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Performance and emissions of biodiesel in a boiler for residential heating

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ABSTRACT

This paper presents the initial results of an experimental investigation of regulated and unregulated emissions of a boiler fueled with biodiesel and heating oil. In particular CO, SO_2, NO_x, particulate matter (PM), Polycyclic Aromatic Hydrocarbons (PAH), Volatile Organic Compounds (VOC) and aldehydes emissions were examined. When using biodiesel, a strong reduction in CO and PM emissions was recorded with respect to home heating oil. The PAHs contained in the PM in the case of biodiesel were nearly 13 times less toxic than in the oil case; the formaldehyde, on the contrary, is nearly double for biodiesel. The VOCs were very low for both fuels. The results indicate there may be benefits to using biodiesel in home heating or in industrial processes.

1. Introduction

The energetic dependence on fossil fuels and the effects of global warming could be diminished by using renewable fuels, such as the biodiesels. In recent years biodiesels have gained the attention of the industrial sector and public regulators, particularly for their application in transportation, space heating, and industrial processes.

Biodiesel can be produced from various vegetable oils, animal fats, and cooking oils by means of a transesterification process, whose final product is a mixture of methyl or ethyl esters. For this reason biodiesels are also known as fatty acid methyl esters or FAME.

The chemical characteristics of biodiesels make any concentration of biodiesel and petroleum distillates possible for use in compression ignition engines or in boilers.

In the USA biodiesel is required to meet the ASTM D 6751 standards regardless of the bio-source and production process, and in Europe to meet the UNI EN 14214 standard, for diesel engines, and UNI EN 14213 standard for heating fuels.

The behaviour of biodiesel in internal combustion engines is well documented in the literature [1–11].

Engine performance is slightly lower when using biodiesel because of its lower heating value with respect to that of diesel fuel; if the injection phase is done well, engine efficiency doesn't significantly change.

Reduction in regulated emissions has been reported as well: pure biodiesel shows an average reduction of 50% for CO, 65% for total unburned hydrocarbons (HC), 50% for particulate matter (PM). NO_x emissions, on the contrary, are 10% higher; for biodiesel–diesel blends' reductions vary almost proportionally with the concentration of biodiesel in the blend. The most promising blend is the mixture of 20% biodiesel 80% diesel fuel, commonly known as B20 blend.

As regards unregulated emissions, such as Polycyclic Aromatic Hydrocarbons (PAH), Volatile Organic Compounds (VOC) and aldehydes, the literature reports reductions strongly depending on the test cycle adopted in the test bench and on the blend ratio [10,11]. Only aldehydes prove to be higher, in some cases almost double, with respect to diesel oil [10].

Biodiesel has also showed interesting results when used in boilers for space heating [12–16]. These studies have shown that boiler efficiency doesn't change significantly whereas the specific consumption increases due to the lower heating values of biodiesel.

A significant decrease in CO, HC and SO_2 emissions with respect to home heating oil has been observed. NO_x emissions, on the contrary, show both reduction [12–14] and increase [15,16]. Win Lee et al. [15], investigating the combustion performance of B20 blend in a residential-scale hot water boiler, reported a 20% reduction in SO_2 and 13% reduction for PM; NO_x and CO emissions were similar or slightly higher with biodiesel to that of the reference heating oil. They also point out an increase in CO emissions during the starting sequence of the boiler and with very low external temperatures.

However, only limited data is available for unregulated emissions (PAH, VOC, Aldehydes) in boilers. In particular Li et al. [17], investigated the PAH emissions from 25 industrial burners fueled with fossil fuels, finding total PAHs between 33 and 119 $\mu g/Nm^3$.

In order to fill this gap in the literature, an experimental study was carried out by the University of Padua and the Regional Agency

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Table 1
Nominal characteristics of the boiler.

Thermal power	kW	300–419
Fire-place power	kW	324–458
Maximum thermal load	kW/m^3	1562
Number of smoke pipes	N°	30
Diam. of the smoke pipe	inch	1″1/2
Boiler capacity	litre	400
Efficiency at 100% load	%	91.5
Efficiency at 30% load	%	92.8
Max. exhaust temp.	°C	188

for Environmental Protection (ARPAV), sponsored by the municipality of Padua. The study was developed within the context of a long-term experimentation whose aim is to study the effect of biodiesel use on boiler components over several seasons.

This paper presents the measurement results regarding regulated and unregulated emissions from a boiler fueled with biodiesel and heating oil, for comparison. In particular CO, SO_2, NO, NO_2, PM, PAH, VOC and aldehyde emissions were measured.

