Waste Management xxx (2017) xxx–xxx

Contents lists available at ScienceDirect

Waste Management

journal homepage: www.elsevier.com/locate/wasman

Fluid dynamics model on fluidized bed gasifier using agro-industrial biomass as fuel

Tamer M. Ismail [a,*], M. Abd El-Salam [b], Eliseu Monteiro [c,d], Abel Rouboa [e,f]

[a] Mechanical Engineering Department, Suez Canal University, Ismailia, Egypt
[b] Department of Basic Science, Cairo University, Giza, Egypt
[c] CIENER-INEGI/Faculty of Engineering, University of Porto, Porto, Portugal
[d] C3i – Interdisciplinary Center for Research and Innovation, Polytechnic Institute of Portalegre, Portalegre, Portugal
[e] CIENER-INEGI/Engineering Department of University of Trás-os-Montes e Alto Douro, Vila Real, Portugal
[f] MEAM Department, University of Pennsylvania, Philadelphia, PA, USA

ARTICLE INFO

Article history:
Received 3 February 2017
Revised 4 June 2017
Accepted 5 June 2017
Available online xxxx

Keywords:
CFD
Fluidized bed
Gasification
Peach stone
Miscanthus
Biomass

ABSTRACT

The present study shows the experimental and numerical results of thermal gasification of biomass, on the energy potential of agro-industrial waste from the Portalegre region. Gasification tests were performed in a pilot-scale fluidized bed gasifier, in order to study the behavior of peach stones and miscanthus to investigate the effect of gasification temperatures at 750 °C, 800 °C and 850 °C at a constant biomass flow rate of 45 kg/h. In order to optimize the operating conditions of the biomass gasification process, a numerical model is developed namely COMMENT code. This model is a computer model of two dimensions describing the biomass gasification processes in a fluidized bed gasifier using peach stone and miscanthus as fuel. Both phases, solid and gaseous, were described using an Eulerian-Eulerian approach exchanging mass, energy, and momentum. The numerical model results are then compared with experimental results. The produced results show the impact of the increased temperature in the calorific value of the syngas. The tests carried out at 750 °C shown an increase in CO_2 and N_2 and a decrease of CO in the range of 5% comparing to the tests carried out at 850 °C. In addition, increased temperature favors a decrease in tar production in thermal gasification process. Numerical results shows to be in good agreement with the experimental data.

1. Introduction

At the beginning of the 19th century, gasification technology was widely applied to convert biomass into synthetic gases used to produce energy and electricity. With the opportune technology, energy generation from biomass does not participate in the greenhouse effect, because the biomass fuel is carbon neutral to the surroundings (Saidura et al., 2011).

It has been recently observed that there is an outstandingly fast decrease in fossil fuel sources in coincidence with the increased demand for fossil fuels, environmental concerns, and energy security. Thus, a lot of attention has been focused on technologies of biomass and municipal solid wastes.

Among these, combustion and gasification are two of the most important technologies related to the type of fuel that helps control greenhouse gas emissions (Kirkels and Verbong, 2011). Currently, biomass and biofuels are being considered because of their environmentally-friendly characteristics and their ability to supply much more energy. One of the most pressing concerns regarding the use of biomass as a renewable energy source is increasing its efficiency. In order to improve energy efficiency it is necessary to optimize the gasification process, by developing numerical models that optimize the design and operation conditions.

Therefore, gasification technology offers the possibility of using clean and efficient energy, from carbon-based feedstock that would otherwise be expelled away as waste and biomass. Moreover, the gasification technology will assist developing countries in relying on renewable energy more than oil in industry, and in generating more electricity. The resulting gaseous fuel can be employed, as an alternative of natural gas, to generate electricity and act as

* Corresponding author.
E-mail addresses: temoil@aucegypt.edu, tamer.ismail@eng.suez.edu.eg (T.M. Ismail), mohamedelsheikh@cu.edu.eg (M. Abd El-Salam), elmmonteiro@portugalmail.pt (E. Monteiro), rouboa@utad.pt (A. Rouboa).

