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Enhancing the lubricity of an environmentally friendly Swedish diesel fuel MK1

E. Sukjit, K.D. Dearn*

School of Mechanical Engineering, University of Birmingham, Edgbaston, Birmingham, B15 2TT, United Kingdom

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ABSTRACT

The lubricity of diesel fuel has a direct effect on the service life of the fuel injection equipment, and when alternative fuels are specified, is of vital importance. One such fuel is the Swedish diesel fuel, MK1 which contains low levels of sulphur and low lubricity. This paper investigated the use of ultra low sulphur diesel (ULSD) and fatty acid methyl esters derived from rapeseed (RME) blends to improve MK1 lubricity. Fuel lubricity was assessed using a high frequency reciprocating rig. The wear scar diameter of the ball specimen was measured using optical microscopy while the wear profile and surface roughness of the disc were analysed using a profilometer. Scanning electron microscopy with an energy dispersive spectrometer was used to evaluate the microscopic topography and chemical compositions of the surfaces. Results confirm that MK1 has poor lubricity when compared to other base fuels. Of the blended fuels, ULSD showed little improvement. However, a small percentage of RME improved the lubricity of both the pure MK1 and the blends. Analysis of the worn surfaces indicated that chemical compositions of MK1 did not adsorb and react as well when compared with those of ULSD, RME and selected blended fuels.

1. Introduction

There are many ways in which diesel engine manufacturers have sought to reduce exhaust gas emissions to meet European standards for emissions control. These include the use of exhaust gas aftertreatments, the development of high pressure fuel injection equipment (FIE) and high quality fuel refinement. In accordance with the specification of fuel properties, the European Union set a maximum limit of 50 ppm sulphur in diesel fuel, which has applied since 2005. Diesel fuels containing extremely low levels of sulphur are becoming more widely available in the United Kingdom, Germany and other European countries. The Nordic countries have also taken similar action. In Finland, a fuel known as City Diesel with a maximum 50 ppm of sulphur has over 80% of the market share [1]. The Swedish Government has already acted by introducing the environmentally adapted diesel fuel (MK1) with ultra low sulphur specifications (max. 10 ppm) and limits on the total aromatics content (max. 5%, v/v) since 1991. In case of the MK1, almost complete desulphurization is required [2]. To investigate a decrease in emissions, Westerholm et al. [3] compared regulated emission measurements of environmentally classified Swedish diesel fuel to reference diesel fuel used in a European Program on Emissions, Fuels and Engine Technologies programme (EPEFE). The results indicated a reduction in CO, NOx and particulates by 2.2%, 11% and 11% respectively.

The introduction of low sulphur diesel fuel brings about some serious problems in fuel properties due to the desulphurization process, which eliminates not only quantities of sulphur in diesel fuel but also that of lubricity-imparting compounds such as polyaromatics and oxygen containing compounds [4–7]. This reduction in lubricity can have a damaging effect on the FIE. To prevent premature failures of this equipment, several standards have been developed to ensure lubricity levels in fuels are maintained at acceptable standards. To meet the lubricity standards the wear scar diameter generated under specified conditions must not exceed 460 μm and 520 μm in European and U.S. regulations respectively [8,9]. Therefore, diesel fuels with low content of sulphur require suitable additives to restore their lubricating properties.

In recent years, fatty acid methyl esters (FAME), commonly known as first generation biodiesel, derived from vegetable oils or animal fats by transesterification, have successfully been used as diesel fuel lubricity enhancers. In Europe, rapeseed methyl ester (RME) is the principle crop for the production of first generation biodiesel giving the fuel enhanced flow, pour and cloud point characteristics [10]. Furthermore oxygen containing moieties, particularly carboxylic acid groups, in this biodiesel improve the lubricity [11,12]. Numerous studies have investigated the effect that the various components of FAME have on the lubricating properties of the bulk fuel. Geller and Goodrum [13] tested and compared the lubricity enhancing effect of FAME mixtures. The results showed that the methyl esters obtained from vegetable oils, composed of a mixture of several fatty acids, had better lubrication performance than the single fatty acid methyl esters. Knothe and Steidley [14] found that low blend levels of commercial

* Corresponding author. Tel.: +44 121 414 4190; fax: +44 121 414 3958.
E-mail address: k.d.dearn@bham.ac.uk (K.D. Dearn).

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Table 1
Fuels properties.

Properties	ULSD	MK1	RME
Cetane number	53.9	53.8	54.7
Density at 15 °C (kg m^{-3})	827.1	816.9	883.7
Viscosity at 40 °C (cSt)	2.467	2.03	4.478
50% distillation (°C)	264	239	335
90% distillation (°C)	329	271	342
LCV (MJ kg^{-1})	42.7	43.2	39.0
Sulphur (mg kg^{-1})	46[a]	0.7[b]	5[a]
Aromatics (wt%)	24.4	3.6	–
C (wt%)	86.5	84.8	77.2
H (wt%)	13.5	13.5	12.0
O (wt%)	–	–	10.8

[a] Based on ASTM D2622.
[b] Based on ASTM D3120.

Table 2
Fatty acid profile of rapeseed methyl esters.

