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Review

The effect of additives on properties, performance and emission of biodiesel fuelled compression ignition engine

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ABSTRACT

With growing concern over greenhouse gases there is increasing emphasis on reducing CO_2 emissions. Despite engine efficiency improvements plus increased dieselization of the fleet, increasing vehicle numbers results in increasing CO_2 emissions. To reserve this trend the fuel source must be changed to renewable fuels which are CO_2 neutral. As a renewable, sustainable and alternative fuel for compression ignition engines, biodiesel is widely accepted as comparable fuel to diesel in diesel engines. This is due to several factors like decreasing the dependence on imported petroleum, reducing global warming, increasing lubricity, and reducing substantially the exhaust emissions from diesel engine. However, there is a major disadvantage in the use of biodiesel as it has lower heating value, higher density and higher viscosity, higher fuel consumption and higher NO_X emission, which limits its application. Here fuel additives become essential and indispensable tools not only to minimize these drawbacks but also generate specified products to meet the regional and international standards. Fuel additives can contribute towards fuel economy and emission reduction either directly or indirectly. Their use enable vehicle performance to be maintained at, or near, optimum over the lifetime of the vehicle. A variety of additives are used in automotive biodiesel fuel to meet specification limits and to enhance quality. For example, metal based additives, oxygenated additives, antioxidants, cetane number improvers, lubricity improvers and cold flow improvers are used to meet specifications and quality. This article is a literature review of the effect of various additives on biodiesel properties, engine performance and exhaust emission characteristics and the corresponding effect factors were surveyed and analyzed in detail. The review concludes that the use of additive in biodiesel fuel is inalienable both for improving properties and for better engine performance and emission control. Therefore, in order to find the appropriate fuel additives in the combustion applications, more experiments are needed to explore the different related mechanisms.

1. Introduction

A large amount of energy is consumed in transportation sector largely by diesel engine. The petroleum fuels play significant role in the development of transportation sector, industrial growth and agricultural sector as well as to fulfill other human needs. However the reservation of total petroleum fuel in the world, is shortening day by day. Therefore most of the scientists and researchers are worried thus looking for the substitute or alternative fuel [1,2]. The lack of fossil fuel reserve will make renewable fuels more attractive [3]. Even though most of the renewable energy technologies are more environmental friendly than conventional energy options, their acceptance is very slow because of factors such as lack of supply, economic constraints etc. [4]. As an alternative fuel, biodiesel will be able to meet the present and future energy demand. It is formulated from vegetable oil and animal fat, which are non-toxic and more bio degradable [5], eco-friendly and more reliable [6]. In terms of environmental issue biodiesel is more adoptable compare to fossil fuel as it forms low carbon and smoke which are responsible for global warming [7–9]. On the other hand biodiesel has higher molecular weight, density, viscosity and pour point than conventional diesel fuel [10–12]. Higher molecular weight and viscosity of biodiesel causes low volatility and poor fuel atomization, injector coking, piston ring sticking and leading incomplete combustion [13] as well as it has cold flow property which is a barrier to use it in cold or chill weather [14].

Biodiesel is an oxygenated fuel consisting of long chain fatty acid which contain 10–15% oxygen by weight [15,16] and it contains neither sulfur, nor aroma. These facts lead biodiesel to enhance more complete combustion and less emission of particulate matter

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Nomenclature

BP	brake power
BSFC	brake specific fuel consumption
BTE	brake thermal efficiency
BHA	butylated hydroxyanisol
BHT	butylated hydroxytoluene
CO_2	carbon dioxide
CO	carbon monoxide
CFPP	cold filter plugging point
DEE	diethyl ether
DMC	dimethyl carbonate
DW	distilled water
EVA	ethylene vinyl acetate
EHN	ethyl hexyl nitrate
EDA	ethylenediamine
FBC	fuel born catalyst
FAME	fatty acid methyl ester
HC	hydro carbon
NO_2	nitrogen dioxides
NO	nitric oxide
NPAA	nonyl phenoxy acetic acid
DPPD	N, N-diphenyl-1, 4 phenylenediamine
NO_X	oxides of nitrogen
SO_2	oxide of sulfur
PM	particulate matter
PXAP	paraffin–xylene–acetone and polymer
PPDA	P-phenylene-diamine
PPM	parts per million
TBHQ	tert-butylhydroquinone

