



Full Length Article

Experimental investigation of the combustion of crude glycerol droplets



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ABSTRACT

The objectives of the work are, first, to determine the combustion characteristics of crude glycerol, a by-product of the synthesis of biodiesel and, second, to systematically investigate the relationship between the behaviors observed and the presence of different components. With that purpose, the combustion of droplets of crude glycerol was studied in a drop tube facility and compared with different blends of pure glycerol with water, alcohol and salts. The evolution of drop size was determined from pictures recorded with a CCD camera and a long distance microscope. After injection, the droplet size initially remains about constant (initial liquid heating) and then decreases depicting a curve in good agreement with the d^2 -law. At some distance from injection, the droplets were shattered due to microexplosions, producing in most cases small fragments. The combustion curves for crude glycerol were compared with those for pure glycerol and its blends with water, alcohols and salts. Pure glycerol droplets displayed a combustion rate practically identical to that of crude glycerol, but did not experience microexplosions. These phenomena could be due to the presence of water or alcohols, with much lower boiling temperatures, but the experiments performed for a wide range of blends of pure glycerol with water, ethanol and/or methanol did not exhibit any kind of disruptive behavior. Additional tests performed with blends of pure glycerol containing alkali salts consistently showed the occurrence of microexplosions, even when the salt was dissolved in pure glycerol without adding any water or alcohol. It was then concluded that the microexplosions observed for crude glycerol droplets were actually induced by the decomposition of alkali salts, and not to the explosive evaporation of water or alcohols as initially expected.

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1. Introduction

Large amounts of crude glycerol are produced in the synthesis of biodiesel (roughly, 1 kg per 10 kg of biodiesel). The quality of this by-product varies from process to process but, in average, the typical composition is 80% glycerol ($C_3H_8O_3$), the rest consisting of water, methanol, salts and NGOM (Non Glycerol Organic Matter) [1–4]. There are many potential uses for crude glycerol, but most of them require some kind of processing or refining, which makes its viability unclear in the present state-of-art and situation of the market [5,6].

In the absence of other alternatives with higher added value, industrial boilers and furnaces could, in principle, absorb the huge amounts of crude glycerol produced in biodiesel plants. Combustion of glycerol has been studied in several works and, actually, is used for heat production in some practical applications, all of them demonstrating the feasibility of its use as a fuel. Neverthe-

less, there are some drawbacks with respect to other fuels, related to some distinctive physical and chemical characteristics of crude glycerol [2,7–10]:

- LHV is roughly 16 MJ/kg, half of that of a conventional hydrocarbon fuel.
- Water presence lowers the flame temperature.
- Flash point is high, 177 °C, for a liquid fuel. This together with low flame temperatures due to water content may cause serious difficulties to achieve stable, attached flames.
- Viscosity is high, which makes it difficult to atomize as a standard liquid fuel.
- Low temperature combustion may yield some acrolein, a highly volatile and toxic compound.
- Salt content in glycerin poses a serious fouling and corrosion threat to combustion equipment.

Therefore, partial or total substitution of conventional fuels (typically, fuel-oil) by crude glycerol is not straightforward. In particular, due to the difficulties to achieve stable, attached flames, glycerol is normally co-fired in practice with significant amounts

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of support fuels (e.g., natural gas). There is still little experience with crude glycerol and further work is needed to develop the knowledge required to design combustion equipment suitable for this by-product.

It is difficult to find detailed results on the combustion of glycerol in real plants, and the information available comes mainly from a few relevant studies at laboratory and semi-industrial scales. Setyawan et al. characterized the combustion of glycerol-methanol [4] and glycerol-water [11] droplets suspended on fibers. With respect to pure glycerol, methanol addition resulted in a reduction of both ignition delay and total burnout times, whereas water-glycerol blends displayed longer ignition delay and similar total burnout times. The differences observed were attributed, among other effects, to the occurrence of microexplosions. This phenomenon was also observed, although only in some of the experiments, by Dee and Shaw [12] in their tests at reduced gravity with propanol-glycerol droplets. Results on the combustion of crude glycerol at semi-industrial scale have been reported in a few works [3,7,9]. Bohon et al. [7] and Steinmetz et al. [10] determined the main combustion results in a small-scale furnace and reported good results with a novel prototype burner, conceived to provide the thermal environment to effectively combust glycerol. The co-combustion of crude glycerol with natural gas, a common solution in practice, was analyzed by Queirós et al. [3] by means of detailed in-flame measurements in a semi-industrial furnace. Jiang and Agrawal [9] demonstrated the good performance of a novel fuel injector (flow-blurring), which can overcome the usual difficulties in achieving the spray fineness required for efficient combustion of crude glycerol.

These and other previous studies have provided valuable information on the characteristics of crude glycerol as a fuel, but there are still some gaps to be filled, not only focused on practical applications but also regarding the distinct combustion behavior with respect to standard liquid fuels or the role of non-glycerol fractions. The initial objective of this work was to provide new experimental data acquired under well controlled conditions on the evaporation and combustion of unsupported droplets of crude glycerol as produced in biodiesel plants, which to the authors' knowledge has not been specifically addressed in previous works. The disruptive evaporation of crude glycerol droplets observed during the course of the work motivated a second objective, which was the investigation on the role of the different components normally present in this by-product on the occurrence of microexplosions.

