061 Energy recovery from wastes: Experience with solid alternative fuels combustion in a precalciner cement kiln

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1 Introduction

Today virtually all cement clinker burning processes take place in rotary kilns. A mixture of calcareous and argilaceous materials is heated to a temperature of about 1450 °C. In this process decarbonation followed by partial fusion occurs, and nodules of so-called clinker are formed. The cooled clinker is mixed with a few percent of gypsum, and ground into a fine meal – cement.

The most modern cement kilns are equipped with a precalciner, in which most of the calcium carbonate decomposes into calcium oxide and carbon dioxide, before the precalcined meal enters the rotary kiln, where the rest of the burning takes place.

The endothermic cement burning process requires large amounts of thermal energy, which is supplied by fuel combustion in the rotary kiln and in the precalciner. Coal and petcoke are most frequently used, but oil and natural gas, are also burnt in some plants. However, due the negative impact of the fossil fuels on the environment, alternative fuels are utilized to an ever increasing extent.

Norcem, Norway's sole cement manufacturer, has experience with alternative fuel combustion since 1987, when combustion of liquid hazardous waste (LHW) was started. Since then, different types of solid alternative fuels, such as solid hazardous waste (SHW) and refuse derived fuel (RDF), has come into regular use.

This paper presents Norcem's experience with combustion of solid alternative fuels in Kiln #6 at the Dalen cement plant in Brevik, Norway.

2 The precalciner cement kiln

A sketch of the precalciner cement kiln system in Brevik is shown in Figure 1.

The raw meal, with the major components $CaCO_3$, SiO_2, Al_2O_3 and Fe_2O_3, is dried and preheated in the cyclone tower (cyclone stage 1-3), partly decarbonated in the precalciner and burnt to clinker in the rotary kiln, whereafter cooling of the clinker takes place in the cooler.

In the cooler, air is supplied to cool the clinker. At the same time, a major portion of the clinker enthalpy is recuperated, since part of the heated cooling air is used as combustion air in the rotary kiln (secondary air) and in the precalciner (tertiary air). A flame temperature of more than 2000 °C is reached in the kiln burning zone. Such a high temperature is required in order to transfer enough heat to the solids in the kiln, and thus obtain a material temperature of about 1450 °C.

[1] Part of Heidelberger Zement

Flowing through the four stages of the cyclone tower, the precalciner exhaust gas is cooled while heating and carrying meal particles in suspension. The preheater exhaust gas is cooled in water conditioning towers and cleaned in electrostatic precipitators as well as bag filters.

Table 1 gives some characteristics of Kiln #6, whereas Table 2 shows typical concentrations of gas components emitted to the surroundings. A more detailed description of the kiln system can be found elsewhere [1].

