An Examination of Fuel Pumps and Sending Units During a 4000 Hour Endurance Test in E20

Gary Mead, Bruce Jones, Paul Steevens, Nathan Hanson and Joe Harrenstein
Minnesota Center for Automotive Research
at Minnesota State University, Mankato

ABSTRACT

The focus of this study was to compare the effects of E20 versus E10 and gasoline on automotive fuel pumps and sending units. Only electric automotive fuel pumps and sending units were tested. A 4000-hour dynamic endurance test was conducted on eight fuel pump models and three sending unit models in three different fuels for a total of 24 fuel pumps and 9 sending units. Performance data was collected before the study started and then every 500 hours until the study's conclusion. At the conclusion of the study the pumps were disassembled and inspected for wear.

INTRODUCTION

Minnesota Governor Tim Pawlenty signed a bill on May 10, 2005 that requires by volume 20% of the fuel sold in the State of Minnesota to be ethanol. Ethanol is considered a renewable fuel and is also classified as an alternative fuel since it can be used as a substitute for gasoline. Currently, gasoline sold in Minnesota contains 10% ethanol (E10) by volume. The 2005 bill allows for two methods of achieving the 20% goal.

First, if by December 31, 2010 the volume of ethanol sold through the combination of E10 and E85 reaches 20% of the total gasoline sold in the State, then the goal will be met and there will not be any changes in the fuel sold. If the combination of the two fuels' ethanol content does not reach at least 20% of the total fuel sold, then by August 30, 2013 the ethanol content of gasoline will be increased from 10% to 20% by volume (Eisenthal, 2005).

Before this mandate can be implemented, extensive research must be conducted to ensure compatibility of fuel systems operating on E20 in automobiles, small engines, and marine applications. This paper represents one in a series of papers that focus on the effects of 20% ethanol-blended fuel (E20) on fuel system components.

The study consisted of running fuel pumps and sending units for a period of 4000 hours in gasoline, E10, and E20. The test procedures were derived from SAE Standard J1537 *Validation Testing of Electric Fuel Pumps for Gasoline Fuel Injection Systems* (SAE, 1990).

TESTING

The E20 fuel pump study was intended to test the effects of a 20% ethanol mixture with gasoline on fuel pumps and sending units. Gasoline and E10 were included in the study as a reference to identify what effects two accepted fuels would have on the pumps and sending units. The inclusion of E10 was significant to this study because ethanol and gasoline often cause different changes to materials. E10 has been used for more than 10 years in all Minnesota gasoline and in many other parts of the United States without causing problems. Therefore, if E20 does not cause any more significant changes than E10, it would be considered acceptable.

FUEL PUMPS

Eight different models of fuel pumps were selected for this study. Three of each type, one for each test fuel, were used for a total of 24 pumps. Pumps were selected to represent a variety of manufacturers, model years, high volume vehicles, and three common pump designs: rollervane, turbine, and gear rotor. The fuel pumps tested are listed below.

- 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)

SENDING UNITS

Three different manufacturers' fuel level sending units were selected for the testing. One of each of the three types was tested in each of the three test fuels for a total of nine sending units. Fewer sending units were tested than pumps due to the similarity in the silver alloy resistive contact strips. The sending units used in the study are listed below.

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

PREVIOUS TESTS

All 24 fuel pumps and 9 sending units used in the endurance study had been previously used in a static fuel study at Minnesota State University, Mankato. The static study consisted of soaking the fuel pumps for 30 days in three fuels: ASTM Fuel C, E10, and E20. Performance measurements of flow, amp draw, pressure, and voltage were recorded before and after the soak. One pump that was soaked in E10 experienced a loss in performance. For more details see *The Effects of E20 on Automotive Fuel Pumps and Sending Units* (2008), available from Minnesota Department of Agriculture's Website.

TEST FUELS

Gasoline composition varies from batch to batch, seasonally, and regionally throughout the United States. Because of the variation in gasoline composition, three standard reference fuels: Tier II, Tier $II(E10)_A$, and Tier $II(E20)_A$ were used for the testing to represent gasoline, E10, and E20, respectively. The composition of these fuels came from SAE Standard J1681 *Gasoline, Alcohol, and Diesel Fuel Surrogates for Materials Testing* (SAE, 2000). The use of standard reference fuels ensured consistent and repeatable results. The three fuels were splash blended out of two main components: Tier II and synthetic ethanol. Tier II is the standard reference fuel used for emissions and fuel economy testing in the United States. Because this fuel is manufactured to a tight set of specifications, it was chosen to represent gasoline for this study. Synthetic ethanol was used because of its purity and lack of water. This allows impurities such as water, acids, and salt to be added in specific quantities to turn synthetic ethanol into aggressive ethanol. Aggressive ethanol is a worst-case-scenario fuel that would still be acceptable under ASTM D4806 *Standard Specification for Denatured Fuel Ethanol for Blending with Gasoline for Use as Automotive Spark-Ignition Engine Fuel* (ASTM, 2006). All components were weighed and splash blended to ensure fuel composition accuracy. The compositions of three test fuels used were as listed below.

Gasoline - Tier II

E10 fuel [Tier $II(E10)_A$] - 90% Tier II + 10% aggressive ethanol (900 ml Tier II, 100 ml aggressive ethanol)

E20 fuel [Tier $II(E20)_A$] - 80% Tier II + 20% aggressive ethanol (800 ml Tier II, 200 ml aggressive ethanol)

Aggressive ethanol consists of synthetic ethanol 816.00 g, de-ionized water 8.103 g, sodium chloride 0.004 g, sulfuric acid 0.021 g, and glacial acetic acid 0.061 g (SAE J1681 Appendix E.1.2). These reference fuels will be referred to as gasoline, E10, and E20 throughout the remainder of this paper.

MEASUREMENT AND DATA ACQUISITION

A test bench to operate and measure the pumps was built using the specifications called out in SAE J1537. The test bench has an adjustable flow control valve to allow the pressure to be regulated. It also has a variable power supply to allow the pumps to be tested from 8 to 18 volts. See Appendix 1 for a detailed diagram of the test bench. The bench also allowed voltage, amperage, fuel flow, and pressure to be measured and recorded. National Instruments NI USB-6009 was used for the data acquisition and National Instruments LabVIEW software was used to view and record the data. See Appendix 2 for the measurement instrumentation used and pictures of the test bench.

ENDURANCE TEST FIXTURE

A test fixture to operate the pumps and sending units for 4000 hours was constructed. This fixture allowed the pumps to be operated at a specific pressure and to be cycled on and off. It also allowed the sending units to be cycled through their sweeps. The test fixture consisted of three 55-gallon, high density polyethylene (HDPE) drums with removable lids to facilitate removal of the pumps for measurement along with fuel changes (see Figure 1). One drum was used per test fuel. Inside each drum was an HDPE disc, which supported eight pumps, the sending unit cycling fixture, and the appropriate wiring, tubes, and hoses (see Figure 2). All metal used inside the drums was stainless steel so that it would not interact with the fuel. Only SAE J30-R10 submersible fuel hose was used to resist attack from the fuels, temperature, and pressure. All pumps were kept completely submerged in their normal application orientation throughout the testing. HDPE connectors were used with the wiring and as a conduit into and out of the drums. The conduits were sealed with Permatex MotoSeal®, which was capable of resisting continuous exposure to fuel. The pump pressure was regulated to the center of the manufacturer's recommended range based on the pump application. The pressure was controlled via stainless steel ball valves. The on and off switching of the pumps was accomplished via timers, which were interfaced into the power supplies.

Figure 1. Endurance test barrels

The sending unit cycling fixture was contained in the center of the drum. The cycling fixture consisted of a 5-gallon HDPE bucket with a float valve system (see Figure 2). This system allowed the bucket to be filled and emptied every 2.5 minutes to cycle the sending units through their sweeps. This also allowed the sending units to operate in both a submerged and unsubmerged state. All sending units were supplied 5 volts throughout the testing.

Figure 2. Fuel pumps and sending unit cycling fixture

FUEL PUMP ENDURANCE TEST

The fuel pump endurance test was designed to validate the usable service life of the pump while operating in a specific fuel. This test was performed to address problems such as corrosion on armatures or pumping mechanisms, corrosion of electrical terminals, and swelling of internal components such as turbines or housings. It was also performed to check for mechanical wear. Problems such as these could lead to reduced pump output, reduced pump life, hard starting, or no start conditions. The procedure for the endurance test was predominantly derived from SAE standard J1537 and was peer reviewed by a group of fuel system experts representing automobile and fuel system component manufacturers. The test procedure deviated in several areas from SAE 1537 to stay within the financial and equipment limitations of this study. First, SAE J1537 specifies a 3000-hour duration, while the Minnesota State University study used a 4000-hour duration to better represent the life expectancy of a fuel pump on a late model vehicle. Next, SAE J1537 requires a minimum of 5 liters of fuel per pump and a change interval of 84 hours. The MSU study used 3 gallons (11.3 liters) of fuel per pump with a change interval of 500 hours. SAE J1537 recommends a minimum of six pumps per specific pump, while the MSU study used eight different pump models. This was done because the goal of this study was to see the effect of E20 on fuel pumps and not to validate the individual fuel pump's lifespan. SAE J1537 also calls out a fuel temperature of 33 ± 3 ˚C with a hot and cold cycling every 1000 hours. The MSU study instead used an elevated running temperature of 43 ± 8 ˚C. SAE J1537 requires a voltage of 13.5 ± 0.5 volts; while the MSU study used 12.5 ± 0.2 volts due to power supply limitations. Finally, SAE J1537 specifies a 20 minute on time with a 6 second off time for the pumps throughout the endurance test. For the MSU test, the pump on time and off time was varied to ensure that the barrel temperature stayed between 43 ± 8 ˚C. This was done because of the large quantity of heat created by running eight pumps in a barrel. Refer to Table 1 for the on verses off times during the test. The full pump test procedure used is available in Appendix 3.