2. Droplet combustion facility

The experiments were conducted in the Droplet Combustion Facility (DCF) developed at LIFTEC and depicted in Fig. 1. This facility has been designed to study the combustion of fuel droplets under well-controlled and, at the same time, realistic conditions.

The evolution of monosized droplets falling in a coflow with controllable properties was studied by means of an optical system for recording droplet images and other techniques (e.g., soot sampling, not used in this work). A piezoelectric device was used to generate monosized droplets in the range 60–180 μm . With the exception of the results shown in Figs. 2 and 3 for $\sim 150 \mu\text{m}$, all the other tests were conducted with initial droplet size $d_0 \sim 180 \mu\text{m}$. Due to the high viscosity, the droplet generator had to be heated to 50–80 $^\circ\text{C}$ in order to properly atomize the different glycerol samples and blends. The shape and amplitude of the voltage signal fed to the piezoelectric atomizer were adjusted to approach as closely as possible the nominal diameters (150, 180 μm), typically with deviations $< 2 \mu\text{m}$; in any case, the actual d_0 values were measured in every case and are used to normalize diameter curves. The size of the droplets used in the tests is considered a good compromise between proximity to typical

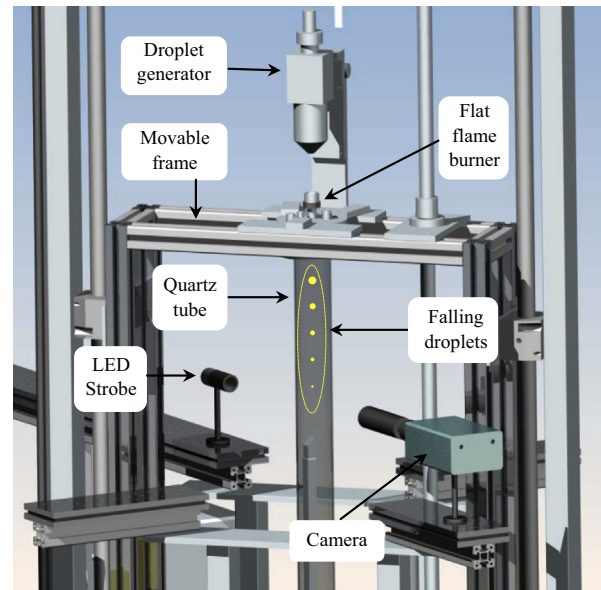


Fig. 1. Schematic of the droplet combustion facility.

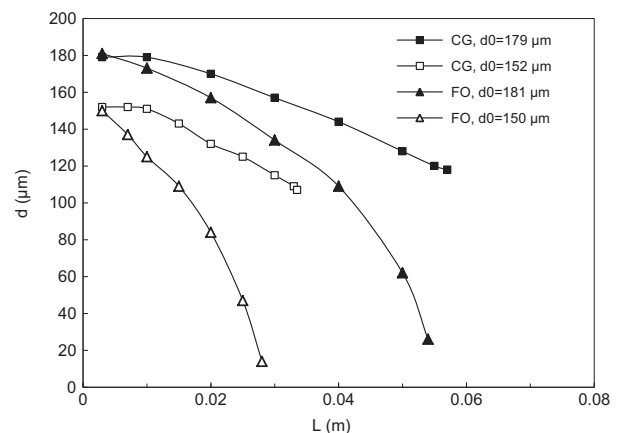


Fig. 2. Evolution of the diameter for two sizes of crude glycerol (CG) and fuel-oil No. 2 (FO) droplets.

diameters in practical applications and the accuracy of the experimental results. The latter is favored for larger sizes (with longer combustion traces and times and lower relative uncertainty in droplet sizing

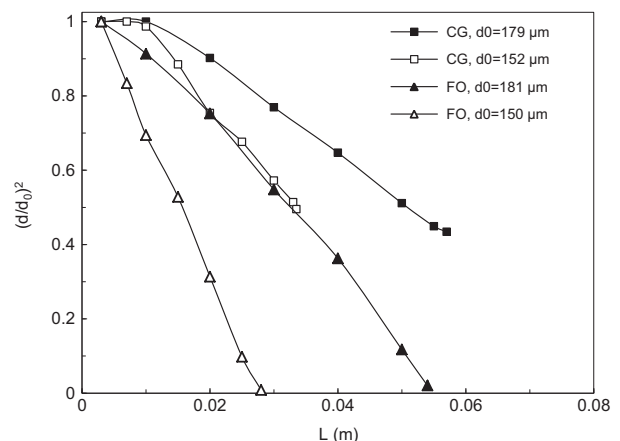


Fig. 3. Evolution of $(d/d_0)^2$ for two sizes of crude glycerol (CG) and fuel-oil No. 2 (FO) droplets.

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