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ISSN: 0976-3031

International Journal of Recent Scientific Research
Vol. 6, Issue, 7, pp.5199-5204, July, 2015

International Journal of Recent Scientific Research

RESEARCH ARTICLE

COMBUSTION, EMISSION AND PERFORMANCE CHARACTERISTICS OF A LOW HEAT REJECTION DIESEL ENGINE OPERATING WITH TOBACCO SEED OIL

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ARTICLE INFO

Article History:

Received 14th, June, 2015
Received in revised form 23th, June, 2015
Accepted 13th, July, 2015
Published online 28th, July, 2015

Key words:

Low heat rejection engine, Tobacco seed oil, Tobacco seed oil methyl ester, Transesterification

ABSTRACT

In the recent years, increasing environmental awareness and depletion of energy resources are forcing the researchers to develop viable alternative fuels from renewable energy sources. Vegetable oils have emerged as a very promising alternative substitute for diesel, since they are renewable and produce less emission. Considering these points, tobacco seed oil (TSO), a non edible vegetable oil is regarded as an alternative fuel for diesel engine. Crude oil derived from tobacco seed has high viscosity; the viscosity is reduced by transesterification technique to obtain tobacco seed oil (TSO) methyl ester (TSOME). In the present study, an effort has been made to utilize the neat tobacco oil and TSOME in a CI engine to study the performance, emission and combustion analysis with metal matrix composite materials coated on piston face.

Initially tests are conducted on a 5.2 kW, single cylinder, four stroke, direct injection, water cooled diesel engine without coating using diesel as fuel. Further the tests are carried out on the diesel engine for TSOME and TSO with metal matrix composite material coating over the piston face. The results obtained with Low heat rejection engine revealed decrease in brake thermal efficiency and increase in emissions with neat tobacco oil compared with normal diesel engine fuelled with diesel. However, with LHR engine using TSOME, slight improvement in brake thermal efficiency and reduction in emissions are observed when compared with neat tobacco oil operation.

INTRODUCTION

Energy is considered as an important factor for the economical growth and social development. Since their exploration, the fossil fuels continued as major energy source. Fossil fuels are limited in reserve. Due to gradual depletion of world petroleum sources and the impact of global pollution of increasing exhaust emissions, there is an urgent need for appropriate alternative fuels for use in diesel engines. To face this challenge in the long term energy security, there is an immediate need to develop suitable alternative fuels, whose properties are similar to gasoline fuels. The thought of using vegetable oils as fuel for diesel engine is not a new concept. Way back in 1900, Rudolph Diesel the originator of the diesel engine used groundnut oil to fuel his engine at the Paris Exposition. However, in spite of technical viability, vegetable oil could not get approval as fuel, as they were more costly than petroleum products. Since the petroleum crisis of the 1970s, created renewed interest of researchers in vegetable oil as alternative fuel for diesel engines. The problems connected with using vegetable oils as fuel in diesel engines identified from the previous studies are filter clogging, carbon deposits on injector exterior, piston ring sticking, filter gumming problems, thickening of lubricating oil (Humke *et al*, 1981; Vellguth 1983; Henham 1990; Hemmerlien *et al*, 1991; Rao *et al*,1989; Michael *et al*, 1998). The high viscosity of raw vegetable oils is accountable for these difficulties. However, these problems can be eradicated or reduced by several ways (Rakopoulos CD 1992), among them blending or dilution with other oils, preheating and transesterification are predominant. Testing of diesel engines with preheating [Bari *et al*, 2002; Kalam *et al*, 2004; Nwafor 2004), blending with diesel (Rao *et al*,1989; Herchel *et al*, 2001; Huzayyin *et al*, 2004) and blending with preheating (Pramanik 2003; Ramadhas *et al*,2005) improves the performance and reduces the emissions compared with raw vegetable oil. It also reduces the filter clogging and enables smooth flow of oil.

The compression ignition engine normally offers better fuel consumption characteristics than its counterpart gasoline engine. Furthermore, theoretically if heat rejection could be reduced, then the thermal efficiency would be enhanced, at least up to the limit set by the second law of thermodynamics (Jaichandra *et al*, 2003). Low heat rejection engines intend to do this by reducing the heat lost to the coolant.

