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Original article

Emission analysis on the influence of magnetite nanofluid on methyl ester in diesel engine

M. Venkata Ramanan [b], D. Yuvarajan [a, *]

[a] Department of Mechanical Engineering, Jeppiaar Institute of Technology, Chennai, India
[b] Department of Mechanical Engineering, College of Engineering, Anna University, Chennai, India

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ABSTRACT

Increase in NO_x emission is one of the most important drawbacks for using biodiesel as a potential alternative fuel for petroleum diesel. Many studies have been carried out to reduce the NO_x emission level in biodiesel. The present work is the result of an attempt wherein ferrofluid is added with rice bran oil methyl ester in the way of analyzing its effects on emission features. Magnetite concentrate is exothermic and is known for its characteristics of releasing copious heat at higher temperatures. Nanofluid using magnetite is synthesized by reacting Iron II ($FeCl_2$) and Iron III ($FeCl_3$) in an aqueous ammonia solution to form Magnetite Fe_3O_4 (Ferro fluid). Release of heat by magnetite during the combustion process counterbalance the conventional limitations related with biodiesel such as increased delay period, inferior combustion rate and higher NO_x emissions etc. Experiments have been conducted with Rice Bran Oil Methyl Ester (RBOME) and Rice Bran Oil Methyl Ester with addition of Ferrofluid (RBOMEF) and are compared with petroleum diesel. Rice Bran Oil Methyl Ester with addition of Ferrofluid has been prepared comprising 98.7% biodiesel (Rice bran oil methyl ester), 1% magnetite based ferrofluid and 0.3% surfactant by volume is used in a CI engine. The experimental analysis reveals a decrease in HC, CO and NO_x emissions of 19 ppm, 0.011% volume and 93 ppm respectively.

1. Introduction

Biodiesel is a promising alternative fuel for diesel due to the fact of emitting less measure of carbon monoxide, hydrocarbon and particulate matter. Conversely, biodiesel fuelled engine also emits considerable measure of nitric oxide (NO_x) when it is compared with petroleum diesel (e.g. Aydin and Bayindir, 2010; Ramadhas et al., 2005; Raheman and Phadatare, 2004). The possible reason for increase in NO_x emission is due to drop of engine power when fuelled with biodiesel (e.g. Ryu, 2010; Karabektas, 2009). There are numerous techniques followed to reduce NO_x emissions when fuelled with biodiesel among which the concept of using water based nanofluids to reduce NO_x emission in compression ignition engines has been an active area of research. Addition of water based nanoparticles in liquid fuels acts as a catalyst to promote the combustion and results in improved combustion characteristics along with drastic reduction in NO_X and other related emissions (e.g. Choi and Oh, 2006). Studies have shown that by adding water based nanofluid to biodiesel results in drastic reduction in heat flux, thermal loading and metal temperature of combustion chamber components. Water based nanofluids alters the chemical composition of fuel which has been encouraging impact on emission characteristics (e.g. Jung et al., 2005). Nanosized energetic metals have enviable combustion characteristics such as high heat of combustion and fast energy release rates. Further, nano sized particles can be dispersed into high-temperature zones for direct oxidation reaction, rapid energy release, and enhanced propulsive performance with increased density impulse (e.g. Selim and Elfeky, 2001). Many studies have been conducted to explore the impact of adding nanoparticles to fluid properties. Results revealed that there is enhancement in thermal conductivity, mass diffusivity and radiative heat transfer (e.g. De Luca et al., 2005).

Nanoparticles with a high surface area to volume ratio increase the contact among fuel and oxidizer and augment the combustion rate thereby reducing unburned emissions (e.g. Galfetti et al.,

* Corresponding author.
E-mail address: dyuvarajan7@gmail.com (D. Yuvarajan).
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Nomenclature

RBOME	Rice bran oil methyl ester
RBOMEF	Rice bran oil methyl ester with addition of ferrofluid
CO	Carbon monoxide
UHC	Unburned Hydrocarbon
NO_x	Nitrogen oxide
PPM	Parts per million

2007). Nanoparticles affect the time scale of chemical reactions and result in reduced delay period and emissions (e.g. Prasher et al., 2006). Additionally, it has been experimentally found that by adding nanoparticles to liquid fuel increases the ignition probability of the mixture thereby reducing emissions (e.g. Krishnamurthy et al., 2006). Though numerous experimental works have been carried out to analyze the impact of nanofluid, magnetic nanofluid has been experimented hardly ever. The present experimental study aims to examine the effect of ferrofluid on the various properties of rice bran methyl ester and also its influence on emissions characteristics.

2. Experimental material and methods

2.1. Materials and reagents

2.1.1. Rice bran oil

Rice bran oil is extracted from the hard outer brown layer of rice after chaff (rice husk). The most important reason for choosing Rice bran oil as a fuel is based on the selection of low-cost feed stock with high value added by-products. Rice bran is the by-product of rice milling that contains 15–23% lipids which cannot be used for edible purposes and hence it is could be used as potential alternative fuel. Usage of low-priced, non-edible feedstock could possibly reduce the cost involved in production process. The alcohol used in this work is methanol. Potassium Hydroxide is used as catalyst for transesterifications.

