

Cold-Start/Warm-Up Vehicle Performance and Driveability Index for Gasolines Containing Isobutanol

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ABSTRACT

Findings from an intermediate ambient temperature vehicle driveability study for isobutanol gasoline blends are reported. The pattern for the study was Coordinating Research Council Project CM-138-02, which investigated the effects of ethanol on cold-start/warm-up performance and Driveability Index [8,9]. Objectives of the present study were: (a) to evaluate the efficacy of the current ASTM Driveability Index (DI) in predicting cold-start and warm-up driveability performance for isobutanol gasolines and (b) if required, identify modifications to the DI definition and specification limits for isobutanol blends. The test fuel matrix included fifteen fuels with nominal vapor pressures of 55 kPa (8 psi) at DI levels of 1150, 1200, 1250, and 1300 and isobutanol concentrations of 0, 16, and 24 volume percent. Twelve port- and direct-fuel injected vehicles, which included US Tier 2 passenger cars and light-duty trucks from model years 2005 through 2008, were used to evaluate the test fuels. Cold-start and warm-up driveability tests were conducted at 4°C (40°F) following CRC E28 procedures as modified for all-weather chassis dynamometer implementation. As found in previous studies, cold-start and warm-up driveability performance deteriorated sharply for all fuels at DI levels above 1250. The present study also found the current DI relationship insufficient for predicting the driveability performance of isobutanol blended fuels. A new driveability performance model was developed which successfully compensates for isobutanol and collapses to the traditional DI relationship when isobutanol is absent. Current ASTM specifications for maximum DI were found to be appropriate for the new relationship as well. Results from this study will provide useful guidelines for blending isobutanol fuels with good cold-start and warm-up driveability performance.

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INTRODUCTION

Vehicle cold-start and warm-up performance describes the engine running and vehicle motion responses to the driver's throttle commands. The cold-start condition is the vehicle at the ambient temperature, even though ambient may not be "cold" in the absolute sense. After the engine is fully warmed-up, ambient conditions do not have a large impact on driveability. This paper summarizes a study conducted at "intermediate" temperatures using fuels containing isobutanol.

Over the years, various investigations and multiple programs by the Coordinating Research Council (CRC) have been conducted to quantify driveability and relate it to fuel characteristics [1, 2, 3]. These efforts culminated in the Driveability Index (DI) that was incorporated into the ASTM D4814 Specification for Automotive Spark-Ignition Engine

Fuel [4]. The ASTM DI equation initially used only distillation temperatures at 10%, 50% and 90% points to calculate the index. In developing the DI equation, the ASTM Task Force had available a wide range of fuel volatility properties including distillation temperatures, evaporated fractions, and Rvp; combinations of these properties could be used as independent variables to correlate driveability performance (as demerits observed in standard driveability tests). However, the Task Force believed a correlation based on the three distillation temperatures (10%, 50%, and 90%) would be the only fuel properties acceptable to most ASTM members, since these distillation points already had specified levels in ASTM D4814 (and its predecessor ASTM D439) and were commonly controlled during gasoline manufacture [4].

The initial DI equation was developed for fuels containing only hydrocarbons. However, oxygenates in fuel can have a significant effect on the distillation that alters the expected driveability performance predicted by the all-hydrocarbon original equation. In particular, ethanol in a hydrocarbon fuel profoundly reduces the front end of the distillation. The widespread use of ethanol-gasoline blends established the need for a DI equation to account for this effect. CRC has conducted driveability studies on oxygenated fuels since at least 1984 [5]. These studies have included fuels containing ethanol, methanol, methanol/tertiary-butanol blend, methanol/ethanol blend [5, 6]; and methyl tertiary butyl ether [3, 7]. These studies led to a revised driveability index which added a concentration-dependent offset factor for ethanol content to the original DI equation [8, 9]. Other index forms were investigated, including correlations using evaporated fractions (instead of distillation temperatures) and a fixed ethanol content factor (e.g., an ethanol factor with no concentration dependence). However, the addition of a concentration-dependent ethanol term to the original DI equation described the observations well while preserving the familiar form and customary independent variables. The revised DI equation was developed using blends containing up to 10.6 vol% ethanol.

