STUDY OF BIODIESEL AS A FUEL FOR CI ENGINES AND ITS ENVIRONMENTAL EFFECTS: A RESEARCH REVIEW

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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. A review of literature available in the field of vegetable oil usage has identified many advantages. Vegetable oil is produced domestically which helps to reduce costly petroleum imports, it is biodegradable, nontoxic, contains low aromatics and sulphur and hence, is environment friendly. The biodiesel shows no obvious NOx emission difference from the pure diesel fuel at low and medium engine loads. Biodiesel blend ratios have little effect on the NO/NOx ratio at medium and high engine loads. The CO emission of biodiesel increases at low engine loads. The HC emissions show a continuous reduction with increasing biodiesel blend ratios. There is a good correlation between smoke reduction and the ratio of the biodiesel blends. The addition of biodiesel fuel increases formaldehyde emission. A series of engine tests, with and without preheating have been conducted using each of the above fuel blends for comparative performance evaluation. The results of the experiment in each case were compared with baseline data of diesel fuel. Significant improvements have been observed in the performance parameters of the engine as well as exhaust emissions, when lower blends of karanja oil were used with preheating and also without preheating. Karanja oil blends with diesel (up to K50) without preheating as well as with preheating, can replace diesel for operating the CI engines.

KEYWORDS: *Biodiesel, emission, environment, energy, precipitation, stoichiometric.*

I. 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[7]. 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[13]. The major pollutants from diesel engine are smoke, particulate matter (PM), carbon monoxide (CO), nitrogen oxides (NO_x) and unburnt hydrocarbon (UBHC)[15]. Incomplete combustion increases the pollution level as compared to proper combustion[6]. Due to reliance on transport consumption of fossil fuels has increase drastically and the world witnesses long-term damage to the climate[20]. 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)[5]. 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 reduce[18]. 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[1]. One of the potential substitutes to the fossil fuel is vegetable oil[10]. Most important aspect of these fuels is that they are biodegradable, non toxic and above all has less emission[8]. 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[2]. 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[10].

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[1]. 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[20]. 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[2]"Biodiesel and environmental impact"[2]. 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[10].With the view that more energy consumption in transport sector makes 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[14].

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[13]. 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[3]. Motor vehicle is mostly accounts for the formation of NO_x. When the fuel is burned, at high temperature the inactive nitrogen reacts with O_2 and nitrogen oxide is formed.

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[3]. 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. Bronchits in children and increase in the risk of cardio vascular and respiratory problems are the effect of PM emission. SO_2 is a colorless gas with pungent, irritating order and it is one of the factors causing the acid rain[5]. High level of SO_2 in ambient air along with high concentration of PM has shown increased death rate during prolonged period of inversion[3].

Impact of biodiesel on emission

1.1 Carbon dioxides (CO_2)

Generally the emission of carbon dioxide increase with increasing load for both biodiesel and diesel[4]. 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 concentrations 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[19]. Biodiesel molecule contains carbon of biological nature. Every molecule of RME (Rapeseed oil methyl ester) contains 94.73% carbon of biological nature[14]. 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[17].

1.2 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 "Biodiesel and environmental impact" [2] 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[11]. 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[12]. This reduction in CO increases as the percentage of biodiesel in the blend increases[10]. Almost at all loads, engine emits less CO, when biodiesel is used as fuel as compare to diesel[11]. 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 CO_2. 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 [19].

1.3 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[14]. On a single cylinder, four stroke and water cooled engine with Mahua oil[14]. 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[6]. 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[7]. 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 [17].The NO_x formation is generally linearly co-related to the actual start of the combustion[8].

1.4 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.The reduction of HC in case of biodiesel is an around 63%[12]. 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[12]. 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 found when the fuel used is methyl ester and ethyl ester of rapeseed oil[21]. 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 "Biodiesel and environmental impact"[2] 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[19].

1.5 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)[12]. 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. Under less than 75% load condition, smoke formation was less and it increases with the increase in load[18]. 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[6]. 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.

