STATEMENT OF WORK #1

Engine Durability Study

Background

At both the federal and state levels, there has recently been legislation that mandates and/or encourages the use of alternative fuels, including ethanol. The Energy Independence and Security Act, passed in December 2007, mandates 35 billion ethanol equivalent gallons of biofuel usage by 2022. On-going and planned increases in ethanol production have made it likely that the supply of ethanol will exceed that required for nationwide 10% blending with gasoline. Although further production increases could expand the pool of E85 available, slow progress on installing E85 infrastructure has produced concerns that an ethanol "glut" could develop. In Minnesota, a law requires the use of ethanol blends up to E20, a blend of gasoline with 20% denatured ethanol, replacing gasoline, by 2013, contingent on EPA granting a waiver for ethanol blends over 10 volume percent. The former assistant secretary of Energy for renewable energy called E15 and E20 and "alternative approach to balance fuel production and use"[1]. Before E20 can be introduced for use by the existing fleet of vehicles its long term effects on engine durability must be investigated.

There are a number of potential areas where E20 could produce abnormal wear in an engine. There are two effects that need to be investigated; the first is the direct effect of E20 on the engine, the second is secondary effects on the engine due to E20's effects on the engine control system.

In investigating the direct effects of E20 on the engine the effects of E85 can be taken as a guide. A common improvement to gasoline engines to enable them to work with E85 is to upgrade the valve seat material. Valve seat wear, whether localized or general can lead to a variety of problems including valve leakage, valve burning, compression loss, misfire, power loss and catalyst damage. Another area of investigation for E85 is bore and ring wear. This can be caused by the increased solvency of ethanol washing the lubricant from the bore. This is exacerbated by the increased fuel volume required and the increased heat of vaporization of the fuel. This increases the likelihood of fuel passing through the open intake port and impinging on the bore wall. The result of bore and ring wear is increased blow-by, oil consumption, and compression and power loss. High blow-by can overwhelm the oil separation system allowing engine oil into the combustion chamber and its sulfur and phosphorus constituents onto the catalyst thus poisoning it and reducing its efficiency.

Although E20 should not be as severe as E85 for inducing wear there are many engines design features that would see increases sensitivity to its effects.

---

[1] "Congressional Testimony of Alexander Karsner, Assistant Secretary for Energy Efficiency and Renewable Energy, Before the Committee on Energy and Natural Resources, United States Senate. Topic: Improving the Nation's Renewable Fuels Infrastructure", http://www1.eere.energy.gov/office_eere/congressional_test_073107_senate.html

These are:

- Use of mechanical valvetrains that do not use hydraulic lash adjusters; these designs have the smallest ability to accommodate valve and valve seat wear.
- Use of hydraulic lash adjusters with a very small allowable travel; these designs have the second smallest ability to accommodate valve and valve seat wear and are typically found in overhead cam designs.
- The use of non-premium valve seat materials that were not designed for ethanol fuels; these should show the most rapid wear rate regardless of the fuel or valvetrain used.
- Valvetrains that need a high engine speed to initiate valve rotation; these designs would tend to localize wear and accelerate poor sealing and compression loss.
- Engines with injector positioning that injects fuel through an open port
- Engines with calibrations that inject fuel onto an open valve.
- Engines with oil separators that do not have a large excess flow capacity

The use of mid-level ethanol blends such as E20 results in a lean combustion mixture that will cause elevated exhaust temperature and thus oxygen sensor and catalyst temperatures. Modern closed loop engine control systems will prevent this from occurring by adjusting the fuel flow to ensure stoichiometric operation. However, most vehicles use switching type oxygen sensors and are in open loop control during periods of commanded enrichment such as heavy throttle operation. This is when the combustion mixture is enriched to cool the exhaust gases and thus the pistons, valves, exhaust manifold, catalyst and oxygen sensor. This is called “piston protection mode” or “catalyst protection mode”.

