Process Safety and Environmental Protection xxx (2017) xxx–xxx

Contents lists available at ScienceDirect

Process Safety and Environmental Protection

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

A study of the tribological impact of biodiesel dilution on engine lubricant properties

S.H. Hamdan[a,b], W.W.F. Chong[c,d,e,*], J.-H. Ng[b,f], C.T. Chong[c,d], S. Rajoo[c,d]

[a] Faculty of Mechanical and Manufacturing, University Kuala Lumpur Malaysia France Institute, Bangi, Selangor, Malaysia
[b] Faculty of Engineering and the Environment, University of Southampton Malaysia Campus, Iskandar Puteri, Johor, Malaysia
[c] UTM Centre for Low Carbon Transport in Cooperation with Imperial College London, Universiti Teknologi Malaysia (UTM), Johor, Malaysia
[d] Faculty of Mechanical Engineering, Universiti Teknologi Malaysia (UTM), Johor, Malaysia
[e] National Centre for Advanced Tribology (nCATS), Faculty of Engineering and the Environment, University of Southampton, Southampton, UK
[f] Energy Technology Research Group, University of Southampton, Southampton, UK

ARTICLE INFO

Article history:
Received 23 January 2017
Received in revised form 15 May 2017
Accepted 19 May 2017
Available online xxx

Keywords:
Biodiesel dilution
Tribometer
Lubrication Stribeck curve
Friction
Engine lubricant
Palm Methyl Ester

ABSTRACT

The switch from petro-diesel fuel to biodiesel blends for Compression Ignition engines have raised tribological performance concerns among major automobile manufacturers. Biodiesel dilution on engine lubricants could have adverse long-term effects on the engine efficiency, which will reduce the fuel economy, thus, leading to higher greenhouse gas emissions. Therefore, this study investigates the tribological impact of palm methyl ester (PME) diluted in SAE5W40 and SAE10W40 engine lubricants along different lubrication regimes under engine cold start condition. Through lubrication Stribeck curve analysis conducted using a pin-on-disc tribometer, coefficient of friction (CoF) for both engine lubricants showed parabolic maximum behaviour with increasing PME dilution. The CoF reduction beyond these peak values is attributed to the improved friction modifier effect from the now-dominant PME but with reduced load carrying capacity. An effective lubricant should possess both reasonable friction modifier effect and highest load carrying capacity in mitigating boundary friction. Hence, through the study, it could be deduced that the acceptable PME dilution threshold level for SAE5W40 is up to 17.5-vol%, while for SAE10W40 is between 28.0-vol% and 34.5-vol%. PME dilution levels beyond these thresholds could easily cause lubrication film rupture under high load, high shear rate conditions during application along the mixed to boundary lubrication regimes, inducing material wear.

1. Introduction

During the 2015 United Nations Climate Change Conference (COP21), participating countries agreed to keep the increase in global average temperature to well below 2 °C as compared to the pre-industrial era, by committing to reduce their countries' green-house-gas (GHG) emissions. Being a major contributor to global GHG emissions (up to 23% global CO_2 emissions from fuel combustion (IEA Statistics, 2016)), it is only imperative that the transportation sector also undertakes significant

* *Corresponding author at*: UTM Centre for Low Carbon Transport in Cooperation with Imperial College London, Universiti Teknologi Malaysia (UTM), Johor, Malaysia.
E-mail address: william@mail.fkm.utm.my (W.W.F. Chong).
http://dx.doi.org/10.1016/j.psep.2017.05.007

decarbonisation measures. This could be achieved by moving towards alternative fuels to relieve the heavy reliance of the transportation sector on fossil fuels. One of the examples of decarbonisation effort include the blending of bioethanol or biobutanol with gasoline, which has so far been proven to be effective in reducing CO_2 emissions (Martinez-Gomez et al., 2016).

For compression ignition (CI) engines, biodiesel is a very attractive biodegradable alternative to petro-diesel fuel because it has been widely observed to reduce emissions of particulate matter, carbon monoxide and unburned hydrocarbons (Graboski and McCormick, 1998; Murillo et al., 2007). It is nowadays commonly used as a blend with petro-diesel fuel. However, in a typical CI engine, injected fuel does not always completely burn within the combustion chamber, leaving a non-negligible amount of unburned fuel impinging on the cold walls of the cylinder liner. This proportion of unburned fuel will mix with existing engine lubricant once being scrapped by the piston ring pack to the lubricant sump during engine operation, leading to fuel dilution of the lubricant. Ironically, the application of post-injection strategies in CI engines, which is meant to decrease NO_x emissions, also encourages further fuel dilution of the lubricant.

