Tribology International 46 (2012) 174–182

Contents lists available at ScienceDirect

Tribology International

journal homepage: www.elsevier.com/locate/triboint

Investigation of long-term engine oil performance using lab-based artificial ageing illustrated by the impact of ethanol as fuel component

Charlotte Besser [a,*], Christoph Schneidhofer [a], Nicole Dörr [a], Franz Novotny-Farkas [b], Günter Allmaier [c]

[a] Austrian Centre of Competence for Tribology, AC^{2}T research GmbH, Wiener Neustadt, Austria
[b] OMV Refining & Marketing GmbH, Vienna, Austria
[c] Institute of Chemical Technologies and Analytics, Vienna University of Technology, Vienna, Austria

ARTICLE INFO

Article history:
Received 21 July 2010
Received in revised form
27 June 2011
Accepted 29 June 2011
Available online 5 July 2011

Keywords:
Lubrication oil
Chemical degradation
Oxidative degradation
Condition monitoring

ABSTRACT

The effect of ethanol and its combustion products on the lubrication system is not very well understood. In this paper, a novel lab-based artificial ageing method for the evaluation of engine oils for bio-fuelled automotives and the results thereof are presented. Artificial ageing of three fully formulated engine oils with addition of ethanol, acetaldehyde, and acetic acid was carried out. The oil formulations chosen represent a consequent series of optimisation steps based on the engine oil performance in terms of preservation of typical oil parameters, e.g. base reserve and oxidation, observed during the artificial ageing procedure. It was shown that ethanol as well as acetaldehyde has almost no effect on the oil degradation especially in the case that advanced additive technology was used. On the contrary, acetic acid significantly affected the formulated oil showing influence on the detergent chemistry and even caused sludge formation. The use of the novel artificial ageing method proved to clearly differentiate the impact of the respective compounds added with the possibility to simulate enhanced stress conditions without the need of time-consuming and expensive engine bench tests. Hence, the novel setup offers valuable input for the formulation and the pre-selection of future engine oils suitable for bio-fuel.

1. Introduction

1.1. General introduction

In recent years, there has been a growing interest in the use of bio-fuels. The main reasons for this worldwide interest are the awareness of the limitation of fossil fuel resources closely linked with the increase of oil prices, the reliability of supply, and hence the interest in the reduction of the dependence on foreign petroleum resources. Additionally, global warming gains increase the significance and so the need for a drastic reduction of CO_2 emissions.

These strategic, economical and environmental issues found their way into legislation related to energy and fuel, respectively, and had a direct impact on the formulation of fuels. In May 2003, the European Union released the directive 2003/30/EC [1], commonly known as the 'bio-fuels directive'. This non-binding directive asked for replacing 2% of all transport-related fossil fuels by bio-fuels until December 31, 2005, and required a further increase in substitution to 5.75% until December 31, 2010. In 2009, the directive 2003/30/EC was replaced by the now binding directive 2009/28/EC [2] with the mandatory target to replace 10% of common fuels by bio-components until 2020.

When using bio-fuels as an additional component in fuels for automobiles, bio-diesel for diesel and ethanol for gasoline engines are very commonly utilised. Bio-diesel and its impact on the engine performance, emission profile and the lubrication system have been the object of intense research: Sinha et al. analysed deposit formation and carried out long-term endurance tests [3]. Borrás et al. investigated the exhaust emissions of light-duty diesel engines and found rape oil methyl ester bio-diesel to be effective in reducing polycyclic hydrocarbon (PAH) emission [4]. Jain et al. presented an overview over the different aspects of stability of bio-diesel. Methods to measure and improve the stability were mentioned in this publication [5]. There are various papers that report about fuel dilution of engine oil by bio-diesel and the resulting effects. Peacock et al. found for example an accumulation of 0.5% fatty acid methyl ester (FAME) in the lubrication system after 3240 km car operation [6]. Non-published experience indicates that an uptake between 5% and 10% of bio-diesel into lubricants is very common. At the end of oil change intervals elevated contents up to 20% of bio-diesel in the oil are possible and were found.

* Correspondence to: AC^{2}T research GmbH, Viktor Kaplan-Straße 2, 2700 Wiener Neustadt, Austria. Tel.: +43 2622 81600 151.
E-mail address: besser@ac2t.at (C. Besser).

0301-679X/$ - see front matter © 2011 Elsevier Ltd. All rights reserved.
doi:10.1016/j.triboint.2011.06.026

On the other hand, alcohols such as methanol and ethanol have to be considered as a serious alternative to fossil gasoline. The global production of fuel ethanol increased from 31.3 billion litres in 2005 to over 85.6 billion litres in 2010 [7]. Ethanol for example offers a variety of benefits, due to different aspects [8]: it is available from renewable resources and therefore CO_2 neutral; ethanol possesses positive properties for the use in internal combustion engines, e.g. higher auto ignition endurance due to a research octane number between 100 and 106, enabling this way higher compression ratios and engine efficiency as well as the increase in specific power; its broader inflammable limit allows adjustments of leaner fuel mixtures with about 15%; besides, it is stable in common tanks at room temperature and does not undergo accidental polymerisation as observed for some other fuel components with low stability; for storage and transportation, the existing infrastructure for fossil fuel distribution can be used; finally, the dependence of foreign fossil fuel import is decreased and a source of higher revenue for the local agriculture system is created, which is heavily discussed due to replacement of farmland.