Isobutanol has recently emerged as a renewable component of interest for blending into gasoline. Like ethanol, isobutanol is a high-octane component with good materials compatibility. However, isobutanol has higher energy density and lower oxygen content by volume than ethanol, thereby enabling higher volumetric blend ratios and greater renewable content per gallon of fuel at constant tank mileage and stoichiometric air/fuel ratio. Isobutanol offers further compliance benefits to fuel manufacturers from low blending vapor pressure and dilution of sulfur and benzene (due to the higher blending ratio). However, although isobutanol blends comfortably in the middle of the gasoline boiling range, the impact of relatively large fractions of isobutanol on volatility and, hence, cold-start and warm-up driveability performance were unknown. This study was undertaken to address the volatility/driveability knowledge gap with isobutanol blends.

The study reported in this paper was patterned after CRC project CM-138-02 [8, 9]. Its objectives were to evaluate the efficacy of the current DI equation for predicting cold-start and warm-up driveability performance of isobutanol containing gasolines and, if needed, identify modifications to the DI equation and specification limits that provide satisfactory performance for gasoline containing this oxygenate.

TEST FUELS

Fuel factors of interest in planning the study were Driveability Index (DI) and isobutanol concentration. As shown in Figure 1, the basic matrix of twelve fuels comprised four nominal DI levels (1150, 1200, 1250, and 1300) and

three isobutanol concentrations (0, 16, and 24 vol%). The selected DI levels extended both above and below ASTM D4814 maximum DI limits to ensure a broad range of vehicle driveability responses. Isobutanol levels of 0, 16, and 24 vol % were chosen to correspond with the oxygen content of ethanol-blended fuels E0, E10, and E15, respectively. A nominal vapor pressure of 55 kPa (8 psi) was selected to represent typical summer (ASTM Class A) gasolines.

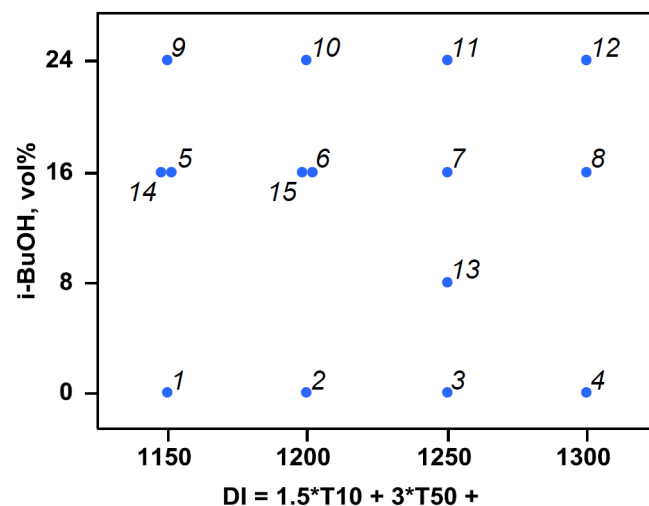


Figure 1. Test fuel matrix design.

The basic matrix was augmented with three more isobutanol fuels. As shown in the diagram, Fuel 13 was added with an intermediate isobutanol concentration of 8 vol% at the 1250 DI level to check curvature effects. Fuels 14 and 15 each contained 16 vol% isobutanol with DI levels of 1150 and 1200. Although matched in DI and isobutanol with Fuels 5 and 6, respectively, Fuels 15 and 16 differed in detailed distillation characteristics not reflected in the DI parameter.

Detailed properties for all fifteen test fuels are presented in Appendix 1, Table A1. Fuel identification numbers in Table A1 correspond to those in the matrix diagram Figure 1.

TEST VEHICLES

Descriptions of the twelve vehicles used in the study are provided in Table 1. The vehicles were selected from about 80 light-duty cars and trucks operated as a fuels test fleet by BP Product North America at the company's Naperville Complex in Illinois. Following the pattern of CRC Project CM-138-02, desirable characteristics of the test fleet were a composition of about half passenger cars and half light trucks (to reflect recent-year vehicle sales trends) certified to low-emissions standards (US EPA Tier 2 or California LEV II) [9]. Late-model vehicles have been preferred in recent CRC driveability studies because they are readily available, generally free from confounding mechanical driveability faults and, most importantly, because cold-start enrichment tends to decrease as tailpipe emissions requirements are lowered with progressing model years; the cold-start enrichment limitations in late-model vehicles certified to low

Table 1. Test vehicles.

