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Effect of enclosed flame on spray characteristics and emissions from preheated bio-oil using an air-blast atomizer

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Abstract

Global atmosphere pollution has become a serious problem for today. The emissions from the combustion of fossil fuels contribute a notable part to this pollution. Given a wide spread of different biofuels available for combustion applications, the present study concentrates on atomization spray characteristics of vegetable oils. In this study preheated vegetable oil (VO) is used to reduce the kinematic viscosity, and thus, improve atomization. A commercial air-blast atomizer operated at ambient conditions of temperature and pressure is used to atomize the VO. Flame spray characteristics are measured using a laser sheet visualization system and a Phase Doppler Particle Analyzer system. Experiments are conducted for unheated and preheated VO at 100 °C for a given ALR of 2.0 in enclosed flame conditions simulate realistic gas turbine conditions. VO is combusted in an atmospheric pressure burner with air blast atomizer and swirling combustion air around. The mean axial and RMS velocities, SMD and drop size distribution data are acquired. The measurements are taken for preheated VO at 100 °C and 150 °C respectively. The transverse profiles of mean axial velocity showed peaks at the center while they showed a decreasing trend at the outer edges of the spray. RMS axial velocity increases for flame spray compared to cold spray. Higher VO inlet temperatures led to smaller droplets and higher mean axial velocity for a given ALR. Results also suggest that insulated enclosure provide additional heat feedback from the flame to improve the overall spray characteristics, an effect that has been quantified in the present study.

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Keywords: Bio-fuels; Laser diagnostics; Spray measurements; Atomization; PDPA.

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1. Introduction

Global atmosphere pollution has become a serious problem for today. The emissions from the combustion of fossil fuels contribute a notable part to this pollution. Environmental care together with the limited stock and growing prices of fossil fuels has given alternative fuels the potential to supplant a significant portion of fuel for combustion applications such as gas turbine engines and IC engines. Given a wide spread of different biofuels available for combustion applications, the present study concentrates on atomization spray characteristics of vegetable oils. Vegetable oils have energy density, cetane number, heat of vaporization and stoichiometric air/fuel ratio comparable to diesel fuel. Different ttechniques have been employed so far to improve on the physical properties of bio-oils and thus opening the doors to clean combustion. The high kinematic viscosity has an adverse effect on the combustion of vegetable oils, posing problems in the associated fuel supply line and injector system, as discussed in chapters 2 and 3. Some well-known techniques to deal with high kinematic viscosity levels of neat vegetable oils include dilution, pyrolysis, micro-emulsion and trans-esterification. These techniques however, require additional energy input to improve the physical properties of the fuel. Preheating of the fuel is also one of the ways that reduces the kinematic viscosity to improve the atomization. Preheating is employed in the present study to investigate the spray characteristics in a non-evaporating spray as well as flame spray. The atomization and subsequent propagation of the fuel droplets, their vaporization and combustion are the most important processes concerning the formation of pollutants with the use of liquid fuels. For example in diesel engines, gas turbine engines, and oil burners, the combustion rate of fuel is controlled by effective vaporization of the fuel. The liquid fuel atomization rate has a strong influence on vaporization rates because the total surface area of the fuel is increased greatly by the atomization process. The fundamental mechanisms of atomization have been under extensive experimental and theoretical study for more than a century [1]. Still, one of the major thrusts in worldwide combustion research has been to gain insight into the physics of liquid fuel combustion in the primary zone of the combustor [2].

Physical properties such as kinematic viscosity, surface tension and volatility are the key parameters that affect the process of fuel atomization and evaporation. The liquid kinematic viscosity affects not only the drop size distribution of the spray but also the fuel injector pressure drop. An increase in kinematic viscosity lowers the Reynolds number, hindering the development of any natural instabilities in the fuel jet or sheet, which help to further disintegrate the drops. These combined effects delay any further disintegration thus increasing the droplet sizes in the spray. Many alternative fuels are expected to have high kinematic viscosity which makes them difficult to atomize well and thus affecting the combustion efficiency.

A comprehensive study on turbulent diffusion flames using intrusive probing techniques was made by [3]. They suggested that the spray flame structure is similar to that of a gaseous diffusion flame in turbulent flow. The study conducted by [4], used a non-intrusive detection technique to measure the Sauter Mean diameter (SMD), drop velocity, and number density of air assisted spray and spray flames. A series of experimental and numerical studies of air assisted sprays and spray flames have been made by [5, 6]. Their observations concluded that the presence of fuel drops and reactions alters the structure of the gas-phase turbulence and that local clustering of drops exists for both non-reacting and reacting cases. A large portion of the experimental research in liquid fuel combustion is focused on pressure atomization mainly in the diesel engine applications. Relatively few studies have been reported on air blast atomization and their potential optimum strategies in alternative fuel combustion. Moreover, very little attention has been given to the evaporation characteristics of the air blast atomized sprays of alternative fuels. Detailed studies on the characteristics of spray flames are necessary to mitigate environment problems and enhance the performance and efficiency of liquid bio fuel combustion systems.

The present work seeks to experimentally investigate the spray characteristics of the fuel droplets in a non-evaporating as well as flame spray conditions using the Phase Doppler Particle Analyzer. An air blast atomizer is selected for the present investigation to generate the spray. The objective of the present work is to investigate the effects of combustion on enclosed spray flames of bio-oil for which little experimental data are available. Experiments are conducted using an insulated enclosure as well as VO heated at 100 °C and 150 °C. The mean axial and RMS velocities, SMD and drop size distribution data are acquired. The primary focus is placed on liquid fuel spray characteristics, and their effects on emissions. It can be envisioned that smaller droplets in the spray would lead to premixed combustion and hence lower emissions. The inferences from this study would aid in designing future liquid