EFFECTIVE UTILIZATION OF B20 BLEND WITH OXYGENATED ADDITIVES

by

Vara Prasad U. SATYA, K. Madhu MURTHY, and Gaddale Amba Prasad RAO *

Department of Mechanical Engineering, National Institute of Technology, Warangal, Andhra Pradesh, India

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In the recent times' fatty acid methyl ester popularly called as biodiesel has become more prominent alternate fuel for compression ignition engines based on a single fuel concept. Since, use of neat biodiesel on a large scale is raising certain difficulties and is being adopted in a blended form with petro-diesel fuel and B20 blend has become standardized. However, the HC and NO_x *emissions of B20 are still on the higher side. Present work aims at experimental evaluation of a single cylinder water-cooled diesel engine by adopting various proportions of ethanol and di ethyl ether blends in order to improve performance and emission characteristics of B20 blend. Besides employing different amounts of ethanol and di ethyl ether, simultaneous influence of injector nozzle hole size and fuel injection pressure are also investigated to arrive at an optimum configuration. Brake specific fuel consumption and hydrocarbon emissions values are lower with B20 and DEE 5 whereas B20 with DEE15 yielded lower* NO_x *emissions. It is observed that addition of oxygenates have improved the combustion process and lower emissions are obtained. The present investigation revealed that blends with oxygenated additives having higher cetane rating are superior to neat blend.*

Key words: *direct injection Diesel engine, B20 blend, oxygenated additives, di ethyl ether, ethanol, emissions*

Introduction

Diesel engine continues to be reliable power source for light, medium and heavy duty applications and as such there can be no replacement for it in agriculture and transportation sectors. The direct injection Diesel enginies high fuel conversion efficiency and cheaper diesel fuel cost are the main driving factors for its wide popularity. However, fluctuating petroleum-fuel prices in the international market and associated environmental degradation have stimulated the researchers to develop various ways of developing clean diesel engines. Nature of Diesel engine combustion process is unsteady, turbulent, diffusion, and heterogeneous and due to these effects the understanding makes more complex [1]. The combustion process is highly influenced by the way of fuel-air mixing in the engine cylinder. One approach is to adopt a good fuel injection system as it plays a crucial role to bring fuel

* Corresponding author; e-mail: ambaprasadrao@gmail.com

and air in intimate contact with each other. The geometry of the nozzle in an injector plays a vital role in controlling diesel spray atomization and combustion. In order to bring fuel droplet size small, the nozzle-hole size is required to be reduced to produce smaller droplets. By decreasing the nozzle-hole size, the spray tip penetration is reduced due to the low spray momentum. High injection pressures with small nozzles are common in the modern Diesel engine as they reduce injection duration and improve combustion efficiency [2]. Numerical simulations were performed to study the effect of reduced nozzle-hole size and nozzle tip hole configuration on the combustion characteristics of a high speed direct injection Diesel engine [3].

Another approach followed widely by the researchers to tackle the problems of burden on conventional fuels and reduction of pollution problems was adopting alternate fuels; by suiting the engine to the fuel or make modifications for fuel to the suit the engine combustion system. The domain of biofuels inculcates self-sustainability. Among various biofuels, vegetable oil based fuel has occupied prominent position due to its thermo-physical properties being close to petro-diesel**.** Researchers have tackled difficulties associated with the use of neat vegetable oils either by adopting modifications on engines or processing the fuel to suit an engine. Transesterification, a chemical process, yields biodiesel, is widely accepted technique to reduce high viscosity of vegetable oils as it permanently changes the composition of vegetable oils and brings down viscosity close to diesel fuel. Use of biodiesel in engines will significantly reduce emissions of CO, HC, and particulate matter (PM) exhaust compared with petro-diesel fuel. Biodiesel is attractive as it is biodegradable, sulfur-free, non--toxic and can significantly reduce exhaust emissions and low overall life cycle emission of CO_2 from the engine when burned as a fuel [4-10]. With the use neat biodiesel researchers observed higher NO_x levels and were able to overcome the difficulty with retarding of injection timing or employing exhaust gas recirculation. These in turn led to higher particulate matter and lower power at higher concentrations of EGR [11-14]. Effects of fuel injection parameters such as injection pressure and supercharging pressure were also investigated and observed better performance with increasing injection pressure or supercharge pressure [15, 16].

