EXTENDING AND CHARACTERIZING THE FUEL FLEXIBILITY OF A 4.97 CC ROTARY ENGINE

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Abstract: The goal of this research was to improve the fuel flexibility of a 4.97 cc Wankel rotary engine for use in various military, disaster relief and consumer applications. The design, construction and testing of a fuel flexible engine dynamometer and fuel delivery system is presented along with experimental data that demonstrates the fuel-flexible capacity of the tested small-scale Wankel engine. The maximum mechanical power produced from Gasoline, Glowfuel (methanol+nitromethane mix), JP8, Diesel and Biodiesel were 334 W, 508 W, 313 W, 239 W and 322 W respectively.

Keywords: fuel flexibility, rotary engine, portable power, small-scale dynamometer

INTRODUCTION

Portable electronics are getting smaller and the power supplies that drive them also need to shrink in order to address market demand [1]. Specifically, fuel flexible portable power is utilized by the military for special ops missions [2], emergency crews for disaster relief communication needs and potentially auto manufacturers for fuel-flexible hybrid vehicles, enabling better access for renewable fuel consumption. And as portability improves, so increases the need for fuel flexibility in that energy sources vary across every region in the world.

Currently, significant gaps in technology remain as portability requires robustness, light-weight design and mobility; each which typically compete with high power and high energy density. Liquid-based hydrocarbon fuels have been identified to meet these requirements and can be converted into electrical power via fuel-flexible engine generators [3]. Other competitive alternatives are bulky, have slow recharge times, lack fuel flexibility or are not robust. Therefore, a high power density solution using a robust 4.97 cc Wankel engine that converts liquid chemical energy from a variety of fuels into useable output power on the range of 10-1000 W was chosen for these types of applications (Figure 1).

BACKGROUND

Relevant Research

Many researchers are working to solve the small-scale portable power problem [4]. Pello *et al*. are researching mini and micro combustion environments present in small-scale rotary engines. Pisano *et al*. have made advancements in the fabrication of MEMS-based rotary engines [3]. Dunn Rankin et al. focus on mini engines and their performance [5]. Building upon the aforementioned work, this research attempts to enable small-scale power supplies that have essentially zero recharging times, can convert nearly any liquid hydrocarbon into usable power, up to one horsepower.

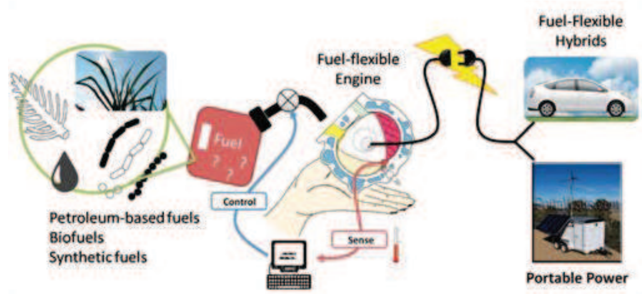

Figure 1: Overview graphic of the research goal: to characterize and extend the fuel-flexibility of small-scale, portable power systems.

Research Challenges

The technical challenges with miniaturizing engines are split into two broad categories: thermal and chemical management [4]. The following represent the most problematic: heat transfer, sealing, stoichiometry and the turbulent mixing of fuel and air are most common [6].

However, in this research, the focus is making fuel flexibility more robust. Because engines are typically designed around one fuel, the challenge became creating a system composed of engine peripherals and controls that permit wide range fuel flexibility. This included sensors, actuators and software to dynamically adjust engine parameters along with a multi-fuel switching system to deliver many fuels to the engine in real time.

Additionally, a more accurate and complete small-scale engine characterization system was needed as the data would drive future engine / sensor design changes.

Dynamometer Design and Construction

Unfortunately, commercially available off the shelf (COTS) dynamometers that met the needs of the fuel flexible engine characterization: long-term endurance testing, output power measurement of over 1000 W, computer controlled loading (among others), did not exist when this research began. Thus, a customized dynamometer system was designed and built (Figure 2).

