The effect of engine and transmission oil viscometrics on vehicle fuel consumption

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Abstract

An extensive programme of work has been undertaken to assess the potential benefits of modulating the properties of both engine and transmission lubricating oils to achieve lower fuel consumption. The performance of the engine lubricants was evaluated on a production Diesel engine on a transient test bed. The main engine lubricating oil viscometric properties investigated were cold cranking shear (CCS), kinematic viscosity at 100°C (KV100) and high temperature high shear (HTHS). Up to 3.5% fuel economy improvement was observed over the New European Drive Cycle (NEDC), relative to current production lubricants. A model relating fuel consumption to oil properties was developed and verified using an experimental programme conducted on a chassis dynamometer.

In a related study, the effects of changes in transmission lubricant properties were evaluated using a standard five speed manual transmission fitted to a light goods vehicle and tested on a chassis dynamometer. The lubricant was heated using an external energy source to simulate the effect of a more rapid warm up, this reduced the viscosity of the lubricant and a fuel consumption improvement of 0.7% was demonstrated over the NEDC from a 25°C start. In addition, a lower viscosity lubricant blend was evaluated, which delivered a 1% improvement in fuel economy over the standard blend from a cold start, and a further 0.4% improvement if heated.

List of Symbols and Units

ACEA	Association of European car manufacturers
BSFC	Brake Specific Fuel Consumption (g/kWh)
CCS	Cold Cranking Simulator - a device used to measure the apparent viscosity of oils under cold (between -5 and -35°C) cranking conditions representative of those found within engines, the abbreviation CCS is commonly used to prefix the resulting viscosity value and often referred to as 'cold cranking shear' (Cp)
CO	Carbon Monoxide
CO_2	Carbon Dioxide
DoE	Design of Experiments
DTI	Department of Trade and Industry
ECE	Also known as UDC – Urban Drive Cycle
ECU	Engine Control Unit
EU	European Union
EUDC	Extra Urban Drive Cycle
EURO3	European emissions limit January 2001
FC	Fuel Consumption
FE	Fuel Economy
HC	Hydrocarbons
HPCR	High Pressure Common Rail
HTHS	High Temperature High Shear, a measure of viscosity at high temperature (typically 150°C) under shearing conditions representative of those found within engines (Cp)
KV_{100}	Kinematic Viscosity measured at 100°C (cSt)
NEDC	New European Drive Cycle
NOx	Oxides of Nitrogen
PM	Particulate Matter
THC	Total Hydrocarbons

Introduction

The average CO_2 for new UK car registrations during 2009 was 158g/km [1], down from 190g/km in 1997. CO_2 reduction proposals and recommendations have changed frequently over the last few years ranging from a voluntary target of 120g/km by 2012 proposed by the association of European car manufacturers (ACEA) [2], to 100g/km by 2020 outlined in the King review in March 2008 [3]. However, with the adoption of the new car CO_2 regulation within the EU in December 2008, reducing the fleet average target to 130g/km by 2015, the automotive industry faces a stiff challenge in the coming years. Manufactures which fail to achieve the necessary CO_2 reductions will face substantial penalties of up to 95 euro per excess gram per vehicle produced [4]. An even more stringent target of 95g/km has been earmarked for 2020 dependant on the findings of an impact assessment [4].

In addition to proposed efficiency savings, an extra 10g/km reduction in CO_2 is required by 2015 through the use of 'complementary measures' [4] such as the use of biofuels and wider adoption of 'eco-driving' principles.

The average UK new car CO_2 emissions over the period 1997-2006 is shown in Figure 1 and these data are further expanded in Table 1.

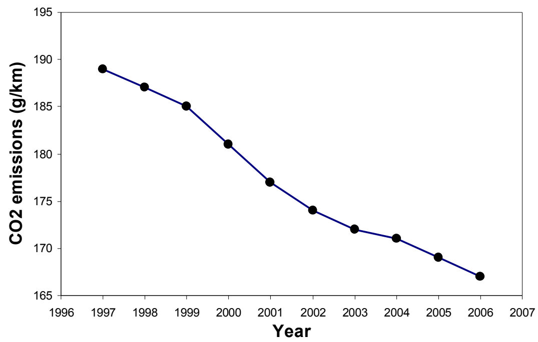

Figure 1 - Average UK new car CO_2 emissions 1997-2006 [1]

	1997	2006
Average new car CO_2 emissions	189.8 g/km	167.2 g/km (-11.9%)
New car sales	2,170,725	2,344,864 (+8.0%)
CO_2 emissions - all cars	72.2 Mt	68.7 Mt (-4.8%)
Total UK on-road cars	25.6 million	29.9 million (+16.8%)

Table 1 - UK car trends 1997-2006 [1]

