Renewable Energy 122 (2018) 196–205

Contents lists available at ScienceDirect

Renewable Energy

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

Effect of additives on performance, combustion and emission behavior of preheated palm oil/diesel blends in DI diesel engine

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ARTICLE INFO

Article history:
Available online 20 January 2018

Keywords:
Preheated palm oil
Diesel engine
BHT
n-Butanol
Additives

ABSTRACT

Internal combustion (IC) engine is an attractive main power resource for transportation and in the foreseeable future also their domination never going to be altered. However, almost half of the energy from the fuel supplied to the IC engines is going as waste heat to the environment in the means of cooling and exhaust systems. This waste heat from the exhaust gasses were used to preheat the Palm Oil (PO)/diesel blends to 60 °C with the help of heat exchanger to obtain a homogenous mixture. This research work emphasizes on the performance, combustion and emission characteristics of a four stroke, single cylinder natural aspirated, water cooled direct injection (DI) diesel engine using preheated Palm Oil (PO)/diesel blends. Engine tests were conducted with preheated palm oil/diesel blends (PO20, PO30 and PO40) and pure diesel at a constant speed of 1500 rpm for different load conditions. The results of engine performance like Brake Specific Fuel Consumption (BSFC), Brake Thermal Efficiency (BTE) and Combustion characteristics of Heat release rate, cylinder pressure and emissions like Carbon Monoxide (CO), unburned Hydro Carbon (HC), Nitrogen Oxide (NOx) and Smoke Opacity of all palm oil blends were compared with pure diesel fuel. The result reveals that, PO20 blend is the most preferable blend among the other palm oil blends. To further improve the performance characteristics of PO20, fuel additives such as BHT (2000 ppm) and n-butanol (20% by volume) is added to the PO20 blend. The brake specific fuel consumption and brake thermal efficiency of the PO20 + BHT blend is 11.4% and 5.1% higher than that of diesel fuel. The CO emission of PO20 + butanol blend shows 37.5% lower, whereas the NOx emission is 1.9% higher than that of diesel fuel. Moreover the smoke and EGT is observed to be 13% and 3.1% lower compared to diesel fuel. This research work reveals that, preheated palm oil and its blends with antioxidant proved better performance and emission levels than diesel fuel. So from an environmental point of view palm oil blends with diesel fuel will be a more promising alternative fuel in the near future.

1. Introduction

A major part of the world's transport and agricultural sector are incredibly dependant on internal combustion engines especially diesel engines. In the past few years due to widespread increase in the cost and depletion of the fossil fuels a number of research works has been diverted towards finding and analysing the feasibility of various alternate fuels. An alternate fuel is expected to be readily available, cheap, clean, efficient and environmentally friendly. Somehow straight vegetable oils, to a certain extent, have good fuel properties and are also cheaper compared to diesel fuel. Therefore, such vegetable oils act as a feasible alternate fuel. The main advantage of these types of alternate fuels is being non-toxic, biodegradable and sulphur-free. Furthermore, in remote and rural areas of India, due to non-availability of grid power, these vegetable oils act as one of the main sources for power generation and electrification of irrigation activities. Due to practical difficulties in rural areas, it may not be a feasible idea to process these vegetable oils using complex chemical processes like micro emulsions with alcohols, thermal cracking and transesterification. Hence, direct blending of diesel fuel with vegetable oils is a promising solution for rural areas. Across the world, the fossil fuel consumption grew 0.6 million barrels per day and the cost is about $ 111.26 per barrel in 2011 which means a 40% increase than the previous year.

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https://doi.org/10.1016/j.renene.2018.01.068

Nomenclature

PO0	100% Diesel
PO20	20% palm oil+80% Diesel
PO30	30% palm oil+70% Diesel
PO40	40% palm oil+60% Diesel
PO20 + BHT	(20% palm oil + 80% Diesel) + Butylated hydroxyl toluene (BHT)
PO20+n-butanol	(20% palm oil + 80% Diesel) + n-butanol
BP	Brake power
BTE	Brake thermal efficiency
BSFC	Brake specific fuel consumption
HC	Hydrocarbon
CO	Carbon Monoxide
NOx	Oxides of Nitrogen

Moreover, at present the capacity of the liquid fuel will meet only half of the global energy demand until 2023 [1]. A major portion of the petroleum reserve is located within a small region of the world. I.e. Middle East countries are the dominant petroleum suppliers in the world, possess 63% of global petroleum reserves [2]. This leads to a disproportionate distribution of petroleum resources and makes other countries dependant on Middle East countries. On the contrary, Renewable energy sources are more evenly distributed than fossil fuel and hence, coming up as a secured energy source in near future. Bioenergy is one of the most important alternate sources to palliate greenhouse gas emissions and also a mere substitute of fossil fuels, but it has some criticalities in their life cycle are well-known, that can cause negative effects on human health and ecosystems, which cannot be ignored [3].

