CFD Simulation of an Entrained-Flow Coal Gasifier for Coal IGCC Process

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ABSTRACT

Coal gasifier is a key process to produce a high-quality gas in Integrated-coal Gasification Combined-Cycle (IGCC) plants. The entrained-flow coal gasifier has been widely used in IGCC plants due to the high gasification rate achievement and a relatively clean gas production.

In this study, a three-dimensional Computational Fluid Dynamics (CFD) model is developed to predict the performance of coal gasification in an entrained-flow gasifier using a CFD code, Fluent (Fluent, Inc., Lebanon, NH). The kinetic model is built by dividing the coal gasification into sub-models such as pyrolysis, char gasification, and gas phase reactions. The discrete phase model (DPM) is used to examine the behavior of coal particles inside the gasifier. Carbon combustion and char gasification are taken into account by using the Multiple Surfaces Reaction (MSR) model, and the gas phase reactions are considered as the Turbulent Reacting Flow (TRF) model.

The simulation results provide the detailed information about the flow field, temperature and species concentration distributions inside an entrained-flow gasifier including dry-feed and slurry-feed types. The numerical results of the CFD simulation are compared to the experimental data from published works.

KEY WORDS: Computational Fluid Dynamics (CFD), Multiple surfaces reaction, Turbulent reacting flow, Coal gasification, Entrained-flow gasifier, Carbon conversion, Gasification performance.

INTRODUCTION

Modeling of coal gasification process has received significant attention over the last two decades. Several mathematical models have been developed for entrained flow gasifiers. Wen and Chaung (1979), Govind and Shah (1984) developed models for Texaco down-flow, slurry-type entrained gasifiers. Ni and Williams (1995) developed a multivariable model for Shell coal gasifiers on the basis of equilibrium, mass and energy balances by means of non-linear programming. Recently, Liu et al. (2000) proposed a model for a pressurized entrained flow coal gasifier to determine the effect of pressure, reaction kinetics and char structure on the gasification reactions. The model predictions were compared to published experimental data.

Coal gasification involves complex physical and chemical phenomena including fluid flow, heat and mass transfer and chemical reactions. Combined with data from existing pilot and commercial scale gasifiers, computational fluid dynamics (CFD) models offer a powerful method for understanding and improving gasification systems. Over the past decade, CFD modeling has played an important role in optimizing the performance of pulverized coal fired electric utility boilers (Shi et al. 2006). Likewise, CFD modeling can provide insights into the flow field within the gasifier, which can be used to enhance its design, analysis, and operation (Shi et al., 2006; Bockelie et al., 2002).

This paper addresses a three-dimensional CFD modeling including two-phase turbulent flow, gas-phase and solid-gas reactions to predict the performance of entrained-bed coal gasifiers. The CFD approach is used to study on both Shell gasifier (dry-feed type) and Texaco gasifier (slurry-feed type) using a commercial finite volume CFD code, Fluent (Fluent, Inc., Lebanon, NH). The predicted numerical results are compared to experimental measurements available in literature.

MODELS AND NUMERICAL METHODOLOGY

To simplify the complexity of the modeling, the entrained-flow gasifiers can be conceptually divided into three zones: (1) pyrolysis and volatiles combustion, (2) char combustion and gasification and (3) gas phase reaction. The model of each zone mentioned above is described in detail as follows.

Coal Devolutilization

The devolatilization of coal has significant influence to the coal ignition and the combustion stability. The coal particle will suffer complicated physical and chemical processes of heating, pyrolysis, ignition, and burning up. There are many models to characterize those processes physically and mathematically, such as the single kinetic rate model (Badzioch and Hawsley, 1970), the two-competing rates model (the Kobayashi model), Solomon general model (Solomon and Colket, 1988), etc. In this work, the two competing rates model is used to simulate the coal particle process, since it has been widely practiced and accepted in engineering (He et al., 2007). One can find the model in details elsewhere (FLUENT 6.3 User's guide, 2007; He et al., 2007; Ajikumar et al., 2009).