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CEMENT MANUFACTURING USING ALTERNATIVE FUELS AND THE ADVANTAGES OF PROCESS MODELLING

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ABSTRACT

Energy costs and environmental standards encouraged cement manufacturers world-wide to evaluate to what extent conventional fuels can be replaced by alternative fuels, *i.e.* processed waste materials. Clinker burning is well suited for various alternative fuels. In order select a suitable alternative fuel a commercial modelling tool (ASPEN PLUS®) is used to model the four-stage pre-heater kiln system of a full-scale cement plant (clinker production ~ 2900 tons/day), using petcoke as fuel. The goal is to optimise process control and alternative fuel consumption while maintaining clinker product quality. Calculations with varying amounts of different fuels are compared with a reference case.

INTRODUCTION

The cement manufacturing process

Cement manufacturing consists of raw meal grinding, blending, pre-calcining, clinker burning and cement grinding. In short, limestone and other materials containing calcium, silicon, aluminium and iron oxides are crushed and milled into a raw meal. This raw meal is blended (in for instance blending silos) and is then heated in the pre-heating system to initiate the dissociation of carbonate to calcium oxide and carbon dioxide. A secondary fuel is fed into the preheating system to keep the temperature sufficiently high. The meal then proceeds to the kiln for heating and reaction between calcium oxide and other elements to form calcium silicates and aluminates at a temperature up to 1450 ^{o}C. Primary fuel is used to keep the temperature high enough in the burning zone for the chemical reactions to take place. The reaction products leave the kiln as a nodular material called clinker. The clinker will be inter-ground with gypsum, limestone and/or ashes to a fine product called cement (1).

Figure 1 shows a cement manufacturing process from raw material quarrying to the bagging of the cement. The waste tyre particles are fed into the lower part of the kilns pre-heating system, hereafter referred to as the riser duct (2).

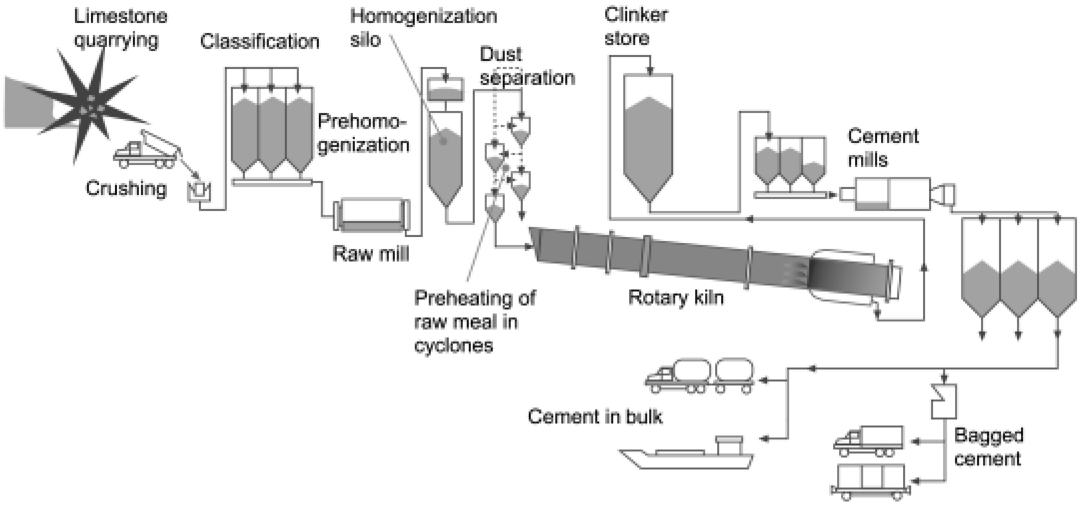

Figure 1. Cement manufacturing process.

Kiln System Chemistry

The chemical reactions that occur in the kiln are described in detail in (3). The temperature is increased when going from the meal feed to the rotary kiln. The most important oxides that participate in the reactions are $CaCO_3$, SiO_2, Al_2O_3 and Fe_2O_3. Up to about 700°C water is removed from the meal. In the preheating section (700-900°C) calcination as well as an initial combination of alumina, ferric oxide and silica with lime takes place. Between 900°C and 1200°C belite, C_2S (= $2CaO*SiO_2$), forms. Above 1250°C a liquid phase appears and this promotes the reaction between belite and free lime to form alite, C_3S (= $3CaO*SiO_2$). During the cooling stage the molten phase forms C_3A, tri calcium aluminate, (= $3CaO* Al_2O_3$) and if the cooling is slow alite may dissolve back into the liquid phase and appear as secondary belite. Usually the production of clinker is done so that one type of clinker allows the plant to manufacture several well-defined types of cement that comply with the physical demands as specified by cement standards.

