Journal of the Energy Institute 88 (2015) 314–322

Contents lists available at ScienceDirect

Journal of the Energy Institute

journal homepage: http://www.journals.elsevier.com/journal-of-the-energy-institute

Euler–Lagrange modeling of wood chip gasification in a small-scale gasifier

Guilin Hu*, Guoneng Li, Youqu Zheng, Zhiguo Zhang, Yousheng Xu

Department of Energy and Environment System Engineering, Zhejiang University of Science and Technology, 310023 Hangzhou, China

ARTICLE INFO

Article history:
Available online 23 September 2014

Keywords:
Wood chip
Gasification
Euler–Lagrange
Numerical simulation

ABSTRACT

The mathematical model for physical and chemical processes during wood chips gasification in a gasifier is presented in this paper to offer some reference data for the gasifier structure design and operation optimization. The RNG $k-\varepsilon$ model is employed in the numerical simulation of turbulent combustion gas flow. Non-premixed combustion model is used to describe the species reaction and transportation. The movement and gasification of wood chip particle is described by Lagrange model. The Eulerian conservation equations of gas phase are solved using the control volume approach. The distributions of temperature and chemical species, residence time of wood particles are numerically obtained. The results indicate that this design will cause vortex structure at lower chamber for the interaction between the forwarding flow of air and the reverse flow of syngas. This vortex will make produced syngas to combust further; the productions are CO_2 and H_2O substituting CO and H_2, which will decrease the temperature inside the chamber and quality of syngas. In order to optimize operational case, five different equivalence ratios of airflow are computed and compared with experimental test. The predicted temperatures of outgoing gas agree well with the experimental results. Modeling results can provide some references for gasifier structure design and optimum operation case.

1. Introduction

Along with the rapid economical development, the problem of energy shortages and environmental pollution is becoming more severe. More and more severe haze attack many Chinese metropolises like Beijing and Shanghai, clean energy utilization and environment issues become more and more concerned. Biomass as a renewable energy is concerned more and more all over the world. Among them wood is considered as one of the most important renewable energy sources. At the same time the technology of biomass gasification has been rapidly developed. Despite the long history of utilizing the combustible fuel gas from wood gasification there still is a lack of detailed scientific knowledge about the complex gasifications reactions and fundamental research on the gasifier design and operational case. Gasification is a complicated process involving combustion, heat/mass transfer, turbulent flow and interaction between gas flow and particles. Furthermore, many homogeneous and heterogeneous reactions occur during gasification including devolatilization at the initial stage and carbon combustion at the final stage. The modeling of this complicated process is a big challenge. Numerical methods like Euler–Euler [1–4] or Euler–Lagrange [4–6] methods can complement experiments for a better understanding of the physical and chemical processes for the particle movement. In order to improve and optimize the thermal efficiency and to predict product gas composition and emission rates, numerous mathematical models for biomass gasification have been developed. Euler–Euler and Euler–Lagrange models are both comprehensive models suitable for fundamental investigations of the chemical and fluid mechanical aspects of gasifier. At present, both of these two models are still generally accepted. In Euler–Euler model [7], the Euler model for particle can get more detailed particle information, but need more equations to solve, more computer resources. So Euler–Euler models are more suitable for describing dense phase flow when there are good models to describe the interaction between particles. The Euler–Lagrange models allow a detailed modeling of mass, momentum, and energy transfer on the individual particle level. However, the detailed modeling capabilities of

* Corresponding author.
E-mail address: enehgl@163.com (G. Hu).

