MODELLING OF FURNACES AND COMBUSTION SYSTEMS

(610) - MODELING OF RADIATION HEAT TRANSFER IN THE DENSE-BED FLOW OF SOLID PYROLYSIS IN INDIRECTLY HEATED ROTARY KILNS

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This work presents a comprehensive model for the simulation of the thermal conversion inside an indirectly heated rotary kiln fed with a continuous flow of wet biomass. The developed Eulerian-Lagrangian numerical tool integrates three-dimensional, time-resolved simulation of the essential chemical and physical processes occurring within and in-between the moving bed of particles. This is realized by combining the particle collision models for non-reactive dense flows with models for heat transport, phase change and chemical reaction for multiphase reacting flow in the framework of OpenFOAM®.

For the thermal treatment of solid particles, convection and radiation heat transfer methods couple the reactor wall, gas- and disperse phase. The well-known Ranz-Marshall model is used for the convective heat transport between particles and their surrounding gas within each computational cell. The original implementation of the finite volume Discrete Ordinate Model (fvDOM) for the dilute particulate phase neglects the effect of local opacity due to the existence of particles. However, in the present application, a dense-packed bed of the particulate phase exists in the reactor. Therefore, in this study, this direction-based radiation model is adjusted for a computational cell with arbitrary particle volume fractions.

A laboratory-scale rotary kiln reactor is used to validate the developed numerical tool and to perform parameter studies to determine the wall temperature for achieving the maximum yield of char at minimal energy consumption. The validations are carried out to justify whether the new models can accurately simulate the complex physical processes that govern the heating, drying and carbonization inside the reactor. After the successful validation, the numerical tool is adjusted and applied to an independent design of an industrial-scale rotary kiln reactor with 350 kg/h (~ 2000 tons/year) throughput. This requires employing supercomputers for the simulation of extremely long physical times in which, at the steady-state solid flow, the residence time exceeds 40 minutes.

This article focuses on the further development of a radiation heat transfer model available for dilute solid-gas interaction which is additionally extended to consider the effect of a fully-packed dense phase. This is settled by the calculation of shielding of neighboring particles within one computational cell. The objective is to appyl the simulation tool for designing low-temperature thermal conversion of particles in rotary kiln reactors at minimal energy expense.

Despite the immense computational power, performance optimizations are required to simulate the industrial-scale rotary kiln reactor. Thus, numerical performance optimizations are presented which are carried out on a supercomputer using up to 1120 CPU cores. Grid independence studies, mesh optimization and decomposition method, as well as parallelization performance tests, were applied to enhance the computational performance. Finally, a numerical setup is presented, which is capable of accomplish simulations on the available supercomputer.

Palavras-chave : Rotary kiln, Eulerian-Lagrangian, Radiation heat transfer, Biomass conversion, Comprehensive numerical simulation

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