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Reduction of pollutant emissions from a rapeseed oil fired micro gas turbine burner

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ABSTRACT

In the past decade numerous studies have been performed on using biodiesel derived from rapeseed oil for micro gas turbines. Much less attention has been devoted to the study of crude rapeseed oil due to the fact that the latter cannot be burnt without modifications in micro gas turbines designed for crude oil derivatives (diesel oil, kerosene, etc.). The series of experiments presented in this study were aimed at examining the combustion characteristics of crude rapeseed oil. The experiments were performed on a burner test rig, which allowed to modify the factors affecting fuel atomization and to measure the emission of pollutants from a gas turbine burner equipped with an airblast atomizer selected for the purposes of the experiment. Measurement results confirmed that by preheating the rapeseed oil and performing the atomization using steam instead of air, the burner can easily be changed to burning crude rapeseed oil instead of diesel oil without increasing the emission of pollutants.

1. Introduction

Micro gas turbines applied widely in distributed electricity generation can be suitable for utilizing various renewable liquid fuels economically. However, these types of equipment operable with liquid fuels were originally designed for the use of crude oil derivatives. Chemical, physical, and combustion related properties of vegetable oils are significantly different from those of liquid fossil fuels, therefore, either the existing constructions have to be made suitable for using these renewable fuels or the properties of the fuels have to be modified according to the demands of the equipment. A good example for the latter one is using biodiesel. The other solution, the modification of the equipment requires thorough studies and experiments but when implemented, the need for energy and auxiliary materials entailed by the modification of fuel subsides.

Numerous studies have been made earlier in the field of utilizing renewable liquid fuels in micro gas turbines. In most cases comparative tests were carried out with biodiesels of various origin and diesel oil on Capstone C30 micro gas turbines without any modification. Nascimento et al. [1] have noted, while using biodiesel derived from castor oil, an increase of carbon monoxide (CO) emission of 50–100% depending on the load and a reduction of nitrogen oxide (NO_x) emission of 5-10% compared to the operation based on diesel oil. During the series of experiments conducted by Brookhaven National Laboratory [2] with soy methyl ester, CO and NO_x emission did not change under full load, however, with a partial load the concentration of both pollutants decreased, at minimum load even by more than 45%. Experiments by Bolszo and McDonell [3] showed, as opposed to the preceding, that the use of soy methyl ester results in a CO emission higher by 2–3% and a NO_x emission higher by 50% than with the use of diesel oil fuel. They made an attempt to improve the quality of atomization by increasing the quantity of the atomizing fluid approximately by three times. Applying this solution decreased the NO_x emission of the biodiesel operation by 7%. In their conclusions they recommended to redesign the burner in order to increase the quantity of the atomizing fluid without pressure loss. None of the three series of experiments mentioned produced any significant changes in the efficiency of the micro gas turbine. The results referred to reveal that even when using esterified vegetable oils one has to take into consideration possible increase in the emission of pollutants.

The use of crude vegetable oils for micro gas turbines was examined in relatively few researches earlier. Prussi et al. [4] used crude sunflower seed oil as fuel also in a Capstone C30 micro gas turbine. The vegetable oil was introduced into the combustion chamber while preheating it at 130 °C. In the course of the experiment NO_x emission increased by 100% compared to diesel oil fuel while the CO emission did not change at nominal load. At 60% partial load, however, there was an increase of 100%. The micro gas turbine was operated during 500 h with preheated sunflower oil. On completing the experiment, inspection of the gas turbine revealed deposits only in the pre-mixing chamber of the burner which contained mostly phosphor, iron, chrome and sodium. Chiaramonti et al. [5] used diesel oil, biodiesel, and rapeseed oil preheated to 120 °C in a Garrett GTP 30-67 type micro gas turbine. Compared to diesel oil fuel, biodiesel resulted in a CO emission increase by 30% and rapeseed oil resulted in 60%. A change in the concentration of NO_x could not be demonstrated with the available instruments due to the low level of emission. Cavarzere et al. [6] burned preheated

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rapeseed, sunflower, and soy bean oil in a Solar T-62T-32 type micro gas turbine. Compared to diesel oil fuel, they noted an increase by 30% in CO emission and 30% in NO_x emission for all the three fuel types.

Our research examined the solutions applicable for making a micro gas turbine suitable for using crude rapeseed oil as fuel without any problems and with low pollutant emissions. The original fuel of the Capstone C30 micro gas turbine selected for the analysis included diesel oil and kerosene. For successfully implementing a later change to crude rapeseed oil, the operation of the burners of the micro gas turbine had to be analyzed thoroughly. For a better observation of the combustion processes and for an easier execution of the measurements, it was reasonable to examine a demounted burner separately in operation, consequently, a burner test rig was prepared within the framework of the research.

2. Materials

Fossil fuels applicable for small scale liquid fired gas turbines include diesel oil, kerosene, and jet-engine fuels. Diesel oil is the most widely used in stable energy-producing micro gas turbines. In our research, we examined the use of crude rapeseed oil for micro gas turbines, whose chemical, physical, and combustion properties significantly differ from those of the diesel oil.

