

The Effect of Oxygenates on Fuel Economy

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SUMMARY

Many countries are implementing the use of oxygenates in gasoline for economic and environmental reasons. Ethanol in particular is gaining ground as the oxygenate of choice as it presents a renewable and environmentally friendly alternative to other octane boosters such as tetraethyl lead and MTBE. However, given the relative energy content compared to gasoline, the use of ethanol/gasoline (10/90) blends can negatively effect overall fuel economy by up to 5%. Improvements of between 1% and 3% appear to be achievable with the use of additives. However, the measurement of the true fuel economy benefit is challenging. On the one hand, laboratory tests, although precise and repeatable, do not fully represent the real conditions in the engine. On the other hand, in engine testing, the benefits in fuel economy from the additive may be hidden by the many other factors that can affect fuel economy; especially during field testing. Additionally, measurements can be confounded by the presence of oxygenates in the fuel. This paper reviews previous work on fuel economy and engine performance, discusses testing regimes to demonstrate performance and improved fuel economy in the presence and absence of oxygenates and additives.

INTRODUCTION

Against the background of the obligations of global, national and regional environmental efforts, the pressure to reduce gasoline consumption and to reduce transport emissions is increasing. With the phase out of common octane boosters such as tetra ethyl lead, MMT and MTBE it is now generally accepted that ethanol is the octane booster of choice. Unlike other octane boosters however, ethanol must be used at high levels (10% on average in the US) to have a practical effect. As ethanol has a much lower energy content than gasoline and therefore a lower fuel value, blending ethanol into a gasoline causes a noticeable decrease in fuel economy by 2-5 % depending on vehicle and driving conditions. From the perspective of gasoline consumption this is tolerable because the petroleum based component is still conserved. However, from the

perspective of the actual consumer, a tank of fuel does not last as long.

Gasoline fuel economy additives delivered to the engine through the fuel are now being used to achieve benefits in fuel economy. Improvements of between 1% and 4% appear to be achievable and the effects of such additives in gasohol are now beginning to be explored.

This paper references bench testing and examines engine testing methods which have been used for the evaluation of fuel-borne friction modifier additives, and reports initial performance results of fuel-borne friction modifiers in gasohol.

THE MECHANISM OF ACTION OF FUEL-BORNE FRICTION MODIFIER ADDITIVES.

It is necessary to understand the mechanism by which fuel-borne friction modifier additives work before we can discuss test protocols in more detail.

Fuel-borne friction modifier additives can provide both an instantaneous effect, and a longer term accumulated effect. The instantaneous effect can arise within one tank-filling; the accumulated effect builds up between oil drains. The principle is to reduce the internal friction of the engine, thus reducing the amount of fuel that must be burned to overcome the internal friction.

The instantaneous effect is caused by fuel which contains the friction modifier arriving at the upper surfaces of the cylinder, and particularly around the ring reversal area. Although a proportion of the additive will be burnt in the combustion process, a substantial amount can actually exist on the upper surfaces, particularly during cold driving cycles (eg urban driving with frequent cold starts). And even during hot driving, additive can exist on surfaces, as there is a quench zone in the proximity of the surfaces where combustion does not take place, and additive will not be burned.

The accumulated effect builds up over time as oil containing the fuel-derived friction modifier drains from the upper combustion chamber into the crankcase. The friction modifier then has access to other areas of the engine where it can reduce the internal friction of the engine. This benefit applies even in the cases where the oil itself contains a friction modifier. It is well known that such oil-based friction modifiers deplete over time, and that the benefits rapidly diminish. By replenishing continuously with fuel-derived friction modifier, the friction properties of the oil can be improved throughout the drain period, until fresh oil is introduced into the engine. These effects are portrayed in figure 1.

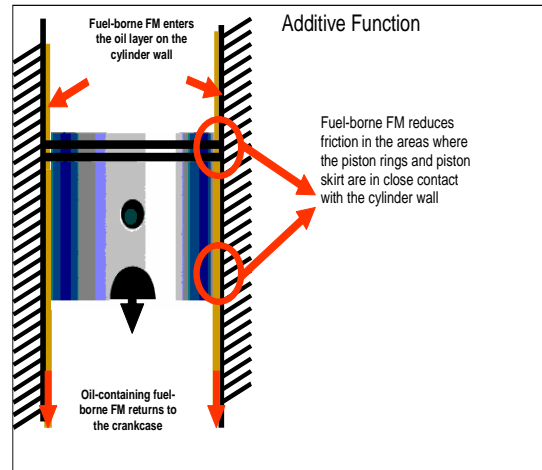


Figure 1

It is more problematic to measure the accumulated benefit, and this paper will discuss just the measurement of instantaneous effects, and the accumulated effects after a short driving period (2-3 tank fills).

