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Advanced fuels for gas turbines: Fuel system corrosion, hot path deposit formation and emissions

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ABSTRACT

To further expand the knowledge base on the use of innovative fuels in the micro gas turbines, this paper provides insight into interrelation between specific fuel properties and their impact on combustion and emission formation phenomena in micro gas turbines for stationary power generation as well as their impact on material corrosion and deposit formation. The objective of this study is to identify potential issues that can be related to specific fuel properties and to propose counter measures for achieving stable, durable, efficient and low emission operation of the micro gas turbine while utilizing advanced/innovative fuels. This is done by coupling combustion and emission formation analyses to analyses of material degradation and degradation of component functionality while interpreting them through fuel-specific properties. To ensure sufficiently broad range of fuel properties to demonstrate the applicability of the method, two different fuels with significantly different properties are analysed, i.e. tire pyrolysis oil and liquefied wood. It is shown that extent of required micro gas turbine adaptations strongly correlates with deviations of the fuel properties from those of the baseline fuel. Through the study, these adaptations are supported by in-depth analyses of impacts of fuel properties on different components, parameters and subsystems and their quantification. This holistic approach is further used to propose methodologies and innovative approaches for constraining a design space of micro gas turbine to successfully utilize wide spectra of alternative/innovative fuels.

1. Introduction

Increased energy independence and the aim to transform to the low carbon intensive society motivate the increased use of locally available and carbon neutral primary materials, which in practice mostly address renewables. In parallel, albeit the net positive carbon emissions, the ever-growing issue of waste is supporting the energy recovery from wastes with high energy content [1]. In both cases, combustion in externally fired Rankine cycle is still a prevailing technology even though the electrical efficiency of such systems is usually lower than 25% [2]. To obtain electric efficiencies in excess of 30%, internal combustion principle is much more suitable. Here, two options are available on the low end of the power scale – reciprocating engines and gas turbines. The first ones are attractive due to their availability, low price and generally higher efficiency. In addition, biomass-to-liquid fuels [3], alcohols [4] and advanced 2nd generation biofuels [5] were also utilized several times in reciprocating engines. Gas turbines are particularly suitable for fuels with less favorable physical and/or chemical properties due to their continuous combustion principle and thus inherent ease of fuel injection and mixture preparation.

Published works on internally fired micro gas turbines generally cover straight vegetable oils – in [6], numerical simulations of spray pattern, supported by experimental evaluation of power output and emissions were done with 100% vegetable oil, while in [7] several blends of vegetable oil and diesel fuel were tested up to 100% vegetable oil and in [8] 10% and 20% blends of different oils with JET A1 fuel were experimentally evaluated with regards to performance, gaseous and particulate emissions. Some studies were also analyzing the possibility to use waste trap grease [9]. Several studies were focused also on methyl esters but they can be at present time considered as an industrial standard, since recent EN590:2013 standard already allows up to 7% content of fatty acid methyl ester. To utilize the full potential of robust burning characteristics of microturbines, fuels with even less favorable properties or additional advanced biofuels could be exploited. Such systems are currently limited only to medium power range turbine

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Nomenclature

MGT	micro gas turbine
TPO	tire pyrolysis oil
D2	diesel fuel according to EN:590:2013
LW	liquefied wood
PAT	primary air temperature
TIT	turbine inlet temperature
LHV	lower heating value
SEM	scanning electrone microscope
EDX	electron dispersive X-ray
XPS	X-ray photoelectron spectroscopy
pTSA	para-toluensulfonic acid
SMD	Sauter mean diameter
PAH	polyaromatic hydrocarbons
FBN	fuel bound nitrogen

engines and are mainly focused on biomass pyrolysis oils. An example is the Mashproekt 2.5 MW gas turbine, where industrial solution was developed [10] and 2 MW OPRA gas turbine, where research is still under way.

