Understanding gasoline volatility and ethanol effects

Joint programmes on driveability and evaporative emissions

Although well researched in the past, there has been little recent work on fuel effects on driveability performance or evaporative emissions from European gasoline vehicles. Recently, the Biofuels Directive has stimulated interest in blending ethanol into gasoline, with consequent questions on the effects on gasoline volatility, driveability and evaporative emissions.

In France, the GFC (Groupement Français de Coordination) has developed new test procedures for both hot and cold weather driveability, but had not previously used them for detailed fuel effect studies. CONCAWE therefore undertook a joint programme with the GFC to evaluate the impact of gasoline volatility and ethanol content on the driveability performance of modern European vehicles using these procedures.

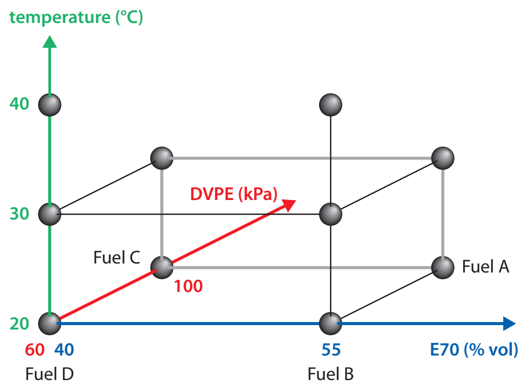
Eight vehicles, three with DISI fuel systems and five with MPI systems, were tested for driveability. Hot tests were carried out at 20, 30 and 40 °C, and cold tests at +5 and –10 °C. A matrix of four hydrocarbon test fuels at two levels of vapour pressure (DVPE) and E70 was blended for the hot weather testing, and three fuels with varying E100 but essentially parallel distillation curves for the cold weather tests. For each hydrocarbon fuel, two other fuels containing 10% ethanol were made, one 'splash' blend and one with matched volatility. Some tests were also carried out using 5% ethanol blends.

A recent CONCAWE report (3/04) has reported the hot and cold weather driveability results in detail. This article provides an overview of the main findings on driveability and briefly describes a further programme now under way to investigate evaporative emissions.

Hot weather testing

Eight cars were tested for hot driveability based on the test matrix shown in Figure 1. The GFC hot weather test procedure requires a trained driver to follow a specific set of driving sequences, comprising a motorway hot-soak test, a mountain climbing test and a 'canister loading' test designed to simulate stop and go driving in heavy traffic. Driveability malfunctions (stall, hesitation, loss of acceleration, stumble, surge, roughness) are recorded by the driver and given demerit ratings using pre-defined scales, described in the report.

Figure 1
Hot driveability test fuel/temperature matrix



An alternative rating approach was also used which considers each fault type separately and assigns it a colour-coded 'severity category', in addition to a demerit level, i.e.:

- **None**
- **Trace**
- **Moderate**
- **Customer Unacceptable**
- **Safety Unacceptable**

The total demerits and severity ratings for each test are given in the report. The main results are summarised below.

Vehicle effects

Three of the MPI vehicles showed good hot weather driveability on all fuels tested, with ≤24 demerits. Another showed <24 demerits in all tests, except for fuel A 10% ethanol splash blend at 30 °C (34 demerits). In view of these low demerit levels, three vehicles were also tested on the highest volatility hydrocarbon fuel (A) at 40 °C. Despite this extreme combination of temperature and volatility, all gave ≤20 demerits, confirming the excellent hot driveability of these modern MPI vehicles. Generally the highest demerits were seen on fuel A at 30 or 40 °C, showing a slight sensitivity to volatility.

Vehicle 4 had an MPI fuel system but no throttle; instead it relied on varying inlet valve lift to control engine power. This vehicle showed low demerits (<12) under all test conditions except for the highest volatility fuels at 30 °C, when demerit levels of 16–95 were seen.

One of the DISI vehicles showed good hot driveability performance in all test conditions, similar to the four MPI vehicles. The other two DISI vehicles showed much poorer driveability, with many tests giving 100–500 demerits. DISI vehicle 2 showed high demerits on high volatility fuels, with highest demerits of 471 in a test on fuel A at 30 °C. Vehicle 3 also gave high demerits (270–314) on high DVPE fuels A and C at 30 °C and on fuel B 10% ethanol splash blend at 40 °C. These high demerits were accompanied by an engine warning message that fuel pressure was out of range; indicating that classical vapour lock was taking place somewhere in the fuel system. For both of these vehicles, tests on D-series fuels gave low demerits (≤17) at all temperatures.