It is very difficult to keep the ring reversal area supplied with lubricating oil, and this area can make quite a high contribution to the total frictional losses of the engine. Oil films which do form here can easily be washed away by fuel. The contribution of the piston assembly to friction losses has been measured in a number of studies. For example, R.I. Taylor measured the contribution of the piston assembly in a Mercedes-Benz M111E engine containing SAE-15W/40 multi-grade oil and operating at 2500 rpm and medium load at 42% of the total internal losses (3). When a fuel which contains a friction modifier is used, the additive can coat the surfaces directly, or more likely, absorb into the film of oil already on the surface.

PROCEDURES FOR MEASURING FUEL ECONOMY PERFORMANCE OF FUELS.

Currently there is no clearly defined procedure for measuring the fuel economy

benefit of fuel additives. Engine tests exist for measuring the fuel economy benefit of lubricating oils (M111E fuel economy test CEC L-54-T-96 and Sequence VIA and VIB tests) but these would need modifying to be suitable for fuel testing. The Motor Vehicle Emissions Group (MVEG) is in the process of proposing a procedure for evaluating fuel additives. However, this is still only in draft form. The procedure is designed to cover a wide range of possibilities for performance benefits, including improvements to regulated emissions as well as fuel economy. Therefore while the procedure can address such aspects as vehicle quantity and type, test cycles and practice, test design, statistical analysis and no-harm testing in detail, it is unable to address the specifics of how the testing on the individual vehicles is to be carried out. The application of the additive in the test will depend on its mode of action and on the performance attribute it is addressing, and must therefore be tailored to the application.

Several bench tests exist for measuring the friction properties of oils. Such tests include the HFRR, scuffing BOCLE, Cameron-Plint, and MTM traction measurement instrument. These bench tests have been developed to measure primarily the frictional properties of crankcase lubricants. In fact, a combination of such tests, together with viscosity measurements, has been used to model the fuel economy performance of oils as measured in the Sequence VI and VIA tests (4). One exception to the exclusive use of these tests for engine oils is the HFRR, which has been modified to measure the lubricating properties of diesel and gasoline fuels also.

There is a fundamental problem with using any of these methods to predict the fuel economy properties of a fuel additive. Unlike with lubricating oil testing, a suitable fluid cannot be chosen as substrate, as the exact nature of the fluid in contact

with the upper cylinder surfaces is unknown. It will likely be a mixture of oil, fuel and additive, but the proportions of oil, fuel and additive, and the extent of decomposition of the fluid and its components, will be dependant on the engine type and the operating cycle. It is of course desirable to use bench tests as screening tests to identify components of potential interest, and these tests may be run with the additive dosed into oil, into fuel, or into some other organic medium. But it is not clear how to use these results to predict the potential fuel economy benefit that might be achieved from the use of the additive. Previous studies have demonstrated the shortfalls of using HFRR as a tool to predict fuel economy performance of a fuel borne friction modifier. It has been shown that HFRR results do not correlate to engine testing.

ENGINE TESTING PROTOCOL.

Although no standard test exists for the measurement of fuel economy performance of fuels, there is sufficient knowledge from related procedures to set a good starting point. For example, the fuel economy performance of crankcase lubricants has been measured in the M111E engine in Europe, and in the Ford 4.6L engine (Sequence VIA and VIB tests) in the United States. Emissions have been measured using the New European Drive Cycle in Europe, and its equivalent, the FTP and Highway Fuel Economy Test (HWFET) in the United States. In Japan, the 10 mode test is used to measure emissions. These tests are intended to replicate real driving situations, both urban and extra-urban or highway. Hence, a sensible starting point would be to adopt such driving cycles on the M111E/Ford 4.6 (ILSAC Seq VIB) engines. However, as mentioned earlier, it is necessary to adopt specific procedures in order to both enable the additive to function as intended, and to ensure genuine back-to-back comparisons

with reference fuels can be made. Account must be taken of certain effects which can interfere with the integrity of the data. The most important are considered below.

Engine Drift.

It is possible for engines to drift over time. This effect is well recognised from lubricant testing. It is neutralized by interspersing candidate tests with reference tests, or bracketing a test sequence with reference tests (see fig. 2 for a test sequence which uses interspersed reference tests to monitor drift).

Oil Changes.

