Overview of Necessary Modifications for Commercial Diesel Engines in Military Vehicles

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ABSTRACT

Over the past fifteen years, the United States Environmental Protection Agency (EPA) has greatly restricted emission standards significantly impacting diesel engine and exhaust system technologies. These commercial off-the-shelf (COTS) engines represent the most modern innovations available to the Army for powering its ground vehicles. Although progress has made in reducing fuel consumption, increasing power, and restricting emissions, some of these modifications are not as effective or not compatible with Jet Propellant type 8 (JP-8), the military's fuel. This requires COTS engines to undergo optimization and calibration to achieve maximum performance. In this paper, a summary is given of some issues addressed in this process.

OPTIMIZATION AND CALIBRATION

FUEL PROPERTIES

In the late 1980s, JP-8 was chosen under the single-fuel concept (SFC) to replace diesel fuel type 2 (DF2) [1]. This was done to address fuel waxing in DF2 under cold weather conditions. In addition, other benefits include improved logistics in managing a single fuel and increased longevity during storage [1].

The fuel quality of both JP-8 and DF2 are rated by their cetane number (CN). CN represents the propensity of which autoignition occurs [2]. The time between the start of injection (SOI) and autoignition is known as the ignition delay. Increasing the duration of ignition delay can have detrimental effects on torque and horsepower. This is usually because peak cylinder pressures and temperatures have occurred after the piston has already reached top dead center (TDC) causing less work to be extracted during the power stroke. Although combustion phasing can be adjusted to account for changes in ignition delay, this calibration requires reprogramming of the engine control module (ECM). Therefore, it is necessary to have consistent CN values. The CN for fuel is not an intrinsic property, but varies with the level of fuel refinement. Preferred values for CN reside in the mid to upper forties. Fluctuations in JP-8's CN can vary from 30-54 based on Continental United State (CONUS) and Outside the Continental United States (OCONUS) procurement data [3]. This degree of variance is undesirable for optimum performance.

The sulfur content of JP-8 varies widely in comparison to DF2. In 2010, the EPA mandated all highway diesel fuel must have sulfur content of 15 ppm or less [4]. According to MIL–DTL–83133E, the military specification for JP-8, sulfur can be as high as 3000 ppm. The EPA restricted sulfur because of its poisoning effect on diesel oxidation catalyst (DOC) and selective catalyst reduction (SCR) systems [5, 13]. Once sulfur is introduced into these devices, it reduces their effectiveness to control emissions. Because of this, most aftertreatment systems are not compatible with JP-8. Another reason high sulfur is undesirable resides in its tendency to form corrosive sulfur oxide species after combustion. Engines using cooled exhaust gas recirculation (EGR) are particularly susceptible to corrosion.

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14. ABSTRACT
Over the past fifteen years, the United States Environmental Protection Agency (EPA) has greatly restricted emission standards significantly impacting diesel engine and exhaust system technologies. These commercial off-the-shelf (COTS) engines represent the most modern innovations available to the Army for powering its ground vehicles. Although progress has made in reducing fuel consumption, increasing power, and restricting emissions, some of these modifications are not as effective or not compatible with Jet Propellant type 8 (JP-8), the military?s fuel. This requires COTS engines to undergo optimization and calibration to achieve maximum performance. In this paper, a summary is given of some issues addressed in this process.

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A factor in a fuel's exhaust emissions is its aromatic content. Specifically, the presence of polycyclic aromatic hydrocarbons (PAHs) contributes to NO_x and particulate matter (PM) emissions [2]. Typical values for JP-8 aromatic content are about 15% based on volume compared to 30% for DF2 [2-3, 6].

The heating value of a fuel is a measure of the heat of reaction at constant pressure or at constant volume for complete combustion per unit mass or volume [7]. In essence, the higher the heating value the more energy a fuel possesses. JP-8 has a lower heating value per unit volume than DF2, but a higher heating value per unit mass. Typical values on a mass basis for JP-8 are 43.4 MJ/kg and for DF2, 42.5 MJ/kg [8]. On a volume basis, heating values for JP-8 are 34.5 MJ/L and 36.2 MJ/L for DF2 [8].

