EFFECT ON CO_2 DILUTION ON RAPESEED OIL COMBUSTION IN A STATIONARY BURNER

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Abstract
Application of CO_2 diluted combustion to existing fossil fuel/biofuel energy systems to facilitate CO_2 capture presents several challenges. This paper investigates the combustion characteristics of Rapeseed oil and its blends with Diesel oil in swirling spray flames. It focuses on the stability of flames, NOx, CO and particle emissions. We observed that CO_2 dilution decreased the NOx emission (up to 20 times) due to the lower furnace temperature at fixed oxygen concentration. Although the dilution of combustion does not produce significant effect on the shape of the size distribution functions, this modifies significantly the absolute concentrations of the emitted particles. Finally, the produced diluted flames were stable and more luminous than the air/fuel flames.

Introduction
There is a growing concern that the use of fossil fuels and the associated carbon dioxide emissions are contributing to global warming. The Energy Information Administration estimates that world carbon dioxide emissions from energy production will increase by 51% by 2030, from 28.1 billion metric tons in 2005 to 42.3 billion metric tons in 2030 [1]. As energy use grows, concerns over global warming may lead to imposing limits on greenhouse gas emissions from fossil fuel plants. This has stimulated extensive research on the subject of carbon capture and sequestration. The International Energy Agency estimates that carbon capture and sequestration could play an important role in decreasing carbon dioxide emissions [2]. To achieve a deep reduction in carbon dioxide emissions through carbon capture and sequestration within power generation systems, several technologies are being investigated, one of which is oxy-fuel combustion. In oxy-fuel combustion, fuels are burned in a nitrogen-lean and carbon dioxide-rich environment, which is achieved by feeding the combustor with an oxygen-rich stream and recycled flue gases. The recycled gases are used to control the flame temperature and replace the nitrogen separated prior to

combustion [3]. Oxy-fuel combustion yields flue gases consisting of predominantly carbon dioxide and condensable water, whereas conventional air-fired combustion flue gases are nitrogen-rich with only about 15% (by volume) of carbon dioxide [4, 5]. The high carbon dioxide concentration and the significantly lower nitrogen concentration in the oxy-fuel raw flue gases is a unique feature that lowers the energy and capital costs of oxy-fuel carbon dioxide capture when compared to alternatives [6]. The interest to oxy-fuel combustion in the last decade is mainly oriented to low rank fuels for energy production. A more recent interest is devoted to oxygen enriched and CO_2 dilution combustion of methane [7], but a few studies for first generation liquid biofuels are present in the literature. Some papers dealing with second generation are available [8]. The use of the first generation biofuels was widely studied as fuels for energy production [9, 10] and they could be useful to further lower CO_2 emission, while enhancing sequestration. The present study presents experimental results on CO_2 dilution combustion of pure rapeseed oil and its blends with diesel oil. A particular interest is focused on the size distribution functions of the emitted solid particles.

Experimental Set-up

Combustion apparatus: Measurements were carried out on spray flames obtained by atomising the fuels in a 100 kW three-flux low-NOx burner inserted in a cylindrical vertical furnace of ceramic fibre (0.36 m ID and 2.5 m height) equipped with optical accesses. The carbon dioxide dilution was obtained in the tertiary duct to simulate exhaust gas recirculation. Carbon dioxide weas fuelled at 20°C. The fuels used in this work were rapeseed oil and diesel oil, whose main physical and chemical characteristics are reported in Table 1. The commercial name of the rapeseed oil is "DNS" (Degummed Neutral Dried). The diesel oil is commercial heating fuel.

Table 1: Fuel properties

		RAPESEED OIL	DIESEL OIL
Density, 15°C	kg/m^3	920	870
Viscosity @50°C	mm^2/s	28	6 (@20°C)
Flash Point	°C	>290	58
Gross Calorific Value	MJ/kg	40.5	39.5
C	%	76.9	83
H	%	11.8	13
O	%	11.3	-
S	%	-	0.2

Blends of 50%vol. (B50) and 20%vol. (B20) Rapeseed oil-Diesel oil were prepared. The fuel atomisation was obtained by using a commercial mechanical spray nozzle (Danfoss 45°, 1 USgal/h full cone) fed at constant flow rate of 4.5 l/h, measured with a flow meter with 0.1% accuracy. The distribution function of the spray droplet diameter was preliminary measured for each fuel and their blends [11]. Similar spray and fluid dynamic conditions were obtained by heating the rapeseed oil at 100°C, and the blend B50 at 60°C. The blend B20 did not need to be heated before atomization. At these temperatures the viscosity of the rapeseed oil and its blends are very similar to the diesel oil one.