Volatility effects

For the five vehicles with low overall demerits, no analysis of volatility effects was possible. The other 3 vehicles showed clear effects of increasing volatility. For example, Figure 2 shows tests on vehicles 2 and 3 at 30 °C, plotted against volatility as 'bubbles', with the area of the bubble proportional to the number of demerits, and its colour indicating the severity rating. For vehicle 2, increasing DVPE at 30 °C (and E70 at 40 °C, not shown) gave a clear increase in demerits, while vehicle 3 at 30 °C only showed an increase on the most volatile fuel A.

Statistical modelling indicated that three critical vehicles, which showed substantial driveability problems and effects of variation with volatility, were more sensitive to fuel DVPE than to E70. The effect of DVPE over the range 60–100 kPa was more than double that of E70 over the range 40–55%v/v.

In all cases substantial increases in demerits were only seen at high temperatures on fuels with volatility beyond the summer limits of EN228.

Ethanol effects

As described earlier, several vehicles showed very low demerits on all fuels. Four vehicles generated enough demerits to perform a meaningful analysis of ethanol effects. Two examples of the effects of ethanol in the responsive vehicles are shown in Figure 3; generally the effects are only evident with high volatility fuels and at high temperatures. In these cases, ethanol splash blends increased demerits and in some cases overall severity rating. Matched volatility blends gave similar driveability to the equivalent hydrocarbon fuels. This suggests that the effects seen are not due to the presence of ethanol *per se* but are a consequence of the increase in volatility that is caused by the addition of ethanol.

Effect of DVPE and E70 of HC fuels on hot driveability of vehicles 2 and 3 (bubble area represents total demerits)

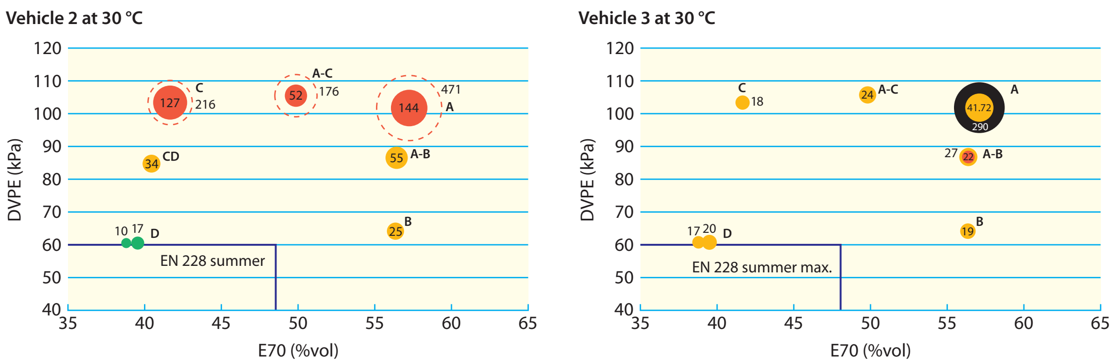


Figure 2
At 30 °C, increasing DVPE gave a clear increase in demerits for vehicle 2, while vehicle 3 only showed an increase on the most volatile fuel A.
Substantial increases in demerits were only seen at high temperatures on fuels with volatility beyond the summer limits of EN228.

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Effect of ethanol on vehicles 3 and 4

