Applied Energy 111 (2013) 882–893

Contents lists available at SciVerse ScienceDirect

Applied Energy

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

Impact of palm biodiesel blend on injector deposit formation

A.M. Liaquat [a,*], H.H. Masjuki [a], M.A. Kalam [a], M.A. Fazal [a], Abdul Faheem Khan [b], H. Fayaz [b], M. Varman [a]

[a] Centre for Energy Sciences, Faculty of Engineering, University of Malaya, 50603 Kuala Lumpur, Malaysia
[b] UM Power Energy Dedicated Advanced Centre (UMPEDAC), Level 4, Wisma R&D UM, University of Malaya, Jalan Pantai Baharu, 59990 Kuala Lumpur, Malaysia

HIGHLIGHTS

- 250 h Endurance test on 2 fuel samples; diesel fuel and PB20.
- Visual inspection of injectors running on DF and PB20 showed deposit accumulation.
- SEM and EDS analysis showed less injector deposits for DF compared to PB20 blend.
- Engine oil analysis showed higher value of wear particles for PB20 compared to DF.

ARTICLE INFO

Article history:
Received 28 December 2012
Received in revised form 16 May 2013
Accepted 18 June 2013
Available online 17 July 2013

Keywords:
Injector deposit
Palm biodiesel
SEM–EDS
Lubricating oil
Fuel economy
Exhaust emission

ABSTRACT

During short term engine operation, renewable fuels derived from vegetable oils, are capable of providing good engine performance. In more extended operations, some of the same fuels can cause degradation of engine performance, excessive carbon and lacquer deposits and actual damage to the engine. Moreover, temperatures in the area of the injector tip due to advanced diesel injection systems may lead to particularly stubborn deposits at and around the injector tip. In this research, an endurance test was carried out for 250 h on 2 fuel samples; DF (diesel fuel) as baseline and PB20 (20% palm biodiesel and 80% DF) in a single cylinder CI engine. The effects of DF and PB20 on injector nozzle deposits, engine lubricating oil, and fuel economy and exhaust emissions were investigated. According to the results of the investigation, visual inspection showed some deposit accumulation on injectors during running on both fuels. Scanning electron microscopy (SEM) and energy dispersive X-ray spectroscopy (EDS) analysis showed greater carbon deposits on and around the injector tip for PB20 compared to the engine running with DF. Similarly, lubricating oil analysis presented excessive wear metal concentrations, decreased viscosity and increased density values when the engine was fuelled with PB20. Finally, fuel economy and emission results during the endurance test showed higher brake specific fuel consumption (bsfc) and NO_x emissions, and lower HC and CO emissions, for the PB20 blend compared to DF.

1. Introduction

In recent years, the use of biodiesel in modern CI engines with advanced injection systems has been widely tested [1]. However, diesel fuel injection equipment (FIE) systems are susceptible to the formation of a variety of deposits [2]. The formation of deposits within the holes of the injector nozzle or on the outside of the injector tip may have an adverse effect on overall system performance [3] because the injection pattern and fuel flow rate are affected by the nozzle deposits. It has been reported that deposit formation begins on the injector nose, which is the coldest part of the combustion chamber of a diesel engine, followed by the rings and the throat, the chamber walls, then the cylinder head, etc. [4]. Therefore, it is likely that fuel stored in the injector tip is heated during the combustion process and expands during the expansion stroke. A combination of evaporation of the lighter fractions of the fuel and degradation are considered responsible for sticky deposits. The process is affected by elemental fuel contaminants, reactive combustion products, soot and volatilized lubricating oil [5]. Moreover, recently the trend for smaller holes and high efficiency nozzles in direct injection (DI) and high speed direct injection (HSDI) engines has resulted in many more instances of injector spray-hole deposits causing problems. The reasons for this increase include [2]:

(i) Smaller holes which for a given deposit level will result in a proportionately larger reduction in flow area and therefore larger flow rate reduction, resulting in loss of torque and power.
(ii) High efficiency nozzles with honed entry to nozzle holes and/or tapered nozzle holes resulting in reduction or elimination of cavitating flow within the nozzle.

* Corresponding author. Tel./fax: +60 3 79674448.
E-mail address: liaquat2@yahoo.com (A.M. Liaquat).

