Energy 57 (2013) 344–351

Contents lists available at SciVerse ScienceDirect

Energy

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

Combustion performance and emission characteristics study of pine oil in a diesel engine

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ARTICLE INFO

Article history:
Received 10 September 2012
Received in revised form
23 March 2013
Accepted 31 May 2013
Available online 1 July 2013

Keywords:
Pine oil
Biofuel
Trans-esterification
Combustion
Emission

ABSTRACT

A new type of biofuel, pine oil, is introduced in this work for the purpose of fueling diesel engine. The viscosity, boiling point and flash point of the reported oil are lower, when compared to that of diesel. Also, the calorific value of pine oil biofuel is comparable to diesel. As a result, it can be directly used in diesel engine without trans-esterifying it. Pine oil biofuel and their blends of 25%, 50%, and 75% with diesel were tested in a single cylinder, four-stroke, direct injection diesel engine and the combustion, emissions and performance results were compared with diesel. The results show that at full load condition, 100% pine oil reduces CO (carbon monoxide), HC (hydrocarbon) and smoke emissions by 65%, 30% and 70%, respectively. The brake thermal efficiency and maximum heat release rate increase by 5% and 27%, respectively. However, the NO_x (oxides of nitrogen) emission is higher than that of diesel fuel at full load condition. The experimental work reveals that 100% pine oil can be directly used in diesel engine and potential benefits of pine oil biofuel have been reaped.

1. Introduction

Diesel engines are being used as one of the vital prime movers for generating power and electricity in many industrial and agricultural applications. Reports emanating from research studies on alternate or renewable fuels unanimously predict an unprecedented demand for petroleum fuels by 2030 and the repercussions of this have been already felt by the sudden surge in petroleum prices [1,2]. In addition to this petroleum fuel demand, its use is also associated with increased environmental problems [3]. Considering the future energy security, sustainability and environmental damage, the study on various alternate, clean and renewable sources of fuel has grabbed the interest and attention of many researchers [4]. Among which, biodiesel is one of the most commonly used alternative fuel for diesel engine [5,6].

Biodiesel is normally produced from vegetable oil or animal fats through trans-esterification in the presence of catalyst at elevated temperature [6–10], while higher fatty acid oil even demands double stage trans-esterification process [11–13]. The conversion of triglycerides into methyl or ethyl esters, through the trans-esterification process, reduces the molecular weight to one-third that of the triglyceride and also reduces the viscosity by a factor of about eight, with a marginal increase in volatility [7]. Thus, after trans-esterification process, the properties of the biodiesel are so conducive for its use in diesel engine. Recent studies on engine performance using biodiesel have shown significant improvements when compared to that of diesel [14,15]. Furthermore, emissions such as smoke, HC (hydrocarbon), CO (carbon monoxide) and CO_2 (carbon dioxide) were also found to be reduced at the expense of slight increase in NO_x (oxides of nitrogen) [16–19]. Nevertheless, the use of biodiesel has also shown several apprehensions due to its higher viscosity, lower calorific value, and lower horse power output [20].

Apart from biodiesel, researchers have conceived the idea of using alcohol and emulsion fuels in diesel engine as an alternative fuel. Experimental studies with micro emulsion fuel have reported a drastic reduction of NO_x emission in diesel engine [21]. However, the use of emulsion fuels has also shown significant increase in CO and HC emission levels and drop in BTE (brake thermal efficiency) at lower loads [21,22]. Therefore, in order to address these shortcomings of emulsion fuels, a recent research on novel emulsion fuel with the addition of nanoparticle additives has shown an increase in BTE by 14.2% and decrease in NO_x emission by 30.6% than diesel [23]. Furthermore, the application of ethanol in diesel engine has come to lime light in recent decades as it has the potential to reduce environmental emissions [24]. Ethanol is an oxygen enriched fuel and when used in blends with diesel, the fuel viscosity is reduced, resulting in enhanced combustion [25]. Though ethanol is less viscous, the heating value is very low and suffers limited miscibility with diesel [26].

Besides emulsion fuel and ethanol, there have been reports about using turpentine oil derived from resin of pine tree in diesel engine. The engine operated at manufacture's injection pressure –

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0360-5442/$ – see front matter
http://dx.doi.org/10.1016/j.energy.2013.05.061

time setting (20.5 MPa and 23° BTDC (before top dead centre)) had lower CO, HC, NO_x, smoke and particulate matter for only 30% turpentine with diesel [27]. The same report also suggests that there is an increase in BSFC (brake specific fuel consumption) and decrease in BTE for all the blends of turpentine with diesel. Similarly, another study pertaining to the use of turpentine in diesel engine claimed 60–65% replacement of diesel with turpentine while operating the engine in dual fuel mode [28]. The reported experiment was performed by inducting turpentine as main fuel through induction manifold and diesel was admitted in to the engine through conventional fuel injector. Further, an increase in CO, HC and NO_x emissions were noticed at high load condition when compared to diesel.

Until now, ample studies on biofuel haven't reported substantial improvement in performance and emission while using 100% biodiesel, ethanol and emulsion fuel in diesel engine. It has been categorically reported that biodiesel can only be used in blends with diesel, where the recommended blend is B20 as the study conducted using mahua oil biodiesel claims that biodiesel can be safely blended with diesel up to 20% for getting fairly accurate performance as that of diesel [29]. Therefore, the present research has taken all the above-mentioned considerations in the selection of biofuel. Further, we have attempted to use pure biofuel and its blend in diesel engine.