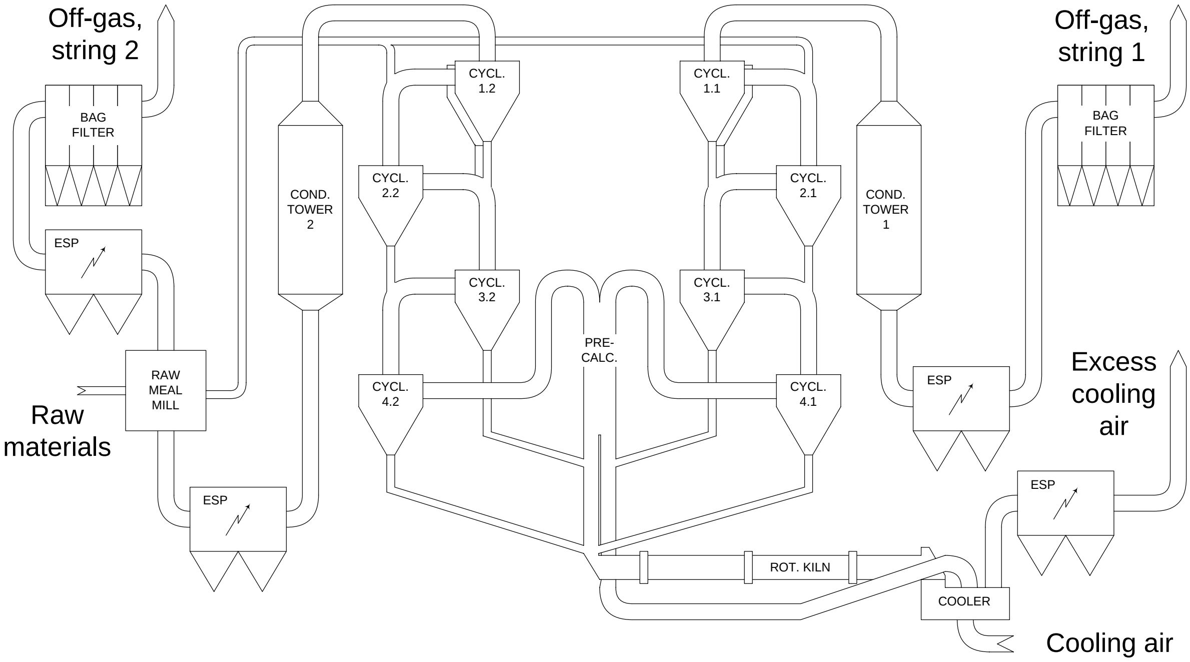

Figure 1: *Schematic drawing showing the kiln system, including gas-cleaning equipment.*

Table 1: *Characteristics of Kiln #6, Norcem, Brevik.*

Rotary kiln length	68	m
Rotary kiln (outer) diameter	4.4	m
Design clinker production capacity	3300	t/d
Typical specific fuel consumption	3300	kJ/(kg clinker)
Representative temperature interval in the rotary kiln	1100-2000	°C
Representative temperature interval in the precalciner	850-1050	°C
Typical gas residence time in the rotary kiln	5	s
Typical gas residence time in the precalciner	3	s
Typical O_2 concentration in rotary kiln exhaust gas	3	% (dry)
Typical O_2 concentration in precalciner exhaust gas	4	% (dry)

Table 2: *Average concentration of selected gas components in the off-gas from Kiln #6, 1999.*

Component [mg/Nm^3, dry @ 11 % O_2]	**Emitted**	**SFT[1] limit**
NO_x as NO_2	750	-
SO_x as SO_2	188	300
Dust	7	40
Chlorine compounds, as HCl	5.1	10
Total organic carbon, TOC	9.7	10
Dioxins	0.011	0.1
Sum Sb, As, Pb, Cr, Co, Cu, Mn, Ni, V and Sn	0.086	1.0
Mercury	0.012	0.1
Fluorine compounds, as HF	0.049	1.0
Sum Cd and Tl	0.002	0.1

[1] "Statens Forurensningstilsyn", i.e. the Norwegian State Pollution Control Authority

3 Experience with alternative fuels at Norcem Brevik

The utilization of alternative fuels in cement kilns is becoming more and more common, since this is usually economically as well as environmentally favourable. That is also the motivation for Norcem's commitment to alternative fuels;

- solution of a social waste problem through safe destruction of hazardous wastes
- reduced greenhouse effect through replacement of fossil fuels by partly CO_2 neutral fuels
- cost reduction through replacement of more expensive fuels, such as coal, by alternative fuels (disposal fees justify investments in proper handling and transportation equipment)

In the following sections, different aspects of utilizing solid alternative fuels are discussed.

3.1 Permits, contracts and fuel quantities

Following permission from the Norwegian State Pollution Control Authority, the Brevik Cement works is allowed to burn solid and liquid hazardous wastes in compliance with a special permit. LHW has been burnt in the primary burner of Kiln #6 since 1987, and since 1994 SHW has been combusted in the precalciner.

In 1998 a new state-owned national plant for collection of organic hazardous waste, NOAH[2], was built in Brevik, close to the cement works. All solid and liquid organic hazardous waste generated in Norway is supposed to be collected and pre-treated by NOAH. The fuels produced, SHW and LHW, are to be incinerated in Norcem's Kiln #6. Norcem has now permission from SFT to incinerate 31,000 tons of organic hazardous waste per year.

