Energy 115 (2016) 458–467

Contents lists available at ScienceDirect

Energy

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

Spray combustion characteristics of kerosene/bio-oil part II: Numerical study

S.I. Yang*, T.C. Hsu, M.S. Wu

Department of Power Mechanical Engineering, National Formosa University, Yunlin County, 63202, Taiwan

ARTICLE INFO

Article history:
Received 8 December 2015
Received in revised form
4 May 2016
Accepted 6 September 2016

Keywords:
Biomass
Fast pyrolysis
Kerosene
Bio-oil
Spray combustion
Droplet
Numerical simulation

ABSTRACT

A numerical method was employed to simulate kerosene with a bio-oil additive derived through a fast pyrolysis process in a model for spray combustion flow field. The influences of various oxidizer velocities and proportions of the bio-oil additive on kerosene spray combustion were investigated. The results indicate that for the kerosene with the bio-oil additive, an increase in the oxidizer velocity decreased and intensified the spray combustion regime mainly because an increase in the spray angle reduced the unit area of the droplets, and the turbulence increased the mixing of fuel and oxidizer. The kerosene spray combustion regimes with the bio-oil additive were reduced when the proportion of the additive was increased, mainly because the bio-oil was derived from the biomass in a fast pyrolysis process; specifically, the condense temperature influenced the volatility of the bio-oil components. Compared with pure kerosene, the volatile bio-oil underwent early vaporization into fuel vapor; this resulted in an early reaction after mixing with the oxidizer and an indirect early kerosene reaction, thereby contributing to the decrease in the kerosene spray combustion regime with the bio-oil additive. Because the heating value of the bio-oil was low, the addition of excessive bio-oil reduced the combustion efficiency.

© 2016 Published by Elsevier Ltd.

1. Introduction

Our research team previously synthesized bio-oil through the fast pyrolysis of biowaste commonly available in Taiwan [1]. The produced bio-oil was subsequently mixed with diesel and then tested in a diesel engine [2]. The results revealed that adding bio-oil improved the engine performance; however, increasing the proportion of the bio-oil added reduced engine performance. In addition, we observed knocking and slag phenomena in the engine combustion chamber and nozzle. Therefore, we mixed the bio-oil with kerosene to conduct experimental measurements [3] and to execute numerical simulations to identify the effect of bio-oil additive on fossil fuel. Biomass sources undergoing fast pyrolysis in a high-temperature anaerobic environment can convert cellulous, hemicellulous, and lignite in the biomass into biochar, noncondensable gases, and condensable gases through thermal conversion [4–10]. Two bio-oil phases, namely, oily and aqueous phases, can be produced according to the difference in condensation temperatures. These two phases differ in water content and compositions, thereby presenting distinct results in characteristics such as viscosity, heating values, and pH values.

Atomization reduces liquids into small droplets, generating vapor and oxidizers after vaporization, which are subsequently mixed for combustion. Efficient atomization is closely associated with the relative velocity between ambient gas and spray fluid; efficiency indices comprise the droplet size, droplet velocity, and spray angle, and these indices are correlated with the atomization conditions, fuel properties, and atomizer configuration. Atomization characteristics, particularly liquid viscosity and surface tension, affect the operating performance of thermal devices; the droplet size increases with liquid viscosity and surface tension. Because the viscosity and surface tension of bio-oils are typically higher than those of petroleum fuels, severe constraints are associated with the use of bio-oils. For example, bio-oils require preheating, and, consequently, their viscosity must be reduced or atomization pressure increased (or both). Chiaramonti et al. [11] produced bio-oil through standard nozzle atomization, and they measured the droplet size distribution after atomization. They revealed that the Sauter mean diameter of the bio-oil spray was lower than 50 μmin, when the bio-oil was heated to 80 °C and the operating pressure exceeded 0.6 MPa. Compared with petroleum oil, bio-oils are more difficult to ignite because of their chemical composition. One of the

* Corresponding author. Tel.: +886 5 6315432; fax: +886 5 6312110.
E-mail address: ianyang@nfu.edu.tw (S.I. Yang).

http://dx.doi.org/10.1016/j.energy.2016.09.047
0360-5442/© 2016 Published by Elsevier Ltd.

