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Experimental Studies on Use of Additive to Reduce NOx in the CI Engine fuelled by Jatropha Based Biodiesel

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ABSTRACT

Experimental work was carried out using di-tert-butyl peroxide (DTBP) additive mixed with Jatropha based biodiesel fuel in naturally aspirated CI engine. Experiments are performed for pure diesel, pure biodiesel from Jatropha oil and 0.5%, 1.0% and 2.0% of additives mixed with Jatropha biodiesel. The task was accomplished for three different engine loads of 1.4, 2.8 and 4.2 kW. Emissions of CO, CO_2, HC and NO_x was measured and compared with emission characteristics of pure diesel, pure biodiesel and biodiesel with additives as fuel. The result shows improvements of emission of CO, CO_2 and HC with biodiesel however slight increase in NO_x with biodiesel. Nevertheless NO_x emission characteristics are improved with addition of DTBP additives in biodiesel.

Keywords: Jatropha Oil, Emission Characteristics, Biodiesel, DTBP additives

NOMENCLATURE

BD	Bio diesel
CO	Carbon monoxide
DCN	Derived cetane number
DTBP	Di-tert-butyl peroxide
EGR	Exhaust gas recirculation
EHN	Ethylhexyl nitrate
HC	Hydro carbon
kW	Kilo watt
NO_X	Nitrogen oxides
ppm	Parts per million

INTRODUCTION

Many researchers are currently looking into biodiesel as a potential replacement fuel for internal combustion engines. Typically, biodiesel may be used as fuel in diesel engines without requiring modifications to the engine. When biodiesel is used in a traditional diesel engine, it significantly lowers the amount of carbon monoxide, particulate matter, and unburned hydrocarbons. But the main challenge is the rise in NO_x production from biodiesel. Researches also try to reduce NO_x production when biodiesel blend is used with the diesel. Literature of few investigators on NO_x reduction when biodiesel is used in blend with the diesel is given below.

Szybist et al (2003) investigated stability of 2-EHN and DTBP for short period of .35 days in the blending of 20% of biodiesel with diesel which can be used for NO_x reduction. The changes in the flash point, viscosity, and peroxide number are also checked. It was found no significant change in the flash point or viscosity of the fuel blend, never the less concentration of additives remains constant. It was concluded the stability of 2-EHN and DTBP with B20 blends during short durations is perfect. The change in the bulk modulus of synthetic high methyl oleate biodiesel is not significant and only a marginal reduction in the inadvertent advance in the fuel injection timing caused by biodiesel. Chapman et al (2003) used two approaches for getting saturated biodiesel fuel for NO_x reduction. The first one is blending of the biodiesel fuel with short-chained, saturated methyl esters and the second one is the hydrogenation of soybean oil prior to transesterification. The conclusion gave reduction of NO_x emission by 1.5 to3% using both the options relative to B20 fuel. Szybist et al (2005) investigated on NO_x effect by lowering iodine value of soy-derived biodiesel fuels and addition of cetane improvers. To lower iodine value the concentration of methyl oleate was raised in the biodiesel which will increase DCN value of biodiesel blended fuel. In their study it was found insensitiveness of NO_x emission to DCN. It was observed insensitiveness of NO_x emission to the maximum cylinder temperature and the maximum rate of heat release and sensitive to the timing or crank angle at which these maxima occurred. The most important factor of NO_x emissions was an advance in the start of injection timing. McCormick et al (2005) reported that use of 2-ethyl hexyl nitrate as cetane number improver has no significant effect of NO_x reduction in engines using biodiesel as blend with diesel. Kang et al (2007) reported that high NO_x conversion and N_2 selectivity were demonstrated by manganese oxide catalysts for low temperature selective catalytic reduction of NO_x with NH_3. Varatharajan et al (2011) experimentally examined effect of antioxidant additives on NO_x emission in a Jatropha methyl ester fuelled diesel engine. The additives used in the work were L-ascorbic acid, α tocopherol acetate, butylated hydroxytoluene, p-phenylenediamine and ethylenediamine. It was observed that among all the additives p-phenylenediamine demonstrated the superior emission performance with biodiesel. The order of NO_x reduction capability was found as per p-phenylenediamine > ethylenediamine > α-tocopherol > butylated. Lamas and Rodriguez (2012) have described primary and secondary methods for NO_x reduction in marine diesel engines. The primary method includes decrease of injection duration, delay of start of injection and pre-injection, modification of fuel injectors, modification of the combustion pressure, scavenging air cooling, miller cycle, water injection and exhaust gas recirculation (EGR), whereas secondary method is selective catalytic reduction that involves mixing of ammonia with the exhaust gas passing over a catalyst. It was concluded that primary methods are the first choice to use in ships. Further it is seen that EGR and water addition are the most employed primary measures. Dąbrowski et al (2013) experimentally show improvement in the NO_x emission by selective catalytic reduction. In that work ammonia and NO_x combined gas stream passes through the catalyst which convert the mixture into nitrogen N_2 and water steam and reduced NO_x. Palash et al (2013) investigated various factors on NO_x emissions in engine with biodiesel fuel. They also worked on retarded injection timing and EGR approaches for the NO_x reduction. Several conclusions on NO_x are drawn from their study. As oxygen is present in biodiesel fuel, more heat is released during the premixed phase combustion, which is thought to be the primary cause of the rise in NO_x emissions. Because of the advanced combustion timing and prolonged residence period, higher combustion temperatures are obtained throughout the combustion process for biodiesel fuel, which increases NO_x emissions. By enhancing the fuel's viscosity, density, and other characteristics, additives efficiently lower the amount of NO_x emissions from biodiesel. Nevertheless, this raises concerns about engine longevity and running costs. By using the delayed injection timing, NO_x emissions can be decreased by 8.2 – 40% in comparison to the initial injection timing. Exhaust gas recirculation, water injection and lowering the premixed combustion temperature techniques are effective to lower NO_x.

