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# Study of carbon and carbon–metal particulates in a canola methyl ester air-flame

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ABSTRACT

In this study we show that the interaction of a solid metal in the form of wire in the post flame region formed using a biodiesel or fatty acid methyl ester (FAME) fuel (an oxygenated compound) can contribute significantly to the oxidation of the probe's surface resulting in the deposition of metallic nanoparticles and carbon particulates with complex structural morphologies. The FAME used for forming the flame was canola methyl ester (CME). The interaction of the solid support within a flame medium formed using CME resulted in the formation of a distinct material deposition layer covering the surface of the probe. The formed layer was found to consist of clusters composed of aggregates of primary particles with a nearly spherical shape. The aggregates are composed of primary particles of carbon and of metallic characteristics. Other unique features include carbon networks containing numerous encapsulated ultra-small metal particles (<2.0 nm in diameter), elongated carbon nanofibers, metallic nanorods, and carbon–metal composites. High resolution transmission electron microscopy analysis reveals that the metal nanoparticles have a high degree of crystallinity. It is observed that the time and flame height parameters of the probe–flame interaction are important factors for varying the morphological characteristics of the deposits. Residence times ranging from 40 s to 5 min established a strong correlation to deposit morphology. Energy dispersive X-ray (EDX) analysis of material samples on the formed layers reveals the presence of carbon, iron, nickel, chromium and oxygen. The introduction of a probe with similar characteristics in the post flame region formed with No. 2 diesel fuel and air resulted in a thicker material layer covering the surface of the probe. Electron microscopy and EDX analysis showed that the deposits are composed mostly of carbon clusters and no metal content or other complex form of carbon morphology were detected.

## 1. Introduction

During the last decade research efforts in the area of biofuels have been focused on synthesis processes, type of catalyst, and performance of these alternative fuels [1–8]. Numerous studies on biodiesels or fatty acid methyl esters (FAMEs) have been conducted on the thermo [2,9,10], catalytic pyrolysis [11–13], and heat of combustion. These fuels are seen either in blends with No. 2 diesel fuel or as "neat" biofuel (B100 or pure biofuel). Biodiesels are essentially a multicomponent mixture of long chain fatty acids and mono-alkyl esters [14]. Typical plants that have been utilized for FAME production include soy, canola, jatropha, rapeseed, and palm, among others. Biodiesels are oxygenated compounds and are known to have various advantages and disadvantages compared to traditional fuels. Among the advantages is the decrease of combustion by-product emissions including particulate matter as well as total hydrocarbons and carbon monoxide during a combustion process. A negative of biodiesel, however, is the increase of nitrogen oxides ($NO_x$) during the combustion process. Recently, Merchan-Merchan et al. [15] studied the sooting behaviors of various FAMEs including B100 CME (canola methyl ester), B100 SME (soybean methyl ester), a blend of 50% SME/50% animal fats, and No. 2 diesel fuels. In that study, utilizing the thermophoretic sampling technique and transmission electron microscopy (TEM), it was shown that particle size of the soot generated in all tested biodiesel–air flames is much smaller than that produced in the diesel–air flame. The smaller the size of the particles, the greater the potential for harm. Due to their size and light weight soot particles can be suspended in the air for weeks and travel long distances before settling. Recent research has also been conducted on the reactivity of liquid bio-alcohols and biodiesels with metal surfaces and has shown that biodiesels are more corrosive than diesel. Several studies have recently reported the corrosive effect on metal

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surfaces exposed to biodiesel. Biodiesels and bio-alcohols erode and corrode the metal at the fuel film/metal interface and increase the metal content in the fuel [16–22]. It has been reported in recent studies that biodiesel fuels become even more reactive with the surface of a metal with a very slight increase of temperature (80 °C) [16]. What can be gained from these and other such biodiesel/metal corrosion studies is that surface metals exposed to biodiesels and bio-alcohols corrode much more rapidly than when the metal surfaces are exposed to petroleum-based fuels. Despite all of these research studies, very few studies have been devoted to occurrences within the biodiesel flame itself.

In this work we study the reactivity of a CME–air diffusion flame by introducing a 0.6 mm-diameter nichrome probe in the post-flame yellow luminous zone of the flame. The tests were conducted using two different fuels, CME ($C_{19}H_{36}O_2$) and Diesel ($C_{16}H_{34}$). A layer of carbon material was formed on the surface of the nichrome probe after introduction into the post-flame region for both types of produced flames. Electron microscopy and electron diffraction X-ray (EDX) analysis of the formed layer in the CME–air flame show unique physical and chemical characteristics compared to those present in the layer formed using diesel–air.

