Heat Transfer in Granular Flow in Rotary Calciners: Experiments and Particle Dynamics Simulations

M. Silvina Tomassone*, Bodhisattwa Chaudhuri and Fernando J. Muzzio
Rutgers University, Piscataway, New Jersey 08854 (USA)
*silvina@soemail.rutgers.edu

Introduction

Heat transport in particulate materials is an essential component of modern technologies such as high performance cryogenic insulation, heterogeneous catalytic reactors, construction material and powder metallurgy. In catalyst manufacturing, heat transfer through granular media occurs in the drying and calcination stages. In this paper, we describe experiments and particle dynamics simulations to examine flow, mixing, and mass & heat transport in rotary calciners. A cylindrical vessel made of aluminum, representing a slice of a calciner (8 inches diameter and 3 inches long) is used for the experiments. In parallel to the experimental studies we also use Discrete Element Method (DEM) simulations to model flow, mixing, and heat transport in granular flow systems in rotary calciners. Granular flow and heat transport properties of alumina and silica are studied systematically in order to develop a fundamental understanding of their effect on calcination performance. Two basic mechanisms of heat transfer are involved: the transient conduction in the particle bed during its contact with the wall and convective thermal mixing originated by the rotation of the calciner. Heat transport processes are simulated accounting for initial material temperature, wall temperature, specific heat capacity, effective granular bed heat transfer coefficient, baffle configuration, and granular flow properties (cohesion and friction).

Materials and Methods

Alumina powder (200µm) and cylindrical silica pellets (2mm diameter and 3mm long), which are common support materials for catalysts, are used in our experiments. Two insulated walls made of Teflon are located at the side of the calciner to avoid contact of the hot metallic walls of the calciner with the rollers on which the calciner is located. At one side of the cylinder, 10 thermocouples are inserted vertically through one of the side Teflon walls, to measure the radial temperature distribution of the granular bed. The other side Teflon wall has a thick glass window used for visualization. The thermocouples are connected to an Omega 10 channel datalogger interfaced to data acquisition software in an adjacent PC. The calciner is initially loaded with the material of interest at room temperature. Industrial heat guns are used to uniformly heat the external wall of the calciner. During the experiments, the wall temperature is maintained at 100^{o}C. The calciner is rotated at varying speeds using a computer controlled step motor. A parametric study was conducted by varying materials properties, filling ratios, and rotational speeds of the calciner. For our DEM model, the calciner system consists of 20,000 particles of 2 mm diameter in a cylindrical vessel of similar dimensions to those used in the second set of experiments. To minimize the finite size effects the flat end walls are considered frictionless and not participating in heat transfer.

Results and Discussion:

Simulations and experiments show that the rotation speed has minimal impact on heat transfer. As expected, the material with higher thermal conductivity (alumina) warms up faster in experiments and simulations. Similar to experiments, simulations show that the temperatures are higher near the wall and at the cascading layer of the powder bed, while minimum temperature remains at the core of the bed. In both simulation and experiments, the granular bed with lower fill fraction heats up at a faster rate. Faster mixing is also achieved for the lower fill fraction case, which causes rapid heat transfer from the vessel wall to the granular bed. The granular bed reaches the steady state maximum temperature at 654s, 750 s and 846 s for 20%, 35% and 50% fill fractions respectively. In the simulation, we observe the granular cohesion has no effect on the heat transfer in the calciners. Various baffle configurations (rectangular and L-shaped flights) in the calciner and their effects on the flow are simulated. The average wall-particles heat transfer coefficient and the effective thermal conductivity of the bed are also estimated from the experimental findings.

Significance: Over the last fifty years, a large number of empirical correlations relating bed temperature to heat transfer coefficients for a given range of operating variables have been proposed. These correlations, however, cannot be easily generalized to different equipment geometries and it is risky to extrapolate their use outside the experimental range of variables studied. Moreover, most of the proposed models do not capture particle-surface interactions or the detailed microstructure of the powder bed. Understanding the role of system parameters and the mechanisms of heat transfer in the bulk and boundary surfaces can lead to improved techniques and equipment manufacturing in the calcination process of catalysts.

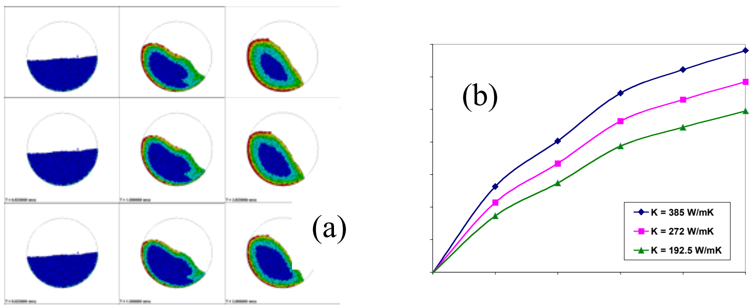

Figure 1(a) shows a time sequence of axial snapshots of color-coded particles in the calciner. Time increases from left to right (t = 0, 1.5 and 3 secs), while the thermal conductivity increases from bottom to top (k_s = 192.5, 272, 385 W/mK). **Figure 1(b)** shows the growth of average bed temperature over time for materials with different conductivity. The granular bed heats up at a faster rate for materials with higher conductivity.

Acknowledgments:
We acknowledge support of the companies in the Catalyst Manufacturing, Science and Technology Consortium at Rutgers (Albermarle, Chevron, ExxonMobil, Grace, HaldorTopsoe, Johnson Mathey, UOP-LLC).