Not simply calcining

While the primary purpose of the calciner in a cement plant is to aid decomposition of calcite from the preheated raw meal, the need to lower CO_2 emissions and the introduction of alternative fuels has broadened the range of requirements that modern-day calciners need to address.

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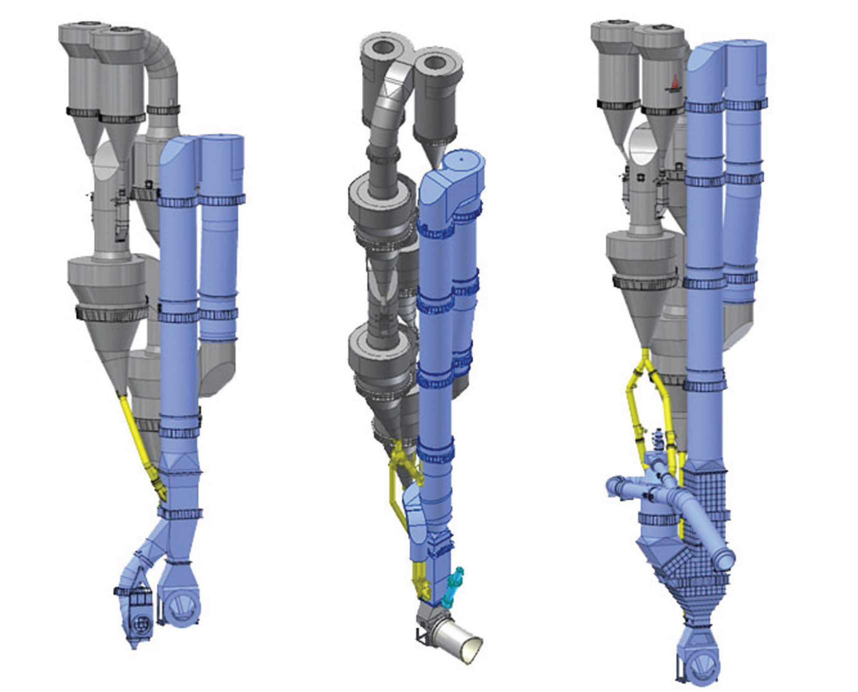
The main purpose of a calciner is still the decomposition of calcite from the preheated raw meal. This is the most energy-intensive process during the production of clinker in a cement plant. The use of calciners results in a considerable reduction of the kiln's thermal load, enabling much higher clinker capacities with the same kiln size.

But since calciner technology was first introduced into the cement world by KHD in 1965, additional requirements have arisen, leading to the development of different types of calciner. Today the main drivers for further development are the necessity to reduce emissions such as NO_x to meet emission limits and the use of alternative fuels to reduce fuel cost.

This has resulted in the development of different KHD PYROCLON® calciner types and the system's modular design, which is suitable for new plants as well as for retrofits.

Figure 1: the main purpose of the calciner is to decompose calcite from the preheated raw meal, which is the most energy-intensive process during clinker production



Calcining technology

Calcination process

The calciner, installed between the preheater and the rotary kiln and directly supplied via the tertiary air duct with hot recuperation air from the clinker cooler, is responsible for almost completely calcining the hot meal before it is fed into the kiln.

To perform the precalcination, 55-60 per cent of the total fuel is supplied to the calciner, which then can be expected to achieve a hot meal precalcination rate of 90-97 per cent.

Depending on the raw material and fuel used, this corresponds to a temperature of 860-890˚C at the calciner outlet. Higher precalcination rates result in a considerable rise in temperature in the calciner, which causes increasingly severe coating in the calciner, bottom cyclone and inlet chamber, leading to corresponding operational issues.