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A review by Jaichandar *et al* (2003) concluded that, a large number of experimental studies have been carried out on low heat rejection engine performance but much more attempts are considered necessary to conquer the practical troubles. The engine that is applied with thermal barrier coating is termed as low heat rejection (LHR) engine. The LHR theory is based on suppressing the heat rejection to the coolant and recovering the energy in the form of useful work. Average in cylinder gas temperature and amount of energy carried away by the exhaust gases escalates because of insulation in LHR engines which could be also utilized (Hejwowski *et al*, 2002; Toyama *et al*, 1983). Sun *et al* (1994) reported that combustion characteristics of LHR CI engines are different from naturally aspirated CI engine in four ways: (i) ignition delay period shortens; (ii) diffusion burning period increases while premixed burning period decreases; (iii) total combustion duration increases; (iv) heat release rate in diffusion burning period decreases.

Although the usage of LHR engine found to be promising, many of the reported investigations revealed paradoxical outcomes. Most of the investigators have concluded that insulation reduces heat transfer, increases thermal efficiency, and improves energy availability in the exit gases. On the other hand, contrary to the above presentations some investigational reports revealed that there was no improvement or little improvement in thermal efficiency and exhaust emissions deteriorated as compared to those of conventional water cooled engines (Cheng *et al*, 1989; Dickey 1989).

The major purpose of this work is to investigate the effects of using biodiesel as an alternative fuel in a diesel engine that has its piston face coated with metal matrix composite materials, to determine any significant effects on performance, emissions and combustion. LHR engine is fuelled with tobacco seed methyl ester, tobacco seed oil and normal diesel engine fuelled with diesel fuel are referred to by TSOME, TSO and NDE, respectively, throughout the paper.

MATERIALS AND METHODS

The engine used in this study is 5.2 kW, computerized Kirloskar make, single cylinder, four stroke, vertical, water cooled, direct injection diesel engine. An eddy current dynamometer is used to load the test engine. Exhaust emission from the engine is measured with help of AVL DiTEST 1000 (Five gas analyzer) and smoke emission is measured with the help of AVL DiSMOKE 480 (Smoke meter).

Crude tobacco seed oil is selected for the preparation of biodiesel. 3.5 grams of sodium hydroxide (NaOH) and 200 ml of methyl alcohol (CH_3OH) are used for esterification of 1 litre of tobacco seed oil. The catalyst is dissolved in the alcohol then the alcohol-catalyst mixture is poured into the tobacco seed oil which is heated and mixed thoroughly. The temperature of the tobacco seed oil, alcohol and catalyst mixture is maintained at 60^{o}C for an hour. When the transesterification is finished the mixture is taken into a separating funnel to settle. After the settlement of the biodiesel and the glycerine, the glycerine is drained. The biodiesel is washed thoroughly with pure water to remove alcohol and catalyst residue. After washing, the biodiesel is heated to a temperature of 110^{o}C in order to remove the traces of water in the form of vapours. The properties of the diesel, tobacco seed oil and its methyl ester are determined with the help of standard procedures. As can be seen from Table 2, the calorific value of TSOME is lower than that of diesel and other properties are higher than the diesel.

Table 2 Properties of the test fuels

Property	Diesel	TSO	TSOME
Calorific value(kJ/kg)	42600	36125	38928
Kinematic Viscosity at 50 ^{o}C(mm^2/sec)	3.12	27.97	4.69
Density (kg/m^3)	840	924	887
Flash point (^{o}C)	51	258	145
Fire point(^{o}C)	57	285	162
Carbon residue (%)	00	0.23	0.20

The tests are conducted for variable brake power of 0%, 10% 25%, 50%, 75% and 100% at 1500 rpm speed. First, diesel fuel is used as fuel in the normal engine. After completion of the test on normal engine, the piston face is coated with metal matrix composite materials. The metal matrix thermal barrier coating is made of 25% ZrO_2 + 75% Al_2O_3 of 0.1 mm thick, 50% ZrO_2 + 50% Al_2O_3 of 0.1 mm thick and 100% ZrO_2 of 0.1 mm thick by using plasma coating method over the base of Ni-Cr bond coat of 0.150 mm thickness. Now the engine is converted to a LHR condition. Then, the TSO and TSOME which have the properties given in Table 2 are used as fuel. After completion of the test on LHR engine, the results are compared.

RESULTS AND DISCUSSIONS

The main objective of this work is to investigate the performance, emission and combustion characteristics of LHR engine fuelled with TSOME and TSO and are compared to that of normal engine fuelled with diesel.

Performance analysis

Important engine performance parameters, such as brake thermal efficiency, brake specific fuel consumption and brake specific energy consumption for LHR engine fuelled with TSOME, TSO and normal engine fuelled with diesel are calculated, analyzed and graphically represented. The variation of brake thermal efficiency with brake power for TSOME, TSO and NDE are shown in Fig. 1.