The present work investigates use of Di-tert-butyl peroxide additive with biodiesel fuel from the Jatropha oil and compares for the emission characteristics of reducing NO_x for the complete biodiesel and 0.5%, 1.0% and 2.0% of DTBP additive mixed with biodiesel.

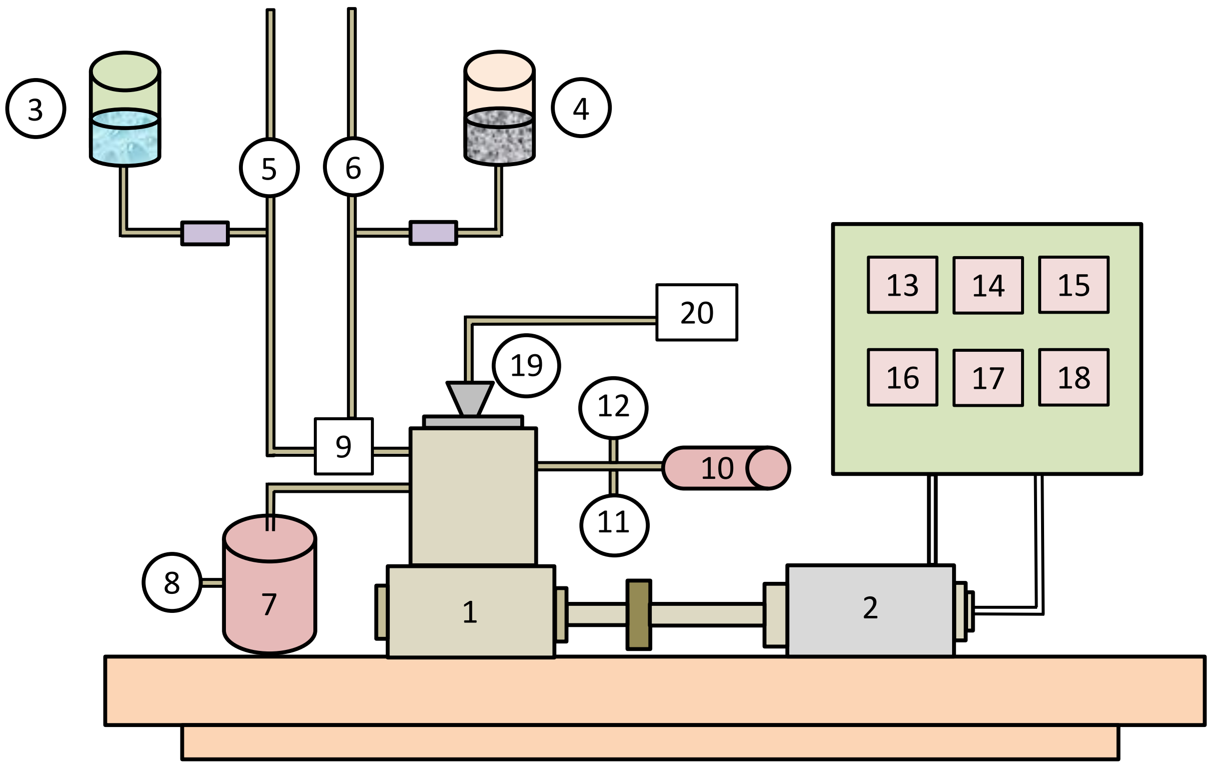
EXPERIMENTAL METHODOLOGY

Experimental test set up consisted of a naturally aspirated, water-cooled diesel engine, designed to operate on a four-stroke cycle. This engine had the capacity to deliver 6 kW of power at 1500 revolutions per minute and featured a compression ratio of 17.5. A schematic of the experimental setup is depicted in Figure 1. Load was applied to the engine via an electric dynamometer. Airflow was measured by a turbine meter connected to a large tank attached to the engine. To identify the engine's top dead center, an optical encoder system was installed. Engine speed was monitored using a digital RPM indicator coupled with a photo sensor. Fuel consumption was gauged by noting the change in fuel level over a fixed time interval, using a burette and a stopwatch. Exhaust gas temperatures were recorded using a digital temperature indicator and chromel-alumel (K type) thermocouples. Cylinder pressure was captured using a piezo-electric transducer linked to a high-speed digital Data Acquisition System. Emissions of HC, CO, and NO_X in the exhaust gas were measured using an infrared exhaust gas analyzer.

Jatropha oil was converted into its methyl ester via transesterification, a process where triglycerides of Jatropha oil react with ethyl alcohol in the presence of a sodium hydroxide catalyst to yield glycerol and fatty acid esters. For this, measured amounts of Jatropha oil, methanol, and sodium hydroxide were combined in a round-bottom flask and vigorously stirred to overcome their immiscibility until ester formation commenced. The mixture was then heated to 65°C and maintained at this temperature without stirring for 60 minutes, followed by an overnight cooling without stirring. This resulted in the formation of two distinct layers: glycerol at the bottom and the ester on top. Ester, as compared to vegetable oil, has lower viscosity and higher cetane number.

