Fuel 228 (2018) 405–417

Contents lists available at ScienceDirect

Fuel

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

Full Length Article

A novel strategy of periodic dosing of soy-lecithin as additive during long term test of diesel engine fueled with straight vegetable oil

Pinkesh R. Shah[a,*], Anuradda Ganesh[b]

[a] Department of Energy Science and Engineering, Indian Institute of Technology Bombay, Mumbai, India
[b] Advanced Engineering, Cummins Technologies India P. Ltd, Pune, India

A R T I C L E I N F O

Keywords:
Soy-lecithin
Straight vegetable oil
Bio-additive
Long-term test
Periodic dosage

A B S T R A C T

The vegetable oil has become a frontier area of research in rural and remote areas for small or decentralized power generation applications. However, the biggest challenge in use of straight vegetable oil (SVO) in a diesel engine is the problem of injector deposits. Soy-lecithin has been identified as bio-additive to overcome the deposits problem due to its natural surfactant and emulsifying properties. Though short-term performance test using soy-lecithin as bio-additive with non-edible karanj oil showed quite good results, its effect on engine performance during long-term test needs to be experimentally investigated for its reliability. The key objective of the current work is to examine the performance of diesel engine operated with karanj oil (*Pongamia pinnata*) by adopting a novel strategy of periodic dosing of bio-additive during a long-term test. This study also intends to focus on lubricating oil analysis to evaluate the effectiveness of soy-lecithin as bio-additive with karanj oil. Long-term engine test was performed on a Cummins DXP, direct injection diesel genset at a constant speed and load for 130 h. A test was conducted by adopting a novel strategy of periodic dosing of bio-additive in karanj oil in a repeated cycle during engine running condition. Experimental results showed that immediately switched over to additive improved the performance of engine but its continuous use lead to degradation of engine performance. Thus, running of engine continuously with either additive or w/o additive independently would lead to degradation of the engine performance but with periodic dosing of soy-lecithin as bio-additive improved the performance of the engine. The present work suggests the strategy of running the engine with bio-additive in discreet dosages for 2 h after every 7–8 h of engine run without additive in a repeated cycle. This approach would lead to smooth running of the engine which is an improvement over the baseline performance of karanj oil either with or without soy-lecithin alone. The lubricating oil analysis revealed the normal physicochemical properties and normal wear metal level within the discarding limit after 130 h of the long run test. The information coming out of this research would be helpful to researchers working with SVO to overcome the engine problems for its long-term durability or endurance test by adding an additive in a strategic manner.

1. Introduction

Use of vegetable oils as compression ignition engine fuel has been investigated by numerous researchers during the last twenty years. The vegetable oil has gained attention in rural and remote areas, where diesel fuel is not easily available [1]. Millions of small diesel engines of conventional design are present in India for small stationary decentralized power generation (2–20 kW) applications like drinking water supply, irrigation and electrification, where grid power is not easily available [2,3]. While many researchers have investigated vegetable oil as CI engine fuel either by blending with diesel or converting into biodiesel, [4–8] very few publications are available on studies with its direct use in the diesel engine. Henceforth, in this paper, direct use of crude vegetable oil, called as straight vegetable oil (SVO), has been undertaken in the existing diesel engine without any modifications.

The SVO can be effectively used in CI engine by four techniques namely, blending/dilution with diesel, micro-emulsion, transesterification and pre-heating [9]. Though short-term engine performance test showed good potential for most vegetable oils as fuel [10], its long-term test causes various issues like formation of carbon deposits, injector coking, poor atomization, cold starting, etc. This could adversely affect the engine performance and exhaust emissions [11]. Not only that, direct use of vegetable oil created some operational problems in the form of starting, unreliable ignition- misfire and degraded thermal efficiency during long run test [12]. Thus, longevity study is essential while using SVO directly in a diesel engine to check the durability and

* Corresponding author.
E-mail address: pinkeshrshah@gmail.com (P.R. Shah).

https://doi.org/10.1016/j.fuel.2018.04.121
Received 19 January 2017; Received in revised form 21 April 2018; Accepted 24 April 2018
0016-2361/

smooth running of an engine as test results vary widely depending on the source of oil, engine type, test conditions and measurement approach.

Out of large pool research on SVOs, only fraction of it is dedicated to long-term test in the existing diesel engines. The majority of experience says that durability problems are more severe in direct injection (DI) engine than an indirect injection engine. The DI engines did not complete the test, experienced piston and lubrication failure, after 155–250 h test due to buildup of carbon on the injector nozzles [13]. Basinger et al. [14] reported an increase in wear of diesel engine parts fuelled with waste vegetable oil during a 500 h durability test. In contrast to this, Agarwal et al. [15] concluded that utilization of karanj oil is a viable option for stationary power generation engines based on long-term endurance test conducted on DI compression ignition engine fuelled with pre-heated karanj oil. Similarly, Karaosmanoglu et al. [16] studied engine behaviour with sunflower oil for a 50 h period (considered long-term test) and did not observe any remarkable changes. The use of emulsion fuel in the old buses showed improvement in the smoke opacity and no adverse effect on engine operability or lubricant while traveling about 50,000 km [17].

Hossain and Davies [18] reviewed more than a dozen of published papers on durability tests involving plant oils or plant oil-diesel blends. However, it has been hard to compare these research results, since they have all used different test cycles. They found that results differed widely due to significant variation in oil sources, operating hours, ambient conditions, engine type and measurement approaches. It was concluded in general that use of plant oils in a diesel engine lead to operational and durability problems during longevity tests. The combustion of SVO in a diesel engine has shown conflicting results in emissions, power and engine longevity depending on the type of oil and engine [19]. There is no specific solution for injector deposits problem of the diesel engine fuelled with SVO as it depends on many interrelated factors [12].