		Oil Property		
Oil #	Oil Condition	CCS @ -30°C (cP)	HTHS @ 150°C (cP)	KV_{100} @ 100°C (cSt)
1	Fresh	7180	4.01	14.53
	Aged	7100	3.71	13.61
	Change (%)	*-1.1*	*-7.5*	*-6.3*
2	Fresh	4720	4.07	15.33
	Aged	4280	3.72	14.32
	Change (%)	*-9.3*	*-8.6*	*-6.6*
3	Fresh	7340	2.89	8.12
	Aged	7040	2.73	8.28
	Change (%)	*-4.1*	*-5.5*	*2.0*
4	Fresh	4720	2.77	8.45
	Aged	4350	2.75	8.41
	Change (%)	*-7.8*	*-0.7*	*-0.5*
5	Fresh	657	2.69	9.57
	Aged	1330	3.43	12.18
	Change (%)	*102.4*	*27.5*	*27.3*

Table 3 - Oil Sample Analysis

Figure 2 shows the average BSFC for all 5 oil formulations over the whole NEDC drive cycle with error bars showing the 95% confidence interval of multiple repeat tests. Of the 4 oils falling within generally accepted viscometrics (oils 1-4), the oil with low values of CCS, KV_{100} and HTHS performed the best both when fresh and when aged. The high values of CCS, KV_{100} and HTHS seen in oil 1 resulted in approximately a 10g/kWh (3.2%) increase in BSFC compared with oil 4 regardless of oil age.

Oil 5 exhibited a much reduced BSFC when fresh compared with the other oils manifesting as a 3.2% reduction in BSFC over oil 4. However, oil 5 did not display the characteristic reduction in fuel consumption normally seen with increasing oil age, instead demonstrating a marked rise. The reason for this is evident in Table 3. CCS, HTHS and KV_{100} values for oil 5 significantly increased with age by 102.4, 27.5 and 27.3%, respectively, in agreement with the observed increase in BSFC, thus adding confidence in this trend as a real result. This trend of increasing CCS, HTHS and KV_{100} values with age was likely to be caused by lighter, more volatile organic compounds within the oil evaporating off over time and causing the oil to thicken. Oil 5 would be particularly susceptible to this effect due to it containing a higher than normal proportion of these volatile fractions in order to achieve the much-reduced CCS value.

Oil 2 provides an interesting comparison to oil 5 as it too displayed an increase in fuel consumption with time, however fully aged data for oil 2 were subject to a larger-than-normal degree of experimental scatter resulting in reduced confidence in the sample mean representing a true population mean. Looking again at Table 3, it can be seen that CCS, HTHS and KV_{100} all decrease (9.3%, 8.6% and 6.4%, respectively) as oil 2 is aged, which would be expected to cause a reduction in fuel consumption, thus implying that the slight increase in observed BSFC can be attributed to experimental error.

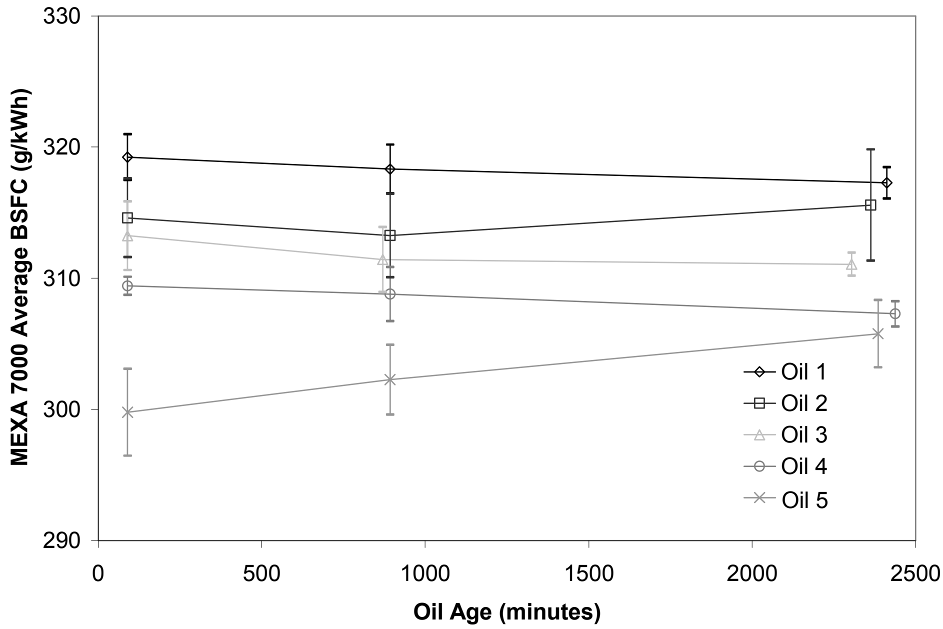

Figure 2 - NEDC Oil Performance (BSFC)