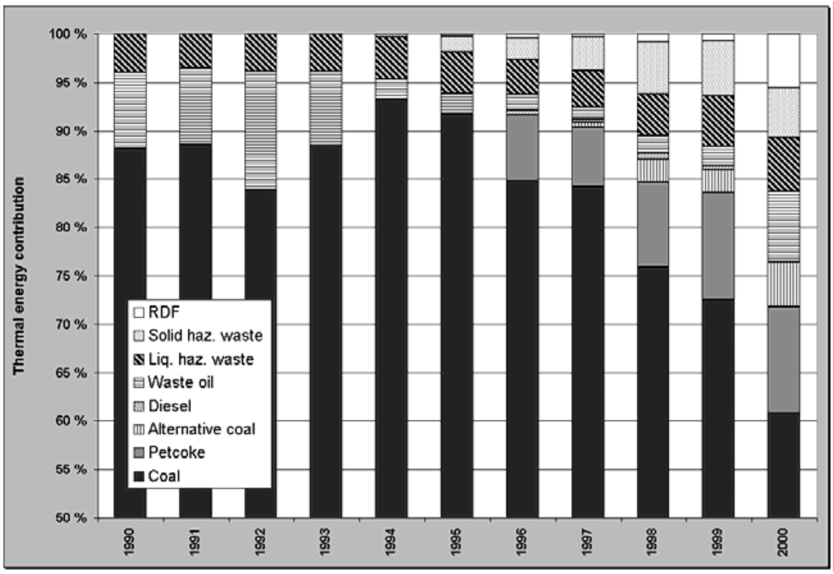

Figure 2: *Alternative fuel utilization (in terms of energy units) at Kiln #6, Norcem, Brevik, from 1990 to 2000.*

Norcem also has a general permit to burn biofuels, plastic and waste residue (free of wet organic components), without any quantity limitations. Since 1999 RDF[3] has been burnt on a regular basis. Norcem has signed RDF supply contracts of 40,000 tons/year with local municipal waste

[2] "Norsk Avfallshandtering AS", Norwegian Waste Treatment Ltd.

[3] Refuse derived fuel is residue from classified municipal and industrial waste, mainly consisting of paper, plastic and wood. RDF does not contain any wet organic components, and it is supposed to be free of glass and metals.

treatment companies based in the vicinity of the plant. Hence, a considerable increase in RDF utilization is planned in the near future. Plastic waste is burnt occasionally, but not on a regular basis.

In addition, Norcem has a permit to burn 30,000 tons of waste oil and 12,000 tons of car tyres and car fragmentation waste. Waste oil is today burnt at typical rates of 1-2 t/h, whereas car tyres is no longer in use due to certain operational problems (more on that below).

In addition to the above-mentioned alternative fuels other fuels such as charcoal, waste coal and petcoke are also used as a replacement for coal (these are mixed and ground with coal). More recently, tests with animal meal (AM) have been performed showing promising results. Figure 2 shows the increased alternative fuel utilization the last decade.

3.2 Pre-treatment, storage and transport

The SHW and the RDF is produced and fed according to certain specifications, partly dictated by the authorities, partly by process and combustion requirements. For instance, a maximum RDF particle size of 30 mm has proved to be an acceptable trade-off between preparation work and particle burnout.

The hazardous waste is mixed with saw dust to reduce its stickiness and homogenize it. Increasing the percentage of saw dust is a way to improve the conveying properties of SHW.

Every batch of SHW is accompanied by a fuel quality certificate. Norcem always checks this certificate against the quality criteria before the batch is accepted (or, in rare cases, rejected).

To be able to handle the different fuels, Norcem has invested more than NOK 100 millions in fuel storage and transport systems as well as gas cleaning equipment during the last five years. And at the time of writing further investments are being made to increase even more the transport capacity of solid fuels. Accordingly, a 40 % replacement of fossil fuels is expected towards the end of 2001.

SHW, RDF, plastic, AM and possibly other types of solid fuels are intermediately stored in a dedicated reception plant at ground level; the effective storage capacity is about 1300 m^3. The respective fuels are then transferred from the reception silos to feeding bins by a closed belt conveyor with a capacity of 75 m^3/h. There are three different feeding bins of 25 m^3, all of which are push floor dischargers (type Saxlund).

Many solid alternative fuels have a very low bulk density (RDF ~ 150 kg/m^3; SHW ~ 350 kg/m^3). This underlines the importance of installing transport equipment with sufficient capacity.

3.3 Feeding

The system for feeding solid alternative fuels from the push-floor discharger to the precalciner is shown in Figure 3. Today, alternative fuels such as SHW and RDF are fed either to the tertiary air side of the calciner or to the kiln riser duct, as indicated in the figure.

To ensure troublefree feeding, it is of vital importance that the fuels are free of foreign objects which might cause blockages of conveyors or rotary feeders. Furthermore, the fuels should be as homogeneous as possible and as little sticky as possible to avoid clogging problems.

