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Combustion of vegetable oils under optimized conditions of atomization and granulometry in a modified fuel oil burner

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HIGHLIGHTS

- Combustion of heating fuel oil and cottonseed oil in a modified burner is compared.
- Atomization and granulometry optimization are necessary for vegetable oil combustion.
- Riello 40N10 can achieve spray conditions and particle size recommended for burners.
- Cottonseed oil must be sprayed at 28 bars and preheated up to 125 °C.
- Non-condensable gases and most organic compounds emissions are close for both fuels.

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ABSTRACT

The use of vegetable oils in burners represents an attractive alternative to the use of heating fuel oil (HFO) in heat production for domestic heating, small industrial units, drying of various products etc. In this work, a characterization of the combustion of cottonseed oil in a modified burner (type Riello 40N10) was performed to assess its ability to achieve proper combustion of vegetable oils in optimized conditions of atomization and granulometry. The quality of the combustion has been evaluated by the analysis of combustion products (CO, O_2, CO_2, NO, NO_2, SO_2) and organic compounds including PAHs. Results show that the modifications made on the burner type 40N10 can achieve suitable spray conditions and give particle size within the recommended values for burners. In the case of Riello 40N10 burner, a fuel pressure of 28 bars is adequate and the minimum temperature required for oil preheating is 125 °C. When these conditions are achieved, cottonseed oil combustion leads to the emission of non-condensable gases and the organic compounds species as well as their concentration close to those of HFO.

1. Introduction

The growing energy needs in developing and emerging countries, even in rural areas, give more and more importance to biofuels in general and to vegetable oils in particular. This trend is supported by the declining petroleum resources and the role that biofuels could play in reducing emissions of greenhouse gases. At the local scale, biofuels called "first generation Biofuels" may appear as a real factor of development. As such, the use of pure vegetable oils as alternative fuels to diesel oil or heating fuel oil (HFO) for local (domestic heating), as well as industrial use or applications such as farming, electrification and drying of products can prove to be interesting if used with some precautions.

Many studies on the characteristics of vegetable oils or their derivatives and their use in diesel engines have been achieved over the last four decades. These studies showed a behaviour close to that of diesel oil [1–12].

However, diesel fuel, HFO and each vegetable oil or animal fat have their own characteristics and specific behaviour that distinguish it from another. This is related to their specific physical and chemical nature. In particular, the fatty acid composition, high viscosity and low volatility are key factors of differences in the behaviour of vegetable oils [2]. This can lead to ignition problems as well as coking of the colder parts of the combustion chamber due to thermal decomposition and polymerization under certain conditions of temperature [13–16].

These differences in characteristics require specific operating conditions of use for their proper combustion in diesel engines or burners. Indeed, the use of pure vegetable oils in standard

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domestic burners leads to cooking of cold parts of the burner (especially the air deflector) and draining of unburned fuel [17]. So, most of the studies on the use of vegetable oils on burners have focused on the use of preheated oil or pure biodiesel or their blends with heating oil on standard domestic burners [18–26]. This use in standard domestic burners requires several adjustments [26]. As shown by [22], blending of vegetable oil with a minimum of 30% HFO, under specific conditions, is necessary for a proper combustion in a standard domestic burner.

To overcome these constraints and limitations to the use of vegetable oils in standard domestic burners, a modified burner for vegetable oils has been designed (derived from Riello 40 N series burner). This burner was set up specifically to allow the use of various vegetable oils.

The first objective of this work was to assess the ability of this burner to achieve the required spray conditions of atomization and granulometry with a refined cottonseed oil (RCO). Then, under these suitable conditions of atomization and granulometry, the second objective was to verify the quality of the combustion, at the same thermal power output, of this refined cottonseed oil compared to heating fuel oil by analysis of non-condensable combustion products (CO, O_2, CO_2, NO, NO_2, SO_2), and of organic compounds including PAHs.

2. Materials and Method

Tests were carried out in the CIRAD Biomass Energy laboratory in Montpellier (France), with the collaboration of the "Laboratoire de Physique et de Chimie de l'Environnement" (Burkina Faso) and the "Institut de Recherche en Sciences Appliquées et Technologies" (Burkina Faso).

2.1. Equipment

Fig. 1 shows the schematic diagram of the experimental setup. It includes a modified burner, a combustion chamber and two devices for analyzing combustion products. The burner used is a Riello burner (type 40N10) [27] with a preheating and a recirculation system of the fuel similar to that used for heavy fuel. Its main technical characteristics are indicated in Table 1. A 1 kW electrical heater and a recirculation system of the fuel (Fig. 2) are located downstream of the pump. The fuel can be heated up to temperatures from 50 °C to 200 °C.

