RADIATIVE TRANSFER WITHIN A FLUIDIZED BED REACTOR FOR STEAM-GASIFICATION OF COAL

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Radiation heat transfer coupled to chemical kinetics is analyzed for a fluidized bed of coal particles undergoing steam gasification. The reactor consists of a transparent quartz tube containing coal particles fluidized in steam and directly exposed to an external source of concentrated radiation. The coal particles serve simultaneously as radiant absorbers and chemical reactants, providing efficient heat and mass transport. The advantages of using a concentrated radiation source for supplying high-temperature process heat are three-fold: 1) the calorific value of the fuel is upgraded; 2) the gaseous products are not contaminated by combustion by-products; and 3) if the radiation source is derived from renewable energy, e.g. solar energy, the emission of greenhouse gases is avoided (v. Zedtwitz and Steinfeld, 2003).

The Monte Carlo ray tracing method is used to determine the radiation heat transfer from the source to the reactor, through the reactor quartz layer, and within the fluidized bed. Spectral and directional dependent optical properties are employed for both the quartz tube and fluidized bed. Refraction and reflection at the quartz/air boundaries as well as absorption and emission within the quartz layer are considered. The fluidized bed is treated as an absorbing-emitting-scattering participating medium. Two approaches are examined to describe the radiative transfer within the fluidized bed for large particles of size parameter > 10. In the first approach, the bed is modeled as a continuous medium, using spectral absorption and scattering coefficients based on measured spectral reflectivity, and scattering phase functions for diffuse reflecting spherical particles. In the second approach, the bed is modeled as a cloud of randomly-positioned spherical particles, with spectral reflection, absorption, and emission taking place at the particle surface.

The bed region is divided into elemental disks in axial direction. Energy balances that account for radiation, convection, particle-mixing, and enthalpy change are applied in each element and solved numerically to calculate temperature profiles throughout the bed for particles, gas phase, and quartz tube. Composition of gaseous products is determined using kinetic rate laws based on elementary reaction mechanisms (Müller et al., 2003). Since all the terms in the energy balance equations are dependent on temperature, which is not known a-priory, the system is solved iteratively. Each iteration step requires a complete Monte Carlo ray tracing.

The numerical model has been validated with experimental data obtained from tests in a 25 mm-outer diameter, 1.5 mm-thickness, 25 cm-height quartz tubular reactor containing a fluidized bed of charcoal particles of 1 mm mean particle size. The radiation source consisted of a high-pressure argon arc close-coupled to precision elliptical-trough mirrors to produce continuous radiative power at peak fluxes exceeding 4250 kW/m^2. Details of the experimental set-up and reactor operational parameters are found in Müller et al. (2003).