Alcohols and ethers are also explored as other alternatives as oxygenated fuels or Diesel fuel additives for compression ignition (CI) engines. Alcohols are produced from fossil or renewable resources such as methanol, ethanol, *etc*., are generally added to diesel fuel to reduce emissions especially smoke or particulate emissions [17]. Dimethyl ether (DME) and diethyl ether (DEE) were tried out as alternatives to petro-diesel. DEE is liquid at the ambient conditions, which makes it attractive for fuel storage and handling. DEE can be a renewable fuel as it is produced from ethanol by dehydration process. It has several favorable properties, including exceptional cetane number, reasonable energy density, high oxygen content, low auto-ignition temperature, and high volatility. Therefore, it can assist in improving engine performance and reducing the cold starting problem and emissions when using as a pure or an additive in diesel fuel. Sezer [18] investigated performance and emission characteristics of a diesel engine with DME and DEE and felt that the two fuels hold promising alternatives. Qi *et al.* [19] studied experimentally the effect of diethyl ether and ethanol additives and concluded that the additives could be a promising technique for using biodiesel/diesel blend efficiently in diesel engines without any modifications in the engine. Effect of oxygenates on the stability and low temperature storage were also studied [20].

Of late, non-edible oils, tallow based oils and fried-waste oils obtained from restaurants were also being tried out as feed stock for biodiesel production. One of the kinds of non-edible seed oil is *Jatropha Curcas* (*Euphorbiaceous* plant) oil was being tried by many investigators. It is popularly known as *physic nut* in some parts of the world. It is a drought-resistant perennial plant living up to 50 years; *Jatropha Curcas* seeds contain about 32 to 35% non-edible oil. Composition of Jatropha oil obtained by using gas-liquid chromatography as saturated and unsaturated fatty acids contribute 20.1% and 79.9% of oil, respectively [21-24].

Total replacement of fossil fuels with biodiesel is raising the issues such as food *vs*. fuel and land use, blends of biodiesel and diesel fuel were extensively studied experimentally [25, 26]. Studies incorporating blends concluded that 20% biodiesel and 80% diesel fuel was a better option to circumvent the undesirable emission problems associated with both fuels without affecting engine performance. From the literature review it was observed that, there is lot of research work going on, on the use of biodiesel in engines. Countries which have limited resources can adapt to B20 blend to reduce burden on fossil fuels and obtain the benefits of biodiesel [27]. Fuel injection parameters such as injection pressure and injector nozzle hole size were studied independently by various researchers for petro-diesel as the fuel. The present work aims at employing B20 blend in order to improve its utilization effectively with addition of oxygenates such as ethanol and di-ethyl ether in different proportions. The vegetable oil under consideration was *Jatropha curcas* oil. Besides studying the effect of these additives, simultaneous influence of fuel injection pressures and fuel injector nozzle hole size were also investigated on the performance and emission characteristics of a single cylinder Diesel engine under naturally aspirated (NA) condition.

Experimental procedure

Fuel preparation

The commercial Diesel fuel employed in the tests was obtained locally. Laboratory samples of methyl esters of Jatropha oil (biodiesel) were prepared in accordance with the procedure well documented in literature by a method of alkaline-catalyzed transesterification. The formation of methyl esters by transesterification of vegetable oil required raw oil, 15% of methanol, and 5% of sodium hydroxide on mass basis. However, the transesterification process required excess alcohol to drive the reaction very close to completion. Table 1 gives the typical properties of fuels. The biodiesel thus produced through the above process was blended with diesel in, procured from the nearby commercial vendor in different proportions along with and without additives. The ethanol is an analysis-grade anhydrous ethanol (99.7% purity). The diethyl ether is an analysis-grade anhydrous diethyl ether (99.5% purity). Table 2 gives the details of different blends/fuels employed with their key properties.

Table 1. Typical properties of fuels

Parameter	Diesel	Ethanol – E	Diethyl ether – DEE
Relative density at 30 ºC	0.832	0.789	0.715
Latent heat of evaporation, [kJkg^{-1}]	250	840	350
Lower heating value, [MJkg^{-1}]	42.9	26.8	36.84
Cetane rating	40-55	5~8	>125
Auto ignition temperature, [°C]	315	235	160

Table 2. Composition of blends and key properties

Blend	Biodiesel	Diesel	DEE	E	Kinematic viscosity, [cSt]	Relative density	LHV [$MJkg^{-1}$]
B20	20	80	–	–	4.2	0.845	42.16
B20 DEE5	20	75	5	–	3.9	0.835	41.8
B20 DEE10	20	70	10	–	3.82	0.832	41.45
B20 DEE15	20	65	15	–	3.76	0.83	41.15
B20 E6	20	74	–	6	3.9	0.842	41.11
B20 E10	20	70	–	10	3.8	0.84	40.54

Engine performance tests

The specifications of the engine, Kirloskar AV1 (DI) Diesel engine, used in present investigation are given in tab. 3.

