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# Spectroscopic analysis of crude rapeseed oil flame

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ABSTRACT

Utilizing crude vegetable oils in all types of heat engines can be a part of a sustainable economy in the future. Focusing on their local usage, they can possibly compete with fossil fuels. Furthermore, to keep the pollutant emissions at the lowest possible level, the feedback control of the equivalence ratio is essential. Regarding the harsh environment of the combustion chambers, optical flame diagnostics is a potential tool. Therefore, in order to examine its feasibility, the comparison of flame emission spectroscopy (FES) of rapeseed oil with standard diesel oil was carried out at atmospheric conditions in a lean premixed prevaporized (LPP) burner at 15 kW of firing power. The well-known chemiluminescence intensity ratios of $OH^*$, $CH^*$, and $C_2^*$ at 516 nm ($C_{2,\,516}^*$) were investigated. A further significant peak was found at 554 nm in case of rapeseed oil firing, which probably corresponds to $C_2^*$ ($C_{2,\,554}^*$). The corrected chemiluminescence intensity ratios as a function of air–fuel equivalence ratio are shown in the current work. It was found that these ratios involving $C_2^*$ at either 516 or 554 nm show less sensitivity to the pressure of atomizing air than $OH^*/CH^*$, therefore they are more suitable for diagnostics and for the control of the equivalence ratio of liquid fired burners.

## 1. Introduction

A lot of effort has been made in the past decades to reduce the overall ratio of fossil fuel consumption in the energy industry. Biodiesel production in a global range is currently an expensive process, due to the high cost of transesterification [1]. The utilization of crude vegetable oils is a more economical option, therefore the firing possibilities of crude rapeseed oil were investigated in the present paper. The potential applications are internal combustion engines, small-scale or micro gas turbines, furnaces, and boilers.

Vegetable oils at ambient temperature often have higher kinematic viscosity and surface tension, compared to that of standard diesel oil, due to their larger molecular size. These two physical properties are the major obstacles of adequate atomization, thus efficient combustion. Hence, preheating the fuel is necessary [2]. Furthermore, during the startup and shut down process the usage of a more volatile fuel might solve all the practical problems.

The continuously stricter emission standards force engineers to develop advanced combustion systems for heat engines. Therefore, the widely used dry low emission (DLE) burners [3] were developed in order to lower the emission of nitrogen oxides ($NO_X$) [4,5]. While a proper geometry design can provide low emission of carbon monoxide, $NO_X$ production is mainly the function of temperature [6] as vegetable oils are typically free from fuel-bonded nitrogen [3]. Furthermore, they contain no sulfur.

The currently examined burner test rig is equipped with a lean premixed prevaporized (LPP) burner, which is a widely applied DLE solution. The local equivalence ratio of the burner has the greatest impact on emissions. Flame emission spectroscopy (FES) is a potential tool for controlling the equivalence ratio with the help of active elements (i.e., containing actuators) since it only requires the optical access to the flame. It has a low unit, data processing, and maintenance costs if purged properly [7,8]. The measured data provides a good basis for combustion control through the estimation of air–fuel excess ratio, using the ratio of chemiluminescence intensities of $OH^*$, $CH^*$, and $C_2^*$ typically [7,9,10].

The scope of the current paper is to analyze and compare the chemiluminescence intensity spectra of rapeseed oil with that of the standard diesel oil in an atmospheric LPP burner equipped with an air blast atomizer. The literature consists mainly of FES investigations of premixed, laminar methane–air flames at laboratory conditions (see e.g., [10–12]). There are available high pressure and industrial applications as well (see e.g., [13–15]). The investigations of non-premixed flames (see e.g., [16,17]) are generally out of scope due to their corresponding higher pollutant emission. The spectrometry of liquid-fueled steady flames, such as crude vegetable oils, is absent in the literature according to the best knowledge of the authors. However, publications on reciprocating engine related measurements are available (see e.g., [18,19]).

It was proposed by Nicolas Docquier et al. [9] that the $CH^*/OH^*$ chemiluminescence intensity ratio of methane/air flame is measurable with a fair signal to noise ratio (SNR) even at the pressure of 20 bar. The favorable $C_2^*$ chemiluminescence intensity at 516 nm (further marked as $C_{2,\,516}^*$) under ambient conditions weakens with increasing

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pressure. Furthermore, it blends to the background noise above 10 bar, which makes the control of the flame cumbersome based on the chemiluminescence signal at such high pressure levels. Small-scale gas turbines typically operate below the pressure ratio of 5. Consequently, $C_{2,\,516}^*$ chemiluminescence intensity seems to be feasible for diagnostics and active control purposes for such heat engines as well. However, Muruganandam et al. [20] pointed out that the presence of unevaporated fuel droplets can affect the chemiluminescence intensity ratio measurement.