II. C. I. ENGINES

The engine used in this study was a light-duty, direct-injection, four-cylinder, and four-stroke, turbocharged, intercooled diesel engine with a high-pressure common-rail fuel system. The common-rail fuel injection system was from Bosch, and has a high-pressure (over 1000 bar) fuel rail. The engine has a 3.3-L displacement, with a rated power output of 79 kW at 3200 rpm and a peak torque output of 275 N m at 2000 rpm. The test engine was coupled with an electric dynamometer, and an AVL PUMA test bed automation system was used for running and controlling the test engine. The regulated gaseous emissions, including NOx, CO and HC, were measured by an AVL AMA i60 gas analyzer. In the analyzer, the analysis of the measurement gas is implemented by means of a chemiluminescence detector (CLD) for NOx/NO, a flame ionization detector (FID) for HC, and a non-dispersive infra-red analyzer (NDIR) for CO and its uncertainties of the three measuring devices are 2.6%, 9.2% and 5.5%. Exhaust smoke was measured by an AVL 415 smoke meter, and its standard error is 1.5%. The unregulated gaseous emissions, including formaldehyde, acetaldehyde, acetone and toluene, were measured by an AVL SESAM (System for Emission Sampling and Measurement) FTIR (Fourier Transform Infrared) analyzer, and measuring limits for the four gaseous emissions are 0.5 ppm, 1.0 ppm, 1.0 ppm and 1.0 ppm. The SESAM FTIR analyzer integrates an FTIR spectrometer with a sampling system, including a sampling pump and heated sample lines. Samples were collected from the exhaust emissions of the diesel engine.

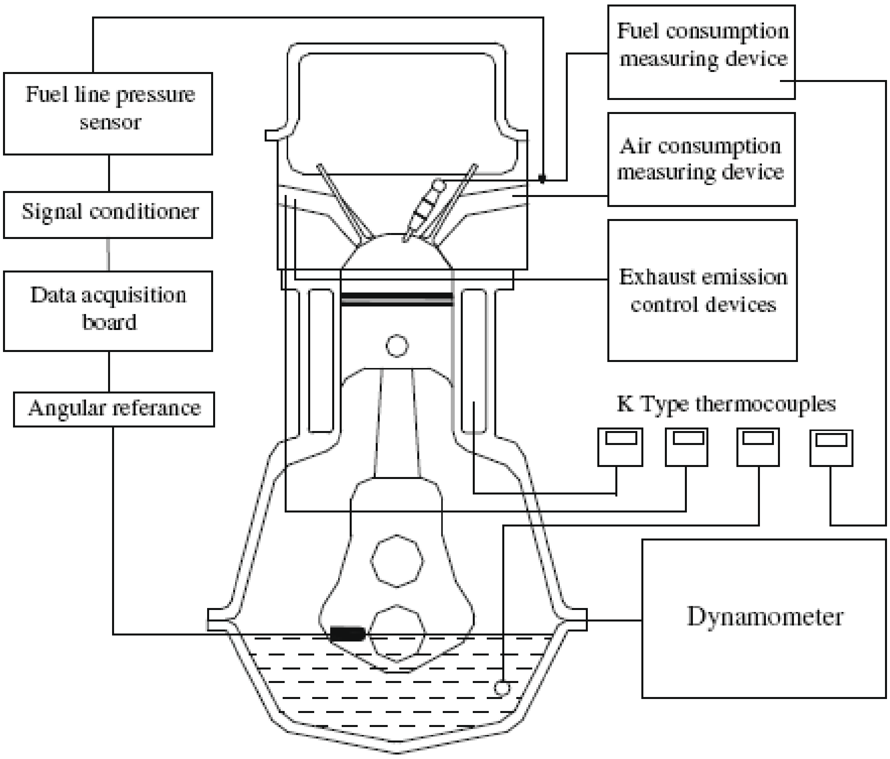

Figure 1 CI Engine

2.1 Biodiesel Production Process

Biodiesel is a mixture of fatty acid alkyl esters obtained by transesterification (ester exchange reaction) of vegetable oils or animal fats. These lipid feedstocks are composed by 90–98% (weight) of triglycerides and small amounts of mono and diglycerides, free fatty acids (1–5%), and residual amounts of phospholipids, phosphatides, carotenes, tocopherols, sulphur compounds, and traces of water . Transesterification is a multiple step reaction, including three reversible steps in series, where triglycerides are converted to diglycerides, then diglycerides are converted to monoglycerides, and monoglycerides are then converted to esters (biodiesel) and glycerol (by-product). Even though 350 oil-bearing crops are identified, only few are potential biodiesel like sunflower, rapeseed, palm and jatropha. It is observed that biodiesel has similar combustion characteristics as diesel and also found that the base catalyst performs better than acid catalyst and enzymes. It is also inferred that the engine performance was inferior when using vegetable oil/ diesel blend as the high viscous oil caused injector coking and contaminated the lubricating oil. The tests with refined oil blends indicated considerable improvement in performance. The emission of unburnt hydrocarbon from the engine was found to be more on the all the fuel blends as compared to diesel. The emission of oxides of nitrogen from the engine found to be higher on the all fuel blends as compared to diesel.