Initially, experiments were conducted using diesel as the baseline fuel to collect reference data. Injection timing was set at 26° before top dead center, and the temperature of the cooling water was kept around 70°C. The engine was brought to steady state before measurements were recorded. Subsequent experiments compared the use of diesel and methyl ester of Jatropha oil. During these trials, parameters such as exhaust gas temperature, fuel consumption, ambient temperature, noise level, and more were measured. A microprocessor-based flue gas analyzer was employed to determine the emission constituents, allowing for an analysis of emission characteristics.

Later on experiments were repeated for the biodiesel fuel for the same load conditions and then observations are recoded by adding Di-tert-butyl peroxide additive of various proportions like 0.5%, 1.0% and 2.0%. The results are recorded and compared with diesel and biodiesel fuel result.



1. Engine
2. Dynamometer
3. Jatropha oil
4. Diesel tank
5. Burette for Jatropha oil
6. Burette for diesel
7. Air tank
8. Air flow meter
9. Injector
10. Silencer
11. Smoke pump
12. HC/CO Analyzer
13. Stop watch
14. RPM indicator
15. External temperature indicator
16. Coolant temperature indicator
17. Lubricating temperature indicator
18. Rota meter
19. Pressure sensor
20. Data acquisition system

Fig. 1 Experimental test facility

RESULTS AND DISCUSSION

1. Comparison of fuel consumption for all the configuration of fuel used

Present work are performed for engine loads of 1.4, 2.8 and 4.2 kW and for various configuration of fuel like diesel, bio diesel and biodiesel with 0.5%, 1.0% and 2.0% of Di-tert-butyl peroxide additives. Observations on fuel consumption rate for all the cases of experiments are shown in Fig. 2. The plot shows an increase in the rate of fuel consumption with load on the engine. Higher load needs more amount of input energy. It is also seen from the plot that for a given load, rate of fuel consumption is higher when pure biodiesel is used as the fuel. The effect of adding additives of varying proportion shows the decrease in the rate of fuel consumption as the proportion of DTBP increases from 0.5 to 2.0%. It is also observed that adding additives reduces the rate of fuel consumption compare to pure biodiesel fuel.