As an alternative to combustion in the precalciner, a system for feeding alternative fuels to the primary burner has been built. A Pyrojet low-NO_x burner has been modified by Norcem to make possible multi-fuel feeding: In addition to pulverized coal waste oil, LHW and solid alternative fuels may be burnt simultaneously by injection through three separate channels, see Figure 4.

Feeding solid, sticky fuels pneumatically is a very challenging task. On Kiln #6 the transition from mechanical to pneumatic transport has proven particularly difficult. If the fuel is not "dry" enough, the rotary feeder tends to clog, whereas foreign objects will easily block the pneumatic conveying line and thus interrupt the fuel supply. This may disturb the clinker burning process.

In Norcem's case, the fuel pre-treatment is the responsibility of the fuel suppliers. Norcem has an ongoing dialogue with the different suppliers in order to improve the fuel quality through proper preparation of the different fuels.

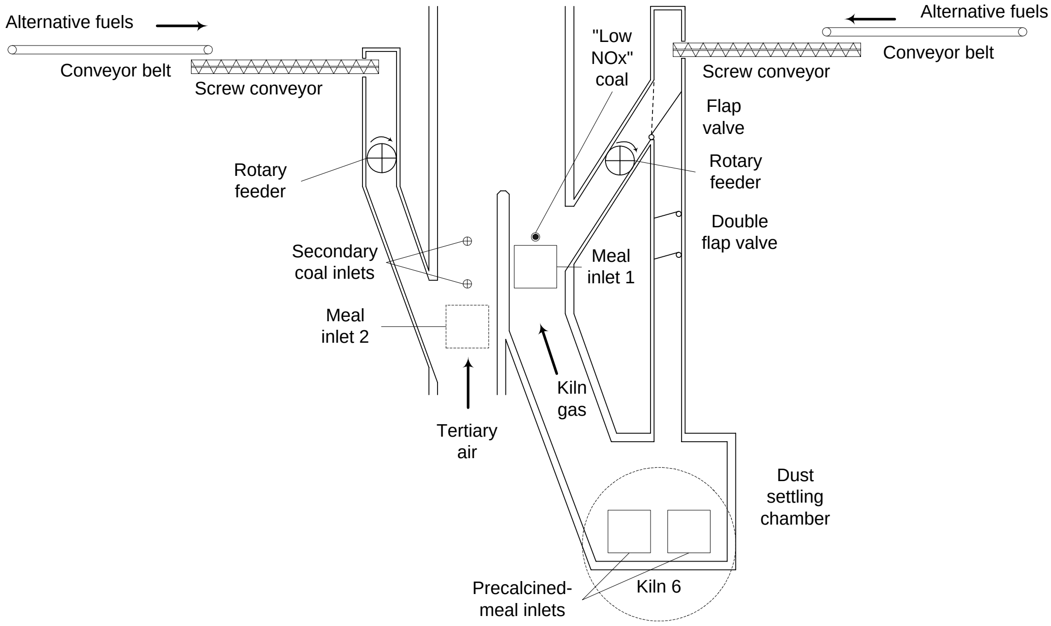

Figure 3: *System for feeding solid alternative fuels to the precalciner, Kiln #6, Norcem, Brevik.*

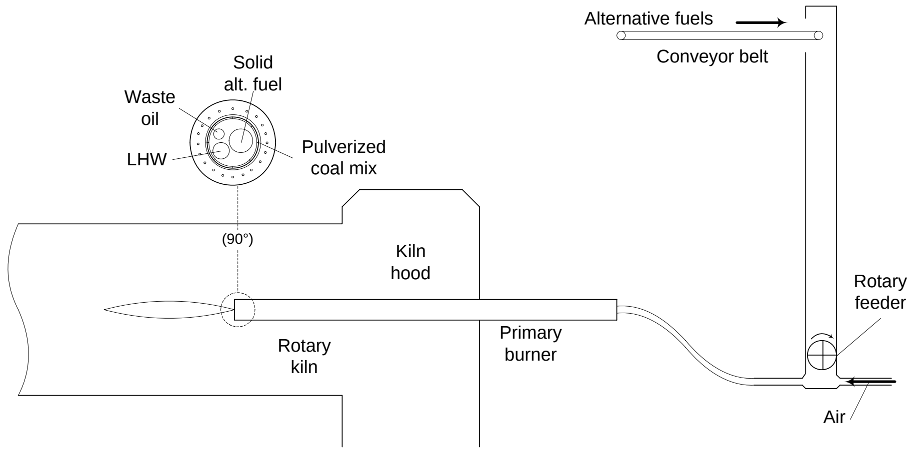

Figure 4: *System for feeding solid alternative fuels to the primary burner, Kiln #6, Norcem, Brevik.*