Test Interval (hours)	Minutes	
	On	Off
Initial to 504	8.1	1.5
505 - 1008	7.4	2.2
1009 - 1512	7.2	2.4
1513 - 2016	5.8	3.8
2016 - 2520	5.1	4.5
2521 - 3024	6.5	3.1
3025 - 3528	8.3	1.3
3529 - 4032	8.9	0.7

Table 1. Pump cycle time (on vs. off in minutes)

PUMP TEST PROCEDURE

Since each pump had been used in a prior static study, they underwent the break-in procedure again to clean out any contaminants before measurements were recorded. This consisted of running the pumps for 30 minutes at 13.5 volts with the output pressure held at the manufacturer's recommended specification for the pump's application. Stoddard solvent (MIL-C-7024B) was used during the break-in period. After the break-in period, all of the pumps were photographed. The performance of each fuel pump was measured from 8 to 18 volts in 2-volt increments. Again, pressure was held at the manufacturer's recommended specification for the pump's application and the current and flow were measured.

Finally, the fuel pumps were operated in their designated fuel (gasoline, E10, and E20) to flush out the Stoddard solvent from the measurement process. Once the pumps were flushed, they were secured in the test barrels and connected to a pressure regulating valve set to the manufacturer's recommended pump pressure. After all electrical and hose connections were made the barrels were sealed. The pumps were then supplied 12.5 volts and cycled on and off. The flow and current draw of each pump was measured at 500-hour intervals at the 12-volt increment. The fuel was also changed every 500 hours. The test fuel was kept at a temperature of 43 ± 8 ˚C throughout the endurance test.

After the 4000-hour test, the pumps were photographed and visually inspected for any corrosion or material degradation. Each fuel pump was installed onto the test bench and the flow and current draw was measured from 8 to 18 volts in 2-volt increments. Again, pressure was held at the manufacturer's recommended specification for the pump's application. After the performance data were gathered, the pumps were disassembled to measure wear.

For the purpose of this study, complete failure was defined as a pump that either would not run anymore, or could no longer produce its specified pressure at 12 volts. The end of a pump's useful service life was defined as when the pump's flow dropped below 30 percent of its initial flow. Also, a pump was considered a failure if its amp draw increased 30 percent more than its initial draw. For E20 to be considered acceptable, the pumps must not display greater negative results than they did in gasoline or E10.

SENDING UNIT ENDURANCE TEST

The sending unit test was designed to test the effects of E20 on sending units in a dynamic state. This test was performed to address problems such as corrosion, build up, wear, and degradation of the sending unit wiper and resistive material. Problems such as these could lead to improper fuel gauge readings, which could cause a vehicle to run out of fuel and/or interfere with other functions on the vehicle that rely on the fuel level such as canister purging or evaporative system checks. Standardized sending unit test procedures could not be located so the procedures used were developed from SAE standard J1537 and peer reviewed by a group of fuel system experts representing automobile and fuel system component manufacturers. See Appendix 4 for complete sending unit test procedures.

SENDING UNIT TEST PROCEDURE

Since each sending unit had been used in a prior static study, they underwent the break-in procedure again to ensure they were clean and properly functioning. This consisted of submerging the sending unit in Stoddard solvent (MIL-C-7024B) and cycling the wiper arm 50 full-range sweeps with 5 volts applied to the sending unit. After the break-in, the sending units were measured both dry and wet (in the test fluid that the unit was going to be tested in) by moving the wiper arm through its full range of motion with a fixed resistance in series while recording the voltage change and checking for signal dropout. They were also photographed. After all the sending units were measured, they were placed into the cycling fixture. Proper wiper arm movement was visually verified before sealing the barrels. Each sending unit was then supplied 5 volts. The sending units were cycled through their full sweep at a rate of 1 cycle per 2.5 minutes for 4000 hours. The temperature of the test fuel was kept at 43 ± 8 ˚C throughout the testing. The test fuel was changed every 500 hours.

After the completion of the 4000-hour period, the sending units were removed and measured in the same manner as they were at the beginning of the test. The sending units were visually inspected for corrosion or degradation and photographed. A sending unit was considered a failure if it underwent a significant change in voltage, resistance, or had any areas of signal dropout (opens). For E20 to be considered compatible, the sending unit could not exhibit any more significant changes in resistance than it did with gasoline or E10.

RESULTS

FUEL PUMP VISUAL INSPECTION RESULTS

The fuel pumps were inspected visually and photographed before and after the endurance test to check for discoloration, corrosion, and swelling. All of the pumps tested in gasoline had a grayish-black residue coating on all of the pump pieces. This coating was especially thick on the armature, masking out the color of the windings. The pumps tested in E10 had a very light coating of the same grayish-black residue, but the color of the pieces and armature windings could be clearly seen. This residue was very faint and only found in a few spots on the pumps soaked in E20. The color of various pieces and the armature winding could be clearly seen (see Figure 3).

Figure 3. Comparison of residue on armatures after 4000 hours; note commutator wear on the one tested in gasoline

Next, light surface corrosion was noticed on the housings of the Ford, GM TBI, Volkswagen, and GM rollervane pumps soaked in E20 (see Figure 4). This corrosion was extremely light and did not affect function. Finally, the rubber pieces on the filter socks on the Ford and Jeep pumps soaked in gasoline became very hard and cracked. These same rubber pieces on the pumps tested in E10 and E20 also hardened slightly but did not crack (see Figure 5).

Figure 4. Comparison of pump housings after 4000 hours; note the light surface corrosion on the E20 housing

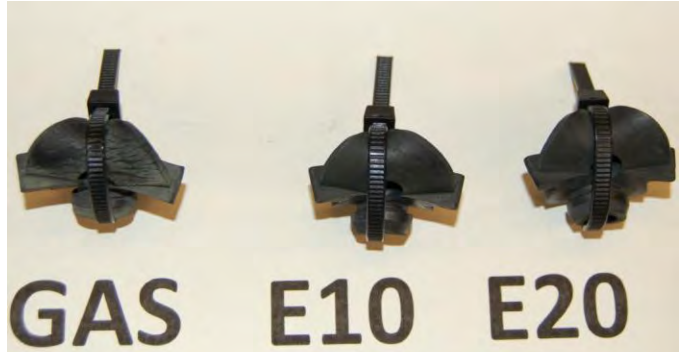

Figure 5. Comparison of rubber sock filter gasket after 4000 hours; note the cracking on the one tested in gasoline

FUEL PUMP PERFORMANCE RESULTS

Performance data on pressure, fuel flow, and current was collected before the test and then every 500 hours until the test concluded at 4000 hours. Refer to Appendixes 5 through 12 for the performance data. By the end of the 4000-hour test, four fuel pumps had either completely stopped working or were unable to produce the proper amount of pressure for testing. The GM TBI pump tested in gasoline completely stopped after the 2520-hour interval. Next, the GM port pump tested in E10 completely stopped after the 3024-hour interval. Two pumps, the Ford pump tested in E10 and the GM rollervane tested in gasoline were still running at the end of the test but could not produce the specified amount of pressure for testing at 12 volts. This occurred on both of these pumps after the 3528-hour test interval. Finally, the GM port pump tested in E20 stopped working due to a procedural error after the 504-hour test interval. The filter was not installed after the measurements were made and the pump ingested a small piece of debris preventing it from turning. Due to this failure being a procedural error, this pump was not included in the analysis.

The usable service life was calculated by adding up the amount of time that the pump was tested before its flow rate decreased and stayed below 30% of its initial flow. Next, the total hours was divided by the number of pumps to provide an average. For pumps that did not drop below 30%, 4000 hours was used in the calculation. The average test life of the pumps in gasoline, E10, and E20 was 3087, 3213, and 3168 hours, respectively. The pump life was very similar in each of the three fuels.

In terms of current draw, trends were very similar among pumps of the same make and model in each of the three fuels. Nine of the pumps saw an increase in current draw while the rest of the pumps saw a decrease. The current draw increases were small and did not raise a concern for the potential to overload the fuel pump circuit.

By the end of the 4000-hour test, many of the pumps required a higher voltage (2 to 4 volts) to produce the same amount of flow as they did at the beginning. Also, by the end, 12 pumps could not reach their specified pressure at 10 volts. Five of these were in gasoline, four in E10, and three in E20 (note, this was out of seven pumps in E20 and eight in gasoline and E10). These trends were very similar among pumps of the same make and model in each of the three fuels.

FUEL PUMP WEAR RESULTS

After the 4000-hour test, the fuel pumps were cut apart so that the internal components could be examined and measured. Original factory dimensions and tolerances could not be obtained for the pumps. Instead a comparison of components of the same pumps of the same make and model were compared along with an average of all of the parts. One group of pumps, the GM port, was omitted from the dimensional measurement data because there were only two pumps and a comparison could not be made. Three main wear measurements that were common to all of the pumps were taken: brush length, commutator wear, and shaft-to-bushing clearance. The armatures were also checked for opens and shorts. Finally, the gear rotor and rollervane pump mechanisms were checked for wear. Refer to Appendix 13 for component measurement data.