As soon as oil starts its job in the engine, changes take place in that oil which can affect the fuel consumption performance of the engine. The viscosity modifier, which consists of long polymer chains, can be sheared in the engine machinery, causing the oil to lose viscosity. Countering this, combustion products can lead to oil thickening over a prolonged period. The net effect is that oils generally lose viscosity at first, then stabilize, and then thicken towards the end of their life. Overlaying these processes is the effect of fuel dilution. Fuels, together with their additives, can adsorb into the oil film on the cylinder wall, or simply drain past the piston during cold starts, when vast excesses of fuel are injected into the cylinders in order to generate a combustible mixture. The fuel which makes its way into the crankcase causes significant thinning of that oil, leading to a reduction in fuel consumption. The level of fuel dilution depends on the drive cycle and on the sump temperature; lower sump temperatures leading to higher levels of fuel dilution. In order for the effect of additives to be measured, these changes in oil properties must be neutralized; either by running a conditioning stage to stabilise the oils before starting the testing, or by using oils

in the same condition for each test, e.g. fresh oil for each fuel change.

Induction Period and Carry-Over Effects.

The intention of using a fuel containing a friction modifier is to put a layer of friction-modifier onto the internal surfaces of the engine. While fuel containing friction modifier is being used, the surfaces will be continually replenished, and a dynamic balance will develop after an initial induction period. Time must therefore be allowed for this balance to become established, before the full effect of the additive can be measured. On changing back to a fuel without friction modifier, it will take time for the friction modifier already present on the surface to be removed. This will lead to a 'carry-over effect' which must be accounted for in the flushing procedure of the test design.

Development of Test Procedure Based on M111E Engine.

The M111E engine using the NEDC cycle to measure fuel consumption gravimetrically is an obvious selection for measuring the fuel economy performance of fuel-borne friction modifiers in Europe. The engine is widely available in European laboratories, together with the necessary fuel-consumption measuring equipment and oil-flushing system. Reference fuels and oils are established.

The extent by which oil aging, induction period for the additive and carry-over effects may influence the additive, together with the importance of the test cycle have been investigated in a number of experiments. But firstly, tests were run on reference fuel and reference oil in order to establish the repeatability of the testing.

Repeatability.

The following procedure was adopted from the standard M111E FE lubricant test procedure.

- Oil flush to fresh oil (RL191)
- 3 hr ECE cycle at 20⁰C, 33⁰C, 75⁰C / EUDC cycle (90⁰C) – Fuel consumption measured
- 5 hr aging period (3000rpm / 90Nm)
- 3 hr ECE cycle at 20⁰C, 33⁰C, 75⁰C / EUDC cycle (90⁰C) – Fuel consumption measured
- 5 hr aging period (3000rpm / 90Nm)
- 3 hr ECE cycle at 20⁰C, 33⁰C, 75⁰C / EUDC cycle (90⁰C) – Fuel consumption measured
- 5 hr aging period (3000rpm / 90Nm)

The three fuel consumption measurements were summed to give a total consumption for each stage. This was repeated three times on reference fuel (RF86). Figure 2 shows the results of the total fuel consumed during each fuel measurement– 3 sets of average results in total. It can be seen that the results vary by less than 0.2%.

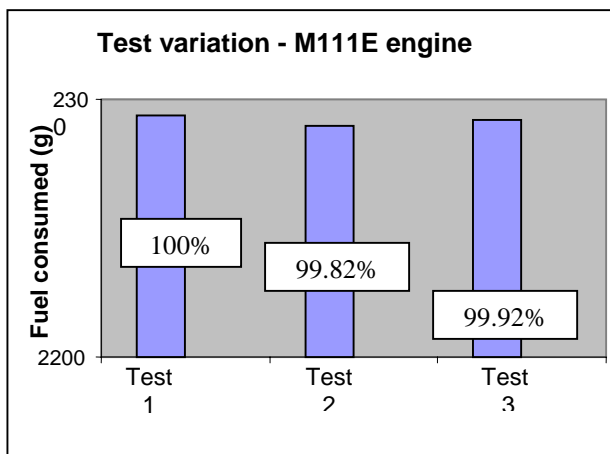


Figure 2.

Oil Effects.

Figure 3 below shows the change in fuel consumption for each of the three cycles of each stage, using the above procedure. This was repeated with different oil. In each case, the fuel consumption decreased as the

oil aged. Since this decrease occurred with un-additised fuel, it could only be caused by changes in the oil. The changes which might cause this effect are shear of the viscosity modifier or fuel dilution, both effects leading to a drop in viscosity and a decrease in fuel consumption. The test was repeated, but this time the five-hour condition periods were eliminated; the oil was only submitted to the mild ECE/EUDC cycles. Again, a decrease in fuel consumption was seen with time.