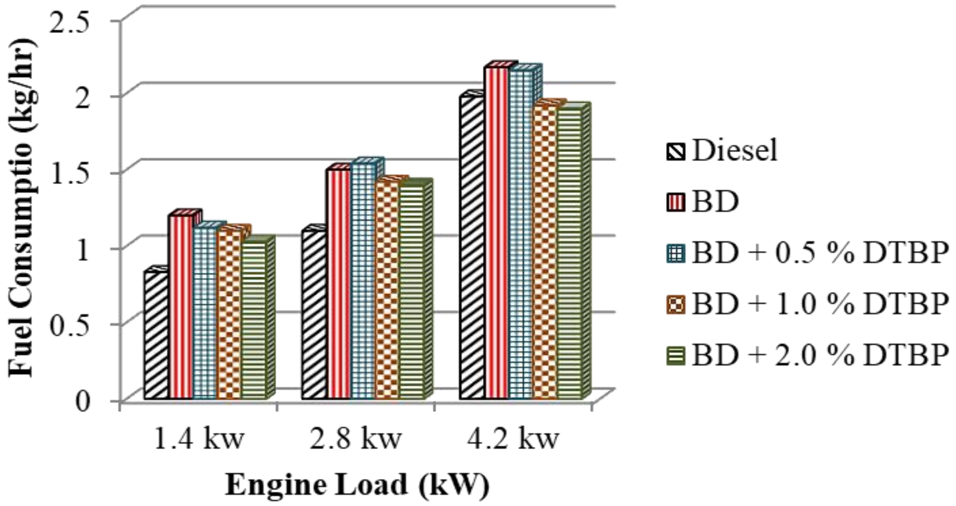


Fig. 2 Comparison of rate of fuel consumption for different fuel configuration

2. Engine performance on the basis of emissions using additives mixed with biodiesel fuel

Comparison of engine emissions of diesel, biodiesel and biodiesel with different proportions of additives is made. Emissions of CO_2, CO, hydro carbons (HC) and NO_x measurement of the engine are compared and results are plotted. Experiments are repeated and readings are taken at the stabilized conditions of the test engine.

2.1 Comparison of CO_2 emissions

CO_2 emissions for all the tree configuration of fuel are shown in Fig. 3 for the different load conditions on the engine. The observations show the production of CO_2 emissions increases as the load on engine increases. It is also concluded from the graph that for a given engine load condition, emissions of CO_2 is lower for all the fuel configuration compare to diesel is used as fuel. Further it is noticed that as proportions of DTBP additives increases from 0.5% to 2.0%, formation of CO_2 emissions also increases.

