

## Criteria for the selection of precalciner kilns

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### 1 Introduction

New rotary kiln plants are equipped with precalcining technology without exception today. Selecting the proper kiln system configuration for a given project is a complicated task that involves a number of considerations. During the initial planning stage it will often be useful to consult experts who have gained a wealth of experience from a large variety of cement projects. As a general guide to choosing the most suitable new kiln system, a number of criteria should be considered, the most important of which are as follows:

- Production and investment costs
- Operation and maintenance
- Energy efficiency
- Raw material properties
- Burning conditions
- Fuel mix (e.g. utilization of alternative fuels)
- Fuel properties (e.g. volatile components, calorific value, particle size)
- NO<sub>x</sub> reduction potential

Starting with the selection of a kiln system the individual strategy or objective of the cement producer, like maximum production capacity or enhanced use of secondary fuels must be taken into account. The above mentioned criteria are all important for the selection of the complete kiln system. However, the expected fuel mix, the fuel properties and NO<sub>x</sub> reduction potential play also a decisive role for the selection of the right calciner design itself.

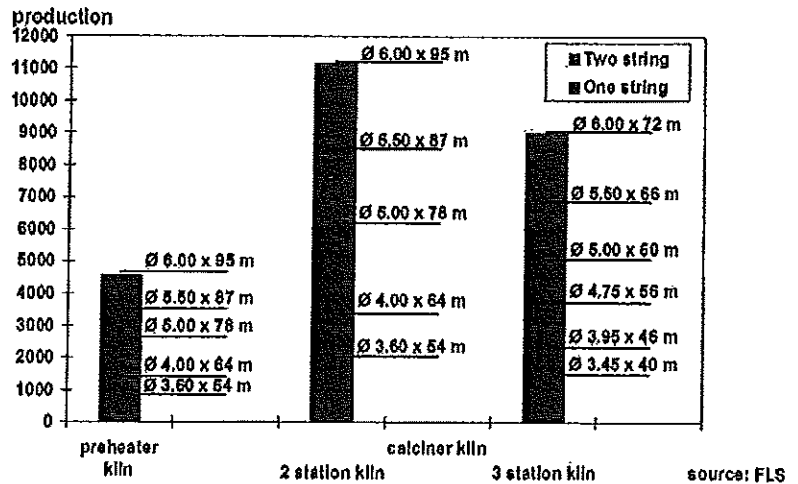


Figure 1 Different preheater/precalciner configurations as a function of production capacity

## 2 Common criteria for the complete kiln system

### 2.1 Production capacity and investment costs

For any given production capacity, a precalcining system requires considerably smaller rotary kiln dimensions than a suspension preheater system. Usually it is recommended to build a rotary kiln with a diameter not exceeding 6 metres to ensure reasonably long lining life. For this reason, it is advisable to employ a precalcining system (with tertiary air duct) for kiln production capacity usually above 2000-2500 tpd. Single-string preheaters are preferred as long as the cyclone diameter remains within reasonable limits (max. 10 meters). Figure 1 shows different preheater/precalciner configurations as a function of production capacity along with standard kiln sizes. The usual kiln system is also shown for comparison, although this would not normally be a preferred solution for a new installation.

### 2.2 Operation and maintenance

These days, precalciner systems are generally preferred as common kiln systems due to the fixed degree of calcination of the material entering the kiln and the shorter material retention time in the system. Longer lining life and lower kiln refractory weight enable precalcining kiln systems to remain in operation for longer periods than conventional preheater kilns, thus reducing down time and refractory costs. Generally, the maintenance costs of a single-

string kiln system are lower than those of a double-string kiln system. Consequently, a single-string preheater is always preferable to a double-string preheater for small-to-medium production capacities, provided there are no tower height limitations.

