

Investigating Malfunction Indicator Light Illumination Due to Increased Oxygenate Use in Gasoline

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ABSTRACT

The Energy Independence and Security Act of 2007 requires the U.S. to use 36 billion gallons of renewable fuel per year by 2022. Domestic ethanol production has increased steadily in recent years, growing from less than 5 billion gallons per year (bgpy) in 2006 to over 13 bgpy in 2010. While there is interest in developing non-oxygenated renewable fuels for use in conventional vehicles as well as interest in expanding flex-fuel vehicle (FFV) production for increased E85 use, there remains concern that EISA compliance will require further use of oxygenated biofuels in conventional vehicles. The Environmental Protection Agency (EPA) recently granted partial approval to a waiver allowing the use of E15 in 2001 and newer light-duty vehicles. Despite EPA's determination that E15 will not contribute to increases in full-useful life emissions in these vehicles, there remains concern amongst some vehicle manufacturers that the vehicle malfunction indicator light (MIL) may be displayed (or activated) due to increased use of oxygenates in gasoline. Similar concerns also exist for isobutanol and isopentanol, which are emerging as potential blending components for future gasoline formulations. This paper describes a test program in which increasing amounts of ethanol were added to gasoline to gradually increase the long term fuel trim (LTFT) until the MIL was displayed. When the MIL was activated, the threshold LTFT was recorded. Vehicles used in the MIL study were also used in the recently completed Department of Energy Catalyst Study (during which they were exposed to ethanol blends up to E20). No incidence of fuel-related MILs occurred during the 2 year catalyst aging program on the 86 vehicles from six of the largest manufacturers (Chrysler, Ford, GM, Honda, Nissan, Toyota). In the current MIL study, vehicles were driven on a specified 4-day cycle with multiple cold starts, idles, and hot soaks. Ethanol levels were increased steadily until the MIL was activated. Estimates of the rate of increase of LTFT as the fuel oxygen content increased were also determined. LTFT MIL thresholds were determined to vary from 18% to 38%, with the rate of LTFT increasing between 4-5% for a 10% increase in the ethanol blend level (or 3.5% oxygen in the fuel). These data were utilized in combination with statistical data on LTFT variability and mean values determined by the CRC E-90 study to project an estimate of the MIL activation frequency for the vehicle models tested in this study when they are used with 10%, 15%, and 20% by volume ethanol blends, and for equivalent oxygen content in blends of butanol and pentanol. A sensitivity analysis was also conducted to examine the relative importance of the variables to the estimated MIL occurrence rates for each vehicle. The results show that some vehicles are likely to exhibit some MIL illumination events when using E10, while others are estimated to have few, if any, MILs illuminate with E20. In general, the estimated rate of MIL illumination increases as the ethanol blend fraction increases, although in some cases few, if any, MIL illuminations are predicted. The results show that the greatest frequency of MIL activation is expected for vehicle models that utilize an LTFT threshold of 20% or less for MIL activation.

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INTRODUCTION

Utilization of biofuel is rising in the United States, due largely to the statutory requirements put in place by the Energy Independence and Security Act (EISA) of 2007.

EISA specifies that the U.S. will utilize 36 billion gallons per year of biofuel by the year 2022 [1]. Compliance with EISA requires taking advantage of many opportunities to increase biofuel utilization.

Increasing the utilization of ethanol in flex-fuel vehicles (FFVs) is one means of displacing gasoline use and increasing ethanol consumption. The FFV market represents a largely-untapped resource that could accommodate an additional 5-9 billion gallons of ethanol use per year (depending on assumptions) if the vehicles were routinely fueled using E85 instead of gasoline. Additional growth potential is expected as the number of FFVs in the fleet increases [2]. Data from the Energy Information Administration (EIA) shows that less than 1% of the 13 billion gallons of ethanol consumed in 2011 were sold as E85 [3]. However, increasing the FFV utilization of ethanol alone may not be sufficient to meet the EISA biofuel utilization mandates; increased use of biofuels in conventional (non-FFV) vehicles is also required.

Increasing the use of biofuels by conventional vehicles is not as straightforward as could be the case with FFVs. The US light-duty fleet is made up of more than 240 million cars and trucks. Of these 240 million cars and trucks, over 8 million are FFVs and the remainder are conventional vehicles. These conventional vehicles were designed and built to use gasoline fuel with no more than 10% ethanol. A number of oxygenated species have been added to gasoline over the years, the most notable being ethanol, which was historically limited to a maximum of 10% by volume in the fuel. Fleet turnover in the U.S. is relatively slow (in 2007 over half of the registered vehicles were 1999 or older [4]), meaning that rapid, substantial increases in the utilization of biofuels other than through the FFV market must necessarily involve the “legacy” vehicles that are already in use but not designed for fuel containing more than 10% ethanol (E10). Increasing the fuel ethanol content (or the content of other alcohols, such as isobutanol or isopentanol) may cause higher occurrences of fuel-related failures or unintended operation in the legacy fleet. There have been a number of studies to date that have investigated the potential for various fuel-related failures in the legacy fleet, including, but not limited to, the emissions control and fuel delivery systems [4, 5, 6, 7, 8, 9, 10, 11, 12].