Exhaust emissions measurement: The monitoring of the gaseous emissions has been performed with a portable flue gas analyzer (TESTO 350 S). The detected gases were O_2, NO, NO_2, CO, SO_2 and CO_2. Temperature and pressure have been also measured. The flue gas analyzer is provided with a Pelletier gas preparation unit with a hose pump to regulate condensate disposal as well as a fresh air valve for long-term measurements lasting several hours. A software manages all the functions of the analysis system and records data with a maximum sampling rate of 1 Hz. All the measured pollutants concentrations were corrected to be conventionally reduced to 3% O_2 content.

Particle size measurements: Studies of aerosols require extractive sampling. In this work, commercially available instruments were used to sample particles and to measure their size distribution functions. An Electrical Low Pressure Impactor ELPI™ was employed to determine particle size distributions. It is a real-time particle size spectrometer for real-time monitoring of aerosol particle size distribution in the range of 0.03−10 μm with 12 channels. With filter stage the size range was extended down to 7 nm. The operating principle is based on particle charging, inertial classification in a cascade impactor, and electrical detection of the aerosol particles. Humidity and volatile compounds affect ELPI™ results since it measures the sample particle concentration in real time which usually means that wet concentration of the particles is measured. This problem was overcome heating the ELPI™ unit: the exhaust gases are sampled by a heated line (180°C) before entering in the ELPI™ unit heated at 180°C. The inlet gas temperature is continuously monitored.

Test protocol: stable gas emission and size distribution functions of the emitted particles were continuously recorded for the following test sequence:

1. Baseline for all the fuels (pure and blends);

2. Carbon dioxide dilution (up to 30%vol. of exhaust gases referred to stoichiometric concentration under normal conditions).

Results and Discussion

<u>Gaseous emissions characterization:</u>

The first step was the measurement of the emissions at the exhaust gas under the baseline condition. These results represent the reference figures and are presented in table 2. In fact, they will be compared later on with the emissions measured during the test protocol. We can observe that CO emissions are very low, close to the instrument error, while NOx concentrations are lower than the diesel oil. This trend is similar to those observed previously for such kind of furnace [12].

Table 2. Emissions at the exhaust under baseline condition, @3%O_2

	[CO] ppm	[NOx] ppm
Diesel oil	3	40
Rapeseed oil	0	38
Blend B20	1	42
Blend B50	3	45

The combustion dilution presented a reverse situation respect to oxygen–enhanced flames. The results are presented in figure 1, where are plotted the time evolutions of CO and NOx concentrations changing CO_2 concentration from 0 to 30%vol. We observe that the plots follow an almost linear evolution regarding the increase of the CO_2 addition. A high NOx reduction is induced when increasing CO_2 concentration, while CO concentrations increase. Nevertheless, CO concentrations keep final low value and are within the emissions rules.