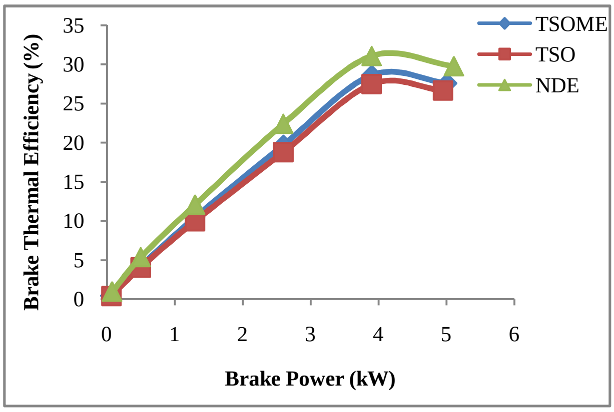

Figure 1 Variation of brake thermal efficiency with brake power.

Brake thermal efficiency of TSOME is close to NDE for the entire range of operation. Maximum brake thermal efficiency of TSOME is 28.62% against, 31.09% of NDE, which is lower by 8.63%. We can say that brake thermal efficiency of TSOME is near with that of diesel. The maximum brake thermal efficiency of TSO is 27.47% against, 31.09% of diesel.

From Fig 2, it is observed that, LHR engine using TSOME and TSO as fuel have higher brake specific fuel consumption as compared to normal diesel engine using diesel as fuel. This is due to the differences in heating value and density between TSOME, TSO and normal diesel. The minimum BSFC of neat tobacco seed oil and tobacco seed oil methyl esters are 0.32 kg/kW-h and 0.36 kg/kW-h which are higher than that of diesel.

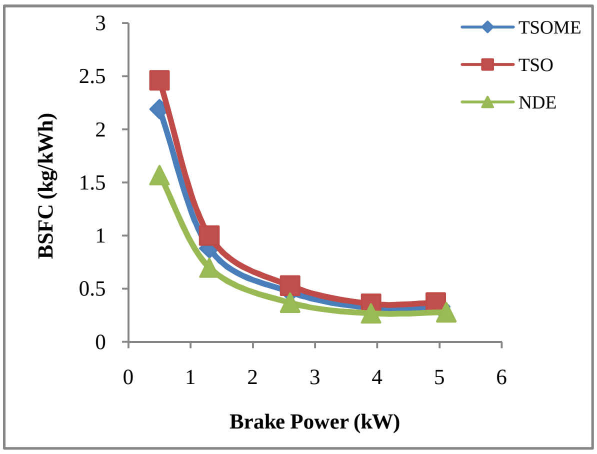

Figure 2. Variation of BSFC with brake power

Fig 3 indicates the variation of brake specific energy consumption with brake power for all the oils in the test engine. The brake specific energy consumption of all the tested fuels are higher at lower loads than at higher loads. The minimum brake specific energy consumption of neat tobacco seed oil and tobacco seed oil methyl esters are 12.45 MJ/kW-h and 13.0 MJ/kW-h which are higher than that of diesel. The reason for this is the viscosity of TSOME and TSO.

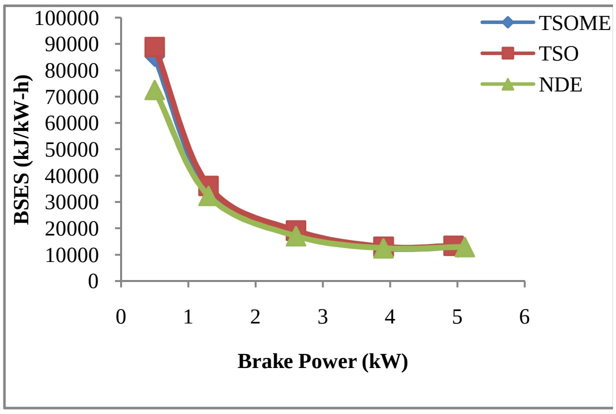

Figure 3 Variation of BSEC with brake power.

Emission analysis

Fig. 4 shows the variation of exhaust gas temperature with brake power for TSOME, TSO and NDE. It shows increasing exhaust temperature with increase in brake power for TSOME and TSO. The reason may be poor volatility and higher viscosity of these biofuels and higher flash points in TSOME and TSO than diesel. Those constituent having higher flash points are not adequately evaporated during the main combustion phase and continued to burn in the late combustion phase. This resulted in a slightly higher exhaust gas temperature (EGT).