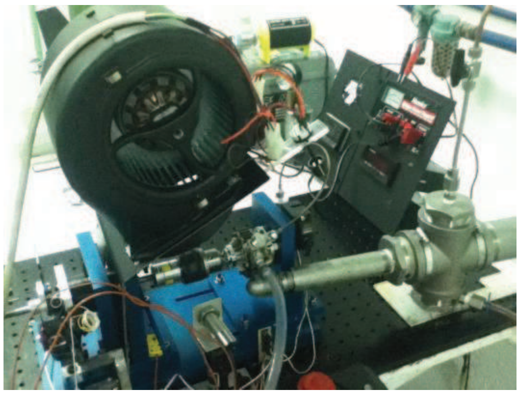

Figure 2: The custom dynamometer system designed and built to measure output power for small engines.

The main challenge in designing and building the dynamometer presented in Figure 2 was the loading system: which applies resistive torques to the motor for mechanical power measurement. Others were starting the motor, accurately measuring the position of the throttle, carburetor needle valve and glowplug current and compiling all these data in real time to understand parameter correlations and improve the experimental repeatability. Difficulty in fully loading the engine using the electrical impedance method used in prior research [2], [6], led to the construction of a mechanical system comprised of a low-cost, electronically controlled disc brake.

Multi-fuel Switching System Design

A multi-fuel containment and switching system has been designed and built to automatically switch fuels in real-time and improve repeatability. The design utilized low-cost COTS components and LabVIEW dynamometer software--specifically designed for the fuel-flexible mechanical power measurements (Figure 3).

The tall structural system is composed of a low-cost personal spirit dispenser called the “BarBuddy” that was modified to support four fuel containers and the electronically controlled fuel valves. These valves made by M&M International contained internal components composed of Viton to prevent corrosion damage typically caused by fuels. These valves were each then connected to relays that were controlled by a ArduinoUNO, a low-cost and open-source microcontroller.

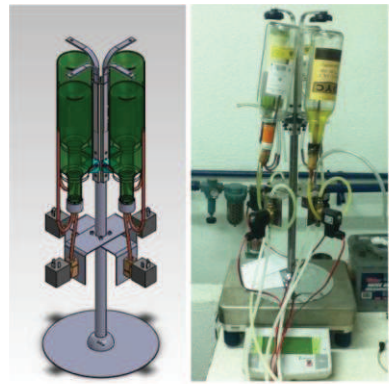

Figure 3: The multi-fuel switching system designed and built to enable electronic switching between 1-8 different liquid-hydrocarbon fuels.

Embedding MEMS Sensors in engines

Embedding MEMS sensors into combustion chambers and testing their survivability would further support the miniaturization of engine-based portable power and related research. Rotary engines are well suited for small-scale MEMS integration because of their planar construction [3]. Thus, a small pocket was precision milled into the wear plate of the 4.97 cc Wankel engine to inlay the prototype Si temperature sensor fabricated by S. Wodin-Schwartz [8].

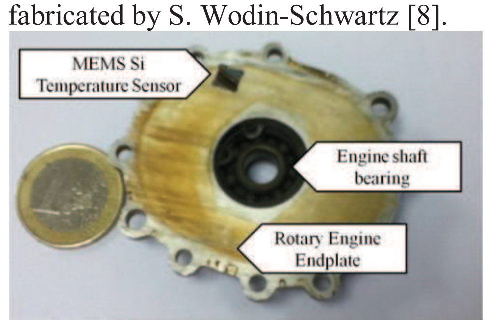

Figure 4: the 4.97 cc Wankel engine endplate with embedded prototype MEMS temperature sensor for survivability testing.

The sensor was bonded to the aluminum endplate using a high temperature ceramic adhesive (Cotronics 490LE) [8] and was shown to survive the harsh environments of larger scale combustion environments. This research put the device in a smaller combustion environment where sensors like these would significantly improve future performance.

Experimental test procedure

The data collection on this dynamometer system was conducted per recommendations presented at the Land & Sea website (a manufacturer of many styles and sizes of dynamometers) [9].

EXPERIMENTAL RESULTS

Overall performance data

The fuels and their constituents used in this set of experiments are presented in the following table:

Table 1: Fuel properties and their constituents.