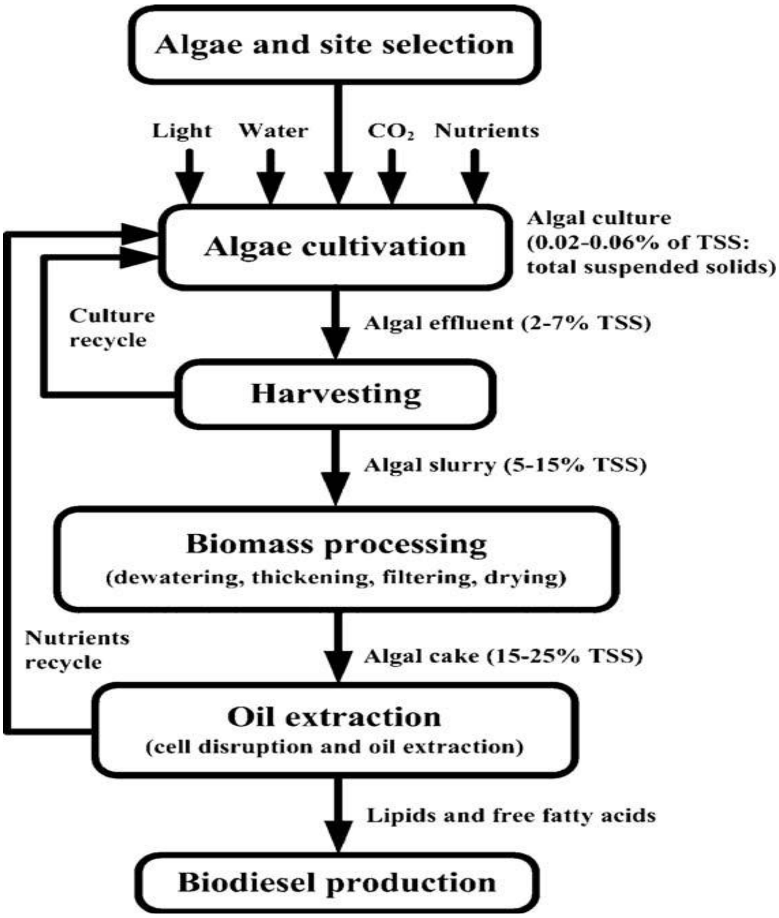

Figure 2 Biodiesel Production Process

III. RESULTS AND DISCUSSION

Biodiesel blend ratios have little effect on the NO/NOx ratio at medium and high engine loads. CO emissions for biodiesel, from B5 to B100, increase at low engine loads, and remain unchanged or decrease at high engine loads. The HC emissions show a continuous reduction with increasing biodiesel blends at all test operating conditions. Smoke emissions have a consistent decreasing trend with increasing biodiesel blends. Smoke reduction shows a good correlation with biodiesel blend level, which indicates that the biodiesel blend level has a direct effect on engine smoke emissions.
The addition of biodiesel increases formaldehyde emissions. Except for the B20 fuel, the formaldehyde emissions of the other four biodiesel fuels show a clear increasing trend with biodiesel addition. Compared to pure diesel fuel, acetaldehyde emissions for the B5 fuel show a distinct increase. However, the acetaldehyde emissions of the B10 and B20 fuels show a decrease. Acetaldehyde emissions of the B100 fuel are lower than the pure diesel fuel at low and medium engine loads, but are higher at high engine loads. Overall, acetone emissions are very low, with all values lower than 3 ppm. However, acetone emissions increase when compared to pure diesel fuel.

IV. CONCLUSION

It can be concluded that 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. Compared to pure diesel fuel, NOx emissions from the biodiesel fuels exhibit no obvious change at low and medium engine loads.