### 2.3 Raw material properties

Beyond burnability and moisture of the raw material mix also the content of volatile components (potassium, sodium, sulphur and chlorine) play a decisive factor when choosing the appropriate kiln system. The resulting internal circulation of volatile matter in the kiln system and the concentration of these components in the kiln gases flowing to the preheater eventually reach such levels that it affects kiln operation. The higher concentration of volatile matter increases dust stickiness which can cause coating formation and cyclone blockages. The type of process selected sets an upper limit to the acceptable content of the various volatile components in the raw mix without installing a bypass system. The upper limit is lower with a precalcining system (with tertiary air duct) than with a conventional kiln system due to the higher volatile concentration in the gases of a precalcining system which is caused by the lower specific gas flow through the kiln. If the content of volatile components in the raw mix is higher than a certain limit, the kiln system must be equipped with a bypass system that enables extracting some of the kiln gas from the system before it reaches the preheater. In this way, internal circulation of volatile compo-

nents is reduced. Bypassing a few per cent of the kiln gases is usually sufficient to reduce the internal circulation of chlorides in the kiln system to an acceptable level. To produce low-alkali cement it may also be desirable to remove large quantities of alkalis through a kiln bypass. This requires a high bypass rate, and a precalcining system with tertiary air duct will be appropriate. For a given amount of kiln gas extracted, higher alkali reduction is obtained in a precalcining system than in a conventional kiln system.

### 2.4 Burning conditions

In a conventional preheater kiln (without precalciner) it is only possible to burn fuels in the kiln inlet up to 25 to 30%. This means that 70 to 75% have to be fired in the main firing. In precalciner kilns usually up to 65% of the total fuel energy input is fired into the calciner and a minimum of 35% through the main kiln burner. Therefore, the total kiln system is less sensitive to fluctuations for example in fuel quality. On the other hand, changes or fluctuations in the main kiln firing have a significant effect on kiln operation. Therefore, - if alternative fuels are used - most operators first increase the alternative fuel substitution in the precalciner until nearly 100% related to the calciner firing. After this, they start to burn alternative fuels also in the sintering zone firing. Problems can occur especially if a kiln is quiet short. As a short precalciner kiln needs a short and hot flame in the sintering zone it is difficult to burn a high quantity of coarse and low reactive alternative fuels in the kiln firing. Therefore, in a precalciner kiln it is even more important compared to a conventional preheater kiln to install a burner which creates a hot and a not too long flame even with low reactive fuels.

The main modifications which have been carried out with respect to the main kiln burner are:

- the increase of the total axial momentum
- the increase of the injection velocity of the axial air
- the increase of the transport velocity of the coarse waste fuels

Even with these modifications it is in most cases still not possible to burn 100% waste fuels in the kiln firing.

In the calciner alternative fuels are usually fed directly. In individual cases they are also introduced via a multi-channel vertical burner directly or into a combustion or gasification device.

## 3 Criteria for the selection of the calciner design

### 3.1 Calciner design

All suppliers offer calciner concepts that are innovative and nevertheless technically mature for the production of cement; for new plants as well as plant modernisations and tailored to the desired production capacity.

In figure 2 different available calciner designs are schematically illustrated. Besides the classical separate-line configuration for multi-string plants (especially for upgrades) and the proven in-line configuration also the hybrid solution can be advantageous for plants with higher clinker capacity. In this case the calciner string and the kiln string are both equipped with calciners in order to maintain equal quantities of gas and numbers of cyclones in both strings. In order to use lumpy fuels it might be useful to incorporate a pre-combustion chamber, or pre-gasification device in the calciner. The calciner fulfils in each case the function of heating-up and calcining the raw material and of burning the supplied fuel. The burning of the different types of fuel takes significantly more time than heating-up and calcining the raw meal and is therefore the

determining factor for the dimensioning of the calciner.

In addition to assuring complete combustion of the fuel, the calciner has to function with great flexibility, in order to cope with the wide range of fuel grades used (from highly reactive to extremely unreactive). Today, great importance is placed on systems incorporating also measures for emission reduction, and this trend is increasing. Therefore not only the increasing use of alternative fuels but also the NO<sub>x</sub> reduction potential is a main driver when selecting a new calciner system.

The enormous cost pressure the cement industry is facing has led to a continuous rise in the utilisation of alternative fuels over the past years. On average, 20% of the energy requirement in Europe is currently covered by alternative fuels; this figure may be as high as 80 - 90% in individual cases. Precalcining systems provide particular flexibility, as alternative fuels can be fed at several firing places at different temperature levels. To comply with the very strict and tightened environmental regulations (e.g. BREF-document [1] and the draft of the Industry Emission directive [2]) also the necessary application of staged combustion and /or SNCR in the calciner are more and more important. The aim to be pursued in this context should be to achieve high flexibility with regard to the fuels utilised and controllable coating formation in the calciner on the one hand, and effective NO reduction and good burn-out on the other hand.