2.1.2. Ferrofluid

The ferrofluid used in this study is water-based. The synthesis involved the reaction between Iron II ($FeCl_2$) and Iron III ($FeCl_3$) ions in presence of aqueous ammonia solution to form magnetite (Fe_3O_4) adapting the following Equation (1).

$$FeCl_2 + 2FeCl_3 + 8NH_3 + 4H_2O \rightarrow Fe_3\ O_4 + 8NH_4Cl. \quad (1)$$

The cited procedure claims that those nano particle diameters are on the order of 10 nm (e.g. Berger et al., 1999). In addition, aqueous tri methyl ammonium hydroxide ($(CH_3)_3NOH$) solution which is used as a surfactant can surround the magnetite particles with hydroxide anions and tetra methyl ammonium cations to create electrostatic inter particle repulsion in an aqueous environment (e.g. Berger et al., 1999). The most significant benefits of using ferrofluid compared to other nano particles are that the magnetic nano particles can be collected from exhaust. Furthermore, it can be easily diluted to biodiesel and as a result it can collect the benefits of water-biodiesel emulsions.

2.2. Apparatus and procedure

2.2.1. Preparation of base fuel (RBOME)

Ester is prepared by following batch transesterification process in a 1000 ml glass vessel reactor equipped with a magnetic stirrer, resistance heater & ‘K’ type thermocouple. Suitable arrangements have been provided to control reaction temperature and stirring speed. Molar ratio of 5.9:1(methanol to Rice bran oil) and catalysts of 0.51% (wt/wt) to Rice bran oil was used in transesterification procedure. 700 g sample of Rice bran oil in the reactor is heated till 60 °C. Measured mixture of solution containing catalysts mixed in methanol is added and mixed at a constant stirring speed of 300 rpm for 60 min. This ensures uniform reactivity of solution by accelerating the reaction rate. The mixture is subsequently allowed to cool in the vessel yielding two distinct layers of ester and glycerol. Ester is then separated, washed with water and dried for further investigation. The ester is obtained following conventional procedure and it is referred as RBOME. Table 1. shows fatty acids compositions of Rice bran oil.

2.2.2. Preparation of modified base fuel (RBOMEF)

Copper strip corrosion test plays a significant role in selection of dosage level limit of metal based additive to biodiesel. Fe_3O_4 (Ferrofluid) has a property to corrode the engine parts if the limit exceeds 1% by volume as listed in ASTM limit of class 1b. The measure of ferrofluid and surfactant (aqueous tetra methyl ammonium hydroxide solution) in the base fuel (RBOME) is 1% and 0.3% respectively by volume basis. The required quantity of the RBOME, ferrofluid and surfactant is measured and mixed by ultrasonic agitator with constant agitation for 60 min for better mixing and homogeneous suspension. Modified base fuel with ferrofluid is kept in a glass vessel with stopper for a period of one month at room temperature to observe the phase change characteristics. In stability test, due to the presence of surfactant ferrofluid showed long term stability and homogeneity with Rice bran oil methyl ester; hence the modified fuel can be used reliably for engine tests. Although the modified base fuel proved encouraging results on stability and homogeneity it is used straight away after preparation to understand the accurate consequence of ferrofluid and its impact on various characteristics of Rice bran oil methyl ester. The fuel thus obtained following above procedure and it is referred as RBOMEF. A detail for ferrofluid is listed in Table 2.

2.3. Comparison on fuel properties of RBOME and RBOMEF

The effect of adding ferrofluid on fuel properties such as kinematic viscosity, flash point, water content, calorific value, cetane index and density is investigated. The comparison of fuel properties between RBOME, RBOMEF and Diesel is presented in Table 3. As it can be seen, Adding up to 1% (by Volume) of ferrofluid enhances the fuel properties along with maintaining friendliness with engine components. Kinematic viscosity is increased by “3.56%” with addition of ferrofluid. This is due to increase in resistance between fluid layers and thereby increases viscosity. It is also observed that the flash point is increased by “3 °C”. Higher flash point is desirable for safer handling of fuel; hence RBOMEF is comparatively safe when compared to base fuel. Water content is increased by 0.02% with addition of ferrofluid. Since ferrofluid has considerable measure of water present in it, there is a marginal increase in water

Table 1
Fatty acids compositions of Rice bran oil.

Fatty acids	Percentage
C14:0 Myristic acid	0.8%
C16:0 Palmitic acid	21.6%
C18:0 Stearic acid	2.8%
C18:1 Oleic acid	37.5%
C18:2 Linoleic acid	35.4%
C18:3 α-Linolenic acid	1.9%