No clear trends existed in terms of shaft-to-bushing clearance wear. The GM TBI pump tested in gasoline was the only pump to display extreme wear on the shaft and bushing leading to a clearance of 0.020 in., whereas the other pumps had clearances in the 0.000 - 0.003 in. range. Also, the gear to rotor housing and rollervane clearances were measured. No clear trends were discovered in these measurements.

The overall brush length of pumps of the same make and model were compared along with an average of all brushes from one fuel. The average brush length of a pump tested in gasoline was 0.35 in., in E10 was 0.37 in., and in E20 was 0.38 in. The brushes tended to show the most wear in pumps tested in gasoline as compared to E10 or E20.

The commutator wear of pumps of the same make and model were compared along with an average of wear on commutators of pumps tested in the same fuel. Although original specifications could not be obtained, the grooving on the commutator where the brush rides verses where the brush does not ride allowed the amount worn off to be determined. The commutators showed the most wear of any part of the pumps. In five of the pumps (Ford, Toyota, Jeep, Volkswagen, and GM rollervane) run in gasoline the commutator wear was substantially greater (0.015 to 0.060 in. more) than in E10 or in E20. The wear was so severe on the GM rollervane tested in gasoline that four segments of the commutator were worn through to the insulation underneath. This most likely was the reason that this pump could not develop its rated pressure at the end of the study. The severity of commutator wear can be seen in Figure 3 and Figure 6.

Figure 6. Comparison of armature wear after 4000 hours; note the commutator is worn through to the insulation on the one tested in gasoline

The Honda pumps had equal wear in all of the fuels. The GM TBI pumps wore 0.009 in. more in E20 than gasoline, but the gasoline pump stopped working 1500 hours earlier than the E20 pump. The average commutator wear of a pump tested in gasoline was 0.046 in., in E10 was 0.016 in., and in E20 was 0.015 in. There was a clear trend that the commutator wear was greater in gasoline than in E10 or E20.

The armatures of the pumps were checked for opens and shorts. Three pumps were found to have issues. The Ford pump test in E10 had two sets of windings with high resistance. This was the most likely reason that this pump could not develop its rated pressure at the end of the study. Next, the GM rollervane pump and the GM port pump tested in gasoline had four and five commutator segments, respectively, worn to the insulation.

SENDING UNIT VISUAL INSPECTION RESULTS

The sending units were photographed and visually inspected before and after the testing. This was done to determine discoloration, corrosion, and swelling. All of the sending units soaked in gasoline had a thick grayish-black residue covering. This residue was not found on the sending units soaked in E10 or E20. Also the white plastic components on the sending units soaked in gasoline were discolored gray. This discoloration was slightly noticeable on the plastic components soaked in E10 but was not present on the sending units soaked in E20. Refer to Figure 7 for a comparison of the discoloration.

Figure 7. Comparison of residue coatings and discoloration after 4000 hours

The wiper arm tip and resistive strip on all of the sending units, regardless of which fuel they were tested in, were clean and shiny. There were no visual signs of open or burnt areas. The other metal surfaces (float arm, bushing, and electrical connectors) on the sending units soaked in gasoline were not discolored where the residue was removed. There were a few instances of discoloration and/or light surface corrosion on the sending units soaked in E10 and E20. The electrical connectors and the solder on the Jeep sending units exhibited discoloration in both E10 and E20, but to a greater extent in E20. The electrical connector on the Honda sending unit soaked in E20 had minor dots of surface corrosion. And, the electrical connectors and the solder on the GM sending units exhibited discoloration and light surface corrosion in both E10 and E20, but to a greater extent in E20. None of the visual difference between the sending units soaked in any of the fuels appeared to affect functionality.

SENDING UNIT PERFORMANCE RESULTS

The voltage change of each sending unit was checked as the wiper arm was moved through its full sweep while being supplied 5 volts. The resistance change of each sending unit was also measured through a full sweep. Refer to Appendix 14 for a comparison of sending unit voltage and resistance changes. By the end of the study, all of the sending units had failed regardless of which fuel they were tested in. They underwent excessive changes in resistance and had areas of signal dropout (opens). No significant differences in performance or failure were noted between sending units tested in gasoline, E10, or E20.

CONCLUSIONS

This study tested and compared the effects of E20 to that of E10 and gasoline on eight fuel pump models and three sending unit models in three different fuels for a total of 24 fuel pumps and 9 sending units. Both the pumps and sending units were subjected to a 4000-hour dynamic endurance test. Throughout the test, the cleansing effect of the ethanol fuels was very apparent. The pumps, sending units, and test fixtures immersed in gasoline were coated with a grayish-black residue while the same items in E10 or E20 displayed little to no residue. It was noticed that some pumps tested in E20 had light surface corrosion, but not to the extent to affect their function.

In terms of performance, fuel flow and current draw, four pumps either completely failed or could not develop sufficient pressure at the end of the study. Two of these were in gasoline and two were in E10. No clear trends in pump performance between any of the fuels were found. A clear trend in commutator wear was found between gasoline, E10, and E20. The commutators of several of the pumps tested in gasoline wore substantially more than in either ethanol fuel. This wear was significant enough that if the test would have continued longer, several of the pumps tested in gasoline would have stopped because their commutator would have worn through. Overall, E20 did not cause any greater negative effects than gasoline or E10 on the fuel pumps tested.

By the end of the study all of the sending units tested had failed, regardless of which fuel they were in. All exhibited excessive resistance changes along with regions of signal drop out (opens). Visual differences were noted between the sending units tested in E10 and E20 when compared to gasoline, but these did not affect the functionality. No significant differences in performance or in failure were noted between the sending units in any of the three fuels.

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S&S Cycle
TI Automotive
Toro
Toyota
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SAE J1537 (1990, June). *Validation Testing of Electric Fuel Pumps for Gasoline Fuel Injection Systems*. Warrendale, PA.

TERMINOLOGY

E10 - Fuel consisting of 90% gasoline and 10% ethanol

E20 - Fuel consisting of 80% gasoline and 20% ethanol

Stoddard Solvent (MIL-C-7024B) - A standard reference fluid used for flowing pumps. It is similar to mineral spirits.

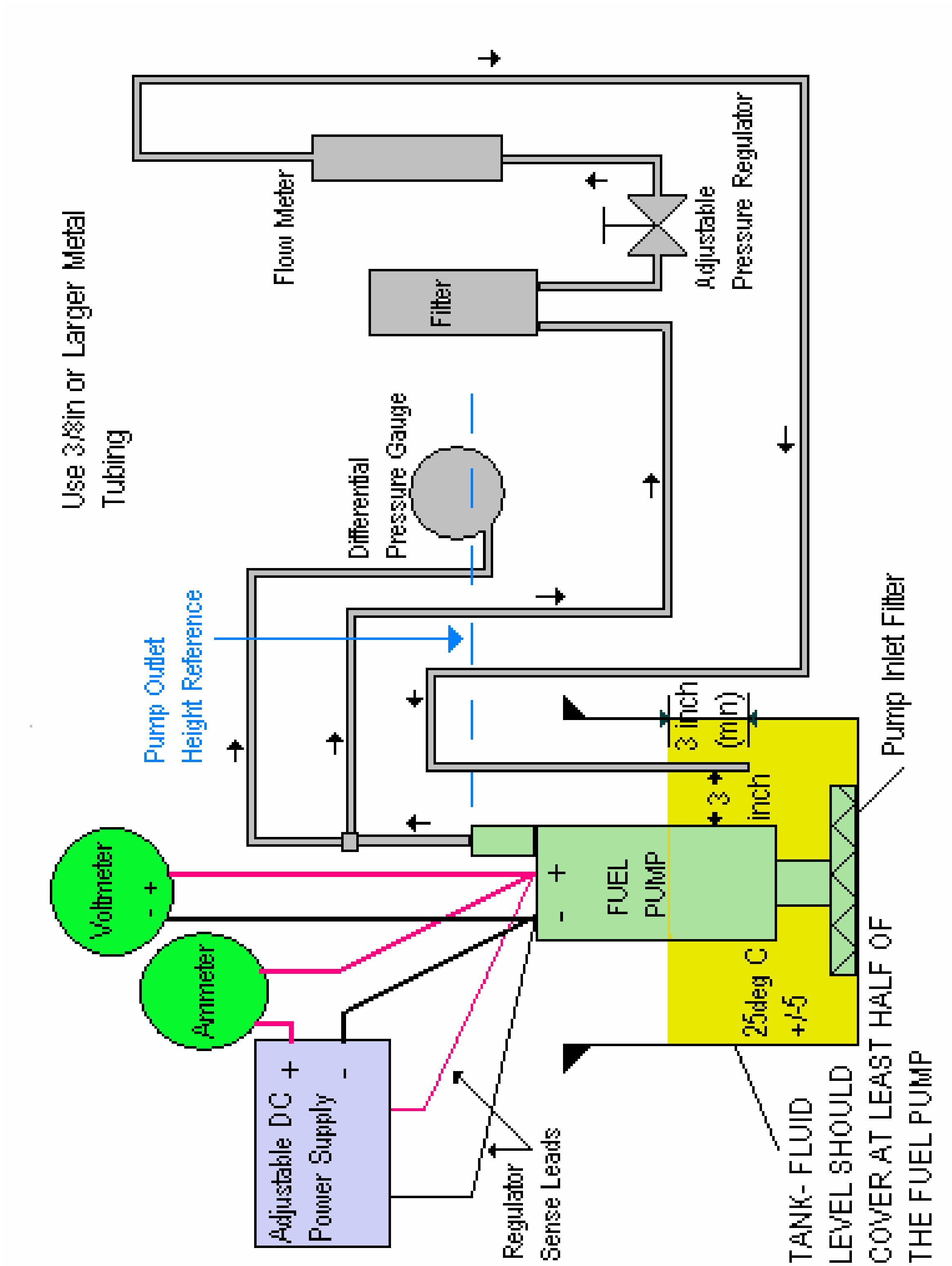
Aggressive Ethanol - A fuel used for material testing that is designed to be a worst-case-scenario fuel that is still acceptable under ASTM D4806. It consists of synthetic ethanol 816.00 g, de-ionized water 8.103 g, sodium chloride 0.004 g, sulfuric acid 0.021 g, and glacial acetic acid 0.061 g.

