The impact of HEFA on Emissions and Performances of a Micro Gas Turbine Using Combustion Vibrations Detection

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Abstract

The paper reports a quantitative comparative assessment of particulate matter emissions from a Micro Gas Turbine (MGT) for power generation, providing electrical power up to 30kWe powered by conventional aviation kerosene and its blend with Sustainable Aviation Fuel (SAF). The analysis was based on emission concentrations and particle size distributions. Different liquid fuels, including commercial JP8, blends of JP8 with HEFA, were tested under fixed load. Primarily attention has been focused on the measures of the micro vibrational distributions and their correlation with gas turbine emission and performances, by a chaos theory approach.

Introduction

The field of researching and testing new Sustainable Aviation Fuels (SAF) for air transport is becoming a rising challenge. This is confirmed by the recently European Parliament in 2023 [1], where The *RefuelEU* aviation rules are part of the "Fit for 55 package", the EU's plan to reduce greenhouse gas emissions by at least 55% by 2030 compared to 1990 levels and to ensure the EU becomes climate neutral by 2050. They seek to encourage the aviation sector to use sustainable aviation fuels in order to cut emissions. Previous research program were undergone using HEFA ("Hydrotreated Esters and Fatty Acids"), e.g. ITAKA—Initiative Towards Sustainable Kerosene for Aviation [2], BFSJ—Production of a fully synthetic jet fuel from timber and other biomass, BIOREFLY—Industrial scale demonstration biorefinery on lignin-based aviation fuel [3]. The aim of these projects was to promote the use of alternative jet fuels derived from non-conventional sources. Environmental and Health effects of emissions from aircraft engine reviews present a negative effect on climate change and air pollution [4-6]. In the literature, the positive impact of Sustainable Air Fuels on the carbon footprint has been confirmed. The positive impact of SAF on air quality, particularly in airport areas and their vicinity, should be considered separately [7-9]. Currently, one of the major issues of air pollution is particulate matter. Scientific studies indicate that airport areas are contaminated with nanoparticles [10]. In the context of aviation, these particles can result from the combustion of jet fuels and are associated with adverse respiratory effects and environmental damage. SAF's cleaner combustion profile, attributed to its renewable feedstocks and advanced production processes, leads to a notable reduction in particulate matter emissions compared to conventional aviation fuels. This positive environmental impact aligns with global efforts to enhance air quality and mitigate the adverse health effects associated with particulate matter exposure [11]. The objective of the research presented in this article was to conduct a quantitative comparative assessment of particulate matter emissions from a MGT for power generation, providing electrical power up to 30kWe powered by conventional aviation kerosene and its blend with SAF. The analysis was based on emission concentrations and particle size distributions. Different liquid fuels, including commercial JP8, blends of JP8 with HEFA, were tested under fixed load. Primarily attention has been focused on the measures of the micro vibrational distributions and their correlation with gas turbine fueling.

Experimental set-up

The Micro Turbine Capstone C30 is a turbine of last generation system with a maximum power output of 30kWe with 26% electrical efficiency and up to 90% combined heat power efficiency. It is widely used in the aeronautical field; in particular, as energy provider for the aircrafts on parking. It can be also operated with different liquid fuels. The fuel supply system is composed of three nozzles (one main and two auxiliaries). In this paper, JP8 as fuel and its blend with HEFA at 20%v/v, at 40%v/v, at 60%v/v, 80%v/v and 100%v/v were used. The choice of HEFA is to verify an eventual difference between fuels in terms of machine performance. The Micro Gat Turbine (MGT) rotation was set at 85000rpm close to its maximum speed (i.e., 90000rpm) for all the fuels. All parameters of the turbine (i.e., rotational speed of the turbine, power output, exhaust gas temperature, etc.) were continuously acquired every two seconds by means of a PC and analyzed at the end of test. The vibrational signals were acquired by means of two unidirectional micro accelerometers, model PCB 352 C22. The acquired data through the accelerometers have been synchronized with each other and were stored in the computer. Synchronization here means that the accelerometer signals were acquired in parallel and aligned on a time basis through a LMS SCADAS data acquisition system. Hence, no electromechanical synchronization system was used for each accelerometer signal (e.g., tachometer signal). Front and side views of the turbine and the location of the accelerometers are shown in fig.1 (left and right respectively). Exhaust gas emissions (O2, CO, CO2) were recorded with continuous gas analyzer Hartmann&Braun, while the real-time particulate distribution functions in the range 7 nm-10 μm) were acquired using an electro-impactor ELPI™.

Methods

The proposed method for distinguishing regular from chaotic dynamics is successful if the noise-level is sufficiently small but also because the balanced dynamics of turbine are essentially stationary and deterministic. Many methods desensitize the test performed on noisy signals but damps the ability to detect slow growth of the features as well as the signature for time series data of moderate length. For such a reason each accelerometric signal was sampled at 102 400 Hz for 10s, for a total of 1 025 024 sampled points. The calculations were performed by using the MATLAB® software. The nonlinear method introduced in this work consists primarily in the decomposition of the accelerometric signal into two mutually orthogonal components [12] for projecting them on a plane other than phase space. More detailed about the method are given in ref [13].