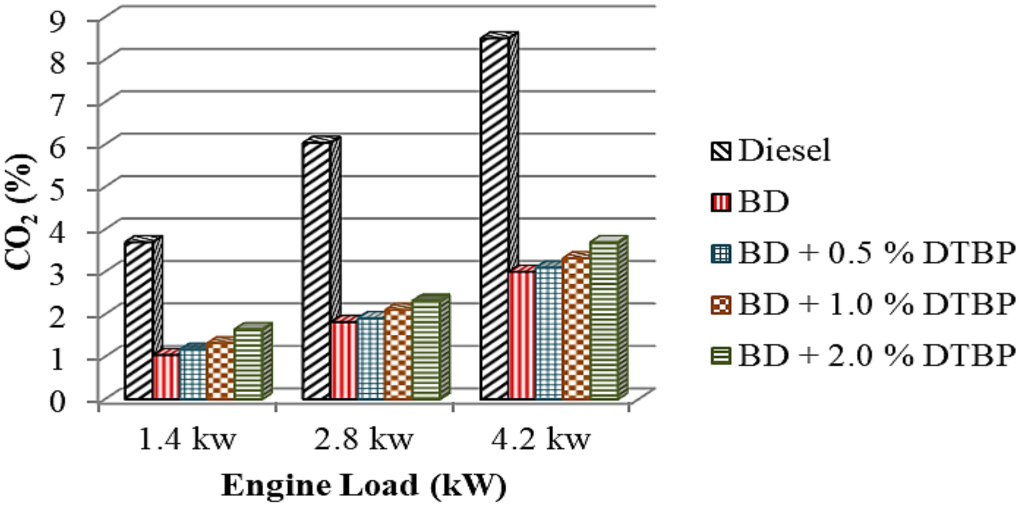


Fig. 3 Comparison of emissions of CO_2 for different fuel configuration

2.2 Comparison of emissions of CO

While engine runs for different load conditions of 1.4, 2.8 and 4.2 kW, emissions of measured CO for different fuel configurations is shown in Fig. 4. The observations from the plot show higher emissions of CO with the load on the engine. If comparison is made for a given load, it is seen that CO formation is highest when engine runs on pure diesel. With the use of biodiesel fuel, CO emissions decrease. The result shows addition of DTBP additives, CO emissions further reduces. However it is seen that formation of CO with increasing proportion of additives is different at different load on the engines. So, as conclusion use of biodiesel and additives with biodiesel reduces production of CO in the flue gas compared to flue gas from pure diesel fuel.

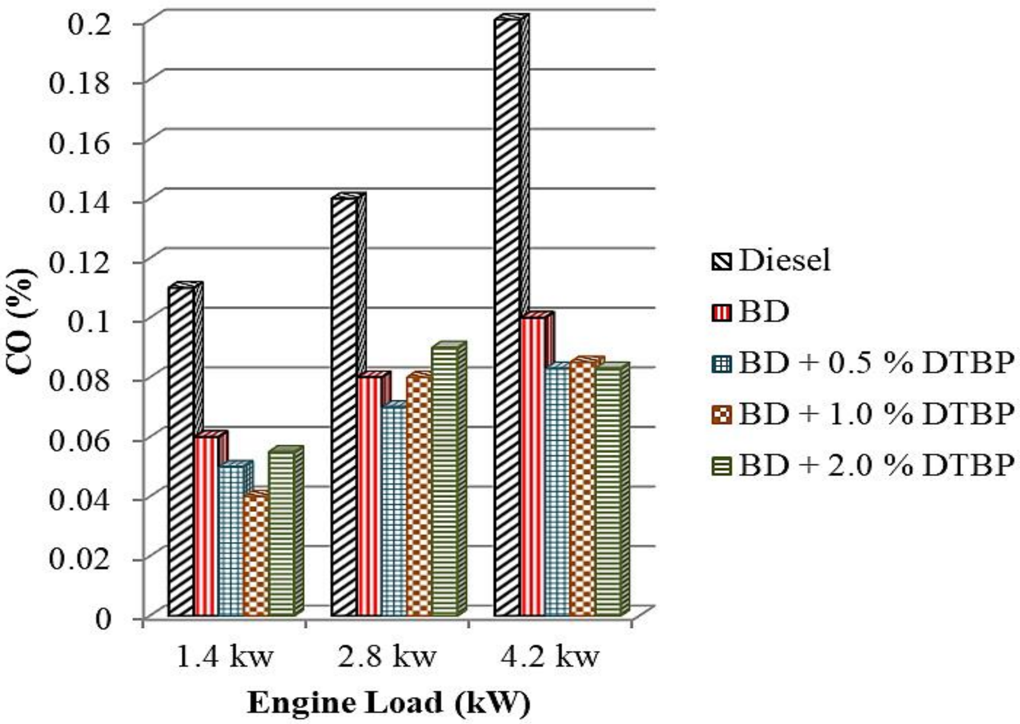


Fig. 4 Comparison of emissions of CO for different fuel configuration

2.3 Emissions of HC and its comparison for different fuel configuration

Measured emissions of hydro carbon (HC) at different engine load for different additives proportions with biodiesel are shown in Fig. 5. The observation from the plot shows the rise in the emissions of HC with the engine load for pure diesel fuel. It is also seen that HC emissions are lesser using biodiesel fuel compared to the 100% diesel fuel for all the load conditions. It is also observed that additions of DTBP additives of varying proportional with the biodiesel, there is no significant variation of HC productions in the flue gas.

