ARTICLE IN PRESS

Waste Management xxx (2015) xxx–xxx

Contents lists available at ScienceDirect

Waste Management

journal homepage: www.elsevier.com/locate/wasman

Designing the microturbine engine for waste-derived fuels

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ARTICLE INFO

Article history:
Received 31 January 2015
Revised 1 June 2015
Accepted 3 June 2015
Available online xxxx

Keywords:
Internal combustion engine
Methodology
Microturbine
Thermodynamic cycle
Waste derived fuel

ABSTRACT

Presented paper deals with adaptation procedure of a microturbine (MGT) for exploitation of refuse derived fuels (RDF). RDF often possess significantly different properties than conventional fuels and usually require at least some adaptations of internal combustion systems to obtain full functionality. With the methodology, developed in the paper it is possible to evaluate the extent of required adaptations by performing a thorough analysis of fuel combustion properties in a dedicated experimental rig suitable for testing of wide-variety of waste and biomass derived fuels. In the first part key turbine components are analyzed followed by cause and effect analysis of interaction between different fuel properties and design parameters of the components. The data are then used to build a dedicated test system where two fuels with diametric physical and chemical properties are tested – liquefied biomass waste (LW) and waste tire pyrolysis oil (TPO). The analysis suggests that exploitation of LW requires higher complexity of target MGT system as stable combustion can be achieved only with regenerative thermodynamic cycle, high fuel preheat temperatures and optimized fuel injection nozzle. Contrary, TPO requires less complex MGT design and sufficient operational stability is achieved already with simple cycle MGT and conventional fuel system. The presented approach of testing can significantly reduce the extent and cost of required adaptations of commercial system as pre-selection procedure of suitable MGT is done in developed test system. The obtained data can at the same time serve as an input for fine-tuning the processes for RDF production.

1. Introduction

Advances in classification of refuse derived fuels and solid recovered fuels (RDF/SRF) with better quality management concepts (Rada and Andreottola, 2012) are paving the way toward utilization of a wide portfolio of different RDFs in micro gas turbines (MGT) by offering potential for rendering their characteristics through different processes for their conversion. By this it is possible to target also the systems in the very low power range where externally fired systems are not available. Thereby it is possible to obtain similar efficiencies as on a large scale (Lombardi et al., 2015). The most promising products for this purpose are pyrolysis oils and gasses from waste polymer materials (Williams, 2013) and waste lignocellulosics (Mohan et al., 2006), products of gasification (Arena, 2012) and products of direct liquefaction. Although these processes yield fuels with attractive physical and chemical properties, the utilization of the fuel in MGTs requires at least some research work to identify the main and barriers at MGT operation considering the main fuel properties, which are as follows:

- viscosity that influences mixture formation, increases CO emissions and dictates the complexity of fuel system (Sallevelt et al., 2014; Chiaramonti et al., 2005),
- heating value and stoichiometric ratio that influence energy density of the mixture and thus available power output or potential power de-rating (Hossain and Davies, 2013),
- density and heating value, which determines volumetric energy content and influences mixture formation as well as injection system performance.

Availability of research publications on utilization of waste-derived fuels in MGT setups is scarce and it is mainly focused on 1st generation biofuels. Thus, studies by Prussi et al. (2012) and Chiariello et al. (2014) used straight vegetable oil and their blends with diesel in a 30 kW unit, Cavarzere et al. (2012, 2014) studied the combustion of straight vegetable oils from rapeseed, sunflower and soybean in a 50 kW MGT, Chiaramonti et al. (2013) tested refined rapeseed vegetable oil in 50 kW APU derived MGT whereas Al-Shudeifat and Donaldson (2010) studied waste trap grease as a fuel in 150 kW MGT. Other authors focused mainly

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http://dx.doi.org/10.1016/j.wasman.2015.06.004
0956-053X/© 2015 Published by Elsevier Ltd.

on methyl esters from various feedstock. Habib et al. (2010) presented a study on 30 kW system firing methyl esters from soy, canola, rapeseed and hog-fat, Chiaramonti et al. (2013) also tested methyl esters from mixed vegetable oils. Several studies on various methyl esters blended with diesel were also conducted, however they are at present time considered as an industrial standard, since recent EN590:2013 standard already allows up to 7% fatty acid methyl ester content. Some work was already performed also on externally fired systems (EFGT) (Al-attab and Zainal, 2010; Riccio and Chiaramonti, 2009), but due to significant differences to internal combustion engines, this area will be omitted here.