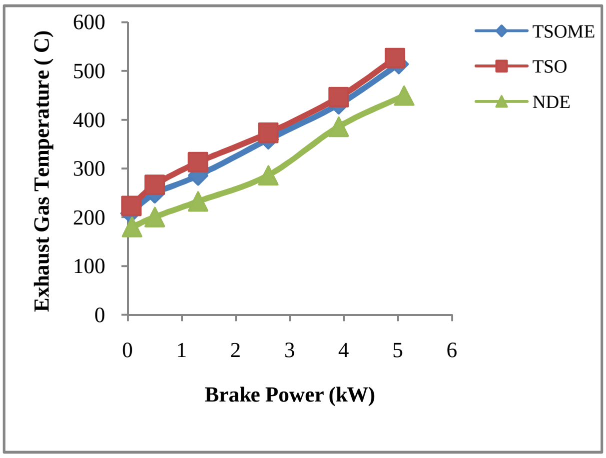

Figure 4 Variation of exhaust gas temperature with brake power.

The effect of brake power on carbon monoxide is shown in Fig. 5. It is seen that, the carbon monoxide emission increases with increasing load for all test oils. The carbon monoxide emission values for LHR engine using TSOME and TSO are higher than that of normal diesel engine fuelled with diesel fuel at all loads and this could be because of fuel viscosity effect.

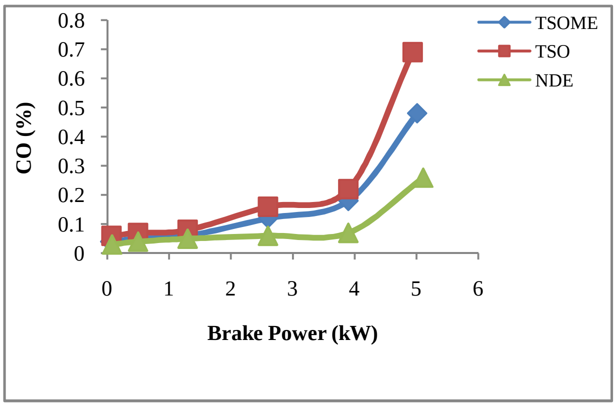

Figure 5 Variation of CO with brake power.

Fig. 6 shows variation of hydrocarbons with brake power. It is seen that, unburned hydrocarbon (HC) emission for LHR engine fuelled with TSOME is close to normal engine fuelled with diesel for the entire range of operation and in LHR engine the emission values for TSO are higher than TSOME. The effect of fuel viscosity on fuel spray quality would be expected to produce some HC with vegetable oils. At rated load, the hydrocarbon emissions attain respectively 94.26 ppm, 108.2 ppm and 85.65 ppm with TSOME, TSO and NDE.

The variation of oxides of nitrogen with brake power is shown in Fig. 7. In LHR engine the NO_x emission values for TSOME and TSO are very close up to 25 % loading and are higher at higher loads when compared to that of normal diesel engine fuelled with diesel. The maximum NO_x emission values for

TSOME and TSO is 721.86 ppm and 688.12 ppm respectively against 622.15 ppm of NDE at rated loading. In LHR engine generally the NO_x emissions are higher than the normal diesel engine because of higher combustion temperature.

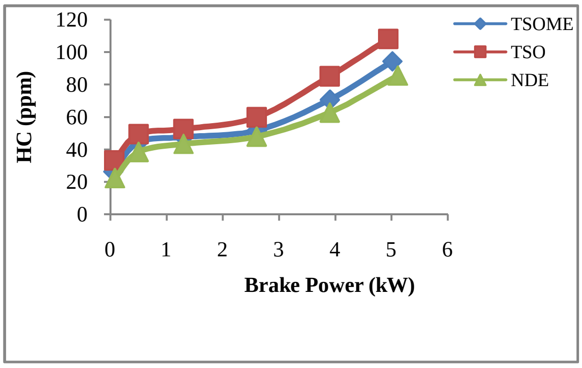

Figure 6 Variation of Hydrocarbon with brake power.