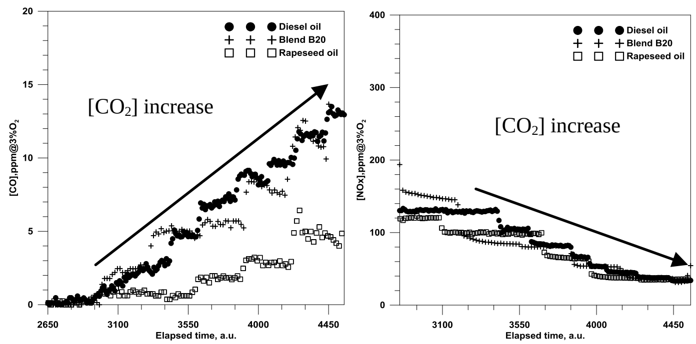

Figure 1. Time evolutions of [CO] and [NOx]@3%O_2 vs. [CO_2] variation

<u>Particle emissions characterization</u>:
The size distribution functions of the emitted particles were recorded and averaged over ten minutes. The data were background corrected taking into account the size distribution function of the ambient air. Since we are more focused on the shape of the distribution functions, the curves were normalized to their maximum. This is more helpful for the understanding of the influence of combustion dilution on the formation of particulate. The results about CO_2 dilution are presented in figure 2 for the different fuels. It is worthwhile to note that the dilution mainly changes the shape of the distribution function of Diesel oil and the Blend 20. For Diesel oil we observe a decrease of particle formation in the range 0.4-1μm, while for the blend 20 the reduction of particle formation occurs for sizes over 1 μm. this phenomenon is clearly visible for high CO_2 dilution (30%vol.). For the others fuels, the dilution tends to slightly increase the formation of particles with sizes higher than 100 nm without creating any benefit in terms of small particle formation. The dilution apparently does not influence the kinetics of particle formation.

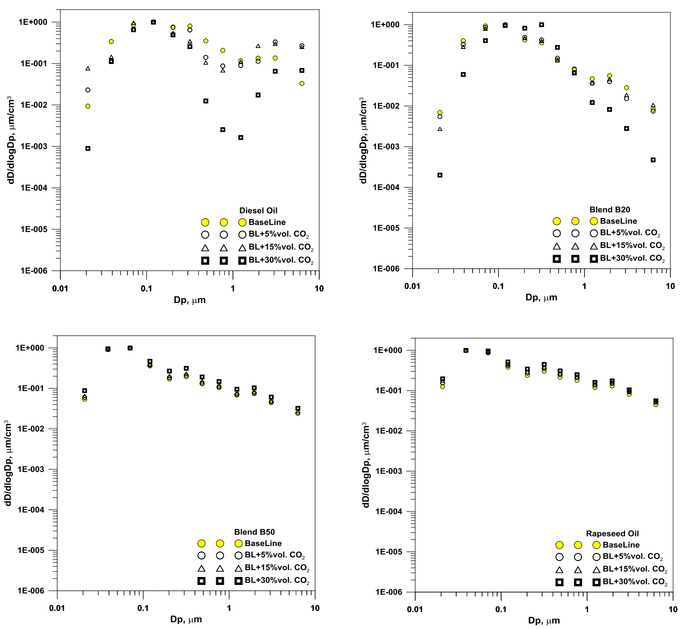

Figure 2. Normalized particle size distributions measured for Diesel oil and rapeseed oil blends under different CO_2 dilution rates.

Although the dilution of combustion does not produce significant effect on the shape of the size distribution functions, this modifies significantly the absolute concentrations of the emitted particles. We clearly observe two tendencies, one for Diesel oil, and one for the rapeseed oil and its blend B50. One more time, we observe that the blend B20 presents a different behavior respect to the others fuels. In fact, a high dilution rate produces an increase of one order of magnitude respect to the others conditions of dilution. In the case of Diesel oil, the CO_2 effect stands in a drastic formation reduction of the particles with sizes ranged between 0.2-2 μm. For the rapeseed oil and the blend B50, the dilution enhances the particle emissions with a higher reduction over all the range. Finally, the flame height was unaltered by increase of CO_2 concentration.

Conclusion

In the present study, two types of combustion tests were carried out to investigate the effects of CO_2 dilution of combustion on the pollutant emissions such as CO, NOx and particulate. The influences of diluted combustion on the CO/NOx emissions, flue gas temperature, and flame characteristics were examined. The general conclusions drawn from the results of this work can be summed up as follows:

CO_2 dilution effects:

1. The NOx emission decreased sharply due to the lower furnace temperature at fixed oxygen concentration during the tests. When the CO_2 concentration was high (30%vol.), the NOx concentration was reduced up to 20 times, while CO emissions slightly increased.
2. Although the dilution of combustion does not produce significant effect on the shape of the size distribution functions, this modifies significantly the absolute concentrations of the emitted particles.

The produced flames were stable and more luminous than the air/fuel flames.

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