Chen Hui, Ph.D., "Integrated Analyses of Biomass Gasification in Fluidized Beds", The University of Western Ontario, August 2007.

Abstract:

Biomass gasification in fluidized beds is one of the most promising conversion processes in meeting future ecologically compatible and sustainable energy demand, based on a combination of flexibility, efficiency, and environmental acceptability. In order to comprehensively understand the gasification process and provide the theoretical basis for the optimized operation and scale-up/down designs, the present work presents systematic integrated analyses of biomass gasification in the fluidized beds.

A two dimensional computational fluid dynamics (CFD) model based on Eulerian-Eulerian approach coupled with granular kinetic theory is developed to simulate the hydrodynamics and flow structures of the bubbling fluidized beds under different operating conditions. A parametric analysis is performed to comprehensively investigate the influences of particle properties (FCC catalysts, sand and its sizes), operating parameters (gas velocity, temperature, and pressure), reactor geometries (reactor diameter, exit structure), and multi-scale interactions (particle to gas, particle to particle and particle to wall interactions) and numerical methods (mesh sizes, discretization methods, time step sizes), etc. The simulation results are in good agreement with the experimental data obtained from the present experiments and the correlations reported in the open literatures.

A general-function equilibrium model based on the global Gibbs free energy minimization at the equilibrium state in the system combined with energy balance and elemental balances (e.g. C, H, O, N and S, etc.) is then formulated to predict the maximum achievable thermodynamic limits of seven biomass gasification processes: air, O_2-rich air, pure O_2 gasification; steam, CO2 gasification; air–steam, air-CO_2 gasification. A comprehensive parametric analysis is conducted to investigate the effects of the operating parameters, i.e. ER (equivalence ratio), O_2 content, S/B (mass ratio of steam to biomass), CO_2/B (mass ratio of CO_2 to biomass), operating temperature, pressure, agent preheating temperature, on the product gas compositions, ideal product components, i.e. H_2, CO and syngas (H_2+CO), ideal product selectivity (H_2/CO) and (CO/CO_2), dry gas yields, dry gas lower heating value (LHV), carbon conversion and gasification efficiency.

A two-dimensional CFD reactor model coupling biomass gasification reaction network with heat transfer, mass transfer and gas-solid flow in the fluidized bed gasifier is established to examine the global and local behavior of the gasifier. The model takes into account drying, fast pyrolysis, combustion, gasification, and shift and reforming processes in detail. Parametric analysis is carried out to investigate the influences of operating parameters, i.e. ER, S/B, reactor temperature and biomass particle sizes, on the performance of the fluidized bed gasifier.

Finally, the outputs of actual gasification processes and the predicted results from the equilibrium model and the CFD reactor model are compared for agreement and /or discrepancy. Based on the comprehensive comparative analysis, the optimum operating and design parameters in three main operating modes, i.e. max H_2, max CO and max syngas production, are obtained.

The hydrodynamics investigation of fluidized beds, the thermodynamic equilibrium model and the CFD reactor model are the three integral parts to comprehensively understand biomass gasification in the fluidized beds. This is the first time that a comprehensive and systematic integrated analyses of biomass gasification in the fluidized beds has been carried out. The integration of the CFD reactor model and the thermodynamics equilibrium model is a very powerful tool to gain insights into the global and local behavior of the fluidized bed biomass gasifier. The integration is not only applicable to fluidized bed biomass gasification, but also applicable to coal gasification, MSW gasification, co-gasification of coal and biomass, biomass and MSW or two different types of biomass in the fluidized beds and can be extended to other industrial processes such as combustion, pyrolysis, petroleum processing. The integration provides the powerful theoretical basis for optimized operations and scale-up/down designs.