Table 3. Specifications of Diesel engine

Model	AV1, vertical
Make	Kirloskar oil engines, Pune
Working cycle	4-stroke
Rated power	3.68 kW (5 HP)
Rated speed	1500 rpm
Combustion chamber	Direct injection
Bore × stroke	80 mm × 110 mm
Compression ratio	16.5:1
Cooling system	Water cooling
Fuel nozzle opening injection pressure	190 bar
Number of holes in nozzle (standard)	3
Static fuel injection timing	23^o bTDC

The details of the nozzles and fuel injection pressures employed are given in tab. 4. Constant speed performance tests were conducted maintaining jacket water temperature at 60 ^{o}C in order to maintain steady-state conditions. An eddy current dynamometer was used for loading the engine. Each trial was repeated three times and on different days, enough care was taken to load the engine accurately at each step of load and also to maintain ambient conditions constant. The results of the three repetitions were averaged to decrease the error/uncertainty. During the experimentation, the air flow was measured through an air flow sensor. A homogenizer was used to prepare blends of biodiesel and petro-diesel fuel blends and fuel additives just an hour before the conduct of experiments.

Table 4. Details of fuel injection parameters

Nozzle type	Fuel injection pressure, [bar]	Number of holes	Diameter of each hole
NH1	190, 210, and 230	3	0.28 mm
NH2	190, 210, and 230	4	0.29 mm
NH3	190, 210, and 230	4	0.32 mm

The schematic representation of the experimental set-up employed is shown in fig. 1.

The experiments were carried out according the following order.

(1) Performance tests with three fuel injectors and three different fuel injection pressures with diesel fuel for optimizing nozzle hole size and fuel injection pressure.
(2) Tests with B20 blend with optimized nozzle hole size and fuel injection pressure.
(3) Tests with B20 blend with fuel additive of DEE in 5, 10 and 15% amounts, and
(4) Tests with B20 blend with fuel additive of E in 6% and 10% amounts.

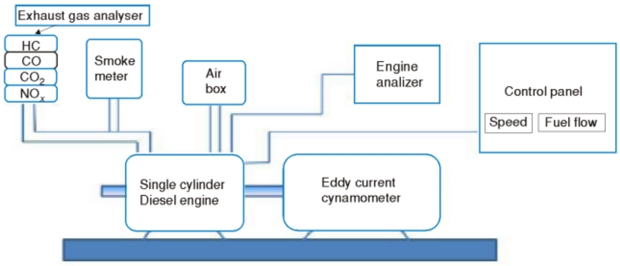

Figure 1. Schematic lay-out of experimental set-up

Results and discussion

Experiments are performed on the Diesel engine by varying fuel injector nozzle hole size, fuel injection pressures with and without oxygenated additives to arrive at optimum configuration. The results are discussed below.

Baseline performance tests with diesel fuel

Experiments were performed in combinations with three different nozzle holes and three fuel injection pressures to develop baseline required for further comparison. For the engine under consideration, the recommended nozzle is NH1 with an injection pressure of 190 bar. The experiments were aimed to arrive at an optimum nozzle size and fuel injection pressure that would give better fuel economy. It can be noticed from the figure that the values of brake specific fuel consumption (BSFC) are lower for an injection pressure (IP) of 210 bar compared to recommended IP of 190 bar. Further increase in the IP beyond 210 bar has resulted in higher values. This could be due to the fact that with increase in IP, not only the fuel droplet size decreases but also increases the momentum of the droplets. Therefore, too high increase in pressures would have developed even small droplets but with increase in momentum the droplets could have got impinged on the cylinder inner wall and to develop same power, the fuel consumption should have increased. Thus, at the prevailing conditions, an IP of 210 bar yielded lower BSFC. Figure 2(a) shows the variation of BSFC with brake power for different fuel injection pressures maintaining standard nozzle, NH1 same. Figure 2(b) illustrates the BSFC variation for three different nozzles for an injection pressure of 210 bar. It can be observed that BSFC with 3-hole nozzle and IP 210 bar is the lowest, therefore from these set of experiments it is confirmed that the NH1 and IP of 210 yielding lower values and is treated as baseline data. Also, it was

