Review and Evaluation of Studies on the Use of E15 in Light-Duty Vehicles

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Engine and Fuel System Durability

Introduction and Background

Studies reviewed involved soaking or operating fuel system components, engines, or whole vehicles on E15 or E20, typically with a control group operating on E0 or on E10 (or corresponding test fluid). It is important to note that in comparison to material compatibility testing fuel system and engine durability testing adds another level of complexity because of the following factors:

- The large number of different makes and models of vehicles each of which may react differently to different fuels, even when limited to MY 2001+, making it difficult to use individual tests to provide fleet-wide estimates of the impact of changing fuels. The most comprehensive test reported here included only 27 different make/model/model year combinations.
- Only a very low failure rate is acceptable. A recent CRC document states that OEMs typically consider parts failure rates of less than one in one thousand acceptable.[1] Testing of a thousand or more repeats of each different component would be necessary to ensure this level of dependability in a statistically defensible manner. Many of the tests here included no replications; the most was 6 of the same component in the same fuel.
- The high cost of testing components, engines, and entire vehicles is a severe practical limitation. Engines and vehicles may cost $15,000 or more per test and even small components can represent significant expense. Then it is necessary to add in the cost of developing and building systems to operate the components or vehicles for an extended time period to represent a lifetime of vehicle operation.

In addition, the issues associated with choosing appropriate test and control fluids and scaling up short term testing results to long term predictions are applicable.

Discussion

Fuel System Component Durability. The CRC published two reports on fuel system component testing intended to identify the most sensitive components and vehicles. The first, CRC Report No. 662,**Error! Bookmark not defined.** reported on pilot testing using Modified Aggressive TF20 on a selection of fuel pumps, fuel dampers, level senders, fuel injectors and entire fuel system rigs in an attempt to identify sensitive parts for further testing. Testing was done on new components sold as service parts for MY 1996 to 2009 vehicles and purchased from local OEM dealerships. Design changes may have occurred since the original designs, and thus the tested parts may not be exactly the same as those originally installed in the vehicles.

The complete fuel system rigs were tested on all fuels, but for the other components only some of those tested on Modified Aggressive E20 were tested on either E10 or E0. Generally, the only components which were tested on E10 were those which did poorly on Modified Aggressive TF20. These strategies, while understandable from a cost perspective, can mask the possibility that failures are due to random component defects or excessively harsh test fluids or test conditions rather than fuel effects. Additionally, when comparing the results of Modified Aggressive TF20 with E10, it is necessary to consider whether the differences were due to changes in ethanol content or due to the additional acids in Modified Aggressive TF20. Some qualitative differences attributed to differences in fuels were found on visual inspection of fuel system rigs after testing, but nothing significant enough to lead to the loss of pressure over the test period.

Fuel pumps were tested in a soak test and an endurance test, which included operation of the pump. All ten soak durability tested fuel pump models were tested on the Modified Aggressive TF20, three were tested on Modified Aggressive TF10 and one on E0. None of the tested pumps failed, defined as a decline in flow rate of more than 30%. The endurance aging study was conducted on eight pumps. Three of the pump models tested in E10 showed a lesser decline in flow rate than the Modified Aggressive TF20 pump, one showed a greater decline in flow rate. Only one pump model (Pump A) exceeded the acceptable 30% flow rate loss, and it did this in both Modified Aggressive TF20 and regular E10, but not when tested in E0.

Eight different fuel level sender models were tested in two different aging protocols with Modified Aggressive E20. A selection of these models were retested in E10 and E0 on one or both tests, but there was no explanation as to why the specific models were selected for testing in E10 or E0, although generally those that had no problems operating in Modified Aggressive E20 were not (with one exception) retested in E10 or E0, and those which failed on both Modified Aggressive TF20 and E10 were not tested on E0. Thus, only three models were tested in E0, and these were tested on only one of the aging protocols, but all passed. Some testing was done in replicate, although there is no consistent or stated strategy. The results are presented as a qualitative description, and so in some cases it is not clear which senders exhibited unacceptable levels. Only two out of the eight senders exhibited no problems at all in Modified Aggressive TF20 in either test, but given the uneven testing strategy it is not possible to compare these results summarily to those in E10 and E0.

