Numerical Modeling of Rotary Kilns

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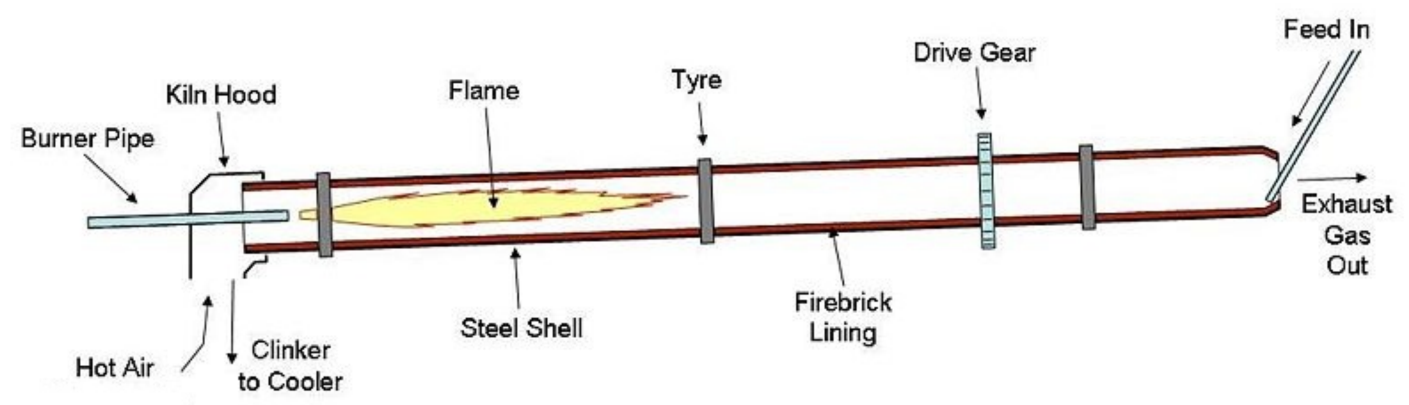
Objectives

A rotary kiln is a pyro-processing device used to raise materials to high temperatures. It is a long horizontal cylinder with a certain inclination with respect to its axis. Material within the kiln is heated to high temperatures so that chemical reactions can take place. A rotary kiln is therefore fundamentally a heat exchanger from which energy from a hot gas phase is transferred to the bed material. The energy originates from the combustion of hydrocarbon fuels via a main burner at the hot end.



The rotary kiln in question is a counter- current gas direct fired Calcium Aluminate Cement rotary kiln.

- Increasing market demand for high purity cement
- Unscheduled shutdown due to ring formation
- Restrictive emission regulations (i.e.: NOx)
- Future project to expand the plant by building a new kiln

have triggered the industrial partner's management to increase its knowledge base on kiln processes. The model is a platform to understand and optimize the operation of the process

Physical Phenomena

The physical phenomena occurring inside a rotary kiln can be separated in two parts: gas phase (freeboard) phenomena and granular bed phenomena.

In the freeboard the main phenomena are:
- Turbulent non-premixed combustion
- Heat Transfer including Radiation

On the granular bed the main phenomena:
- Heat Transfer
- Chemical Reactions
- Phase changes

Due to the complexity of the physical phenomena of a rotary kiln, one can divide the model in two:

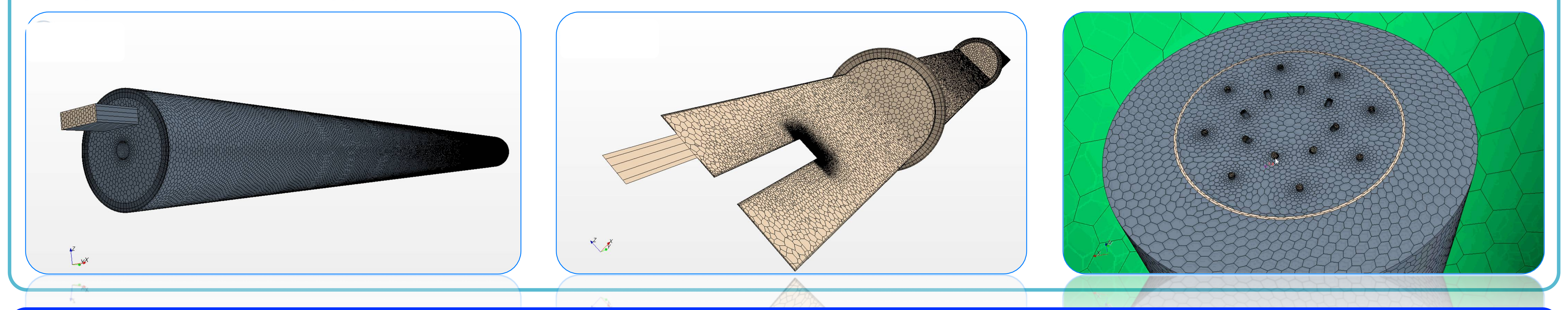
- **Freeboard CFD model**
- **Granular Bed model**