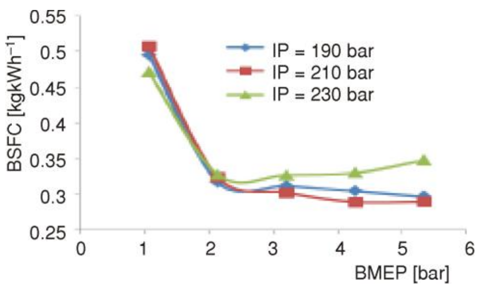

Figure 2(a). Comparison of BSFC of engine for three IP with NH1 – diesel

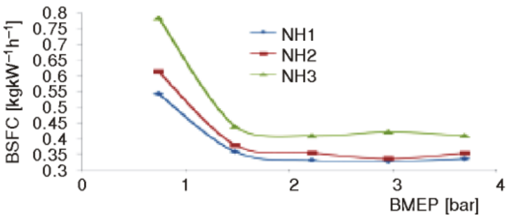

Figure 2(b). Comparison of BSFC for three nozzles at IP of 210 bar-B20

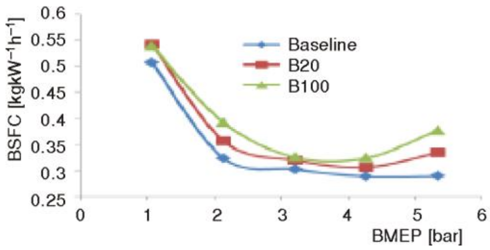

Figure 2(c). Comparison of BSFC with NH1 nozzle at IP = 210 bar for three fuels

observed that for the same number of holes, small size hole nozzle at any given injection pressure yielded better performance. This is indicating the fact that smaller nozzle requires higher injection pressure to ensure complete combustion and to bring down fuel consumption. Further experiments were conducted with NH1 and IP of 210 bar. With optimized values of nozzle hole size and fuel injection pressure, a comparison is made among three fuels: diesel, B20, and B100. Since the viscosity of B20 blend is in between neat biodiesel and petro-diesel, the BSFC values of B20 blend are lying between the remaining two fuels as shown in fig. 2(c).

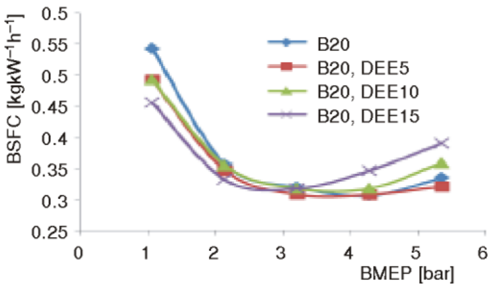

Figure 3(a). Comparison of BSFC for B20 with and without DEE additive

Performance tests employing B20 with and without additives

Second set of experiments were performed for effective utilization of B20 with different variants of additives. These experiments were aimed at a best proportion of any of the additives and also observe the efficacy of each additive. Figure 3(a) illustrates the results of BSFC obtained with and without DEE as additive for B20. Among these combinations, it is observed that B20 with DEE5 yielded lower BSFC values. Figure 3(b) shows the results for E as additive. Among these combinations, it is observed that B20 with DEE5 yielded lower BSFC values. The best results obtained for B20 blend with DEE and E additives are compared with that of neat B20 blend in

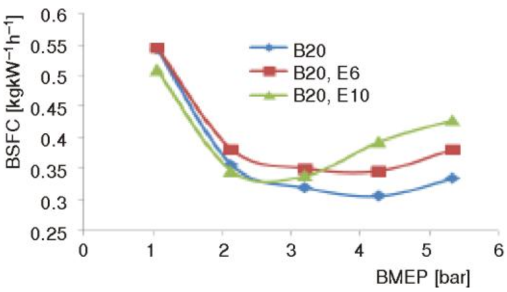

Figure 3(b). Comparison of BSFC for B20 with and without E additive

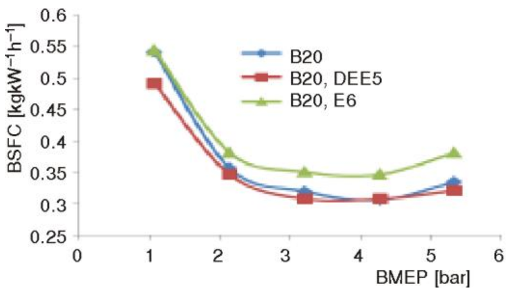

Figure 3(c). Comparison of BSFC for B20 with both additives

fig. 3(c). The results indicate the importance of additives especially DEE, to obtain best possible economy since highest BSFC were realized with neat B20 during the entire load range of operation. As it is known that the DEE being oxygenated compound with high cetane rating helped neat B20 fuel to undergo complete combustion. The reason could be that blends with additives were lower dense and higher heating value fuels. This is emphasizing fact that blends with additives could be better substitutes for petro-diesel rather than neat biodiesel.

