

Biodiesel as an alternative fuel for CI engines: environmental effect

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Abstract

Biodiesel will play an increasing role in fulfilling the world's energy requirement. The world has experienced negative effect from the fossil fuel such as global warming and acid rain etc. With the increase in consumption of biodiesel, its impact on environment has raised a discussion around the world. Energy requirement of the world will increase in coming future and is projected to increase by 50% from 2005 to 2030. The paper presents the results of biodiesel combustion emission on the environment.

Keywords: Biodiesel, emission, environment, energy.

Introduction

Most of our energy requirements are met by fossil fuels for good technological reasons. Depletion of the petroleum reserves is a big concern, it is estimated that the world resources of oil will be exhausted within 50 years. Environmental concern about air pollution caused by the combustion of fossil fuels has also lead to serious implications (Oman, 2003). The diesel engine is main prime mover compare to any other engine in transportation, power generation and many miscellaneous applications i.e. in industries and agriculture (Agnes *et al.*, 2007). The major pollutants from diesel engine are smoke, particulate matter (PM), carbon monoxide (CO), nitrogen oxides (NO_x) and unburnt hydrocarbon (UBHC) (Raja *et al.*, 2003). Incomplete combustion increases the pollution level as compared to proper combustion (Jeffrey & Nancy, 2009). Due to reliance on transport consumption of fossil fuels has increase drastically and the world witnesses long-term damage to the climate (Duncan & Youngquist, 1999). As transport is one of the few industrial sectors where emissions are still growing and this fact has made transport a major contributor of greenhouse gases (GHGs) (WBCSD, 2001). Generally carbon dioxide, methane, nitrous oxide, ozone etc are known as greenhouse gases. These gases interact with solar terrestrial radiation and causing imbalance on the Earth's climate system and increases earth surface temperature. The significant effect of global warming has been felt for last two decades. This rise in earth surface temperature is known as global warming.

Reducing the emission of these gases will lead to the solution to the climate change problem. Different methods of reducing the climate change problem could be increasing the use of carbon capture and storage (CCS) techniques, increasing energy efficiency and promoting the use of renewable energy and carbon free fuels. Different methods, like modifying the engine design, treating the exhaust gas and by fuel modification exhaust

gas emission of an engine can be reduced (Sethi & Salaria, 2004). To overcome the problems associated with the use of petroleum derived fuels, it is urgently needed to develop a renewable energy source of energy which must be environmentally clean (Huang & Wu, 2008, Marchetti *et al.*, 2007). One of the potential substitutes to the fossil fuel is vegetable oil (Hanumantha Rao *et al.*, 2009; Math *et al.*, 2010). Most important aspect of these fuels is that they are biodegradable, non toxic and above all has less emission (Padma *et al.*, 2005; Meher *et al.*, 2006). The main obstacle in using the vegetable oil as fuel is its high viscosity. Trans-esterification of the vegetable oils is mainly used to decrease the viscosity of the vegetable oil; however, other properties of the oil remain same and this new fuel was called as biodiesel (Leon *et al.*, 2004). In fact biodiesel contains no petroleum, even though it can be used in pure form in the compression ignition engine with little or no engine modification, or it can be used in blend with petroleum diesel at any level (Pugazhvadivu *et al.*, 2009).

World emission scenario

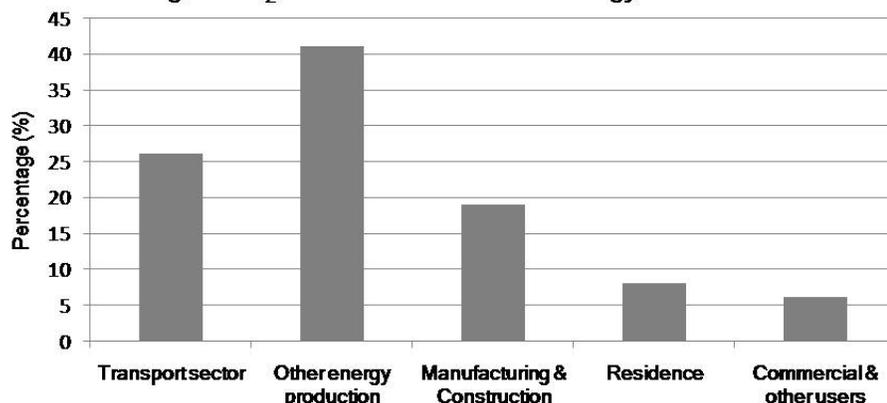
The world energy consumption was around 382 quadrillion BTU (British thermal units) in 1999 and the energy usage in 2005 is estimated as 462 quadrillion Btu. The energy consumption is projected to increase by 50% from 2005 to 2030 (International energy outlook, 2001; International energy outlook, 2008). The transport sector energy consumption was about 42 EJ in 1971 and increases to a value of 87 EJ in 2000 with an annual growth rate of 2.6%. Petroleum is the primary source of transportation energy, fueling 97% of transportation energy usage in the United States (Thomas & Ragasen, 2001). In 2005, world liquid fuel consumption was 83.6 million barrel oil equivalent per day. From 2005 to 2030, total world liquid consumption is expected to increase by 35% and the transport sector will account for nearly three fourth of the expected increase (International energy