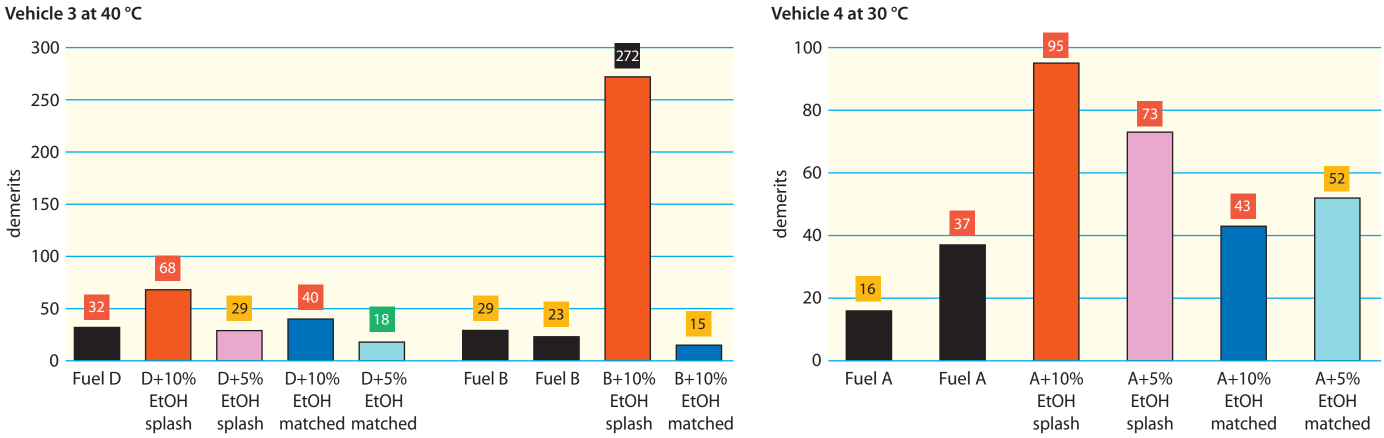


Figure 3

In general, the effects of ethanol on hot driveability are only evident with high volatility fuels and at high temperatures. The effects observed are likely to be a consequence of the increase in volatility caused by the addition of ethanol, rather than the presence of ethanol per se.

Cold weather testing

Tests were carried out at +5 °C and –10 °C, as representative of moderate European winter conditions. The same basic principles were followed as for hot weather testing, i.e. a trained driver followed a set drive cycle and reported driveability malfunctions which were converted to a demerit rating and an overall severity rating. The GFC drive cycle consists of five phases, carried out immediately after engine start and repeated six times. The detailed test cycle and definitions of demerit ratings can be found in the CONCAWE report.

Three hydrocarbon fuels were tested with approximately parallel distillation curves as high (A), medium (G) and low (E) volatility fuels. Two matching fuel matrices with 10% ethanol splash blended and with matched volatility were tested, and 5% ethanol fuels were tested in some cases. Only 4 cars (2 MPI, 2 DISI) were tested in depth at both temperatures on the full range of fuels. One other car (4) was tested only on the hydrocarbon fuels and the other 3 cars were only tested on fuels G and E at –10 °C.

Volatility effects

The majority of vehicles showed some increase in total demerits with reducing fuel volatility, most pronounced at –10 °C. In some vehicles the effect of fuel volatility was small, whereas other vehicles showed a clear increase in the level of demerits on the lowest volatility fuels at –10 °C. An example of this effect (vehicle 7) is given in Figure 4. Further work would be needed to accurately determine a critical E100 level below which the demerits begin to increase, however, from these results, this is estimated to be around 50% v/v.

Ethanol effects

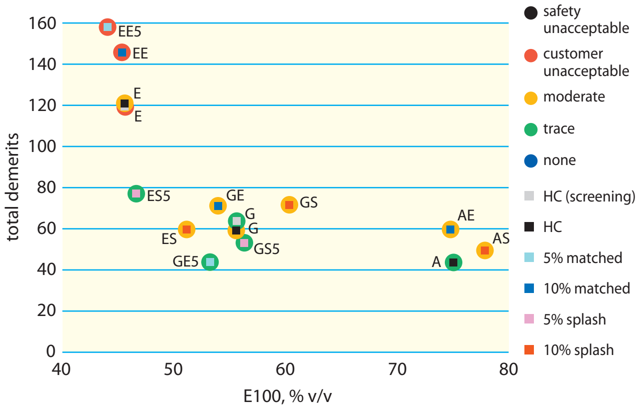
Splash blending ethanol into a fuel increases its mid-range volatility (E70 and E100). However the higher latent heat of ethanol means that it may not vaporise as well in a cold engine where the availability of heat is limited. Matched volatility blends must have other light components removed, so might be expected to perform less well than hydrocarbon fuels.

There was substantial variability in the data, and ethanol effects were not consistent across the whole data-set. However, on the lowest volatility fuel, splash blending ethanol generally improved driveability at –10 °C (though not at +5 °C). The matched volatility ethanol blends behaved similarly to the HC fuels (see example in Figure 5). It is likely that the effects seen are a consequence of the increase in volatility caused by the addition of ethanol rather than the presence of ethanol *per se*.