Emission tests employing B20 with and without additives

Hydrocarbons

Figures 4(a) and 4(b) represents the variation of percentage drop in HC emissions when using B20 blend with DEE and E as additives for 75% and 100% of full load power, respectively. The variation represents for the B20 as a base data and it illustrates what happens when different blends are adopted. Since the Diesel engine is generally operated under 75-100% of the full load power and moreover, HC emission variation is significant during this range of load. From fig. 4(a) it can be noticed that reduction is more in case of DEE additive and as the proportion of DEE is increasing, the drop is getting reduced. Another interesting feature is that for the lower amounts of either DEE or E, the drop is substantial. Similar observation can be made for the 100% full load power values as shown in fig. 4(b). Between the two blends, the drop is more for the case of 100% load full load power. Another feature of interest is that when neat biodiesel (B100) is adopted, the drop is decreasing, indicating the fact that the additives are improving the combustion process and thus reducing the unburned HC emissions in the engine exhaust. Since the cetane rating of DEE is high, addition of DEE has enhanced the combustion process. The unburned hydrocarbons in case of B100 are far higher than blends with additives. Thus, it can be said here that with higher amounts of DEE, engine BSFC not improved when compared to emission reduction. Therefore, to obtain lower emissions more amounts of DEE are required.

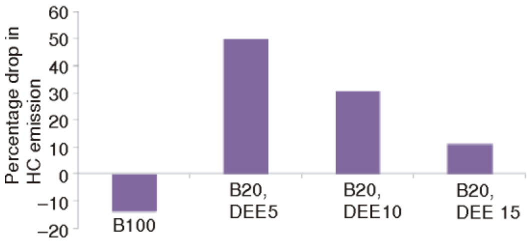

Figure 4(a). Percentage drop in HC emission for different B20 and DEE blends at 75% full load power

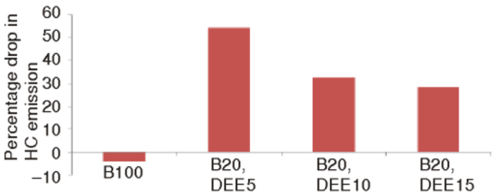

Figure 4(b). Percentage drop in HC emission for different B20 DEE blends at 100% full load power

Oxides of nitrogen

Among the different cases of DEE and E, lower NO_x levels were observed with DEE15 and E6 additives. The NO_x emissions are plotted for two cases only and compared with B100 for 75% and 100% of full load power, respectively. Since the Diesel engine combustion experiences high in-cylinder temperatures in 75-100% of the full load power. From fig. 5(a) it can be noticed that drop is more in case of DEE additive than with E addition. Similar observation can be made for the 100% full load power values as shown in fig. 5(b). Between the two blends, the drop is more for the case of 100% load full load power. Another feature of interest is that when neat biodiesel (B100) is adopted, the drop is decreasing, indicating the fact that the effect of properties when added to B20 is overplaying in reduction of NO_x emissions. This is due to the fact that DEE has higher cetane rating than ethanol. Prevalence of lower peak cycle temperatures is the reason for not favoring the thermal-prompt reactions responsible for formation of higher levels of NO_x [1].

