

MODELLING A CEMENT MANUFACTURING PROCESS TO STUDY POSSIBLE IMPACTS OF ALTERNATIVE FUELS

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Abstract

Energy costs and environmental standards have encouraged cement manufacturers world-wide to evaluate to what extent conventional fuels can be replaced by different alternative fuels, *i.e.* processed waste materials. The clinker burning process is well suited for the use of various alternative fuels because of the long residence times in both rotary kiln and gas channels.

In order to make a proper choice from a wide range of alternative fuels it was decided that a commercial modelling tool should be used to model the four-stage pre-heater plus kiln system for a full-scale cement plant (daily clinker production ~ 2150 tons) that uses, for example, scrap tires as secondary fuel. The process equipment is described as inter-connected blocks simulating the set-up at the plant, and steady-state mass and energy balances and thermodynamic equilibrium for the chemical species are calculated. The aim is to compare the calculated results with the existing process values.

The model is used to optimise process control and the use of alternative fuels while maintaining clinker product quality. It is also used to predict the possible changes in the combustion, pre-calcining and clinker formation processes. The waste tyre fuel for example also acts as a raw material in the clinker manufacturing process. Calculations with different descriptions of the clinker chemistry were made and evaluated against real process data where possible.

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Introduction

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 and then heated in the pre-heating system (cyclones) to start the dissociation of calcium carbonate to oxide. The meal goes further into the kiln for heating and reaction between calcium oxide and other elements to form calcium silicates and aluminates at a temperature up to 1450 °C: so-called clinker burning. The cyclone system is attached to the rotary kiln by a riser duct. Secondary fuel is fed to the riser duct, the main fuel mixture, coal/petcoke, fires the kiln. Reaction products leave the kiln as a nodular material called clinker. The clinker will be interground with gypsum and other materials to cement [1]. Figure 1 shows a simplified flowsheet presenting the cement manufacturing process.

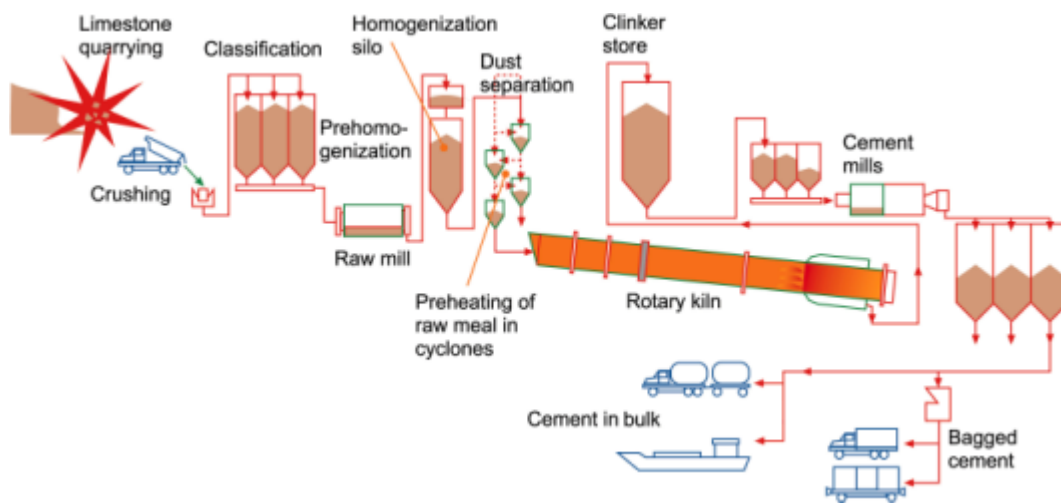


Figure 1. Cement manufacturing from the quarrying of limestone to the bagging of cement.

The process model

The process model (set up under Aspen Plus[®] 10.2) consists basically of mass balances for compounds and reactors. Incoming and outgoing compound flows are studied to get the chemical processes and their changes in the kiln system under better control [2]. At the same time, the calcium silicate system typical for cement manufacture is studied more closely including alkali species, chlorides and heavy metals.