CFD Freeboard Model

Turbulent combustion results from the two-way interaction of chemistry and turbulence. When a fame interacts with a turbulent flow, turbulence is modified by combustion because of the strong flow accelerations through the flame front induced by heat release, and because of the large changes in kinematic viscosity associated with temperature changes.

- **Reynolds stress tensor:** **Realizable k-epsilon model (Turbulence Model)**
- **Turbulent scalar flux:** **Eddy diffusivity model**
- **Mean source term:** **Eddy break-up model (EBU)**
- **Radiation:** **Participating Media Radiation Model (DOF)**
- **NOx:** **Zeldovich Model**

The grid was done using polyhedral elements: **2.8 Million elements**

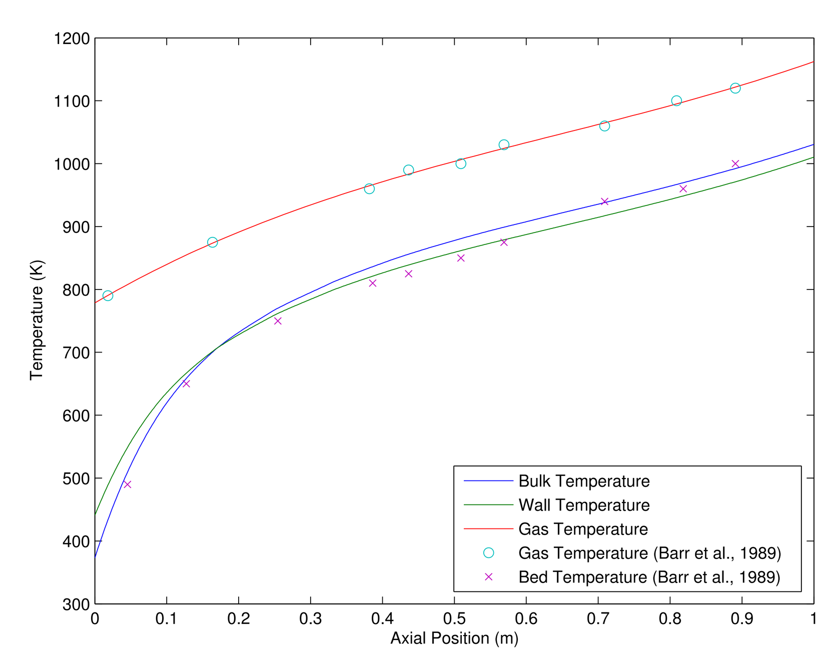


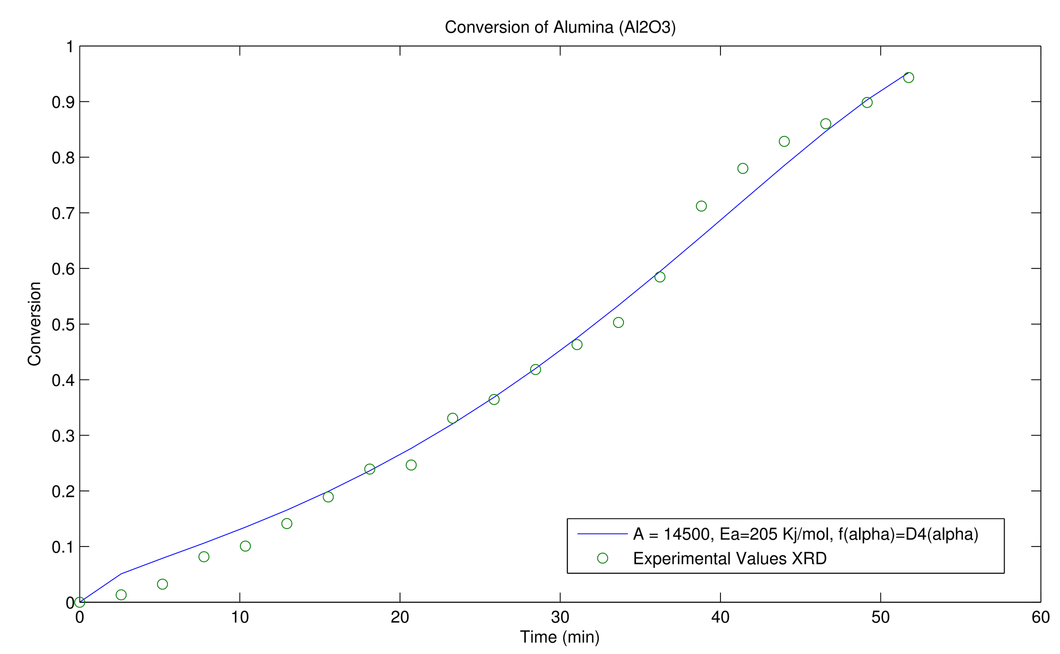
Granular Bed Model