In this study, we introduce pine oil biofuel, which is in contrary to the regular use of trans-esterified biodiesel, for fueling diesel engine. Not much attention has been paid to use pine oil in diesel engine and hence significant endeavors have been made to test the characteristics of diesel engine using pine oil. Pine oil, a renewable source, is synthesized from pine oleoresin which in turn is obtained from pine trees. The thermo physical properties of pure pine oil such as density, viscosity, calorific value, cetane index, sulfur content, flash point and boiling point have been evaluated by standard ASTM (American Society for Testing and Materials) methods and are listed in Table 1. From the properties tested, it is comprehended that the total acidity of pine oil is very low and the oil is toxic free. The pine oil manifests itself as a light oil liquid biofuel, as its viscosity is too low and the measured properties are found to be suited for its use in diesel engine [30]. For the current study, the pine oil being used has been procured from the commercial store and has been utilized as it is. Various blends of pine oil biofuel with diesel such as 25%, 50%, 75% and 100% were used and various parameters such as BSFC, BTE, EGT (exhaust gas temperature), cylinder pressure, heat release rate and exhaust emissions such as CO, HC, smoke and NO_x were analysed at constant speed and various power output of the engine.

2. Pine oil – an overview

In this study, oil derived from oleoresins of pine tree, widely grown for its bark, wood, tar and essential oil, has been decidedly chosen to be used as fuel for diesel engine. Pine oil, stable under all conditions of use and storage, is unique in that the feedstock originates from the forest and can be blended with petro-based diesel fuel readily. For the current study, gum pine oil is being used and extracted from pine oleoresin, which is traditionally obtained from pine tree by the process of tapping. This essential oil, obtained from pine tree, is pale yellow in color with fresh forest smell and is soluble in alcohols and other mineral oils. The estimated world production of pine oil was reported to be 30,000 tons per annum [31] and the demand for pine oil by 2022 was predicted to be 853,894 tons [32].

The constituents of pine oil are terpineol, which is a tertiary alcohol, dipentene (an isomer of pinene), unreacted pinene and some minor quantities of other by-product and impurities. The α-pinene, collected from pine tree, has been converted in to α-terpineol ($C_{10}H_{18}O$) by acid-catalyzed hydration process. It could be comprehended from the molecular formula of pine oil that it contains inherent oxygen within the structure, which is obtained as the result of the hydration reaction, catalyzed by an acid. Similar to lower alcohols such as ethanol and methanol, pine oil has C, H and O atoms in its structure, emerging as a renewable feedstock in the realm of other alternate fuels. However, contrary to other alcohol type of fuels, pine oil has higher calorific value, which make it as one of the appropriate biofuel to be used in diesel engine. Moreover, pine oil has lower viscosity and boiling point, which could increase the fuel atomization and its vaporization. All the other properties of pine oil, determined by ASTM methods, comply with the standards and it qualifies as a potential candidate for diesel engine.

Table 1
Pine oil properties.

Property	Measurement standards	Pine oil	Diesel
Density at 15 °C in kg/m^3	ASTM D1298	875.1	822
Kinematic viscosity at 40 °C in m^2/s	ASTM D445	1.3 * 10^{-6}	3.6 * 10^{-6}
Flash point in °C	ASTM D92	52	74
Boiling point in °C	ASTM D1160	150–200	180–340
Gross calorific value in kJ/kg	ASTM D240	42,800	42,700
Sulfur content in %	ASTM D5453	Less than 0.005	Less than 0.005
Calculated cetane index	ASTM D976	11	52
Copper strip corrosion @100 °C for 3 h	ASTM D130	Not worse than No. 1	Not worse than No. 1

3. Experimental setup and arrangement

3.1. Test engine and instrumentation

The experimental setup encompasses a Kirloskar stationary diesel engine and a water cooled eddy current dynamometer. The engine employed for the current investigation is a naturally aspirated engine and it has hemispherical shaped bowl in piston combustion chamber. Fig. 1 clearly depicts the experimental setup and various instrumentation. The engine develops a power of 5.2 kW and is operated at an injection pressure of 220 bar. The operating and design conditions of the engine are kept at manufacturer's default value. Mechanical type fuel injection system is used and the engine is tested using pine oil without any modifications. The specifications of the engine are shown in Table 2.

To avert any fluctuations with air flow in the manifold, an injection tank was deployed, which ably damps out the pulsation produced by the engine. By this measure, the suction pressure was maintained constant, facilitating constant flow of air through the inlet manifold. The orifice meter was intended to measure the air flow rate and the pressure drop caused in the orifice meter was measured using a manometer. The fuel flow rate was measured on volume basis using a burette and stop watch. The measurements were repeated for three times and finally the average value of the three readings was taken for the calculation. The in-cylinder pressure, pressure rise rate, heat release rate and cycle variations are recorded using AVL 619 Indi meter hardware and Indwin software version 2.2. While AVL transducer with the sensitivity of 16:11 pC/bar was installed over the top of the cylinder head to measure combustion chamber pressure, a crank angle encoder was placed in the engine crank shaft to record the crank angle signal. The charge output of the piezo electric transducer, quantified as desired in-cylinder pressure, was amplified and converted into digital signal using analog to digital converter. The recorded pressure and crank angle signals, captured and averaged after 100 cycles of operation, were processed by the software in a PC interface to obtain the