outlook, 2008). Among all transport means, road transport has the biggest share of energy consumption and it accounts for 81% of the total energy used by the transport sector (Jeffrey & Nancy, 2009). With the view that more energy consumption in transport sector makes

One of the reasons of the ground level formation of ozone is NO_x , which cause serious respiratory problem. NO_x also contribute to the formation of acid rain. Particulate present in the exhaust is a complex mixture of organic and inorganic substance (EPA, 1998). Particulate matters (PM) are suspended in air and it consists of solid, liquid or both. Generation of the PM is the result of anthropogenic process, mainly from fuel consumption. Bronchitis in children and increase in the risk of cardio vascular and respiratory problems are the effect of PM emission. SO_2 is a colourless gas with pungent, irritating order and it is one of the factors causing the acid rain (Ando *et al.*, 2000). High level of SO_2 in ambient air along with high concentration of PM has shown increased death rate during prolonged period of inversion (Green, 1969).

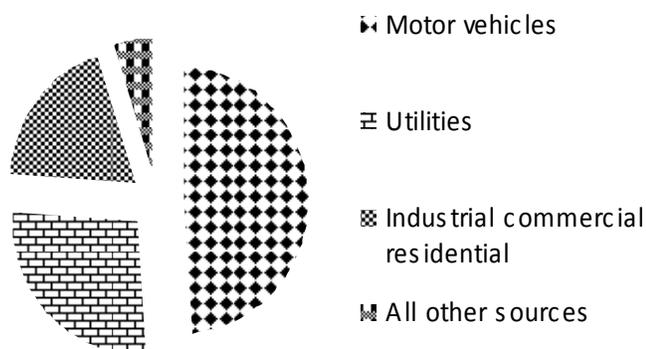
Fig. 1. CO_2 emission from different energy sources



it one of the major contributors of anthropogenic emission. Broadly the impact of environmental pollution can be grouped in two categories local issue concern with the health related problems and global issue related with acid precipitation, photochemical smog and climate change. Transport sector in fact account for one fourth of the world's energy related carbon dioxides emission as shown in the Fig. 1 (Chapman, 2007).

CO_2 is considered as one of the major sources of greenhouse effect. The level of CO_2 in the atmosphere has increases sharply in the post industrial era. During 1999-2004 the growth rate of CO_2 emission was found as 1.8 ppmv/year. The concentration of the CO_2 was 377 ppmv (parts per million in volume) in 2004 (Quadrelli & Peterson, 2007). Conventional vehicles emit more than 20 kg of GHG for every 100 km distance travel. Among these polluting agents, NO_x is the poisonous gas producing the most injuring effects (Marco & Poncia, 1998). Motor vehicle is mostly accounts for the formation of NO_x as shown in Fig. 2. When the fuel is burned, at high temperature the inactive nitrogen reacts with O_2 and nitrogen oxide is formed.

Fig. 2. NO_x emission from different sources (EPA, 1998)



Impact of biodiesel on emission

Carbon dioxides (CO_2)

