MINNESOTA DEPARTMENT OF AGRICULTURE
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Minnesota Pollution Control Agency

E20: The Feasibility of 20 Percent Ethanol Blends by Volume as a Motor Fuel

Executive Summary
Results of Materials Compatibility and Drivability Testing

Introduction

The State of Minnesota and the Renewable Fuels Association (RFA) recently completed a yearlong scoping study on the effect and performance of gasoline blended fuels containing 20 percent volume fuel ethanol on today's motor vehicle engines and engine components. The study was in response to legislation passed by the State of Minnesota requiring that the state's total consumption of fuel include at least 20 percent ethanol or requiring the use of 20 percent volume ethanol blended gasoline.

In order to move forward with 20 percent ethanol blends, a variety of tests must be conducted. This initial scoping study was comprised of three main areas of investigation: materials compatibility, drivability, and emissions. The emission testing is still ongoing and the results will be released as soon as the comprehensive testing is complete. The following is an executive summary of the final report on drivability and materials compatibility.

Key Findings

- The vehicle fuel system materials study used both hydrocarbon-only fuel (gasoline) and 10 percent ethanol blended fuel to compare to 20 percent ethanol blended fuels. The year-long project culminated in four (4) separate and distinct material compatibility documents which conclude that **the effects of 20 percent ethanol blended fuels do not present problems for current automotive or fuel dispensing equipment.**
- The drivability study showed that **E20 provided similar power and performance to 10 percent ethanol blended fuel throughout the entire calendar year**, which included a broad range of ambient weather conditions.
- Based on the materials compatibility and drivability testing results of this scoping report, there are no issues that would prevent moving forward with the comprehensive testing required to certify E20 as a federally-approved motor fuel.
- Final recommendations on how to proceed with respect to E20 must be withheld until the ongoing emissions testing is complete.

Research Sponsors

This research was a cooperative effort by the State of Minnesota, The Minnesota Corn Growers, The Council of Great Lakes Governors, Minnesota State University Mankato, University of Minnesota, and the Renewable Fuels Association with input from fuel refiners, automakers and small engine manufactures

Background

There is very limited information available on ethanol blended fuels outside of the normal blending strategies such as 10 percent and 85 percent volume. An evaluation of 20 percent volume ethanol blended fuels for spark ignition engines used in Brazil has been conducted by nearly every engine manufacturer, however this information is deemed proprietary. One public evaluation of 20 percent ethanol blended fuels was completed by the Orbital Engine Company in Australia in 2002 and 2003. While this evaluation had no unexpected results, it did however lack a complete evaluation of the fuel comparison to 10 percent ethanol blended fuels. In an effort to increase the amount of research and publicly available literature on higher ethanol blends, the State of Minnesota and the Renewable Fuels Association developed and conducted a technical assessment of 20 percent volume ethanol blended gasoline, adhering strictly to nationally recognized standards.

Methodology

The research projects completed by the State of Minnesota adhered to nationally recognized standards, namely SAE, ASTM, and other technically reputable standard organizations, as recommended by both automotive and fuel industry experts. A comprehensive list of automotive, small engine, and marine engine components was assembled and evaluated against automotive components determined as acceptable for use in high ethanol blended fuel vehicles and flex fuel vehicles. Materials and components utilized in Flex Fuel Vehicles, able to use up to 85 percent volume ethanol, are accepted as already proven compatible for fuels containing >10 percent volume ethanol. The remaining materials and components were then evaluated in various high stress scenarios against 10 percent volume ethanol blended fuels as the benchmark. Ten percent volume ethanol fuels have been proven compatible through inclusion in the warranty statements of engine manufacturers. Once the materials selections were made, the various evaluations were performed independently. The individual reports provide a detailed listing of the reference methods and evaluations.

An elemental portion of this research was the selection of fuels to be evaluated. If only fuels commonly found in the marketplace were used, least common fuels could precipitate an unknown or unevaluated condition once actually in place for use by the consumer. After careful consideration, project designers and consulted experts determined that SAE J1682, *Gasoline alcohol and diesel fuel surrogates for materials testing,* was the most appropriate fuel composition. The fuels represent both commercially acceptable fuels, but also represent the least desirable fuel properties for compatibility with fuel system components. These fuel mixtures are selected to initiate compatibility interactions and were utilized throughout the various test protocols. The three test fuels included:

- Surrogate gasoline (C) – ASTM fuel C, 50/50 toluene, isooctane mixture (500ml toluene, 500ml iso-octane)
- E10 Fuel [$C(E10)_A$] – 90 percent Fuel C + 10 percent aggressive ethanol(450ml toluene, 450ml iso-octane, 100ml aggressive ethanol)

- E20 Fuel [C(E20)A] – 80 percent Fuel C + 20 percent aggressive ethanol (400ml toluene, 400ml iso-octane, 200ml aggressive ethanol)
- Aggressive Ethanol – synthetic ethanol 816.00g, de-ionized water 8.103g, sodium chloride 0.004g, sulfuric acid 0.021g, glacial acetic acid 0.061g.

