Conclusion

The use of scientific techniques for optimization of kiln combustion systems and for getting the best performance from a cement kiln has been well proven in many projects, and this case study again confirms the FCT approach.

Kiln burners are relatively cheap items, but the wrong burner can have a very high cost in lost opportunity, if output, fuel consumption, clinker quality and refractory life are not optimized. A kiln burner is one item of a plant that should not be evaluated by raw capital cost alone, but according to its total impact on plant economics.

Scientific techniques such as combustion and heat transfer modeling provide the basis for more confidence in designs, and reduce the risk of negative impact on plant economic performance.

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