CONTACT

Department of Automotive Engineering Technology
Minnesota State University, Mankato
205 Trafton Science Center East
Mankato MN, 56001
(507)-389-6383

APPENDIX 1

TEST FIXTURE DIAGRAM



APPENDIX 2

PART NUMBERS OF MAJOR COMPONENTS

Data Acquisition

National Instruments model NI USB-6009

Flow measurement

Flow meter: Omega model FTB-90507

Signal converter: Omega model FLSC-64

Pressure control

Flow Valve: Deltrol fluid products model EF25SS

Pressure Transducer

American Sensor Technologies AST4100A00100P1B0103

Power Supply

Pumps powered by: Hewlett Packard 6553A

Instruments powered by: Delta Electronics model DPS-200PB-125A

Minnesota State University's Test Fixture

Minnesota State University's Test Fixture Side View

Instrument Power Supply

National Instruments NI USB-6009

APPENDIX 3

MnCAR

Minnesota Center for Automotive Research

This document is intended to outline the fuel pump endurance testing procedure that was used by the Minnesota Center for Automotive Research (MnCAR). The effects of running fuel pumps in E20 were compared to gasoline and E10 in terms of performance (flow and current draw), material degradation, corrosion, and mechanical wear. The fuel pumps were subject to a 4000-hour dynamic endurance test in each of the test fuels using the procedure listed below which was derived from SAE J1537.

Test Standards

Testing followed the procedures outlined in SAE J1537 and J1681.

SAE J1537 (Jun90) *Validation testing of electric fuel pumps for gasoline fuel injection systems*.

SAE J1681 (Jan00) *Gasoline, alcohol and diesel fuel surrogates for materials testing*.

Test Fuels

Three test fuels used consisting of

- Gasoline- Tier II
- E10 fuel [Tier II(E10)$_A$]- 90% Tier II + 10% aggressive ethanol (900 ml Tier II, 100 ml aggressive ethanol)
- E20 fuel [Tier II(E20)$_A$]- 80% Tier II + 20% aggressive ethanol (800 ml Tier II, 200 ml aggressive ethanol)

Aggressive ethanol consists of synthetic ethanol 816.00 g, de-ionized water 8.103 g, sodium chloride 0.004 g, sulfuric acid 0.021g, and glacial acetic acid 0.061g (SAE J1681 Appendix E.1.2)

Required Materials

A. Three of the same fuel pumps, one for each test fluid
B. Twenty-five gallons of test fuel per barrel
C. DC power supply to operate the pumps
D. Sealable, 55-gallon, HDPE barrels with appropriate holding fixtures, hoses, regulation valves, and wiring
E. Test fixture to measure the flow, pressure, voltage, and current draw of the pumps
F. Fluid for testing flow: MIL-C-7024B (Type II) Laboratory test fluid (SAE J1537, 3.1.10)
G. Calipers/ micrometers to measure mechanical wear on disassembled pumps

Test Preparation

1. Break in new pumps by operating them at the manufacturer's recommended pressure for 30 minutes while running in Stoddard solvent (Mil-C-7024B) prior to measuring each pump (SAE J1537, 3.2.3).
2. Measure the pump at voltages ranging from 8 to 18 volts DC in 2-volt increments. Pump pressure will be set and maintained at the manufacturer's specification as per the pump application. Pump flow and current draw will be measured at each increment (SAE J1537, 4.3.2).
3. Run the pumps in their designated test fluids for a minimum of 30 seconds to clean out the Stoddard solvent from the pump.
4. Clean the 55-gallon barrel to be used for the endurance test thoroughly, making sure it is free of any contaminants.

5. Mount the pumps to the holding fixture in the 55 gallon barrels and connect the appropriate hoses/regulation valves and power leads to the pumps.

Testing

1. Fill each 55-gallon barrel with a minimum of 25 gallons of test fluid to completely submerge the pumps.
2. Turn on all of the pumps and check current draw along with the pump. Return hoses to ensure all connections are made correctly and that the pumps are working.
3. Turn off the pumps and seal the barrels.
4. Restart the pumps using the electric timers to cycle the pumps on and off (This time may be varied to maintain barrel temp.).
5. Check to ensure that voltage is set to 12.5 volts.
6. Check the barrels twice a day for fluid loss, temperature, and amp draw.
7. Allow the pumps to run for 500 hours at a temperature of 43 ± 8 ˚C.
8. Pump data is to be collected every 500 hours (SAE J1537, 4.7.5).
9. Test fuel is to be changed every 500 hours.

Measurement

1. After 500 hours, remove the pumps from the test fluid.
2. Photograph each pump and note any corrosion or material degradation.
3. Check the filter sock on the pump and note any issues.
4. Place the pump into the test bench.
5. Hook the pump up to the power supply. NOTE: The pump will be tested at 12 volts in the same manner as the initial data was collected. At the conclusion of the study re-measure the pump at voltages ranging from 8 to 18 volts DC in 2-volt increments. Pump pressure will be set and maintained at the manufacturer's specification as per the pump application. Pump flow and current draw will be measured at each increment (SAE J1537, 4.3.2).
6. Maintain a test fluid temperature of 25 ± 5 ˚C during flow testing (SAE J1537, 3.1.10).
7. Return the pumps to the endurance fixture if the study has not concluded.

Validation

1. Pump must meet or exceed its rated flow at 500-hour intervals throughout the test (SAE J1537, 4.7.5).

3/25/09

APPENDIX 4

Minnesota Center for Automotive Research

This document is intended to outline fuel sending unit endurance testing procedures used by the Minnesota Center for Automotive Research (MnCAR). The effects of E20 as compared to gasoline and E10 on the performance of automotive fuel sending units were tested. The sending units were subjected to a 4000-hour dynamic endurance test in each of the test fuels. The sending units' resistances and voltage drops were measured before and after the test.

Test Standards

No standardized testing procedures for fuel level sending units could be located. Because of this, procedures were developed using some of the recommendations contained in SAE J1537.

SAE J1537 (1990, June) *Validation testing of electric fuel pumps for gasoline fuel injection systems*.

SAE J1681 (2000, January) *Gasoline alcohol and diesel fuel surrogates for materials testing*.

Test Fuels

Three test fuels used consisting of

- Gasoline- Tier II
- E10 fuel [Tier II(E10)$_A$]- 90% Tier II + 10% aggressive ethanol (900 ml Tier II, 100 ml aggressive ethanol)
- E20 fuel [Tier II(E20)$_A$]- 80% Tier II + 20% aggressive ethanol (800 ml Tier II, 200 ml aggressive ethanol)

Aggressive ethanol consists of synthetic ethanol 816.00 g, de-ionized water 8.103 g, sodium chloride 0.004 g, sulfuric acid 0.021 g, and glacial acetic acid 0.061 g (SAE J1681 Appendix E.1.2).

Required Materials

A. Three of the same sending unit, one for each test fluid
B. Enough test fluid to submerge the sending unit
C. Variable DC power supply
D. Series resistor of appropriate value
E. Test fixture to hold and cycle the sending units' floats during the endurance test
F. Meter to measure voltage drop and resistance change

Test Preparation

1. Break in all new sending units by cycling the arm 50 times across the contacts from the full to empty positions with either 5 volts or 12 volts (depending on the manufacturer's specifications) while in Stoddard solvent.
2. After the break-in period, rinse the sending units in their designated test fluid.
3. Measure the voltage change through a full sweep of the sending units with the correct voltage applied and appropriate resistor in series both wet and dry. Record the data. Watch for any signal dropout.
4. Measure the resistance change through a full sweep of the sending units both wet and dry. Record the data. Watch for any signal dropout.
5. Thoroughly clean the test fixture to be used for the cycle testing.
6. Mount each sending unit securely to the fixture.

Testing

1. Fill the container with the appropriate test fluid.
2. Verify proper operation of cycling test fixture.
3. Seal the container.
4. Apply appropriate voltage to the sending units.
5. Allow the sending units to cycle for 4000 hours at a temperature of 43 ± 8 ˚C.
6. Test fuel is to be changed every 500 hours.

Measurement

1. After 4000 hours, remove the sending units from the test fluid.
2. Photograph each sending unit and note any corrosion or material degradation.
3. Measure, both wet and dry, the voltage change through a full sweep of the sending unit with the correct voltage applied and appropriate resistor in series. Record the data. Watch for any signal dropout.
4. Measure, both wet and dry, the resistance change through a full sweep of the sending unit. Record the data. Watch for any signal dropout.