Materials Compatibility:

The compatibility study was designed to identify metals, elastomers, plastics and common fuel sending unit and fuel pump combinations currently used in automotive, marine, small engine, and fuel system dispensing equipment. University of Minnesota-Mankato researchers identified the most commonly used materials in the makeup of fuel system components. Materials that are currently used in fuel systems of Flex Fuel Vehicles were accepted as proven compatible and not included in this program.

Metals

The focus of this study was to compare the effects of E20 versus E10 and non-oxygenated gasoline on metal materials found in automotive, marine, and small engine fuel system components. Specifically, metal samples were prepared using SAE and ASTM standards and exposed to blends of non-oxygenated gasoline (Fuel C); a 10 percent blend (Fuel C and 10 percent aggressive ethanol); 20 percent ethanol blend (Fuel C with 20 percent aggressive ethanol) at an elevated temperature of 45 °C for 2016 hours. The fuel was changed in weekly intervals with photo images and mass loss/gain data recorded at the 1st, 3rd, 6th, and 12th week. Incompatibility of the fuel with metals would be evident with both a physical or chemical effect to the component materials such as pitting, surface texture change, discoloration, and loss of mass. Nineteen different metals were evaluated under immersion, vapor/liquid point, and vapor exposure scenarios. Incompatibility was defined as not meeting a greater than 20-year expected useful life. Metals tested included:

- Brass 260
- Brass 360
- Cast Iron
- Copper 110
- 6061 Aluminum
- 3003 Aluminum
- Cast Aluminum Mic 6
- 60/40 Tin/Lead Solder
- 1018 Steel
- 1018 Steel Tin Plated
- 1018 Steel Nickel Plated
- 1018 Steel Zinc Plated
- 1018 Steel Zinc Tri-Chromate Plated (Hexavalent)
- 1018 Steel Zinc Di-Chromate Plated (Hexavalent Free)
- 1018 Steel Zinc-Nickel Plated
- Terne Plate
- Zamak 5
- Magnesium AZ91D
- Lead

All metals exposed to the E20 fuel mixture showed greater discoloration. At the end of 12 weeks, the Zamak metal showed pitting with both the E10 and E20 fuels and Magnesium AZ 91D and Zamak both showed mass loss indicating a measureable corrosion rate. The remainder of the metals losses was minimal under a 20-year lifecycle scenario.

Elastomers (Rubber materials)

The focus of this study was to compare the effects of E20 versus that of E10 and non-oxygenated gasoline on elastomers found in automotive, marine, and small engine fuel system components along with fuel dispensing equipment. The elastomer samples were prepared using SAE and ASTM standards and exposed to blends of Fuel C; Fuel C and 10 percent aggressive ethanol; and Fuel C with 20 percent aggressive ethanol at an elevated temperature of 55 °C for 500 hours. Changes in the following properties were investigated before immersion, after immersion, and after dry-out: appearance, volume, weight, tensile strength, elongation, and hardness. Elastomers tested included:

- Acrylic Rubber (ACM) [Hytemp®]
- Epichlorohydrin Homopolymer (CO)
- Epichlorohydrin Ethylene Oxide Copolymer (ECO)
- Polychloroprene (CR) [Neoprene]
- Nitrile Rubber (NBR) [Buna N] with medium ACN content
- Nitrile Rubber (NBR) [Buna N] with high ACN content
- Nitrile/PVC blend (OZO) [Paracril®]
- Fluoroelastomer (FKM) with dipolymers of VF2/HFP and 65 percent fluorine [Viton® A]

All of the samples showed some degree of swell in the fuels. There was a slight change in the ECO (tensile strength) and FKM (elongation) elastomers which were deemed insignificant. The other elastomers evaluated showed no significant hardness and tensile strength loss post exposure.