Fuel	Specific Gravity	Fuel Constituent 1	Fuel Constituent 2	Percent Volume
Gasoline (87 Octane)	0.70	87 Octane	2T Synthetic Oil	0.96 / 0.03 / 0
GlowFuel	0.79	Methanol	Nitromethane	0.82 / 0.18 / 0
JP8	0.80	JP8	2T Synthetic Oil	0.92 / 0.07 / 0
Diesel	0.85	Diesel	2T Synthetic Oil	0.98 / 0.02 / 0
BioDiesel	0.85	BioDiesel	2T Synthetic Oil	0.96 / 0.03 / 0

Table 2: Fuel-flexible engine performance characteristics and other operating conditions.

Fuel	Max Power [W]	RPM	External Engine Temp [C]	External Exhaust Temp [C]	Mass Fuel Flow Rate [g/s]	Maximum Efficiency Recorded
Gasoline (87 Octane)	333.7	9700	64.8	77.5	0.09	0.159
GlowFuel	507.5	15900	52.3	46.3	0.49	0.132
JP8	312.8	9600	82.2	66.4	0.22	0.030
Diesel	239.2	12940	112.7	146.2	2.79	0.002
BioDiesel	322.2	9600	137.8	120.8	0.41	0.016

Performance data for Gasoline (87 Octane)

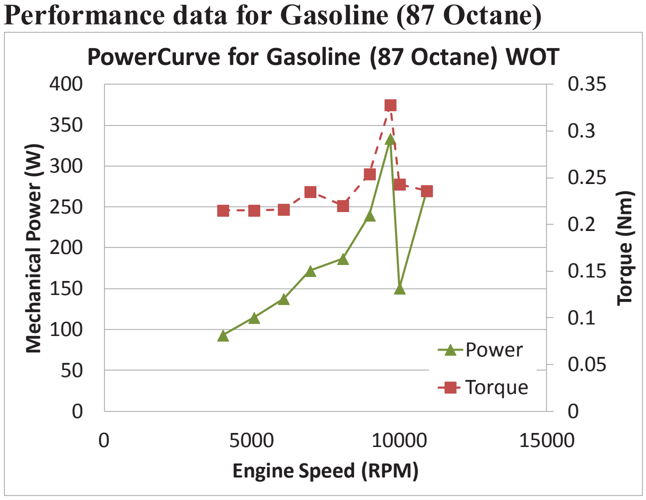

Figure 5: Maximum power observed for Gasoline was 322.2 W at 9600 RPM.

Performance data for GlowFuel

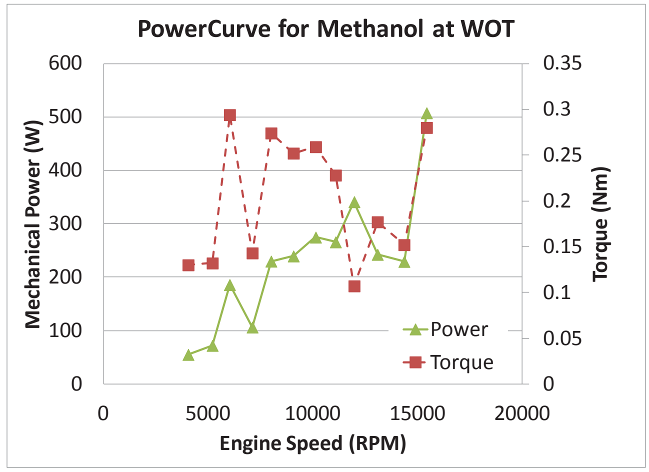

Figure 6: Maximum power observed for Glowfuel was 507.5 W at 15900 RPM.

Performance data for JP8

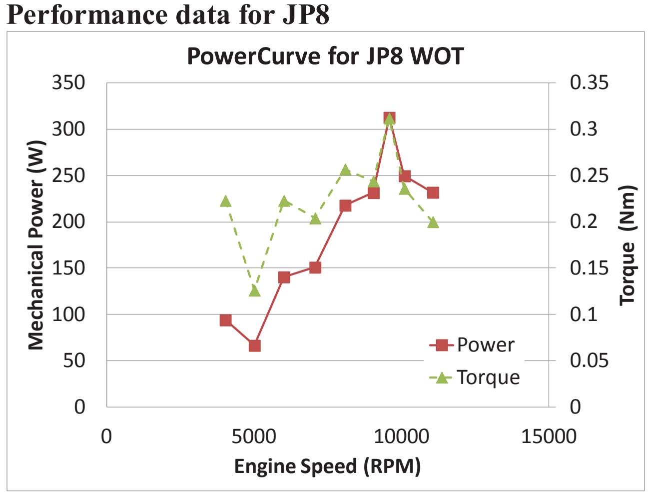

Figure 7: Maximum power observed for JP8 was 312.8 W at 9600 RPM.

