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Performance and emissions of liquefied wood as fuel for a small scale gas turbine

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HIGHLIGHTS

- Performance and emissions of Liquefied Wood in a MGT were investigated.
- Liquefied wood with pure ethylene glycol as a solvent was produced.
- The raw biocrude was upgraded by adding ethanol to further reduce viscosity.
- Notably reduced extent of MGT adaptations was maintained.
- Guidelines of MGTs requirements to allow viscous fuels combustion were presented.

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ABSTRACT

This study investigates for the first time the combustion in a micro gas turbine (MGT) of a new bioliquid, a viscous biocrude, which is a liquefied wood (LW) produced via solvolysis of lignocellulosic biomass in acidified glycols. The test rig includes a modified fuel injection line, a re-designed combustion chamber and revised fuel injection positions. The main novelties of this work are: (1) producing of liquefied wood with pure ethylene glycol as a solvent, and methanesulfonic acid as a catalyst, to obtain a bio-crude with lower viscosity and higher lignocellulosics content than previous tested formulations; (2) upgrading raw liquefied wood by blending it with ethanol to further reduce the viscosity of the mixture; (3) utilizing a commercially available MGT Auxiliary Power Unit (APU) of 25 kW electrical power output, with notably reduced extent of adaptations to use the newly obtained fuel mixture. Fuel properties, and their impact on combustion performance using liquefied wood, are investigated by analyzing MGT performance and emissions response at different load and blend ratios. Emissions revealed that the presence of LW in the blends significantly affects CO and NO_X concentrations compared to conventional fuels. CO roughly increased from 600 ppm (pure ethanol as fuel) to 1500 ppm (at 20 kW electrical power). The experimental study reveals that it is possible to achieve efficient MGT operation while utilizing high biocrude to ethanol ratios, but a number of adaptations are necessary. The achieved maximum share of liquefied wood in the fuel blend is 47.2% at 25 kW power output. Main barriers to the use of higher share of liquefied wood in these type of systems are also summarized.

1. Introduction

1.1. Biocrudes as fuel for gas turbines

The use of bioliquids as fuels for replacing fossil fuels is particularly interesting for small-scale stationary power generation and CHP. Bioliquids, even in the form of viscous biocrudes (derived from thermochemical processing of biomass), can partially substitute fossil sources requiring significant technology adaptation [1–3]. In this category, vegetable oils and biocrudes are particularly interesting for energy generation in decentralized applications [4], reducing the fuel upgrading costs to a minimum.

Among bioliquids, however, vegetable oils compete with food raw materials, so their broad market introduction generated a large debate

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Nomenclature

AC	alternate current
APU	auxiliary power unit
ASTM	American society for testing and materials
C	compressor
CC	combustion chamber
CEN	European Committee for Standardization (in French: Comité Européen de Normalisation)
CHNOS	carbon hydrogen nitrogen oxygen sulphur (elemental analysis)
CHP	combined heat and power generation
DAQ	data acquisition
DEG	diethylene glycol
DIN	German institution for fuel norms and specifications
EG	ethylene glycol
EL	electrical load
EN	European standardization
ER	equivalence ratio
EtOH	ethanol blend
FBN	fuel bond nitrogen
FPBO	fast pyrolysis bio-oil
GL	glycerol
GT	gas turbine
HDPE	high-density polyethylene
HHV	higher heating value
ISO	International Organization for Standardization
LHV	lower heating value
LW	liquefied wood
LW/EtOH	liquefied wood/ethanol blend (in mass fraction)
MGT	micro gas turbine
MSA	methane-sulfonic acid
NDIR	non dispersive infra-red (sensor type)
NDUV	non dispersive ultra-violet (sensor type)
p	pressure sensor
ppm	part per million
PTA	para-toluensulfonic acid
SMD	sauter mean diameter
T	turbine
T_air	external air temperature (at gas turbine inlet section)
T_exh	temperature at the gas turbine exhaust section (exhaust gases)
Th	thermocouple
TIT	turbine inlet temperature
vol.	volume
wt.	weight