As was seen in Australia[2], some vehicles do not use the learned fuel composition when calculating the amount of fuel required to operate in piston or catalyst protection mode. When the fuel contains ethanol, the use of a baseline (unlearned) fuel trim results in open loop operation that is leaner than anticipated. This enleanment is proportional to the fuel’s ethanol content so ethanol blends greater than E10 are more likely to have exhaust gas temperatures that are higher than anticipated and could cause damage. Sixty percent of the vehicles tested in Australia did not use an adapted fuel trim (one that compensated for the ethanol) during open loop control. Further, almost 50% of the late model US market vehicles tested so far by the US Department of Energy also have control systems that do not compensate for ethanol in the fuel during open loop operation.

Vehicles that are sensitive to this behavior are those whose control systems do not use adapted fuel trims in open loop control. Some of these vehicles are being identified by the DOE E20 test program and also by CRC program E-87-1.

In addition, vehicles that are sensitive will be those that spend more time in heavy throttle regimes. These include vehicles with low power to weight ratios and those that are likely to be used for towing, particularly those with optional towing packages.

---

[2] Orbital Engine Company, “Market Barriers to the Uptake of Biofuels Study Testing Gasoline Containing 20% Ethanol (E20),” Phase 2B Final Report to the Department of the Environment and Heritage, May 2004.

TEST PROGRAM

Objectives

The objectives of the test program are to determine engine durability effect of E20 on a group of engines from vehicles that are deemed to be sensitive to the effects of E20 as described above. The vehicles should be selected from among those that are more likely to exhibit some of the issues with E20. This group shall be determined cooperatively by CRC member companies and OEMs in consultation with any outside organization that participates in funding the study.

Approach

The approach will consist of laboratory testing 14 engines using an engine durability cycle adapted for use on whole vehicles. The engines will be tested using whole vehicles. The amount of OEM support and lab labor required to remove engines, mount them on dynamometers and ensure that the production calibrations are operating correctly is expected to be prohibitive. The vehicles procured shall be well-maintained in proper operating condition. Measurements of the valvetrain clearances and datums will be made prior to test but no disassembly beyond removal of the valve covers is envisioned unless, after testing is complete, some engines have experience problems and further diagnosis is required.

It is envisioned that 2 vehicles of each type will be tested initially on E20 fuel and on E0 making 4 in all. In the event that a failure is observed that are not observed on E0 an additional pair shall be tested on E15 and, if failures recur, on E10.

The test procedure calls for accelerated testing to reduce test time and show failures. Accelerated testing is standard practice in the automotive industry. The severity helps reduce test time and compensate for the inherently small sample size associated with these tests. Extended light load operation is an option but this will greatly increase the duration and cost of the test program. Given the emphasis by some on rapid implementation of mid-level ethanol blends accelerated testing is felt to be the best approach. This cycle was developed based on experience with fuel induced valve seat recession and control system affects on engine durability.

Test Program

The objective of the study is to investigate the effects of ethanol blended fuel on engine durability, particularly wear of valves, valve seats and bores and any damage induced by elevated exhaust gas temperatures.

Fuels, Lubricants and Maintenance

Fuels will be federal certification fuel or some other consistent fuel blended by volume with ethanol to the correct level, 19-21%, 14-16%, 9-11%, or 0%.

Standard manufacturer-recommended viscosity grade and API Engine Oil Classification lubricant will be used for all tests and should come from one brand. It is expected that fresh oil will be put in the crankcase at the start of testing and will be changed in accordance with the owner's manual recommendations. Other maintenance shall be performed in accordance to manufacturers' recommendations. Vehicles shall be selected so that no valve adjustments are required during the test cycle.

Vehicles

As indicated before, this program is designed to test engines from vehicles that are likely to be sensitive to fuels with ethanol concentrations greater than 10%. The on-road vehicle population consists of hundreds of different makes and models, each with different fuel and emissions control systems. Ideally, a test program such as this should include over 100 representative vehicles of each of these different makes and models. Because of limited resources, this is not possible for this program. Instead, a sampling of 14 vehicles types is proposed.

