Fuel 132 (2014) 116–124

Contents lists available at ScienceDirect

Fuel

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

Comparative analysis of performance, emission and combustion parameters of diesel engine fuelled with ethyl ester of fish oil and its diesel blends

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HIGHLIGHTS

- We examine the engine performance and emission parameters of fish oil biodiesel.
- Analyze the combustion characteristics of the engine.
- Comparing the engine performance of fish oil biodiesel with base diesel.

ARTICLE INFO

Article history:
Received 27 May 2012
Received in revised form 1 March 2014
Accepted 17 April 2014
Available online 9 May 2014

Keywords:
Fish oil biodiesel
Diesel
Diesel engine
Performance
Emission and combustion

ABSTRACT

The thirst for fuel is steadily increasing as technology continues to open new areas of exploration. At the same time, the indiscriminate extraction of fossil fuels also may result in extinction of petroleum deposits in foreseeable future. Along with this, pollutant emission from diesel engines causes major impacts on ecological systems. In order to overcome the above problems associated with the use of petroleum derived fuels, a suitable source of biodiesel should be used to replace conventional diesel fuel. Hence, in this work, feasibility of using biodiesel prepared from fish oil was investigated. Various properties such as viscosity, density, calorific value, flash point and cetane value of biodiesel and biodiesel–diesel blends of different proportions were investigated. Later, experimental tests were carried out to evaluate the performance, emission and combustion characteristics of a single cylinder, constant speed, direct injection diesel engine using biodiesel–diesel blends, under variable load conditions. It was found that there was a reduction in NO_x, HC and CO emission along with a marginal increase of CO_2 and smoke emissions with the increase in biodiesel proportion in the fuel. The brake thermal efficiency was found to be higher compared to diesel for the entire load. An analysis of the cylinder pressure rise, heat release, and other combustion parameters such as peak pressure, rate of pressure rise, combustion duration and ignition delay was carried out. The ignition delay, maximum heat release rate and combustion duration were lower for biodiesel–diesel blends compared to diesel. Ultimately, fish oil can indeed become the appropriate source for biodiesel, with environmental benefits.

1. Introduction

The world economy depends mainly on energy economy. Currently fossil fuels, namely coal, petroleum and natural gas, dominate the world energy market occupying 26–27% each of total energy consumption. In particular, petroleum products take up the major share since they are mainly used in transportation and industrialization sectors. With the growth of both these sectors, the energy consumption also increases. It is estimated that by 2030, the per-capita energy consumption growth will be at a rate of 0.7% per year. At present, fossil fuels namely coal, petroleum and natural gas dominates the energy scenario with a share of 26–27% each as predicted by International Energy outlook, 2030 [1]. According to US Energy Information Administration (EIA), International Energy Statistics database, the average global energy consumption grows at the rate of 1.6% p.a. This indiscriminate consumption of fossil fuels will lead to depletion of petroleum reserves. Another challenge related to increase in energy

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http://dx.doi.org/10.1016/j.fuel.2014.04.059
0016-2361/

consumption is environmental threats caused by pollutant emissions of petroleum fuels. This causes global warming and ice meltdown due to massive carbon footprints. Hence, IEA presented 450 energy scenarios that insist on emission levels below 450 ppm that could limit the temperature increase to 2 °C. Kyoto protocol and Copenhagen conference (2009) aimed at the stabilization of greenhouse gas concentrations in the atmosphere. The factors listed above triggered many initiatives to search for alternate fuels that can replace or supplement conventional fossil fuels.

Biodiesel is a form of diesel fuel manufactured from vegetable oils, animal fats, or recycled restaurant greases. Biodiesel proves to be a boon to auto industries by providing renewable, non-toxic, biodegradable and cleaner energy source [2]. It also solves environmental problems by reducing greenhouse effect. Biodiesel is going to play an extremely important role in meeting the world's energy needs since it provides energy security, reducing imports [3]. The raw material that is used to produce biodiesel plays an important role in the fuel industry. The tie up between low production costs and large production scale should be balanced. Biodiesel can be produced using renewable resources such as vegetable oils (e.g., soybean, canola, sunflower, rapeseed, peanut and palm oil), animal fats (tallow, lard, poultry fat, fish oils, etc.) and waste cooking oils [4]. While considering the biodiesel from vegetable oil, cultivation of crops for biodiesel production poses a threat to food security and contributes to decline in soil fertility. The oil percentage and the yield per hectare of vegetable oil are very low. Biodiesel produced from vegetable oils such as palm oil, sunflower oil, soybean oil, rape seed and peanut oil also appears to have a larger weight fraction of polyunsaturated fatty acids than the fish oil biodiesel. Biodiesel with polyunsaturated fatty acids with more than three double bounds is prone to deterioration in its oxidation stability, thus causing the precipitation of the biodiesel components in a fuel feeding system or combustion chamber [5,6]. On the other hand, waste cooking oil from restaurants and domestic kitchens is not a continuous source of raw material for biodiesel fuel [7]. Thus, one of the better alternative fuels is the biodiesel obtained from animal fat. Biodiesel can be obtained from less expensive animal fat such as inedible beef fat, pork fat, duck fat, fish fat and yellow grease [8].