The developed one-dimensional granular bed model encompasses two phenomena in the kiln: the axial heat transfer and the sintering reactions occurring in the bed. A one-dimensional axial heat transfer model was developed and validated with data from the literature. The sintering reaction kinetics model was developed taking as basis information found in literature and experimental XRD (X-Ray Diffraction) data handed by the industrial partner.

- **Energy balance for Granular Bed:** $\dot{m}_s c_{p,s} dT_s = q dA \quad [W],$
- **3-D diffusion controlled sintering reaction model:** $\dfrac{d\alpha}{dt} = A p e^{-(E_a/RT)} f(\alpha),$
- Correlations coming from literature were used to determine the **Heat Transfer Coefficients** for the different heat transfer paths that there exist in the granular bed system.
- The model uses results from the **CFD freeboard model as input**.
- **Validation** was done by modeling an inert bed and comparing the model with existing data from the literature.

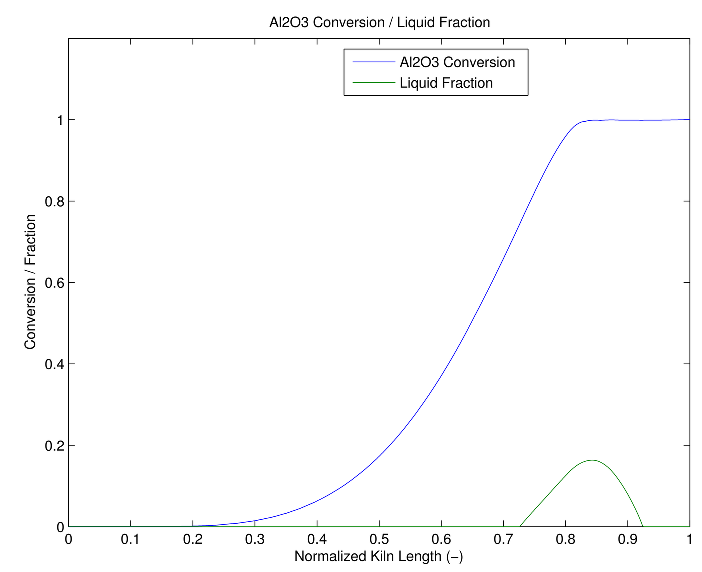
Validation Results:



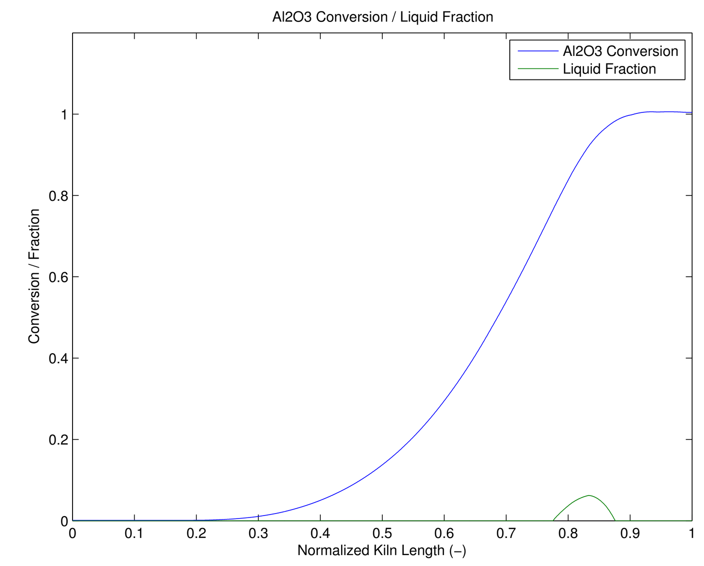


Industrial Case Results

- The freeboard CFD model was used to evaluate how by having an excess air one could reduce the peak temperature of the kiln. The model was used to determine that a 120% air excess would reduce the peak temperature to avoid ring formation. The result was validated in situ.
- The granular bed model was used to analyze the plant observations regarding the product quality alterations with respect to the operating changes derived with the freeboard model. It is concluded that the proposed operating changes increase product quality due to a slower conversion of Alumina.



100% Base Air (ring blockage)

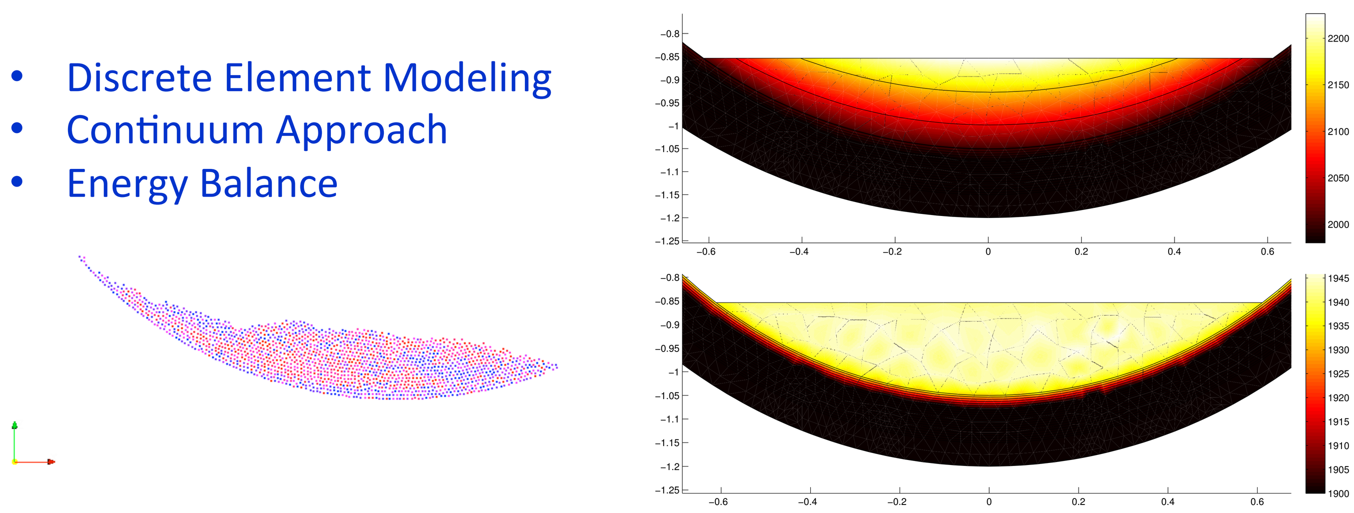


120% Excess Air (no rings)

Further Work

Transversal Granular Flow + Heat Transfer Model

- Discrete Element Modeling
- Continuum Approach
- Energy Balance



References

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Numerical Modeling of Rotary Kilns, in preparation
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