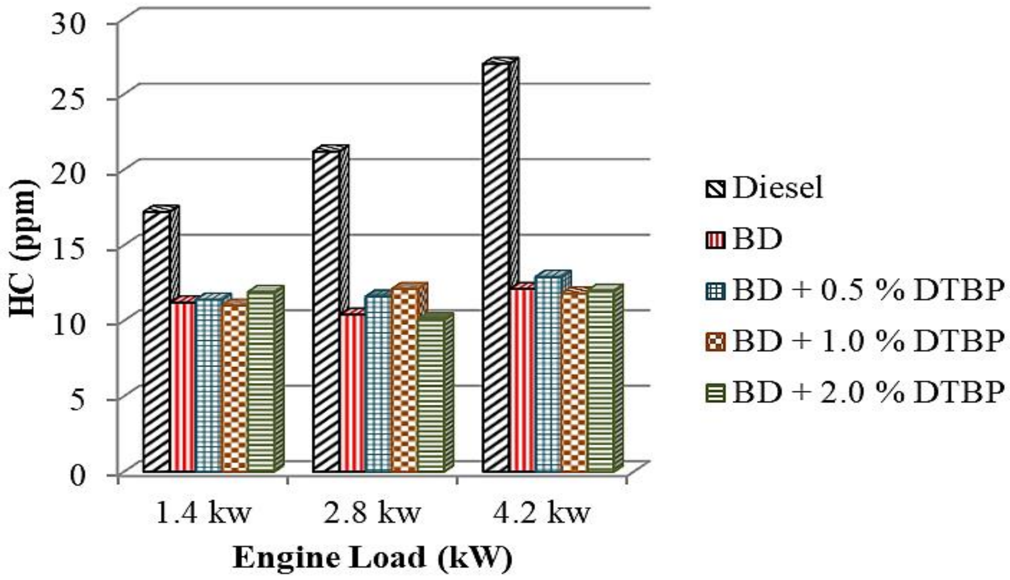


Fig. 5 Comparison of HC emissions for different fuel configuration

2.4 NOx emissions for different additive proportions

Emissions of NO_X using biodiesel fuel are higher in comparison with the 100% diesel fuel. The same can be seen in Fig. 6 which gives experimental measured value of NO_X formation of biodiesel, biodiesel with DTBP additives of varying proportions of 0.5, 1.0 and 2.0% mixed with biodiesel fuel. The emissions of NO_X are shown for three loads on the engine 1.4 kW, 2.8 kW and 4.2 kW. The plot at each load conditions shows similar characteristics. It is seen that emissions of NO_X increases with load for all the fuel configurations. Emissions of NO_X are higher for biodiesel compared to diesel fuel. The plot at different load also shows NO_X emissions with additives. It is seen that for a given engine load as the proportions of additives increases, emissions of NO_X decreases. Thus using DTBP additives formation of NO_X reduces hence it can be used as NO_X suppressor in engine with biodiesel fuel.

