Biodiesel as alternative fuel for Compression Ignition engines: A review

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Abstract— This paper reviews biodiesel as an alternative fuel for automotive engine application for compression ignition (CI) engines. It also includes common significant considerations for use of alternative fuels in CI engines and the Fuel requirements for CI engines. The production, fuel properties and its effects on spray characteristics as well as combustion is discussed. Further the emission characteristics of CI engine run on biodiesel is discussed. Gradual rise in commercial use of biodiesel is expected to contribute to meeting greenhouse gas (GHG) emission in the future.

Index Terms— Alternate Fuels, Bio Diesel, Combustion, Compression Ignition Engine, Emission, Spray Characteristics.

1 Introduction

Internal combustion (IC) engines are widely accepted as power sources for passenger and commercial vehicles, electricity power generation, and in other industrial fields, owing to their high power density and high efficiency. They rely on combustion process which converts the chemical energy of fuel is directly into heat. We greatly depend on fossil fuels for meeting our energy demands. Forecasts have been made for possible fossil fuel exhaustion ranging from few decades to couple of centuries. [1]

Two primary fuels used in today's I C Engines are Diesel, in Compression Ignition CI engines and Gasoline in Spark Ignition engines. Despite the long history of a steady supply chain and the availability of gasoline and diesel as conventional automotive fuels in the market, the search for alternative fuels gradually started to emerge back in the 1980s. [2]

2 Alternative fuels for CI engines

Alternative fuels are those fuels other than conventional gasoline and diesel fuels, covering a wide variety in terms of final forms and manufacturing sources. For example, ethanol fuel is considered an alternative for SI engines. Other alternative fuels are non-conventional fuels, including alcohols, including blends with gasoline; natural gas and liquefied fuels domestically derived from natural gas; liquefied petroleum gas (LPG); coal-derived liquid fuels; hydrogen (H2); biodiesel (B100); fuels derived from biological materials; and fuel that is substantially non-petroleum that produce substantial energy security and environmental benefits. [3]

Another aspect of using bio fuels is the emissions resulting from fuel combustion in IC Engines.

Use of alternate renewable biofuels can form a CO2 life cycle, which can contribute to total CO2 emission mitigation.

For example, a full life cycle assessment (LCA) that was performed to compare the GHG impacts of conventional fuels and biofuels showed that the biofuels derived from vegetable oil, as well as corn- and wheat-based ethanol when they are produced using biomass as a primary energy source, would cut GHG emissions on a well-to-wheel (WTW) basis to about half of that of conventional fuels [4]. This analysis took into account all the GHG emissions generated from their production, transport and storage, as well as emissions associated with their use in vehicles, subtracted by the amounts of CO2 taken in from the atmosphere by the biomass in its growth phase. Biofuels accounted for around 3% of the total global transportation fuels by 2012.

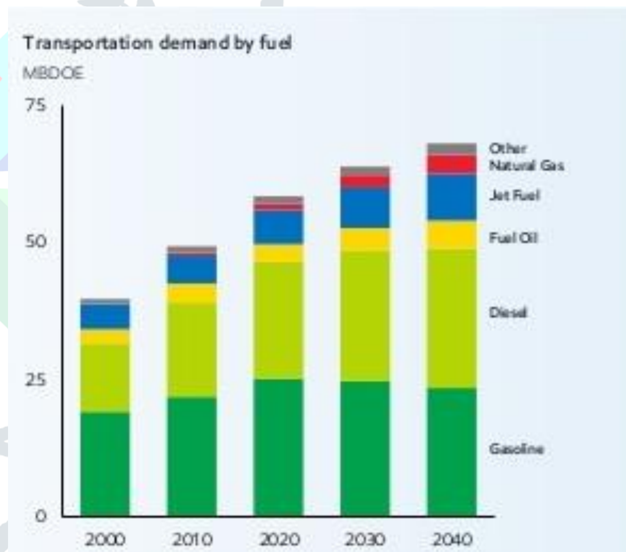

Fig. 1. Global transportation demand by fuel [5].

Figure 1 shows that as the energy demand in the transportation sector keeps increasing in the near term, the ratio of biofuel to the total amount of fuel is also expected to increase [5].

