Clay calcining technologies: the rotary kiln approach

The use of supplementary cementitious materials in the manufacture of green cement has been growing in popularity due to the associated environmental and economic benefits. Over the course of two articles, FCT Combustion is evaluating the different methods, opportunities and challenges of producing green cement. The first article (published in ICR, August 2020) explored the advantages of flash calcining technology, while this second article will instead explore the use of rotary kiln calcining technologies.

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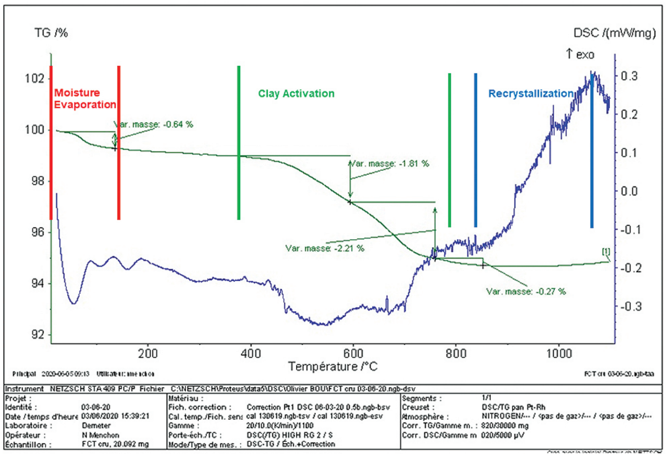
Central to the development of infrastructure worldwide, cement manufacturing – as with every energy-intensive industry – creates substantial amounts of pollutant emissions. Approximately eight per cent of the world's man-made CO_2 emissions arise from the cement production process.

The landmark Paris Agreement, supported by 196 countries around the world, has been a driver in the adoption of stricter policies for greenhouse emission reductions. Attention has become increasingly focussed on ways industry can reduce these emissions without significant cost increase or decrease in quality. One possible solution being widely considered in the cement industry is the partial replacement of clinker with supplementary cementitious materials (SCMs) to create what is known as 'green cement', so-called for its environmental benefits.

Figure 1: there is a specific temperature window for calcination before recrystallisation occurs



Sources of SCMs

Defined as amorphous silico-aluminous material with hydraulically-binding characteristics, popular sources of SCM in recent years have included natural volcanic materials, limestone, and industrial by-products such as fly ash and slag. However, natural materials are not available everywhere, fly ash is a byproduct of coal-fired power stations and therefore becoming scarce, and slag is heavily contested, which has increased its cost and reduced availability.

Subsequently, calcined clay – also known as pozzolan – has become an increasingly popular alternative due to its broad availability and low cost. This form of synthetic SCM has proven to be a sustainable alternative, offering both environmental and economic benefits to production, as well as contributing to enhanced durability and plasticity within the concrete.

Clay deposits tend to be very heterogeneous, but clays suitable for use as pozzolans typically range from 50-65 per cent SiO_2 and 17-38 per cent Al_2O_3. The content of sand and other impurities can vary enormously, usually in a range of 5-50 per cent. Several types of clay can be used, with kaolinite, illite and montmorillonite as the most-common types. Fineness of the clay after drying can range from a few micrometres to a few millimetres.

The main aim of the industrial processing of pozzolans is to remove hydroxyl group from the clay structure (as opposed to removing carbon dioxide from the limestone structure in clinker production), leading to the activation of alumina and silica oxides. It is important to note that too low a calcination temperature will not activate the clay completely and an excessive calcination temperature can cause the recrystallisation of the clay structure, as shown in Figure 1. Both cases substantially decrease the reactivity of the clay.

The temperature window between activation and recrystallisation is widest for kaolinite, which makes it easier to achieve complete activation without recrystallisation. Montmorillonite calcination is the most difficult to control with a narrow calcination temperature window.

The calcination of the clay can be achieved via various methods, but two industrial solutions are the use of a rotary kiln or a flash/suspension calciner.