Alternative fuels

The range of fuels is extremely wide. Traditional kiln fuels are gas, oil or coal. Materials like waste oils, plastics, auto shredded residues, waste tyres and sewage sludge are often proposed as alternative fuels for the cement industry. Also all kinds of slaughterhouse residues are offered as fuel nowadays.

Table 1 Alternative fuel options for the cement industry

Liquid waste fuels	Tar, chemical wastes, distillation residues, waste solvents, used oils, wax suspensions, petrochemical waste, asphalt slurry, paint waste, oil sludge
Solid waste fuels	Petroleum coke ("petcoke"), paper waste, rubber residues, pulp sludge, used tires, battery cases, plastics residues, wood waste, domestic refuse, rice chaff, refuse derived fuel, nut shells, oil-bearing soils, sewage sludge
Gaseous waste	Landfill gas, pyrolysis gas

To be able to use any of these fuels in a cement factory it is necessary to know the composition of the fuel. The choice is normally based on price and availability. The energy and ash contents are also important, as are the moisture and volatiles contents. All kinds of varieties from liquid to solids, powdered or as big lumps can be encountered when dealing with alternative fuels, requiring a flexible fuel feeding system. Somehow they should all be fed into the burning chamber of the process. It may be fed directly into the burning zone in the kiln itself or into the pre-heating system for dissociating part of the carbonates from the meal before it enters the kiln for clinker formation. In Table 1 we can see examples of different alternative fuels. They are separated into three groups (1).

In Table 2 several fuels of interest to the cement industry and their properties are listed. Some of these were used in model calculations reported here. The calculations were made to test the influence of a fuel change on the kiln process, specially the demand of combustion air in the burning zone.

Table 2 Properties of fuels of interest to the cement industry

	BITUMI-NOUS COAL	PET COKE	MEAT AND BONE MEAL	SEWAGE SLUDGE	CAR TYRE RUBBER	COAL-PETCOKE MIX
C (%-wt, dry)	66,6	89,5	42,1	42,9	87,0	75,1
H (%-wt, dry)	3,99	3,08	5,83	9,00	7,82	4,20
N (%-wt, dry)	1,07	1,71	7,52	1,84	0,33	1,70
S (%-wt, dry)	1,22	4,00	0,38	0,12	0,80	3,00
O (%-wt, dry)	8,85	1,11	15,3	27,2	1,81	4,90
Ash(%-wt, dry)	18,4	0,50	28,3	17,9	2,20	11,1
Volatiles (%-wt)	28,3	10,0	64,5	85,0	66,6	20,0
C-fix (%-wt)	47,9	89,5	7,20	5,00	31,1	69,2
H_2O(%-wt)	2,35	1,50	8,09	5,20	0,73	1,30
LHV(MJ/kg)	25,3	33,7	16,2	15,8	35,6	29,71
HHV(MJ/kg)	26,2				37,3	28,97

The process calculations

The process for which the air calculations reported in this paper are done (one of the cement plant of the CRH Co) consists of a rotary kiln and a cyclone string. The pre-heating system consists of four cyclones and a riser duct. The rotary kiln is producing almost 3000 tonnes clinker per day, and so far the main fuel has been petcoke. All these different parts in the process are modelled with different reactors that are defined in the simulation program.

A lot of information on the design and operation of the cement plant is used in the modelling work (4):

- Temperatures and pressures at various locations and of the incoming mass streams
- The dimensions and operational parameters of the cyclones and the electrostatic precipitators (ESPs), defining their grade efficiency performance
- Chemical composition and heating values of the incoming raw meal, the primary and secondary fuel, with different particle size distributions for all materials
- Incoming mass flows of raw meal, primary and secondary fuel and combustion air
- Cooling equipment heat fluxes

The blocks are chosen such that the chemistry in the different parts of the process can be specified as realistic as possible (*e.g.* equilibrium or non-equilibrium reactors), in a user-friendly way. After having connected the various modelling blocks, representing different pieces of equipment in the clinker manufacturing process, the flow sheet of the model is rather similar to the flow sheet of the process.