Combustion process

Combustion in the calciner takes place under totally different conditions from firing in the kiln. Due to mixing tertiary air with kiln exhaust gas, a lower oxygen concentration is present in most calciners. The preheated hot meal is supplied in the immediate vicinity of the fuel feed point. The energy liberated during the oxidation of the fuel components is directly used for calcining the meal, which results in low overall combustion temperatures. In addition, the gaseous CO_2 formed during the calcination reaction has a further retardant effect, inhibiting rapid fuel conversion.

Therefore, the combustion process in the calciner takes place under difficult conditions. The low partial pressure of oxygen and the low overall combustion temperature, caused by the high energy demand of the calcination reaction, result in a kinetic inhibition of the combustion reaction. To counteract this, the calciner should be designed for a retention time of at least 3s. Designing for the required retention time is therefore decoupled from the requirements of the calcination process, so that it is now only dependent on the quality of the calciner fuel.

Nowadays, the usual gas retention times of the calciner are 3-4s for lignite, hard coal, natural gas and oil and over 5s for fuels that are difficult to ignite, such as anthracite or petcoke. The technological characteristics of fuel – taking solid fuels as an example – that influence good burn-out under the combustion conditions in the calciner are then essentially restricted to its reactivity (ignition and char burn-out) and its particle size. The reactivity can only be influenced by the drying and size reduction of the fuel, and is essentially dependent on the content of volatile components. The higher the content of volatiles, the better and faster the ignition of the fuel. The particle size depends on the extent to which the fuel can be costed and effectively ground. The finer the particle size distribution and the lower the amount of oversize material, the shorter the time required for complete burn-out.

In contrast to these primary fuels, the number of possible secondary or alternative fuels is far larger, which significantly increases the range of difference in their combustion properties. In most cases, alternative fuels have higher moisture contents, consist of larger particles and have a lower energy content. The moisture content causes delayed ignition of the fuel and the larger particle size results in a longer burn-out time. Therefore, the calciner geometry has to be designed to achieve gas retention times of >5.5s to obtain the operational flexibility needed for the burning of fuel with constantly altering properties.

KHD PYROCLON calciner series

The standard calciner types of the KHD PYROCLON series are based on in-line calciners in which the tertiary air and kiln exhaust gas ducts both lead into a common riser duct (see Figure 1).

Based on PYROCLON R it is possible to install a staged combustion system for reducing NO_x emissions by modifying the connection of tertiary air duct to the riser duct, resulting in so-called PYROCLON R Low NO_x AF.

If increased AF usage requirements are of the highest priority, the addition of a burning chamber is a proven solution (PYROCLON R CC).

Other PYROCLON calciner types are installed as special solutions for system conversions, such the PYROCLON S without tertiary air, or the PYROCLON RP as a separate-line calciner operated with pure tertiary air, not mixed with the kiln exhaust gases.

Calciner requirements

In addition to calcining raw meal, the main criteria for the calciner design are complete burn-out of the calciner fuel without emission of organic, toxic residues, enough flexibility to enable the broadest possible range of fuels to be burnt, minimisation of emissions such as NO_x and CO, and easy control.

Figure 2: finely-ground solid fuels are fed to the calciner via the patented PYROBOX

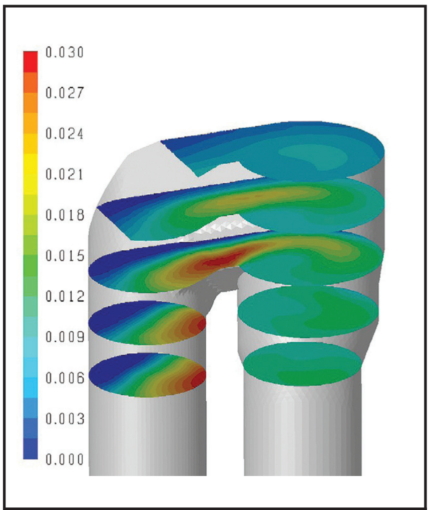


Figure 3: PYROTOP compact – CFD study shows the high efficiency of mixing in achieving an improved burn-out

Oxygen

Sufficient oxygen to suit the combustion properties of the fuel must be present and distributed as uniformly as possible over the cross-section of the calciner. The mixing of tertiary air with kiln exhaust gases, which involves a reduction in partial pressure of the oxygen, is a disadvantage of conventional in-line calciners. To assure more uniform mixing, the design of the PYROCLON R calciner includes high-velocity injection of the tertiary air directly into the top end of the turbulent zone of the kiln orifice.