Evaluating the best method for processing SCM

To heat treat the clay, either a rotary or

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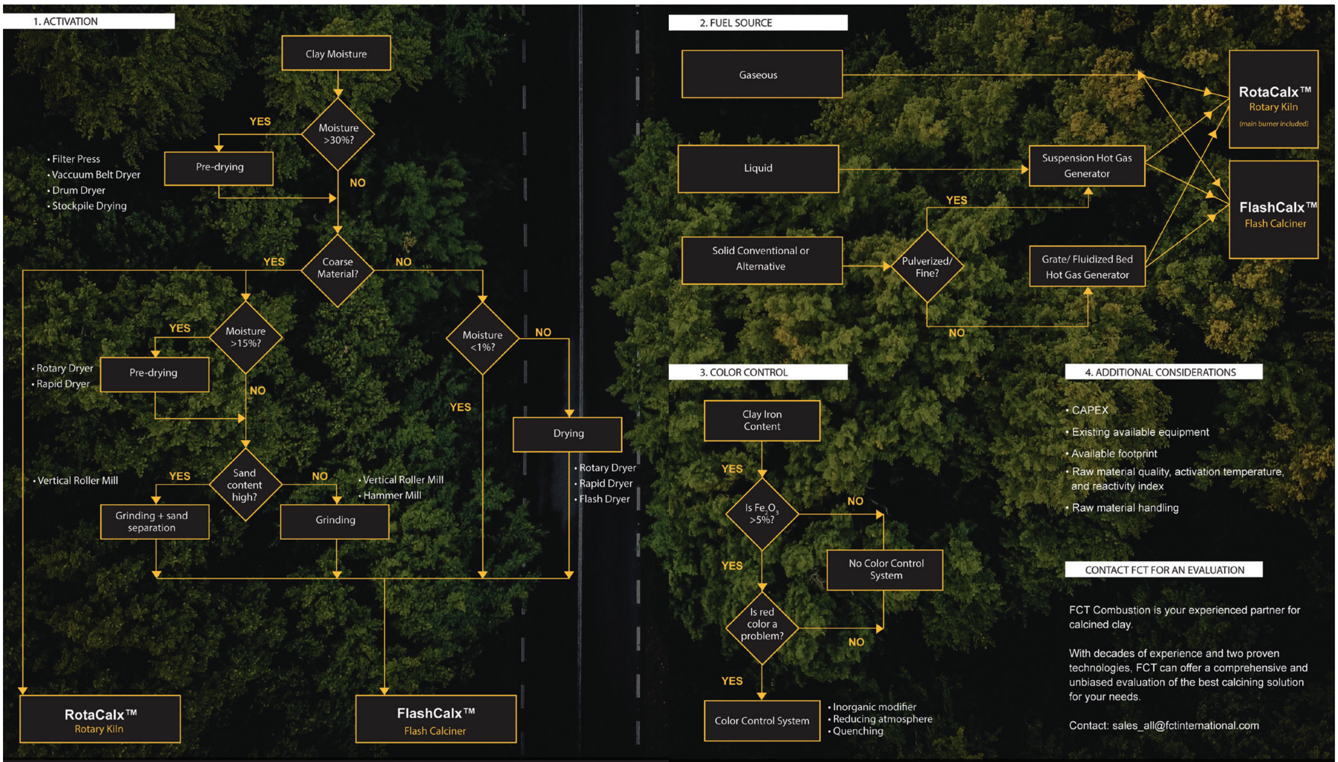


Figure 2: there are many factors that can influence whether a flash calcining or rotary kiln calcining technology is the most suitable solution for a given raw material

flash calciner are suitable, each with their own particularities. The best solution for a specific site depends on the types of fuel, available capex, availability of existing equipment and the characteristics of the raw material.

Trade-off studies should be conducted, and individual projects evaluated with their own specifics and particular costs to find the best solution on a case-by-case basis. FCT's specialist team provide assistance from conceptual engineering to EP(C) to production and have developed both types of clay calcining technologies to support customers in the production of green cement.

Offering both a flash calcining technology, FlashCalx™, and a rotary kiln calcining solution, RotaCalx™, FCT is an unbiased partner to assist producers in assessing which method is most suitable for each specific project, client, set of constraints and especially with each specific type of clay.

Although each case needs to be individually evaluated, Figure 2 provides a general outline of the decision-making process when assessing which method, technology and equipment is best suited to the given raw material characteristics and environment.

In the first article in this series, FCT investigated the advantages of using a flash calciner in the production of green cement. This article focusses on the use of a rotary kiln calciner. Advantages of the rotary kiln approach include:

- drying and calcination in the same piece of equipment
- no raw material grinding required.

Figure 3: FCT has developed the RotaCalx™, a specialist rotary kiln calcining technology

(feedstock only has to be sized to 50mm)

- existing, running or decommissioned equipment can be adapted for clay calcination, which fast tracks a calcination project execution
- longer, adjustable residence time, fostering inorganic modifier utilisation (for colour control)
- easy control philosophy, very similar to a calciner in a clinker kiln.

Producing green cement with the RotaCalx™

FCT Combustion has improved upon the traditional rotary kiln technology for clay calcination to develop RotaCalx™ technology. The RotaCalx is suitable for greenfield plants as well as brownfield projects where a kiln or some associated equipment may already exist.

Rotary kilns use the concept of contacting gas and material in counter current flow. As clays are by nature a fine material (in the range of 1-50µm), this poses a challenge of minimising dust backflow.