Two fuel dampers, both of the same make and model were tested in all three fuels. No difference associated with test fuels was found. Four injectors of each of three models of fuel injector were tested on Modified Aggressive E20 for 600 million cycles. The report concludes that “neither showed any significant difference between pre- and post-aging dynamic response”.

Based on these results the CRC identified fuel pumps and fuel senders as potentially more sensitive than other parts to ethanol content in fuel and so conducted additional testing on those components which was reported in CRC Report No. 664.[1] CRC Report No. 664 does not identify the source of the specific parts only that they were from one of the following five popular vehicles: 2007 Nissan Altima, 2001 Chevrolet Cavalier, 2004 Ford Focus, 2003 Nissan Maxima and 2004 Ford Ranger.

The same laboratory test protocols were followed in this round of testing with fewer models and more replicates. One fuel pump model Vehicle N (of the three tested) failed with Modified Aggressive TF20, Modified Aggressive TF15, and E15 but not with E0 or E10 on soak durability. Interestingly, the same part did not fail in CRC 662 when tested on Modified Aggressive TF20 or TF10, although it was one of the more sensitive pumps of the ten tested in terms of loss of flow rate. During teardown they found vanes of the impeller had been damaged and measuring impeller thickness they found greater variation in width with impellers tested on E15 and Modified Aggressive TF15, than those tested on E0. Six fuel pumps each from two vehicles were also tested for 3000 hour endurance tests in E15 and Modified Aggressive TF15 (did not include Pump from Vehicle N which failed in soak test). Results showed six out of six pumps tested failed in E15, and six out of six in Modified Aggressive TF15. No failures were found in E0. However, since no testing was conducted in E10 or Modified Aggressive TF10, we cannot draw any conclusions regarding the difference in impact between E10 and E15. Vehicle N fuel pumps were retested with E15, Modified Aggressive TF15 and Modified Aggressive TF20 after the results from the other experiments were available. No control E0 or E10 was used for this last round of testing. While failures were observed for Vehicle N fuel pumps in work reported in CRC Report No. 664, the fact that the same pump model operated without failure on E15 in work reported in CRC Report No. 662 renders these results inconclusive.

Three fuel level senders, six replicates each, were tested in E15 and Modified Aggressive TF15. While not consistent and not found in all samples tested, there were some effects on the sender operation. However, since control tests on E10 and E0 were not conducted there is no evidence that these fuel level senders were adversely affected by the higher ethanol content in E15.

However, it should be noted that Pump N was selected as the result of a program to find the most ethanol sensitive pump available. It is not representative of most pumps on the road. No analysis of the ethanol used in this program was included and it presumably did not include corrosion inhibitors, normally considered standard for commercially available ethanol. The certificate of analysis for some of the fuels used in the testing had expired. In light of these irregularities, and considering the results described above on material compatibility testing that showed that differences in effects between E15 and E10 were consistently small and in many cases impossible to detect, results which show six out of six pumps completely failing with E15 and Modified Aggressive TF15 while zero out of six pumps fail under the same conditions with E10 are surprising and potentially worthy of retesting. Unfortunately, the CRC (because of confidentiality agreements with the OEMs) is unable to identify the make or model, or even the materials of either this failed pump or the acceptable components and thus, the benefits of the information in these reports to the general scientific and engineering community are limited.

Similar test procedures were used by the Minnesota Center for Automotive Research[2,3] on fuel pumps and fuel level senders using Reference Fuel C, Aggressive TF10 and Aggressive TF20 (both with Reference Fuel C as base fuel). However, rather than choosing components considered more likely to fail these researchers targeted a "broad sample of high volume vehicles on the road" , by choosing pumps and fuel unit senders from a variety of manufacturers, model years and designs. In the initial soak test individual samples of eight different model fuel pumps and three different model sending units were tested in each fuel. All of the fuel pumps met the performance requirements (J1537) for startup before and after soak. All modern vehicle fuel pumps showed an increase or decrease of less than 20%, which is within the range that is considered normal. Other than that, no trends in flow rate change by fuel were found. Visual inspection found no change in sending units and resistance and voltage drop of the units was unchanged before and after soak.