Apart from upper 1st generation biofuels and studies performed on isolated components (i.e. spray characteristics, droplet combustion, combustion chamber testing,) or studies dealing with isolated phenomena, research activity in the range of micro turbines (MGT) and fuels with less favorable properties is still limited. The pioneering work on the use of pyrolysis oil was presented on a 100 kW simple cycle MGT [11], where actual combustion properties of pyrolysis oil were tested in the MGT for the first time. Recent studies on the use of a wood, liquefied through solvolysis process that has similar properties as the pyrolysis oil in a dedicated experimental MGT were focused on different formulations of the fuel [12], comparison to other polymer-derived fuels [13], influence of fuel temperature [14] and on the effect of primary air temperature [15].

In general, research of alternative/innovative fuels initially focuses on fuel properties and mixture formation, combustion as well as emission formation phenomena. This 1st level analysis is certainly a prerequisite for utilization of such fuel. However, to ensure also stable and durable operation of the MGT while using alternative/innovative fuels a 2nd level analysis is necessary, that addresses also degradation of materials and degradation of component functionality. In case of diesel-like fuels, a decoupled 1st and 2nd level analysis is often sufficient. This is not necessarily the case for fuels with deviant and thus less favorable properties, where potentially a strong interrelation of the phenomena listed in blocks in Fig. 1 might exist. In this case a coupled analysis addressing fuel properties, combustion and emission formation phenomena as well as degradation of materials and degradation of component functionality is necessary. Such holistic approach ensures that the design space is constrained early in the design or adaptation process, providing a basis for efficient and optimized engine adaptation process and eliminating the need for step backs in adaptation procedure. To steer and to support such a decision-making process, the paper presents methodologies and innovative approaches for defining borders of design space and for identifying interrelated phenomena among fuel properties, combustion and emission formation, degradation of materials and degradation of component functionality.

2. Plant, materials and methods

For evaluating and testing the combustion ability of different fuels through the overall thermodynamic and emission response a dedicated MGT system presented in Fig. 2 was developed. Besides serving as a plant for analysing alternative/innovative fuels the MGT system should serve also as an apparatus for testing of hot components and materials and corrosion studies as well as for assessing the impact of thermodynamic conditions in selected parts of the combustion chamber on overall system response.

The key capabilities of the system can be listed as follows:

- possibility to operate with different turbine inlet temperatures,
- possibility to operate with different thermodynamic cycles, i.e. simple and regenerative,
- flexible injection system in terms of fuel pressure, temperature and viscosity,

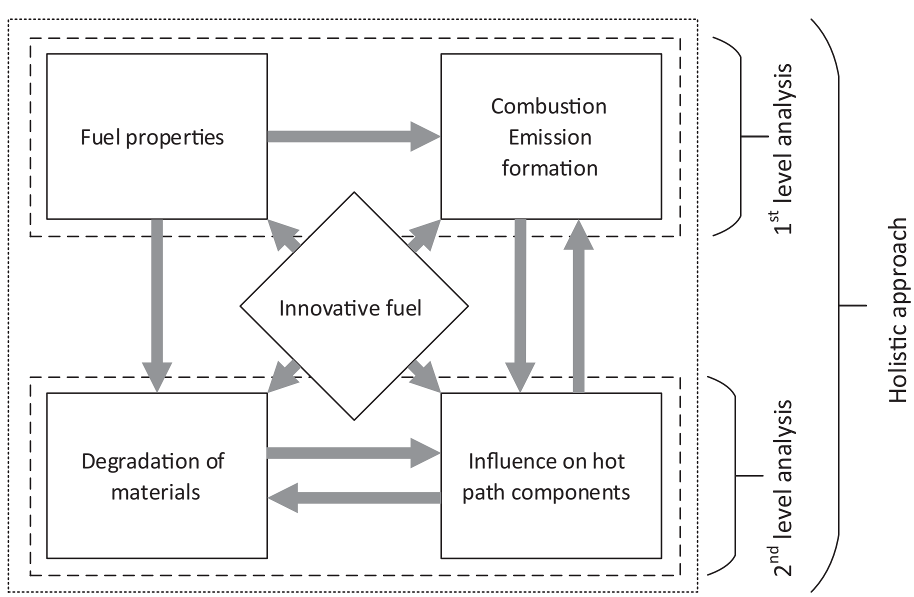

Fig. 1. Feasibility analysis of innovative fuels.