Performance data for Diesel

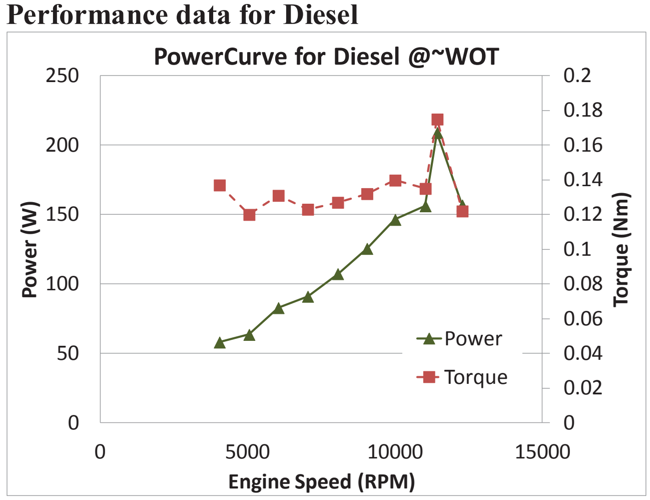

Figure 8: Maximum power observed for Diesel was 239.2 W at 12940 RPM.

Performance data for BioDiesel

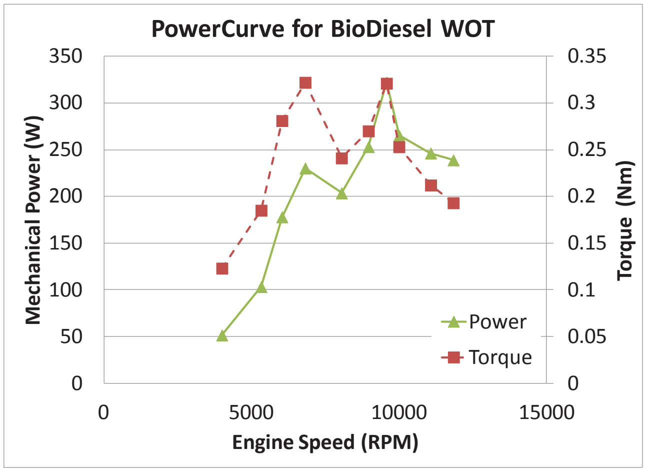

Figure 9: Maximum power observed for BioDiesel was 333.7 W at 9700 RPM.

DISCUSSION

The results suggest that the 4.97 cc Wankel rotary engine is in fact fuel flexible across 5 different fuels, one being a biofuel (BioDiesel). It is interesting to note the variation in both maximum powers and efficiencies of each fuel tested. This is likely due to the inability of the electronically controlled carburetor to adjust sufficiently to ideal fuel stoichiometries (methanol is approximately 7.6:1 while diesel is closer to 15.1:1 thus the engine likely runs beyond its rich flammability limit).

It is interesting to note the variability in the power output coming from the engine likely suggesting non-combustion events. Gasoline and Glowfuel were the only two fuels that could run steadily without constant glowplug heat. The glowplug has a maximum power consumption of 10 W of power.

Considering the manufacturer rates the engine at 1.2 hp using Glowfuel, the maximum recorded mechanical power output using the same fuel in was only 0.68 hp. This is likely due to the limitations of the load cell used to measure torque.

The multi-fuel switching system provided better visibility and monitoring of which fuel was being presently combusted however suffered from large head losses and thus choked the flow of fuel to the engine.

CONCLUSIONS

We have demonstrated that the 4.97 cc Wankel rotary engine is fuel flexible across both liquid petroleum fuels and biofuels. Lastly, we have designed and built systems that better characterize and improve fuel flexibility in small-scale power systems.

ACKNOWLEDGEMENTS

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