Following the soak study, an endurance study, in which the same pumps and senders were operated continuously, was carried out. Performance data was collected before the study started and then every 500 hours. At the end of the study the pumps were disassembled and inspected. Four of the pumps failed before the test was completed, two in Aggressive TF10, two in E0. Commutator wear was consistently higher in gasoline than in ethanol fuels, and the less ethanol the more wear. All of the sending units failed over the course of the 4000 hour study. No significant differences between the time of failure and the fuels tested were found.

Engine Durability. The CRC conducted an engine durability study of intermediate-level ethanol blends effects on several models of current, on-road non-Flexible Fuel Vehicles (non-FFVs).[4] The objective of the study was to assess engine component wear caused by ethanol containing fuels over the course of a 500 hour test cycle simulating 100,000 miles of operation. Engines were tested with E20 and if a failure was observed then tested on E15. Vehicles which failed on both E20 and E15 were tested on E0.

There are several characteristics of standard engines which might be sensitive to higher ethanol content in fuel.[5] Some valve seat materials are claimed to be sensitive to ethanol and can experience increased wear. An increase in valve seat wear can lead to a variety of problems including valve leakage, valve burning, compression loss, misfire, power loss, and catalyst damage. Also, it is possible that increased solvency of lubricants in ethanol containing fuels, could result in an increase in bore and ring wear, leading to increased blow-by, oil consumption and compression and power loss. Finally, if ethanol caused an increase in engine exhaust temperature this could be damaging to catalysts. In order to determine how significant these effects could be for modern non-flexible fuel vehicles, the CRC conducted a durability test program on eight different vehicle models.[4]

As failures among typical vehicles are expected to be rare, the CRC testing was intended to maximize the number of failures in order to make it possible to differentiate between fuels. Several technologies have been developed to improve valve and valve seat performance in modern engines. In order to include the vehicles most likely to have valve problems, the CRC specifically chose vehicles that did not utilize these technologies and were more likely to experience valve problems. They specifically chose engines with the following characteristics:

- Mechanical valvetrains; these designs have the smallest ability to accommodate valve and valve seat wear
- Hydraulic lash adjuster valve trains; these designs also can tolerate only small changes in valve and valve seat wear if they are designed to only allow a small amount of travel.
- Valve trains using less than top grade valve materials

The list of vehicles is included in Table 3 below.[4] This list included several engines already known to have durability issues, including one that was subject to a recall involving valve problems when running on E0 and E10.[6] The vehicles selected were all recruited from the used car market.

Table 3. Vehicle / Engine data for the CRC engine durability study.

Vehicle	Emissions	Valve Train Design	Mileage for E20 vehicles*	OEM specified acceptable leakdown rate [7,8,9,10,11,12,13,14]
2001 Honda CR-V, 2.0L I4	Tier 1 NLEV	Rocker arm, threaded adjuster	71,412/110,681	No leakdown specification provided
2002 Volkswagen Jetta, 2.0L I4	Tier 1 NLEV	Direct acting, hydraulic	77,891/106,761	No leakdown specification provided
2004 Scion xA, 1.5L I4	Tier 2 Bin 9	Direct acting, mechanical	61,351/56,671	No leakdown specification provided
2005 Chevrolet Colorado, 3.5L I5	Tier 2 Bin 9	Roller finger follower, hydraulic	48,109/33,972	“Cylinder leakage that exceeds 25% is considered excessive and may require component service.”
2007 Ford Edge, 3.5L V6	Tier 2 Bin 5	Direct acting, mechanical	17,906/14,450	“Leakage exceeding 20% is excessive.”
2007 Dodge Ram, 5.7L V8	Tier 2 Bin 5	Pushrod, hydraulic	28,597/26,078	“All gauge pressure indications should be equal, with no more than 25% leakage.”
2009 Dodge Caliber, 2.4L I4	Tier 2 Bin 4	Direct acting, mechanical	11,941/12,494	“All gauge pressure indications should be equal, with no more than 25% leakage.”
2009 Chevrolet Aveo, 1.6L I4	Tier 2 Bin 5/4	Direct acting, mechanical (but service literature references 2nd running change design to hydraulic lash adjuster; type is not documented by CRC)	8,327/3,758	No leakdown specification is provided, and leakdown is not even referenced as a diagnostic tool / method.