In the PYROCLON R Low NO_x calciner the opposite principle applies. Here, the tertiary air is fed in further above the orifice, providing the longest-possible section with oxygen deficiency conditions, to assure substochiometric combustion and reliably reduce NO_x compounds.

Temperature

Generally, a high temperature level enables quick drying, pyrolysis, ignition and corresponding burn-out of the fuel. However, in a typical calciner, the high energy demand of the meal calcination reaction and the associated reduction in the surrounding temperature is a limiting factor. To allow better compensation of the low temperature level, finely-ground solid fuels are fed to the PYROCLON calciner via the patented PYROBOX (see Figure 2). The fuel is mixed with the preheated raw meal in the PYROBOX and, thus, dried and heated further before it enters the calciner. Joint feeding of the preheated raw meal/fuel mixture assures good distribution throughout the gas stream. Fuels of lower density or with coarse particle fractions are preferably fed in below the meal feed point to use the higher gas temperatures at this location.

Retention time

One important criterion for calciner design is the gas retention time. Theoretical calculations and practical experience in terms of the degree of hot meal calcination show that at the stated temperature window and normal fineness of the preheated hot meal, the target calcination rate of 90-97 per cent is achieved in less than 3s.

The retention time in the PYROCLON calciner is determined by the diameter and the length of the calcination zone. The PYROCLON calciner for the use of alternative fuels is designed to ensure a retention time of at least 5.5s.

Turbulence

In addition to the retention time in the calciner, turbulence is the most important criterion for ensuring good fuel conversion. To create turbulence, the PYROCLON calciner is equipped with the so-called PYROTOP compact. This compact mixing chamber is installed at the reversal point of the calciner and ensures perfect mixing at this point between the residual oxygen, the burning particles, precalcined meal and the waste gas. Theoretical studies (see Figure 3) and practical experience from converted plants prove the high efficiency of this mixing in achieving better burn-out and correspondingly lower CO emissions.

Gas velocity

The gas velocity in the PYROCLON calciner is considerably higher than that in 'pottype' calciners.

This higher gas velocity provides the advantage of a higher degree of turbulence and results in better mixing and safe transportation of fuel and meal particles in the gas stream.

An additional benefit is the minimised risk of material entering directly into the kiln if the plant is running at reduced capacity.

Emissions

The PYROCLON R Low NO_x calciner enables application of staged combustion (see Figure 1 – centre). In the oxygen-deficient zone, part of the supplied fuel is converted substochiometrically. This generates unburnt gases that have the potential to reduce NO_x. Depending on the reactivity of the fuel, NO_x levels significantly lower than 500mg/Nm^3 of dry exhaust gas (referred to 10 per cent O_2) are achieved. To meet more stringent NO_x emission limits or to enable the use of poorly-reactive fuels, the calciner can be additionally equipped with an ammonia injection (SNCR) system.