Conclusions

The new GFC test procedures appear to be more discriminating than the former CEC procedures for identifying fuel, vehicle and temperature effects on hot and cold weather driveability of modern vehicles.

Cold driveability results for Vehicle 7 at -10 °C
(total demerits vs. fuel E100)



Effect of ethanol on cold driveability of Vehicle 7 at -10 °C

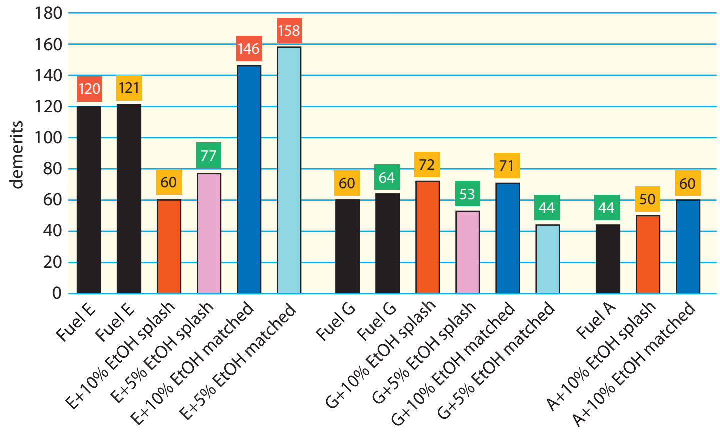


Figure 4 (above left)
Some vehicles showed a clear increase in the level of demerits on the lowest volatility fuels at –10 °C.

Figure 5 (above right)
Ethanol splash blends improved cold driveability on the lowest volatility fuels at –10 °C. It is likely that the effects observed are a consequence of the increase in volatility caused by the addition of ethanol rather than the presence of ethanol per se.

Hot driveability

Vehicles varied widely in their sensitivity to fuel changes. Four of the eight vehicles tested (three MPI and one DISI) exhibited good performance under all fuel/temperature conditions tested. Two MPI vehicles showed some demerits on high volatility fuels, one of them having substantial demerits. Two DISI vehicles showed poor driveability performance with very high demerits on high DVPE fuels at 30 °C, and on some less volatile fuels at 40 °C.

In general, ethanol splash blends without volatility matching increased demerits and, in some cases, overall severity rating. Matched volatility ethanol blends gave similar driveability to the equivalent hydrocarbon fuels. This suggests that the effects seen are due to the increase in volatility from the addition of ethanol rather than the presence of ethanol *per se*.

In all cases substantial increases in demerits were only seen at high temperatures on fuels with volatility beyond the summer limits of EN228.

Cold driveability

Most vehicles showed sensitivity to fuel volatility with higher demerits on less volatile fuels. Several vehicles showed a sharp increase in demerits on the least volatile fuels (E100<~50%v/v) at –10 °C, but not at +5 °C.

One DISI vehicle gave very high demerits on all fuels at both temperatures but showed no sensitivity to fuel volatility, ethanol content or temperature. The other two DISI vehicles gave demerits in the same range as most of the MPI vehicles.

The effects of ethanol were inconsistent, except on the lowest volatility fuel, where splash blending ethanol generally improved driveability at –10 °C (though not at +5 °C). The matched volatility ethanol blends gave similar driveability to the equivalent hydrocarbon fuels, suggesting that the effects seen are due to the increase in volatility caused by the addition of ethanol rather than the presence of ethanol *per se*.

Further work on evaporative emissions

The impact of ethanol and vapour pressure on evaporative emissions is another important aspect where new data is needed. A further project has recently been initiated jointly with EUCAR and JRC Ispra to study this issue. The objectives of this work are:

- to assess the effects of ethanol and vapour pressure on evaporative emissions from a range of latest generation gasoline cars; and
- to provide a technical basis for debates on gasoline vapour pressure limits in relation to ethanol blending for the Fuels Directive Review.

It is planned to test eight vehicles which will be provided by the ACEA. CONCAWE has supplied fuels with two volatility levels (DVPE = 60 and 70kPa) and two levels of ethanol content (5 and 10%), as both splash blends and matched blends. The tests will be carried out in JRC Ispra's test facilities.