*CRC did not report initial mileage for vehicles tested on E15 or E0.

The test cycle selected for this study was a modified engine durability cycle from an unspecified OEM. The durability test cycle schematic published in CRC's report does not contain enough detail to allow it to be independently reproduced, likely to protect OEM intellectual property.[4] In particular, loads (even in terms of manifold vacuum) and details describing the 1-2-3 wide open throttle (WOT) accelerations are absent.

The cycle was modified to limit maximum engine speed to less than 3500 rpm. The speed limitation was intended to "significantly reduce the test severity making it more likely that the test engines will complete the test without failures unrelated to the test objective" (i.e. the intention is to show fuel related failures) but it also had the effect of increasing the likelihood of valve damage, because low speed operation may decrease valve rotation rates and valve rotation is used to clean deposits off the seat, continuously spread the lubricant around the seating and distribute wear and pitting uniformly around the seat. Some scientists have suggested low speed operation decreases oil pullover[15] potentially also increasing wear.

The final CRC report[4] did not state how the (simulated) vehicle data was specified for the engine dynamometer durability test cycle, notably what vehicle and trailer weights were used. So it is not clear if CRC used weights proposed in their Request for Proposals of "vehicles at 80% of GVW or 80% GVW plus 80% of allowable trailer weight for those that allow trailers".[5] The final CRC report only states: "Relating test cycle duration to vehicle mileage involves vehicle weight and tow capacity, transmission and final drive gear ratios, and engine power and torque curves. Nonetheless, the test cycle used should correlate with ~100,000 miles of vehicle usage."[4] The durability cycle was run with engines removed from vehicles and tested on engine dynamometers with umbilical systems to utilize the OEM Engine Control Module, which was retained in the vehicle.

The engines were tested for the following before and after the 500 hour durability cycle for the following parameters

E = emissions during FTP75 (mostly vehicle, but a few test were conducted on the engine dynamometer)

D= presence of diagnostic trouble codes,

V= valve clearance measurement out of OEM specification,

C = compression measurement, compared to OEM specification,

L= leakage measurement on at least one cylinder above 10%

Results are shown in Table 4. Vehicle 8 failed on all fuels and these results were not included in subsequent statistical analysis based on the idea that the test cycle was too severe for this particular engine model because it was sensitive to the low engines speeds with respect to valve rotation. Vehicles 2 and 3 both exhibit failures on E15 for leakdown and Vehicle 2 also fails for emissions.

Table 4. Summary of Engine Durability Test Results

	E20		E15		E0	
	Sample A	Sample B	Sample C	Sample D	Sample E	Sample F
Vehicle 1	Waived**	Pass				
Vehicle 2	Fail (L)	Fail (L)	Fail (E)	Fail (L)	Pass	Pass
Vehicle 3	Pass	Fail (V,L)	Fail (L)	Pass	Pass	Pass
Vehicle 4	Waived* (L)	Pass				
Vehicle 5	Waived* (E,D)	Pass				
Vehicle 6	Waived* (L)	Waived* (L)				
Vehicle 7	Pass	Pass				
Vehicle 8	Fail (E,C,L)	Fail (C,L)	Fail (E,L)	Fail (C, L)	Fail (E,C,L)	Fail (E,C,L)

*Waived = Vehicle did not pass specified criteria, but after OEM teardown decision was made not to retest vehicle on E15 or E0

** According to the study text, Vehicle 1, Sample A "The Engine dynamometer based EOT emission test was waived after technical challenges prevented comparison of the SOT [start of test] and EOT [emission data]."

EPA permits emissions to degrade over the life of the vehicle and emissions are not expected from a regulatory standpoint to meet standards beyond what is considered full useful life of the vehicle, which is typically on 120,000 miles for Tier 2 vehicles and 100,000 for Tier 1 vehicles. The vehicles in this study ranged from 2001 to 2009 model year and were selected to have accumulated no more than 12,000 miles per year. Thus, the older vehicles in this study may have greatly exceeded equivalent full useful life during the course of the 500 hour durability test cycle, given that it was intended to simulate approximately 100,000 miles of use; and thus should not be expected to meet emission requirements. Even the 2009 model year vehicles, assuming they were tested during 2011, could have exceeded full useful life mileage.