Plastics

The goal of this study was to compare the effects of 20 percent ethanol blended fuel (E20) versus that of 10 percent ethanol blended fuel (E10) and gasoline on plastics materials found in automotive and small engine fuel system components. Plastics samples were prepared using SAE and ASTM standards and exposed to various blends of ASTM Fuel C, 10 percent and 20 percent aggressive ethanol at an elevated temperature of 55°C for 3024 hours. The fuel was changed in weekly intervals for the 18 week study. The plastics evaluated include:

- Acrylonitrile butadiene styrene (ABS)
- Polyamide 6 (PA 6), [Nylon 6]
- Polyamide 66 (PA 66) [Nylon 66]
- Polybutylene Terephthalate (PBT)
- Polyethylene Terephthalate (PET)
- Polyetherimide 1010 moldable (PEI)
- Polyurethane 55D-90 Adurameter Hardness (PUR)
- Polyvinyl Chloride flexible version (PVC)

At the end of the 18 weeks of exposure, both the PVC and PUR plastic samples had deteriorated in all three fuel samples to such a degree that impact testing could not be performed. Both PVC and PUR types of materials are not recommended for use with ethanol blended fuels so the results are not entirely unexpected. These failures were not deemed significant as further analysis discovered these plastics are not commonly found in today's automotive fueling systems.

The remaining plastic samples were evaluated using five evaluation techniques: mass loss or gain, volume loss or gain, tensile elongation, impact resistance, and tensile strength. Many of the materials showed discoloration of the fuel in the ethanol blended fuel samples; however, this is not always indicative of incompatibility or reliability.

Fuel Pumps and Sending Units

The goal of this study was to compare the effects of E20 versus E10 and gasoline on automotive fuel pumps and sending units in terms of corrosion and longevity. Only electric automotive fuel pumps and sending units were tested. A 30-day static soak test was conducted on eight fuel pumps and three sending units in three different fuels for a total of 24 fuel pumps and 9 sending units. Pre-immersion and post-immersion performance data were measured and compared. Finally, a 3000 hour endurance test is planned, but only the results of the soak test are reported in this paper. The endurance test data and results will be reported in a subsequent paper. Fuel pumps tested in the program included:

- Volkswagen Passat 93-94 (Part#1H0919051AL)
- Jeep Wrangler 99-00 (Part# 5012952AO)
- Ford truck 90-93 (Part# F8PZ9A213AB)
- GM TBI truck pump 87-92 (Part# 25168719)
- GM PFI early 90's rollervane (Part # 25163468)
- GM Port pump 00-02 (Part# 25345026)
- Toyota Camry LE 02-05 (Part# 232210A030)
- Honda Accord 98-02 (Part# 17040S84A02)

Three sending units were selected based on commonality in design:

- Jeep Wrangler 99-00 (Part# 5012952AO)
- GM Port pump 00-02 (Part# 25345026)
- Honda Accord 98-02 (Part# 17040S84A02)

Although there was some discoloration in the fuel pump soak samples, it was deemed insignificant. All of the fuel pumps passed the flow and pressure tests except one. The GM TBI showed a significant reduction in flow after exposure to the E10 fuel. None of the sending units experienced any significant changes in resistance throughout the study. Overall, E20 was found to have similar affect to E10 on fuel pumps and sending units.

<u>Drivability:</u>

Eighty vehicles, consisting of 40 matched pairs, were selected from the University of Minnesota Twin Cities Fleet Services car pool in order to determine whether E20 can be used effectively in current vehicle technology. The selection of vehicles included a wide cross section of model year 2000 through 2006 Chrysler, Ford, General Motors, and Toyota vehicles; all vehicles were fuel-injected and included hybrid models. The vehicles are part of the University's system of vehicles that include service vans and are used as standard transportation in both city and highway use. Fuel for this study was commercially available non oxygenated gasoline and gasoline upblended to 20 % volume with commercially available fuel grade ethanol.

One vehicle in each pair was fueled with non-oxygenated gasoline while the other vehicle in the pair was fueled with 20 percent ethanol blended gasoline. The vehicles were driven over the course of a year to expose the vehicles and the fuels to weather conditions typical of each of the four seasons. Drivers of the vehicles were trained to complete incidents logs to track issues associated with the performance of the vehicles. Blind refueling cards were supplied for each individual vehicle in order to prevent bias toward either fuel. Experts in vehicle drivability performance were brought to Minnesota once each season to provide and assess additional fuel performance data.

While there were two vehicle issues raised during the fleet testing that were not fuel related, the 20 percent ethanol blended fuel proved effective at both powering the vehicles successfully and was also non-distinguishable in performance by either the University drivers or the professionally trained drivers.

Electronic copies of the drivability and materials compatibility reports may be found at the Minnesota Department of Agriculture website at www.mda.state.mn.us.