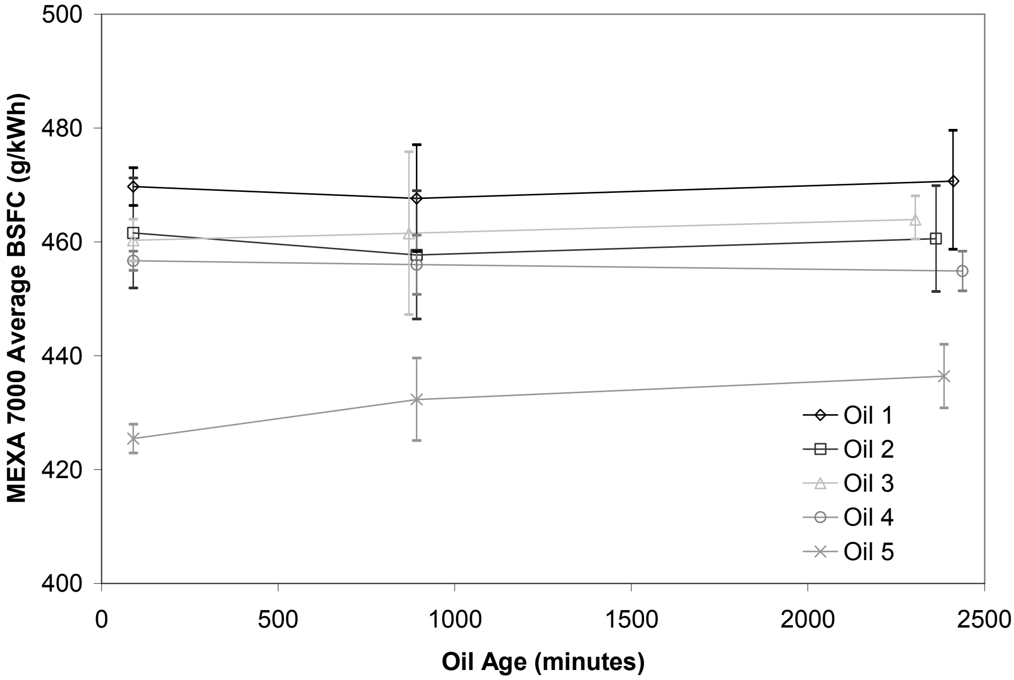

Figure 3 - ECE Oil Performance (BSFC)

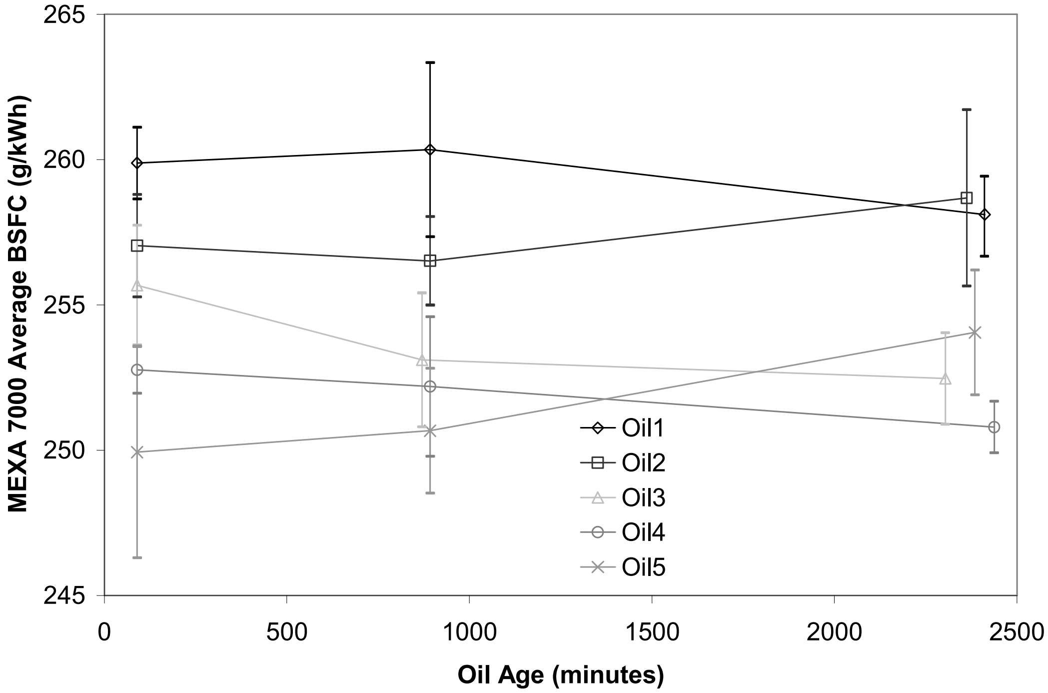

Figure 4 - EUDC Oil Performance (BSFC)