The selection of leakdown loss of 10% or less as passing is very significant in the analysis of the data. All of the vehicles which failed for leakdown, with the exception of Vehicle 8, had leakdown values of 22% or less on the worst performing cylinder. As seen in Table 3, Honda[7] and Scion[9] do not specify leakdown in their service literature. VW also states no OEM leakdown specification, instead stating, "leakdown limit specifications are usually supplied by the equipment manufacturer,"[8] referring to the leakdown testing equipment. Ford specifies leakage exceeding 20% to be excessive and that leakdown be used as part of a comprehensive analysis including other measurements.[11] Chrysler specifies no more than 25% leakage.[12,13] General Motors specifies 25% leakage to be excessive for the Chevrolet Colorado in its manual,[10] but specifies no limit and does not reference the use of leakdown testing diagnostics for the Chevrolet Aveo.[14] To further complicate the issue, diagnostic instructions related to an intake valve seat recall on the Chevrolet Colorado (one of the vehicles studied), General Motors recommended using the leakdown test to find the leak path, and did not specify a threshold acceptable leakdown number.[16]

CRC used the same Snap-On® EEPV309A leakage tester for all measurements in the study. The owner's manual for the Snap-On® EEPV309A leakage tester provides a summary for its use: "*The cylinder leakage tester is a useful diagnostic test, however, it is a test for which vehicle manufacturers do not provide* *specifications. Due to standard engine tolerances and normal wear, no cylinder will maintain 0% leakage. Engines with larger cylinders diameters will tend to show a larger percentage of leakage than engines with smaller cylinder diameters, given that both engines are in the same condition. Because of these factors, this tool is best used to compare a suspect cylinder to a known good cylinder on the same engine."*[17] The use of leakdown testing as a qualitative diagnostic tool is most valuable to identify a suspect cylinder (higher leakage than other cylinders) and locate the leak path (intake, exhaust, crankcase, water jacket, or to an adjoining cylinder) to troubleshoot the issue. Ford reinforces this diagnostic methodology in their service manual.[11]

Engines found to fail leakdown in the report were torn down and evaluated. However, since the valve seats were not inspected prior to the 500 hour/100,000 mile durability test and some of the vehicles had potentially more than 100,000 miles on them at the start of testing, it does not seem possible to determine what valve seat damage was done during the test period with the test fuel, and what was done prior to the test.

Oak Ridge National Laboratory explored the limitations of both leakdown and compression testing, concluding they are "not useful in their present forms for monitoring incremental changes in engine leakage".[18] In contrast, CRC selected a 10% leakdown failure limit, more restrictive (50% below) than that of the lowest value specified by OEMs for engines in the study. Unfortunately, CRC did not report the leak path (intake, exhaust, crankcase, water jacket, or adjoining cylinder) for any of the engines that were deemed to have failed due to leakdown. The diagnostic values that may have linked engine failure to possible ethanol effects (intake valve) versus likely unrelated failures (water jacket or adjoining cylinder) were not reported.

Based on the factors discussed above, the conclusion that engines marginally failing emissions beyond full useful life, or showing cylinder leakdown between 10% and 25%, have experienced a fuel related mechanical failure is not supported by the study data.

The report also included a statistical analysis of the data. The purpose of the analysis was to determine whether the failure rate was associated with the ethanol content of the fuel, or some other variable. However, the values used in the analysis assumed that every vehicle that passed on E20 also passed on E15 and E0. Assumed values were put in for vehicles that were not tested, and those values had a consistent bias in relation to the question that the analysis was intended to determine. The analysis did not include testing on the 8th vehicle, which failed on all fuels. If all of the actual test results (i.e. including Vehicle 8), and only those values are used for the analysis, there is a 32% chance that E15 and E20 failures are completely unrelated to ethanol content, as opposed to the 7% chance that is asserted in this report. Moreover, at the very simplest level, 5 out of 16 tested vehicles failed on E20 – 31%; 5 out of 6 on E15 – 83%; and 2 out of 6 tested vehicles failed on E0 - 33%.

