

The Effect of Low Viscosity Oil on the Wear, Friction and Fuel Consumption of a Heavy Duty Truck Engine

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ABSTRACT

This paper describes the results of a series of tests on a heavy-duty truck diesel engine using conventional and low viscosity lubricants. The objectives were to explore the impact of reducing lubricant viscosity on wear, friction and fuel consumption. The radiotracing Thin Layer Activation method was used to make on-line measurements of wear at the cylinder liner, top piston ring, connecting rod small end bush and intake cam lobe. The engine was operated under a wide range of conditions (load, speed and temperature) and with lubricants of several different viscosity grades. Results indicate the relationship between lubricant viscosity and wear at four critical locations. Wear at other locations was assessed by analysis of wear metals and post test inspection.

The fuel consumption was then measured on the same engine with the same lubricants. Results indicate the relationship between oil viscosity and fuel consumption under a wide range of operating conditions. Expected fuel consumption improvements over a typical drive cycle were calculated.

Friction of the whole engine was calculated from measurements of cylinder pressure and brake torque, with two of the low viscosity oils and, in addition, a five stage motored friction teardown test was performed. Together these results were used to explore the relationship between lubricant viscosity and friction across a range of operating conditions.

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INTRODUCTION

Increasing fuel costs and climatic impact of greenhouse gases have made fuel efficiency one of the most important issues for the transportation industry. Fuel economy and CO₂ emission regulations for light duty vehicles have been in place in many countries for a number of years [1]. On August 9, 2011 the first US standards for GHG emission and fuel consumption for heavy and medium duty diesel vehicles were formally adopted [2].

Use of low viscosity lubricants is known to be an effective way to achieve good fuel economy. However there are many important questions related to the use of such lubricants that have not been adequately addressed in the literature, e.g., how low can one go in viscosity before fuel economy benefits begin to fade away? Similarly, how does

lubricant viscosity affect engine wear and how such effects might be mitigated?

In anticipation of the rising importance of fuel economy lubricants for the HDD market, a large scale R&D program was initiated to answer some of these questions. The objectives of this program were to explore the boundaries of the lubricant formulation space for fuel economy and engine durability and to develop new additive approaches to optimize these attributes.

The work reported in this paper was carried out in a joint program by Infineum and Ricardo. The main objective of this program was to explore the extremes of the lubricant viscosity range, and to examine its effect on fuel consumption and engine wear.

The fuel efficiency benefits of lower viscosity engine oils have been extensively reported in the literature [3, 4, 5, 6].

Similarly, it is known in the literature that magnitude of the fuel economy benefits depend strongly on the engine operating load and speed [7 and 8]. One of the objectives of the current work was to quantify this relationship between oil viscosity and fuel consumption under different drive cycles representative of typical heavy duty truck engines.

Reduction of oil viscosity also results in lower oil film thickness in the loaded contacts in the engine and this can lead to increased wear rates, and even locally increased friction at some contacts, if the oil film thickness becomes so low that increased level of asperity contact occurs. Quantification of this wear risk, when using some very low viscosity oils, was a further objective. To reduce testing duration and increase sensitivity an on-line wear measurement technique was used.

The third objective was to gain understanding of the relative contributions to reduced friction when using low viscosity lubricants. Engine friction is difficult to measure and calculate, so friction was deduced from measurements made under a wide range of fired engine conditions and a motored teardown test was performed. Advanced CAE modeling of the friction power losses at the major tribological contacts (piston, rings, bearings etc.) was also performed and results compared with measured data. This work has been previously published [9].

A total of 4 test oils were used in this program. All of the test oils contained the same performance additive system but were formulated to different viscosities, as shown in Table 1. Details of the additive system are proprietary to Infineum. The additive pack was selected using Infineum's prior experience in formulating low viscosity engine oils and has field-proven engine durability characteristics in the baseline lubricant (B in the table).

Table 1. Lubricant properties

Name	Baseline (B)	Low viscosity (LV)	Very low viscosity (VLV)	Ultra low viscosity (ULV)
Kinematic viscosity at 40°C (mm ² s ⁻¹)	75.77	46.21	33.64	21.22
Kinematic viscosity at 100°C (mm ² s ⁻¹)	12.28	8.13	6.53	4.82
High Temp High Shear viscosity at 150°C, 10 ⁶ s ⁻¹ shear rate (mPas)	3.52	2.71	2.26	1.82

It is important to note that in this study even the baseline lubricant (5W/30) employed here had a reduced viscosity compared with many oils used in current truck engines. The viscosity of the ULV lubricant was significantly lower than described by current SAE specifications for engine oils.

WEAR MEASUREMENTS

Wear Test Method

The test engine was an IVECO Cursor 13 Euro V engine which is a typical heavy duty truck engine of I6 configuration having 12.9L displacement with bore of 135 mm and stroke of 150 mm. This engine delivers peak torque of 2500 Nm between 1000 and 1600 rpm and peak power of 412 kW at 1900 rpm. Before the beginning of the testing the engine had completed 300 hours of mixed speed and load on a durability cycle.

Wear was measured in real-time and on-line using a thin layer activation (TLA) technique. This technique is sometimes called surface layer activation (SLA) or radio nuclide technique (RNT).

Following discussion with development engineers at Ricardo the following locations were selected for real-time wear measurement based on the perceived risk when running with very low viscosity lubricants.