In order to reduce the vehicle fleet size from over 100 to 14, the auto industry will propose 7 non-FFV vehicles types for the test fleet based on the following guidelines:

- Vehicles built since 2000 that do not use adapted fuel trim in open loop control.
- Vehicles built since 2000 that use adapted fuel trim in open loop control.
- Vehicles built since 2000 that use mechanical valvetrains.
- Vehicles built since 2000 that use hydraulically adjusted valvetrains.
- Vehicles built since 2000 that use economical valve seat materials.
- Vehicles built since 2000 that have tow packages.

The remaining 7 should be selected to give a balanced fleet for both this test program and any other test programs that will use this fleet to evaluate a different failure mode.

The contractor will acquire the identified 56 vehicles for initial testing. Before acquiring the vehicles, the contractor should inspect, where possible, to insure valve clearances and cylinder compressions are within design guidelines. The contractor shall inspect the vehicles and replace tires and brakes as needed at the beginning of the test and as needed during the test. The test vehicle mileage should be 8,000 to 12,000 times the vehicle age in years.

Test Procedure

The engines shall be examined and measured prior to test to determine each engine's baseline condition. This condition shall be compared with design tolerances for new engines and also end of test limits. Engines must be within the better 50% of specification limits described in the vehicles' shop manuals to be included in the evaluation.

Measurements shall include:

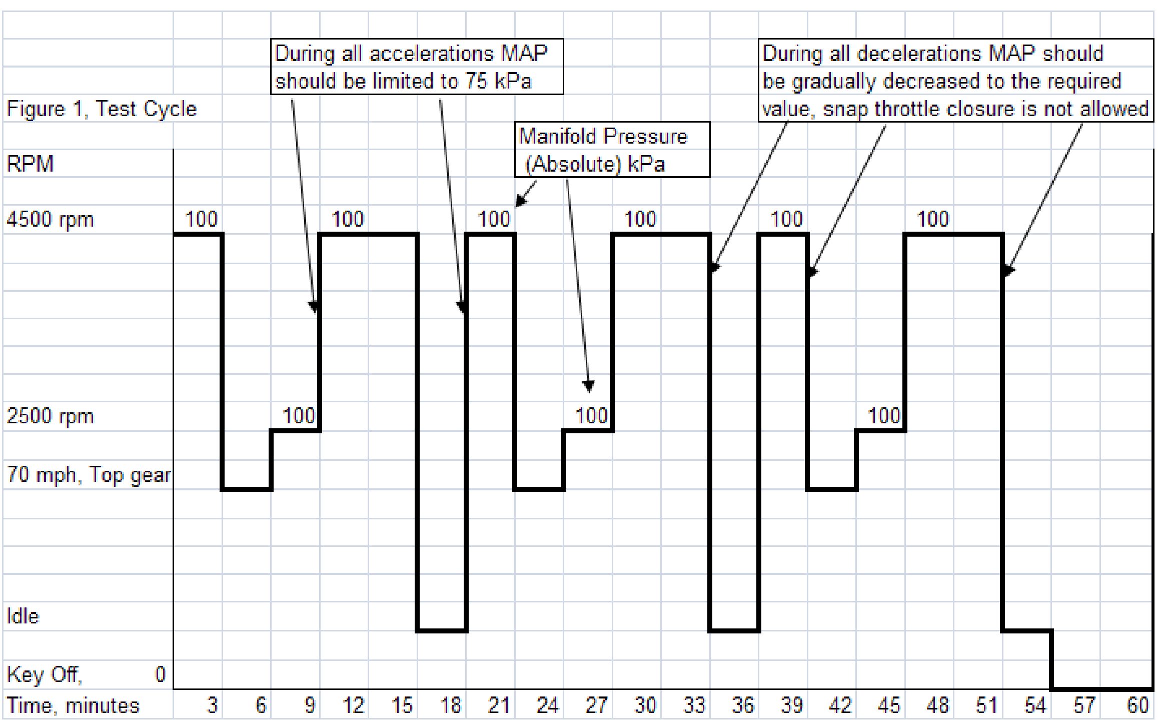
- Compression loss and leakdown
- Valve clearances