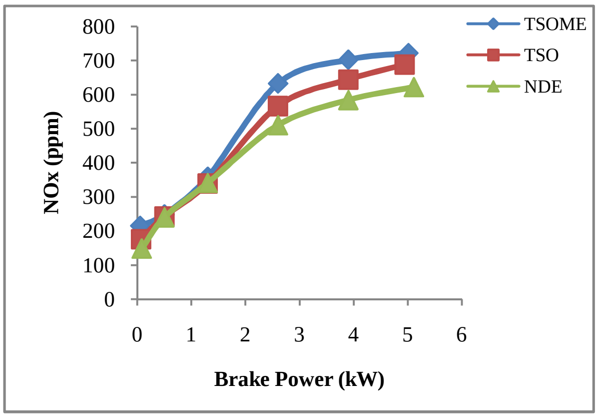

Figure 7 Variation of NOx with brake power.

Figure 8 shows the comparison of smoke emission with brake power for Tobacco Seed oil and its biodiesel. The LHR engine fuelled with TSOME and TSO produces higher smoke emissions compared to normal diesel engine fuelled with diesel fuel. These results are due to heavier molecular structure and higher viscosity of TSOME and TSO than diesel fuel. At 75 percent load, the smoke emissions with LHR engine using TSOME and TSO as fuel are 69.2% and 74.81% respectively, against 61.58% of normal diesel engine using diesel as fuel.

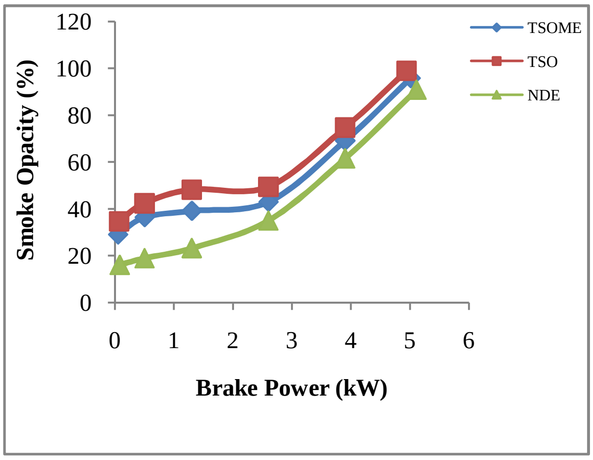

Figure 8 Variation of Smoke opacity with brake power.

Combustion analysis

The analysis of cylinder pressure and other combustion parameters provide accurate information about combustion method with tobacco seed oil and tobacco seed oil methyl ester. In diesel engine cylinder pressure depends on the burned fuel fraction during the premixed combustion phase. Cylinder pressure describes the fuel ability to mix well with air and burn in good conditions. The cylinder pressure crank angle data is taken by averaging 100 cycles for TSO and TSOME at 75 percent load.

Fig. 9 shows the variation of cylinder pressure with crank angle at 75% load for TSOME, TSO and NDE. It is observed that, the peak pressure for the TSOME and TSO are 56.35 bar and 55.01 bar respectively and the peak pressure for the NDE is 56.96 bar. The cylinder peak pressure for normal engine fuelled with diesel engine is higher than LHR engine fuelled with TSOME and TSO. The reason is due to higher viscosity and lower calorific values of TSOME and TSO than diesel fuel. It is also seen that, the crank angle at which peak pressure occurs slightly shifts away from TDC i.e. the peak pressure for TSOME occurred at 10^o CA after TDC, for TSO, it is 10^o CA after TDC and for NDE it is 12^o CA after TDC.

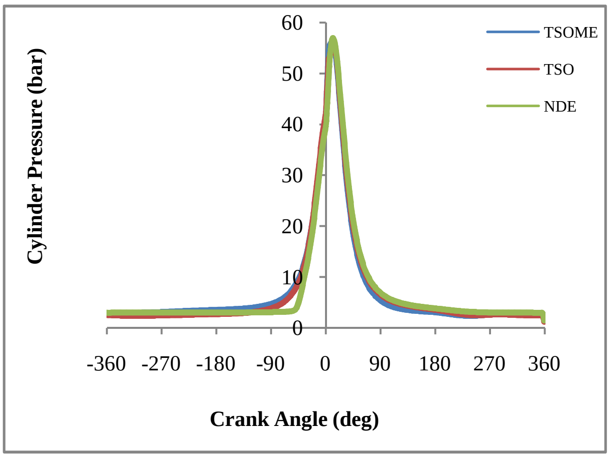

Figure 9 Variation of cylinder pressure with crank angle.

Fig. 10 shows variation of net heat release rate with crank angle for TSOME, TSO and NDE at 75 percent load. The premixed burning phase associated with a high release rate is important for normal diesel engine and is responsible for the higher peak pressure and higher rates of pressure rise.

