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ScienceDirect
Applied Thermal Engineering 27 (2007) 2314–2323
APPLIED THERMAL ENGINEERING
www.elsevier.com/locate/apthermeng

Performance and emissions characteristics of Jatropha oil (preheated and blends) in a direct injection compression ignition engine

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Received 2 July 2006; accepted 9 January 2007
Available online 26 January 2007

Abstract

The scarce and rapidly depleting conventional petroleum resources have promoted research for alternative fuels for internal combustion engines. Among various possible options, fuels derived from triglycerides (vegetable oils/animal fats) present promising "greener" substitutes for fossil fuels. Vegetable oils, due to their agricultural origin, are able to reduce net CO_2 emissions to the atmosphere along with import substitution of petroleum products. However, several operational and durability problems of using straight vegetable oils in diesel engines reported in the literature, which are because of their higher viscosity and low volatility compared to mineral diesel fuel.

In the present research, experiments were designed to study the effect of reducing Jatropha oil's viscosity by increasing the fuel temperature (using waste heat of the exhaust gases) and thereby eliminating its effect on combustion and emission characteristics of the engine. Experiments were also conducted using various blends of Jatropha oil with mineral diesel to study the effect of reduced blend viscosity on emissions and performance of diesel engine. A single cylinder, four stroke, constant speed, water cooled, direct injection diesel engine typically used in agricultural sector was used for the experiments. The acquired data were analyzed for various parameters such as thermal efficiency, brake specific fuel consumption (BSFC), smoke opacity, CO_2, CO and HC emissions. While operating the engine on Jatropha oil (preheated and blends), performance and emission parameters were found to be very close to mineral diesel for lower blend concentrations. However, for higher blend concentrations, performance and emissions were observed to be marginally inferior.

Keywords: Jatropha; Bio-fuels; Straight vegetable oils; Blending; Preheating; Performance and emission characteristics

1. Introduction

Diesel engines are the most efficient prime movers. From the point of view of protecting global environment and concerns for long-term energy security, it becomes necessary to develop alternative fuels with properties comparable to petroleum based fuels. Unlike rest of the world, India's demand for diesel fuels is roughly six times that of gasoline hence seeking alternative to mineral diesel is a natural choice [1].

Alternative fuels should be easily available at low cost, be environment friendly and fulfill energy security needs without sacrificing engine's operational performance. For the developing countries, fuels of bio-origin provide a feasible solution to the twin crises of fossil fuel depletion and environmental degradation. Now bio-fuels are getting a renewed attention because of global stress on reduction of green house gases (GHGs) and clean development mechanism (CDM). The fuels of bio-origin may be alcohol, vegetable oils, biomass, and biogas. Some of these fuels can be used directly while others need to be formulated to bring the relevant properties close to conventional fuels. For diesel engines, a significant research effort has been directed towards using vegetable oils and their derivatives as fuels.

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1359-4311/$ - see front matter
doi:10.1016/j.applthermaleng.2007.01.009

Vegetable oils have comparable energy density, cetane number, heat of vaporization, and stoichiometric air/fuel ratio with mineral diesel. In addition, they are biodegradable, non-toxic, and have a potential to significantly reduce pollution. Vegetable oils and their derivatives in diesel engines lead to substantial reductions in emissions of sulfur oxides, carbon monoxide (CO), poly aromatic hydrocarbons (PAH), smoke, particulate matter (PM) and noise [2–5]. Furthermore, contribution of bio-fuels to greenhouse effect is insignificant, since carbon dioxide (CO_2) emitted during combustion is recycled in the photosynthesis process in the plants [3,6,7].

Vegetable oils mainly contain triglycerides (90% to 98%) and small amounts of mono- and di-glycerides. Triglycerides contain three fatty acid molecules and a glycerol molecule. They contain significant amounts of oxygen. The fatty acids vary in their carbon chain length and number of double bonds present in their molecular structure. Vegetable oils contain free fatty acids (generally 1–5%), phospholipids, phosphatides, carotenes, tocopherols, sulfur compounds and traces of water. Commonly found fatty acids in vegetable oils are stearic, palmitic, oleic, linoleic and linolenic acid. Vegetable oils can be produced even on a small scale for on-farm utilization to run tractors, pumps and small engines for power generation/irrigation. Suitability of vegetable oils as fuels for diesel engines depends on their physical, chemical and combustion characteristics as well as the type of engine used and operating conditions [8].