In some of upper cases, MGT systems required different levels of adaptations (e.g. fuel preheating, increased injection pressure) to obtain stable combustion process with manageable emission levels. When aiming at the usage of RDF it is thus important to select an MGT system being as suitable as possible for the use of target fuel in terms of its physical and chemical properties, which minimizes the required upgrades of the system. The main focus of the study is thus to establish an interaction between specific fuel properties, required system modifications and their impact on MGT performance and exhaust emissions, by:

- Designing a dedicated experimental microturbine engine being a versatile platform for exploring a wide test space with the aim of assessing impact of specific changes to identify suitable commercial MGT setups with intention to minimize the required changes for a target fuel.
- Developing holistic methodology for selection of appropriate microturbine system considering specific properties of RDFs, which is applicable also as guiding strategy for fine-tuning of fuel production process. The presented methodology can significantly reduce the complexity and cost of commercial system adaptation by pin-pointing the critical components in the early stage of development.
- Identifying and analyzing design requirements on injection system suitable for utilizing wide variety of fuels by taking into account correct nozzle design, suitable turn-down ratio, proper atomization performance and sensitivity to thermal loading.
- Providing detailed insight into combustion chamber conditions with time-resolved thermodynamic and exhaust emission data in different operating regimes.
- Demonstrating the above items through the analysis on the overall system response with two different RDFs: diesel-like fraction of tire pyrolysis oil (TPO), obtained through vacuum pyrolysis of shredded waste tires which in certain properties resembles diesel fuel, and liquefied wood (LW), obtained through chemical liquefaction (solvolysis) by decomposing main constituents of lignocellulosic material in acidified multifunctional alcohols, with high viscosity and low energy content.

2. System development

In Fig. 1 a dedicated experimental system layout is presented with indicated key components and characteristic points for measuring the thermodynamic parameters of the working fluid and emission measurement devices. In the subsequent sections analyses will follow fuel and gas path in the downstream direction.

2.1. Fuel delivery system

Design of a fuel system is most profoundly influenced by the physical and chemical properties of the fuel that dictate the required performance of the system. Fuel properties that need to be considered when designing the fuel delivery system are summarized in Table 1.

As presented in Table 1, TPO and LW feature significantly different composition and thus also fuel properties and can thus be considered as two fuels representing outmost (or near to

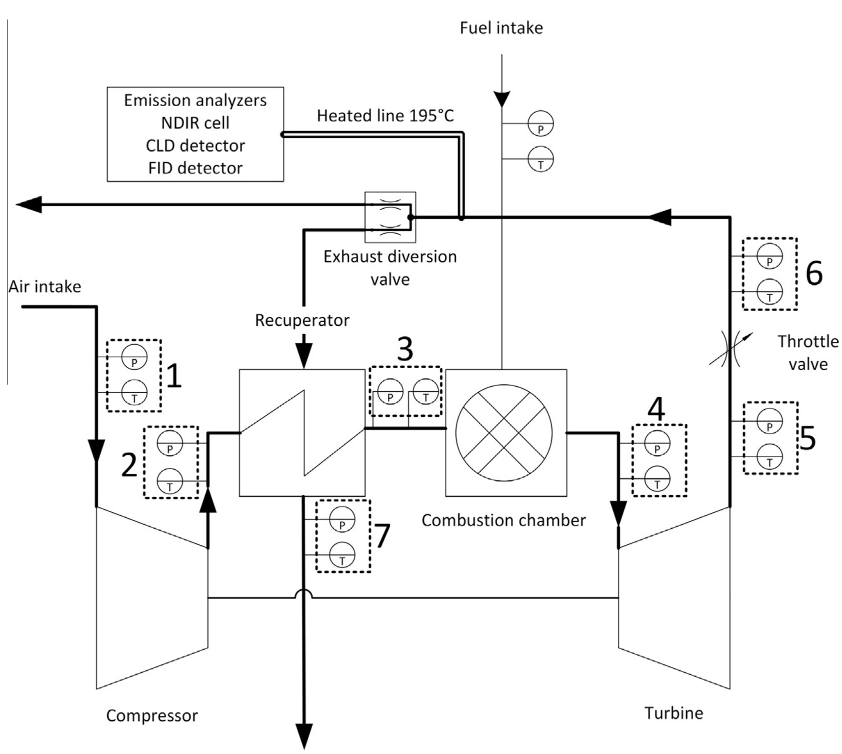

Fig. 1. Experimental system layout with marked characteristic points.

Please cite this article in press as: Seljak, T., Katrašnik, T. Designing the microturbine engine for waste-derived fuels. Waste Management (2015), http://dx.doi.org/10.1016/j.wasman.2015.06.004