Methyl esters	wt%
Palmitic C16:0	4.51
Stearic C18:0	1.47
Oleic C18:1	63.12
Linoleic C18:2	19.85
Linolenic C18:3	9.03
Gadoleic C20:1	0.55
Erucic C22:1	1.47

biodiesel restored the lubricity of petrodiesel to acceptable levels. This they attributed to the fatty compounds which contain polarity-imparting oxygen atoms. Matzke et al. [15] examined the tribological performance of common rail FIE components using a high temperature oscillating rig (HiTOM) and compared these to lubricity test results from a high frequency reciprocating rig (HFRR). They found that a content of 5% biodiesel derived from RME in ultra low sulphur diesel (ULSD) increased the lubricity of the fuel. Similar results published by Sulex et al. [16] reported that as little as 5% RME in diesel fuels decreased friction coefficient and wear scar diameter by approximately 10% and 50% respectively. In addition to improving the lubricating properties of fuels, RME shows a low mutagenic potency [17].

The objective of this work is to investigate the effect of RME as a lubricity enhancer on the lubricating properties of MK1 to obtain a correlation between wear quantities and percentage content of bioadditives. The lubrication performances of the tested fuels were carried out on a HFRR. Moreover the lubricity of the Swedish diesel fuel blended with ULSD was also studied in this study.

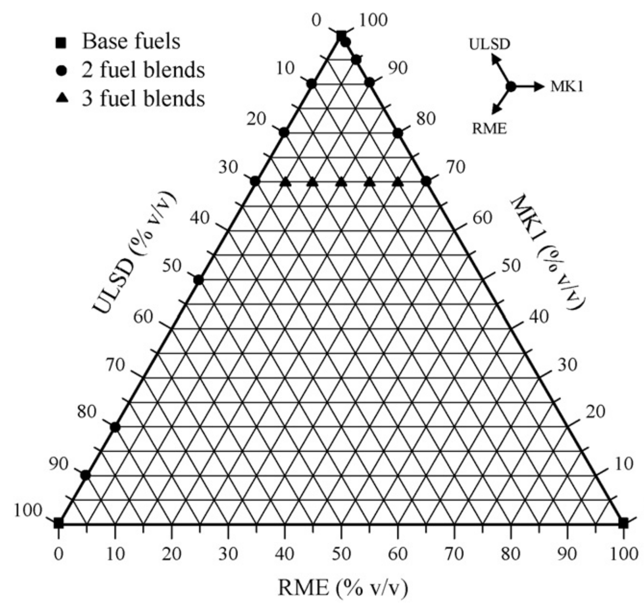

Fig. 1. Ternary diagram representing the tested blends.

2. Methodology and materials

2.1. Fuel specification and fuel blends

The ULSD and RME were provided by Shell Global Solutions UK. The main characteristics of these fuels and the MK1 are given in Table 1. The ULSD is supplied with a lubricity enhancer to keep the corrected wear scar below the prescribed limitation in the European petrodiesel standard EN 590 (460 μm) for commercial reasons. The fatty acid composition of RME that are given in Table 2 were analysed according to the ISO Standard EN 14103. A Perkin Elmer Clarius 500 chromatograph (GC) equipped with a flame ionization detector (FID) was used for the gas chromatographic determinations. The basic properties of Swedish MK1 diesel fuel are taken from [3].

This investigation includes three series of lubricity tests as shown in Fig. 1. In the all tests, the principle fuel was MK1 and this was then blended with RME and ULSD in the first and second tested series respectively. The methyl ester proportions of MK1/RME blends were 1%, 5%, 10%, 20% and 30% (v/v) and the

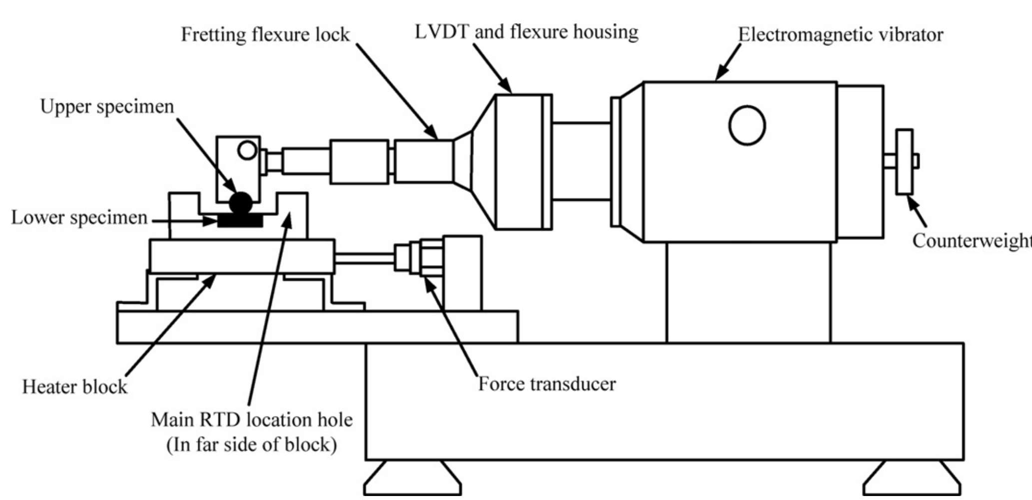

Fig. 2. Schematic diagram of mechanical unit of high-frequency reciprocating rig (HFRR) [18].