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Assessment of the carbonized woody briquette gasification in an updraft fixed bed gasifier using the Euler-Euler model

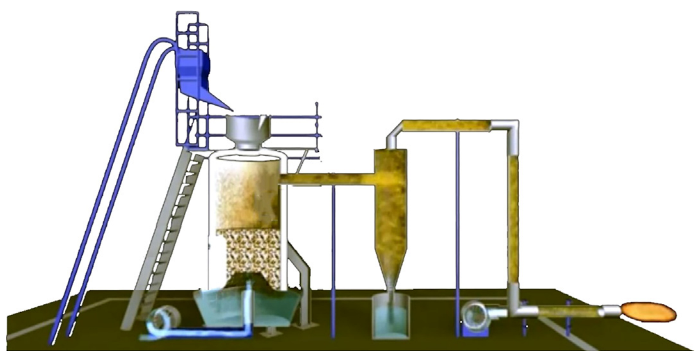
Ding Lu[a,*], Kunio Yoshikawa[a,*], Tamer M. Ismail[b,*], M. Abd El-Salam[c]

[a] School of Environment and Society, Tokyo Institute of Technology, G5-8, 4259 Nagatsuta, Midori-Ku, Yokohama 226-8502, Japan
[b] Mechanical Engineering Department, Suez Canal University, Ismailia, Egypt
[c] Department of Basic Science, Cairo University, Giza, Egypt

HIGHLIGHTS

- The first study on carbonized briquette gasification by both simulation and experiment.
- Effects of ER, and particle size were well evaluated by simulation.
- Carbonized briquette can be well utilized for the low tar production issues.

GRAPHICAL ABSTRACT



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ABSTRACT

This paper reports on the numerical simulation and experimental studies of carbonized woody briquettes gasification employing an updraft fixed bed gasifier. There is a strong industrial stake when it comes to the optimization of this gasification process, in terms of the flexibility of the type of biomass and its conversion efficiency. The influences of the gasification temperature and the equivalence ratio (ER) on the gaseous production and the tar yield were examined. In order to optimize the operating conditions of the biomass gasification process, a numerical model was developed using the COMMENT code (Combustion Mathematics and Energy Transport). This model is a two-dimensional computer model describing the biomass gasification process in an updraft gasifier using carbonized woody briquettes as fuel. The present study proved that ER significantly influenced the composition of gaseous species and its optimization is important to obtain a higher gasification rate. The particle size presented considerable effects on the temperature distribution within the gasifier and the syngas compositions produced during the gasification process as well. The numerical model presented was validated by the experimental results and it provided a promising way to simulate the gasification of solid fuel, which is considered to be a versatile and useful computational tool to optimize the biomass gasification process and to design fixed bed gasifiers.

* Corresponding authors.
E-mail addresses: dinglu101@163.com (D. Lu), yoshikawa.k.aa@m.titech.ac.jp (K. Yoshikawa), temoil@aucegypt.edu, tamer.ismail@eng.suez.edu.eg (T.M. Ismail).

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Nomenclature

A	pre-exponent factor, particle surface area [1/s, m^2]
C_p	specific heat capacity [J/kg K]
C_{sw}	swilling coefficient
D	diffusion rate [m^2/s]
d_p	particle diameter [m]
E	activation energy [kJ/mol]
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]
K	extinction coefficient
K	turbulent kinetic energy [m^2/s^2]
k_c	char combustion reaction rate [(kg/s)]
k_{cr}	kinetic rate [(1/s)]
K_{cd}	diffusion rates [kg/atm m^2 s]
k_f	thermal conductivity of the fluid [W/m K]
k_s	thermal conductivity of the pure [W/m K]
k_{eff}	effective thermal conductivity [W/m K]
$k_{eff,0}$	the thermal conductivity for no fluid flow [W/m K]
l_s	equivalent thickness a layer of solid [m]
P_{O2}	partial pressure of oxygen [Pa]
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]
Sh	Sherwood number
S_Φ	Source term
T_∞	environment temperature [K]
T_g	gas temperature [K]
T_s	solid temperature [K]
t	time [min]
X	degree of burnout $\left[\frac{kmol}{kmol}\right]$
Y_i	mass fraction of species
u	velocity component in x-direction [m/s]