- Outer face of top piston ring (chromium and aluminium oxide)
- Cylinder liner in upper area on thrust side (cast iron)
- Small end bearing of connecting rod on the highly-loaded lower side of the bush (bronze)
- Peak lift area of intake cam lobe (steel surface)

Each of these surfaces was "activated" using high energy protons. The process changed the identity of a thin layer of the target element from the usual stable isotope to another radioactive isotope with the same physical and chemical properties. Typically these isotopes emitted low level gamma radiation, with half-lives of a few weeks or months. Each isotope emitted radiation of different energy. As wear occurred at each contact, some radioactive particles from the surfaces were transferred to the engine lubricant. This was then passed through a highly sensitive detector able to discriminate particles emitting radiation of different energies. Consequently, the identification of wear at each of the above locations was achieved by quantifying the total radiation measured at different energy levels. The on-line data from the wear particles counted in this way was supplemented by further data taken from periodic measurement of particles trapped in the oil filter and data were automatically corrected for reductions in radioactivity related to the natural decay of the isotopes. This improves the absolute accuracy of the wear measurements [10].

In addition to on-line wear measurement at these locations the wear at other areas in the engine was assessed by the following.

- Regular sampling of the lubricant and analysis, by inductively coupled optical emissions spectrometry (ICP-OES), of wear metal content
- Visual inspection of all contacts following disassembly at the end of the project

During the wear testing the engine oil temperature was controlled to be either $90\pm1^{\circ}\text{C}$ or $130\pm1^{\circ}\text{C}$ at the main oil gallery using an external oil conditioning circuit with connections in and out of the sump. In addition, the engine coolant was controlled to $90\pm1^{\circ}\text{C}$ at the coolant outlet using an external cooling circuit.

The variation of load and speed during the 18 hour steady state test cycle is shown in Figure 1.

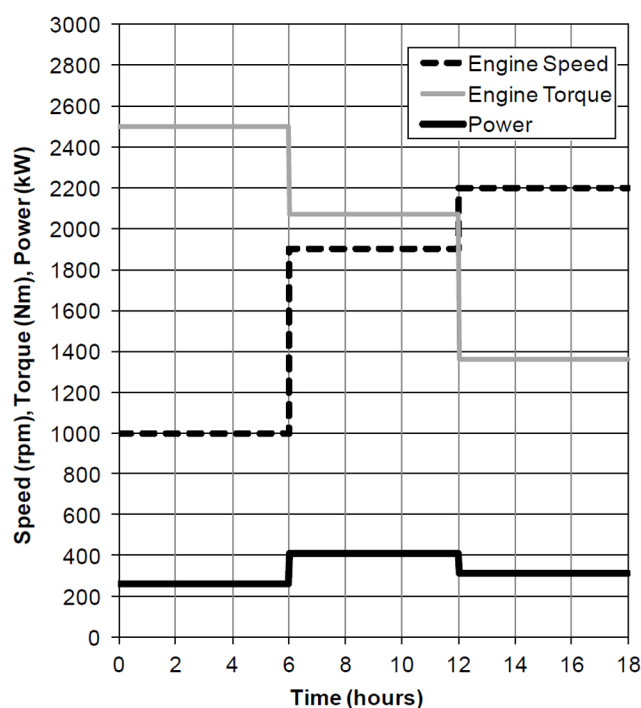


Figure 1. 18 hour steady state test cycle

A steady state idle period of 6 hours at 550 rpm was also tested. A 12 hour transient test cycle as shown in Figure 2 was also used.

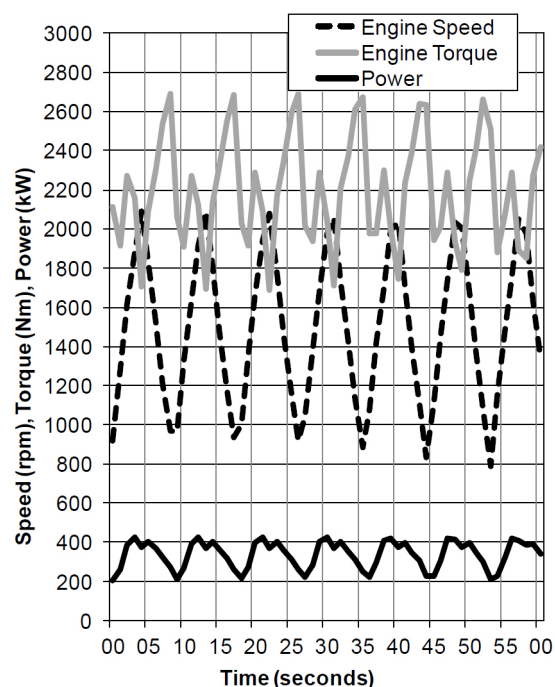


Figure 2. 12 hour transient test cycle

Wear testing was performed using baseline lubricant (B), very low viscosity (VLV) lubricant and ultra low viscosity (ULV) lubricant having the viscosity properties defined in Table 1.

Wear Test Results

The wear tests generated a large quantity of data. It is not possible to show all of this data in this paper so a few representative plots are presented.

Figure 3 shows the raw accumulated wear from the on-line measurements against time when using the baseline oil. The four component surfaces are indicated. The level of wear at all locations was considered to be very low. The top ring showed the highest level of wear and the cylinder liner and camshaft showed the lowest level. Bands on the graph indicate prevailing test conditions during part of the test. The time between 0 and 24 hours was spent commissioning. After 84 hours the full test sequence indicated on the graph was repeated. The accumulated wear at the top ring increased until about 100 hours and then stabilized. This indicated a further running-in process, following the engine build with irradiated parts, during which ring wear rate reduced.

Figure 4 shows raw accumulated wear from the top piston ring covering the same period when using three different lubricants. The highest wear occurred with the lowest viscosity lubricant, as expected, and a similar response was seen at the other component surfaces. The ring appeared to experience a new running-in process each time the lubricant was changed. For the baseline and VLV oils the wear rate stabilized but for ULV oil it was not known if the process stabilized as the test was stopped for budgetary reasons.