Nomenclature

B	constant
C	constant
C_d	drag coefficient
D	mass diffusivity
E	energy
F	body force
h	enthalpy of ideal gases
J	diffusion flux of species
k	thermal conductivity
k_t	turbulent thermal conductivity
K	wave number
p	pressure
Pr	turbulent Prandtl number
r	diameter of droplet
Re	Reynolds number
S	mass source vaporized
S_{ct}	effective Schmidt number for the turbulent flow
T	temperature
Ta	Taylor number
Y	mass fraction of species
v	droplet velocity
Z	Ohnesorge number
We	Weber number
Λ	wave length
Ω	frequency

Greek Symbols

τ	time scale
μ	dynamics viscosity
ρ	density (kg/m^3)
σ	surface tension
τ	stress

Subscript

d	droplet
ε	dissipation rate
g	gas phase
i	species
k	turbulence kinetic energy
l	liquid
m	mass
t	turbulent
KH	Kevin–Helmholtz model
RT	Rayleigh–Taylor model

main reasons for this difficulty in ignition is that bio-oils contain water, which possesses a high vaporization latent heat. Therefore, bio-oil systems require high ignition energy. In many bio-oil systems, the ignition efficiency is elevated by using a pilot flame, adding ignition improvers, preheating the combustion chamber, and preheating the combustion air. Shihadeh et al. [12,13] tested two types of bio-oils in a high-speed diesel engine and reported that these bio-oils exhibit higher ignition activation energy levels compared with diesel; hence, bio-oils require preheated air for achieving autoignition. Different biomass types are produced under different pyrolysis conditions, and they thus possess unique combustion characteristics, which are mainly influenced by the water content of the bio-oils.

Examining bio-oil combustion characteristics in an engine is difficult, and this increases the cost associated with relevant investigations. Numerous studies have established numerical computing models to simulate the spray combustion processes of biofuels. Park et al. [14] adopted experimental and numerical methods to explore the effect of fuel temperature and atmospheric conditions on soybean oil methyl ester fuel. The experimental measurement and computation parameters for atomization included the axial distance from the nozzle tip as well as the local and overall Sauter mean diameter. The results revealed the occurrence of higher fuel steam at the axial position, and this was attributed to the rapid evaporation of smaller droplets. Ban-Weiss et al. [15] proposed a theory on NOx production in biodiesel to modify numerical methods, and they demonstrated that double-bonded molecular structures induced a tendency of NOx growth. The determined tendency is consistent with that observed in the experimental measurements, thereby facilitating the future application of the model in numerical simulations. Choi and Reitz [16], Arcoumanis et al. [17], and Golovitchev and Yang [18] have used numerical methods to simulate biodiesel, dimethyl ether (DME), and biofuel combustion models, respectively, in an internal combustion engine. Battistoni and Grimaldi [19] adopted computational fluid dynamics methods to simulate the injection process of pure diesel and biodiesel. They also applied the Eulerian–Eulerian two-fluid model to compute the unsteady status caused by cavitating flows. Differences in viscosity and density between diesel and biodiesel results in distinct atomization phenomena, including spray penetration, atomization, and cone-angle, between these fuels. Som and Longman [20] determined that petrodiesel and biodiesel have dissimilar physical and chemical properties, in addition to distinct fuel atomization structures. However, numerous studies have only inferred the effect of various physical and chemical characteristics of different fuels on combustion. Compared with petrodiesel, biodiesel has a higher liquid penetration length, because of its higher heat of vaporization, and a lower ambient air entrainment, because of its slower atomization and breakup. These phenomena influence product emissions after combustion as well as flame stability. Studies have established numerical simulation models for using biomass fuels in dynamic machines. Nevertheless, the materials investigated in these studies were generally biodiesel or DME, which are biomass fuels derived from food crops. By contrast, the present study used nonfood biowaste to produce bio-oil through fast pyrolysis. Relevant atomization and chemical parameters were experimentally measured and then applied to establish a numerical simulation model for identifying the chemical reaction mechanism of bio-oil injection combustion. The combustion characteristics of petroleum fuel mixed with the bio-oil was also investigated. The results can serve as a reference for the development of high-performance bio-oil spray combustion burners.

2. Numerical method

Different biomass materials that are subjected to fast pyrolysis processes involving dissimilar operating parameters exhibit specific bio-oil compositions. Biomass sources differ according to regional, seasonal, and species characteristics; therefore, developing a spray combustion mechanism for mixing petroleum fuels and bio-oil is necessary. The atomizer required for designing high-efficiency spray combustion mechanisms must undergo repeated testing, resulting in considerable monetary and time costs. This

Download English Version:

https://daneshyari.com/en/article/5476687

Download Persian Version:

https://daneshyari.com/article/5476687

Daneshyari.com