V. FUTURE WORK

The present work will help in providing the base for future studies that will be carried out for reducing the various emissions i.e. CO_2, CO, NOx, UBHC, SMOKE. Other blending combinations with diesel may be carried out and results can be compared with this research work.

REFERENCES

[1]. International energy outlook (2008) U.S. Department of Energy, Energy Information Administration, Office of integrated analysis and forecasting, Washington, DC.
[2]. J.Sci.Technol. 3 (3), 318-321. Domain site: http://www.indjst.org.
[3]. Maunder DH, Brown KA and Richards KM (1995) Generating electricity from biomass and waste. Power Engg. J. 9(4), 188-196.
[4]. Meher LC, Sagar DV and Naik SN (2006) Technical aspects of biodiesel production by transesterification-a review. Renew Sustainable Energ. Rev. 10, 248-268.
[5]. Monyem A, Van Gerpen JH and Canakci M (2001) The effect of timing and oxidation on emission from biodiesel fuels engines. Trans. Am. Soc. Agri. Engrs. 44(1), 35-42.
[6]. Nabi N, Rahman M and Akhter S (2009) Biodiesel from cotton seed oil and its effect on engine performance and exhaust emissions, Appl. Therm. Engg. 29(11-12), 2265-2270.
[7]. Oman H (2003) Energy sources for the worlds post petroleum era. IEEE Aerospace Elec. Sys. 18, 35–39.
[8]. Padma V, Sharma S and Kumar A (2005) Liquid fuel from biomass: An overview. J. Scientific Ind. Res. 64, 822-831.
[9]. Predd P (2005) A market for clean air: China adopts emissions trading to curb pollution. IEEE Spectrum. 42 (6), 60.
[10]. Pugazhvadivu M and Rajagopan S (2009) Investigations on a diesel engine fuelled with biodiesel blends and diethyl ether as an additive. *Indian J.Sci.Technol.* 2 (5), 31-35. Domain site: http://www.indjst.org.
[11]. Puhan S, Vedaraman N, Boppana VB, Ram GS and Jeychandran K (2005) Mahua oil (Madhuca Indica seed oil) methyl ester as biodiesel-preparation and emission characterstics. Biomass Bioenerg. 28(1), 87-93.
[12]. Puhan S, Vedaraman N, Sankaranarayanan G and Bharat Rama BV (2005) Performance and emission study of Mahua oil (Madhuca indica oil) ethyl ester in a 4-stroke natural aspirated direct injection diesel engine. Renew. Energ. 30, 1269-1278.
[13]. Quadrelli R and Peterson S (2007) The energy–climate challenge: Recent trends in CO_2 emissions from fuel combustion. Energ. Policy. 35, 5938-5952.
[14]. Rahman H and Ghadge SV (2007) Performance of compression ignition engine with mahua (Madhuca indica) biodiesel. Fuel. 86, 2568–2573.
[15]. Raja A, Sarvanan B, Sitharthaseelan J, Sudhkar S and Sarvanan GS (2003) Fumigation of methanol in diesel engine through recovering waste heat from exhaust gas with fuel additives. IE (I) J. 83, 153–157.
[16]. Rakopoulos CD, Rakopoulos DC, Hountalas DT, Giakoumis EG and Andritsakis EC (2008) Performance and emissions of bus engine using blends of diesel fuel with biodiesel of sunflower or cottonseed oils derived from Greek feedstock. Fuel. 87(2), 147–157.
[17]. Ramadhas AS, Muraleedharan C and Jayaraj S (2005) Performance and emission evaluation of a diesel engine fueled with methyl esters of rubber seed oil. Renew. Energ. 30, 1789–1800.
[18]. Sethi VP and Salaria KS (2004) Exhaust analysis and performance of a single cylinder engine run on dual fuels. IE (I) J. 85, 1- 7.
[19]. Sureshkumar K, Velraj R and Ganesan R (2008) Performance and exhaust emission characteristics of a CI engine fueled with Pongamia pinnata methyl ester (PPME) and its blends with diesel. Renew. Energ. 33(10), 2294–2302.
[20]. Thomas HO and Ragasen P (2001) Trends in transportation sector technology energy use and greenhouse gas emissions. Proc. of the IEEE, 89(12), 1837-1847.
[21]. Usta N (2005) An experimental study on performance and exhaust emissions of a diesel engine fuelled with tobacco seed oil methyl ester. Energ. Convers. Mgmt. 46, 2373-2386.

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