

The Performance of a Modern Vehicle on a Variety of Alcohol-Gasoline Fuel Blends

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ABSTRACT

An unmodified, conventionally fuelled, 2009 Class D vehicle with a 2.0L turbocharged gasoline direct injection engine was operated on a range of gasoline, gasoline-ethanol and gasoline-butanol fuel blends over NEDC drive cycles and WOT power curves on a chassis dynamometer. Engine performance, engine management system parameters and vehicle out emissions were recorded to investigate the response of a current state-of-the-art technology vehicle to various alcohol fuel blends.

The vehicle fired on all fuels and was capable of adapting its long term fuelling trim to cope with the increased fuel flow demand for alcohol fuels up to E85. Over the NEDC tests, the volumetric fuel consumption was very strongly related to the calorific content of the fuel. CO and NO_x emissions were largely unaffected for the mid alcohol blends, but CO emissions decreased and NO_x emissions increased significantly for the high alcohol fuels. THC emissions were largely unaffected. Particulate mass initially reduced as the alcohol content increased, but then increased significantly for the higher alcohols. This was likely due to the poor vaporisation during cold start.

During the power curves, WOT performance increased with the oxygen content in the fuel. The performance on 95RON was slightly restricted by occasional activation of the knock controller, which retarded the mean spark timing. The alcohol fuels did not suffer from knocking events but were able to use additional fuel-sourced oxygen to increase the power output and increase the turbine enthalpy.

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INTRODUCTION

Ethanol fuels have been considered for use in internal combustion engines since the early part of the 19th century [1]. However, concerns about the effect of CO₂ emissions on the global climate has seen a renewed interest in the use of alcohol-based 'biofuels' due to their potential for lower lifecycle emissions of CO₂. The CO₂ benefits are highly dependent upon the source crop and the manufacturing process, but ethanol from food crops such as corn, wheat, sugar cane and sugar beets have been shown to reduce net carbon emissions compared to fossil fuels. Specifically, the EPA has calculated a 21% mean reduction in lifecycle GHG emissions for corn ethanol produced by a 2022 natural gas powered facility compared to 2005 gasoline, and a 61% mean reduction for sugarcane ethanol. Second generation technologies which produce ethanol from non-food crops

have also been developed, mitigating concerns over the potential for rising food prices, and EPA calculations suggest a CO₂ reduction of up to 110% for cellulosic ethanol from switchgrass, due to the potential for excess electricity generation at the ethanol plant [2].

Ethanol and gasoline are fully miscible and have been blended together in a wide range of concentrations. In the European Union, a target was set to reach 5.75% of transport fuel energy coming from bio-fuel sources by December 2010, and 10% by 2020 [3]. In practice, the market is currently achieving slightly over 4% [4]. In the US, numerous states and cities have imposed legislation requiring various levels of bio-fuel content in the blend, varying between 2% to 25% [5]. In Brazil, a minimum blend of anhydrous E25 was mandatory between 2007 and 2011, and since then a minimum blend of E18 has been regulated. Furthermore, hydrated E100 pumps (typically 93% ethanol in 7% water) are also available which

Table 1. Vehicle Properties [9]


Engine	I4 DOHC 16V
Displacement (L)	1.984
Dry Weight (kg)	1,441
Gearbox	6 spd manual
Max Torque (Nm/rpm)	280/1700
Max Power (kW/rpm)	150/5100
Compression Ratio	9.6:1
CO ₂ Emissions (g/km)	186
CO Emissions (mg/km)	478
THC Emissions (mg/km)	54
NOx Emissions (mg/km)	26
Urban (L/100km)	11.0
Extra Urban (L/100km)	6.1
Combined (L/100km)	7.9

can be blended together on the forecourt resulting in a wide variety of real world operating blends.

Blending ethanol and gasoline alters the properties of the mixture, with properties such as the calorific content and density exhibiting a linear response to ethanol concentration, while the vapour pressure and octane rating are decidedly non-linear. In fact, the vapour pressure of E22 is higher than either of its constituents.

Recently, butanol has been considered as an alternative blending component to ethanol [6, 7, 8]. Butanol has a lower RON number than ethanol, but a higher net calorific value. As such, it can be used to increase the RON number of the blend without exhibiting the same loss in part load fuel consumption. Butanol is also less hygroscopic than ethanol and does not have the same concerns with water absorption [6].

A range of gasoline alcohol blends was tested in an unmodified gasoline vehicle to determine the response of a modern vehicle to various concentrations of alcohol fuels. The vehicle was operated over the New European Drive Cycle, (NEDC) as well as a power curve consisting of 11 operating points.

METHODOLOGY

VEHICLE PROPERTIES

A 2009 model year class D vehicle fitted with a 2.0L, turbocharged gasoline direct injection engine was installed on a chassis dynamometer. The 4-cylinder engine featured a direct injection system with under port injectors, variable intake cam timing, a turbocharger and a modern 3-way catalyst. The vehicle was also fitted with a 6 speed manual gearbox. It was chosen to be representative of a state-of-the-art gasoline engine. The published data for this vehicle is shown in [Table 1](#).