Under two different methods of testing, the lubricity of JP-8 is less than that of DF2. Both the high-frequency reciprocating rig (HFRR) and ball-on-cylinder lubricity evaluator (BOCLE) determine lubricity by measuring the length of the wear scar incurred on a steel ball bearing [9-10]. Under the HFRR test, DF2 produced a wear scar of 0.444 mm and JP-8 was 0.675 mm. On the BOCLE test, DF2 measured 0.46 mm and JP-8 0.69 mm [8].

FUEL INJECTION SYSTEM

Although many diesel fuel injection system designs exist, high pressure common rail (HPCR) is a favored choice in COTS engines. HPCR usually offers fuel pressures of 2000 bar and above. These injection systems are sensitive to the change of fuel from DF2 to JP-8. As mentioned above, the energy density of JP-8 is lower than DF2 on a volume basis. Since fuel injection systems meter fuel on a volume basis, there is less input energy to the cylinder resulting in lower power. However, by modifying the software in the engine control unit, the duration of the injection pulse width can be lengthened to compensate for this [11].

Another concern in switching to JP-8 lies in its lower lubricity. In HPCR fuel systems, the fuel injection pump and internal components are lubricated by the fuel itself. Lowering the lubricity of the fuel has potential to increase wear and degrade performance. However, in a study by Ford Motor Company using JP-8, no significant wear was discovered after a 210-hr Tactical Wheeled Vehicle Cycle [8].

Due to high sulfur content that can be found in JP-8, problems with the fuel injectors can occur. Over time, dense sulfur particles can collect near the ports on the fuel injector tip [12]. These particles can deflect or even obstruct the spray pattern of the fuel [12]. Significant power degradation can result from deviations of the spray pattern from the original design.

EGR SYSTEM

In order to reduce engine emissions, EGR is standard equipment on COTS engines. EGR reduces engine emissions by channeling a percentage of the exhaust gases back into the air intake system. This reduces high cylinder temperatures which in turn reduces NO_x emissions [13]. In cylinder temperatures can be further reduced by using a heat exchanger to cool the exhaust gases flowing through the EGR system. High sulfur fuel causes corrosion to the EGR cooler by depositing sulfur particulates [2]. These sulfur deposits can serve as a bed for sulfuric acid forming and absorption [2]. Since the Army's non-tactical ground vehicles are only bound to the 1998 EPA emissions standards, EGR is not necessary to meet engine emission regulations. The EGR system can be eliminated by removing the EGR valve, EGR plumbing, and EGR cooler and installing blocking plates to cover their ports [13].

TURBOCHARGING

If the EGR system is removed from a COTS engine, changes to the turbocharger mostly likely will need to be made. Typically, EGR makes up about 10-20% of the intake mixture.

After the EGR system is removed, the compressor needs to compensate by drawing more fresh air. For optimum power and response, the turbocharger needs to be resized to handle the new engine breathing requirements [13-14].

EXHAUST EMISSIONS

An advantage that JP-8 has over DF2 is lower engine emissions output. Three pollutants of main concern are NO_x, soot, and particulate matter (PM). As was already mentioned, JP-8 has a lower aromatic content than DF2. Because of this, lower peak cylinder temperatures result [11]. Lower temperatures reduce NO_x emissions. Because JP-8 has a higher volatility then DF2, it possesses a higher degree of fuel-air mixing before being burned [11]. This prevents oxygen rich pockets from forming which also reduces NO_x [11].

Better fuel-air mixing in JP-8 also contributes to lower soot emissions. Soot results from fuel rich pockets during combustion [11]. Lower soot emission is very important because the black plume it produces stands as a visual signature.

Lastly, better fuel-air mixing due to JP-8's increase volatility reduces PM [11]. Historically, there has been a trade-off between NO_x and PM. With DF2, it is hard to reduce one without increasing the other. However, with JP-8 lower of levels of both NO_x and PM are possible.

CONCLUSION

Many modifications are necessary for COTS engines to achieve top performance on JP-8. The reason for this primarily resides in the difference in fuel properties of JP-8 versus DF2. Both hardware and software changes are required for a complete conversion for military application. Once completed, engines are ready JP-8 usage while retaining the majority of the technological advancements that industry has to offer.

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