Almost half of the vehicles (Vehicles 4, 5, and 6) in the initial E20 tests were treated as Passed, not due to the quantitative criteria initially chosen for the study, but rather on an assessment of the engine at end-of-test (EOT) by different OEMs – which may or may not be consistent with the OEM inspections done on Vehicles 2, 3, and 8 – which Failed. Vehicle 4 failed leakdown and was passed based on the recommendation of the OEM and noting that leakage was 11%. Vehicle 5 failed emissions and had a related DTC, however the OEM stated that there were known catalyst problems with Vehicle 5 and that the type of failure observed was not caused by increasing ethanol content of the fuel. Vehicle 6 (both engines A and B) failed for leakdown but upon engine tear down the valve seats did not show any abnormal deposits or wear and were acceptable to the OEM. Because these failures were determined by the OEM to not be fuel related, these engines would be equally likely to fail with testing on E15 or E0.

Whole Vehicle Testing. Two programs operated relatively large numbers of vehicles for extended times on various ethanol concentration fuels. The first, at the University of Minnesota[19], conducted from 2006 to 2007 included 40 pairs (80 total) of similar 2000 to 2006 model year vehicles with matched usage patterns. One of each pair was fueled with commercially available E0, and the second set was fueled with E20 (additional ethanol splash blended with commercially available E10). The fuels did not have the same hydrocarbon base fuel. Over the 13 month test period no additional fuel related maintenance problems emerged in the E20 fuelled vehicles. Two vehicles in the program had check-engine lights illuminate. In one case, the fuel system pressure regulator failed. The shop manager indicated that this was a common problem with the specific make and model. The other case involved mice damaging the electronic control unit. The data presented in this study does not show any performance differences between E10 and E20.

In the second program[20], the Oak Ridge National Laboratory and the National Renewable Energy Laboratory conducted an extensive aging study on 82 MY 2000-2009 vehicles. The primary purpose of the testing was to assess the effect of different fuels on catalyst aging. Four vehicle pairs were aged with E0 and E15. Five vehicle sets, each comprising four matched vehicles were aged with E0, E10, E15 and E20. The remaining eighteen vehicle models were aged with E0, E15 and E20. Vehicles were aged at least 50,000 miles using EPA's Standard Road Cycle (SRC) at three different facilities, the Southwest Research Institute, the Transportation Research Center, and Environmental Testing Corporation.

Unscheduled maintenance was logged, and affected equipment was removed and analyzed for potential fuel effects. Transmission, spark plug and radiator failures were unrelated to fuel use. Possible impacts on tailpipe emissions systems are discussed elsewhere. However, impacts on the fuel supply system include the replacement of two fuel pumps in 2001+ MY vehicles (plus a fuel pump and a fuel level sender in a 2000 MY vehicle). The first was in a 2006 Chevrolet Silverado, the second was in a 2006 Chevrolet Cobalt. Upon further inspection both failures in these used cars were determined to be unrelated to fuel effects by the researchers. In addition, an evaporative emissions hose, believed to be made of nitrile rubber, failed on a 2002 Dodge Durango. No differences could be detected between the inside and the outside of the hose, so the failure was attributed to general aging, rather than fuel effects. All three (E0, E15 and E20) 2006 Chevrolet Impalas experienced canister vent solenoid failures, that were determined to not be fuel related given that failures occurred on all fuels.

After vehicle aging was complete the ORNL did a tear-down study[21] of eighteen (six makes and models from the model years 2006 to 2008, each run on E0, E15 and E20) of the vehicles. Of greatest concern with the E15 vehicles was an increase in intake valve deposits (IVD) which authors attribute to the fact that the detergent in the gasoline was diluted by ethanol. The weight of IVD in vehicles run on E15 was higher than that of those run on E0 and E20 was generally higher than both. While normally BOBs are dosed with the appropriate detergent level to account for the added ethanol that was not done for the test fuels in this study. The integrity of the emissions system was pressure checked and all of the tested systems maintained pressure. Valve seat width and valve surface contour were assessed and no differences were found between fuels. Fuel injector flow rates were equivalent to within +/- 3%. The evaporative canister working capacity shows a slight decreasing trend with higher ethanol content fuels for two of the six vehicles. Fuel tanks, fuel lines, and evaporative emissions lines were visually inspected and no "serious differences" between E0, E15 and E20 were reported. Effects on cam lobe wear, valve stem height, and valve seals were measured but the results were considered inconclusive because similar measurements were not made at the beginning of the study, before mileage accumulation.