## 2. Experimental setup and procedures

The experimental setup employed in this study consists of a wick burner, unislider assemblies, a Pyrex cylinder and a probe stabilizer assembly (Fig. 1). A cotton wick absorbs and transports the liquid fuel from the fuel chamber located at the bottom part of the burner to the other end of the wick where the fuel vaporizes and combusts with air to form a flame. The fuel and oxidizer are not pre-mixed prior to entering the burn zone. Through this method a laminar diffusion flame was formed using CME biodiesel and diesel fuel. The burner nozzle, with a diameter of 4.6 mm, forms a stable flame inside the Pyrex cylinder, which acts as a draft deflector to stabilize the flame. Both ends of the Pyrex chamber are open. A distance of a few mm was kept between the bottom of the Pyrex cylinder and the base of the burner holder platform to provide a stream of continuous air to the burn zone (Fig. 1). Two burners of identical characteristics were employed in this study; one for creating the biofuel–air flame and the other for the diesel–air flame. The probe assembly is mounted on a movable platform, which allows for precise control of the probe's axial height within the flame. The physical and chemical characteristics of the solid probe are a 0.6 mm-diameter wire consisting of 73%Ni + 17%Cr + 10%Fe (nichrome). The burner is mounted on a two-dimensional unislider assembly, which is driven by an 8300 series stepping motor controller (Model VXM-2, Velmex, Inc.). The vertical and horizontal unisliders allow the burner to move up and down as well as forward and backward as necessary.

Fuel employed for this study was B100 canola methyl ester (CME) biodiesel. CME ($C_{19}H_{36}O_2$) fuel is composed of the following compounds with the approximate different weight percentages: Methyl Palmitate ($C_{17}H_{34}O_2$) (~5%), Methyl Stearate ($C_{19}H_{38}O_2$) (~3%), Methyl Oleate ($C_{19}H_{36}O_2$) (~62%), Methyl Linoleate ($C_{19}H_{34}O_2$) (~20%), and Methyl Linolenate ($C_{19}H_{32}O_2$) (~10%) [23]. Similar experiments were also conducted using a fossil fuel for comparison. For both types of flames, the fuel flow rate is fixed, as the fuel is absorbed through a wick. The fossil fuel used in this study is an ultra-low sulfur diesel (ULSD) No. 2 obtained locally. Like CME and other biodiesels, diesel fuel is a mixture of several organic compounds mostly composed of saturated hydrocarbons, aromatics, and it can contain small amounts of dye and other additives. A typical low-sulfur No. 2 diesel fuel contains mostly saturated hydrocarbon components (75.3% by volume) and aromatic components (24.7%). The flowrate of the fuels are approximately 9.41 and 16.48 ml/h for CME and diesel, respectively. Corresponding to a fuel velocity for CME and diesel of 0.016 and 0.027 cm/s,

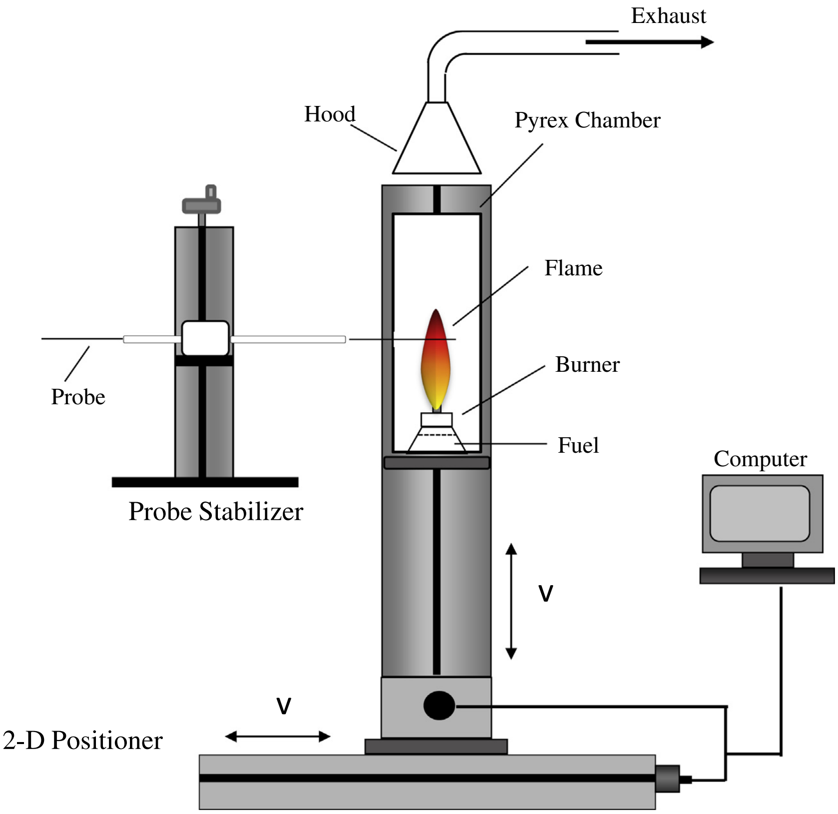

**Fig. 1.** Schematic of the experimental setup.