One goal of the modelling work is to find out how well a certain type of reactor or separator can describe a certain function in the process. The final target is to be able to describe the behaviour of the kiln process in a realistic way, when the fuel is fully or partly replaced by an alternative fuel. The outcome could possibly be called “quality control” giving vital information about the chemical changes caused by the alternative fuel, the heat transmission in the kiln, and possibly also other parameters controlling the clinker burning process. It is important to quantify how these affect the clinker composition. Figure 2 shows a flowheet chart of the process model. The material streams from one reactor or block to another, the in- and out- going flows are shown, as are also different

(alternative) fuel feeding locations. The feed of alternative fuels is possible to both the rotary kilns burning zone and to the pre-heating system, in this case meaning the riser duct with the pre-calciner cyclones. Several fuel-blocks are attached to both pre-calciner and burning zone in order to make it easier to simulate different fuel mixes. Chemical analyses are needed both for the kiln feed and the fuels that are intended to be tested with this model.

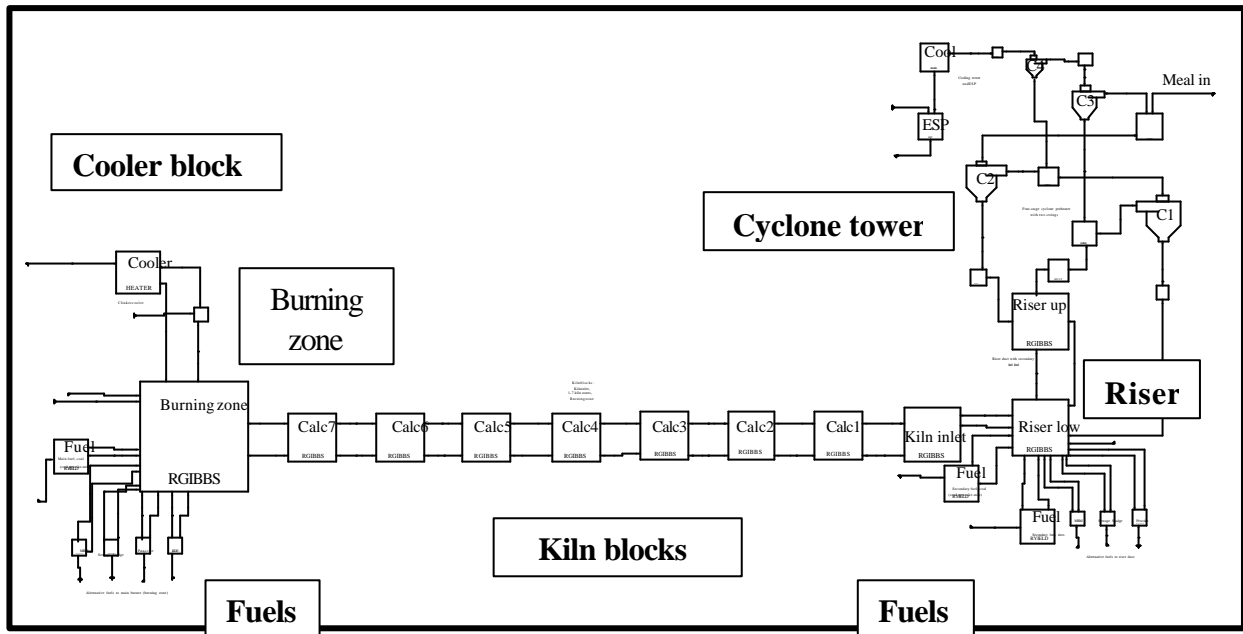


Figure 2. The visual view of a process flowsheet model showing the structure of the model and streams to and from the "blocks".

To be able to build a simulation model, detailed knowledge of the process is necessary and a lot of information on the design and operation of the cement plant at Parainen is used in the modelling work [2]:

- Temperatures and pressures at various locations and the incoming mass streams
- The dimensions and operational parameters of the cyclones, defining their grade efficiency performance
- Chemical composition and heating values of the incoming raw meal, the primary and secondary fuel, with particle size distributions for all these materials
- Incoming mass flows of raw meal, primary and secondary fuel and combustion air

Several things could not be implemented straightforward into the model, as an example the calcination of the raw meal taking place in the pre-heating system, cyclones [2]:

- In the heat exchange section, the cyclones act as separators in which also the calcination reaction $\text{CaCO}_3(\text{s}) \rightarrow \text{CaO}(\text{s}) + \text{CO}_2$ is taking place. This was modelled as a cyclone separator with a perfectly stirred reactor at the inlet in which the calcination reaction can take place, depending on temperature and CO_2 partial pressure, see Figure 3.