3.4 Combustion conditions

As indicated in Table 1, the conditions should be well-suited for burning alternative fuels, especially in the rotary kiln, but also in the precalciner: The temperature is high, there is an overall oxidizing environment, and the gas residence time is long. Furthermore, the flow regime in both reactors is strongly turbulent (Re $\approx 10^6$). Table 2 shows that, with the exception of TOC, which is close to the limit, all emission concentrations are well below the limit.

The precalciner (which is of the type "KHD Pyroclon R Low-NO_x") has some some features that influence its suitability for burning alternative fuels:

- Feeding may take place by means of pure mechanical transport (belts, screw conveyors and rotary feeders), facilitated by gravity. Pneumatic transport, which is less robust (and usually required in the main burner) can be avoided.
- The flow regime inside the precalciner is pneumatic conveying. However, solid particles, such as lumpy fuels like SHW, tend to rise and fall repeatedly in the gas riser. This motion increases the solids residence time in the reactor, which facilitates burnout of the fuel particles.

- The fuel particles are distributed over the entire cross-sectional flow area and mixed with meal particles. Heat liberated by the combustion of fuel particles is instantly consumed by the decarbonation process, which keeps the temperature at an equilibrium of about 900 °C. This means that fuels with a relatively low heating value can be accepted without operational problems.
- Cascade control is applied to control the feeding rate of coal: The coal feed rate is automatically adjusted until the temperature setpoint is reached. This gives a certain tolerance regarding the input of alternative fuels, since small variations in alternative fuel energy is compensated by a corresponding automatic adjustment of coal energy input.

In the rotary kiln, the temperature is even higher and the gas residence time is longer than in the precalciner.

Hence, combustion of solid alternative fuels in a precalciner cement kiln is a good alternative to incineration in dedicated plants.

3.5 Impact of alternative fuels on NO_x emissions

The special design of the Pyroclon R Low-NO_x calciner facilitates NO_x reduction by staged combustion: If fuels are supplied to the kiln inlet or to the kiln riser duct at sufficiently high feeding rates, a reducing zone is created, in which NO formed in the rotary kiln may be converted to N_2, bringing about an overall reduction in NO_x emissions [2].

Norcem has put much effort into utilizing this concept, testing a number of different fuels [1-7]. Figure 5 shows the great potential of this NO_x reduction measure, nearly 40 % reduction in NO_x emissions was achieved when supplying 15 % of plastic waste to the kiln inlet [2].

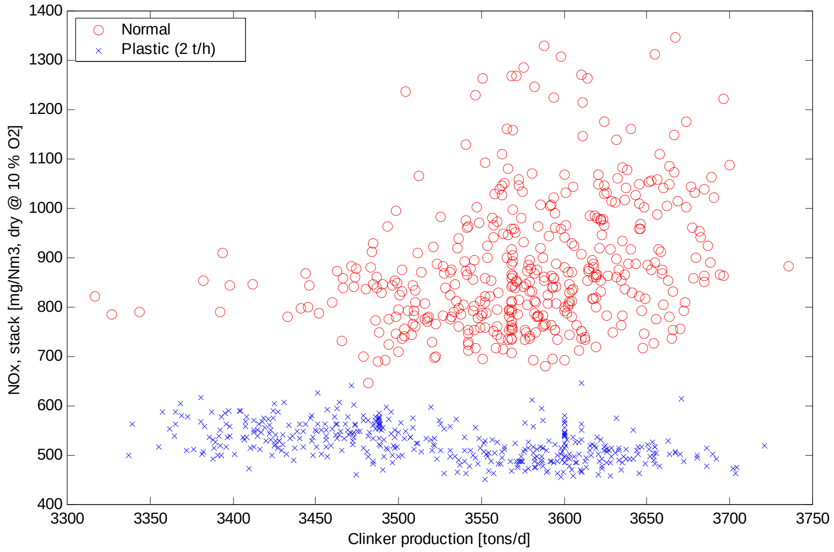

Figure 5: *NO_x reduction by staged combustion feeding 2 t/h of plastic to the kiln inlet of Kiln #6, Norcem, Brevik [2].*

Another favourable effect originates from the fact that many alternative fuels contain less nitrogen than coal. This means that less fuel-NO_x is formed in the process, and reduced NO_x emissions result.