Greek letters

α	burning mode
β	gas–solid friction coefficient
μ	dynamic viscosity [kg/m s]
ϕ	void fraction in bed
ε	dissipation rate of turbulent kinetic energy [m^{-2} s^{-3}]
ϵ	emissivity
$\varnothing$	mechanism factor
ρ	density [kg/m^3]
λ_g	thermal dispersion coefficient
λ_{mix}	effective dispersion coefficient
Φ	dependent variable

1. Introduction

At the beginning of the 19th century, gasification technologies were widely applied to convert biomass into synthetic gases used for thermal energy and electricity supply. With the opportune technology, energy generation from biomass does not cause the greenhouse effect, because the biomass fuel is carbon neutral to the surroundings [1].

It has been recently observed that there is an outstanding fast decrease in fossil fuels in coincidence with the demand of environmental concerns, energy security and care for fossil fuels. Thus a lot of attentions became the focus on technologies of biomass and MSW conversion.

Among these, combustion and gasification are the most important technologies for that kind of fuel which help control of greenhouse gas emissions. Combustion converts fuel energy directly into thermal energy, while gasification thermally converts the fuel into syngas, which can be utilized in many applications [2,3]. Therefore, gasification technologies offer the possibility of using clean and efficient energy, from carbon-based feedstock that would otherwise be expelled away as biomass wastes. Moreover, the gasification technologies will assist the developing countries, to use the renewable energy rather than oil in industry and in generating electricity.

Updraft fixed bed gasifiers are the oldest and simplest type of gasifiers. In such gasifier, the atmospheric air as the gasifying agent enters from the bottom and moves towards the top while the biomass is fed from the top and moves downward. A grate is fixed at the bottom of the gasifier where biomass is ignited, thus the temperature in the oxidation zone increases. The hot gas with a low oxygen content moves upward transporting heat to the other zones of the gasifier; consequently, as the biomass enters from the top, it experiences drying, devolatilization, gasification and combustion, respectively. The syngas temperature at the outlet is low and the tar content is high, since the syngas does not experience high temperature reactions [4]. But in our case, by using carbonized briquettes as gasification fuels, the tar content in syngas is much lower compared to other biomass feedstock used in conventional updraft fixed bed gasifiers.

In order to improve the energy efficiency of the gasification process, it is necessary to improve the gasifier performance by developing numerical models that can optimize the design and operating conditions. Mathematical models can produce a large number of data points with less experimental data.

The main models used for biomass gasification are the thermodynamic equilibrium model and the kinetic model. The first one is the equilibrium model that is used for predicting the thermodynamic limits of the chemical reactions within the gasification processes [5–16]. On the other hand, the kinetic model is beneficial for predicting the compositions of the outgoing gas, as well as providing the equilibrium temperature, and the solid composition. However, the kinetics-free equilibrium model cannot be used for reactors' design [17].

The equilibrium model cannot be applied to predict the profiles of the temperature or the gaseous concentration across the gasifier's axial direction. Consequently, its results provide the same final composition for different lengths of the reduction zone in biomass gasifiers. As a result, it is necessary to integrate the transport and kinetic models and consider the following: the kinetics of heterogeneous and homogeneous reactions, the transport of the volatiles generated, the mass and heat transfer that occur from the shift of solid to gaseous phase and pyrolysis reactions.

However, no complete models including pyrolysis, combustion and reduction zones, have been reported for biomass updraft fixed bed gasifiers. In terms of gasifier manufacturers, the updraft fixed bed gasifiers are the most popular type. Therefore, it is important to develop a complete model for this type of gasifier. Despite this urgency, carbonized wood briquettes are not yet to be investigated numerically or experimentally in a model for updraft fixed bed gasifiers.

Based on previous experiences, no matter for downdraft or updraft fixed bed gasifiers, they can be operated best using densified fuels (pellets/briquettes) instead of fine light biomass. Many researchers have been doing a lot of work on making high quality pellets/briquettes from raw biomass [18–22]. With the awareness that fuel quality could be significantly improved through torrefaction (200–300 °C) or carbonization at a low temperature (350–500 °C) [23–27], some other