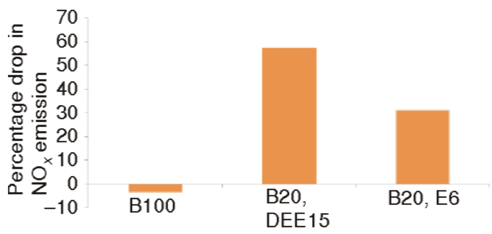

Figure 5(a). Drop in NO_x emission using different B20 and oxygenates at 75% full load BMEP

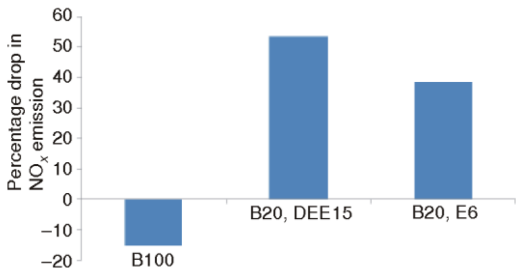

Figure 5(b). Drop in NO_x emission using different B20 and oxygenates at 100% full load BMEP

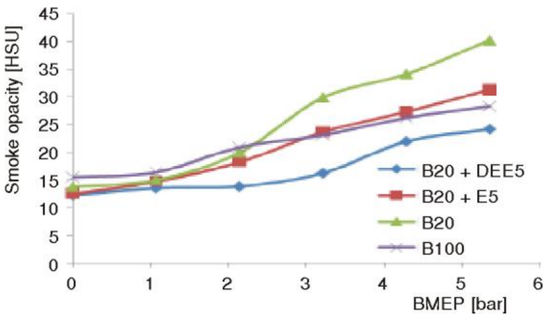

Figure 6. Variation of smoke opacity with BMEP

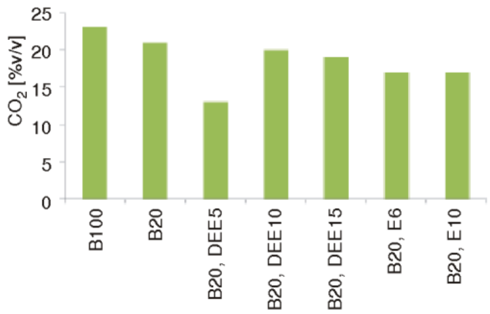

Figure 7. CO_2 emission levels with different fuels

Many investigators have established that higher NO_x emissions will be realized when B100 is adopted and present study revealed that employing blends along with oxygenated additives will be superior in performance and emissions too. The smoke opacity exhibited by different fuels were sampled and for the optimized cases are plotted in fig. 6. It can be seen that smoke opacity values are on the lower side for the B20 blend with additives. The values for any fuel are varying marginally under part load operation where as highest during 75-100% power range. Lowest values are observed for the case of B20 with DEE5 and highest being B20. Since the unburned HC emissions for lower DEE5 case, smoke opacity values are also lower for the same combination. Improved and complete combustion could be the reasons for obtaining lower smoke opacity values with oxygenated additives. Therefore, it can be concluded here that DEE has proven to be eco-friendly additive to improve the performance and emissions of B20 blend. It can be observed from fig. 7 that the CO_2 levels are high in case of neat samples of B20 and B100, respectively. Also, the emissions are slightly higher in case of B20 when DEE additive is increased. This may be attributed to the fact that these samples and B100 are heavier with carbon content. The lower values could be due to lower content in E added samples of either of the biodiesel blends. Also, more CO_2 levels indicate more complete conversion of carbon in the fuel to CO_2 (which is the stable compound). Thus, it can be concluded at this stage that the BSFC, HC, smoke opacity, and NO_x values are lower with the addition of DEE compared to E addition. This may be due to higher cetane rating for DEE in comparison with E.

Conclusions

Based on the experimental investigations carried out with 5, 10, and 15% DEE and 6%, 10% of ethanol to B20 blend with simultaneous influence of fuel injector nozzle hole size and fuel injection pressures, the following conclusions are drawn.

- Both performance and emissions gets improved with small nozzle hole injector and high fuel injection pressure due to intimate contact of air and fuel droplets.
- In the event of deriving larger benefits using biodiesel-diesel blends, addition of oxygenate with higher cetane rating are preferable.
- Smaller nozzle hole and high pressure injection pressure fuel system with oxygenates are beneficial than neat biodiesels.
- For the chosen engine configuration, NH1 nozzle size and fuel injection pressure of 210 bar have yielded lower BSFC and HC emission with DEE addition.
- The higher cetane rating of DEE is an advantageous for obtaining lower smoke opacity and also lower NO_x emission.

Acknowledgments

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Acronyms

B100 – neat biodiesel
B20 – 20% biodiesel + 80% petro-diesel
bTDC – before top dead center
BSFC – brake specific fuel consumption
BMEP – brake mean effective pressure
CI – compression ignition
DI – direct injection
DEE – diethyl ether
DME – dimethyl ether
HSU – hartridge smoke units
IP – injection pressure
LHV – lower heating value
NA – naturally aspirated

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