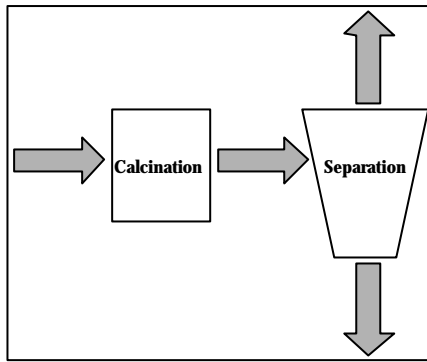


Figure 3. Modelling block for a cyclone in which separation as well as limestone calcination takes place.

The blocks are chosen in such a way 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 attached the various modelling blocks to each other, representing different pieces of equipment in the clinker manufacturing process, the model is rather much according to the flowsheet of the real process. One of the differences is the modelling block for the pre-calciner cyclones, as mentioned above. Also processes like separation or splitting of streams are modelled with specified blocks, while the flowsheet of the process only shows “pipelines” directing the flows to different pieces of equipment.

All the participating components are specified and listed on the same data sheet. In addition, the particle size distribution must be defined for all streams where solids are involved. Proximate fuel analyses are listed, as well as the elemental analysis data for the fuels. Pieces of the summary sheets with the input data and how the possible results may look are shown in Tables 1 and 2.

Table 1. An example of the input data used in the simulation.

	Primary air	Primary coal	Secondary coal	Raw meal
Temperature C	20	70	70	70
Pressure bar	1	1	1	1
Mass VFrac	1	0	0	0
Mass SFrac	0	1	1	1
*** ALL PHASES ***				
Mass Flow kg/hr	59184,049	9500	1200	69970
Volume Flow m ³ /hr	50000	6,85	0,865	23,036
Enthalpy MMkcal/hr	-0,071	0,654	0,083	-208,511
Density kg/m ³	1,184	1386,811	1386,811	3037,406

Table 2. Results from one of several calculations done to balance up the kiln system (results are not verified).

	Gas, burning zone	Clinker	ESP, dust	ESP, gas	Material stream from cyclones	Dust stream from cyclones
Temperature C	2000	275	160	160	200	950
Pressure bar	0,997	1	0,8	0,8	0,945	0,983
Mass VFrac	1	0	0	1	0,941	0
Mass SFrac	0	1	1	< 0,001	0,059	1
*** ALL PHASES ***						
Mass Flow kg/hr	81077,765	86217,861	8749,883	139479,344	148229,227	37000,747
Volume Flow m ³ /hr	521242,764	11,315	4,01	187409,231	173239,426	9,228
Enthalpy MMkcal/hr	-5,08	-255,151	-23,929	-159,956	-182,408	-104,084
Density kg/m ³	0,156	7619,836	2182,126	0,744	0,856	4009,669
Mass Flow kg/hr						
N2	55631,251			64768,753	64768,753	
O2	89,401					
H2O	3922,878			4637,925	4637,925	
NO2	0,01					
NO	86,684					
S	0,058					
SO2	243,643			0,005	0,005	
SO3	0,027					
H2	24,054			2,541	2,541	
CL2	trace					
HCL	9,653			21,335	21,335	
C			559,145	0,001	559,146	144,287
CO	3512,936			0,915	0,915	
CO2	17557,172			70047,861	70047,861	
CACO3			6116,251	0,006	6116,257	
CAO						7586,793
SIO2			1130,676	0,001	1130,677	
AL2O3			249,226	< 0,001	249,227	
CA3SIO5		72571,435				
CA2SIO4						23485,907
CA3AL2O6		10633,699				4785,553
CASO4			344,607	< 0,001	344,608	
C12A7		382,485				
NA2O						
K2O						
NACL				trace	trace	
KCL				trace	trace	
NA2SO4			97,959	< 0,001	97,959	
K2SO4			121,433	< 0,001	121,433	51,987
NA						
K						
FE2O3		1657,654	130,585	< 0,001	130,585	946,22
ASH		972,587				

Kiln System Chemistry

The chemical reactions that occur in the kiln are illustrated in Figure 4 [3]. Reading the picture from the left-hand side the temperature is increased when going from the meal feed to the burning zone in 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 ($700\text{--}900^\circ\text{C}$) calcination as well as an initial combination of alumina, ferric oxide and silica with lime takes place according to the Figure. However, due to the short residence time in the pre-calciner section (*i.e.* several seconds), this initial reaction does not occur, but compounds such as spurrite, $2(\text{CaO})_2\cdot\text{SiO}_2\cdot\text{CaCO}_3$, and sulphate spurrite $2(\text{CaO})_2\cdot\text{SiO}_2\cdot\text{CaSO}_4$ are formed. From 900°C to 1200°C belite, C_2S ($= 2\text{CaO}\cdot\text{SiO}_2$), forms, partly from spurrite decomposition. Above 1250°C a liquid phase appears and this promotes the reaction between belite and free lime to form alite, C_3S ($= 3\text{CaO}\cdot\text{SiO}_2$). During the cooling stage the molten phase forms C_3A , tri calcium aluminate ($= 3\text{CaO}\cdot\text{Al}_2\text{O}_3$) and if the cooling is slow alite may dissolve back into the liquid phase and appear as secondary belite [5].