Countries offering commercially available fuels with high amounts of ethanol also show increased use of flexi fuel vehicles (FFV). USA, Sweden and in particular Brazil with ethanol contents of 25 vol% [9] and more have to be mentioned in this context. There significantly shortened oil change intervals are observed. But a direct comparison between the oil drain intervals in European and Brazilian vehicles cannot be drawn due to different levels of engine and oil technology, respectively, and the different climates.

In former years, the influence of methanol on the engine was the object of quite a number of investigations. For example, Moritani et al. showed that blends of methanol and gasoline caused less sludge formation, in particular at methanol concentrations higher than 50 vol% [10]. Shah et al. carried out oxidation stability and wear tests with different lubricants designed for the application in methanol fuelled cars. They showed that contamination with methanol could separate additives and less viscous portions of the base oil by some kind of liquid–liquid extraction, which led to reduced oxidation stability and declined wear properties [11].

In contrast to this, the effect of ethanol on the lubrication system is still not well known and therefore a strong need for detailed investigations is given. Because of its high volatility (boiling point of 78 °C at 1 bar) it usually easily evaporates out of the lubrication system. Nevertheless, partial combustion can form more reactive compounds emerging from ethanol, which could be accumulated in the engine oil. There are reports, which show the presence of increased levels of ethanol and water in the lubrication system after certain driving conditions. Boons et al., for example, carried out a field test with 85% ethanol–gasoline-blends in cold climate and with short driving cycles. They found significantly higher contents of water and ethanol in the lubricant, but no problems in the engine or driving performance have been observed [12].

Additionally, complementary investigations examined the impact of ethanol on the emission characteristics of different engines. Maheshwari et al. found out that ethanol reduces emissions of carbon monoxide (CO) from two-wheelers but slightly increases of hydrocarbon (HC) emission. However, in passenger cars both the CO and the HC emissions are significantly decreased, but on the other hand the content of nitrogen oxides marginally increased [13]. Tseng et al. stated a significantly increase of 41.3% in the exhaust of acetaldehyde by motorcycles when using 3% ethanol in gasoline [14]. Ginnebaugh et al. showed in their studies that the level of formaldehyde, acetaldehyde, and peroxyacyl nitrates (PAN) in the emissions of vehicles was much higher during the use of a blend of gasoline with 85% of ethanol than with neat gasoline [15]. Gaffney et al. stated that ethanol combustion causes development of acetaldehyde, which in turn is responsible for the formation of products like ozone, H_2O_2, formic acid, and CO, as well as PANs and peracetic acid [16]. Chen et al. found out that the optimum ethanol content in gasoline for cold starting conditions lies between 20% and 30% concerning emission characteristics [17].

Given the matter of facts above, there is an obvious demand to accomplish in-depth investigation to reveal the impact of components from renewable resources in fuels on the lubrication system.

1.2. Fuel specific consideration of artificial ageing of engine oils

Artificial ageing means applying harsh conditions to the oil sample to accelerate oil degradation at a very short-term scale. Nevertheless an artificial ageing procedure should consider the relevant oil degradation mechanisms occurring under real engine operating conditions.

Currently used standardized methods for the artificial ageing of lubricating oils evaluate different parameters of the oil performance. Most standards examine the thermal-oxidative stability of oils by exposing it to elevated temperatures and oxygen from air [18,19]. Partly, they use metallic catalysts to accelerate ageing or lubricant degradation [20,21]. Other procedures investigate the potential for deposit development of oils at high temperatures [22,23] or the corrosiveness of oils on different reference metals is tested [24].

But no standard being currently in use evaluates the impact of unburnt or partially combusted fuel components that are taken up by the engine oil via blow-by gases. In particular, the impact of bio-fuel on the oil is not considered. Hence, the aforementioned artificial ageing procedures cannot provide satisfactory knowledge about the lubricant performance under the special conditions emerging from fuels containing bio-components, especially on a long-term basis.

Dealing with the new circumstances in bio-fuelled engines, new artificial ageing methods with strong connection to this special application have to be introduced. Requirements of these procedures are the consideration of fuel components as well as combustion products thereof, the contemplation of different oil types like automotive or stationary engine oil, the investigation of oil degradation caused by these compounds by regular sampling and oil condition monitoring, the economic simulation of engine procedures.

The following valuable benefits in comparison to existing test methods are expected by the implementation of a novel artificial ageing method: a knowledge gain in complex ageing mechanisms according to engine oil quality, the study of the long-term performance even far beyond conventional oil drain intervals being relevant for the knowledge of oil failure, and economic as well as efficient means of evaluating novel oil formulations by pre-selection and hence reduction of candidate formulations for time-consuming and expensive engine bench tests.

Based on these requirements and targets a novel lab-based artificial ageing method was developed. This paper presents the first use of the method and first results in an intense study carried out as a fundamental research on lubricant deterioration and investigation of deterioration mechanisms. The focus is to evaluate the potential of the method illustrated by the development of new engine oil formulations. These oils have been optimised for the use of ethanol containing fuels.

It will be demonstrated that the limitations exhibited by standardized methods have been overcome by the addition of typical compounds caused by bio-fuel to the oil during artificial