Validation

1. Compare the measurements taken before the study to the measurements taken after the study.
2. Post-endurance test measurements must be within 10% of pre-endurance test measurements.

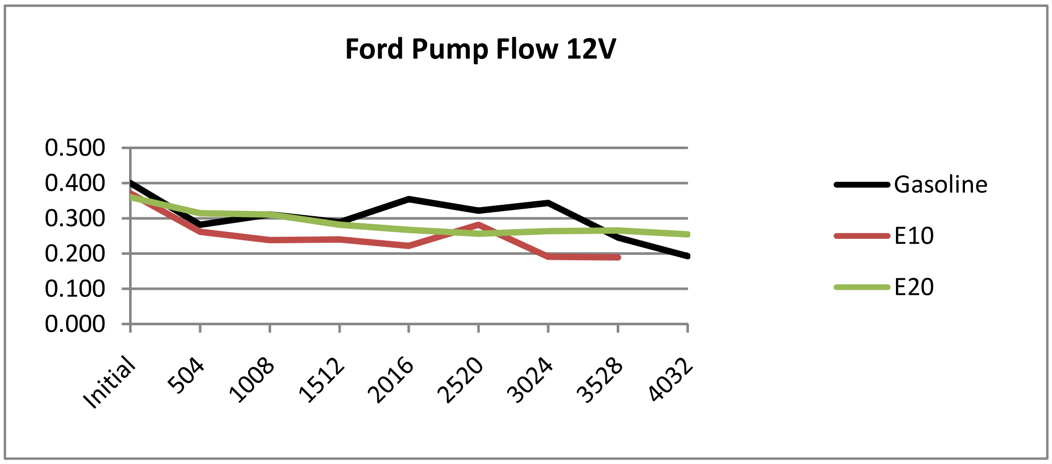
APPENDIX 5

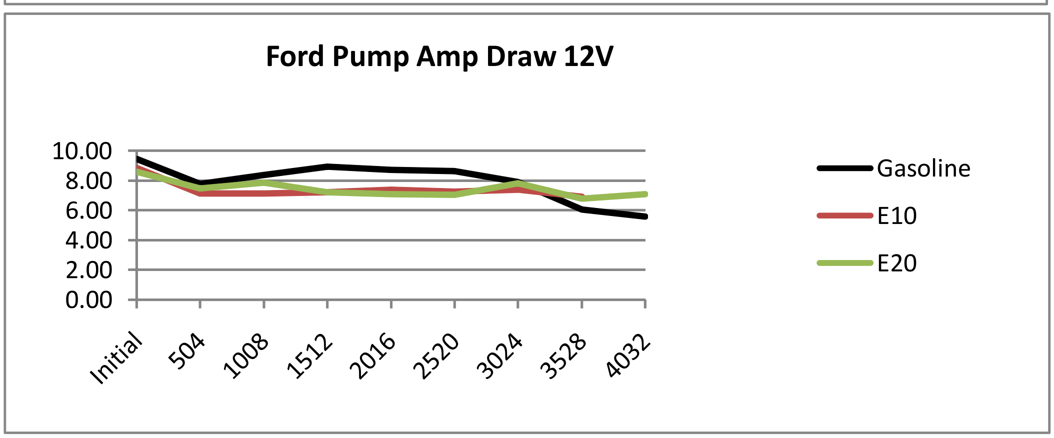
PERFORMANCE DATA FORD TRUCK PUMP

Ford Truck Pump (90-93) **12 volts** **43 ± 1 psi**

	Flow (GPM)			Current (Amp)		
Hours	Gasoline	E10	E20	Gasoline	E10	E20
Initial	0.400	0.370	0.360	9.48	8.88	8.59
504	0.280	0.260	0.314	7.78	7.13	7.50
1008	0.310	0.237	0.310	8.41	7.11	7.86
1512	0.288	0.239	0.280	8.96	7.20	7.21
2016	0.355	0.221	0.266	8.74	7.37	7.10
2520	0.321	0.281	0.255	8.65	7.27	7.06
3024	0.344	0.190	0.262	7.91	7.37	7.81
3528	0.244	0.188	0.264	6.03	6.91	6.80
4032	0.191	FTP	0.253	5.57	FTP	7.08
% Difference in Initial to 4032 hours	-52	NC	-30	-41	NC	-18

Ford pump (E10) could not produce the required pressure at the 4032-hour interval.





FTP= Failure to Produce Pressure
CS= Complete Stop
ND= No or Lost Data
EF= Early Fail No Comparison
NC= No Calculation

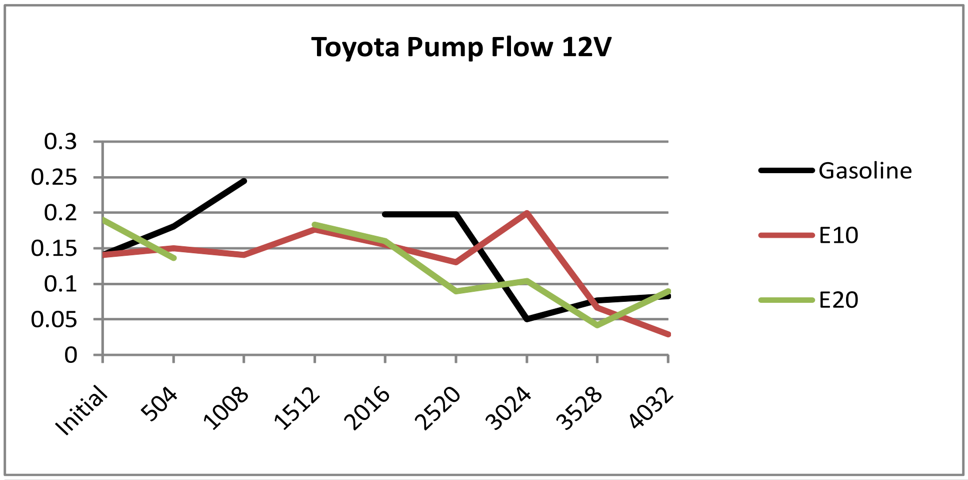
APPENDIX 6

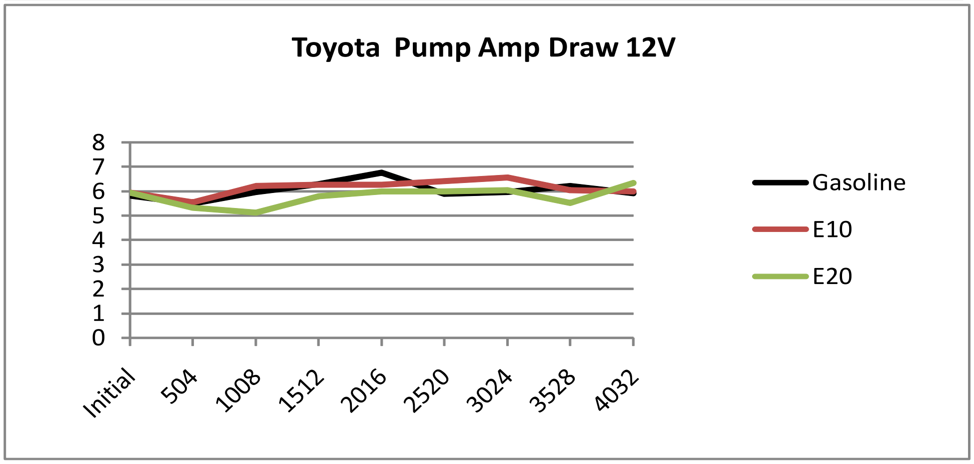
PERFORMANCE DATA TOYOTA CAMERY

Toyota Camry 92-94 **12 volts** **49 ± 3 psi**

	Flow (GPM)			Current (Amp)		
Hours	Gasoline	E10	E20	Gasoline	E10	E20
Initial	0.140	0.140	0.190	5.81	5.93	5.95
504	0.180	0.150	0.136	5.49	5.54	5.32
1008	0.244	0.140	ND	5.97	6.22	5.12
1512	ND	0.176	0.183	6.30	6.27	5.79
2016	0.197	0.155	0.160	6.77	6.27	6.00
2520	0.197	0.130	0.090	5.90	6.41	5.99
3024	0.050	0.199	0.104	5.97	6.57	6.04
3528	0.076	0.066	0.042	6.23	6.04	5.51
4032	0.082	0.029	0.090	5.92	5.99	6.34
% Difference in Initial to 4032 hours	-41	-79	-53	2	1	7

Toyota pump (gasoline) data for hour 1512 was recorded incorrectly.
Toyota pump (E20) data for hour 1008 was recorded incorrectly.