The balance between fuel efficiency and hazardous emissions has always been an important issue in the engine research. The wide use of renewable biofuels or alternative fuels can also directly contribute to improvements in engine performance and emission characteristics. Since the combustion of fuel is determined by the air–fuel interaction, the unique properties of alternative fuels can be advantageously utilized during the engine combustion process. Research is being conducted worldwide on the application of alternative fuels to IC Engines to reveal their potentials.

Some of the common significant considerations for use of alternative fuels in CI engines are:

1. Combustion properties (chemical properties, such as octane and cetane number)
2. Physical properties (spray or mixture formation for combustion, and engine operability over a wide range of temperatures)
3. Lower heating value (LHV)
4. Compatibility (including approval by engine and vehicle manufacturers and costs)
5. Manufacturing cost and infrastructures

3 Fuel requirements for CI engines

Diesel fuels are the conventional fuels for CI engines. In CI engines the fuel is directly injected into the cylinder, and it auto-ignites due to the high cylinder temperature toward the end of the compression stroke. Therefore, the auto-ignition ability of the fuel is vital for its use in CI engines. Some important criteria to measure the quality of CI engine fuels are: [6]

1. Cetane number
2. Boiling point
3. Narrow density and viscosity spread
4. Low aromatic compounds (particularly polyaromatic compounds) content

The alternative fuels having various physicochemical properties may result in different engine performance and engine-out emissions, due to different mixture formation processes.

4 Biodiesel as fuel for CI engines

Biodiesel is an alternative fuel based on bio- originated feedstock. A range of oil feedstock can be processed into fuel. These include vegetable oil, animal fat, and waste cooking oil. Rapeseed oil and soybean oils are the most commonly used biodiesel raw materials. Recently the reutilization of waste cooking oil has gained attention, because it can reduce dumping problems [7]. Waste cooking oil derived biodiesel showed the lowest WTW GHG emissions, with around 82% GHG emissions saving compared to conventional diesel [8]. Preferences of feedstock differ in different countries, based on regional production cost, environmental impact, and agricultural strategies. The focus of second generation biodiesel is the use of agricultural residues.

Blends with small portions of biodiesel do not require major modifications in the engine, because the physiochemical characteristics of biodiesel are generally similar to those of diesel.

5 Biodiesel properties and their effects on combustion

The LHV of biodiesel is less than that of conventional diesel fuel, while it generally has a higher cetane number. Biodiesel also exhibits a higher flash point compared to conventional diesel, which is advantageous for fuel storage and transportation safety. Biodiesel has higher cloud and pour points compared to conventional diesel, due to the higher portion of saturated fatty acids. Cloud and pour points show the lowest temperatures, at which a fuel can be pumped, before turning into a wax of crystals. Higher cloud and pour points mean disadvantages in cold start, and represent an obstacle to the use of blends with large biodiesel portions. [9]

The lower LHV of biodiesel may become an obstacle to achieving maximum torque under full load condition. Tests performed with various soybean biodiesel blends from B10 to B100 showed that the average maximum brake torques decreased by 1.57%–4.7%. The indicated specific fuel consumption (ISFC) of the biodiesel was up to 15% higher than that of the diesel fuel. The start of combustion (SOC) for pure biodiesel or biodiesel blends is advanced compared to conventional diesel fuel, due to their higher cetane number [10].

Biodiesel is denser and more viscous. It has higher surface tension, compared to conventional diesel. The viscosity of the biodiesel slowed down the valve speed, and decreased the flow performance of the injector [11].

Macroscopic spray images of waste cooking oil (WCO) biodiesel and palm biodiesel in a constant volume chamber revealed that the biodiesels had longer injection delay and liquid length, while the spray angle, area and volume were smaller than those of conventional diesel. The higher viscosity of biodiesel led to a smaller spray angle, and thus poor air entrainment, and higher SMD. However, the local equivalence ratio, which is dominant for soot formation, was lower than that of diesel. The equivalence ratio along the axial direction of biodiesel spray showed leaner value compared to that of diesel, due to the presence of inherent oxygen atoms in the fuel molecule [12].