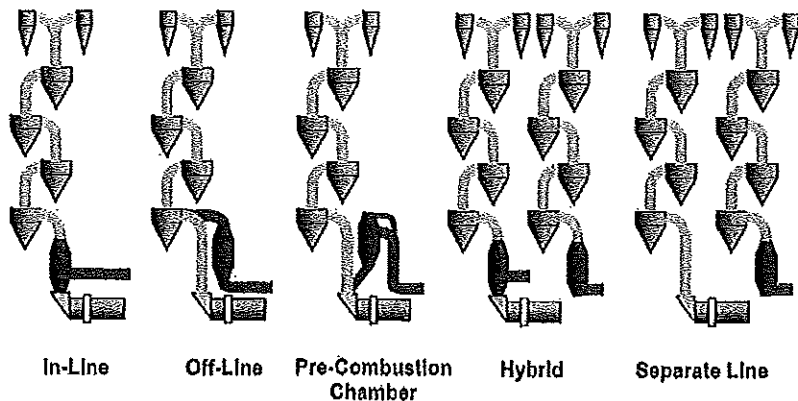


Figure 2 Schematic illustration of different precalciner concepts

### 3.2 Fuel mix and fuel properties

All kiln systems can be fired with natural gas, heavy fuel oil, standard-coal grades or a combination of these fuels. Special fuels, however, require special considerations when selecting the appropriate kiln or calciner system configuration:

Fuels such as anthracite, petroleum coke, and other low-reactive fuels are widely used in the kiln firing which operates at high temperatures up to 2,000°C. The kiln burner, however, should be of the modern flame-shaping type, which has a suitable flow pattern that ensures rapid and stable ignition. The use of low-volatile fuels in the calciner (that usually operates at a temperature around 850-900°C) can cause problems unless the system is provided with a meal staging facility or a so-called hot spot (combustion chamber). All calciner systems can be suited for the use of low-volatile fuels if they are designed to allow raising the temperature in the lower parts of the calciner without affecting the rest of the system. This is accomplished by means of a dividing gate that leads a relatively large amount of raw meal to the calciner and/or the kiln riser duct (meal staging).

In a combustion chamber low grade fuels can be suited together with a high calorific fuel at a temperature up to 1,200°C outside the calciner itself. Combustible alternative fuels can be used in all kiln systems as a substitute for fossil fuels, provided that such

substitution does not result in negative consequences for the kiln system operation. Each type of alternative fuel must therefore be assessed on an individual basis, by evaluation (the impact on clinker quality, production capacity, kiln system stability and emissions).

Also health and safety issues must be taken into consideration. For many solid alternative fuels products, the physical size may be a challenge.

#### Utilization of alternative fuels

The type of alternative fuel to be used in a calciner depends on various factors, the most important of which are summarised in table 1. In addition to economic criteria, physical (e.g. density) and chemical (e.g. chlorine, sulphur, alkali and phosphate content, reactivity, fuel-induced nitrogen content and heavy metal content) criteria play a decisive role in the selection of alternative fuels as they may have an impact on kiln operation and emissions, respectively.

Alternative fuel utilisation contributes to lowering the cost of clinker production. An additional advantage might arise from the reduction in CO<sub>2</sub> emissions. The additional effort and expense involved in storing (hall, silo, tank), preparatory processing if necessary, conveyance and metering of the alternative fuels must, however, not be underestimated. Furthermore, additional monitoring measures must be introduced to ensure product quality. If the quality of the alternative fuels (calorific value, chlorine content, inter-

ferents etc.) fluctuates, continuous monitoring is required.

Also the moisture content relative to calorific value is a very important parameter. Moisture content is in most alternative fuels higher than in conventional fuels. Accordingly, the exhaust gas volume flow may increase when conventional fuels are replaced by alternative fuels. Furthermore, changes in combustion-related variables, such as specific air requirement, specific flue gas volume flow, etc., must be taken into account. Experience shows that the maximum proportion of alternative fuels that can be utilised may be limited by the capacity of the ID fan, since the fans were initially designed for the use of conventional fuels.