The model is first run with the “normal operation” values (reference case) meaning that only petcoke is used as fuel both in the burning zone and in the riser duct (primary and secondary fuel). The pre-heated air to the burning zone is varied between 430000 m^3/h and 500000 m^3/h (800°C, 1 bar). Calculations with alternative fuels are done by partly replacing the primary or secondary fuel. Meat and bone meal and sewage sludge are considered: their amounts are varied, giving a base load of heat into the kiln system that is roughly that of the reference case. The raw meal feed is according to process values for both chemical composition and amounts.

RESULTS

Fuels involved in the calculations are petcoke, meat and bone meal (MBM) and sewage sludge (SS). Their analyses are shown in Table 2. Depending on the cement plant’s location some alternative fuels may be more favourable than others, important issues are for instance transport costs and the availability of the fuel.

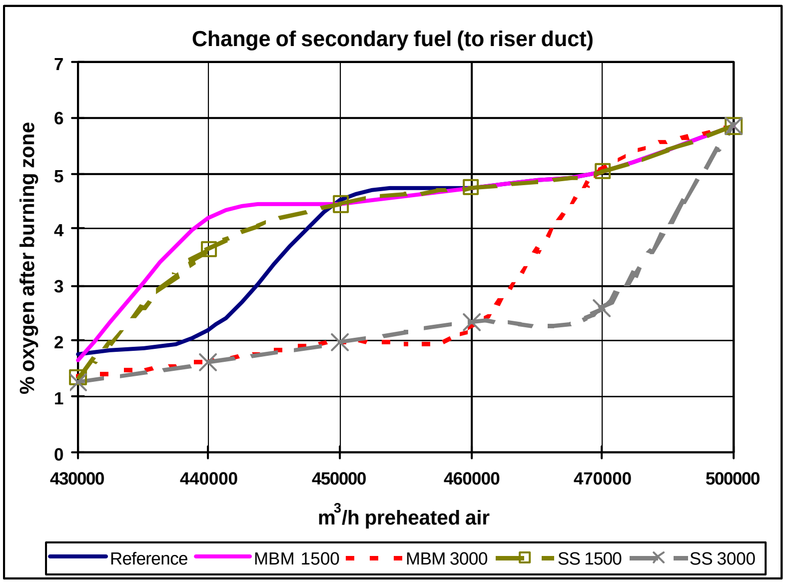

Figure 2 Plotted results for different fuel combinations when the secondary fuel is partly replaced by an alternative fuel (primary fuel: petcoke).

First the reference case was calculated, *i.e.* 12500 kg/h and 1500 kg/h petcoke as primary and secondary fuel, respectively. The combustion air requirement was calculated to a volume that gives 2% oxygen after the burning zone. This value is considered preferable with respect to CO emissions and ESP filter performance. For the reference case Figure 2 shows that the need of preheated air for combustion is close to 440000 m^3/h. Figure 2 also shows that using 1500 kg/h MBM or SS as secondary fuel instead of petcoke, gives a lower demand of combustion air compared to the reference case. The result is the opposite when the fuel feed of MBM or SS is 3000 kg/h. The primary fuel is petcoke in these cases; the combinations with the secondary fuels were varied as to get a total heat input to the kiln system that is higher or lower then for the reference case.

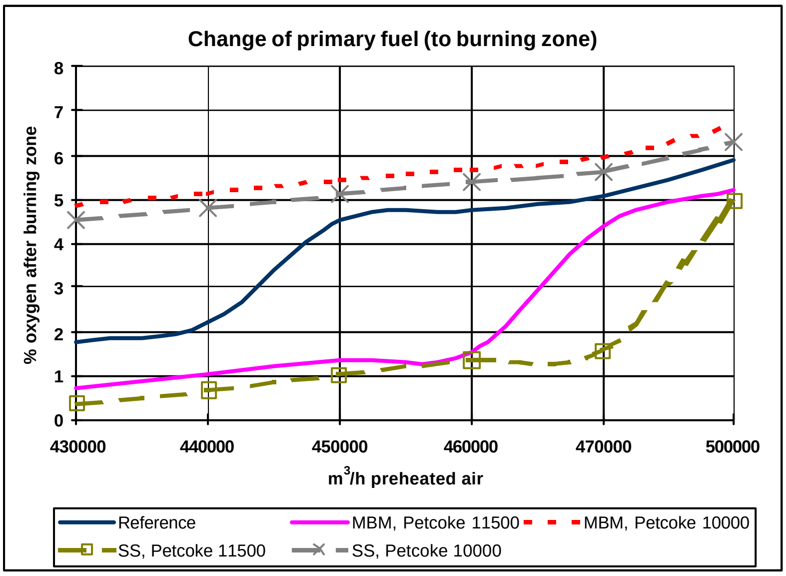

Figure 3 Results for different fuel combinations when the primary fuel petcoke is partly replaced by an alternative fuel. (alternative fuel 3000 kg/h, petcoke kg/h as indicated)