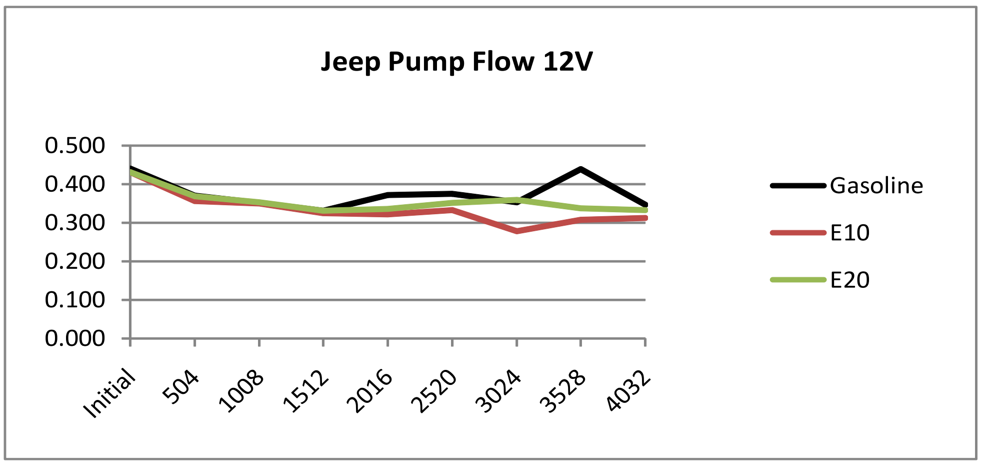
FTP= Failure to Produce Pressure
CS= Complete Stop
ND= No or Lost Data
EF= Early Fail No Comparison
NC= No Calculation

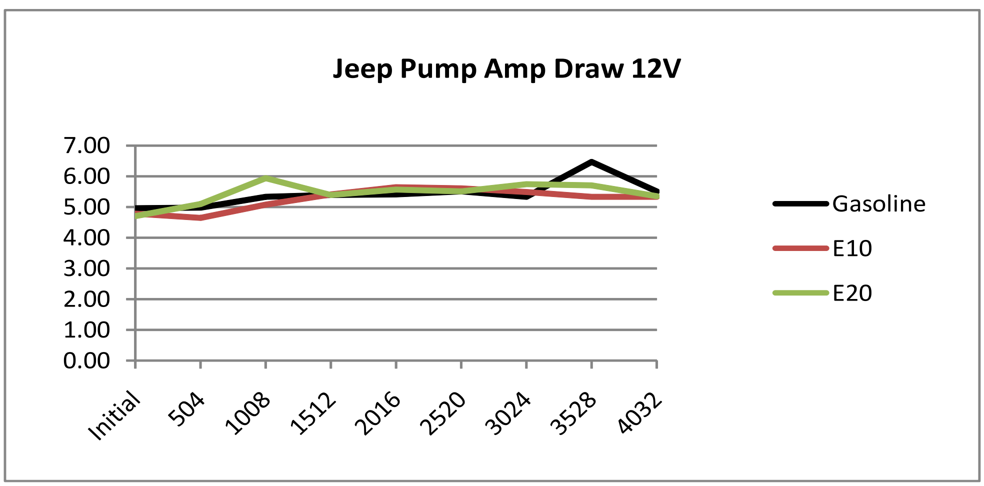
APPENDIX 7

PERFORMANCE DATA JEEP WRANGLER

Jeep Wrangler (99-00) 12 volts 53 ± 3 psi

	Flow (GPM)			Current (Amp)		
Hours	Gasoline	E10	E20	Gasoline	E10	E20
Initial	0.440	0.430	0.430	4.95	4.77	4.69
504	0.370	0.355	0.367	4.96	4.64	5.08
1008	0.350	0.349	0.352	5.32	5.08	5.94
1512	0.330	0.324	0.330	5.38	5.40	5.38
2016	0.371	0.321	0.334	5.41	5.64	5.57
2520	0.374	0.331	0.351	5.51	5.60	5.51
3024	0.352	0.277	0.358	5.33	5.48	5.75
3528	0.439	0.306	0.336	6.47	5.33	5.70
4032	0.346	0.311	0.331	5.50	5.32	5.34
% Difference in Initial to 4032 hours	-21	-28	-23	11	12	14





FTP= Failure to Produce Pressure
CS= Complete Stop
ND= No or Lost Data
EF= Early Fail No Comparison
NC= No Calculation

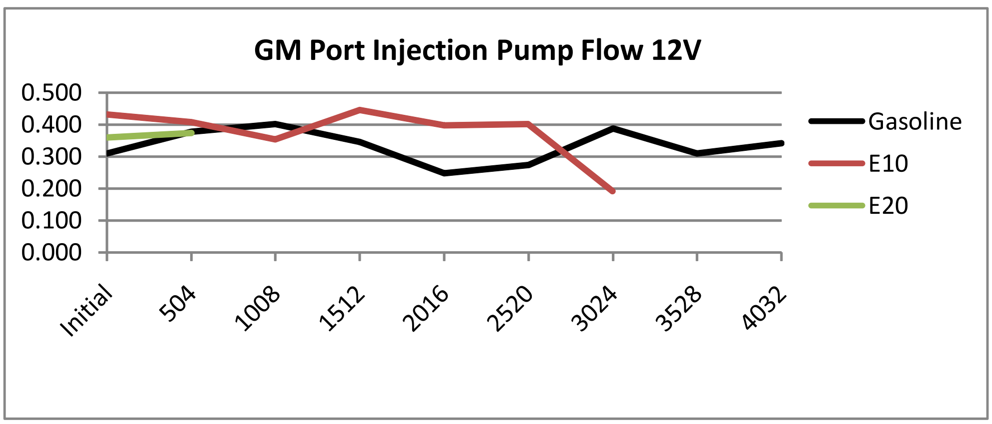
APPENDIX 8

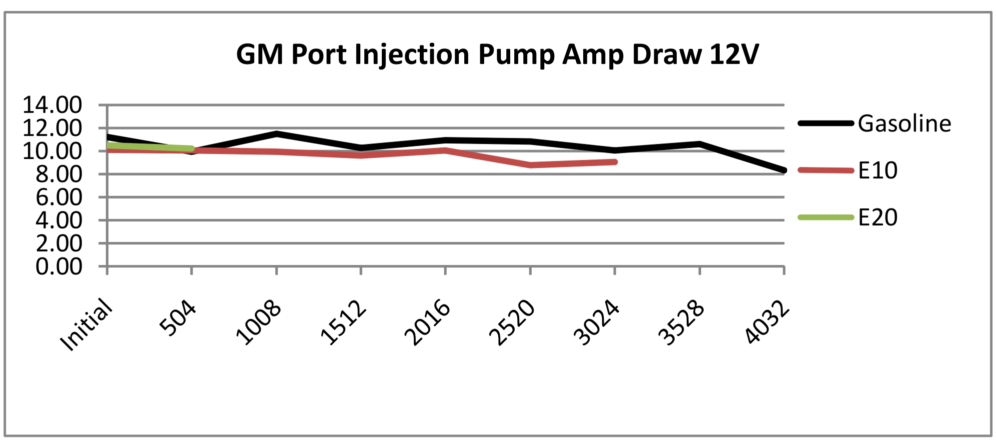
PERFORMANCE DATA GM PORT

GM Port Injection (99-02) 12 volts 55 ± 2 psi

	Flow (GPM)			Current (Amp)		
Hours	Gasoline	E10	E20	Gasoline	E10	E20
Initial	0.310	0.430	0.360	11.19	10.08	10.49
504	0.378	0.407	0.374	9.95	10.05	10.19
1008	0.401	0.353	EF	11.47	9.92	EF
1512	0.345	0.445	EF	10.27	9.59	EF
2016	0.248	0.396	EF	10.91	10.04	EF
2520	0.273	0.401	EF	10.80	8.77	EF
3024	0.387	0.191	EF	10.06	9.06	EF
3528	0.310	EF	EF	10.60	EF	EF
4032	0.342	EF	EF	8.32	EF	EF
% Difference in Initial to 4032 hours	10	NC	NC	-26	NC	NC

GM port pump (E20) stopped completely after the 504-hour interval due to procedural error.
GM port pump (E10) stopped completely after the 3024-hour interval.





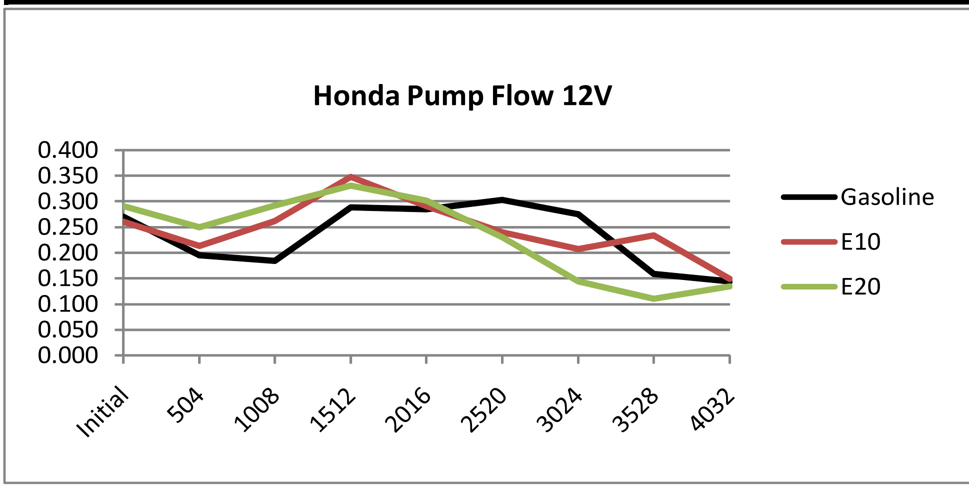
FTP= Failure to Produce Pressure
CS= Complete Stop
ND= No or Lost Data
EF= Early Fail No Comparison
NC= No Calculation