3.6 Impact of alternative fuels on the process conditions

When utilizing alternative fuels, the clinker production process should not be disturbed. However, such process disturbances have indeed been experienced, for instance when burning shredded and whole car tyres in the kiln inlet [5-7].

Motivated by the observed disturbances, i.e. sulphur accumulation in precalcined meal, increased free lime concentration in clinker and reduced clinker production, the impact of different alternative fuels on the clinker production process has been analyzed by different methods. In addition to full-scale experiments mathematical modelling as well as lab-scale experimental methods have been applied [1].

The main conclusions of that work is that staged combustion has to take place solely in the precalciner – contact between precalcined meal, fuels and kiln exhaust gas in the kiln inlet has to be avoided. If not, the internal cycles of sulphur, chlorine and alkalis in the kiln system will be altered, and the operation of the kiln will be disturbed: An accumulation of sulphur in the precalciner gives material buildups in the precalciner as well as a transfer of energy from the rotary kiln to the precalciner, which eventually leads to a reduced production rate. Figure 6 shows a typical distribution of sulphur in the kiln system; the accumulation of sulphur in the precalciner is evident.

This means that fuels should not be supplied to the kiln inlet, but instead to the kiln riser duct. Furthermore, fuel particles that are too heavy to entrain by the kiln gases (even though they are fed to the kiln riser duct) will fall down into the kiln inlet; thus they can not be used. At Norcem, chopped car tyres is an example of such a fuel.

The current feeding system and fuel characteristics are based on and adapted according to these conclusions. Then the negative impacts on the process are avoided. And still a NO_x reduction of 15-20 % is typically achieved.

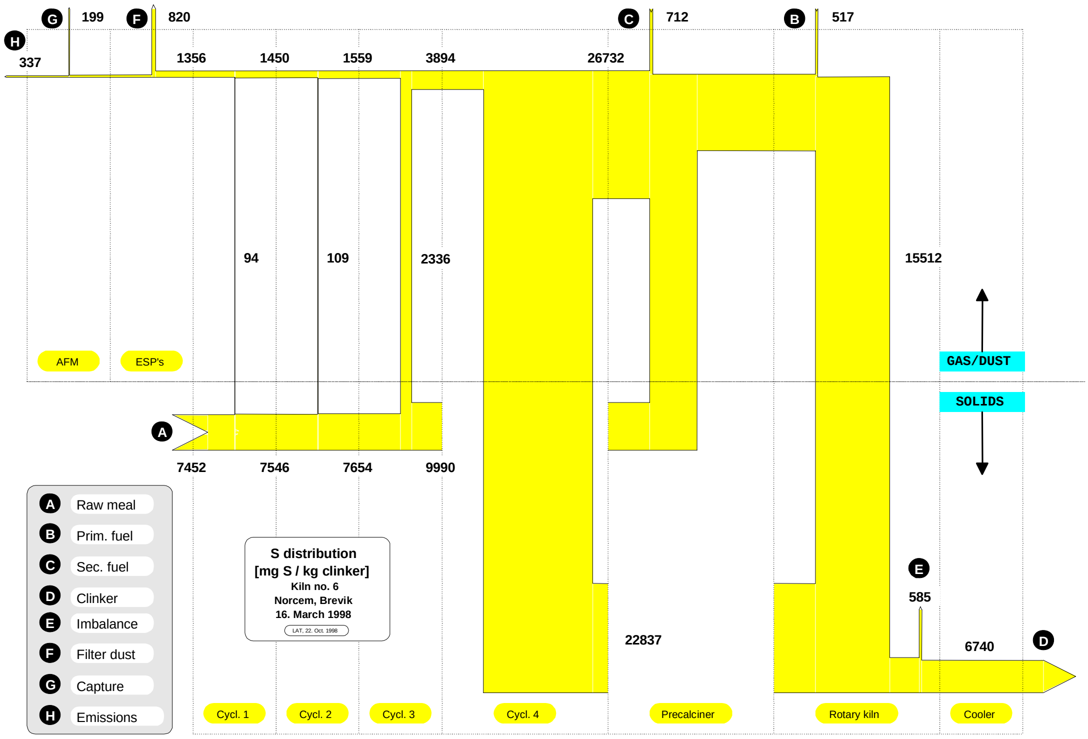

Figure 6: *The distribution of sulphur in the kiln system, Kiln #6, Norcem, Brevik [1]. Numbers are average values based on 16 hours of operation.*