The term PAH indicates a wide range of organic compounds, all characterized by a structure with several condensed aromatic rings; they can be gaseous (3–5 rings) or solid (more than 5 rings). They are originated from incomplete combustion processes of several organic compounds. The most investigated substance is Benzo(*a*)pyrene (BaP), which is composed of 5 condensed rings. Epidemiological studies conducted on workers exposed to emissions have pointed out a correlation between inhalation of PAH and lung cancer. The most involved fraction of PAH in cancer development seems to be that characterized by 3–7 aromatic rings.

In the present work 9 types of PAHs were collected, and all of these were classified as probably or as possibly carcinogenic substances.

Aldehydes are organic compounds whose formula is $C_nH_{2n}O$, with the CHO group in their structure. The simplest compound is formaldehyde, which is classified as "certainly carcinogenic". Moreover, a recent study [18] showed that even a little exposure to it causes an increase in the symptoms in asthmatic people.

In the present study, in addition to formaldehyde, nine other aldehydes were investigated. The term VOC indicates hydrocarbon-based emissions released through evaporation or combustion, which are composed of several substances. In this study 35 types of VOCs were collected; the most important of them is benzene, which has been classified as "certainly carcinogenic". In a recent study, it was demonstrated that the use of biodiesel–diesel blends in internal combustion engines reduces emissions of VOCs in proportion to the percentage of biodiesel [9].

2. The test facility

The experimental investigation was carried out on a fire-tube boiler in a building at the University of Padua normally fueled with pure biodiesel. The boiler can supply 400 kW of hot water and is made up of a reversal flame combustion chamber and the RIELLO RL38 two stage burner, with nozzles rated at 10–20 kg/h and 20–38 kg/h, respectively, with a 60° solid cone spray. The fuel pump pressure was set at 12 bar as recommended by the manufacturer.

The burner operating conditions were set for the biodiesel (the usual fuel) and were left unaltered for subsequent runs with heating oil.

The boiler technical characteristics are summarized in Table 1.

A schematic of the test facility and the major measurement instrumentation are shown in Fig. 1.

3. The fuels

Two types of fuels were used in the investigation: home heating oil and commercial biodiesel B100. The results of the chemical–physical analysis and the correspondent values of the standards for the two fuels are summarized in Table 2. Some of the biodiesel data do not respect the current Italian standards (UNI EN 14213); this is particularly evident for the case of the sulfur, which is six times over the maximum limit, fixed at 10 ppm. Other negative aspects are the very low Net Calorific Value, the flammability point, and above all acidity. This fact should not be surprising as the UNI EN 14213 standards came into action only two years before this study was carried out, and the producers had probably not run out of their old stocks.

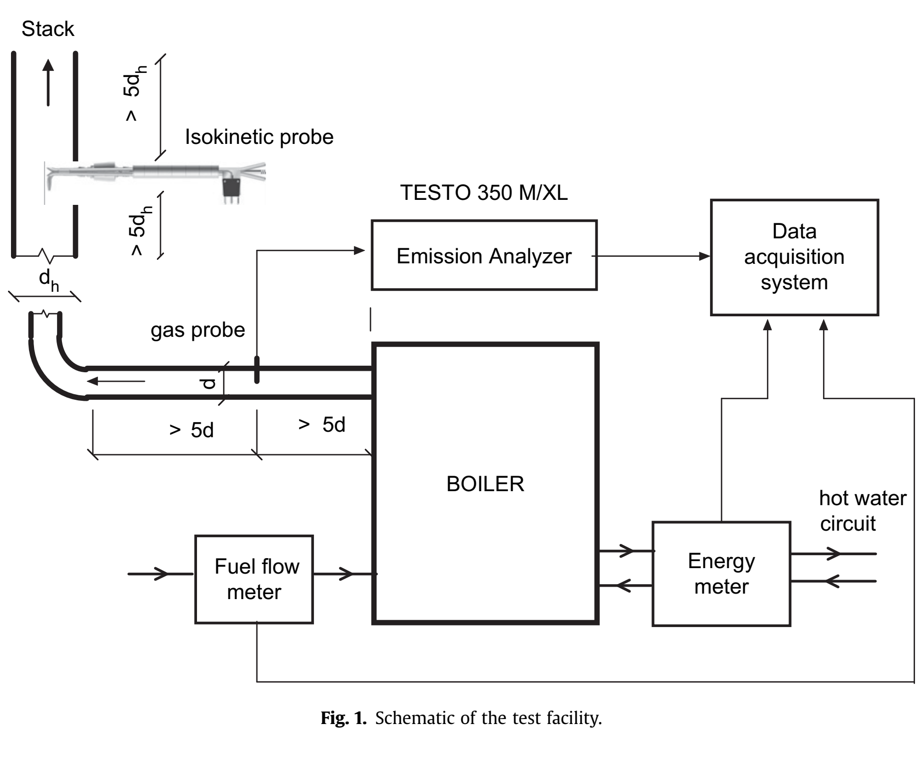

Fig. 1. Schematic of the test facility.