Energy xxx (2014) 1–10

Contents lists available at ScienceDirect

Energy

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

Bio-lubricant-biodiesel combination of rapeseed oil: An experimental investigation on engine oil tribology, performance, and emissions of variable compression engine

S. Arumugam*, G. Sriram [1], R. Ellappan [2]

Department of Mechanical Engineering, Sri Chandrasekharendra Saraswathi Viswa Mahavidyalaya, Enathur, Kanchipuram 631561, Tamilnadu, India

ARTICLE INFO

Article history:
Received 20 June 2013
Received in revised form
21 May 2014
Accepted 23 May 2014
Available online xxx

Keywords:
Bio-lubricant
Bio diesel
Nano CuO
Rapeseed oil
Variable compression engine

ABSTRACT

The substitution of petroleum based synthetic lubricant with rapeseed oil based bio-lubricant in a variable compression ratio diesel engine is explored in this study. Rapeseed oil based bio-lubricant was formulated through chemical modifications like epoxidation, hydroxylation and esterification process for improving its thermo-oxidative stability and cold flow properties. The nano CuO (copper oxide) an anti-wear nano additive was added to chemically modified rapeseed oil to improve anti-wear behavior. To study the compatibility of formulated bio-lubricant, two endurance tests of 150 h each were conducted on a four-stroke variable compression ratio engine fueled with B20 rapeseed oil bio diesel at a standard CR (compression ratio) of 17.5:1 using synthetic lubricant (SAE20W40) and formulated bio-lubricant. The various challenges related to performance and emission analysis are discussed and compared with SAE20W40 from no load to full load conditions and at different CR varies from 12:1, 15:1 and 17.5:1 with B20 rapeseed oil based biofuel/bio-lubricant combination. The main findings show that the combined use of biofuel/bio-lubricant of rapeseed oil reduced Fe, Al, Cu wear, soot and ash content, when compared to bio fuel/SAE20W40 combination. The brake thermal, mechanical efficiencies and brake power with rapeseed oil based bio-lubricant is comparable with SAE20W40 and also the similar emission spectra was observed in the bio-lubricant.

1. Introduction

The rising price of crude oil the world over, the growing environmental awareness and the fast depleting crude oil reserves have spurred renewed research interest and advances in alternative fuel and lubricant development from agricultural feed stock [1–3]. It is proven that bio diesel is a promising fuel for diesel engine up to 20% blend with respect to emission, combustion as well as performance. Systematic efforts have been undertaken by many researchers to determine the suitability of vegetable oil as fuel [4–7]. The use of bio diesel despite its contribution to a large reduction in engine wear concomitantly creates various other long term problems in engine components such as ring sticking, injector and combustion chamber coking and formation of deposits [8,9]. It is felt during usage: the lubrication oil performance especially for the engine fueled with B20 bio diesel is affected by (i) Oil thickening which may be due to the soot loading or oil degradation by oxidation at high temperature operation (ii) Oil thinning, which may be due to fuel dilution (iii) Deposit formation and wear which may be due to the depletion of wear protecting or dispersing additives [10].

Apart from bio diesel, researchers have conceived the idea of using vegetable oil as the lubricant alternative to mineral oil, as the disposal of mineral oil leads to pollution of ecosystem [11,12]. Vegetable oils are perceived to be alternatives to mineral oils for the purpose of lubrication because of certain inherent technical properties like high flash point, high viscosity index, high lubricity, low evaporative loss and their ability of biodegradability [13,14]. Thus, the search for environmentally friendly substitutes to mineral oils (as base oils) in lubricants has become a frontier area of research in the lubricant industry in the new paradigm of sustainable technology development propelled by the alarms of environmental degradation. Bekal and Bhat investigated neat mineral oil, neat pongamia oil, and mixture of mineral oil and pongamia oil as lubricants for the diesel engine fueled with pongamia oil bio diesel.

* Corresponding author. Tel.: +91 99946 99223.
E-mail addresses: aru_amace@yahoo.co.in (S. Arumugam), drg.sriram@gmail.com (G. Sriram), ellsraaj@gmail.com (R. Ellappan).
[1] Tel.: +91 98948 38623.
[2] Tel.: +91 94440 28162.

http://dx.doi.org/10.1016/j.energy.2014.05.087
0360-5442/

Abbreviation

ASTM	American Society for Testing of Materials
BP	brake power
BSFC	brake specific fuel consumption
BTE	brake thermal efficiency
B100	100% by vol. rapeseed oil methyl ester
CA	crank angle
CO	carbon monoxide
CMRO	chemically modified rapeseed oil
CR	compression ratio
CuO	copper oxide
FTIR	Fourier Transform Infrared
HC	hydrocarbon
HSU	Hartridge Smoke Unit
ME	mechanical efficiency
NO_x	oxides of nitrogen
RME	rapeseed oil methyl ester
SAE	Society of Automotive Engineers
TAN	total acid number
TDC	top dead center
VCR	variable compression ratio

Further, they reported that the best results were recorded for the fuel-lubricant combination of neat pongamia oil [15].

