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Performance and durability of a generator set CI engine using synthetic and petroleum based fuels for military applications

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ABSTRACT

The long term performance and durability evaluation of a compression ignition (CI) engine of a diesel power generator using ultra-low sulfur diesel (ULSD) and Synthetic Paraffinic Kerosene, (S-8) fuels have been investigated under military specifications. The brake specific fuel consumptions (BSFC) were 0.308 ± 0.013 and 0.267 ± 0.019 kg/kW-h for ULSD and S-8, respectively. The corresponding brake thermal efficiencies (BTE) were 0.287 ± 0.002 and 0.309 ± 0.005. Degradation of engine performance or engine part wear was not observed during these test periods. Analysis of lubricating oil suggests negligible engine part wear. The frequency and power output of the generator, however, were not as stable with S-8 as those with ULSD. These power and frequency instabilities can be attributed to higher volatility and lower density and viscosity of S-8, all of which affect the fuel injection characteristics.

1. Introduction

The higher efficiency, durability, and improved fuel economy [1,2] of compression ignition engines make them very attractive for use in US military equipment in the battle field from generators to aircraft carriers. Also, the US military has implemented the Single Fuel Forward (SFF or single fuel in the battlefield) policy [3,4]. This means that all equipment in the battlefield from generators to heavy trucks and aircraft must be capable of using the same fuel. The Single Fuel Forward policy requires the use of jet fuel (JP)-8, JP-5, or Jet A-1. This initiative provides that US energy independence can begin with a national alternative fuel initiative to provide the US military with a secure domestic supply of clean fuel synthesized from domestic resources. Investigation of various fuels such as ultra-low sulfur diesel (ULSD) [2,4], synthetic fuels [5–11], JP-8/JP-5 [12–14], and blends of biodiesel [15–20] in military applications is necessary to identify the required operational performance and potential issues. The problematic long-term supplies of oil and increasing knowledge of health effects of JP-8 [21], however, have recently encouraged the US military to develop a new synthetic-8 fuel (S-8), an alternative to JP-8. S-8 is derived from synthetic gas through the Fischer–Tropsch (F–T) synthetic fuel process [17]. Evaluations of F–T fuels, such as synthetic jet fuel (S-8) in military ground vehicles, aircraft, associated equipment, and fuel storage and distribution systems are needed to assess the ability to meet desired and/or required operational performance and to identify potential issues, as well as potential benefits, with the introduction and use of these fuels.

The Fischer–Tropsch (F–T) process has been used to produce Gas-to-Liquid (GTL) fuels since the 1920s [22]. Synthetic S-8 is a clean fuel with no sulfur or aromatics, which has historically been very costly to produce when compared with petroleum fuel. Since the mid-1990s, the world's major energy companies have started to develop modern F–T processes that are less expensive to build and operate. F–T synthetic fuels using this technology should result in reduced exhaust emissions from military diesel engines, including reduced diesel exhaust particulate matter [6–8,11]. These fuels also demonstrate low lubricity, which can be improved with military approved lubricity improvers [8,22].

Modern diesel engines are designed for commercial applications, and their base calibrations are based on the use of diesel fuel, not military fuel. Hence, operating standard engines with S-8 or any other alternative fuels might not lead to optimal engine performance. Modern CI engine technologies with electronic control units make dual-use calibrations viable; however, better understanding of the fundamental effects of alternative fuels on engine operation is required before control strategies can be developed. Given the recent focus on alternative commercial diesel fuels, such as synthetic diesel or biodiesel, correlating fuel properties of various fuels with engine performance and durability has broad interest.

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This paper reports the long term engine performance and endurance of a compression ignition (CI) engine, which is used to generate power utilizing the two fuels ULSD and synthetic fuel (S-8). These findings will help to better understand how these fuels perform in a CI engine generator set that is designed for military and emergency situations. Few reports exist describing use of S-8 fuel in CI engines [11,13]. Most of these reports utilize S-8 blended with ULSD and with altered engine calibrations [11]. The use of unblended S-8 on diesel engines has not been reported. In this study, a Titan Energy Sentry 5000™ Mobile Utility system was used and both fuels were put through static load endurance and load transient tests. Engine operating parameters such as injection pressure and injection timing were kept constant for both fuels. At the completion of each run, the used lubrication oil was collected and analyzed to understand the effects each fuel had on engine part wear and on oil degradation.

2. Experimental

2.1. Evaluation of fuel properties

The ULSD was purchased from RKA Petroleum Corporation (Romulus, MI) and was additized for winter conditions. To eliminate batch to batch variations, seven hundred gallons of ULSD was purchased and stored in a stainless steel container. Seven hundred gallons of synthetic fuel (S-8) produced by Syntroleum Corporation (Tulsa, Oklahoma) was provided by the National Automotive Center, US Army, Warren, Michigan. S-8 was not additized when received, but 60 ppm of NALCO 5430 was added as a corrosion inhibitor/lubricity improver (CI/LI) upon arrival. Several important fuel properties were evaluated using the appropriate ASTM test methods and are given in Table 1. Testing procedures were conducted according to the relevant ASTM test methods. The densities of both fuels were measured as a function of temperature and these correlations were later used to calculate the brake specific fuel consumption (BSFC).