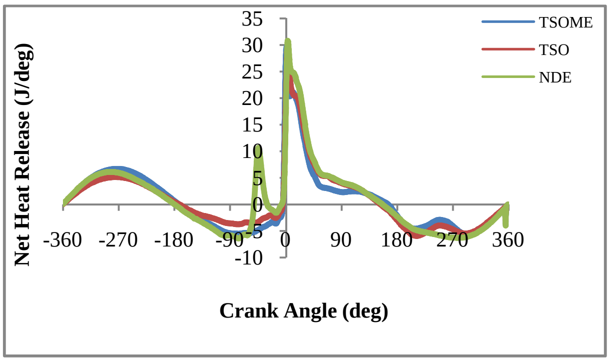

Figure 10 Variation of heat release rate with crank angle.

This may be the reason for higher thermal efficiency with NDE. In LHR engine fuelled with TSOME and TSO there is significant increase in combustion rates during the later stage that has resulted to higher exhaust temperatures and lower thermal efficiency. The TSOME and TSO has reduced heat release rate compared to NDE. The maximum net heat release rate values for TSOME and TSO is 27.71 J/deg and 29.01 J/deg respectively against 30.79 J/deg of NDE at 75 percent loading.

CONCLUSIONS

In this work, the piston face is coated with metal matrix composite materials. Tobacco seed oil methyl ester (TSOME) and tobacco seed oil (TSO) are used in coated engine and diesel is used for uncoated normal engine. The combustion, emission and performance characteristics of TSOME and TSO are analyzed and compared with that of normal engine fuelled with diesel. The summarized conclusions are as follows:

- Brake thermal efficiency of TSOME is near to NDE for the entire range of operation. Maximum brake thermal efficiency of TSOME is 28.62% against, 31.09% of NDE, which is lower by 8.63%. We can say that brake thermal efficiency of TSOME is near to that of diesel. The maximum brake thermal efficiency of TSO is 27.47% against, 31.09% of diesel.
- The specific fuel consumption of TSOME and TSO is higher as compared to NDE. This is due to differences in heating value and density between TSOME, TSO and diesel. The minimum brake specific fuel consumption of TSOME and TSO which are higher than that of diesel.
- The brake specific energy consumption of all the tested fuels are higher at lower loads than higher loads. The minimum brake specific energy consumption of TSOME and TSO which are higher than that of diesel. The reason could be the viscosity of these fuels.
- The smoke emissions for TSOME and TSO are higher compared to diesel fuel. The results are due to heavier molecular structure and higher viscosity. At 75 percent load, the smoke emissions with TSOME and TSO are 12.37 % and 21.97% higher than that of diesel.
- The carbon monoxide emission for TSOME and TSO is higher than that of diesel at all the loads and this could be due to viscosity effect of the fuels.
- The unburned hydrocarbon emission for TSOME is 10.05 % higher than diesel where as the hydrocarbon emission for TSO is 26.32 % higher than that of diesel.
- The oxides of nitrogen emission for TSOME are very close to NDE up to 25% of loading and are higher at higher loads. The maximum NO_x emission for TSOME and TSO is 721.86 ppm and 688.12 ppm against 622.15 ppm of diesel at rated load.
- The cylinder pressure for TSOME is very close to that of diesel and for TSO it is 3.54% less than that of diesel at 10^o CA after TDC.
- TSOME and TSO have reduced heat release rate compared to diesel. The net heat release rate for TSOME and TSO are 11.11% and 6.13% less than that of diesel.

On the whole, it is seen that, the LHR engine operation with TSOME and TSO resulted in reduced brake thermal efficiency compared with normal diesel engine with diesel as fuel. NO_x emissions are slightly higher with TSOME and TSO due to the presence of molecules of oxygen in the fuel. The overall performance of the LHR engine is relatively better with TSOME compared with TSO but lower compared with normal diesel engine fuelled with diesel.

The above comparative study clearly reveals the possibility of using the biodiesel in LHR direct injection diesel engine. The combustion, performance and emission characteristics show the suitability of tobacco seed oil biodiesel in LHR engine.

Acknowledgement

The authors thank the faculty and staff of I.C Engine laboratory, Mechanical engineering department, PDA College of Engineering, Kalaburagi, Karnataka, India for helping in conducting experiment.

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How to cite this article:

Basavaraj.M .Shrigiri *et al*., Combustion, Emission And Performance Characteristics Of A Low Heat Rejection Diesel Engine Operating With Tobacco Seed Oil. *International Journal of Recent Scientific Vol. 6, Issue, 7, pp.5199-5204, July, 2015*

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