Figure 4: functional principle of PYROCLON redox

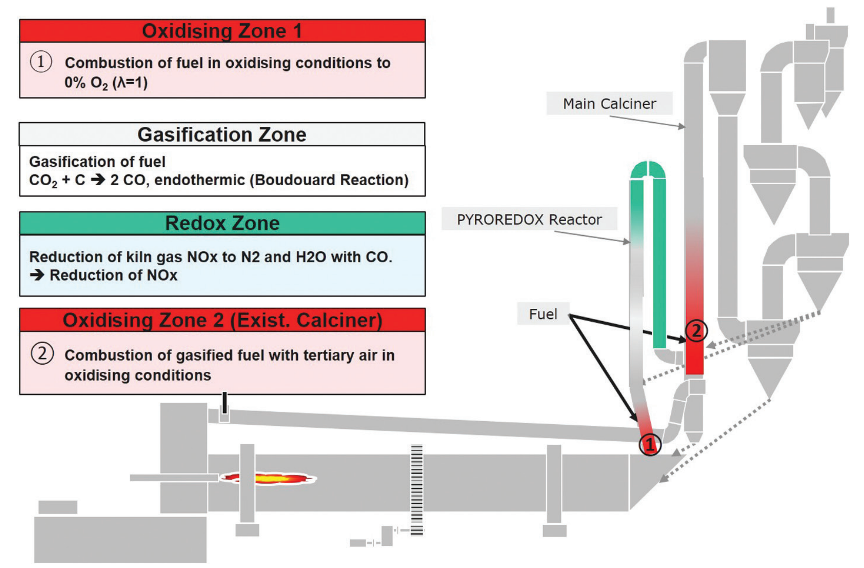
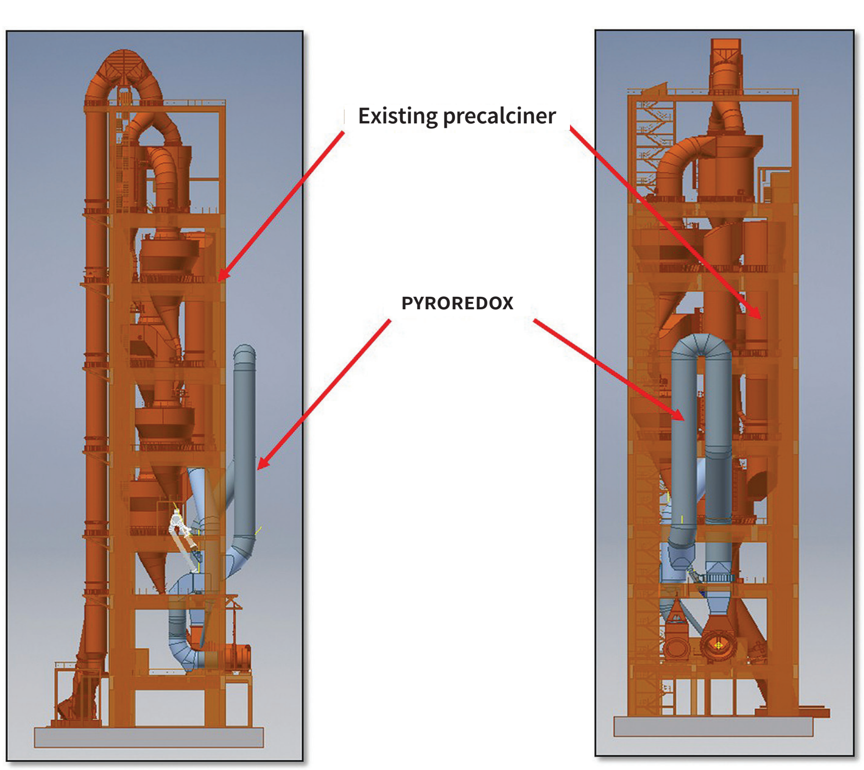


