Renewable Energy 85 (2016) 287–294

Contents lists available at ScienceDirect

Renewable Energy

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

Effects of injector tip design on the spray characteristics of soy methyl ester biodiesel in a blurry injector

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ARTICLE INFO

Article history:
Received 17 October 2014
Received in revised form
4 May 2015
Accepted 9 June 2015
Available online xxx

Keywords:
Blurry injector
Biofuels
Biodiesel
Spray characteristics

ABSTRACT

Atomization plays an important role in combustion and propulsion systems, including applications in transportation and power generation. The uncertainties in oil supply and environmental concerns motivate the development of new combustion technologies using biofuels, capable of operating with high thermal efficiency, low operational cost and reduced environmental impact. Flameless combustion is a promising technology that allows the reduction of pollutant emissions with high combustion efficiency. This work describes the characteristics of soy methyl ester (SME) sprays produced by a blurry injector. Characteristics droplet diameters, discharge coefficients, air-to-liquid mass ratios, air and liquid pressures and spray cone angles were experimentally determined. Three nozzle tip configurations have been tested: cylindrical, conical and conical-cylindrical. All nozzles configurations have presented high atomization efficiency, yielding relatively small characteristics diameters (SMD and MMD) and narrow spray cone angles, favoring its application in compact combustion systems.

1. Introduction

Due to environmental concerns, rising cost and limited supplies of fossil fuels and more stringent regulations on fuel emissions, it is of great interest to investigate new combustion technologies using biofuels in order to reduce energy production costs, increase operating efficiency, reduce pollutant emissions and improve the performance of power generation. Flameless combustion is one of the most promising alternative new technologies for clean and efficient combustion, since it is a homogeneous low temperature burning process leading to strongly reduced pollutant emissions and higher efficiency compared to the traditional processes (1).

Among various alternative fuels, biodiesel is one of the most widely studied biofuels, due to their similarity to conventional diesel fuels [2–10].

Biodiesel is an environmentally clean and renewable energy source, produced from vegetable and animal oils through a transesterification process, in which the triglycerides from vegetable oils react with an alcohol in the presence of a catalyst such as sodium or potassium hydroxide to form biodiesel and glycerol.

Several studies have been performed to evaluate performance of the biodiesel as an alternative energy source for diesel engines [11–18], internal combustion engines [19–25] and gas turbine [26–32].

The atomization of a liquid into small droplets in the form of a spray is an important process in combustion and propulsion systems, including applications in power generation. Liquid fuels are atomized through injectors, aiming to increase the contact area between the fuel and oxidizer and, therefore, to increase the rates of fuel evaporation and mixing, thus reducing the time available and the volume required for complete combustion inside liquid fueled combustion systems [33].

Since the combustion of liquid fuels involves many complex processes such as atomization, dispersion and vaporization of the fuel and mixing of the fuel and gaseous oxidizer, new atomization technologies are needed in order to produce sprays with fine droplets, which are necessary to minimize emissions of nitric oxides (NO_X), carbon monoxide (CO), unburned hydrocarbons (UHC) and particulate matter (PM).

Gañan-Calvo [34] presented a new twin fluid injector, the so-called flow-blurring injector, that yields high atomization efficiency, producing a spray with highest surface-to-volume ratio as compared to conventional air-blast injectors for a given values of liquid flow rate and total energy input. Fig. 1 shows a scheme of the geometry and flow structure inside a blurry injector.

The flow blurring injector consists of a fuel tube and a discharge

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http://dx.doi.org/10.1016/j.renene.2015.06.021
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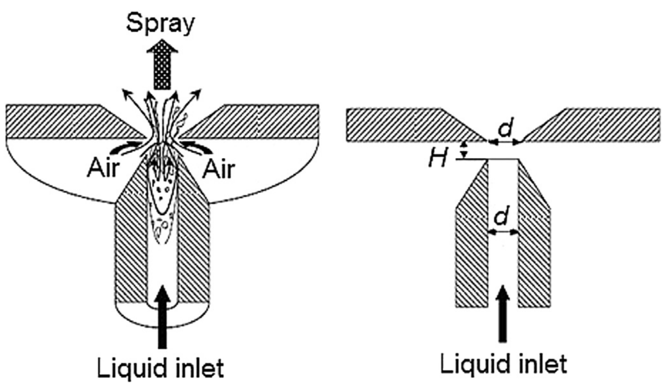

Fig. 1. Schematic of a flow-blurring injector: flow structure and geometric details. Source: [35].

orifice both of inside diameter d and separated by gap H. When $H/d \leq 0.25$, the surrounding air flows back into the liquid tube tip, creating a two phase flow with air bubbles within the liquid exit. This two-phase mixture undergoes sudden decrease in pressure while exiting through the discharge orifice. Consequently, the air bubbles explode due to the pressure drop at the injector exit orifice and then break-up the surrounding fuel into droplets.