- Valve stem location relative to datum on hydraulically operated systems (tip heights)
- Emissions and fuel economy using FTP75 and US06
-

Test Cycle

The vehicles shall be tested following the test cycle shown in figure 1. Four vehicles shall be tested on E20 for 500 cycles (500 hours) each. If the vehicles are run on a chassis dynamometer external heat exchangers will be required to provide adequate engine cooling. This exchanger shall be sized and controlled to supply coolant at 90C for the duration of the test. A valve or other orifice shall be introduced into the coolant loop to simulate the pressure drop through the stock vehicle radiator. The engine coolant pump shall be used to drive coolant through the engine. If the vehicle is run on the track a towed dynamometer shall be used and the air conditioning shall be run at driver discretion. If not already equipped, all vehicles to be fitted with an engine oil cooling system to keep oil temperatures below 140°C during peak power full load operation. The cooler will be a spin-on Modine-type at the oil filter in order to minimize impact on engine lubrication system volume and operation. For tests conducted on a track, the coolant lines to the oil cooler will be plumbed into the passenger compartment heater circuit (to minimize impact on engine cooling).

Vehicles shall be tested at 80% of GVW or 80% GVW plus 80% of allowable trailer weight for those that allow trailers.



<u>Measurements during test</u>

Throttle required to meet 70 mph in top gear.

ALDL outputs.
Diagnostic trouble codes
Exhaust gas temperature and fuel/air ratio
Oil analysis, ASTM D445, ASTM D664, ASTM D5185 (kinematic viscosity, TAN, metals by ICP)

<u>End of test measurements</u>
Compression and compression leakdown check
Valve clearances or valve stem location relative to datum. (tip heights)
Emissions and fuel economy using FTP75 and US06
Diagnostic trouble codes
Oil analysis, ASTM D445, ASTM D664, ASTM D5185

Vehicles must remain within the specification limits described in the vehicles' shop manuals. For compression leak down 10% loss or less is required. Fuel economy must be within test variation of original. Emissions must remain compliant. No diagnostic trouble codes that could be related to fuel.

Data to Record from ECM on Data Link Connector

1. RPM - engine speed
2. MAP - manifold pressure
3. Mass Air flow
4. Spark Advance
5. Calculated Load variable
6. Coolant Temp
7. Vehicle speed
8. Fuel Control System Status
9. Fuel Trim
10. Intake Air Temp
11. Oxygen sensor output
12. Air/Fuel Ratio sensor output.
13. Commanded Equivalence ratio/Air Fuel Ratio
14. Catalyst Temperature (directly measured or estimated)

Project Schedule
The project technical effort including preparation of the draft final report should be completed within XX months. An additional two months will be allowed for review, comments, and revisions to develop an approved final product. Periodic conference calls with the sponsors, especially at the beginning of the project, are required.

Deliverables
The project deliverables will include brief monthly progress reports, a draft final report and, possibly database, and the final report and database. Before work commences, the contractor must identify the specific approach to be used to meet the project objectives

and submit a workplan. The contractor shall include in the proposal a plan to acquire data during the test that will capture relevant events without producing excessive data. The data deliverables shall include fuel analyses results.

For those engines exhibiting problems during the testing: misfire, low compression, high leakdown, loss of power, DTCs, an engine teardown inspection will be performed, if needed, to determine the cause of the malfunction.

Quality Assurance and Quality Control

The individual responsible for quality assurance should be identified in the proposal statement on quality assurance and quality control.