Figure 5: PYROCLON redox arrangement

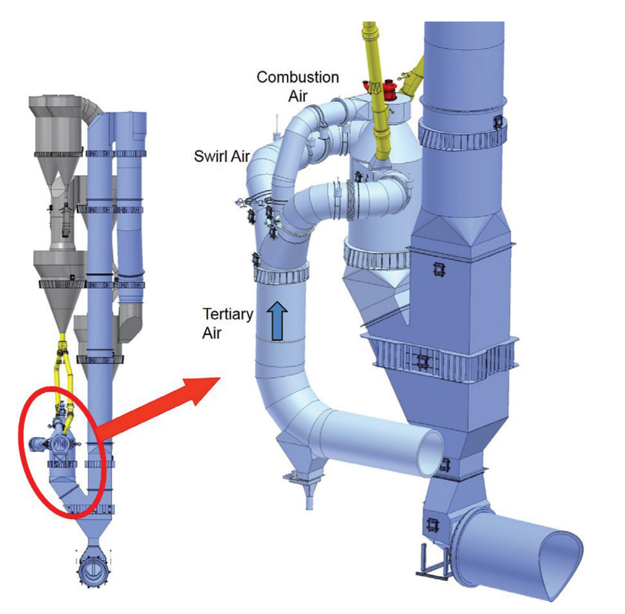


An additional primary measure to reduce NO_x emissions with low volatile fuels is the newly-developed PYROCLON® Redox calciner. The PYROREDOX system, patented by KHD, serves as a gasifying reactor which is connected upstream to the main calciner. The functional principle is shown in Figure 4. As shown, the main calciner itself is disconnected from the kiln inlet chamber but as usual supplied with tertiary air. Therefore, the PYROREDOX reactor is separating the process in fuel gasification and NO_x reduction in the PYROREDOX . The calcination and gasified fuel then burn out at low temperatures in the calciner. To enable this, up to 100 per cent of the fuel will be fed to the PYROREDOX from the penultimate cyclone. Shortly after the connection to the main calciner, only some remaining fuel, along with the major meal portion, is introduced via a second feeding point and serves for the calcination and the final burn-out of the deNO_x gases. This promising concept is planned for new installations as well as for retrofits. The typical PYROCLON PYROREDOX arrangement is shown in Figure 5. The NO_x reduction potential for low-volatile fuels is expected to be in the same range of secondary measures such as SNCR. The benefits are obvious as the system is suitable for many types of calciner fuels, no investment in secondary measures is required and savings can be made in terms of reagent consumption costs. Two PYROREDOX systems have already been sold. One is currently being erected as part of a retrofit while the other system is a new installation with a Low NO_x AF PYROCLON calciner.

Alternative fuels

Depending on the quantity and quality of the alternative fuels, the firing rate in standard in-line calciners is limited. To increase the quantity as well as enable usage of lower-quality alternative fuels the installation of a combustion chamber is the right choice. The combustion chamber is mounted vertically on the side of the riser duct of the calciner. The tertiary air is supplied directly to the combustion chamber in three partial streams. One of these partial streams, the 'top air', is fed into the top point of the combustion chamber in the direct vicinity of the combustion chamber burner. This top air is regulated by a control damper and is actively used to control

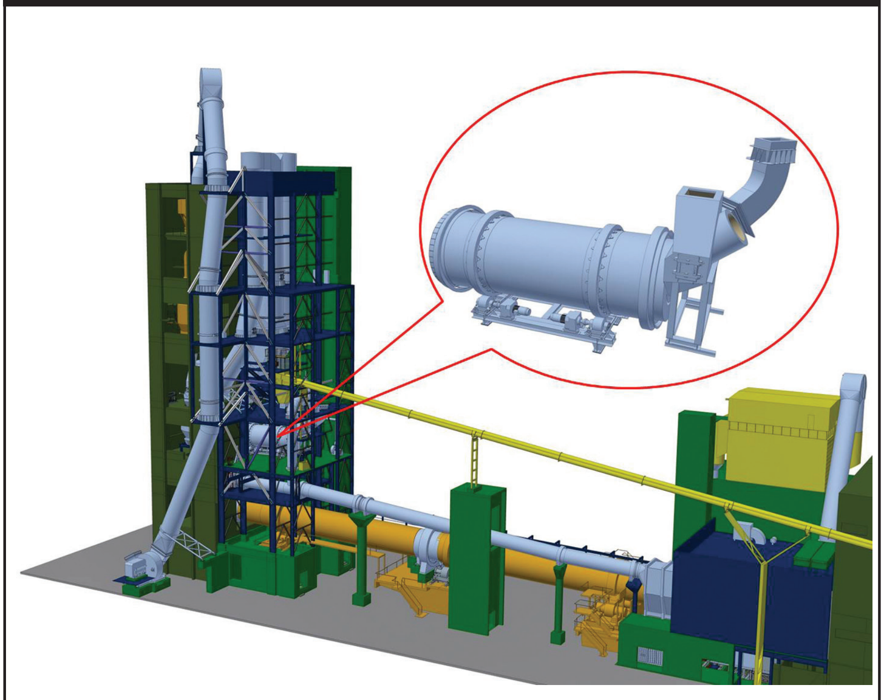
Figure 6: PYROCLON R CC (combustion chamber) – the preheated hot meal supplied from the penultimate cyclone is split and fed into the two tangential air ducts