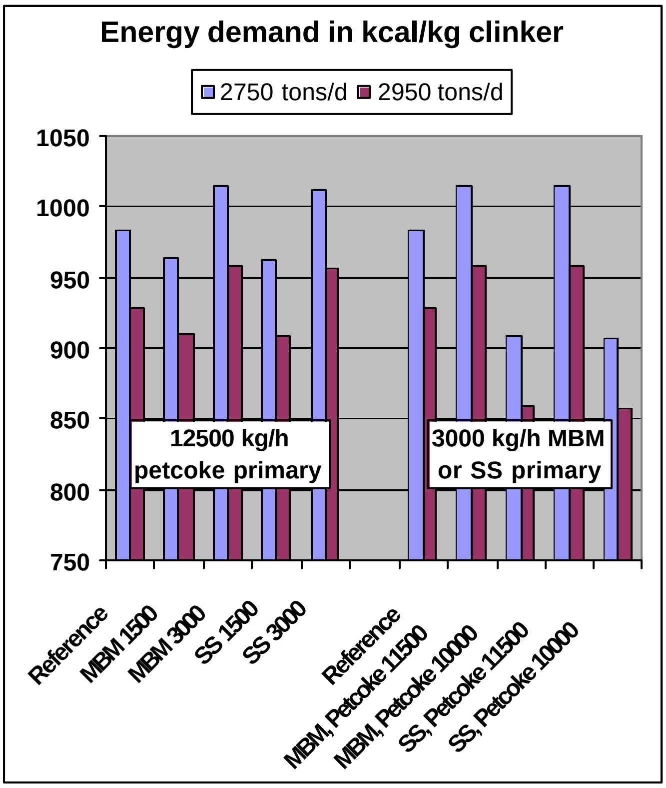

Figure 4 Energy demand for different fuel combinations for two amounts of daily clinker production.

The situation is slightly different when alternative fuels (3000 kg/h MBM or SS) are fed directly into the burning zone and replacing part of the primary fuel petcoke. The secondary fuel is petcoke as well (1500 kg/h) in these calculations. The reference case involves 12500 kg/h petcoke as primary fuel, which was lowered to 11500 and 10000 kg/h, respectively. These differences in petcoke and overall fuel input amounts explain the differences seen in Figure 3.

After calculating the air amounts to the burning zone the total heat input to the kiln system (kiln and riser duct) was calculated for different fuel combinations when compared with the reference case. These calculations were made for two daily clinker production values to validate the efficiency of the kiln system - see Figure 4. Compared to the reference case, different fuel combinations may give a lower or higher energy demand. In Figure 4 the energy consumption values appear somewhat high for the reference case, and may be slightly incorrect.

CONCLUSIONS

When part of the primary or secondary fuel of a cement plant (here: petcoke) is to be replaced by alternative fuels it must be considered beforehand whether the air feeding system allows for that. For alternative fuels like meat and bone meal (MBM) and sewage sludge (SS) it is calculated here that a slightly higher need of air is to be allowed for when operating with larger amounts of alternative fuel fed to the riser. Although it is only a matter of around 3 – 4 % higher need, problems may arise especially when setting the operational values for the process. With 1500 kg/h MBM or SS as secondary fuel the need of combustion air is about 2 % less than in the reference case. The energy input is then only 20 kcal/kg lower than for the reference case.

If alternative fuel is fed to the burning zone and replacing part of the primary fuel the results show that aproximately 5 to 10% more air is needed for combustion for cases MBM 3000/Petcoke 11500 kg/h and SS 3000/Petcoke 11500 kg/h primary fuel. These are also quite close to the reference case when it comes to energy input to the kiln. Cases MBM 3000/Petcoke 10000 kg/h and SS 3000 / Petcoke 10000 kg/h show a very positive result when it comes to air demand, but the energy value is very low when compared with the reference case. On the other hand, this would allow for a higher use of petcoke to supply the extra energy that is needed when increasing the production, and make use of the excess of air in the combustion zone.

If there are doubts about whether one should change fuels in the rotary kiln system it may be of use to simulate the possible cases beforehand and obtain information on how serious the changes involved might be. This can be also used as to check whether the equipment is suitable and flexible enough for the new fuel combinations.

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