Depending on the type of fuel to be utilised, stable fuel metering is fairly complicated. It may therefore be reasonable in individual cases to subject alternative fuels to thermal pretreatment in a separate device first. Basically, two types of plants must be distinguished: in gasifiers the fuel is pyrolysed under extremely low-oxygen conditions, and the lean gas thus produced is subsequently fed to the calciner as fuel. The energy required in this process is either supplied externally or released in a partial combustion process. In precombustion chambers, by contrast, a considerably higher proportion of fuel is converted at over-stoichiometric or slightly under-stoichiometric conditions, respectively. Energy is used - similar to the gasifier - to decarbonate the kiln feed. The unburnt part of the fuel (residual coke) can also subsequently be fed to the calciner.

The devices for thermal pretreatment existing in Europe up to date are the circulating fluidized bed from Lurgi, precombustion chambers from Polysius, KHD, A TEC and Technip Cle and the so called Hot Disc of FLS. The operating experience gained shows that all methods work reliably, although process engineering expenditure should not be underestimated. The circulating fluidized bed is suited for intake of fairly fine-grained fuels only, while the precombustion chambers and the Hot Disc are rather designed for coarse fuels. But also fine-grained fuels can be treated with these technologies. In the precombustion devices usually waste tires, sticky materials, tire chips or fuels with a low volatile content

Table 1 Evaluation of alternative fuels in terms of their use in the calciner

Economic criteria	Handling properties	Physical properties	Operational properties
Primary cost (fuel)	Storability	Dispersibility	Calorific value
Costs in production control (Environmental protection and plant technology)	Safety requirements (e.g. self-ignition, explosion hazard)	Solid, liquid, gaseous or pasty?	Content of volatile compounds (chlorine, sulphur and alkalis)
Fuel availability	Content of contraries	Density	Reactivity, ignition performance, burn-out behaviour
CO <sub>2</sub> certificates (e.g. other EU Emissions Trading Scheme)	Proportioning Transportability	Moisture content	Trace element content
Quality assurance	Industrial health and safety	Particle size	Content of compounds relevant to quality (e.g. phosphate)
Process control	Self-compaction	Nitrogen content	Influence on service life of refractory lining

(e.g. petcoke) are burned. In the Hot Disc for example the waste materials (whole tires or fluffy materials) are dropped to the bottom part which consists of a turntable. The fuel will, when exposed to the hot tertiary air, slowly gasify and burn out while the disc is rotating (10 to 45 minutes). In the pre combustion chambers several fuels like coal, coarse alternative fuels or plastics are burned. At high temperatures (1,000 to 1,600°C) also fuels with a low ignition behaviour (e.g. petcoke) can be burned. The experiences show that the chambers work reliably and the calciner system can be controlled easily.

With a gasifier a wide variety of waste materials, regardless of their calorific value, can be handled. The product gas, generated under reducing conditions in the circulating fluidized bed reactor can be fed directly to the calciner strings, while the combustion residues can be conveyed to the proportioning station, from where they are fed into the raw mill as a raw material component. Any variation in the gas quality (calorific value, CO concentration) can be balanced by the combustion process in the calciner.

The choice of the most suitable system is influenced mostly by investment and operating costs, but also by fuel processing costs, availability of the waste fuels, the removal of contaminants and substances forming recirculating systems as well as safety concepts that might be required. Plant designers are currently making increasing efforts to further optimise existing plants, and to develop and test new concepts. As gasifiers and combustion chambers, respectively, permit a high degree of flexibility in terms of type, composition and nature of the fuels utilised, the number of these plants in the cement industry can be expected to grow in the long run.

#### 4 NO<sub>x</sub> reduction

Burning of cement clinker is a high-temperature process, which requires gas temperatures of up to 2,000°C to form the clinker phases. As a result the formation of thermal NO is more or less unavoidable. Additionally, the formation of fuel NO contributes to the total NO<sub>x</sub> emissions. Also in precalciner kilns the formation of NO is

predominantly determined by the formation in the main firing unit.