2.2. Engine performance evaluation

The Titan Energy Sentry 5000 Mobile Utility contains an in-line five cylinder John Deere 5030TF270 diesel engine (3.0 L displacement, 3.4 × 4.1 in. bore and stroke), in conjunction with a Katolight D50FPJ4T2 50 kW generator. An external load bank (Liberty LPH65 AC, 75 kW, Avtron Manufacturing, Inc., Cleveland OH, USA) was coupled to the genset (generator engine set) to control loading of the engine. The fuel injection system in the John Deere 5030TF270 engine can be characterized at a high level as Pump-Line-Nozzle, and more specifically as a "mechanically governed unit pump system" manufactured by Stanadyne Corporation, that is calibrated for Diesel #2 fuel. This was not altered throughout the testing. The engine is turbocharged with a compression ratio of 19.1:1 [23] and no exhaust gas recirculation (EGR). The exhaust system has no after-treatment devices but was modified to incorporate an in-line Telonic Berkeley (M107, Laguna Beach CA, USA) smoke meter chamber for opacity and smoke density measurements. The engine was instrumented with two turbine type flow meters (Flow Technology, Tempe, AZ, USA) in both supply and return fuel lines. These flow meters were calibrated for each fuel type depending on the viscosity values of the fuel being run. The integrated resistive thermal detectors (RTDs) in the flow meters measure the temperatures at the supply and return fuel lines. Using these two flow meters and with the help of temperature–density correlation, the BSFCs were calculated. In addition, two pressure gauges, each at the supply and return fuel lines and a differential pressure gauge across the fuel filter were installed. The exhaust gas temperature was also recorded using an Omega K type thermocouple.

Fuel was supplied to the engine by a tank with about a two hundred gallon capacity. A hand pump was used to drain fuel in between fuel changes. For every fuel change, the fuel lines were cleaned, and the engine was left to run for at least 2 h to stabilize on the new conditions.

The Katolight generator outputs an electrical load in three phases at 208 volts and 60 Hz utilizing a permanent magnet brushless rotating field. The generator is linked up directly to the engine from the flywheel of the engine to the clutch of the generator, and the frequency of the generator (60 kHz) was kept constant by the constant 1800 RPM of the engine.

The load bank electronically loads the genset with a manually selected stepped load. The load is dissipated as heat through an internal heat exchanger that has a controlled upper set point to prevent overheats of the load bank. Generator power, frequency, voltage, and current can be obtained using the data display meter of the load bank.

Table 1
Properties of ULSD and S-8.

Property	ASTM method	ULSD	S-8
Lubricity (μm)	D6079	336.00	353.00
Cetane number	D6890	42.30	56.10
Cloud point (°C)	D2500	−22.00	<−33.00
Pour point (°C)	D97	<−33.00	<−33.00
Carbon residue	D4530	0.00	0.00
LHV (kJ/g)	D240	41.50	43.78
Flash point (°C)	D93	53.50	40.50
Viscosity (mm /s)	D445	2.96	1.29
Distillation temperature (°C) (90% Recovered)	D86	304.00	248.00
Density (kg/L)	N/A	0.85	0.74

2.3. Data acquisition and engine performance parameters

Data was procured using two methods. Data was recorded manually at certain time intervals from the analog display panel used to monitor the genset. Oil pressure, engine coolant temperature, and engine runtime were all monitored utilizing this method. The second method utilized a Labview controller with data being input from two flow meters, two temperature probes (RTDs), pressure gauges for the fuel input and return lines, a differential pressure gauge across the fuel filter, and a temperature probe to monitor the exhaust temperature. The voltage, power, amperage, and frequency data of the generator measured from the load bank were also recorded using COM-EXT software with a data acquisition frequency of 10 Hz. The Labview data were collected at every 5 s and 100 data points were averaged. The BSFC in kg/kW-h and brake thermal efficiency (BTE) were calculated to evaluate the engine performance during the 240 h of engine testing with each fuel.

2.4. Testing protocol

Both fuels were tested using the same testing matrix: an endurance test of total 240 h, about 8 h per day at 60% of full capacity or 30 kW load; and a transient load testing of 20, 30, and 40 kW for 2 h runtime were performed. A 240 h endurance test was conducted under the military guidelines of MIL-STD-705C, Method 690.1d [24]. The startup procedure calls for the engine to be started with no load and run for an engine temperature and generator voltage stabilization period of 5 min. After the 5 min, a load of 30 kW (60%) is applied and run for 8 h. The time taken to reach the rated voltage and frequency after starting the generator is then recorded. The shutdown procedure calls for the 30 kW load to be