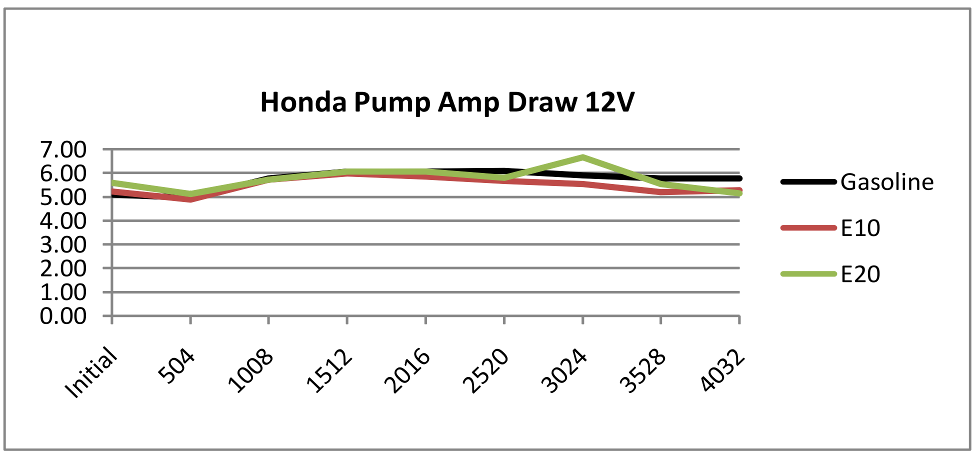
APPENDIX 9

PERFORMANCE DATA HONDA ACCORD

Honda Accord Sedan (03-06) 12 volts 49 ± 1 psi

	Flow (GPM)			Current (Amp)		
Hours	Gasoline	E10	E20	Gasoline	E10	E20
Initial	0.270	0.260	0.290	5.10	5.25	5.59
504	0.195	0.213	0.249	4.96	4.90	5.12
1008	0.184	0.261	0.291	5.80	5.74	5.72
1512	0.288	0.347	0.330	6.07	5.99	6.07
2016	0.285	0.290	0.301	6.07	5.86	6.07
2520	0.303	0.240	0.230	6.11	5.69	5.80
3024	0.275	0.207	0.144	5.92	5.56	6.66
3528	0.158	0.234	0.110	5.80	5.20	5.53
4032	0.144	0.149	0.134	5.78	5.29	5.15
% Difference in Initial to 4032 hours	-47	-43	-54	13	1	-8





FTP= Failure to Produce Pressure
CS= Complete Stop
ND= No or Lost Data
EF= Early Fail No Comparison
NC= No Calculation

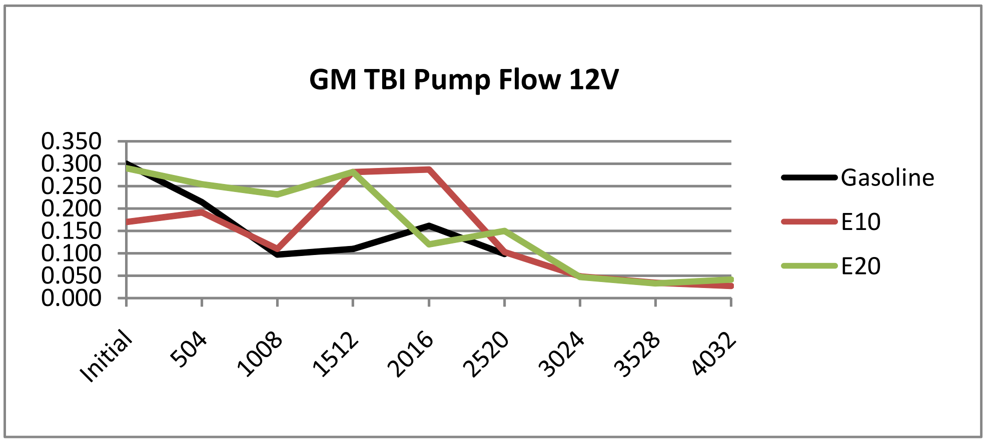
APPENDIX 10

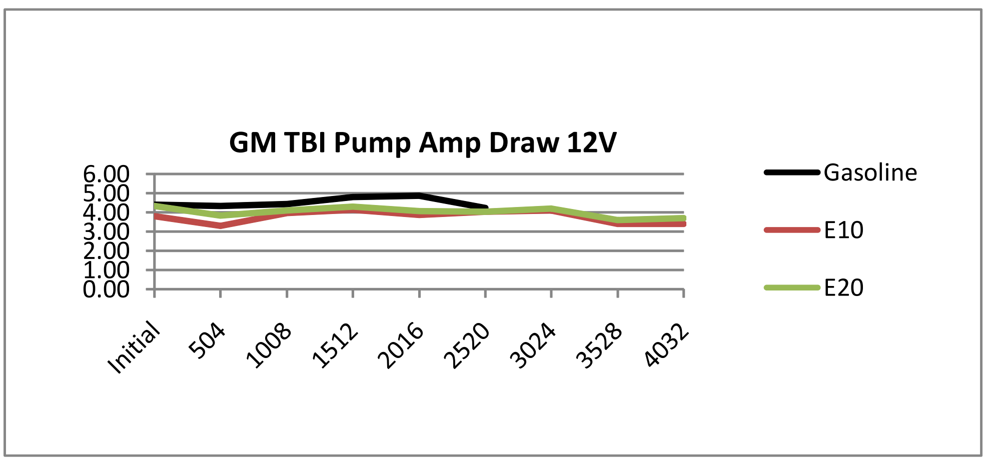
PERFORMANCE DATA GM TBI

GM TBI Pumps (87-92) **12 volts** **10 ± 1.4 psi**

	Flow (GPM)			Current (Amp)		
Hours	Gasoline	E10	E20	Gasoline	E10	E20
Initial	0.300	0.170	0.290	4.38	3.80	4.32
504	0.214	0.190	0.254	4.33	3.30	3.83
1008	0.096	0.110	0.231	4.43	3.97	4.10
1512	0.109	0.281	0.281	4.80	4.15	4.30
2016	0.160	0.286	0.119	4.86	3.89	4.07
2520	0.097	0.103	0.150	4.22	4.04	4.03
3024	EF	0.048	0.047	EF	4.13	4.19
3528	EF	0.034	0.032	EF	3.39	3.61
4032	EF	0.027	0.040	EF	3.40	3.70
% Difference in Initial to 4032 hours	NC	-84	-86	NC	-11	-14

GM TBI pump (gasoline) stopped completely after the 2520-hour interval.



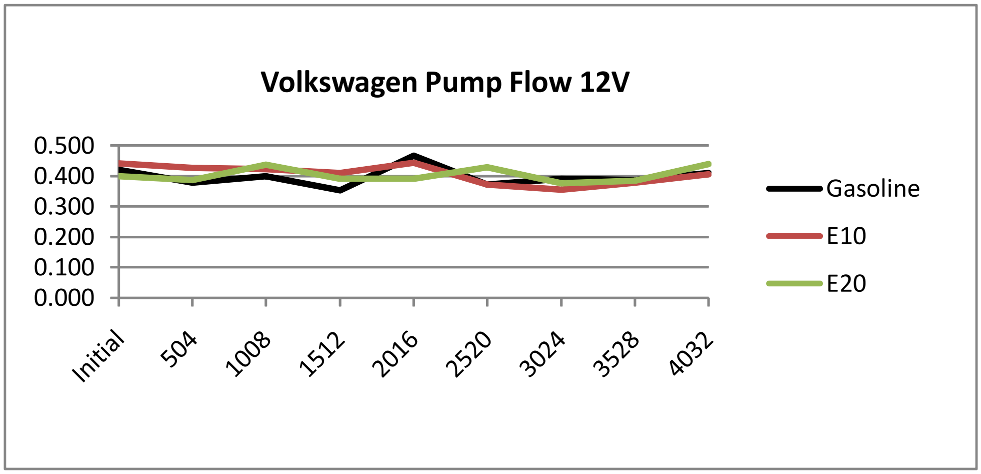


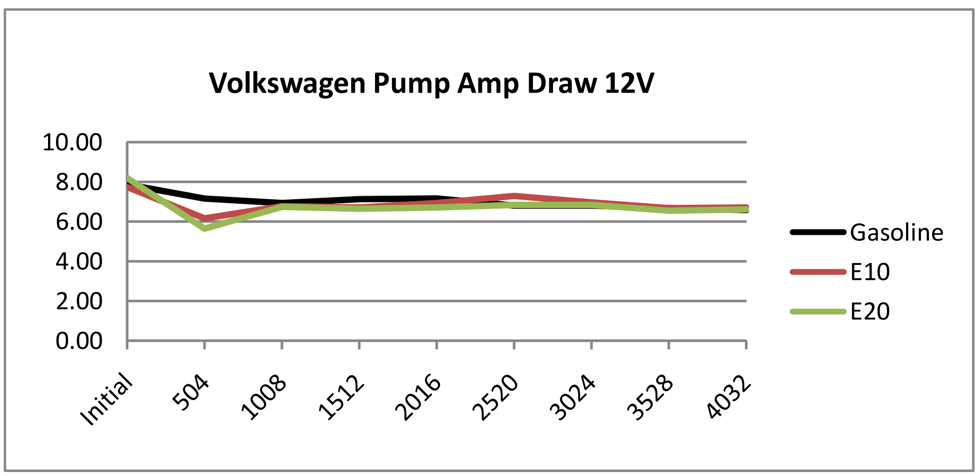
FTP= Failure to Produce Pressure
CS= Complete Stop
ND= No or Lost Data
EF= Early Fail No Comparison
NC= No Calculation