0306-2619/$ - see front matter © 2013 Elsevier Ltd. All rights reserved.
http://dx.doi.org/10.1016/j.apenergy.2013.06.036

Nomenclature

Al	aluminum	Mg	magnesium
bsfc	brake specific fuel consumption	Mo	molybdenum
C	carbon	MOA	multi-element oil analyzer
°C	degree centigrade	Na	sodium
CI	compression ignition	NO_x	nitrogen oxide
CO	carbon monoxide	O	oxygen
CO_2	carbon dioxide	PAHs	polynuclear aromatic hydrocarbons
Cr	chromium	Pb	lead
cSt	centi stokes	PB20	20% palm biodiesel and 80% DF
Cu	copper	ppm	parts per million
DF	diesel fuel	RME	rape methyl ester
DI	direct injection	RSB	rubber seed oil biodiesel
EDS	energy dispersive X-ray spectroscopy	S	sulfur
Fe	iron	SEM	scanning electron microscopy
FIE	fuel injection equipment	SHD	spray hole deposits
HC	hydrocarbon	Si	silicon
HSDI	high speed direct injection	W	tungsten
IID	internal injector deposits	Zn	zinc
IC	internal combustion		

(iii) Combustion and air management trends resulting in higher nozzle tip temperatures, which promote nozzle deposits.

According to Caprotti et al. [6], deposits in the injector can be developed in two separate locations:

(i) Inside the body of the injector like on plungers and internal valves. These types of deposits are called internal injector deposits (IID).
(ii) At the spray-hole, where the fuel leaves the injector and enters the combustion chamber. These are called spray hole deposits (SHD).

In the literature, different investigation reports can be found regarding deposit formation on the injector nozzle using biodiesels and their fuel blends. In short-term operations, renewable fuels derived from vegetable oils are capable of providing good engine performance. With more extended operation, some of the same fuels can cause degradation of engine performance, excessive carbon and lacquer deposits and actual damage to the engine [7]. It has been reported that some biodiesel properties such as higher viscosity, lower volatility [8], and the reactivity of unsaturated hydrocarbon chains can lead to injector coking and trumpet formation on the injectors, more carbon deposits, etc., after the engine has operated for a longer time period [9]. A comparative study of the effects of biodiesel and diesel fuel in two single-cylinder engines with the same injector specifications and fuel injection pump pistons was experimentally analyzed [10]. After the engines were run for 200 h at 2000 rpm, the injectors were examined and compared by performing scanning electron microscopy (SEM) and energy-dispersive X-ray (EDS) analysis. According to the results, SEM images showed greater shrinkage in the diameter of the injector nozzle of the engine using biodiesel. Metal cutting traces in the original, unused machined injector were covered with a layer and completely disappeared as a result of biodiesel use. Moreover, after the 200 h runs, the quantity of carbon (C) element on the fuel injector surface was greater when biodiesel was used compared to petroleum diesel. According to Richards et al. [3], biodiesel has been observed to lead to higher deposit formation in the injector nozzle. Injector deposits using rape methyl ester (RME) have been investigated in swirl chamber injection systems for: indirect fuel injection, current common rail, and future common rail systems [11]. The results showed moderate deposit formation and about 3% power loss when the engine was run on B10 RME for 16 h. A further test was also carried out for an extended period of 48 h. The result showed that deposit formation continued at approximately the same rate and probably beyond, causing a maximum drop in torque of 24%. On the contrary, according to Sinha and Agarwal [12], carbon deposits on the cylinder head, injector tip, and piston crown using a biodiesel blend (20% rice bran oil methyl ester blend with mineral diesel) in a 100 h endurance test were significantly lower compared to mineral diesel fuel. In order to investigate the coking of DI diesel engine injector nozzles, the effect of using neat rubber seed oil biodiesel (RSB) and blends with diesel fuel was studied [13]. It was found that deposit accumulation was greatest on the liners of injectors with B5 and B100 fuel. The surfaces of the injectors were dirtier after B5 and B100 use than with diesel fuel. However, more carbon deposits were observed around the injector tip of the diesel nozzle. Moreover, no significant difference was found in the degree of coking around the injector tips using B5 or B100.

In a lubrication system, wear particles remain in suspension in the lube oil. Sufficient information about wear rate, source of element and engine condition can be predicted after a certain running duration by analyzing and examining variations in the concentrations of the metallic particles available in the lubricant oil [14]. Particularly in diesel engines, the components that are normally subjected to wear are the cylinder liner, bearing, cam, tappet, crankshaft journals, pistons and piston pins, valve guides, valve systems, etc. [15]. Therefore, by analyzing the lubrication oil, direct indications of engine wear and health can be found [16].

The main objective of this work is to carry out the comparative study on the injector deposits, lubricating oil analysis and, engine fuel economy and emission results during 250 h endurance test on DF as baseline and PB20 blend respectively.

2. Materials and methods

For this study, a single-cylinder, four-stroke diesel engine was selected. Its major specifications including the fuel injector and pump can be found in Table 1. The engine was coupled to an eddy current dynamometer. The endurance test was carried out for 250 h at 2000 rpm and 10 N m load on 2 fuel samples: DF and PB20 respectively. The palm biodiesel used in this study was supplied by local company. The analysis report provided by the supplier is summarized in Table 2. The essential measured fuel