Multi-phase flow and fuel conversion in cement calciner

Multi-phase flow and fuel conversion in cement calciner

In recent years, with the main motivation of reducing operating costs, the use of alternative fuels, especially refuse derived fuel (RDF), has become more popular in the cement industry. Besides the fuel costs, the reduction of CO₂ emission and cheap alternative for waste disposal methods are other incentives for using RDF in the cement plants. Around 55–65% of the fuel used in a cement factory is fired in a cement calciner. Compared to the conventional fossil fuels (FFs) fired in cement calciners, such as coal and petcoke, the characteristics of RDFs are very different in both physical (e.g., larger particle size and highly non-spherical particles) and chemical (e.g., different material types, reaction processes, reaction kinetics, etc.) aspects. Furthermore, RDFs have large variations in properties depending on their source and processing technology. The utilization of RDFs in cement calciners is a fairly new subject and has not been studied systematically. In order to design and operate RDF–fired calciners with high fuel conversion and low pollutant emissions, knowledge on the multiphase flows and conversion of RDFs under calciner conditions is required. In this thesis, it has been tried to obtain a fundamental understanding of the use of RDFs in cement calciners, through literature survey, experimental practices of physical, aerodynamic, and combustion characterization of RDFs, and full–scale measurements and CFD simulation of FF/RDF–fired calciners.

As the size and shape of RDF particles are two important factors affecting their aerodynamic and conversion behaviour in cement calciners, the physical and aerodynamic properties of several RDF samples are characterized through wind sieve experiments as well as 2D photographing. Based on the estimated size and shape of particles as well as the terminal velocity and aerodynamic properties (characterized using the wind sieve), the Ganser drag model is modified to provide more accurate aerodynamic modeling of particles in terminal condition. The estimated size and shape of particles as well as the modified Ganser drag model are used as inputs for CFD simulation of RDF–fired calciner. Furthermore, an approach is proposed for estimation of mass distribution of RDF particles from the terminal velocity (characterized using the wind sieve) and the maximum projected area (determined using 2D photographing) of particles.

Plastics are one of the major materials found in RDF, contributing to around 10 to 30 percent of RDF used in Europe. The suspension conversion of man–made pureplastics as well as plastics from an RDF sample is studied under calciner condition in a single particle combustor (SPC). Furthermore, for selected experiments and during the conversion process, the particle center and surface temperatures are measured using an S–type thermocouple and an infrared camera, respectively. The conversion of plastics is mainly composed of two steps of melting and decomposition. The total conversion time is dominantly affected by the particle size and reactor temperature and the particle shape has a minor effect. A 1D mathematical model is developed to model the plastic particle conversion in suspension. This model is validated against the experiments through comparison with the total conversion times as well as the measured surface and center temperatures. Two basic and simplified isothermal models are also developed to be used as sub–models in CFD simulations of reactive systems operating with RDF. The simplified isothermal model can be used in Barracuda Virtual Reactor® solver for CFD simulation of RDF–fired calciner. It is shown that for plastic particles lighter than 1000 mg and in comparison with the 1D model, the discrepancies of predicted total conversion times using the basic and simplified isothermal models are below ±30% and ±25%, respectively.

Characterization of particle dispersion and gas–solid heat transfer is carried out through extensive gas velocity and temperature measurements in a cold pilot scale calciner (carried out prior to the PhD study) as well as CFD simulations using Barracuda Virtual Reactor® solver. The velocity profiles of the particle–free flow are well predicted by the CFD simulations. For the particle–laden flow, two drag models of EMMS and Gidaspow are studied. Both drag models exhibit proper agreement with the measurements. However, using the EMMS drag model, falling of particles into the upstream regions as well as the overall area–averaged temperatures are better predicted.

Full–scale measurements of an ILC system operating with fossil fuel (FF) as well as RDF are carried out with the main purpose of comparison of the measurement data with the CFD simulation results. For five different scenarios, the gas temperature and species concentrations are measured at different locations in the calciner. The effect of fuel type fired in the calciner as well as the amount of raw meal fed to the lower calciner vessel on the calciner performance (e.g., fuel burnout, calcination degree,etc.) are studied. It is shown that as the moisture content of the fuel fired in the calciner is increased, e.g., when higher amount of RDF is fired, the gas temperature is decreased in the bottom calciner vessel. Generally, in the calciner vessels, the degree of fuel conversion is lower when a higher amount of RDF is fired in the calciner. Furthermore, the high temperature oxidation zone induced in the bottom calciner vessel by feeding some amount of raw meal to the upper calciner vessel, improves the fuel conversion degree.

Two of the measurement scenarios are selected for CFD simulations of the calciner operating with FF and RDF using Barracuda Virtual Reactor® solver. For the FF–fired calciner, the gas temperature is well predicted while the O₂ and CO₂ species concentrations are overpredicted and underpredicted, respectively. Consequently, both fuel conversion and calcination degrees are underpredicted. For the RDF–fired calciner, the gas temperature in the lower and upper calciner vessels is overpredicted. The fuel conversion degree is in proper agreement with the measurements while the calcination degree is still under predicted. In the upper calciner vessel and for the FF–fired calciner, the degrees of fuel conversion and calcination are underpredicted by 18.5% and 15.6%, respectively. For RDF–fired calciner, the mentioned parameters are underpredicted by 0.8% and 16.1%, respectively. Overall, the non–uniformity of cross–sectional gas temperature and species concentration profiles is overpredicted in the calciner vessels. In the swan neck, the predicted distribution of the mentioned profiles is in good agreement with the measurements. Possible causes of discrepancies between the measurements and CFD simulations (if any) are described, and suggestions for improvement are discussed.

General information
Publication status: Published