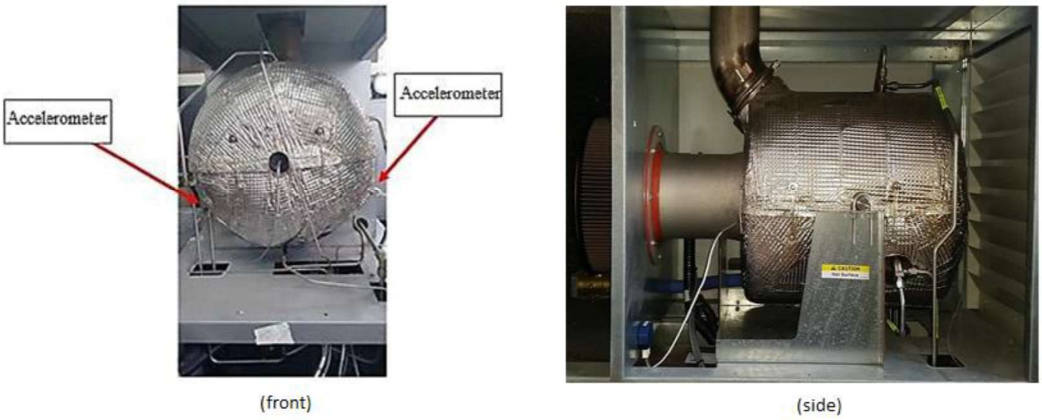

Figure 1 - Turbine with location of accelerometers: front and side view

Results and Discussions

The addition of the biokerosene HEFA in the JP8 did not present any macro-mechanical problem concerning the normal MGT working conditions. For each blend change, we waited for the MGT to thermally and electrically (load) stabilize. The data were acquired after ~30 minutes after the change. Each blend was repeated three times. The presented data represent the average of the measurements. For room reason, not all the results will be presented. From the stable gases emission values presented in Table 1 for the main fuels, we can observe than the addition of HEFA enhances a light decrease of the carbon monoxide and particulate matter, while the nitrogen oxides are stables. This tendency has also been found by Gawron and Bialecki [7] using different turbine rpm modes.

Table 1: Emission values@26kWe

	O_2	NO_X	CO	Particulate
	%	ppm (mg/Nm^3)@15%O_2	ppm (mg/Nm^3)@15%O_2	mg/Nm^3
JP8	18,3	11 (23)	10 (12)	0,23
JP8 – 20%vol. HEFA	18,3	10 (22)	9 (11)	0,22
100%vol. HEFA	18,4	10 (22)	8 (10)	0,20

The time-averaged particle distribution functions are presented in Figure 2 for the different fuels. Dimensions higher than 10 microns were blocked though a cyclone filter in order to focus on small particles. Once again, it is worth to note the positive effect on HEFA addition in JP8. The particle concentration decreased by two orders of magnitude while passing from JP8 to HEFA. The reduction is more evident for particle with diameter higher than 200 nm. Moreover, the bimodal tendency of the JP8 plot tends to disappear while increasing the HEFA concentration in the fuel blend. The positive tendency from HEFA addition has also been found by Jasinski and Przysowa for particle dimension lower than 200 nm [14]. The absence of aromatic compounds could be the main reason of this phenomenon and further kinetics analysis will be performed to assess this assumption.

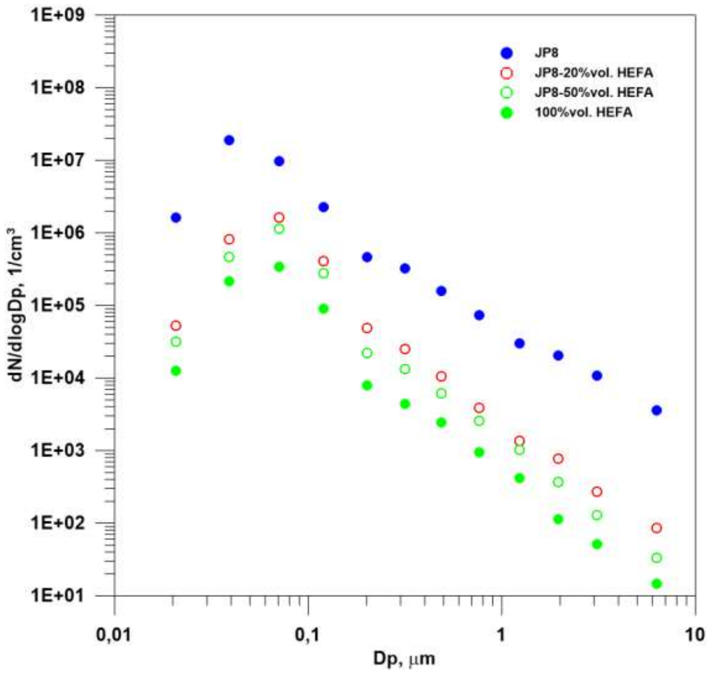

Figure 2 – Averaged particle size distribution functions.