In the course of a more and more demanding European environmental legislation, the cement industry is challenging the need for improved NO<sub>x</sub> abatement. The main driving forces are the European "Directive on the Incineration of Waste" and the IPPC process resulting in the description of Best Available Techniques (BAT) for all relevant industrial sectors. On the one hand, very strict air quality limits have been specified by the European Union. As a consequence, licensing procedures are becoming increasingly complicated, especially when air quality limits for NO<sub>x</sub> are already exceeded in the vicinity of a plant. On the other hand, the revised European BREF Document (Best Available Techniques Reference Document) for the cement and lime manufacturing industries defines an emission level of < 450 mg/m<sup>3</sup> for NO<sub>x</sub>, which should be achievable with the use of so-called Best Available Techniques (BAT).

##### 4.1 Staged combustion

New plants usually are equipped with precalciner and tertiary air duct so that the technique of staged combustion can be applied. The reduction of NO<sub>x</sub> by this technique in the precalciner can be improved by lowering the air ratio in the so-called reduction zone. Scientific investigations have revealed that an air ratio below 0.9 should be adjusted in the reducing zone of the calciner to achieve an optimum NO<sub>x</sub> reduction. Recent investigations of the Research Institute of the Cement Industry show that even a lower stoichiometric air ratio of down to 0.6 have shown favourable results concerning NO<sub>x</sub> reduction. The air ratio in the burnout zone, by contrast, must be higher than 1 (usually 1.1 to 1.2). Experiences show that NO<sub>x</sub> emissions can be lowered up to 30% as a consequence of air or fuel staging under practical conditions. The fact that the CO generated in the low oxygen zone cannot be fully oxidized in the burnout zone constitutes one of the restrictions of air staging.

Furthermore, meal staging (influencing the temperature profile in the calciner), the mixing of fuel and gas streams as well as fuel properties certainly can have an important effect on the NO<sub>x</sub> reduction [3]. Especially the fuel type,

mainly the content of volatile compounds and fuel nitrogen, the calorific value and the fuel fineness have an impact both on combustion kinetics (release of energy) and NO<sub>x</sub> formation and decomposition.

High volatile fuels like e.g. lignite usually allow to obtain the best NO<sub>x</sub> reduction effect in staged combustion. Owing to the high proportion of volatile compounds, fairly large quantities of hydrocarbon radicals and NH<sub>3</sub> compounds are released during fuel pyrolysis which tend to NO decomposition. Thus, the combustion process is rapid and the residual oxygen, present in the combustion gas, is consumed quickly. As a consequence, the air ratio in the low-oxygen zone is lower and the NO decomposition rate is higher than with fuels having a small proportion of volatile compounds, like e.g. petcoke.

The combustion of low volatile or coarse fuels needs some more time for heating up, pyrolysis and burnout. During these few seconds the particles are partly transported out of the reducing zone. As a consequence, the air ratio in the "low oxygen zone" is higher under equal air distribution conditions and less NO decomposes. The proportion of fuel nitrogen remaining in the residual coke of low volatile fuels is higher. Considerable quantities of fuel nitrogen are converted to NO during combustion of residual coke in the downstream burn out zone. Operating experiences show that, on balance, NO is formed in the calciner during the combustion of low volatile fuels.

As an example, figure 3 represents the NO formation and decomposition respectively in the calciner when two fuels having a volatile content of 28 and 47% respectively are used at three different air ratios in the reduction zone. The operational trials showed also that the potential of this technique is limited by process constraints, such as unacceptable increase of coating formation and reduced burnt clinker.

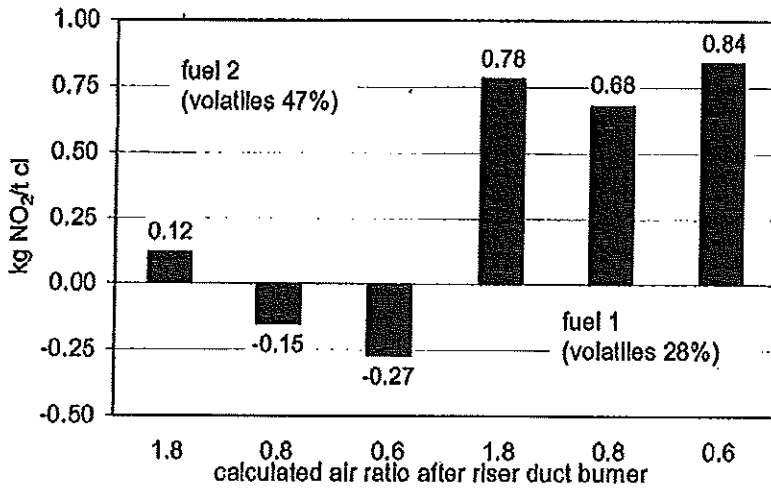


Figure 3 Influence of the air ratio on NO formation and reduction in the calciner using fuels with different volatile matter