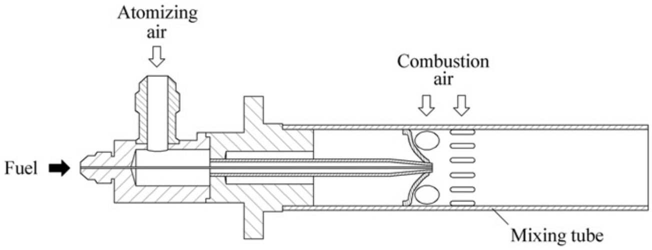

**Fig. 2.** The examined burner.

## 2. Measurement conditions

### 2.1. Burner test rig

Fig. 1 shows the burner test rig with the examined LPP burner. The system is suitable for combustion tests with atomizing air at elevated pressure, using fuel and combustion air preheated to the required temperature. The test rig operates in an atmospheric environment, in the present measurement series at 25 °C, 1.026 bar, which are relatively unfavorable conditions, however, at elevated temperature and pressure the quality of atomization will be even superior [21]. More details can be found about the test rig in the literature [2].

The atomization air passes from the compressed air system through a pressure regulator and a calibrated rotameter (3–30 l/min measurement range, 4% accuracy class according to VDI/VDE 3513) to the air blast atomizer of the burner. The gauge pressure of atomizing air was set within the range from 0.3 bar to 2.3 bar during the measurements. The term *atomization pressure* is used in the rest of the paper instead of gauge pressure of atomizing air. The volume flow rate of the rotameter was set from 10 to 20 liter/s linearly. Hence, the differences among the atomizing pressures continuously increased, which resulted in smaller steps in the lower atomization pressure region. The readings were corrected according to ambient conditions. In order to aid visual interpretation, odd data series are not shown in the figures.

The combustion air supplied by a frequency controlled fan passes via another calibrated rotameter (3–30 $m^3$/h measurement range, 1.6% accuracy class according to VDI/VDE 3513). The pressure drop of the combustion air system was found to be small, therefore the readings were close to the real values. However, correction was also done in this case. The combustion air then enters an electric preheater and leaves it at the temperature of 400 °C. The purpose of this device is to provide a proper environment for firing fuels of lower volatility.

The combustion air at the temperature of 400 °C then enters the mixing tube of the LPP burner (75.5 mm length and 26.8 mm diameter) through four radial orifices and fifteen 45° swirl vanes, shown in Fig. 2. This burner was originally designed for a Capstone C-30 micro gas turbine. It has a plain jet air blast atomizer in which the diameter of the fuel jet is 0.4 mm, and the atomizing air flows coaxially (1.6 mm outer and 0.6 mm inner diameter). The droplets in the mixing tube evaporate, then get mixed with the hot swirling combustion air flow. After ignition, a fully turbulent flame develops. As the combustion air flow rate increases, the straight flame shifts into V-shape, due to the increasing swirl. At each measurement series the mass flow rate of combustion air was increased until blow out for both fuels.

The analyzed fuels were standard diesel oil (EN 590:2009) and crude rapeseed oil. Both were delivered by a separate pump to the fuel mixer allowing a changeover between them. Rapeseed oil arrives at the fuel mixer through an electric preheater, reaching the temperature of 150 °C. As the burner test rig was designed for 15 kW firing power, each setup was investigated under this condition. References [13–15] show that the chemiluminescence intensity is proportional to the mass flow rate of the fuel, hence the intensity ratios are independent from the firing power. Thus measurements at different firing power possibly would not change the final conclusions. The mass flow rate of diesel oil which has 43 MJ/kg lower heating value was 0.35 g/s. The rapeseed oil has a lower heating value of 37 MJ/kg, hence the mass flow rate of it was 0.4 g/s. The fuel consumption was measured according to a certified scale (0.2 g uncertainty, approved by National Office of Measures, Hungary), taking a 30-second-average of the change of mass. The air–fuel equivalence ratio ($\lambda$) was calculated as the sum of the measured flow rates of combustion and atomizing air to the stoichiometric air flow rate demand of the fuel. The latter one is calculated from the composition of the utilized fuels, listed in Table 1. The combined expanded uncertainty of the air–fuel equivalence ratio measurement is shown in the respective figures.

### 2.2. Spectrometry

A fixed spectrometer was used for the measurement, manufactured by OpLab Ltd. The focal length of the 20 mm diameter quartz objective is 0.5 m, leading to a line of sight measurement with 5 mm diameter at the focus. The lower limit of the control volume was 2 mm above the burner lip in all the cases, shown schematically in Fig. 1. The mentioned position corresponds to the maximum intensity. The device has

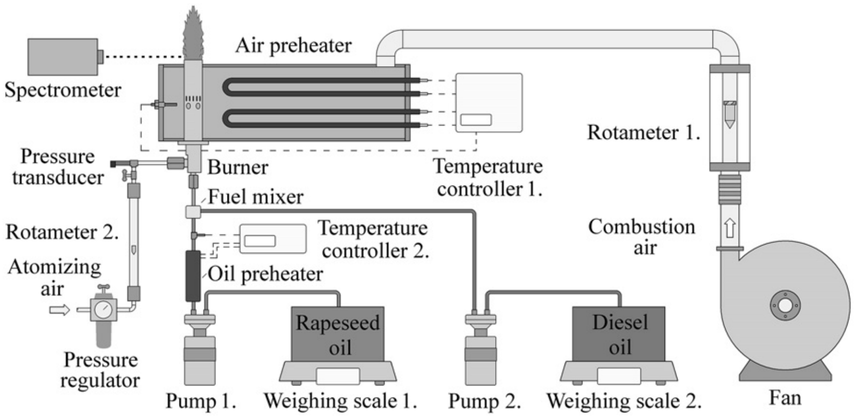

**Fig. 1.** Burner test rig.