When the burner is switched on, the temperature of the heater increases gradually up to the temperature fixed by the setpoint.

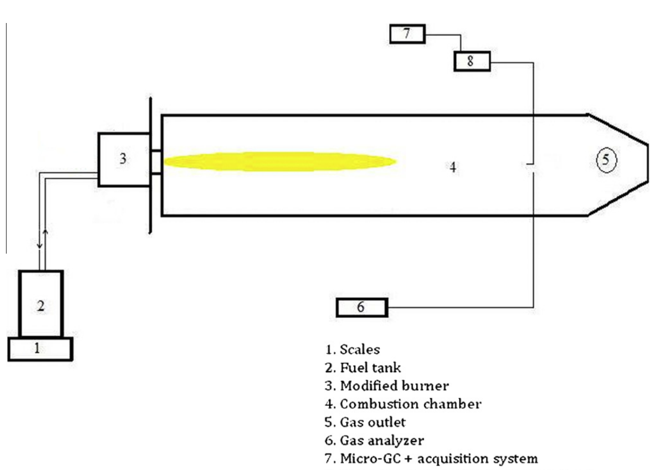

Fig. 1. Schematic diagram of experimental setup.

Once this temperature is reached, the pump allows the fuel flowing and recirculating through the preheating circuit (path 1, 4 and 5 in Fig. 2). This leads to an increase of the temperature of the fuel in the nozzle at a temperature very close to the setpoint. In these conditions, an electrovalve "VR" allows the spraying of the fuel through the nozzle and its return through path 3. The combustion occurs in the combustion chamber which is a horizontal cylindrical steel enclosure. Its dimensions are: length 120 cm and diameter 60 cm. A cone with 8 openings of 10 cm diameter closes the chamber; it has a diameter restriction from 60 to 20 cm over a depth of 22 cm. This chamber, designed for various uses, especially drying of agricultural products, has the advantage of relatively high walls temperature (temperatures above 500 °C). This is favourable to evaporation and complete combustion of unburnt vegetable oils droplets escaped from the spray.

The analyzing system of the combustion products comprises two devices: The first system is a combustion analyzer, the Kane-May Quintox KM9106, equipped with electrochemical cells. This allowed for real time measurement of the O_2, NO, NO_x, CO and SO_2 level in dry flue gases. The CO_2 content was calculated by the analyzer depending on the characteristics of the fuel and the percentage of residual oxygen measured in the emissions. The raw gas stream passed through a blow-pipe and a duct heated to a temperature of 115 °C to avoid condensation and dissolution of certain gases (SO_2, NO_x). Gases were fed through a combustion gas conditioner (KaneMay KM9008), thus allowing for sudden cooling of wet exhaust gases. Gas composition data from the analyzer were then transferred to a computer using the KaneMay FIREWORKS software. The measuring ranges and the uncertainties of the cells are provided in Table 2.

The second device includes a cooling bath for trapping organic compounds in the combustion products and a micro gas chromatograph (micro-GC) as shown in Fig. 3. The collected gas bubble in a series of bottles (which are immersed in the cooling bath) containing isopropanol, and then move into the micro GC for the analysis of non condensable gases (O_2, CO_2, CO). The detection and the quantification of these gases are carried out by mass spectrometry. The organic compounds dissolved in isopropanol were analyzed with an Agilent 6890 chromatograph and a mass spectrometer Agilent 5975. The characteristics of the column used are: type: DB-1701, length: 60 m and inner diameter: 250 μm. A mixture of 1 ml of the sample and 1 ml of phenanthrene (internal standard, concentration: 25 mg/l) is injected into the chromatograph. And then, the identification and quantification of organic compounds follow.

2.2. Fuels used

The heating fuel oil (HFO) was taken as reference. To avoid a possible influence of minor compounds contained in crude vegetable oils on the quality of the combustion, a commercial refined cottonseed oil (RCO) from Burkina Faso was used.

These fuels were used at different fuel pressures (16–28 bars) and following different primary air/secondary air ratios in preliminary tests to determine at first the optimum operating point based on lowest emissions in flue gases (an operating point is defined by setting primary air, secondary air and fuel pressure). The optimum operating point corresponds to an equivalence ratio of 0.55 and a pressure of 28 bars. At this operating point, the conditions of atomization and the granulometry were evaluated by varying the temperature of the vegetable oil from 50 to 150 °C. So, only cottonseed oil temperature was varied when evaluating the atomization conditions and fuels droplets size; fuel mass flow and fuel–air equivalence ratio were kept constant. HFO did not require any preheating. However, given the minimum temperature of 50 °C, necessary for the operation of the burner, the