http://dx.doi.org/10.1016/j.joei.2014.08.002
1743-9671/

Euler–Lagrange models require high computational costs. Lagrange models can trace the particle tracks and get the residence time information. And the statistics characteristics parameters can be obtained. However this can be suitable for diluted particle phase, and the interaction between particles is neglected. Gerber et al.(2010b) compared two different modeling strategies for the simulation of wood gasification in a dense fluidized bed through Euler–Euler and Euler–Lagrange models. For the pyrolysis process of wood, there are also many experimental and numerical researches [8–12] to get a good kinetics model. [13] presented a comparison between the different drag models for granular flows developed in the literature and the effect of each one of them on the fast pyrolysis of wood. Biomass reaction kinetics is modeled according to the literature using a two-stage model. [14] analyzed the characteristics of wood biomass gasification process comprehensively based on least squares support vector machine. Based on this model, a multi-objective optimization function was put forward between control parameters and gasification performance. Besides, the target value of control parameters was optimized. [16] presented a model for pressurized steam/O_2-blown fluidized-bed gasification of biomass with catalytic reforming of hydrocarbons and tars using Aspen Plus simulation software. The parametric analysis of that paper indicated that a significant improvement in the syngas efficiency could be achieved by increasing the filtration temperature and reformer conversions. [15] experimentally investigated the temperature field inside the gasifier and numerically simulated the processes inside the gasifier using CFD to model the Lagrangian particle coupled evolution. The temperature distribution and the evolution of species are computed and compared with the experimental results and with the ideal equilibrium, zero dimensional case. [17] reviewed the state of the art in modeling chemical and physical processes of wood and biomass pyrolysis. Chemical kinetics is critically discussed and different approaches used in the transport models are presented at both the level of single particle and reactor.

In this work we present an Euler–Lagrange model of wood chip gasification in a small scale gasifier. The detailed gas phase chemistry, pyrolysis models, and heterogeneous gasification reactions are considered. The spatial distribution of species concentration, temperature and velocity are computed to explain characteristics of gasifier structure. Different operational cases are computed to obtain the optimum operation.

2. Mathematical model

2.1. Geometrical model and computational domain

The wood chip biomass gasification was carried out in gasifier as shown in Fig. 1. Fig. 1a is the longitudinal section of gasifier, Fig. 1b is the axial section. There are the air inlet and syngas outlet for gas in and out the gasifier. The wood chip and the residual will be taken into and taken out the gasifier by the screw mechanics. The reactor has a capacity of 100 g/h, is constructed by stainless steel with 40 mm in diameter and height of 260 mm. The average particle diameter is 440 μm.

2.2. Governing equation

The governing equation for continuum, movement, heat and mass transfer for gas flow can be written as following section.
Continuum equation:

$$\frac{\partial \rho}{\partial t} + \frac{\partial}{\partial x_i}(\rho u_i) = 0. \tag{1}$$

Momentum conservation equation:

$$\frac{\partial(\rho u_i)}{\partial t} + \frac{\partial(\rho u_i u_j)}{\partial x_j} = -\frac{\partial p}{\partial x_i} + \mu \frac{\partial^2 u_i}{\partial x_j \partial x_j} + \frac{\partial}{\partial x_j}\left[\mu_t\left(\frac{\partial u_i}{\partial x_j} + \frac{\partial u_j}{\partial x_i}\right)\right] + \rho g_i. \tag{2}$$

where $i, j = 1, 2, 3$, ρ is fluid density, t is time, u is fluid velocity vector, x denotes the spatial coordinate, p stands for average pressure, μ is fluid viscosity, μ_t is turbulent viscosity, g_i is gravity in the i direction.

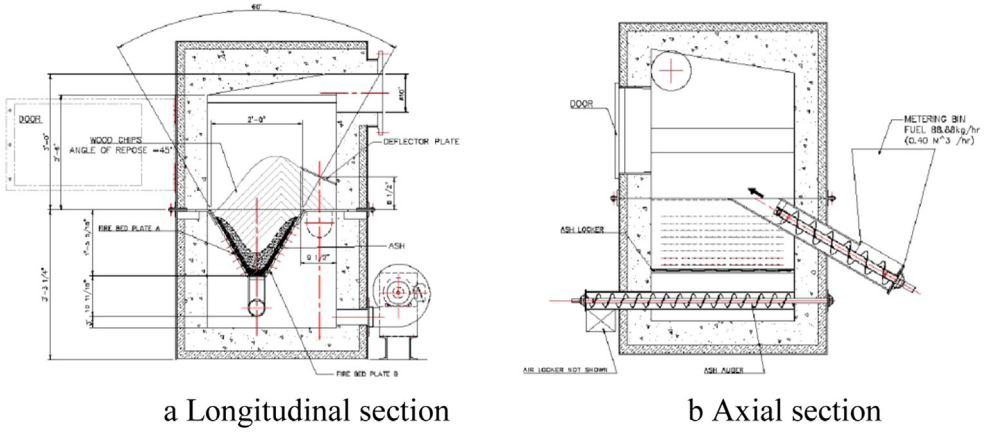

Fig. 1. Gasifier structure diagram.