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Emissions and Combustion Performance of a Micro Gas Turbine Powered with Liquefied Wood and its Blends

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Abstract

The combustion of a viscous biofuel, liquefied wood (LW) produced via solvolysis of lignocellulosic biomass in acidified glycols, has been studied in a small gas turbine rig. The test rig includes a modified injection line which is compatible with acidic, viscous biofuels allowing fuel preheating and two pilot injectors, and a re-designed combustion chamber. The link between fuel properties and combustion performance of liquefied wood is investigated by burning the biofuel at different blending ratios with ethanol. Exhaust emissions have been compared to reference measurements with diesel fuel and ethanol. Combustion analysis is supported by the investigation of the engine operating parameters and the main emission species at different electrical loads. The experimental study reveals that it is possible to establish efficient operation of the micro gas turbine while utilizing liquefied wood-ethanol blends with high share of liquefied wood.

Keywords: Viscous biofuel; Solvolysis; Ethanol; Gas turbine; Emissions; Combustion.

1. Introduction

There are already several market available applications of conventional biofuels confirming relatively high maturity of the related production and application technologies. One of most important difference between fossil-derived fuels

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and biofuels is the presence of oxygen in the chemical structure of the fuel. As a first consequence, the heating value is lower, whereas this is counteracted by lower stoichiometric values of oxygenated fuels.

Representatives of this group of fuels are multicomponent mixtures derived from depolymerization and fragmentation reactions of three key biomass building blocks: cellulose, hemicellulose, and lignin [1]. The results are dense, viscous biofuels, with a significant water content and low pH value [2], such as pyrolysis oil, liquefied wood or products of hydrothermal liquefaction. These are also the limiting factors for utilization of such fuels in combustion engines [3,4], as their direct utilization without upgrading is most often not possible [5,6]. One of the most comprehensive development processes on a small turbine engine was performed by Seljak et al with liquefied wood (LW) - product of solvolysis of lignocellulosic biomass in acidified glycols, initially proposed as a fuel in [7]. The fuel features similar properties as biomass pyrolysis oil and therefore requires extensive engine adaptations. The adaptation process was thoroughly described in several studies together with testing methodology and interlinking of several interrelated influences [8], leading to operational prototype [9], capable of firing several highly viscous fuels [10,11].

The innovative contribution of the presented work is therefore elaboration of an alternative approach for obtaining stable combustion of the liquefied wood and its blends in a modified APU-derived small scale turbine. This premier use of LW-EtOH blends in a modified APU-derived small scale turbine is based on targeted adaptation of baseline fuel formulation and consequent blending with ethanol to bring the viscosity down to acceptable levels. Present test rig was built with the aim to minimize the extent of system adaptations. Combustion analysis is supported by the investigation of operating parameters and the main emission species at different electrical loads. Additionally, the analysis includes the benchmarking of the obtained data against basic design fuel (diesel) and pure EtOH. The experimental study reveals that it is possible to establish efficient operation of the micro gas turbine while utilizing LW-EtOH blends with high share of LW.

2. Materials and methods

2.1. Fuel

The LW was produced according to the procedure described in [16]. Formulation tested in the present study was therefore produced by adding wood flour from European spruce stem to ethylene glycol, acidified with 3% of methane sulfonic acid. The ratio of wood to ethylene glycol was 1:2. Liquefaction residence time and temperature were 3 h and 180 °C at atmospheric pressure. Solid residue in the range of 2% was later removed through a 50 µm filtration.

Due to its high viscosity, the LW was blended with EtOH to reduce the value under 20 cSt to allow a proper fuel atomization into the combustion chamber. EtOH used for blending with LW is a commercial denatured ethanol at 94% volume fraction. The blends were prepared by blending EtOH in two separate liquefied wood tanks, adding respectively the 25 and 50% in mass. Blends were prepared 1 h before tests and presented uniform and stable behavior without the use of other additives.

2.2. Experimental test rig

The test rig developed by CREAR is based on an overhauled micro gas turbine powering a military auxiliary power unit (APU) produced by AiResearch-Garrett Corporation, model GTP 30-67; the engine was acquired from Avon Aero Supply, Inc. (USA). The atomization principle is a single injector, pressure swirl, with a reverse flow silo combustion chamber. The turbine shaft rotates at fixed rotation speed, approximately 53,000 rpm, with an AC output of 25 kVA, 0.8 pF, 400 Hz, 120/208 Volt. The rig was built as test bench for vegetable oils [12] and fast pyrolysis oil [13] and comprises: engine sub-assembly; multi-fuel injection line; control panel; AC generator. The parts are mounted on a mobile frame in aluminium profiles (as shown in Figure 1).