A further mathematical method based on non-linear analysis was performed on data acquired by the accelerometers and processing results are plotted in Figure 3 that represents the instability map for each blend. The mapping of c versus z well illustrates the chaos state of the different blends. It shows that the JP8 looks much more stable compared to its blends with HEFA. The full use of HEFA creates a bigger chaos state compared to JP8. Once again, this tendency could be explained by a “quasi homogeneous” combustion with a lack of intermediate components, e.g. aromatic compounds that kinetically stabilize the combustion. Further investigations need to be performed in that sense. This stability occurs around the high frequency (~2.4 kHz) found by the mathematical analysis. To better understand the role of HEFA in the vibrational aspect of the MGT, the instability was plotted versus the

HEFA concentration in the blends using the MGT rpm variation.

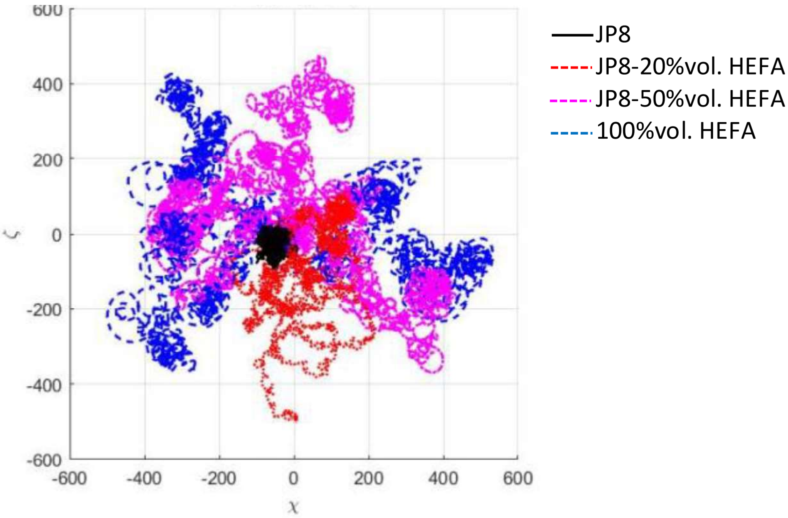

Figure 3 – mapping of c versus z of the different blends.

Figure 4 represents the rpm variation of the MGT for the three sets of measurements performed for each blend. This figure clearly shows that something happens for blends containing 20%vol. and 40%vol. of HEFA. The instability observed for this blends could be due to the competition of the different kinetics of biokerosene and kerosene during their combustion.

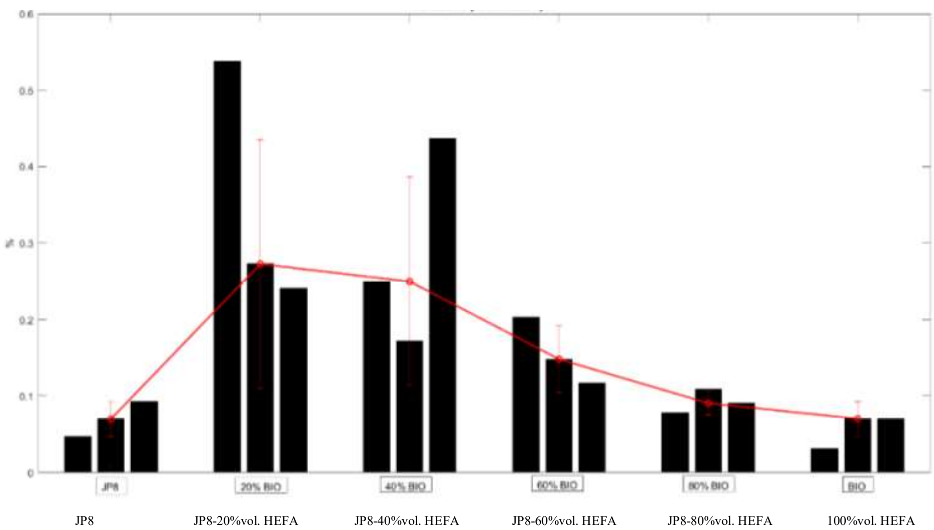

Figure 4 – rpm variation of the MGT vs. blends

Conclusions

A Chaos theory approach based on statistic and non linear mathematical models has been applied for the interpretation of vibration signal acquired on a micro gas turbine for power generation. The technique has shown interesting potential for detecting the correlation between emissions and performances and the use of some Sustainable Aviation Fuels, in particular for HEFA, in different blending conditions.

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