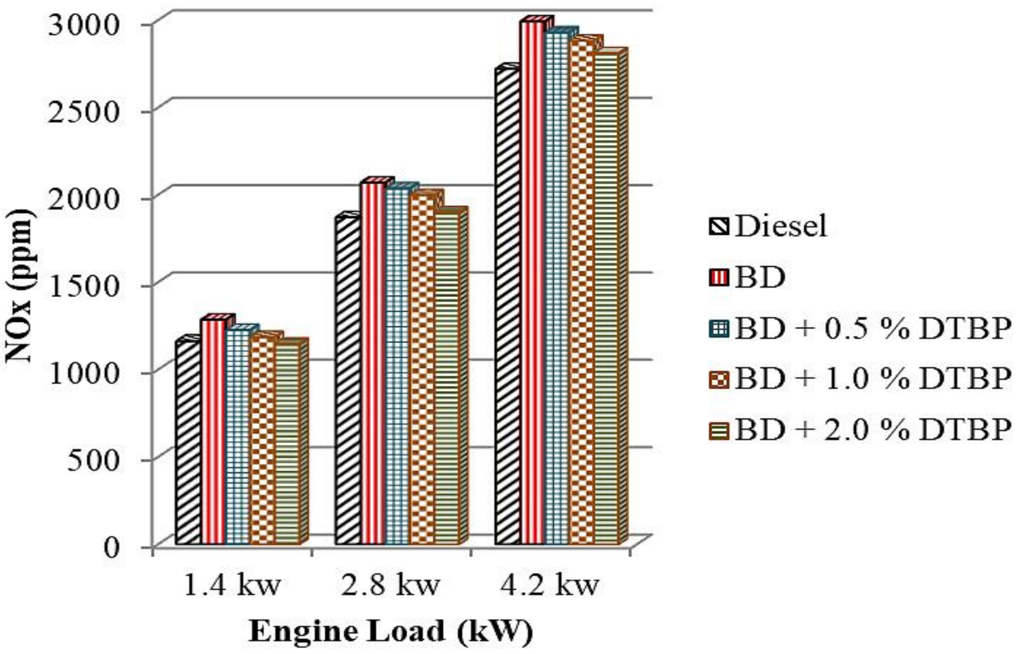


Fig. 6 NOx emission for different fuel configuration

3. Exhaust gas temperature with additives

Figure 7 shows measured value of exhaust gas temperature when engine runs for the different fuel configurations. The plot shows exhaust gas temperature increases with load on the engine. It is also observed that exhaust gas temperature for biodiesel fuel is always higher compared to exhaust gas temperature when pure diesel is used as fuel and this causes more NOx emissions with biodiesel. If comparison of exhaust gas is carried out at given load it is seen that exhaust gas temperature goes on reduces as the proportions of DTBP additive increases from 0.5% to 2.0% values. Thus, it can be concluded that additions DTBP additives with Jatropha based biodiesel, exhaust gas temperature decreases.

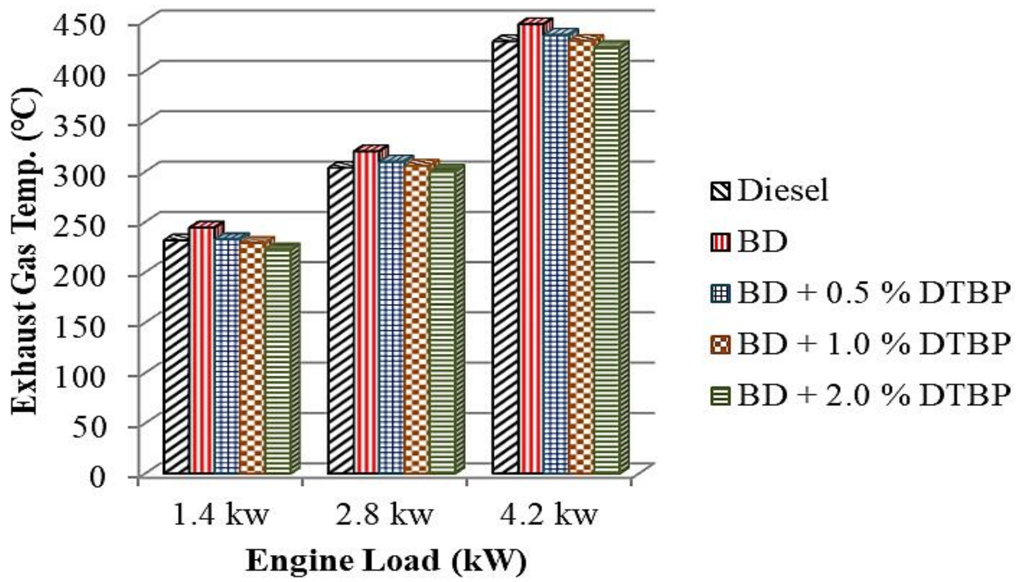


Fig. 7 Exhaust gas temperature for different DTBP additive proportions

CONCLUSION

Use of bio-diesel can be thought of as alternative fuel for the IC engine as it gives cleaner environment compare to pure diesel engine. However biodiesel increases NO_X and put limits to the use of biodiesel. The solution to the raising NO_X is found using DTBP additives. This can be implemented in the present work on CI engines without much additional cost, disturbance and with or without minor changes in the engine. Use of DTBP additives with biodiesel not only reduce NO_X but also minimizes emissions of carbon dioxide, CO and unburnt hydro carbon. Biodiesel with DTBP additives scores well in its contribution to reducing carbon emissions hence its global impact on climate change is low. Following conclusions can be drawn from the present study.

- There is reduction of CO_2, CO and HC compared to pure diesel fuel using DTBP additives in the bio diesel on propionate basis.
- The increase of NO_X emissions using biodiesels can be reduced using DTBP additives in the biodiesel fuel.
- As the proportion of DTBP in biodiesel increases, NO_X emissions decrease. In the present work the lowest NO_X emissions is for 2.0% of DTBP additive which is lower than NO_X emissions of 0.5% and 1.0% of DTBP additive.
- As load increases NO_X emissions also increases.
- For a given load there is slight increase in the fuel consumption rate using biodiesel fuel, however using additives it goes on decreases compared to 100% biodiesel fuel.
- Exhaust gas temperature is higher using biodiesel compared to 100% diesel, however it goes on reduces as compared to 100% biodiesel with the addition of increasing proportion of DTBP additive.

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