Using CFD simulation and FCT's wealth of experience in clay utilisation, the company has developed features to fight back-spillage and undesired material recirculation by engineered transfer chutes, smooth, low velocity

Table 1: summary of results of two case studies applying RotaCalx technology using existing equipment

	Existing 1000tpd preheater kiln		Mothballed 320tpd long kiln
Solutions	• Sizer, grizzly • Raw clay transport system • Combustion system evaluation		• Sizer, grizzly • Raw clay transport system • Pre combustion chamber • Water spraying
	• With lifters	• Without lifters	
Capex	Low	Lowest	Low
Opex	Low	Medium	High
Moisture (%)	20	20	10
Heat consumption (kcal/kg)	570	610	720
Production (tpd)	1050	750	450

transitions and enhanced secondary air split, in the kiln feed and front ends.

Lifters in the drying and preheating zone are used to improve heat transfer, thus decreasing the design length of this zone and maximising the length of the calcining zone. FCT's Turbu-Flex™ turbulent jet burner for gas, solid and liquid fuel, or Gyro-Therm™ precessing natural jet burner are recommended as these technologies guarantee robust combustion in such dusty, low secondary temperature burning conditions.

Case studies

There are various configurations readily available for clay calcination when applying RotaCalx technology. Two such options are demonstrated through the use of two case studies utilising existing machinery:

- a running ϕ4.1 x 60m long, 1000tpd clinker, coal-fired, four-stage preheater kiln with planetary cooler
- a mothballed ϕ3.2 x 90m long, 320tpd clinker, petcoke-fired, wet-process kiln with a short rotary cooler.

Case study 1 – converting a preheater kiln

An existing kiln, which runs for only six months per year for clinker production, was studied. The client approached FCT with an 11 per cent LOI, 20 per cent moisture, kaolinite, low-Fe, coarse clay to verify its capacity to produce SCM, with the kiln being able to swing from clinker to pozzolan and back.

In this case, low dust recirculation occurs due to the fact of having coarse feedstock, thus only minor modifications in the feed end of the kiln are required. A grizzly and sizer system for deagglomeration of the clay and the corresponding transport system conveys the feedstock to the kiln inlet chute.

The whole preheater is not utilised for clay, and the draught is bypassed from the riser to the dedusting system to reduce electrical energy consumption.

The combustion system was slightly modified to obtain a more robust flame.

To install the lifters, refractory would have to be removed, which would prohibit clinker production. By not installing lifters, the kiln will have the following capacities:

- 750tpd, 610kcal/kg, 35m drying zone for 20 per cent moisture
- 480tpd, 720kcal/kg, 39m drying zone for 30 per cent moisture.

By inspection of the data, the kiln is limited in production by its drying capacity. Although it leads to lower pozzolan production, this configuration minimises the capital expenditure.

Lifters increase drying capacity and debottleneck the kiln capacity to handle high moisture feed, which also optimises heat consumption: 1050tpd, 570kcal/kg, 32m drying zone for 20 per cent moisture.

Calcined clay capacity then becomes similar to that of clinker production.

Case study 2 – converting a wet-process kiln

A mothballed long wet-process kiln was assessed for its potential for clay calcination production. The clay had a 10 per cent LOI, 10 per cent moisture, kaolinite, low-Fe and fine clay.

In this case, having a fine feedstock and low kiln cross section demanded special care to minimise dust recirculation.

Again, the grizzly and sizer system for deagglomeration of the clay and the corresponding transport system conveys the feedstock to the kiln inlet chute.

The combustion system had to be updated to improve petcoke burning at a relatively low burning zone temperature. As the velocities between the kiln discharge and the coolers are critical for fine material, high primary air and a precombustion chamber was considered, and second air management applied. Also, a water spray system was considered for the short rotary cooler.

Due to the high length-to-diameter ratio and the low feedstock moisture, no lifters were considered.

The kiln will have a 450tpd capacity for clay calcination, with a heat consumption of 720kcal/kg.

Calcined clay capacity then becomes 35 per cent higher than that of its design clinker production capacity.

Table 1 shows a summary of the results.