http://dx.doi.org/10.1016/j.wasman.2017.06.018
0956-053X/

Nomenclature

A	pre-exponent factor, particle surface area [1/s, m^2]
C_D	drag coefficient
C_{mix}	mixing rate constant
C_p	specific heat capacity [J/kg K]
$C_{w,g}$	moisture concentration in the gas phase [kg/m^3]
$C_{w,s}$	moisture concentration at the solid phase [kg/m^3]
D_g	mass diffusion coefficient of gas [m^2/s]
D_{O2}	mass diffusion coefficient of oxygen [m^2/s]
D_s	particle mixing coefficient [m^2/s]
d_p	particle diameter [m]
E	activation energy [kJ/mol]
E_b	blackbody emission of the gas [W]
e	coefficient of restitution for particle collisions
g_o	radial distribution function
H_{evp}	evaporation heat of the solid material [J/kg]
h_f	enthalpy of formation [J/kg]
h_{rs}	radiation heat transfer coefficient [m/s]
h_{rv}	effective radiation heat transfer coefficient of the voids [m/s]
h_s	convective mass transfer coefficient between solid and gas [m/s]
$h_{s'}$	convection heat transfer coefficient between solid and gas [W/m^2 K]
I	radiative intensity [W]
K	extinction coefficient
k	turbulent kinetic energy [m^2/s^2]
k_d	diffusion rates [kg/atm m^2 s]
k_f	thermal conductivity of the fluid [W/mK]
k_s	thermal conductivity of the pure [W/mK]
k_{eff}	effective thermal conductivity [W/mK]
$k_{eff,0}$	the thermal conductivity for no fluid flow [W/mK]
l_s	equivalent thickness a layer of solid [m]
M	molecular weight [kg/kmol]
P_{O2}	partial pressure of oxygen [Pa]
P_w	partial pressure [Pa]
Q_{cr}	heat absorbed by the solid [W]
q_r	radiative flux density [W]
R	gas universal constant [J/kmol K]
R_{evp}	moisture evaporation rate [kg/s]
R_c	char consumption rate [kg/s]
Re	Reynolds number
R_v	volatile matter in solid rate [kg/s]
Sc	Schmidt number
Sh	Sherwood number
S_Φ	source term
T_{env}	environment temperature [K]
T_g	gas temperature [K]
T_s	solid temperature [K]
t	time [min]
X	molar concentration [$\frac{kmol}{kmol}$]
Y_v	mass fraction of volatile matter
u	velocity component in x-direction [m/s]
v	velocity component in y-direction, volume of particle [m/s, m^3]

Greek letters

α	absorption coefficient
β	gas-solid interphase drag coefficient
δ	Stefan-Boltzmann constant [W/m^2 K^4]
ε	dissipation rate of turbulent kinetic energy [m^{-2} s^{-3}]
ϵ	emissivity
ζ	random number that obeys the Gauss distribution
Θ_s	particle phase pseudo-temperature [m^2/s^2]
λ_g	thermal dispersion coefficient
λ_{mix}	effective dispersion coefficient
μ	dynamic viscosity [kg/m s]
ρ	density [kg/m^3]
σ_p	scattering coefficient
τ_s	stress tensor [Pa]
Φ	dependent variable
ϕ	void fraction in bed
χ	CO/CO_2 ratio

Subscripts

b	bulk
c	char burnout
eff	effective
f	fluid
g	gas
p	particle
s	solid
sb	solid bulk
sg	solid to gas
T	total
v	volatile matter

raw material to make chemicals and liquid fuels. This process requires a gasifying agent such as air, air/steam or pure oxygen under certain temperatures and pressure to completely convert carbonaceous materials into a producer gas (Jangsawang et al., 2006).

Computational fluid dynamics (CFD) modeling is a very elegant and economical tool to study gasification and combustion processes. So when a reliable CFD model is developed, it supports the setting and optimization of such systems. CFD draws temperature profiles of solid and gas phases in bed, predicting the temperature profile of furnaces, the concentration of species and heat flux. A reliable CFD model is considered as one of the most important and the best approaches to predict the critical results and the important requirements to control and guarantee an efficient result.

There are two different models used to key out the gas-solid flow: discrete element method (DEM) and the continuum description model. Discrete element method is the most popular model used; merely due to the increasing in the particle number the model becomes more expensive computationally, because it requires high memory resources to overcome these calculations (Zhong et al., 2006). On the other hand, the continuum model, based on the kinetic theory of granular flow (KTGF), became the method generally employed in identifying the two phase model, particularly because it is less demanding in terms of central processing unit and memory resources (Ding and Gidaspow, 1990; Gidaspow, 1994; Schmidt and Renz, 2000; Subramanian et al., 2011; Couto et al., 2015).

Fluidization is a phenomenon of the movement of solid particles. Each particle is subjected to the force of gravity, to the impulsion of Archimedes and to the drag force. The force balance makes it possible to determine the minimum fluidization velocity, which is the minimum velocity at which the gas must circulate in order to move the particles. This velocity can be determined from empirical correlations. Many researchers have been studying the modeling of biomass gasification based on many parameters, such as the type of gasifier reactor, gasification agent, and type of fuel used, as well as the chemical process reactions (Benyahia et al., 2000;

Please cite this article in press as: Ismail, T.M., et al. Fluid dynamics model on fluidized bed gasifier using agro-industrial biomass as fuel. Waste Management (2017), http://dx.doi.org/10.1016/j.wasman.2017.06.018