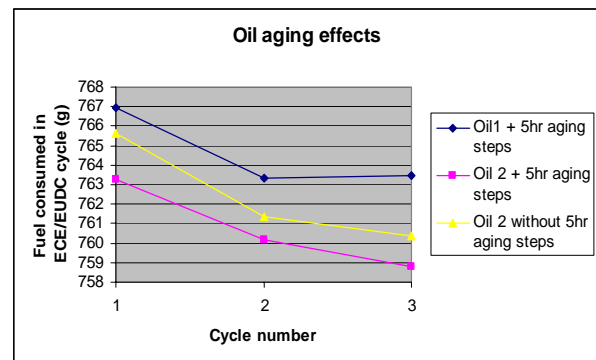


Figure 3.

It is unlikely that the mild test cycle would cause sufficient shear of the viscosity modifier to cause the drop in viscosity, particularly as the change in fuel consumption is similar regardless of whether or not the five-hour aging steps are included. The more likely cause is fuel dilution following the relatively low-temperature test cycle.

This effect shows the importance of using equivalent oil samples for comparative tests between fuels. One way of achieving this is by using fresh oil with each fuel change.

Final Test Procedure for M111E.

From the work reported here and previous studies, the following procedure was designed to ensure back-to-back comparisons of fuels, neutralize any aging effects from the oils, remove any carry-over between tests, and monitor any drift in the engine. It also allows the build-up of

the friction modifier effect to be monitored over time.

1. Flush in Fresh test oil : Reference fuel
 - **3 hour ECE/EUDC FE test** (*This is the front-end reference data in fresh oil*)
 - ECE15 cycle at 20⁰C, 33⁰C, 75⁰C, EUDC cycle at 90⁰C
 - 5 measurements at each stage
2. Flush to Fresh test oil : Candidate fuel
 - **3 hour ECE/EUDC FE test** (*This is instantaneous candidate data in fresh oil*)
 - 3 hour ECE/EUDC FE test (*Conditioning and measuring oil-aging effect*)
 - 3 hour ECE/EUDC FE test (*Conditioning and measuring oil-aging effect*)
4. Flush to Fresh test oil : Candidate fuel
 - **3 hour ECE/EUDC FE test** (*Candidate data in fresh oil after 9 hrs running*)
 - 3 hour ECE/EUDC FE test (*Conditioning and measuring oil-aging effect*)
 - 3 hour ECE/EUDC FE test (*Conditioning and measuring oil-aging effect*)
7. Flush to Fresh test oil : Candidate fuel
 - **3 hour ECE/EUDC FE test** (*Candidate data in fresh oil after 18 hrs running*)
8. Extended flush with high detergent oil : Reference fuel + EtOH
9. Flush to Fresh test oil : Candidate fuel + 10% EtOH
 - **3 hour ECE/EUDC FE test** (*This is instantaneous candidate data in fresh oil*)
 - 3 hour ECE/EUDC FE test (*Conditioning and measuring oil-aging effect*)
 - 3 hour ECE/EUDC FE test (*Conditioning and measuring oil-aging effect*)
12. Flush to Fresh test oil : Candidate fuel

- **3 hour ECE/EUDC FE test** (*Candidate data in fresh oil after 9 hrs running*)
 - 3 hour ECE/EUDC FE test (*Conditioning and measuring oil-aging effect*)
 - 3 hour ECE/EUDC FE test (*Conditioning and measuring oil-aging effect*)
15. Flush to Fresh test oil : Candidate fuel
 - **3 hour ECE/EUDC FE test** (*Candidate data in fresh oil after 18 hrs running*)
 16. Flush to Fresh test oil ; Reference fuel + EtOH
 - 3 hour ECE/EUDC FE test (*Monitoring if flushing has removed FM from cylinder bores*)
 17. Flush to Fresh test oil ; Candidate fuel + EtOH
 - 3 hour ECE/EUDC FE test (*Monitoring if flushing has removed FM from cylinder bores*)
 18. Flush to Fresh test oil ; Reference fuel
 - **3 hour ECE/EUDC FE test** (*This is the back-end reference data in fresh oil*)

This procedure was repeated four times on reference fuel containing Additive 1 and once on reference fuel + ethanol and Additive 1 as before. The results are shown graphically in figure 4.