The poor evaporation characteristics hindered the early formation of ignitable air–fuel mixture due to poor atomization and evaporation of biodiesel blends. As a result the peak heat release rate of biodiesel blends was also lower than that of diesel fuel at higher engine load.

The U.S. EPA produced a review of published biodiesel emissions data for heavy-duty engines. Figure2 summarizes the overall results for CO, HC, NO*x* and PM emissions. As the biodiesel concentration in diesel increased, a clear trend of reduced CO and HC emissions was observed which means higher combustion efficiency. These results were due to the oxygenated nature of biodiesel, where more oxygen was available for burning, and for reducing the emissions in the exhaust [13].

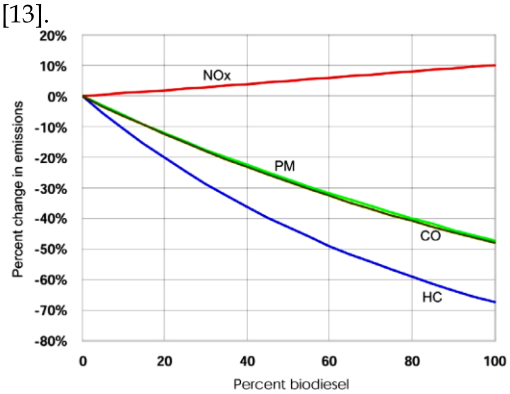

Fig.2. Average emission impacts of biodiesel fuels in compression ignition engines.

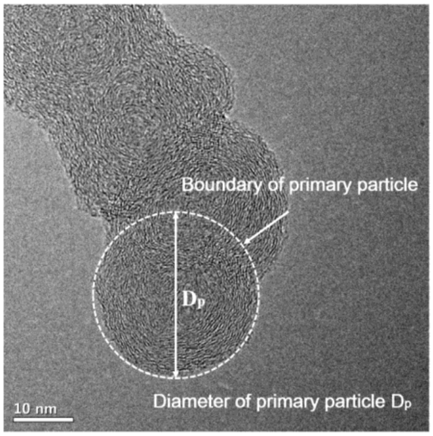

Fig. 3. (a) Transmission electron microscopy image of WCO biodiesel soot particles [14].

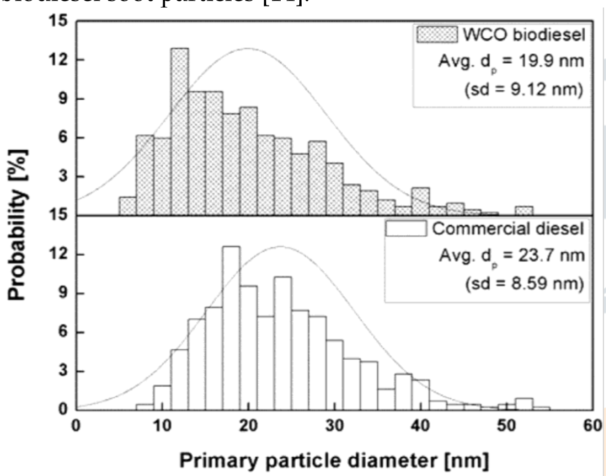

Fig. 3. (b) Comparison of primary particle size between WCO biodiesel and diesel [14].

Figure 3 (a) and (b) show the comparison of primary particle size from WCO biodiesel and diesel soot. The soot particles from the biodiesel were composed of smaller primary particles than those from conventional diesel.

Various studies have attempted to explain the increase in NO*x* emissions when using biodiesel fuels. One persuasive explanation is the increased flame temperature with biodiesel, caused by a reduction in the heat dissipation through radiation as a consequence of the lower amount of soot emitted [14].

5 Conclusion

The major portion (up to 90%) of propulsion for transportation will still rely on the internal combustion engine (ICE), even up to 2040. Research on alternative fuels are made not only to seek alternative solutions to energy security and sustainability, but also to seek benefits that alternative fuels can provide to engine efficiency improvement and emission reduction. Gradual penetration of biodiesel as an alternate fuel in CI engines is expected to contribute to meet greenhouse gas (GHG) emission norms in the long term.

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