Vegetable oils can be used directly or blended with diesel to operate compression ignition engines. Use of blends of vegetable oils with diesel has been experimented successfully by various researchers in several countries [9–13]. Caterpillar (Brazil) used pre-combustion chamber engines with a blend of 10% vegetable oil while maintaining same power output without any engine modifications [9]. It has been reported that use of 100% vegetable oil is also possible with minor fuel system modifications [14]. Short-term engine performance tests have indicated good potential for most vegetable oils as fuel. The use of vegetable oil results in increased volumetric fuel consumption and BSFC [15]. Emissions of CO, HC and SO_x were found to be higher, whereas NO_x and particulate emission were lower compared to diesel [16–20]. Some studies reported lower exhaust emissions including PAHs and PM [14,21].

However, long-term endurance tests reported some engine durability issues related to vegetable oil utilization such as severe engine deposits, piston ring sticking, injector coking, gum formation and lubricating oil thickening [22–24]. These problems are primarily attributed to high viscosity and poor volatility of straight vegetable oils due to large molecular weight and bulky molecular structure. High viscosity of vegetable oils (30–200 cSt @ 40 °C) as compared to mineral diesel (4 cSt @ 40 °C) lead to unsuitable pumping and fuel spray characteristics. Larger size fuel droplets are injected from injector nozzle instead of a spray of fine droplets, leading to inadequate air-fuel mixing. Poor atomization, lower volatility, and inefficient mixing of fuel with air contributes to incomplete combustion. This results in an increase in higher particulate emissions, combustion chamber deposits, gum formations and unburned fuel in the lubricating oil.

Since straight vegetable oils are not suitable as fuels for diesel engines, they have to be modified to bring their combustion related properties closer to diesel. This fuel modification is mainly aimed at reducing the viscosity to eliminate flow/atomization related problems. Four techniques can be used to reduce the viscosity of vegetable oils; namely heating/pyrolysis, dilution/blending, micro-emulsion, and transesterification [25–28].

Undoubtedly, transesterification is well accepted and best suited method of utilizing vegetable oils in CI engine without significant long-term operational and durability issues. However, this adds extra cost of processing because of the transesterification reaction involving chemical and process heat inputs. In rural and remote areas of developing countries, where grid power is not available, vegetable oils can play a vital role in decentralized power generation for irrigation and electrification. In these remote areas, different types of vegetable oils are grown/produced locally but it may not be possible to chemically process them due to logistics problems in rural settings. Hence using heated or blended vegetable oils as petroleum fuel substitutes is an attractive proposition. Keeping these facts in mind, a set of engine experiments were conducted using Jatropha oil on a engine, which is typically used for agriculture, irrigation and decentralised electricity generation. Heating and blending were used to lower the viscosity of Jatropha oil in order to eliminate various operational difficulties.

1.1. *Jatropha curcas*

It is a non-edible oil being singled out for large-scale plantation on wastelands. *J. curcas* plant can thrive under adverse conditions. It is a drought-resistant, perennial plant, living up to fifty years and has capability to grow on marginal soils. It requires very little irrigation and grows in all types of soils (from coastline to hill slopes). Fig. 1 shows a typical Jatropha plant growing on rocks in mountainous regions. The production of Jatropha seeds is about 0.8 kg per square meter per year [29]. The oil content of Jatropha seed ranges from 30% to 40% by weight and the kernel itself ranges from 45% to 60% [10,30]. Fresh Jatropha oil is slow-drying, odorless and colorless oil, but it turns yellow after aging [10].

The only limitation of this crop is that the seeds are toxic and the press cake can not be used as animal fodder. The press cake can only be used as organic manure. The fact that Jatropha oil can not be used for nutritional purposes without detoxification makes its use as energy/fuel source very attractive. In Madagascar, Cape Verde and Benin, Jatropha oil was used as mineral diesel substitute during the Second World War [31,32]. Forson et al. used Jatropha