Previous studies compared experimentally a flow blurring injector with a commercial airblast injector and showed that the flow blurring injector produces a finer spray than the airblast injector for equivalent conditions, whereas requires lower energy input or lower pressure drop in the atomizing air line [36,37]. Combustion experiments show that for a given equivalence ratio, heat release rate, and atomizing air-to-liquid mass ratio, the flow blurring injector produced three to five times lower NO_x and CO emissions in diesel and kerosene flames, compared to the airblast injector [35]. Besides, liquid fuel, such as kerosene, diesel, biodiesel, straight vegetable oil and glycerol, atomized by a flow blurring injector can mainly burn under lean premixed mode producing extremely low emissions of CO and NO_x [38–41]. An experimental study evaluated the effects of nozzle geometry on sprays produced by a blurry injector using water as test fluid and significant differences on the sprays formed by the injector were observed for cylindrical, conical-cylindrical and conical nozzle exit configurations [42].

Rapid fuel vaporization and mixing with oxidizer are key requirements for liquid-fueled small-scale combustion systems. The flow-blurring injector presents high atomization efficiency adjacent to the nozzle tip and excellent fuel vaporization and mixture with air, favoring its application in compact combustion systems. Therefore, this work presents the characterization of SME (soy biodiesel) sprays formed by a blurry injector for applications in a flameless compact combustion chamber. Several operational characteristics are determined for cylindrical, conical-cylindrical and conical nozzle exit configurations, including average droplet diameters, discharge coefficients, air-to-liquid mass ratios, and spray cone angles.

2. Experimental methods

2.1. Injector design

The schematic cross-sectional view of the blurry injector developed that will be used in a flameless compact combustor for burning SME (soy biodiesel) is shown in Fig. 2. Three nozzle exit geometries were investigated in this study: cylindrical, conical and cylindrical-conical.

The blurry injector consists of a central liquid tube ($d = 0.5$ mm) and a coannular atomizing air passage with inner diameter 6 mm. The two-phase mixture exits through the orifice of diameter $d = 0.5$ mm in the discharge plate located at $H = 0.125$ mm, corresponding to $H/d = 0.25$, as recommended by Ref. [34]. The angle of the feeding tube edge was 30° in order to minimize the gas friction losses. The blurry injector parts were manufactured with stainless steel and the geometric parameters such as distance H and

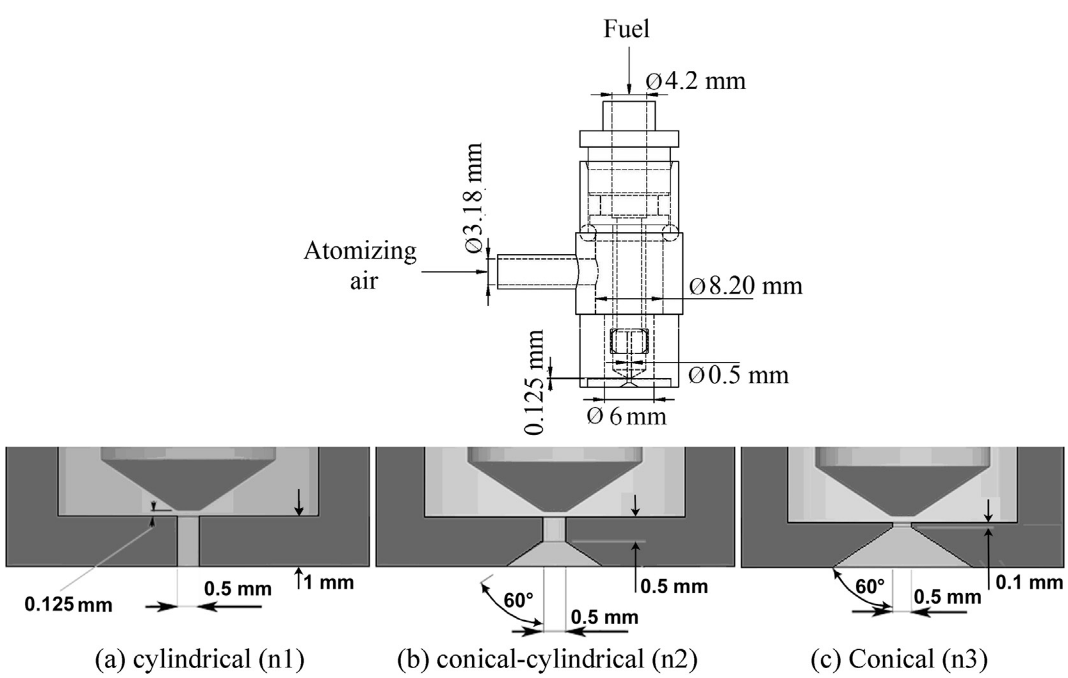

Fig. 2. Schematic of the blurry injector and nozzle tip configurations tested.