Lubricating oil consumption was measured over the course of the testing. One of the 2007 Honda Accords was found to use excessive levels of lubricating oil when operating on E10 and the vehicle was replaced in the test program. Engine oil drain samples were monitored several times over the course of the test. There was no evidence of excessive metals in any of the engine oil samples. There were no statistically significant differences in oil consumption attributed to the ethanol level in the fuel.[22]

Analysis

Four studies of fuel system component durability, one of engine durability, and two whole vehicle studies were reviewed.

The fact that E10 comprises more than 95% of the US commercial fuel market suggests that it is the appropriate control fuel for testing. The use of E0 in place of E10 as the control fuel is not appropriate, because various studies have demonstrated that the effects of ethanol are not linear. There is a much more significant difference between E0 and E10 than between E10 and either E15 or E20 as shown in material compatibility testing. If a study tests E15 or E20 in comparison to E0 and sees no negative effects of ethanol, then the E10 control may not be necessary. If, on the other hand, E15 or E20 cause problems, it is unclear if the problems are caused by higher levels of ethanol in the fuel or if they are caused by other factors such as test components not being compatible with E10, the dominant marketplace fuel. If a component is incompatible with E10 then it would be logical to assume that it will be equally incompatible with blends marginally higher than E10 such as E15.

Component durability studies used aggressive test fluids with undefined acceleration factors and poorly understood connection to real world fuels, as described above in the Materials Compatibility section. Two CRC studies employed a Modified Aggressive Ethanol that contained nitric and hydrochloric acids in place of sulfuric acid.[Error! Bookmark not defined.,1] The recipe for Modified Aggressive Ethanol is shown in Table 1, and compared to commercial ethanol samples and Aggressive Ethanol in Table 2, both presented in the previous section. The stated reason for using nitric and hydrochloric acids was to reduce the sulfate content, to below that of the requirement set in D4806, and raise the chloride content to closer to the

D4806 limit. CRC stated it was essential to keep the pHe low even though the resulting value was far lower than the allowable D4806 value, and so added nitric acid instead of sulfuric.

The use of nitric acid in CRC's Modified Aggressive Ethanol is a concern, since nitric acid is both a strong acid, and an oxidizing agent. Sulfuric acid can also act as an oxidizing agent, but not at the low concentrations in J1681 Aggressive Ethanol. Copper, in particular, reacts with nitric acid, while being impervious to sulfuric acid at the low concentrations in Aggressive Ethanol. Elastomers are also consistently less resistant to nitric acid than sulfuric acid as shown in the table below. The table considers solutions several orders of magnitude more concentrated than those in Aggressive Ethanol and Modified Aggressive Ethanol, but this was the best comparison information available and is representative of the relative reactivity of the two acids in the presence of elastomers. Modified Aggressive Ethanol, with its lower pHe and the use of nitric acid in place of sulfuric acid, is expected to have more severe effects on many materials than Aggressive Ethanol.

Table 5. Compound compatibility rating with sulfuric acid (used in Aggressive Ethanol) versus nitric acid (used in Modified Aggressive Ethanol) from Parker O-Ring Handbook.[23] 1= Satisfactory, 2=Fair (usually OK for static seal), 3=Doubtful (sometimes OK for static seal), 4=unsatisfactory.