the temperature. The two other partial streams are called ‘swirl air’ and are fed tangentially into the upper cylindrical section of the combustion chamber. The preheated hot meal supplied from the penultimate cyclone is split and fed into the two tangential air ducts (see Figure 6). Compared to conventional in-line calciner high oxygen concentration, there is little presence of meal in the flame zone and correspondingly-high temperatures are clear benefits in terms of fuel ignition and combustion.

The high oxygen concentration results from the use of pure, hot tertiary air in the combustion chamber. The burning mixture does not mix with the gases from the kiln until it reaches the end of the combustion chamber. The high temperatures of over 1200˚C at the centre of the combustion chamber are achieved by feeding the hot meal into the tangentially-connected tertiary air ducts. The meal is guided into a radial entry line and, due to the swirl, mainly becomes concentrated near the combustion chamber wall. At the centre of the combustion chamber, the meal concentration remains low. Therefore, the chamber is divided into two zones, the area of the flame and the area close to the combustion chamber wall. The hot flame, located in the centre of the combustion chamber, expends most of its energy on heating up the gas and the fuel particles, which accelerates the combustion reaction. The concentration of meal at the combustion chamber wall protects the refractory lining against thermal overload. The complete fuel burn-out subsequently takes place in the calcination section. Including the combustion chamber, an overall gas retention time of normally more than 7s is achieved.

Figure 7: principle of the combustion reactor module added on to the calciner. A split stream of tertiary air is routed through the PYROROTOR, which is connected between the tertiary air duct and the precalciner riser duct



Highest flexibility in regard of alternative fuel quality and particle size is provided by KHD’s newly-developed PYROROTOR® combustion reactor. The PYROROTOR rotary kiln reactor, patented by KHD, finds its first technical application as part of a customised solution mutually developed with a cement plant producer to fulfill the extensive demand for alternative raw material and fuel scenarios. The developed CALCINER-PYROROTOR® solution allows the utilisation of lump size fuels which are normally not suitable for the utilisation in a standard calciner system. Material residence time inside the PYROROTOR is in the range of 10min. The principle of these modules added on to the calciner is shown in Figure 7. A split stream of tertiary air is routed through the PYROROTOR. The PYROROTOR itself is connected between the tertiary air duct and precalciner riser duct. The coarse alternative fuels can be nearly completely combusted inside the PYROROTOR reactor. Temperature can be controlled by availability of oxygen. Hot waste gas from the reactor is entering the calciner for further calcination process and complete gas burn-out.

Conclusion

In addition to the main purpose of the calciner, which is the calcination of preheated meal, modern calciners are expected to deliver high usage ratios of alternative fuels as well as the reduction of NO_x emissions. To follow these market requirements KHD developed a modular calciner system that cannot only be integrated into new kiln lines but also can be used for retrofit projects. The modular system contains the PYROTOP mixing chamber for improving the burn-out, different types of calciner burners like the PYROBOX burner, staged combustion systems and gasification systems like the PYROREDOX reactor for reducing NO_x emissions, and special combustion reactors like the combustion chamber or PYROROTOR for the flexible use of a wide range of alternative fuels. ■