Generally the emission of carbon dioxide increase with increasing load for both biodiesel and diesel (Jeong *et al.*, 2006). Increasing percentage of biodiesel in the blend, decrease the emission of CO_2 . For B-20 biodiesel the CO_2 emission is comparable with diesel, and for B-40 and B-60 biodiesel the emission is less than diesel. This may be because of the fact that biodiesel is a low carbon fuel and also biodiesel has low elemental ratio of carbon to hydrogen as compare to diesel. However, if the concentration of biodiesel increases further an increase in CO_2 emission is noted. B-100 emits more amount of CO_2 as compare to that of diesel. This indicates complete combustion of fuel which is also indicated by the higher exhaust gas temperature (Sureshkumar *et al.*, 2008). Makareviciene *et al.* (2003) has shown that biodiesel molecule contains carbon of biological nature. Every molecule of RME (Rapeseed oil methyl ester) contains 94.73% carbon of biological nature. REE (Rapeseed oil ethyl ester) contains almost 100% carbon of biological nature. Thus all CO_2 released by the burning of biodiesel has no adverse effect on greenhouse gas formation. However in case of diesel, all CO_2 releases are contributing to the formation of greenhouse effect. The advantage of biodiesel lie in the fact that CO_2 level is kept in the balance as the crops of biodiesel are readily absorbing the CO_2 , thus biodiesel are CO_2 neutral (Maunder *et al.*, 1995; Ramadhas *et al.*, 2005).

Carbon monoxides (CO)

Carbon monoxide is a poisonous gas and it is perfect emission product assessor. More CO emission indicates more loss of thermal energy. Generally CO emission is caused due to poor mixing of fuel and air, locally rich zone and incomplete combustion of fuel. When a homogeneous mixture of fuel and air burned either at

stoichiometric homogeneous air-fuel ratio mixture, or the lean side of stoichiometric, the exhaust contains negligible concentration of CO. However with the air fuel ratio more than stoichiometric value, the CO concentration in the emission increases (Ramadhas *et al.*, 2005). Nabi *et al.* (2008) has shown in his experiment that for biodiesel mixtures CO emission was lower than that of diesel fuel. Compare to neat diesel fuel, 30% biodiesel mixtures reduced CO emissions by 24%. CO emitted by all biodiesel blends is lower than the ones for the corresponding diesel fuel case. This reduction in CO increases as the percentage of biodiesel in the blend increases (Rakopoulos *et al.*, 2008, Gattamaneni *et al.*, 2008; Ghobadian *et al.*, 2009). Usta *et al.* (2005) has shown in his experiment that almost at all loads, engine emits less CO, when biodiesel is used as fuel as compare to diesel. The reduction in CO emission is more significant at lower speed and full load conditions. The difference may be due to the fact that, at full load and low speed sufficient oxygen is not available for the combustion in the cylinder, the oxygen contain in the biodiesel provide oxygen for the complete combustion, hence reduction in the CO emission. But at partial load, enough oxygen is available due to lean mixture and there is no stable variation. This causes practically not much difference in the CO emission for the different fuels. Again at very low load (25%) the CO emission of biodiesel is significantly lower than diesel. At lower load, low temperature of combustion chamber, prevents the conversion of CO into CO₂. Thus at lower load, the less emission of CO may be attributed to the fact that the biodiesel contains less carbon in comparison to diesel. A detail investigation of the behavior of biodiesel reveals the CO emission is lower for lower percentage of (up to 40-60%) of the biodiesel and higher for higher biodiesel in the blends. At low concentration of the biodiesel in the blend, the inbuilt oxygen helps in complete combustion of the fuel. But high concentration of biodiesel increases the viscosity of the fuel and there is a slight increase in the specific gravity. This causes poor atomization of biodiesel which results in poor combustion of fuel. This suppresses the complete combustion process and as a result the emission of CO increases (Makareviciene *et al.*, 2003; Sureshkumar *et al.*, 2008).

Nitrogen oxides (NO_x)

Most of the researchers have shown in their work that emission of NO_x increases with the use of biodiesel. Conversion of atmospheric nitrogen into NO_x depends upon the temperature, as the high activation is required for the conversion during reaction. Hence, NO_x formation depends generally on the exhaust gas temperature (EGT). It was observed that exhaust gas temperature increases around 5°C with every 20% increase in the proportion of biodiesel in the blend (Raheman & Ghadge, 2008). Rahman & Ghadge (2007) conducted experiment on a single cylinder, four stroke