Vegetable oils classified into two types; edible and non-edible oil. The use of non-edible oil compared to edible oil is to be more important due to the social problems related to food crisis. But at present, more than 95% of the world's biodiesel is produced from edible vegetable oils due to its abundant availability [4]. In industries to produce sustainable fuels, the most widely used edible vegetable oils are palm, soybean, rapeseed and sunflower oil. The palm is the most productive plant among all biofuel feedstock due to its higher production yield. The scenario in the Palm oil production is that, around 45 million tonnes of Palm oil are produced per year in the world, Southeast Asia is dominating in its production, and especially Malaysia is one of the leading palm oil producers in the world [5]. But the cost of feedstock is almost 70% of the total expenditure of biodiesel production. This brings about the need for using straight vegetable oils blended with diesel in regular diesel engines and the same were confirmed by various researchers.

The utility of straight vegetable oils as an alternate fuel without engine modification creates poor atomization due to high viscosity leads to incomplete combustion and carbon deposits on engine parts such as piston rings, cylinder walls, injectors etc. Georgios Fontaras et al. [6] studied the application of three untreated straight vegetable oils (cottonseed, sunflower, and rapeseed)/diesel blends in the ratio of 10–90% by volume as automotive fuels for passenger cars, under various conditions and concluded that regulated pollutant emissions persisted almost in all three cases very close to standard levels. During cold start, significant increase on CO_2, CO and HC were observed due to the presence of the vegetable oil, on the other hand it suppresses the formation of nucleation mode particles. Corsini et al. [7] studied the behaviour of multi-jet Diesel engine by using straight vegetable oils (rapeseed oil) and bio-diesel produced from waste cooking oil as fuel and concluded that at lower loads, power loss has been observed due to its a higher density and viscosity of straight vegetable oils varies the injection time, leads to increase in HC emission. Misra et al. [8] reviewed the direct blending of straight vegetable oils with diesel fuel in compression ignition engine and concluded that due to its higher viscosities of the blends causes poor fuel atomization, intern leads to incomplete fuel combustion and also carbon deposition on the injector and valve seat, resulting in serious engine fouling. On the other hand the same is true also for direct injection engines; injectors become choked after a few hours of operation leads to poor fuel atomization and incomplete combustion. Further, because of incomplete combustion, partially burnt straight vegetable oil in the combustion chamber runs down the cylinder walls and dilutes the lubricating oil results in thickens the lubricating oil. But still the scope for research by blending the straight vegetable oils with diesel fuel is that, the potential to reduce NOx emissions, which is one of the major concerns of the world today. Silvico et al. [9] investigated the heated palm oil (100%) as fuel in naturally aspirated DI diesel generator. The authors reported that the deposits presents on the cylinder head is more when the engine operates with the preheated palm oil at 50 °C whereas at 100 °C the operation of the diesel generator is almost similar to diesel fuel due to its lower viscosity, better combustion and less deposits. Moreover the EGT and SFC increased with an increase in charge percentage. At higher loads, there is an increase in CO emissions due to lack of oxygen at higher equivalence ratios. But NOx emissions were observed to be lower than diesel fuel. Bari et al. [10] studied the effects of preheating of crude palm oil (CPO) on injection system, performance and emission of a diesel engine. The authors revealed that at room temperature, the viscosity of CPO is about 10 times higher than that of diesel fuel. To have the similar viscosity of diesel at least a heating temperature of 92 °C is needed to provide the smooth flow of fuel through the injector.

One of the most common methods to reduce the viscosity of vegetable oil is an addition of n-butanol. Due to this addition of additive improves the fuel atomization during combustion results in complete combustion and thereby reduces the carbon deposits on engine parts such as piston rings, cylinder walls, injectors etc. The concentration of n-butanol blended in the diesel fuel plays the major role in the emissions, i.e. for lower concentrations of n-butanol (5–10%) produces low level of CO and higher NOx emissions than diesel fuels, whereas higher concentrations of n-butanol (20%) caused a higher level of CO and HC emissions on the other hand lower smoke opacity, EGT and NOx emission than diesel fuel. In addition to that, there is an increase in the BSFC and BTE with increasing n-butanol content in fuel blends and also it will provide stable alternative fuels even at low temperatures [11–14].

Rakopoulos et al. [15] investigated the effects of using blends of n-butanol/diesel with the ratios of 8/92, 16/84 and 24/76 (by volume) in a high-speed DI diesel engine and revealed that the smoke density, CO, NOx emissions significantly reduced compared to neat diesel fuel. This reduction is being observed to be higher with respect to increase in the percentage of n-butanol in the blend. On the contrary, HC emissions were increased with respect to increase in the percentage of n-butanol in the blend. Butanol is an attractive alternative fuel for CI engine, one of the reasons for such a preference is due to butanol's superiority over ethanol and methanol in various factors such as higher cetane number, lower heat of vaporization, higher heating value, and better miscibility with diesel fuel therefore n-butanol was depicted as a promising and safe alternative fuel that can be used in diesel engines with high blend ratios [16].

Further studies showed that addition of antioxidants would improve the emission characteristics as well as the storage capability of the fuel and fuel degradation can be significantly reduced.