4.2 Staged combustion and SNCR

If higher reduction rates are required for meeting stricter emission limits, the application of secondary measures is often inevitable. The SNCR process (selective non-catalytic reduction) is the most promising technique to achieve significant NO<sub>x</sub> reduction rates at moderate costs. Up to now, SNCR plants have been installed at more than 60 cement kilns in Europe, with rising tendency. One of the main advantages is that SNCR is applicable at most types of rotary kilns, provided the appropriate "temperature window" (850 – 1,050°C) is usable for ammonia injection. Depending on the initial NO<sub>x</sub> level, reduction rates of more than 50% are achievable. The standard reducing agent is a 25% aqueous ammonia solution. However – especially for economic reasons - increasing use is being made of ammonium containing waste waters.

In recent years, operational trials were carried out in the cement industry to investigate the reduction potential of the SNCR process. It turned out that NO<sub>x</sub> emission values of less than 500 mg/m<sup>3</sup> could be achieved with the combination of staged combustion and SNCR technology. The SNCR process can be applied to a wide range of O<sub>2</sub> and CO concentrations. The reducing agent can generally be introduced both in reduction and also in the burnout zone. Rapid and uniform mixing of the reducing agent in the NO loaded gas flow is also crucially important for the effectiveness of the SNCR process when used in a calciner.

Trials of the Research Institute of the Cement Industry have shown that NO<sub>x</sub> abatement increases with rising NH<sub>3</sub>/NO molar ratio, whereas to some extent high reduction rates can be achieved. However, the interaction between the technologies increases and herewith the impact on the CO burnout. The carried out trials have shown that the CO burnout is delayed by the SNCR reaction. A noticeable delay took especially place when the reducing agent was inserted into the reduction zone at a low air ratio. This delay of the CO oxidation can have an impact on the CO emission when the residence time in the calciner is not sufficient for a complete burnout. According to experience, for a complete burnout a residence time of a minimum of 2 seconds is needed in the calciner.

Especially the combustion of low or medium calorific industrial waste in the calciner requires even longer residence time. To find the optimum input position of the reducing agent investigations at each individual calciner have to be carried out because numerous factors (temperature, fuel properties, residence time, O<sub>2</sub>, NO and CO concentrations, input of reducing agent as well as location of the meal input) influence the effectiveness of the SNCR process. Under certain circumstances, the SNCR process alone can be – in the face of NO<sub>x</sub> abatement and a simultaneous optimization of CO burnout – more effective than the combination with staged combustion. However, the ammonia slip increases significantly with increasing NH<sub>3</sub>/NO molar ratio, especially, if mixing is poor, reaction time for SNCR reaction is short or temperature is at the lower end of the appropriate temperature window. Under these conditions, significant NH<sub>3</sub> emissions can occur during direct operation. On the other hand no significant NH<sub>3</sub> slip during mill operation was detected. This means that very effective binding of the ammonia occurs in the raw mill on the surface of the raw meal particles, which can cause a build-up of ammonium compounds in the external circulation system. The ammonium levels in the filter dust and in the kiln meal can rise with increased molar ratio and reduced NO<sub>x</sub> (see figure 4).

These circulation build-ups take place over several days or weeks, meaning that a real SNCR test has to be carried out over an appropriate period of time.

