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A comprehensive review of biodiesel as an alternative fuel for compression ignition engine

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ABSTRACT

In search of alternative fuels for CI engines, many experimental studies have been carried out and posted in the literature during the last few decades. This paper presents a comprehensive review on the production, performance and emissions from a compression ignition engine using biodiesel as alternate to fossil based diesel fuel. The properties of biodiesel produced from different sources and their fatty acid composition have also been described. The experimental set up used by different researchers for the investigations and their findings regarding performance and emissions with respect to mineral diesel have been presented in short for a large number of studies. For better illustration of the facts, results of a few experimental studies available in the literature have been presented in the form of different graphs for selective important performance and emission parameters as case studies. The overall impression is that the performance of the engine slightly deteriorates with the use of biodiesel partially or fully instead of diesel, but the environmental aspects are significantly improved.

Contents

Abbreviations: ASTM, American Society for Testing and Materials; BSFC, Brake specific fuel consumption; bTDC, Before top dead centre; CI, Compression ignition; COME, Canola oil methyl ester; DI, Direct injection; EGR, Exhaust gas recirculation; EGT, Exhaust gas temperature; EN, European standards for products and services by European Committee for Standardization; ESG, Eruca sativa gars; FFA, Free fatty acid; GHG, Green house gas; GTL, Gas to liquid; H_2SO_4, Sulfuric acid; HOME, Honge oil methyl ester; IS, Indian Standard; JOME, Jatropha oil methyl ester; KOH, Potassium hydroxide; MEPS, Methyl ester of paradise oil; MOEE, Mahua oil ethyl ester; MOME, Mahua oil methyl ester; NaOH, Sodium hydroxide; NOME, Neem oil methyl ester; PBDF, Petroleum based diesel fuel; PKOME, Palm kernel oil methyl ester; PNOME, Peanut oil methyl ester; RME, Rapeseed methyl ester; SOME, Seasame oil methyl ester; SVO, Straight vegetable oil; THC, Total hydrocarbon; VOME, Vegetable oil methyl ester; WFO, Waste frying oil; WPOME, Waste palm oil methyl ester

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1. Introduction

The availability of adequate amount of conventional fossil fuel for internal combustion engines and the associated effects of global warming and other environmental issues arising due to the combustion of fossil fuels are the two most threatening problems of our present day civilization. The rapid industrialization and urbanization are also making our planet unsafe for us and for the generations to come. People are now all well aware of the lethal effects of environmental pollution created by the random use of fossil fuels. China tops the list of green house gas emitters and India is not far behind. In fact, India is already the fifth largest greenhouse gas emitter of the world and is expected to become the third largest GHG emitter by the year 2015. Transport sector contributes significant amount of GHG emission [1–3] particularly in the developing and developed countries. The maximum amount of green house gases added to the atmosphere are from electricity and transportation sectors and the corresponding values are 34% and 27% [3]. Also the vehicle population throughout the world is increasing rapidly and in India the growth rate of automotive industry is one of the largest in the world. It has been anticipated quite clearly that the problem cannot be solved with the conventional fossil fuels as their reserves are limited and also the emission norms are expected to be more stringent in future [4]. This situation can be handled by using biofuels as fuels for compression ignition (CI) engines wherever possible.

Another concern is the peak oil theory, which predicts a rising cost of oil derived fuels caused by severe shortages of oil during an era of growing energy consumption. According to the “peak oil theory” [5], the demand for oil will exceed supply and this gap will continue to grow, which may cause a growing energy crisis starting between 2010 and 2020. According to Demirbas [6], a peak in global oil production may occur between 2015 and 2030. After that the production process will highly decelerate. India is the world’s fourth largest petroleum consumer after United States, China and Japan [7] which makes India dependent upon the oil exporting countries for meeting its own energy demand.

Diesel engine is the most fuel efficient combustion engine among the available ones and the transport sector mainly uses diesel fuel due to its better fuel economy and more effective power. Several countries such as USA, Germany, France, Italy, Brazil, and Indonesia are using biodiesel blended with diesel. Malaysia normally uses palm biodiesel as an alternative to diesel in their country despite the use of palm oil as edible oil also [8]. The soyabean and the rapeseed biodiesels are generally used in USA and Europe respectively [9]. In a country like India, biodiesel also can be used as alternative automotive fuel and also in other sectors as CI engine fuels. Biodiesel is a fastest growing alternative fuel. India has huge potential for biodiesel, but it is not yet explored properly to replace at least some percentage of mineral diesel with biodiesel. It will be more effective and sustainable, if biodiesel is produced from non-edible type oil seeds, like karanja (Pongamia Pinnata) and ratanjyot (Jatropha Curcus) [10–13]. The above oil seeds can be cultivated in the wastelands available in India. Another advantage of biodiesel is that it can be used in internal combustion engines in a similar fashion as petro diesel without any modification of engine geometry.

Rudolf Diesel, the father of diesel engine, demonstrated the first use of vegetable oil in compression ignition engine. He used peanut oil as fuel for his experimental engine. With the availability of cheap petroleum and appropriate methods for the refinement of crude oil to obtain petro-diesel, diesel engine started evolving. Later after 1940, vegetable oils were used again as fuel in emergency situations, during the period of Second World War.

Because of the increase in the crude oil prices, limited reserve of fossil fuels and also for the environmental concern, researchers showed renewed interest on vegetable oils for producing suitable alternate to the diesel fuel. Researchers from different corners of the world are making sincere attempts to find out the suitable alternative to diesel fuel which does not require major engine modifications. The literature is already rich with many experimental findings, but the observations are not always unidirectional. Thus, there is a need of summarizing most of the works carried out on biodiesel in the last few decades. Motivated by this, the authors have attempted to review the important works on biodiesel to get the state of the art of biodiesel production processes, its performance and emission characteristics as CI engine fuels. The authors have also presented some of the experimental results from the literature to supplement the summarization process.

2. Production of biodiesel and its properties

Biodiesel are produced from feedstocks which are renewable in nature. Since biodiesel is thought to be the alternative fuels for compression ignition engines which use diesel as the fuel, the properties of biodiesel should match with the fuel properties as specified by ASTM and/or EN as well as IS standard in India.

2.1. Production of biodiesel

For the commercialization of biodiesel as CI engine fuel throughout the world, different production processes of it should be identified and made available to the people working at grass root level. The raw materials needed for its production may vary from country to country. Keeping this in mind researchers are trying to find several ways to produce biodiesel from locally available different feedstocks such as vegetable oil – both edible and non-edible, animal tallow, waste cooking oil and algae. As the viscosity of the oils and fat derived from the above mentioned feedstocks is much higher and unsuitable for using in unmodified CI engines, the first step is to reduce its viscosity. This is done through a chemical reaction called transesterification. In this process, the triglyceride present in the oil or fat reacts with alcohol (methanol or ethanol) in the presence of a catalyst which is alkalime in nature. A catalyst such as sodium or potassium hydroxide is required. Glycerol (also called glycerin) is produced as a byproduct. The overall reaction of the transesterification process has been shown in Fig. 1 following Saka and Kusdiana [14].

Generally, methanol is used to produce biodiesel because of its availability and lower reaction time, and the final product (biodiesel) is called as methyl ester of the raw oil used. Sometimes, ethyl alcohol is also used for the production of biodiesel, and it is called as the ethyl esters of the corresponding oil. Ideally, transesterification is potentially a less expensive way of transforming the large, branched molecular structure of the bio-oils into smaller, straight chain molecules of the type required in regular diesel combustion engines. The approximate proportions of different