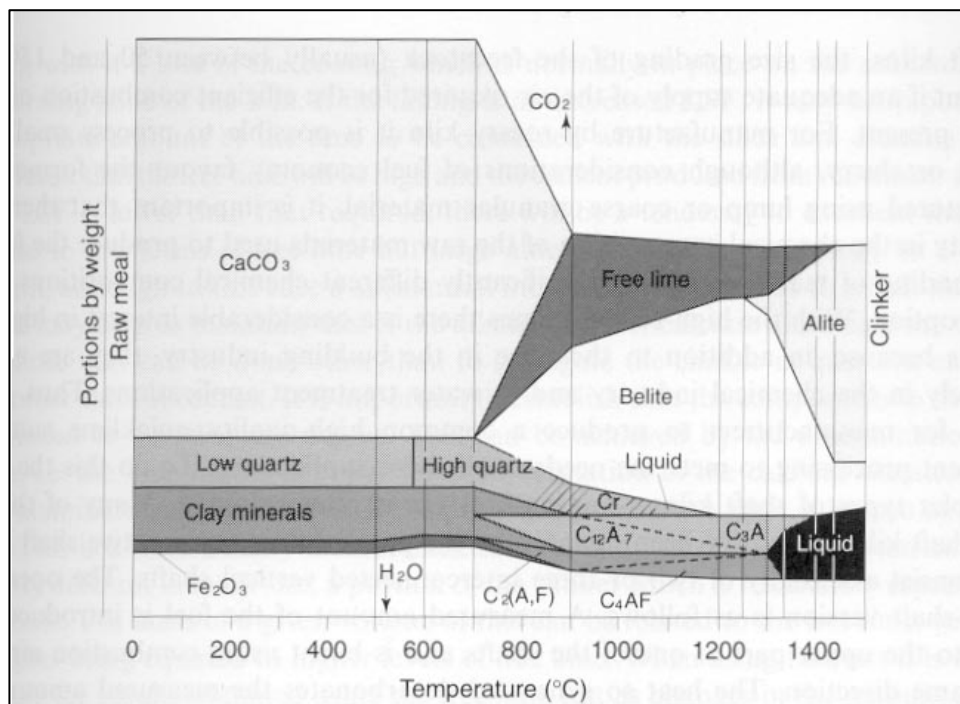


Figure 4. A schematic view of the clinker formation reactions [5].

Clearly, it is important that the combustion process and the composition of the meals fed to the kiln system is well understood. Usually the production of clinker is done in such a way that one type of clinker allows the plant operators to manufacture several well-defined types of cement that comply with the physical demands as specified in the cement standards.

Figure 4 does not show the effect of sulphur and alkali on the melt formation in the kiln, neither does it show the substitution reactions that will occur when alkali, sulphur or trace elements are interchanged with, for example, the elements Ca, Si or Al. Free lime is present as well as periclase (MgO) and anhydrite (CaSO_4). The formation of these phases will be taken into account in the modelling work later.

Also when it comes to the chemical components it was necessary to make several changes to be able to specify the reactions related to clinker formation [4,5]:

- Iron containing silicates, which are formed during clinker production (such as C_4AF , *i.e.* $4CaO \cdot Al_2O_3 \cdot Fe_2O_3$) are not included in the standard databases of the modelling software. There fore a separate databank was created and used in the calculations, which contained C_4AF , NAS_6 (*i.e.* $Na_2O \cdot Al_2O_3 \cdot 6SiO_2$) and KAS_6 (*i.e.* $K_2O \cdot Al_2O_3 \cdot 6SiO_2$) [6].

There is still work to be done with the created ‘inhouse’ data bank. Other chemical compounds related to clinker formation will be added, such as for spurrite, if thermodynamic data for these can be found. Below, results calculated with the modelling softwares’ standard database are compared with results calculated with the additional databank included.