FUEL PROPERTIES

All test fuels were obtained from a specialist fuel blending plant and in each case were splash blended to a particular specification. These specialist research fuels possessed physical and chemical properties, including RON number, that were chosen directly for the investigation, and they were not intended and did not reflect nominally similar current or potential market place fuels. Two types of gasoline with octane ratings 95 RON and 102 RON were tested, along with three gasoline-ethanol and two gasoline-isobutanol blends. The ethanol and isobutanol were blended with a 95 RON base fuel so that E10 represents 10% ethanol in 90% 95 RON gasoline by volume. No additive packages were included

with the exception of 102 RON gasoline. The specification of the fuel blends is provided in [Table 2](#). The alcohol concentrations were chosen to have similar RON values (E22 & 102RON), similar oxygen contents (E10 or Bu16) or similar energy content of the alcohol component (E85 & Bu68). The vaporisation curves for the fuels are provided in [Figure 1](#).

Table 2. Fuel Properties

Fuel	RON	ρ	RVP	IBP	FBP	C_{MF}	H_{MF}	O_{MF}	En of Alc%	NCV
				°C	°C	%m	%m	%m	MJ/kg	MJ/kg
Pump 95Ron B'lines	95.5	0.73	-	28	195	85.0	13.7	1.3	-	-
95 RON	95	0.74	48	37	167	86.6	13.3	0.1	-	43.2
102 RON	102	0.74	52	37	123	84.7	12.8	2.5	-	41.8
E10	99	0.75	52	40	166	82.7	13.3	4.0	2.7	41.4
E22	102	0.75	53	41	164	78.5	13.4	8.1	5.9	39.4
Bu16	98	0.75	43	41	163	82.9	13.4	3.7	5.3	41.5
Bu68	104	0.78	35	-	-	73.1	13.5	13.4	22.5	36.9
E85	106	0.78	39.5	68	82.8	56.9	13.0	30.1	22.8	29.6

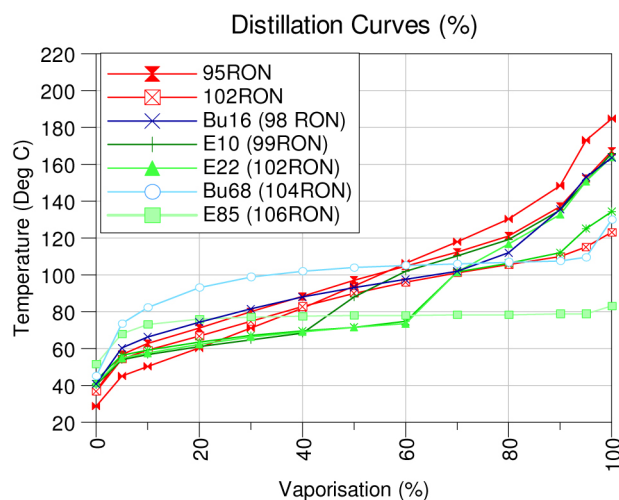


Figure 1. Vaporisation Curves

TEST PROCEDURE

A 10,000-mile break in program consisting of various engine speeds and loads was conducted on the vehicle with pump 95 RON gasoline to ensure that the engine friction had stabilised before testing began. This was determined by consistent CO₂ emissions over three NEDC tests. At least

three consecutive NEDC cycles were also conducted on the same fuel at the start, end and on two occasions during the test program to ensure that the engine behaviour was consistent for all tests.

Tests were then conducted in the following order:

- Baseline 1 (Fuel: Pump 95RON baseline)
- 102RON
- 95RON
- Baseline 2
- Bu16
- E10
- E22
- Baseline 3
- Bu68
- E85
- Baseline 4

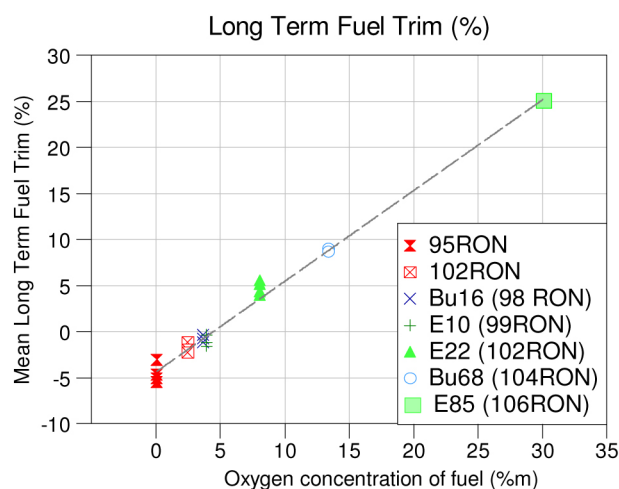


Figure 2. LTFT adjustments prior to testing

Before all NEDC tests, the vehicle was preconditioned by allowing it to soak for 24 hours at 20°C. Between fuels, the vehicle's fuel tank was drained by disconnecting the fuel line and allowing the low pressure fuel pump to empty the fuel tank. The oil and filter of the vehicle was changed and the vehicle was filled with approximately 50L of new fuel. The vehicle was then subjected to an unmeasured NEDC test to flush any remaining fuel out of the lines and also allow the vehicle calibration to adapt to the new fuel. The vehicle was not calibrated for E85 use and was not fitted with a fuel type sensor, but during the tests the state of adaptation was monitored by the injection pulse width and the long-term fuel trim (LTFT) from the engine management system through the diagnostic link. The state of adaptation related linearly to the