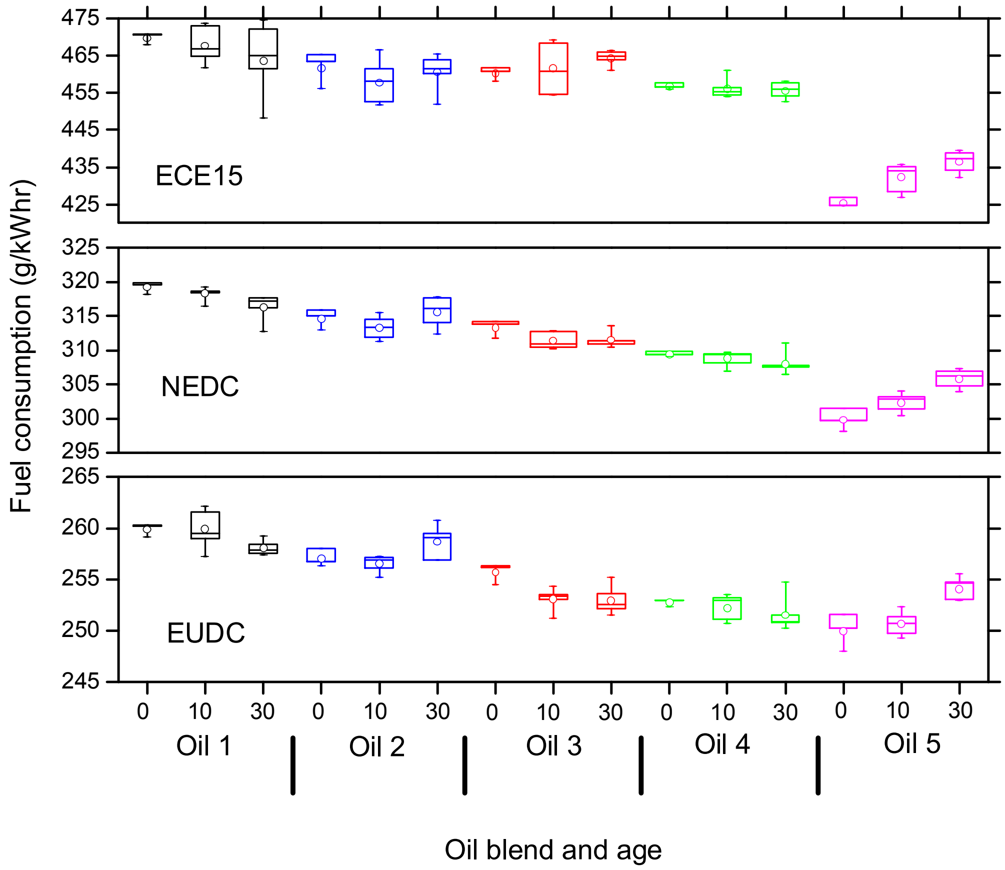

Figure 5 - Oil Performance (BSFC) Comparison

The effect of the differing oil formulations on BSFC during the initial ECE portion of the NEDC can be seen in Figure 3. As would be expected from the oil CCS values, oil 4 exhibits a 3.4% reduction in BSFC compared with oil 1 when aged, while oil 5 reduces the BSFC by an additional 4.1%.

Results for the EUDC given in Figure 4 correlate exceptionally well with the high temperature oil viscometrics, HTHS and KV_{100} values, with the measured rank order of oils 1 and 2 having the highest fuel consumption with oils 3, 4 and 5 performing better. Once the oils are fully aged, the increase in HTHS and KV_{100} for oil 5 (due to evaporation of volatile fractions) causes a rise in BSFC to a level greater than oils 3 and 4 but still less than that of oil 1 and 2. This trend is as expected based on aged oil sample property analysis.

EUDC data suggests a maximum BSFC improvement of 3.1% (between oils 2 and 4) can be obtained for aged oil by varying the high temperature viscometric properties.

Figure 5 shows the impact of oil viscometrics on fuel consumption for each section of the NEDC cycle in boxplot form[1]. It should be noted that the

[1] In descriptive statistics, a boxplot (also known as a box-and-whisker diagram or plot) is a convenient way of graphically depicting groups of numerical data through their five-number summaries (the smallest observation, lower quartile (Q1), median (Q2), upper quartile (Q3), and largest observation). A boxplot may also indicate which observations, if any, might be considered outliers. The boxplot was invented in 1977 by the American statistician John Tukey.