2.1. Chemical properties

The molecules of rapeseed oil and diesel oil show significant differences in their composition and chemical properties. Diesel oil is primarily composed of saturated hydrocarbons with a straight carbon chain consisting of 12–20 carbon atoms. Rapeseed oil consists of non-saturated triglycerides of diverging carbon chains composed of 55–57 carbon atoms. Triglycerides are esters of three fatty acids and a glycerol (trivalent alcohol).

In the vegetable oils of various origins the fatty acids of different types, which differ in their number of carbon atoms and double bonds, are linked to the glycerol in varying proportions. Palmitic and steraic acids are saturated. Oleic acid has one double bond, linoleic acid has two, linolenic acid has three, thus, these are unsaturated fatty acids. Soy bean, sunflower, and rapeseed oil compositions are shown in Table 1. The exact composition depends on the type of the oleic plant, the circumstances of production and oil extraction, thus, the composition data are but of informative character.

Due to the differences in the fatty acid composition, the usability of vegetable oils of various origins as fuels also varies. The non-saturated bonds of fatty acids composed of vegetable oils enable the polymerization of the molecules. As a result of the reaction, giant molecules form and the viscosity of the oil increases to its multiple. By the escalation of the process, solid material parts may arise which can possibly form deposits in the fuel system. Polymerization may occur by oxidative or thermal polymerization, or the combination of these. Oxidative polymerization may take place even at room temperature. Oxygen connects two triglycerides in the course of the reaction by the dissolution of the double bonds of the non-saturated fatty acids. If the triglycerides composing the vegetable oil contain at least two non-saturated fatty acids, giant molecules may arise by new reactions. The process is enhanced by higher temperature or higher oxygen concentration, respectively. Thermal polymerization takes place according to the Diels–Alder reaction [10], below 250 °C it is of negligible extent (Fig. 1), above 250 °C its extent is highly dependent on fatty acid composition and temperature. The thermal polymerization tendency of linoleic acid and linolenic acid (highly non-saturated fatty acids) is several times higher than that of the oleic acid [11]. This is shown by the result of the experiment performed with safflower oil containing a high proportion of linoleic acid (78%) and a high proportion of oleic acid (79%) displayed in Fig. 2.

Table 1
The average fatty acid composition of vegetable oils [7–9].

	Fatty acid composition [wt.%]				
	Palmitic 16:0	Stearic 18:0	Oleic 18:1	Linoleic 18:2	Linolenic 18:3
Soy bean oil	8	4	25	55	8
Sunflower oil	6	3	17	74	0
Rapeseed oil	3	1	64	22	8

Oxidative polymerization has an unfavorable influence on the evaporation of vegetable oils. Figs. 3 and 4 [12] show the thermogravimetric analysis results of rapeseed oil in argon gas and air. In the presence of oxygen, the rate of evaporation decreases due to heavily evaporating large-size molecules caused by oxidative polymerization, and evaporation takes place in a wider temperature range and finishes at a higher temperature than in argon gas.

The polymerization of vegetable oils can be an unfavorable process from the aspect of combustion due to the aforementioned consequences, if the reactions could occur in a considerable extent before combustion. [11] and [13] state that it can happen, but in the future we are planning to measure this phenomenon. If the oxidative polymerization really plays a role, then there are two possibilities for limiting this process. If the evaporation of the vegetable oil took place isolated from the oxygen of the air before combustion, the arising of giant molecules would be highly reduced. The second possible solution for this problem is to apply vegetable oils with more favorable chemical properties. Vegetable oils with high oleic acid content have low polymerization tendency, therefore, rapeseed oil as a fuel can be an advantageous choice (see Table 1).

2.2. Physical properties

In order to burn the rapeseed oil in the gas turbine, it has to be atomized. From this point of view, the outstanding physical properties include kinematic viscosity and surface tension. These physical properties are highly dependent on temperature. The relationships are shown in Fig. 5 [14] and Fig. 6 [15].

The kinematic viscosity of rapeseed oil at room temperature is 15 times that of the diesel oil, however, by increasing the temperature the difference may be reduced significantly. From the aspect of surface tension, the difference between the two materials is smaller, values decrease in proportion to increasing the temperature. Consequently, the most important physical properties of rapeseed oil can be approximated well to those of the diesel oil.

2.3. Combustion-related properties

Due to differences in molecular structure, the combustion-related properties of diesel oil and rapeseed oil are also different. The most important ones are listed in Table 2 [16].

The average weight of molecules forming rapeseed oil exceeds four times that of the molecules forming diesel oil. Therefore, the combustion reactions of rapeseed oil take place at a lower rate, and the reaction zone is of a higher volume. The heat exchange with the environment is higher, thus, the temperature of the flame is lower than with diesel oil

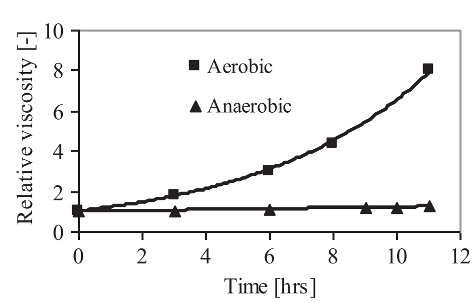

Fig. 1. Oxidative and thermal polymerization at 250 °C [11].