and water cooled engine with Mahua oil. It was found out that the increasing percentage of biodiesel in the fuel blend, increases the emission of NO_x (within 6%). The emission of NO_x was 17 to 50 ppm for varying concentration of biodiesel in the blend; while for diesel the emission vary from 17 to 44 ppm (Jeong *et al.*, 2006). The most acceptable explanation for is that higher bulk modulus of the compressibility of the biodiesel and its blends causes some advance in the injection timing of the certain injection system. Hence a faster transfer of the pressure wave from injection pump to the nozzle take place, therefore the needle lifted in advance. As a result, at the same crank angle, the injection of the biodiesel in the combustion chamber start earlier with high pressure, and at the same time mass of the fuel injected is more for biodiesel than diesel due to its high density. The amount of the fuel undergoing premixed combustion at early stage increases due to increased injection pressure. Combined effect of both, causes higher temperature and pressure inside the cylinder. The increased amount of fuel delivery inside the cylinder causes shorter time period for the combustion and probably lesser time for the cooling of the engine; this resulted in the rise in the temperature inside the cylinder (Tsolakisa *et al.*, 2007). The oxygen contain in the biodiesel facilitate in the oxidation of the nitrogen present in the air resulting in the formation of the NO_x (Ramadhas *et al.*, 2005). Monyem *et al.* (2001) has found during his test, that the NO_x formation is generally linearly co-related to the actual start of the combustion.

UBHC (Unburnt hydrocarbon)

Hydrocarbon (HC) emission occurs due to incomplete combustion of fuel. Better atomization, mixing and proper ignition results in efficient combustion which depends upon the physical properties of fuel. The emission of HC decrease as the diesel is substituted by biodiesel. Puhan *et al.* (2005) has reported that the reduction of HC in case of biodiesel is an around 63%. Monyem *et al.* (2001) has experimented biodiesel and oxidized biodiesel, result shows that a deduction in HC emission level for all fuel blends at all injection timing and at all loading condition as compare to diesel. The oxidized biodiesel exhibits maximum reduction in the HC emissions. The oxidized biodiesel reduces the emission of HC by 6% to 9% compare to the unoxidized biodiesel. At light load engine condition, the emission of HC is reported to be reduced by 6-66% compare to diesel. The oxidized biodiesel reduces the HC emission by 20-29% more than unoxidized fuel. Similar result was reported by Makareviciene *et al.* (2003), when the fuel used is methyl ester and ethyl ester of rapeseed oil. The HC emission was decreased by 74% with pure RME (Rapseed oil methyl ester) and 53% with pure REE (Rapseed oil ethyl ester) as compare to diesel. The HC emission decrease as the ignition delay gets shorter. Cetane number of biodiesel is higher than diesel, due to this it exhibits a

shorter delay period which contributes to better combustion of fuel resulting in low emission of HC. Other reason can be the oxygen molecules present on the structure of biodiesel which helps in complete combustion of the fuel and hence decrease in HC emission (Sureshkumar *et al.*, 2008).

Smoke

Smoke formation occurs primarily in the fuel rich zone of the cylinder, at high temperature and pressure. Smoke formation can be controlled by applying partially oxygenated fuel, which reduces locally over-rich regions (it is the region where the fuel is more than required; ie more than required air fuel ratio) (Puhan *et al.*, 2005). When the engine runs under-load at WOT (Wide open throttle), maximum fuel is injected to supply maximum power, which is a rich mixture. Thus at higher load, an increased fuel-air ratio fuel is injected in large quantities and much of the unburnt fuel escape with the exhaust resulting in maximum smoke emission. Jeong *et al.* (2006) shows that under less than 75% load condition, smoke formation was less and it increases with the increase in load. Also, the difference in smoke level between the biodiesel and diesel is more significant at higher load in comparison to lower load. For all tested engine condition, the smoke emission decreases consistently with the increasing amount of biodiesel in the blend. The smoke reduction with pure biodiesel was around 26.05-28.73% as compared diesel. The maximum and minimum reduction in smoke level at different load was found as 46% and 5% respectively by Rahman *et al.* (2007). Also, The average smoke density in percentage were 7.8, 14.8, 20.1, 24 and 34.1 for the diesel while for biodiesel the smoke densities were 8.2, 9.0, 12.0, 14.1 and 22.1 at no load, 25, 50, 75 and 100% load condition. The reduction in smoke level at higher load may be due to better combustion at higher load and more biodiesel is required. Other reason may be the difference in chemical structure and presence of oxygen in the biodiesel.

Conclusion

The environmental benefits of biodiesel can be significant in terms of reductions in the emission of greenhouse gases, and reduction of other pollutants e.g. acid rain, photochemical smog etc. There is growing recognition that the use of biodiesel in large commercial systems based on sustainability, existing resources and residues can help to our natural resources.

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