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Influence of Particle Size Distribution on the Limestone Decomposition in Single Shaft Kilns

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Abstract

This article presents a mathematical process model to simulate the limestone calcination in a single shaft kiln. The process model comprises a set of ordinary differential equations derived from the principle of mass and energy balance, coupled with a discrete particle model based on the shrinking core model. With the computed axial temperature profiles of the gas and solid, the heat loss through the wall as well as the pressure drop is determined. The simulation was done for a shaft kiln with a solid bed height of 13 m and a bed with 70 mm Sauter mean diameter. The width of the particle size distribution was changed to show the influence of the particle size distribution on the process. The results of this study can be transferred directly in the praxis for design, operation, regulation and optimization of the normal shaft kilns.

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1. Introduction

The limestone calcination in a shaft kiln is a complex process which mainly depends on a variety of influencing parameters. These are:

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- operational parameters (throughput, quantity of fuel and air, kind and composition of fuel, ambient temperature, ambient wind velocity).
- dimension parameters (diameter, solid bed height, length of the cooling zone, thickness of the wall)
- kind of limestone (mean particle size, particle size distribution, quantity of calcite and magnetite, thermal conductivity, reactivity).

Since the interaction of these parameters is largely unknown, the optimization of the process as well as the design of the kiln is strongly empirical. A parameter variation becomes apparent only after several days because of the inert behavior of the kiln. Furthermore, continuous measurements inside the kiln are very difficult to realize. That is why theoretical process simulations are indispensable for a safe and accurate design and for an effective optimization of the process.

Many studies have been carried out to study the lime burning in shaft kilns. Significant studies focusing on the temperature and the lime calcination profiles in the kilns are relatively rare. Numerical modeling of thermal processes in mixed feed kilns was performed by Shagapov et al. [1] and YI-Zheng-ming et al. [2]. The basic kiln temperature and calcination profiles were simulated. No investigation on the influencing factors, e.g., operating conditions, was performed. The influence of convective heat transfer coefficient on the lime-burning degree was studied. With CFD (computational fluid dynamics) simulations, Drenhaus et al. [3] modeled the lime burning degree and the temperatures in a pilot vertical (normal) shaft kiln with 2 m bed height. The influence of the particle size on the time of lime calcination process was investigated.

The results of the several researchers above are primary indications for basic understanding of the lime burning process in shaft kilns. However, for the purpose of process regulations and optimizations, further information needs to be explored because many parameters that significantly affect the lime burning process have not yet been investigated. Therefore a comprehensive mathematical model was developed to simulate limestone calcination in a shaft kiln. The model is used to compute the axial temperature profiles of the gas, the surface and core of the solid and the limestone decomposition. On the basis of that, the specific energy demand, the residual CO_2 content, the outlet temperature of lime, the temperature and composition of the flue gas, the pressure drop and the heat losses through the wall will be calculated. The mathematical model and the influence of different parameters have already been described by Hallak et al. [4-6] and Herz et al. [7]. Within the scope of the present contribution, the particle size distribution will be varied to show the effect on the calcination process.

Nomenclature				**Index**	
A	Surface	T	Temperature in °C	a	Air
c_p	Specific heat capacity	X	Conversion degree of limestone	CO_2	Carbon dioxide
h_u	Heating value	x	Mass fraction of the particle	f	Fuel
Δh_{CO_2}	Reaction enthalpy of CO_2	Y_{CO_2}	Mass fraction of CO2 in limestone	g	Gas
L	Stoichiometric air demand	α	Heat transfer coefficient	ls	Limestone
$\dot{M}$	Mass flow	$\lambda_{com.}$	Air excess number	s	Solid
O	Specific surface	λ_{lime}	Thermal conductivity of lime	sw	Surface
$\dot{Q}_w$	Heat loss through the wall	ψ	Porosity		

2. Mathematical modeling

2.1. Process description

In principle, a single shaft kiln is a vertical shaft where limestone is charged at the top of the kiln and lime is discharged at the bottom. The solid moves slowly downwards through the kiln by gravity. The heat is generated by fuel combustion where fuel is introduced with secondary air in the middle of the kiln. Therefore, the solid above is preheated by hot gas in counter-current flow and the solid below is cooled by the air introduced over the total cross section at the kiln bottom. In this way, material entering the kiln at the top is first preheated, then calcined and finally