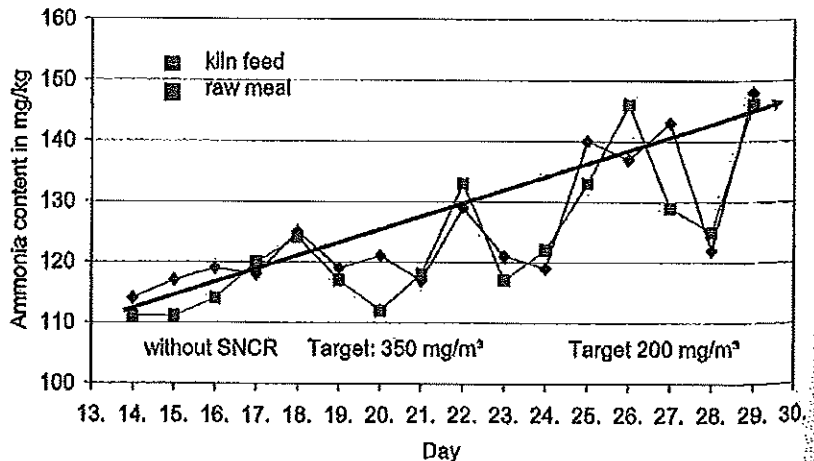


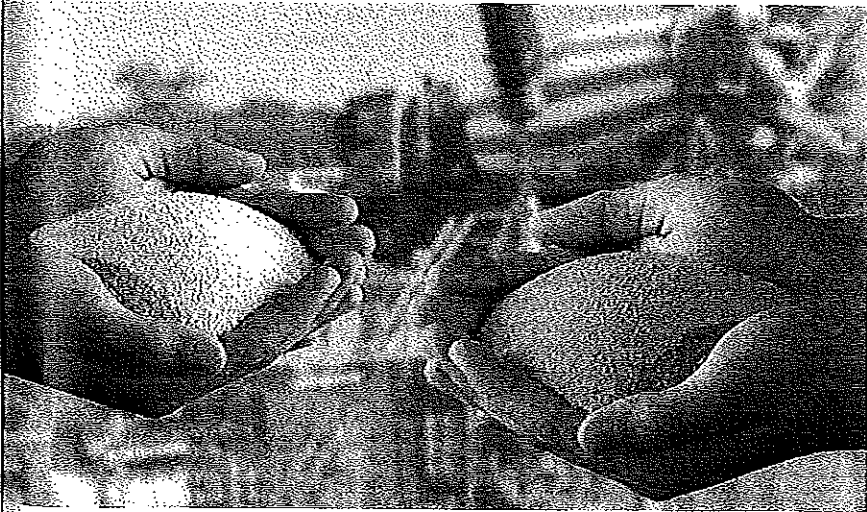
Figure 4 Ammonium levels in the raw meal and kiln meal for different NO<sub>x</sub> limits in a kiln plant

The experiences so far have shown that by combining the staged combustion and the SNCR process in the precalciner a level of  $\text{NO}_x$  emissions to less than  $500 \text{ mg/m}^3$  can be achieved.

Therefore it is recommended to provide sufficient residence time in the calciner for fuel combustion and SNCR, so that the reactions can be some how separated.

**References**

- [1] Draft Reference Document on Best Available Techniques in the Cement, Lime and Magnesium Oxide Manufacturing Industries, May 2009, Sevilla.
- [2] Draft Guideline of the Industry Emission Directive, 2009.
- [3] Bodendiek, N.:  $\text{NO}_x$ -Minderung durch gestufte Verbrennung und deren Wechselwirkung mit dem SNCR-Verfahren bei Vorcalcineranlagen der Zementindustrie. Düsseldorf: Verlag Bau+Technik, 2005 (Schriftenreihe der Zement-Industrie 68).