In particular, one potential issue with increasing the biofuel content of gasoline through the inclusion of oxygenated species (such as alcohols) is the possibility of exceeding the range of authority for the engine control module (ECM) to regulate the air/fuel ratio to stoichiometric conditions. EPA regulations require that the vehicle illuminate the Malfunction Indicator Lamp, or “check engine” display to draw attention to an impending emissions control failure prior to the onset of a non-compliance condition [13]. As a result, if the ECM approaches a condition under which it might not be able to maintain stoichiometric combustion, the MIL should illuminate. The adaptive nature of air/fuel ratio control is utilized, among other reasons, to correct for vehicle-to-vehicle variability due to manufacturing tolerances, fuel formulation variability (including ethanol content up to 10%), and the potential for changes in vehicle subsystem performance due to aging.

Since the addition of alcohols (or other oxygenated species) in higher concentrations adds an increasing level of oxygen to the fuel, the ECM must adapt to this fuel formulation. This adaptation is additive to any trim needed to overcome changes due to system aging or manufacturing variability, and may result in vehicles approaching the limits of the ECM to maintain stoichiometry. A Coordinating Research Council study estimated the rate of occurrence of MILs associated with this problem using statistical information on fuel trim variability gathered from the legacy fleet, but the analysis was limited by the information available on the MIL threshold (level of trim that activates the MIL) [10]. The DOE-sponsored Intermediate Ethanol Blends Emissions Control Durability testing program tested 86 vehicles using fuels containing up to 20% ethanol by volume. No MILs associated with fuel trim levels were experienced during the program [6]. Thus, information about the trim level that causes MIL illumination is still sparse and in need of improvement in order to characterize the MIL illumination potential from the use of increasing levels of oxygenated biofuels in gasoline blends. The study reported in this paper utilized a subset of the vehicles tested in the Intermediate Ethanol Blends Catalyst Durability Study to determine the MIL threshold through tests with increasingly oxygenated fuels.

The ECM often utilizes adjustments in two trim values to control the air/fuel ratio to stoichiometric conditions. These are typically referred to as short-term and long-term trim. Both trims may have multiple values that correspond to different engine load and speed conditions. Long-term fuel trim (LTFT) is most frequently used to adapt the engine to differences in fuel formulation, changes in fuel system performance due to aging, and other longer-period influences on the vehicle systems. Since manufacturers have a broad spectrum of strategies for using these trims in concert with one another, the MIL may be activated by either one or some combination of the two trim levels. For the purposes of this study, the changes in LTFT with fuel oxygen content are investigated. This focus is based on the premise that although increased LTFT alone may not be sufficient for MIL illumination, it is necessary for MIL illumination, and thus, is an appropriate means of estimating fuel oxygen effects on MIL status. This approach is consistent with that used by CRC in their pilot study [10].

EXPERIMENTAL DATA

Test Vehicles

The data reported in this study were gathered using a subset of the vehicles from the DOE Intermediate Ethanol Blends Catalyst Durability program. The 22 vehicle models used for this study are summarized in Table 1. The results from each vehicle are reported according to an anonymous vehicle model number.

Table 1. Test vehicle information.

Model Year	Vehicle Model	Engine Family	Engine Configuration	Emissions Certification
2007	Dodge Caravan	7CRXT03.8NE0	3.8L V6	Tier 2 / Bin 5
2007	Dodge Caliber	7CRXB02.4MES	2.4L I4	Tier 2 / Bin 5
2002	Dodge Durango	2CRXT04.75B0	4.7L V8	Tier 1 / LDT3
2009	Jeep Liberty	9CRXT03.74PO	3.7L V6	Tier 2 / Bin 5
2009	Ford Explorer	9FMXT04.03DC	4.0L V6	Tier 2 / Bin 4
2005	Ford F150	5FMXT05.4R17	5.4L V8	Tier 2 / Bin 8
2009	Ford Focus	9FMXV02.0VDX	2.0L I4	Tier 2 / Bin 4
2008	Ford Taurus	8FMXV03.5VEP	3.5L V6	Tier 2 / Bin 5
2003	Ford Taurus	3FMXV03.0VF3	3.0 V6	NLEV
2003	Chevrolet Cavalier	3GMXV02.2025	2.2L I4	NLEV
2006	Chevrolet Impala	6GMXV03.9048	3.9L V6	Tier 2 / Bin 5
2006	Chevrolet Silverado	6GMXT05.3379	5.3L V8	Tier 2 / Bin 8
2000	Chevrolet Silverado	YGMXT05.3181	5.3 V8	Tier 1 / LDT3
2007	Honda Accord	7HNXV02.4KKC	2.4L I4	Tier 2 / Bin 5
2009	Honda Civic	9HNXV01.8XB9	1.8L I4	Tier 2 / Bin 5
2008	Nissan Altima	8NSXV02.5G5A	2.5L I4	Tier 2 / Bin 5
2002	Nissan Frontier	2NSXT02.4C4B	2.4L I4	NLEV
2006	Nissan Quest	6NSCT03.5G7B	3.5L V6	Tier 2 / Bin 5
2009	Toyota Camry	9TYXV02.4BEA	2.4L I4	Tier 2 / Bin 5
2003	Toyota Camry	3TYXV02.4HHA	2.4L I4	ULEV
2009	Toyota Corolla	9TYXV01.8BEA	1.8L I4	Tier 2 / Bin 5
2005	Toyota Tundra	TTYXT04.0NEM	4.0L V6	Tier 2 / Bin 5