The animal fat present in the waste parts of fish serves to be a good source of crude oil for biodiesel. It is estimated that, every year, a surplus amount of fish parts is discarded by various fish products manufacturing industries. As per department of Animal Husbandry, Dairying & Fisheries, Govt. of India, 20% of the total fish produced is discarded as waste. It is also expected by Central Institute of Fisheries Technology (CIFT) that more than 0.1 million tonnes of shrimp were produced as industrial fish waste. Since large quantities of waste parts are discarded, the complete recycling of these discarded parts is a high priority concern, not only due to the large quantities generated, but also due to their creating an economic and environmental problem [4]. Hence, production of fish oil solves both the problems of processing the waste, thereby saving the environment and biodiesel production. Fish oil can be derived from waste parts of fish like viscera, eyes, fins, head, tails, liver and maw [9]. Further, the fish skins and discarded tissues also contribute to the production of fish oil [10]. Consequently, crude fish oil extracted from these discarded parts may provide an abundant, cheap, and stable source of raw oil.

The following researchers used fish oil biodiesel and discussed its performance and emission characteristics. Vilela et al. [4] tested the possibility of using fish oil as biodiesel by analyzing its acidity level. The effect of esterification reaction time and temperature on the acidity level was observed, keeping other parameters constant. The biodiesel yield obtained from fish oil in the present work ranged from 68% to 90%. Godiganur et al. [11] examined the performance and emission characteristics of diesel engine operated with methyl ester of fish oil and its blends with diesel. The test results showed no major deviations in diesel engine combustion as well as in the engine performance but a reduction in main noxious emissions like CO and HC with the exception on NO_x. For B20 blend, lower BSFC, BSEC and higher BTE compared to diesel was obtained. Lin and Li [12] investigated the fuel properties of fish oil biodiesel obtained from soap stock of a mixture of marine fishes and compared it with waste cooking oil. Marine fish-oil biodiesel appeared to have greater kinematic viscosity, higher heating value, higher cetane index, more carbon residue, lower peroxide value, flash point, and distillation temperature than those of waste cooking oil. Jayasinghe and Hawboldt [13] discussed the engine performance and emissions of crude and blended fish biofuel for various types of engines. It was concluded that crude fish oil in existing stationary diesel engines and combustors (furnaces and boilers) produced good results with reduction in emissions.

Lin and Li [7] studied the performance and emission characteristics of diesel engine fuelled with fish oil biodiesel. The experimental results showed that fish oil biodiesel produced higher brake fuel conversion efficiency, NO_x, and smoke emissions and lower CO emission compared with biodiesel from waste cooking oil. Behcet [14] studied the variation of performance and exhaust emission in a diesel engine when operated with pure and diesel blended biodiesel produced from anchovy fish oil. Emissions like CO_2, CO, HC and smoke decreased while increase in specific fuel consumption, exhaust gas temperature and NO_x emissions had been observed. Steigers [15] used fish oil as fuel in a large stationary diesel engine and observed that, over a 10-month test period, the engines operated normally with no apparent adverse operational or maintenance impacts. Swaminathan and Sarangan [16] tested fish oil biodiesel with diethyl ether as an additive in a direct injection diesel engine. Emissions like CO and CO_2 are reduced for fish oil biodiesel except NO_x. Most of the literature mainly deals with research in performance and emission analysis of methyl ester of fish oil whereas, here, an attempt has been made to use ethyl ester of fish oil as biodiesel to evaluate the performance and emission characteristics along with combustion analysis. Ethanol has cleaner burning characteristics and a high octane rating value which can endure higher compression ratios before combustion [17,18].

The application of ethanol in biofuel may reduce environmental pollution, reduce diesel fuel requirements and thus contribute in conserving a major commercial energy source comparing to methanol. Fatty acid ethyl esters (FAEE) have higher cetane number, heat content, and oxidation stability compared to methyl esters and also the cold flow properties of FAEEs are much better than fatty acid methyl esters (FAME). FAEEs fuel has a better safety and ignition performance. Since FAEEs have one more carbon compared to FAMEs, the calorific value of FAEE is also slightly higher than that of FAME [19–22]. Moreover, the use of ethanol can result in significant savings in carbon dioxide emissions. Ethanol in esterification reduces the potential future risks associated with climate change and it has the added benefit of economic development [23–25].

The purpose of this study was twofold. (1) To prepare ethyl ester of fish oil (biodiesel) from waste fish parts through transesterification method and to determine the important properties of diesel–biodiesel blends. (2) To investigate the performance, combustion and emissions analysis of diesel engine operations on diesel–biodiesel blends and also to compare these results with those operating on base diesel.

2. Materials and methods

2.1. Production of biodiesel from refined fish oil

The waste parts of sardine fish were cooked, squeezed and centrifuged to extract the fish oil. The waste parts of fish were first