about relevant impacts during the entire life cycle as fuels [5]. Non-food derivatives – as liquid biocrudes from thermochemical processing of lignocellulosic biomass – represent a very attractive sustainable opportunity in stationary engines and gas turbines [6]. Bioliquids that fall within this group are multicomponent mixtures derived from the depolymerization and fragmentation reactions of the three main building blocks of lignocellulosic biomass, i.e. cellulose, hemicellulose, and lignin [7]. The thermochemical processes available for the conversion of these biomass components mostly yield very viscous products, with high water/oxygen content and low pH value [8]: among these, it is worth to mention fast pyrolysis bio-oil (FPBO), liquefied wood (LW) or products of hydrothermal liquefaction. Their properties are also a limiting factors for utilization of such fuels in combustion engines [2,9], as their direct utilization without upgrading is most often impossible [10,11]. One of the major issue regards the atomization of a viscous liquid, which comport dedicated experimental study to assess spray performance [12,13]. The complex combustion fundamentals of lignocellulosic-derived biocrudes, mostly fast pyrolysis bio-oil blended with alcohols or kerosene (in form of emulsion), have been mainly investigated in burner test rigs [14–17] to assess flame stability and gaseous emissions of a multi-components fuel. From experimental data, just few numerical studies initiated the combustion modelling of these mixture towards combustors design [18–20]. As regards gas turbines, biocrudes were generally tested in commercial units that presented minor modifications to be fed with acidic, viscous and aqueous fuel. For instance Lopez et al. [9] tested FPBO in turbomachinery applications, which reported the adaptations to the fuel feeding system to obtain injection characteristics comparable to those of fossil fuels. Andrews et al. [21] carried out successful tests on the Orenda GT2500, a 2.5 MWe turbine equipped with an experimental dual-fuel nozzle designed to improve spray quality. A recent work reported a successful test with full FPBO in a medium-sized (1.9 MW electric power) gas turbine, which was properly modified for this scope [22]. Considering small scale GT units, research on viscous biocrudes in gas turbines was very limited. To the knowledge of the authors, apart from few studies using pure vegetable oil [23–25] that is not directly comparable to lignocellulosic biomass oil, only two studies tested bio-oil from biomass pyrolysis: Strenziok et al. [26] investigated the performance and emissions of an adapted Deuz T216 turbine with 75 kW output; Buffi et al. [27,28] tested a mixture of FPBO/ethanol 50/50 vol% in the same test rig discussed in this work.

One of the most extensive development of a small-scale gas turbine engine was performed by Seljak et al. [29] using liquefied wood, a biocrude produced from the solvolysis of lignocellulosic biomass in acidified glycols. This bioliquid features similar properties as FPBO (less water phase but higher viscosity), and therefore extensive technology modifications are necessary before feeding. The adaptation process was thoroughly described in several studies together with the testing methodology and the interlinkages among several interrelated elements [30], leading to the development of an operational prototype [31], capable of firing several highly viscous fuels (e.g. 68 mPa s at 100 °C) [32,33]. These measures are not solely related to the injection system, but rather combines several interventions, in particular:

- implementation of primary air preheating in the range of 400–500 °C [34];
- development of pressurized fuel preheating system using suitable components materials [30];
- improved injection nozzle including a thermal insulation to prevent formation of deposits;
- fine tuning of thermodynamic conditions in the combustion chamber [35].

The described solution relies on state-of-the-art technical devices to make the system suitable for high viscosity fuel feeding and combustion with the aim to retain the cost advantages of a not-upgraded fuel.

The alternative approach to utilize biocrudes in gas turbines designed for conventional hydrocarbons, is to minimize the extent of adaptations on the engine while reasonably adjusting the fuel formulation to comply with the minimum requirements of commercially available units. This approach is more suitable for small throughput system.

In this paper, this second approach is applied to the case of a novel formulation of LW, produced via solvolysis of lignocellulosic biomass in ethylene glycol. The selection of alcohols was up to now limited to glycerol and diethylene glycol, with the addition of a small amount of acid catalyst (paratoluensulfonic acid). Due to very high viscosity of the LW [32,33], the reduction of fuel viscosity has been achieved using a polyalcohol at lower molecular weight. The original injection systems, as in the case of the majority of stationary gas turbines, accept fuel