Whenever the capacity of the exhaust gas fans represent bottlenecks in a kiln system (which will often be the case), alternative fuels may also result in a certain production loss. This is the case on Kiln #6. Partly this can be explained by increased gas flow through the system, since low-grade fuels often has a rather high moisture content (RDF typically contains 30 % moisture); partly it can be explained by the particle fluidization giving increased pressure loss in the precalciner.

In some cases, especially when the system runs at a high production with a high input of alternative fuels, lack of oxygen may lead to CO peaks of the order of 1 %. Due to explosion risks such high CO levels will trip the ESP's and stop all supply of hazardous waste, both in the primary burner and in the precalciner. Such a sudden loss of fuel energy input represents an operational disturbance, which must be avoided.

3.7 Impact of alternative fuels on other gaseous emissions

Due to the special transport of gases and solid materials, the cyclone tower acts like a dry scrubber, which effectively captures acidic gases, like sulphur oxides. This is the reason why only a very small fraction of fuel sulphur is emitted to the surroundings via the exhaust gases [8]. Instead, it is converted to alkali and calcium sulphates and captured in the clinker.

Products of incomplete combustion, such as CO and TOC, may be a problem under certain unfavourable conditions (see previous section), but can in general be avoided if the process is operated with sufficiently high oxygen concentration, temperature and residence time.

It must be admitted, though, that alternative fuels are more demanding than pulverized coal in this respect. Hence, to be able to increase the input of alternative fuels, Norcem is currently looking into precalciner modifications in order to increase the residence time, the degree of mixing and the temperature. Different vendors offer different precalciner designs, but so far, most precalciner systems have been designed for optimization of pulverized coal combustion. In the future, more focus will be put on the development of systems fulfilling the combustion requirements of alternative solid fuels. Norcem will also try to make a contribution in this area.

3.8 Impact of alternative fuels on clinker quality

As long as certain fuel quality criteria are fulfilled and the process is not disturbed in any way, the quality of the clinker is not impacted.

What might influence the clinker, is the composition of the fuel ash, since the ash becomes part of the clinker. Apart from mercury, cadmium and thallium, heavy metals are almost entirely captured in the clinker. Hence, the input of some elements, such as zinc and lead, should not exceed certain limits not to affect the cement quality (i.e. the setting time of concrete).

The ash from most alternative fuels are pretty much alike the ash from the coal mixture. However, AM is an exception: This ash contains much more calcium than do the other fuel ashes. Hence, increasing the input of AM, will increase the lime saturation factor and probably also the free lime content of the clinker, both of which are important quality parameters. Therefore, the raw meal should be composed in view of the ash chemistry to avoid negative impacts on the product quality.

This dependence on fuel ash chemistry means that there is also a link between feeding stability and clinker quality: If the feeding of alternative fuels for some reason is suddenly stopped, the clinker chemistry will change, since in most cases there will not be enough time to adjust the raw meal composition accordingly. The sudden thermal energy deficiency thereby induced will of course also impact the quality. Hence, a stable and robust feeding system is a prerequisite for a stable clinker chemistry.

4 Future work

Norcem will continue the on-going work to increase the percentage of alternative fuels. The goal is to replace 50 % of the coal energy before 2003, mainly by increasing the input of RDF. Probably a modification of the calciner is required in order to reach this goal.

Investigations of the impact of different alternative fuels on clinker quality, process operation and gas emissions is continuously going on. As part of this research work, a laboratory scale circulating fluidized bed combustor (CFBC) has been developed in cooperation between Scancem International, Telemark University College and Norcem. This reactor, shown in Figure 7, can be used to characterize and compare different types of alternative fuels used in the full-scale process at Norcem's plant [9]. A number of CFBC tests are to be conducted in the near future.