Results and Discussion

Calculations were made to test how well simulation results compare with the clinker quality data reported by the production team. In these calculations both the primary and the secondary fuels are coal. Calculations were done with both the softwares’ own thermodynamic databank and in combination with an ‘inhouse’ data bank. In Figure 5 we can see the alite values for different cases. Figure 6 shows the belite content.

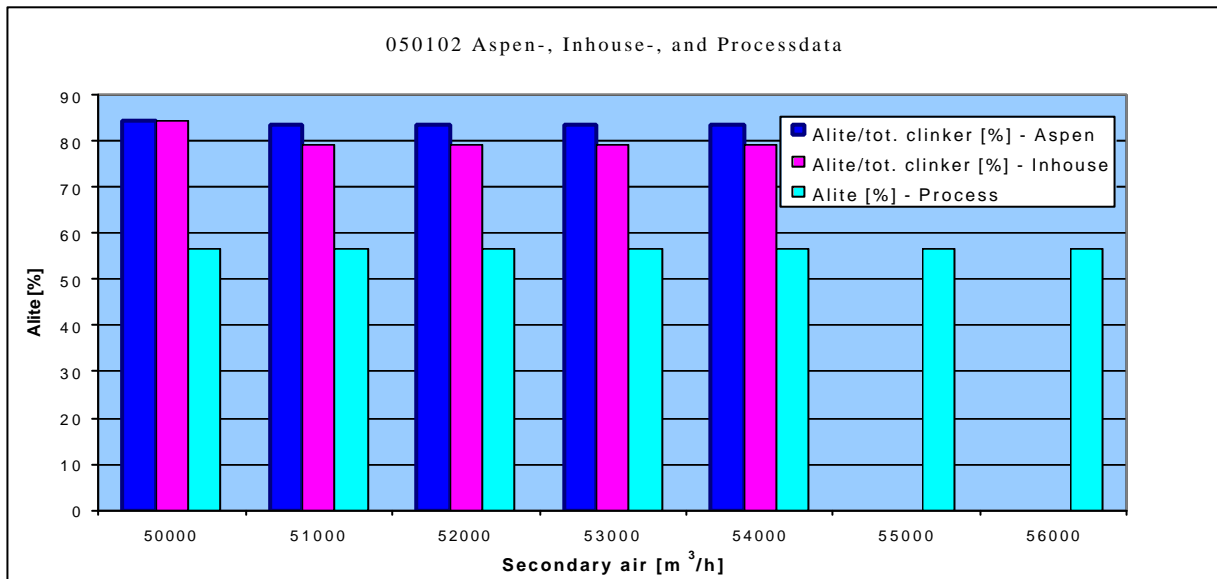


Figure 5. The content of alite in the clinker, process values compared with calculated results. The x- axis shows the amount of combustion air (secondary air) fed to the burning zone.

It has to be noted that variations in the feed of combustion air (secondary air) changes the formation of clinker minerals, as also was expected. As the alite content goes down, the belite content grows

rapidly. The balance can be found somewhere between the amounts 54000 and 55000 m³/h of secondary air.