Use of appropriate fuel additive in fuel is one of the simplest and easiest ways to reduce engine deposits problems. Many researchers have reported that the use of fuel additives effectively control the injector deposits in diesel engines operated with diesel fuel [20,21]. Many industries and automobile sectors have been using various types of multifunctional fuel additives to change the physiochemical properties of fuel for improvement of the combustion characteristics of an engine [22,23]. There are many types of fuel additives such as a metal organic compound, oxygenates, ignition promoter, wax dispersant, anti-knock agents, lead scavengers, fuel dyes, etc. which are added in small concentrations to diesel fuel to improve the engine efficiency and reduce exhaust emissions [24,25]. More literature reviews on these types of additives are given in our earlier publications [26,27].

There is hardly any report in the literature on the influence of fuel additives with SVO on engine performance of CI engines. Therefore, commercially available fuel additives for diesel fuel were used with SVO first time in our earlier work to investigate its influence on the fuel characterization and engine characteristics of diesel engine [28,29]. A comparative study on the influence of commercial fuel additives with edible oil and non-edible oil was also carried out by us under similar operating conditions in the unmodified diesel engine to evaluate the behaviour of additives with fatty acid compositions and engine performance during short-term test [26]. Based on encouraging results of commercial fuel additives, the authors have identified soy-lecithin as bio-additive which is best known for its surfactant and emulsifying properties. Therefore, a novel soy-lecithin as bio-additive with non-edible karanj oil is used first time, as both are agricultural products which are clean, renewable and readily available.

A short-term load performance test was carried out with 0.2% dosage of soy-lecithin as an additive with non-edible karanj oil in the diesel engine to investigate its influence on the emission, combustion and performance characteristics of CI engine. The test results showed that soy-lecithin as bio-additive with karanj oil (KO-additive) significantly reduced surface tension, SMD, cylinder pressure, HRR, ignition delay, etc. in comparison to karanj oil without additive (KO-w/o additive). It showed a reduction in NO_x, CO and BSEC by 15–20%, 7–8% and 3–4% respectively as compared to karanj oil w/o additive throughout the load range. The KO-additive also showed a remarkable reduction in the injector deposits by 25–30% as compared to KO-w/o additive [27].

However, it has been found that renewable fuels derived from vegetable oils are capable of providing good engine performance during the short-term but the same fuels can cause excessive carbon and lacquer deposits and degradation of the engine performance, when extended for long run operations [13]. Thus, its effects on engine performance during prolonged usage need to be experimentally investigated for large-scale and reliable implementation. Direct injection engines are much more dependent upon the ability of the injection system to accomplish a high degree of atomization of the fuel rather than indirect injection engines. Pre-heating is the easiest way to reduce the viscosity of SVO and improves the atomization of fuel in the existing diesel engines. There are some advantages of pre-heating SVO prior to injection as heating reduces injector deposits significantly and improves the combustion as well as emission characteristics of diesel engine [28,30].

Therefore, a long-term test was carried out with the addition of soy-lecithin as bio-additive in pre-heated karanj oil (*Pongamia pinnata*) for preliminary evaluation of smooth running of diesel engines and lubricating oil degradation. In this study, a long-term test was conducted by adopting a novel strategy of periodic dosing of additive during engine running condition.

2. Materials and method

2.1. Fuel selection and conditioning system

In this study, karanj oil (*Pongamia pinnata*) is considered as SVO as it is readily available in India and non-edible in nature. It was procured from a local supplier in Mumbai, India. The soy-lecithin was obtained from a local supplier in Indore, India and it was used in the same form without any additional purification. Soy-lecithin is extracted from soybeans and is a byproduct of a soybean oil production process. Academically, lecithin is known as 'phospholipid' because of containing phosphorous and lipid in its structure. Commercial soy-lecithin contains 45–65% phospholipids (PLs), 34% triglycerides and smaller amounts of carbohydrates, pigments, sterols and sterol glycosides [31]. The most common PLs in lecithin are phosphatidylcholine (PC), phosphatidylethanolamine (PE) and phosphatidylinositol (PI). Phospholipids are lipids containing a phosphoric acid residue which is nature's principal surface-active agent. A combined hydrophilic and lipophilic property of phospholipid molecules gives them surface active effects in many applications. It can be used in its natural form without any chemical process thus saving time and money. It is best known for its surfactant and emulsifying properties thus used as an emulsifier which can eliminate the process of making emulsion fuel. It is renewable, environment friendly and easily available. It is non-corrosive, non-toxic and safe to handle thus no hazardous effects. An excellent emulsifying behaviour and surfactant, lubricity, solubility, wetting, etc. properties made it possible to use soy-lecithin as bio-additive in many fields such as pharmaceutical and cosmetic industries. Thus, soy-lecithin can be directly used as bio-additive without any chemical process in many fields. More details on soy-lecithin are given in our earlier publication [27].

The crude karanj oil was adequately filtered through a cotton cloth and wire mesh filter of 5 μm before taking into the fuel tank. Two filters in parallel are provided at the exit of the tank and one before the fuel pump. An optimum dosage of soy-lecithin was added to karanj oil and the mixture was mechanically stirred for an hour continuously to ensure uniform mixing before taking to fuel tank. The temperature was maintained at 65 °C in the fuel tank with the provision of a heater and