Controlling the colour of calcined clays in green cement

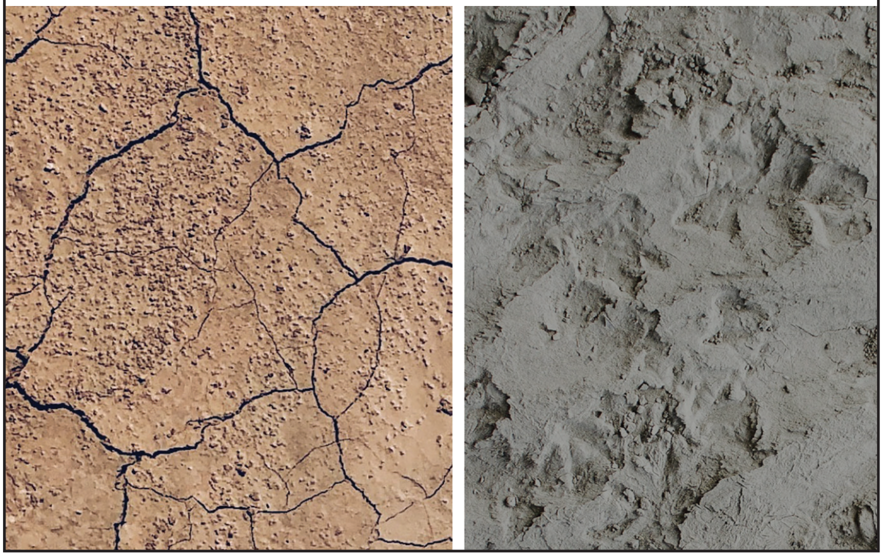
A key challenge to commercialisation of green cement in the past has been the ability to keep the traditional cement grey colouring, as the iron (Fe) content often found in clay can result in the product being a reddish hue depending on how it combines to oxygen (O).

Colour control can be applied, either by controlled atmosphere or inorganic modifiers.

Although the colour of the cement does not correlate with concrete performance, it can have an influence on the end-user's perception and ultimately be rejected in some cases. Different strategies exist to negate this issue, and each has its own advantages and disadvantages.

Iron compounds in the form of hematite (Fe_2O_3) have a reddish hue and, when in the form of magnetite (Fe_3O_4), have a dark-greyish hue. At higher temperatures, the iron is mostly in the form of magnetite. Therefore, it is important to keep the iron

Figure 4: FCT has developed a proprietary solution to ensure the traditional 'cement grey' colour is maintained, regardless of the iron content in the clay



in magnetite form during the cooling of the clay after calcination, somewhat like the requirements in white clinker manufacturing, to allow the traditional grey colour (or white, in the case of white clinker) to be maintained.

One strategy is oxygen depletion, where oxygen is minimised in the kiln operation.

This can be achieved by operating in close to a reducing condition (eg, in the back of the kiln where the oxygen monitor can be set at less than one per cent), injecting fuel close to the kiln discharge, injecting fuel mixed directly with the raw clay.

However, the associated secondary fuel source for colour control will require additional control and more equipment. Mixing fuel to the clay input to the calciner can also cause volatile organic and other hazardous emissions.

Another strategy is quenching, where magnetite is stabilised from high temperatures down to ~350˚C, so that it stays in its form. This can be achieved through water spraying or by direct cooling in an inert environment, though this results in higher heat consumption as heat is not recuperated. Energy is also required for the water spray action and, as more gases are exhausted to extract the water, the installation becomes less efficient so an investment in larger equipment would be required, resulting in increased thermal and electrical energy consumption.

FCT has developed an innovative alternative through the addition of inorganic modifiers to achieve the traditional grey hue, without impacting on fuel consumption or having a negative impact on emissions.

Depending on the structure and mineralogy of the clay, instances where the method has resulted in additional side benefits, including increased mortar compressive strength and improvement of concrete water demand, have been reported.

Although this method implies higher heat consumption, the study of inorganic modifiers involves the pursuit of low cost raw material, and overall savings through concrete performance improvement and clinker substitution.

Specialised support

Achieving environmental and economic benefits of green cement

These case studies have outlined how existing systems can be tailored to create a RotaCalx rotary kiln calcining system according to the raw material, fuel and specific conditions. Alternatively, RotaCalx can be supplied with all the latest technology embedded.

With a specialist team that has successfully commissioned tens of plants around the world for calcined clay, FCT is well placed to provide specialist advice to customers to ensure smooth adoption of their chosen production method.

FCT has developed a process to ensure best outcomes for the client (see Figure 5). The process, from initial evaluation to design and supply, is as follows:

1. raw material investigation looking at reactivity, colour, activation temperature, moisture and other factors
2. pilot plant tests and trial LC3 cement testing
3. plant-scale production of calcined clay and bulk cement plant trials
4. concept plant design and operating conditions, budget pricing
5. design and supply, commissioning, and support of clay calciner.

Shortening the learning curve

The use of calcined clay in substitution of clinker in cement production has many environmental and economic benefits. However, a detailed understanding of the clay activation mechanisms and its particularities is needed to enable optimal outcomes.

Having an experienced partner can avoid possible drawbacks and shorten the learning curve of the plant personnel. ■

Figure 5: FCT has developed a process to ensure best outcomes for the client