	Nitrile NBR	Hydrogenated Nitrile HNBR	Ethylene Propylene EPDM	Fluourocarbon FKM	Hifluor FKM	Perfluoroelastomer FFKM	Neoprene/Chlorprene CR	Styrene-Butadiene SBR	Polyacrylate ACM	Polyurethane AU, EU	Butyl IIR	Hypalon CSM	Fluorosilicone FVMQ	Silicone MQ,VMQ,PVMQ
Sulfuric Acid (3 Molar)	2	2	1	1	1	1	2	3	2	4	1	1	1	1
Nitric Acid (3 Molar)	4	4	2	3	2	2	4	3	4	4	2	2	4	4

One engine durability study was considered in this review.[4] The study concluded that two popular gasoline engines used in 2001-2009 model year vehicles experienced mechanical failure when operated on E15. Care should be used when drawing any conclusions about the likelihood of engine failure on E15 based on this study as it employed an engine test cycle where engine speeds are not high enough to produce valve rotation. Regular valve rotation is an integral part of engine operation, intended to equalize the wear around the entire valve and thus reduce the possibility of valve failure. Moreover, it appears likely that in order to increase the likelihood of failures, vehicles were selected that were expected to be particularly sensitive to valve damage. No E10 control was used to compare the effect of E15 to the normal in-use fuel in the United States, and E0 testing was only conducted on a small subset of the vehicles in the study. The study applied a leakdown failure criterion of 10%, which is inconsistent with shop manuals for these vehicles. A more typical OEM accepted leakdown rate of 20 to 25% would have significantly reduced the number of E15 and E20 failures. More importantly, leakdown is more typically used to locate a leak or for other diagnostics and is not a common metric for mechanical engine failure. Engines failing the 10% criterion were torn down to evaluate valve wear, but no baseline data on the state of valve wear at start of test were collected. Finally, the statistical analysis was conducted using assumed data from tests that were not run, and disregarded test data from Vehicle 8.

Two whole vehicles tests used transparent and standard methodology.[19,20] The first was a comprehensive catalyst durability study of 82 vehicles operated for at least 50,000 miles using EPA's standard road cycle and the second was conducted on a university fleet in normal use. Neither vehicle set showed any evidence of increased maintenance or component failure associated with operation on E15 or E20. These studies were not intended to stress the engine or fuel system components, nor did they attempt to test every type of vehicle, some of which may be more sensitive to ethanol damage.

The conclusion that engines will experience mechanical engine failure when operating on E15 is not supported by the data presented in these studies.

Findings

The CRC studies were designed to identify and test vehicles and components "potentially sensitive to gasoline fuels containing ethanol at concentrations greater than 10 volume percent".[4] Pilot testing using aggressive test fuels (including acids which are potentially more damaging than those included in J1681 Aggressive Ethanol) was used to narrow down the fuel system components most likely to be affected in the fuel system. One pump, identified as Pump N, was shown to have a greater failure rate with standard E15 in comparison to standard E10 in one study, yet did not fail on Aggressive TF10 or Aggressive TF20 in a previous study, and thus the results are inconclusive.

The conclusion that engines will experience mechanical engine failure when operating on E15 is not supported by the data presented in these studies. However, these tests did not include all existing makes and models of 2001+ MY vehicles on the road, and there may be certain components or vehicles which are more susceptible to damage from higher ethanol content fuels. Moreover, vehicle tests which include only eighty vehicles are not adequate to ensure that individual component failure rates will be below the 1 in 1000 rate that OEMs typically expect over the warranty life of a vehicle.

Over two-hundred million vehicles on the road today regularly use E10 without experiencing systemic fuel-related component or engine failures. While higher levels of ethanol may have some effect, the evidence from the material compatibility testing suggests that differences between E10 and E15 are small in proportion to the difference between E0 and E10, and yet there was little impact noted as the fuel supply changed over from 1.6 billion gallons in 2000 to over 13 billion gallons in 2012.[24]

There is insufficient data to statistically support a failure rate prediction. Also, without knowing the test methods and selection criteria used by OEMs in designing the vehicles it is difficult to extrapolate the results of these studies to real world expectations and performance. What these studies can do is to indicate whether or not E15 could cause much larger numbers of failures in a range of vehicles, and/or point out specific components or vehicles which are sensitive to higher ethanol concentrations. Overall, the results showed no evidence that E15 will cause widespread failures, and in the search for sensitive components found a single unidentified pump model which, based on an inconclusive result, may be sensitive to higher ethanol concentrations in fuel formulations.

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