Test 1. M111E results

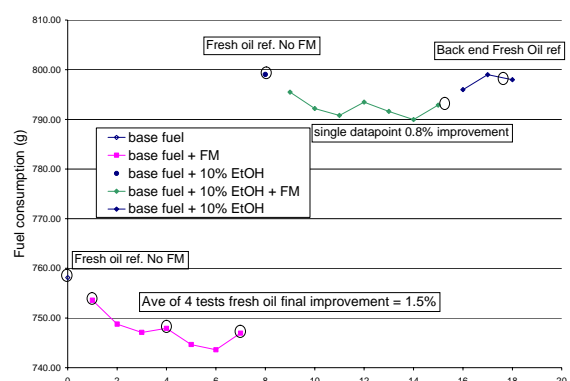


Figure 4.

Results.

For gasoline

1. The candidate fuel gives an immediate FE benefit of 0.6%. This increases over the next 6 hours to 1.5%, and stabilizes at this level.
2. When oil aging (through shearing or fuel dilution) is added, the maximum FE benefit increases to 1.9%.
3. Carry-over of the additive is observed, and three flushes with the high-detergent oil are required before the FE stabilizes, and all residual FM is removed.
4. The front-end and back-end results are within 0.1% of each other, indicating no drift has occurred (Data not shown).

For gasohol (10%)

5. The addition of Ethanol to the fuel had a negative impact on fuel economy of 6% versus the average fuel consumption in the reference fuel.
6. The candidate fuel gives an immediate FE benefit of 0.4%. This increases over the next 6 hours to 0.8%, and stabilizes at this level.
7. When oil aging (through shearing or fuel dilution) is added, the maximum FE benefit increases to 1.1%.
8. Carry-over of the additive is observed, and three flushes with the high-detergent oil are required before the FE stabilizes, and all residual FM is removed.
9. The front-end and back-end results are within 0.1% of each other, indicating no drift has occurred
10. Repeat testing has not been completed yet in each test, measurements are done in triplicate.

Procedure Based on Sequence VIB Fuel Economy

The sequence VIB is a well established standard test for measuring the fuel economy benefits of lubricants in a modern engine. This test utilized similar high detergent flush method as mentioned earlier to prevent carryover from skewing results. In the modified version for measuring fuel borne friction modifiers, this test utilizes the usual first two measurement stages of the sequence VIB and a 3rd modified stage specifically chosen to respond to the presence of friction modifier, such that ultimately, the range of measurement stages employed, varied in speed, load and crankcase temperature. As before in the M111E testing, these tests were conducted with and without additive and in the presence and absence of ethanol, so that in this case the brake specific fuel consumption (BSFC) could be determined. The additive tested was the same proprietary friction modifier, and in one evaluation combined with a synthetic detergent package. As expected, the results varied depending on the test condition, but in each case, the test that contained friction modifier resulted in reduced fuel consumption.

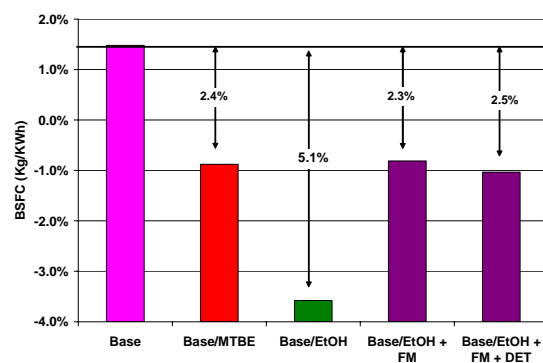


Figure 5.

Results.

11. The addition of MTBE to the fuel had a negative impact on the fuel economy of 2.4% versus the reference fuel
12. The addition of ethanol to the fuel had a negative impact on fuel

economy of 5.1% versus the reference fuel.

13. Addition of friction modifier to the ethanol containing fuel resulted in a fuel economy recovery of 2.8%, back to the relative fuel economy when using MTBE.
14. In a detergent containing package, the friction modifier had approximately the same fuel economy improvement, 2.6%.

CONCLUSIONS.

Modified M111E and Seq. VIB procedures have been designed to ensure back-to-back comparison of fuels, account for and neutralize any oil-aging effects, eliminate

any carry-over between tests, and monitor any drift in the engine.

Fuel-borne friction modification additives can make a substantial contribution to the global commitment to CO₂ reduction. However, in order to realise this contribution, an accurate procedure for evaluating such additives must be used.

Ethanol is widely used as an octane booster and beginning to gain ground in more global markets, however the lower energy content of the resulting fuel blends can negatively effect fuel economy.

The modified M111E and Sequence VIB tests have been used to measure the fuel economy benefit of fuel-borne friction modifiers in the absence and presence of ethanol in gasoline.

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