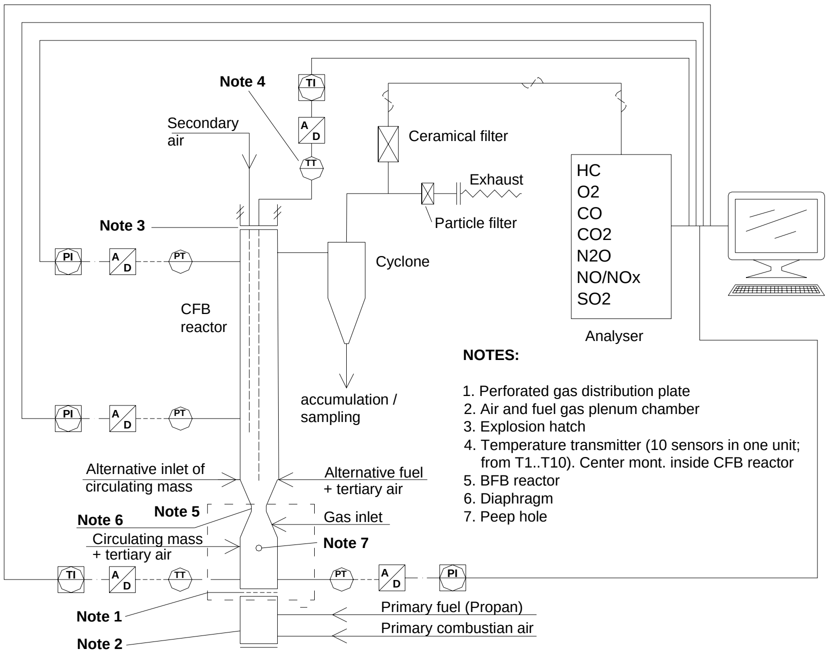

Figure 7: *Laboratory scale circulating fluidized bed combustor for alternative fuel characterization [9].*

5 Conclusion

In this paper, Norcem's experience with solid alternative fuels has been summarized.

Because of the special process conditions prevailing in a cement kiln system, i.e. high temperatures, oxidizing conditions, turbulent flow and long residence times, it is certainly possible to replace a considerable part of the fossil fuels by solid alternative fuels. In Norcem's Kiln #6 the alternative fuel input is currently about 30 %, including liquid and solid alternative fuels.

To be be successful in reaching a high replacement ratio, several requirements should be fulfilled:

- The fuels should undergo a proper pre-treatment: Sufficiently small particle size, homogeneity, absence of foreign objects and low stickiness are required to ensure stable feeding, undisturbed kiln operation and sufficient fuel burnout.
- The concentrations of certain elements (for instance chlorine in SHW) should be sufficiently low, so that supply rates will not have to be reduced due to input or emission limitations.
- A properly designed feeding system, with sufficient capacity in all links of the chain, is required to obtain a robust system with high availability.
- The combustion conditions must facilitate fuel burnout. Different calciner designs offer different conditions for utilizing alternative fuels: Flow pattern, temperature profile and oxygen availability differ, hence certain fuel types (for instance car tyres) may be possible to burn in some precalciners, while being difficult to combust in others.

A particularly interesting feature of alternative fuel utilization in Brevik is the potential for NO_x reduction. Through the special design of Norcem's precalciner, staged combustion in the kiln riser duct is possible; firing 10-15 % of the total thermal energy in this part of the system gives a typical NO_x reduction of 15-25 %.

However, as pointed out, it is of vital importance that reducing conditions in the rotary kiln is avoided, otherwise the kiln operation and the clinker quality will suffer. Accordingly, the solid fuels should be supplied in such a fashion that contact between fuels, precalcined meal and kiln exhaust gas in the kiln inlet is avoided.

In some cases it may be required to change the normal operation procedure: for instance higher oxygen excess in the kiln is required in order to avoid CO peaks, which might disturb the process. A higher oxygen content in the rotary kiln may however result in a reduced production capacity.

Motivated by environmental as well as economic factors, Norcem will continue and intensify the ongoing work to increase the replacement of fossil fuels by alternative fuels. However, most precalciners, including the one at Norcem's Kiln #6, are designed to combust pulverized coal. Accordingly, the precalciner fuel replacement limit of the precalciner in Brevik is about 40 % (of the thermal energy supplied to the precalciner). To be able to increase the alternative fuel input above this level, improvement of process conditions through a precalciner modification is required. Norcem is currently moving into this exciting and challenging innovation process.

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