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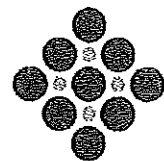
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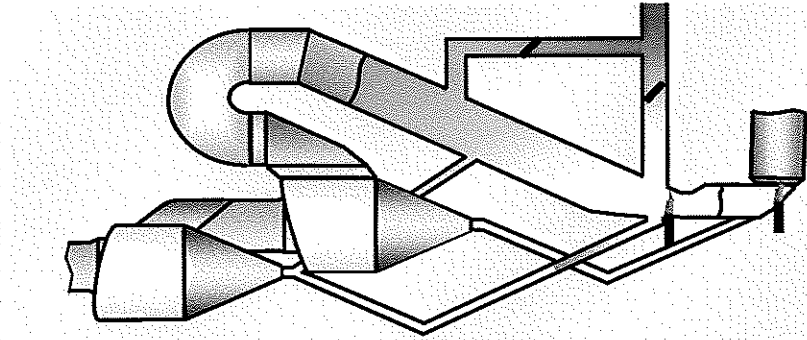
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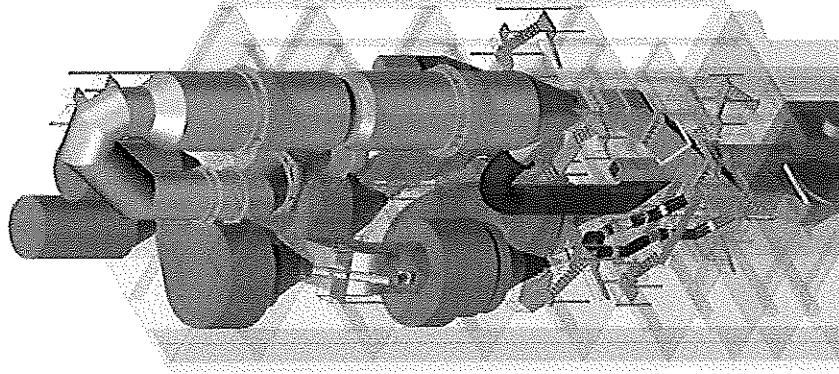


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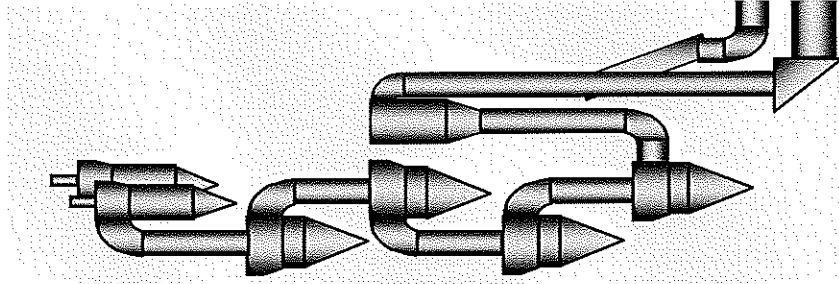
# Different precalciner systems



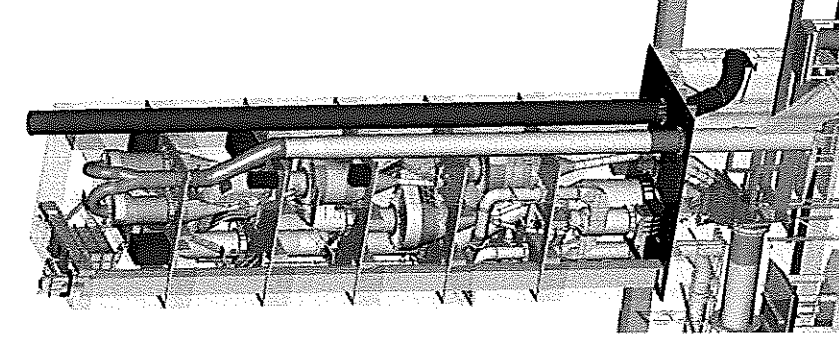
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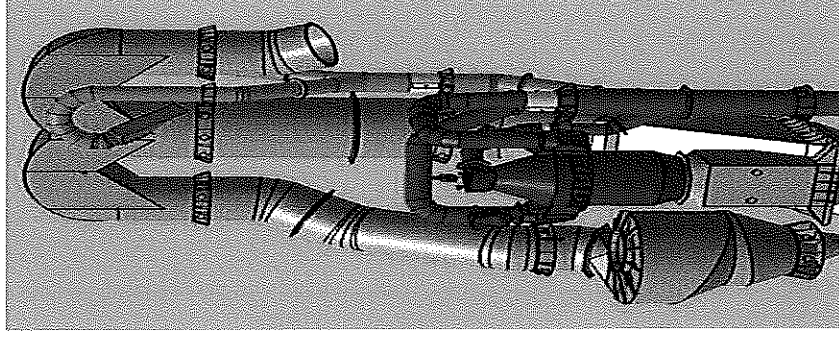
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