APPENDIX 11

PERFORMANCE DATA VOLKSWAGEN

	Volkswagen (93-94)			12 Volts		54 ± 1 psi
	Flow (GPM)			Current (Amp)		
Hours	Gasoline	E10	E20	Gasoline	E10	E20
Initial	0.420	0.440	0.400	7.88	7.73	8.20
504	0.378	0.425	0.386	7.17	6.16	5.66
1008	0.399	0.422	0.437	6.92	6.77	6.76
1512	0.353	0.410	0.391	7.12	6.72	6.67
2016	0.467	0.443	0.391	7.16	6.93	6.72
2520	0.371	0.371	0.430	6.79	7.27	6.84
3024	0.390	0.354	0.376	6.81	6.95	6.84
3528	0.387	0.378	0.384	6.66	6.66	6.55
4032	0.410	0.405	0.440	6.57	6.71	6.61
% Difference in Initial to 4032 hours	-2	-8	10	-17	-13	-19





FTP= Failure to Produce Pressure
CS= Complete Stop
ND= No or Lost Data
EF= Early Fail No Comparison
NC= No Calculation

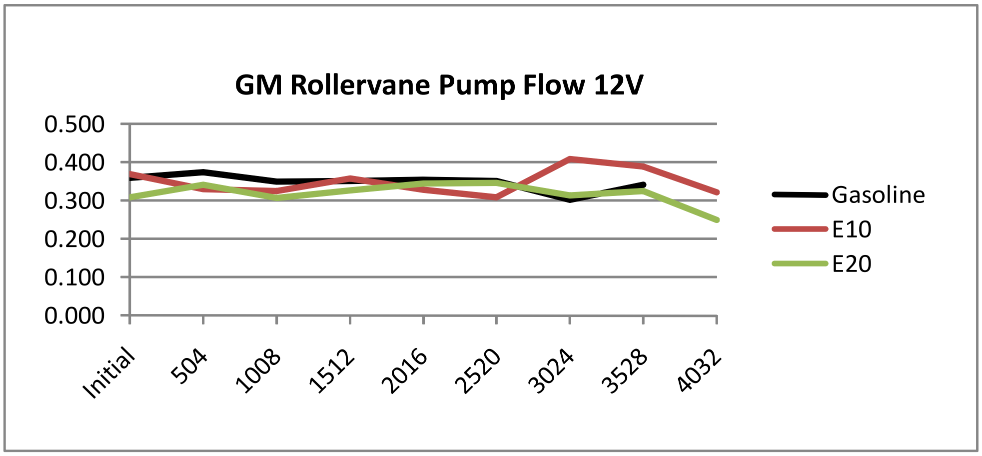
APPENDIX 12

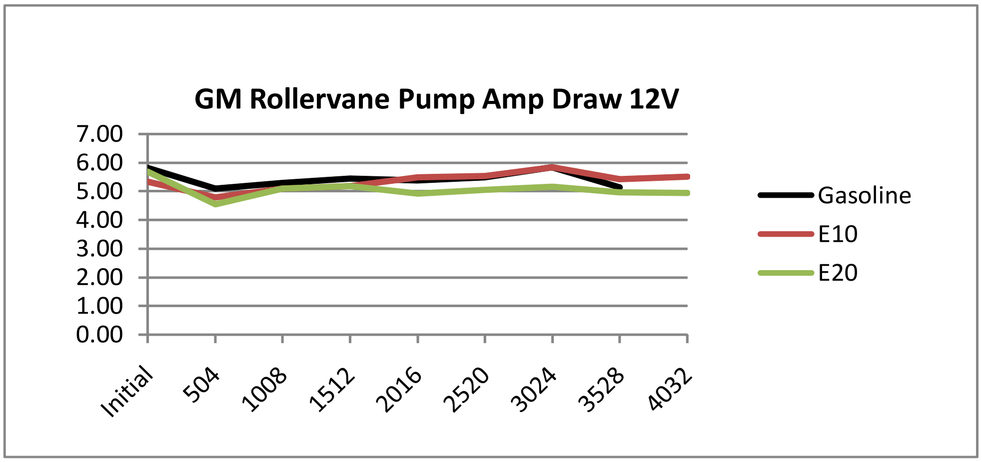
PERFORMANCE DATA GM ROLLERVANE

GM Rollervane PFI (90-92) 12 Volts 42 ± 2.5 psi

	Flow (GPM)			Current (Amp)		
Hours	Gasoline	E10	E20	Gasoline	E10	E20
Initial	0.360	0.370	0.310	5.81	5.33	5.68
504	0.374	0.331	0.342	5.08	4.78	4.54
1008	0.350	0.325	0.308	5.27	5.09	5.09
1512	0.352	0.358	0.327	5.43	5.18	5.18
2016	0.354	0.329	0.345	5.38	5.48	4.92
2520	0.351	0.309	0.347	5.49	5.52	5.04
3024	0.303	0.409	0.314	5.84	5.84	5.16
3528	0.342	0.389	0.326	5.12	5.42	4.96
4032	FTP	0.322	0.250	FTP	5.50	4.94
% Difference in Initial to 4032 hours	NC	-13	-19	NC	3	-13

GM rollervane pump (gasoline) could not produce the required pressure at hour 4032.





FTP= Failure to Produce Pressure
CS= Complete Stop
ND= No or Lost Data
EF= Early Fail No Comparison
NC= No Calculation

APPENDIX 13

DIMENSIONAL AND ELECTRICAL MEASUREMENTS

	Average Brush Length in Inches			Commutator Wear in Inches			Shaft to Bearing Clearance in Inches		
	Gasoline	E10	E20	Gasoline	E10	E20	Gasoline	E10	E20
Ford Truck Pump (90-93)	0.23	0.19 [1]	0.30	0.056	0.041 [1]	0.021	0.001	0.001 [1]	0.001
Toyota Camry 92-94	0.40	0.41	0.40	0.043	0.012	0.015	0.000	0.000	0.001
Jeep Wrangler (99-00)	0.40	0.40	0.40	0.042	0.011	0.014	0.000	0.000	0.000
GM Port Injection (99-02)	No Comparison [2 3]			No Comparison [2 3]			No Comparison [2 3]		
Honda Accord Sedan (03-06)	0.39	0.42	0.42	0.002	0.002	0.002	0.001	0.000	0.000
GM TBI Pumps (87-92)	0.36 [4]	0.38	0.38	0.004 [4]	0.011	0.013	0.020	0.002	0.002
Volkswagen (93-94)	0.37	0.38	0.38	0.106	0.028	0.035	0.000	0.000	0.000
GM Rollervane PFI (90-92)	0.33 [5]	0.39	0.36	0.068 [5]	0.008	0.004	0.001	0.000	0.000
Overall Average	0.35	0.37	0.38	0.046	0.016	0.015			

	Gear to Rotor in Inches			Rotor to Housing in Inches		
	Gasoline	E10	E20	Gasoline	E10	E20
Ford Truck Pump (90-93)	0.0089	0.0125 [1]	0.0139	0.0028	0.0035 [1]	0.0036
Volkswagen (93-94)	0.0118	0.014	0.011	0.0013	0.0016	0.0027

Notes:

[1] Ford pump (E10) could not produce the required pressure at the 4032-hour interval.

[2] GM port pump (E10) stopped completely after hour 3024.

[3] GM port pump (E20) stopped completely after the 504-hour interval due to procedural error and ingestion of debris.

[4] GM TBI pump (gasoline) stopped completely after hour 2520.

[5] GM rollervane pump (gasoline) could not produce the required pressure at hour 4032.

APPENDIX 14

SENDING UNIT RESISTANCE AND VOLTAGE

Jeep Sending Units		Resistance (Ω)		Voltage		Signal Drop Out
		Top	Bottom	Top	Bottom	(Yes/No)
Gasoline	Before	248.8	40.2	1.03	0.2	No
	After	OL	OL	N/A	N/A	Yes
E10	Before	251.4	40.6	1.03	0.2	No
	After	10000	268	1.14	0.4	Yes
E20	Before	279.4	40.3	1.03	0.2	No
	After	150000	13000	4.86	1.35	Yes

Honda Sending Units		Resistance (Ω)		Voltage		Signal Drop Out
		Top	Bottom	Top	Bottom	(Yes/No)
Gasoline	Before	1.224	0.4674	2.77	1.64	No
	After	69000	58900	4.41	4.405	Yes
E10	Before	1.37	0.608	2.87	1.81	No
	After	920	280000	2.453	0.845	Yes
E20	Before	0.784	0.021	2.23	0.1	No
	After	700	280000	2.237	0.558	Yes

GM Port Sending Units		Resistance (Ω)		Voltage		Signal Drop Out
		Top	Bottom	Top	Bottom	(Yes/No)
Gasoline	Before	277.8	20.1	1.08	0.1	No
	After	OL	13000	1.02	0.3	Yes
E10	Before	270.2	20.2	0.86	0.1	No
	After	OL	275	1.89	1.39	Yes
E20	Before	270.3	20.1	1.1	0.1	No
	After	OL	400	1.05	0.287	Yes