Year	Make	Model	Disp., L	Fuel Injection / Induction	VIN	Miles	Cert Level
2005	Dodge	Neon	2.0	PFI / NA	1B3AS56C75D214451	37,483	T2 B8
2005	Ford	Taurus	3.0	PFI / NA	1FAFP53U65A114917	64,131	T2 B8
2006	Toyota	Tacoma	4.0	PFI / NA	5TEJU62N06Z292956	29,159	T2 B5
2007	Dodge	Durango	4.7	PFI / NA	1D8HD38P97F526582	60,716	T2 B8
2007	Ford	Edge	3.5	PFI / NA	2FMDK36C07BA49718	7,273	T2 B5
2007	Toyota	Camry	3.5	PFI / NA	4T1BK46K27U520461	19,075	T2 B5
2007	Volkswagen	GTI	2.0	Direct / turbo	WVWHV71K07W030278	8,434	T2 B5
2008	Chevrolet	Silverado	5.3	PFI / NA	2GCEC130381140882	12,483	T2 B4
2008	Chevrolet	HHR SS	2.0	Direct / turbo	3GNDA63X68S616355	4,044	T2 B5
2008	Ford	Focus	2.0	PFI / NA	1FAHP35N78W157561	3,626	PZEV
2008	Mazda	CX-7	2.3	Direct / turbo	JM3ER293680188093	9,637	T2 B5
2008	Saturn	Outlook	3.6	PFI / NA	5GZER13748J185880	18,648	T2 B5

emission standards thus present the greatest challenges to cold-start fuel vaporization and have been successfully used in past studies to determine fuel volatility requirements for the broader on-road fleet. To further reflect recent technology trends, the present study further selected vehicles with direct injection fuel systems to comprise one-quarter of the test fleet. All vehicles were equipped with torque convertor automatic or dual-clutch automated transmissions.

Vehicles meeting the general criteria were pre-screened by reviewing operating records from previous test programs to eliminate vehicles with known or suspected mechanical faults. Acceptable candidate vehicles were then screened for response to fuel volatility by testing for CS&W driveability performance at 4°C (40°F) using Fuel 3 (all-hydrocarbon, 1300 DI). The twelve vehicles with the highest total-weighted-demerit (TWD) scores in the screening test (ranging from about 10 to 80 TWD) were selected for the program.

TEST PROCEDURES

Test Temperature

Following the pattern of previous CRC programs, the selected test temperature for the driveability tests in this study was 4°C (40°F). As discussed in reference 9, this temperature corresponds to conditions (a) frequently associated with customer complaints of poor cold-start and warm-up performance and (b) representing modest / minimal cold-temperature fuel enrichment in vehicle calibrations. Although relatively infrequent, temperatures in this range can occur during the spring transition to low summer fuel vapor pressure requirements (such as the 55 kPa / 8 psi nominal vapor pressure fuels used in this study), thereby forming challenging conditions for mixture preparation and fuel volatility formulation.

Test Facility

Driveability tests were conducted in the All-weather Chassis Dynamometer (AWCD) facility at BP's Naperville complex. This facility incorporates a large-roll (2.1m) dynamometer in a temperature- and humidity-controlled wind

tunnel with test section air speed synchronized to roll speed, resulting in an accurate and repeatable simulation of on-road thermal and mechanical loads. Temperature-controlled soak rooms within the AWCD complex were used for overnight conditioning to equilibrate vehicle and test cell temperatures prior to beginning each driveability test. The AWCD facility enabled year-round testing at the selected temperature of 4°C (40°F) while reducing day-to-day and test-temperature variability factors to insignificant levels.

Vehicle Preparation

All vehicles were serviced and inspected prior to beginning the test program. None of the vehicles presented prompt or pending diagnostic trouble codes. The vehicles were instrumented with HEM DAWN / SnapMaster OBD-II data acquisition systems for monitoring engine and vehicle operating parameters at about 2 Hz / channel during the tests. The OBD-II data were collected to (a) confirm ECU fuel trims were adjusted to the test fuel oxygen level and (b) provide a basis for investigating outlier test results, if such were to occur.

In preparation for each driveability test, the subject vehicle fuel system was thoroughly flushed and filled with test fuel using fuel-change guidelines developed for CRC driveability programs [10]. After refuelling, each vehicle was conditioned on a closed test track for thirty minutes to allow the engine management system to adjust fuelling for the varying oxygen content of the test fuels. The pre-conditioning cycle covered both cruise and acceleration maneuvers at load and speed conditions selected to maximize coverage of the CRC E-28-94 Cold-start and Warm-up Driveability Test cycle. After pre-conditioning, the vehicles were parked in the AWCD cold-soak rooms for overnight soak to test cell temperature. Thermocouples mounted in the engine crankcase verified equilibration of vehicle and test chamber temperatures prior to driveability tests.

Driveability Tests

Driveability evaluations were conducted according to CRC E-28-94 procedure for Cold-start and Warm-up Driveability Tests, as updated for use in an all-weather



Documents

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