(PM), carbon monoxide (CO) and total hydrocarbons (HC), while increase nitrogen oxides (NO_X) [17,18] compared to conventional diesel fuel. However, net calorific value and energy content of biodiesel is less than diesel fuel. According to EPA B20 (20% biodiesel and 80% diesel) reduces smoke, PM, HC and CO emission by 20%, 20%, 25% and 13% respectively, while increase NO_X emission by 4% [19]. Many researchers investigated the engine performance and emission characteristics of diesel engine operated using biodiesel and its blend. Ekrem [20] carried on the experimental study on the effect of rapeseed biodiesel on performance and emission characteristics and found that biodiesel gave about 11% higher BSFC and higher NO_X but reduce other emission such as smoke, HC and CO. Karabektas [21] studied the effect of biodiesel from rapeseed oil of a diesel engine on performance and emission and found that the low brake power, higher brake specific fuel consumption and higher brake thermal efficiency and higher NO_X emission compared to diesel fuel. Sharanappa et al. [22] found the brake specific fuel consumption and NO_X emission was higher and HC and CO emission was lower with the increase in percentage of mahua oil biodiesel in the blends. Rao et al. [23] reported that the BSFC, soot, HC and CO reduced and NO_X emission was increased for rice bran oil biodiesel. Lin et al. [24] investigated the effect of vegetable oil methyl ester on engine performance and emission of a diesel engine and found, there was no significant change in brake power and reduction in all emission except NO_X. Some researchers [25–27] reported that biodiesel gave higher brake specific fuel consumption and NO_X as compare to diesel fuel.

Due to growth of population, energy consumption and global warming concerns, design and improvement of energy efficient and environmental friendly diesel engines have received substantial attention [28]. In this regard, the various techniques have been employed such as fuel properties modification, engine design alteration, and exhaust gas treatment etc. The purpose of fuel properties modification is to improve the combustion to obtain low fuel consumption and emissions without requiring modifications to the engine, fuel injection or exhaust systems. A few authors [29,30] reported that the biodiesel physical properties can be uplifted by using different additives including metal based additives, antioxidants and oxygenated additives, cold flow improver etc. into biodiesel to solve the problem of cold flow properties for their large number of usage in diesel engines. Some additives were used to improve the performance and reduce exhaust emissions from diesel engines. Lapuerta et al. [29] investigated the effect of alcohol as oxygenated additive in waste cooking oil biodiesel and found higher BSFC and lower CO, HC and smoke emission than diesel fuel. Balaji and Cheralathan [31] reported the effect of antioxidant additives (L-ascorbic) with cottonseed methyl ester on engine performance and emission characteristics and found the brake specific fuel consumption slightly decreased, brake thermal efficiency increased. HC, NO_X, CO_2, and smoke emission decreased however CO slightly increased. Keskin et al. [32] studied the effect of Mn and Ni based additives in tall oil biodiesel on fuel properties, fuel consumption and emission and found lower viscosity and pour point, lower BSFC as well as lower smoke and NO_X emission than diesel.

In this work, the literatures indexed from highly rated journals including some SAE technical conference papers. This present work will be helpful for engineers, industrialists as well as researchers who are interested on biodiesel and engine manufacturers to develop the further researches related to optimize and readjust biodiesel engine and its relevant systems. The effect of several fuel additives on several biodiesel properties are introduced and summarized in Section 3. Then the effect of different additives blended with different biodiesel fuel on engine performances (power performance, economy performance and thermal efficiency) and the exhaust emissions (NO_X, CO, HC, CO_2 and smoke opacity) of compression ignition engines are investigated and compared with those fuelled with diesel fuel and biodiesel without additives in Section 4. Each of the factors are discussed elaborately in different sections and different research results are presented in tabular form in order to have an easy comparison among them. Finally, discussions and conclusions are drawn and further researches are pointed out.

2. Biodiesel and additives

Biodiesel is defined as alkyl (methyl, ethyl, or propyl) esters of fatty acid, obtained by the chemical reactions transesterification and esterification of oils or fats, from animal or plants, with short chain for example methanol and ethanol. An important factor in the reduction of fossil fuel consumption, and hence containment of carbon dioxide emission, is the use of renewable or alternative fuels. Ethanol produced from biomass, frequently itself the discarded vegetation from food crops, is one such renewable component which can be added to gasoline, with benefits in reduced fossil fuel consumption. Similarly, for compression ignition engine, fatty acid methyl ester (FAME) produced from vegetable oil, often derived from seeds, have been added to diesel fuel for many years to extend crude oil derived fuels. Biodiesel is meant to be used in diesel engine because it has engine performance comparable with conventional diesel. It can be used pure and blended with diesel [33,34]. Biodiesel is non-explosive, nontoxic, nonflammable and biodegradable fuel [35] which provides reduction of many