Test Procedure

The test vehicles were operated using fuels of increasing ethanol content on the standard road cycle (SRC). The SRC is an emissions-control aging cycle specified by EPA that includes characteristics of both urban and highway driving [14]. An example speed versus time trace for the SRC is shown in Figure 1. During this cycle, the vehicle experiences a variety of conditions including idle, moderate acceleration, full-throttle acceleration, and cruise conditions. SRC driving was completed using mileage accumulation dynamometers at Southwest Research Institute (SwRI) and Environmental Testing Corporation (ETC), and by driving the vehicles on a closed high-speed test track at the Transportation Research Center (TRC), as was done during the catalyst durability program [6]. As the mileage accumulation facilities at both sites were outdoors, the vehicles experienced a variety of ambient conditions during the course of the testing program.

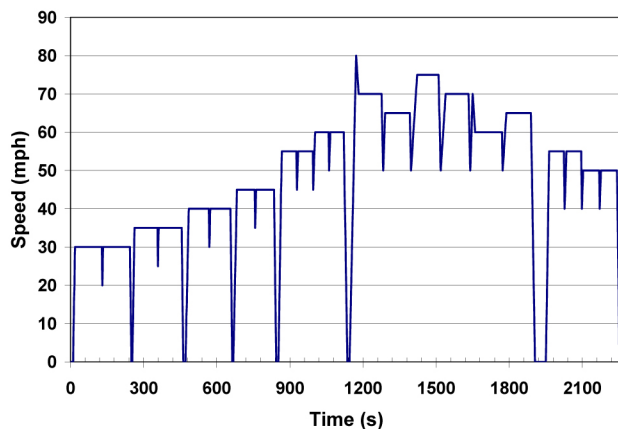


Figure 1. Speed vs. time trace for the standard road cycle for emissions control system aging.

Since the vehicles had previously experienced operation on the SRC using E20 without triggering a MIL illumination, this study began with fuel containing 30% ethanol (E30). If a given vehicle did not set a MIL using E30 throughout the 4-day test sequence, the next fuel tested was E40, and so on, until the MIL was illuminated. If the vehicle was able to run the test sequence using E70 without MIL illumination, the test was ended. The fuels were splash-blends, meaning that fuel properties such as the octane number, distillation, etc, varied according to the ethanol blend. In this case, the fuel ethanol content was used as a means of forcing the vehicles to adjust the fuel trim upwards in response to increasing oxygen in the fuel.

The test vehicles were driven using the SRC over a period of four days, during which operational data was collected via the assembly line diagnostic link (ALDL). The test cycle included multiple SRCs, hot soaks, and idles to meet or exceed specifications for the CRC E-90-2b study [15]. The test cycle used was as follows:

1. Drain and fill fuel tank with ethanol blend

2. Soak 12-36 hours
3. Cold start SRC
4. Engine off soak (20 minutes)
5. Restart - idle 15 minutes
6. Run SRC
7. Repeat 4-6 (total of 5 SRCs)
8. Soak 12-36 hours
9. Cold start SRC
10. Engine off soak (20 minutes)
11. Restart - idle 15 minutes
12. Run SRC
13. Repeat 10-12 (total of 5 SRCs)
14. Soak 12-36 hours
15. Cold start SRC
16. Engine off soak (20 minutes)
17. Restart - idle 15 minutes
18. Run SRC
19. Repeat 16-18 (total of 5 SRCs)
20. Soak 12-36 hours
21. Cold start SRC

22. If no MIL encountered during four-day, 16 SRC sequence, repeat at step 1 with next fuel blend

Thus over a four day test sequence the vehicles experienced 4 cold starts, 16 SRCs (5 per day for 3 days plus one on the last day), and multiple hot soaks and extended idles. The fourth day of testing was omitted for some vehicles. If there were no MILs illuminated by the end of this sequence, the vehicle fuel tanks were drained and re-filled with the next test fuel. In the event that a MIL illuminated, the vehicles were stopped and the MIL investigated. The ALDL data were subsequently evaluated to determine, as best possible, the fuel trim that resulted in the MIL illumination.

The ALDL data were examined to determine the change in fuel trim corresponding to the change in fuel oxygen content and to determine MIL threshold. In some cases the MIL activation criterion appeared straightforward, while in other cases it was not possible to precisely determine the manufacturer's strategy from the data available. In all cases, the LTFT was assessed at MIL illumination under the assumption that reaching a given LTFT value is necessary, but perhaps not sufficient, to illuminate the MIL. Thus, the LTFT threshold occurs just prior to the actual illumination condition in cases where factors other than LTFT impact MIL