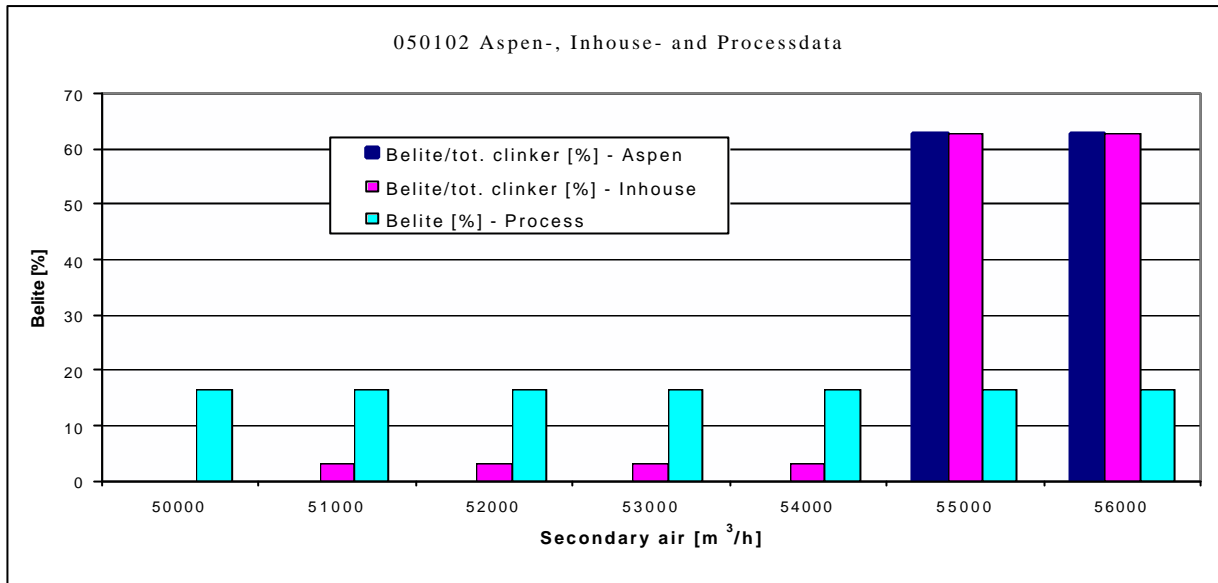


Figure 6. The content of belite in the clinker, process values compared with calculated results.

To be able to figure out what changes in the interval 54000-55000 m³/h secondary air, also a graph for the oxygen content in the flue gases after the burning zone, was plotted. A notable increase in the oxygen amount can be seen. If too large amounts of secondary air is fed to the burning zone it interrupts the clinker formation. The flame becomes unstable, the burning zone is cooled and a lot of dust is in circulation in the kiln and pre-calciner system. The variations in oxygen excess are shown in Figure 7.

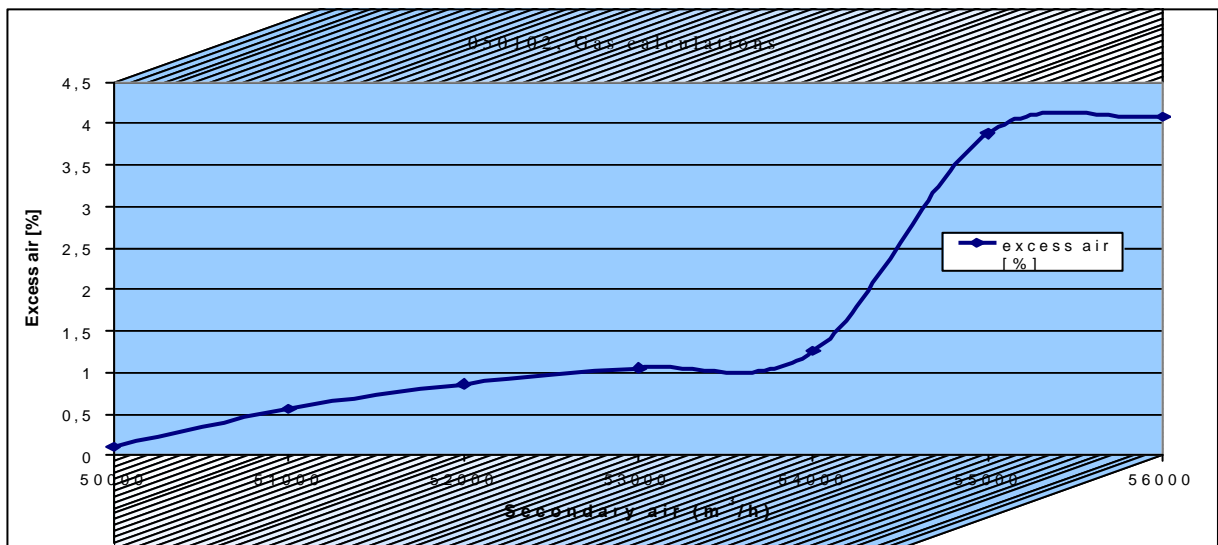


Figure 7. The amount of excess air after burning zone plotted against the amount of secondary air.

The demand of combustion air in the burning zone appears to have a large influence on the results. As mentioned earlier there is a clear connection between the use of alternative fuels and the behaviour of the kiln process. The required air amounts will change significantly when changing from a fossil fuel to an alternative fuel, which may require changes to the process equipment. The model described above will be a powerful tool when selecting an alternative fuel for a cement kiln [7].

Conclusions

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

There are clear differences between the calculated values for clinker compositions and the production values. This is due to the changes in the "description" of the clinker chemistry, and because not all the participating elements are listed in the output of the simulations. Although the results are improved by using the "inhouse" data, further adjustment will be needed. It is also important to balance the fuel and air amounts against the kiln feed to optimise clinker quality.

Acknowledgements

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