Nevertheless, the principal weakness of vegetable oils for lubrication has been their tendency to oxidize at higher temperature, and giving rise to gum, varnish and sludge formation at lower temperature [16]. The existence of an unsaturated C=C bond is responsible for their poor oxidative stability [17]. Many literature revealed that technical solutions such as chemical modification and additivation were suggested to overcome the poor thermo-oxidative stability and low temperature fluidity of vegetable oils. Efforts were made to improve the low temperature fluidity of vegetable oils using an additivation method by blending vegetable oils with diluents such as poly-a-olefin and diisodecyl adipate [18]. Zulkifli et al. made an attempt to improve the oxidative stability, low temperature fluidity and anti-wear characteristics of palm oil by transesterification of trimethylolpropane with palm oil methyl ester [19].

The unsaturation present in the fatty acid molecule of the vegetable oil can be used to introduce various functional groups by carrying out chemical modifications. Among them, epoxidation and hydroxylation are a few of the most widely used reaction. Kim and Sharma discussed the possibilities of utilization of epoxidized products of vegetable oils in PVC (poly vinyl chloride) formulations and bio-thermoset plastics [20]. The application of epoxidized rapeseed oil as a potential biodegradable lubricant was described by Wu et al. [21] and additionally they reported that the chemical modification treatment did not have any adverse effect on the biodegradability of base stock. Although many valuable polymeric materials and lubricants are derived from chemically modified vegetable oil, use of chemically modified oil as automotive lubricant has not been reported. In line with that, the authors have formulated bio-lubricant through chemical modifications of rapeseed oil like epoxidation, hydroxylation and esterification process [22,23]. Further, the issue of friction and wear characteristics of the diesel engine's cylinder liner-piston ring combination under the influence of formulated bio-lubricant and commercial synthetic lubricant (SAE20W40) using a high frequency reciprocating tribometer rig were addressed by Arumugam and Sriram [24]. Though the bio-lubricant enhances the frictional characteristics of liner-ring tribo pair, it does not show any improvement in anti-wear behavior under tested conditions [24]. In the present study, nano CuO (copper oxide) was added to the chemically modified rapeseed oil to improve its anti-wear characteristics.

Concomitantly, the examination of the degradation of vegetable oil based bio-lubricant in long term usage in a biodiesel engine is still to be understood. All the review of literature done has left the scope for the investigators to study the impact of chemically modified rapeseed oil with nano additive as automotive lubricant for the engine fueled with rapeseed oil biodiesel to investigate the engine performance, emissions and long term durability of the lubricating oil.

2. Experimental details

2.1. Preparation of B20 rapeseed oil biodiesel

Raw rapeseed oil, methanol and sodium hydroxide, which are required for transesterification process, anhydrous sodium sulphate, and concentrated hydrochloric acid used in bubble washing process, were procured from M/S Ganapathy Trading Company, Chennai. Table 1 shows the fatty acid composition of rapeseed oil. The transesterification process was carried out for the preparation of RME (rapeseed oil methyl ester). The transesterification process was carried out first by preparing sodium methoxide by mixing NaOH (sodium hydroxide) in methanol. The quantity of methanol used was in the molar ratio of 6:1 with oil. Two hundred milliliters of methoxide and 700 ml of oil were mixed properly and heated in a mantle at 60 °C for one hour using a reflux condenser. Then, it was allowed to settle for another 12 h. Using a separating funnel, glycerol was separated. The bubble wash was done by mixing methyl ester with distilled water to remove excess of alcohol, catalyst and glycerol. Then, to remove the moisture content in the methyl ester, it was treated with anhydrous sodium sulphate, which is commonly used as moisture absorbing agent. Furthermore, B20R biodiesel was prepared by mixing 20% by vol. of RME and 80% by vol. of diesel. Table 2 indicates the properties of biodiesel and diesel fuel. Characterization of diesel and biodiesel was carried out in accordance with ASTM (American Society for Testing of Materials) standards.

2.2. Formulation of rapeseed oil based bio-lubricant

To formulate the rapeseed oil based bio-lubricant, rapeseed oil was chemically modified through epoxidation, hydroxylation or ring opening process and followed by esterification process of the ring opened product in order to improve its thermo-oxidative stability and lower the pour point. The detailed procedure for chemical modification process of rapeseed oil and its mechanism were adapted from our earlier investigation [24]. Furthermore 0.5% w/w nano CuO are in the range of ~40–70 nm supplied by M/S US Research Nano Materials Inc, USA, was used in this experimental study, for which the true size and density were provided by the suppliers. An ultrasonic bath sonicator, Make: OSCAR® model PR-1000, ultrasonic power: 750 W and operating frequency:

Table 1
Fatty acid composition of rapeseed oil.

Fatty acid	% (w/w)
Palmitic acid ($C_{16:0}$)	5.7
Stearic acid ($C_{18:0}$)	2.2
Oleic acid ($C_{18:1}$)	58.5
Linoleic acid ($C_{18:2}$)	24.5
Linolenic acid ($C_{18:3}$)	9.1

Please cite this article in press as: Arumugam S, et al., Bio-lubricant-biodiesel combination of rapeseed oil: An experimental investigation on engine oil tribology, performance, and emissions of variable compression engine, Energy (2014), http://dx.doi.org/10.1016/j.energy.2014.05.087