Biodiesel is known to have good lubrication properties and has been proven to improve the lubrication properties of low-sulfur petro-diesel fuels at blend levels of approximately 2% and higher (Knothe and Steidley, 2005). The lubrication property of biodiesel is not a specified requirement in biodiesel production standards, in spite it is one of its major technical advantages (Knothe, 2010). The good lubrication properties of this fuel is attributed to its polarity imparting oxygen atoms, which has a higher tendency to form sufficiently thick protective film along sliding surfaces to reduce friction and wear (Knothe and Steidley, 2005). Biodiesel lubrication properties are often investigated using High Frequency Reciprocating Rig (HFRR) to evaluate its boundary lubrication behaviour, focusing on the wear scar diameter with the aim to understand its potential as a fuel enhancer (Luo et al., 2013; Farias et al., 2014; Lapuerta et al., 2016).

With good lubrication properties, biodiesel dilution of engine lubricant is expected to improve the tribological performance along the piston ring-liner contact. However, the introduction of biodiesel blended with petro-diesel fuel raised concerns from major automotive manufacturers with regards to the possible tribological impact on the engine lubricant when diluted by this alternative fuel. This is because investigations showed that engine lubricant dilution will be more severe when biodiesel fuel is used since this fuel tends to concentrate in the lubricant (Thornton et al., 2009; Morcos et al., 2009) because of its higher boiling point than petro-diesel fuel (Andreae et al., 2007). It is found that post-injected petro-diesel fuel blended with 20% biodiesel (B20) could lead to as much as 40% methyl ester accumulation on the cylinder walls (Kotrba, 2008). More importantly, it is also suggested that for petro-diesel fuel blended with 10% biodiesel (B10), a dilution level beyond 50% threshold could lead to premature engine wear failure if engine lubricant is not changed more frequently (Kotrba, 2008).

Limited work has been reported in literature on the effect of biodiesel dilution on the lubrication properties of engine lubricants. Among those include the work by Fang et al., who investigated the wear characteristics of the biodiesel contaminated engine lubricant using HFRR and four ball tester (Fang et al., 2007). They concluded that biodiesel can lead to increased engine wear. This is a result of the methyl ester molecules diluting the engine lubricant, forming complexes with the anti-wear additives, such as zinc-dialkyldithiphophate (ZDDP), which affects such additives from forming a protective coating on the metal surfaces (Fang et al., 2006). Shanta et al. also observed the reduction of wear protection when the engine lubricant is diluted by biodiesel, even at small mixture percentages (Shanta et al., 2011). Recently, using a high-stroke reciprocating test rig, Gulzar et al. showed that a B20 fuel accelerated the depletion of engine lubricant additives, leading to undesirable friction and wear performances (Gulzar et al., 2016).

To better understand the lubrication system within the combustion chamber of an internal combustion engine, it is also important to investigate the tribological conjunction along the piston-ring/liner contact. During an engine cycle, the piston continuously reciprocates from bottom dead centre to top dead centre. As a result of such motion, the lubrication between the piston ring and the liner shifts backward and forward between fluid film lubrication and boundary lubrication (Chong et al., 2012). Instead of using HFRR, investigations of biodiesel related lubrication properties along various lubrication regimes could be conducted using the lubrication Stribeck curve, measured with a tribometer (Maru et al., 2013, 2014; Hamdan et al., 2016).

Therefore, the current study aims to investigate the tribological effects of palm oil derived biodiesel or palm methyl ester (PME) diluting SAE5W40 and SAE10W40 engine lubricants at different lubrication regimes using a pin-on-disc tribometer. Such investigation is expected to provide a more in-depth understanding on the extent of the tribological impact on engine lubricants when diluted by biodiesel. In addition to that, the study also attempts to determine the tribologically acceptable palm oil derived biodiesel fuel dilution threshold for both the tested engine lubricants. This is because fuel dilution of the engine lubricant is only acceptable, provided that it is within allowable tolerance limits before the level of dilution starts to have negative tribological effect on the engine's lubrication system.

2. Experimental approach

In this study, the experimental approach is divided into two steps in order to investigate the tribological properties of engine lubricant diluted by palm methyl ester (PME). The first step involves the process to produce lab-grade PME, which is used to dilute two types of engine lubricants: (1) SAE5W40 (fully synthetic) and (2) SAE10W40 (semi-synthetic) at different volume fractions. Both the selected commercially available engine lubricants are formulated to suit the use with biodiesel blended petrol–diesel fuel. This is followed by friction testing using a pin-on-disc tribometer at room temperature.

2.1. *Transesterification of palm oil methyl ester (PME)*

Production of PME from triglycerides of palm oil can be achieved through transesterification process. With the assistance of acid, alkaline or lipase catalysts, the process involves a simple global reaction between the triglyceride reactants and short-chain alcohol at sufficiently high temperature and mixing. This will result in the production of methyl esters with crude glycerol as the co-product. Among the types of catalysts, alkaline catalyst is a better option when high yield of

Please cite this article in press as: Hamdan, S.H., et al., A study of the tribological impact of biodiesel dilution on engine lubricant properties. Process Safety and Environmental Protection (2017), http://dx.doi.org/10.1016/j.psep.2017.05.007