

Experimental Investigations on Exhaust Emissions of Low Grade Heat Rejection Diesel Engine with Crude Rice Bran Oil with Varied Engine Parameters

N. Durga Prasada Rao¹, M.V.S. Murali Krishna², B. Anjaneya Prasad³

Department of Production, Bharath Dynamics Limited, Hyderabad, India¹

Department of Mechanical Engineering, Chaitanya Bharathi Institute of Technology, Gandipet, Hyderabad, Andhra Pradesh, India²

Department of Mechanical Engineering, J.N.T. U. College of Engineering, Hyderabad, India³

ABSTRACT: In the scenario of depletion of fossil fuels, the search for alternative fuels has become inevitable. Vegetable oils and alcohols are important substitutes for diesel fuels. The drawbacks associated with crude vegetable oils (high viscosity and low volatility) and alcohol (low energy content and cetane number) gave rise to combustion problems in diesel engines. However, high viscous vegetable oil calls for low heat rejection (LHR) or semi adiabatic diesel engine. Investigations were carried out to study exhaust emissions of a low grade LHR diesel engine consisted of ceramic coated cylinder head with different operating conditions [normal temperature and pre-heated temperature] of crude rice bran vegetable oil with varied injection timing and injector opening pressure. Comparative studies on exhaust emissions were made with diesel working on similar conditions. Particulate emissions decreased, while NO_x levels increased with LHR engine with crude vegetable oil in comparison with CE with vegetable oil. Exhaust emissions improved with increase of injector opening pressure, advanced injection timing and preheating of crude vegetable oil.

KEYWORDS: Alternative fuels, exhaust emissions, vegetable oils,

I. INTRODUCTION

It has been found that the vegetable oils are promising substitute, because of their properties are similar to those of diesel fuel. They are renewable and can be easily produced. Rudolph Diesel, the inventor of the diesel engine that bears his name, experimented with fuels ranging from powdered coal to peanut oil [1]. Several researchers experimented the use of vegetable oils as fuel on diesel engine and reported that the performance was poor, citing the problems of high viscosity, low volatility and their polyunsaturated character. [2–8].

Experiments were conducted on preheated vegetable oils [temperature at which viscosity of the vegetable oils were matched to that of diesel fuel]. [9–12]. They reported that preheated vegetable oils decreased pollution levels of particulate emissions and NO_x emissions. By controlling the injector opening pressure and the injection rate, the spray cone angle is found to depend on injector opening pressure [13]. Few investigators reported that injector opening pressure has a significant effect on the performance and formation of pollutants inside the direct injection diesel engine combustion. [14–16]. They reported that particulate emissions decreased with increase of injector opening pressure. However, drawbacks associated with crude vegetable oil of high viscosity and low volatility which cause combustion problems, call for engine with hot combustion chamber with its significant characteristics of higher operating temperature, maximum heat release, and ability to handle the low calorific value fuel. The concept of the engine with LHR combustion chamber is to reduce heat loss to the coolant, by providing thermal resistance in the path of heat flow to the coolant. Any saving in this part of the energy distribution would either increase the energy lost through

International Journal of Innovative Research in Science, Engineering and Technology

(An ISO 3297: 2007 Certified Organization)

Vol. 5, Issue 5, May 2016

exhaust gases or increase the power output. Considerable efforts are under way to reduce heat loss to the coolant by various researchers. However, the results are a little confusing as to whether the insulation would improve or deteriorate thermal efficiency. These LHR engines have significant characteristics of higher operating temperature, maximum heat release, and ability to handle low calorific value fuel. Three approaches that are being pursued to decrease heat rejection are (1) Coating (low grade LHR combustion chamber or low grade semi adiabatic engine or LHR-1 engine) with low thermal conductivity materials on crown of the piston, inner portion of the liner and cylinder head, (2) air gap insulation (medium grade LHR combustion chamber or LHR-2 or medium grade semi adiabatic engine) where air gap is provided in the piston and other components with low-thermal conductivity materials like superni, cast iron and mild steel and (3). High grade LHR combustion chamber or LHR-3 engine or high grade semi adiabatic engine is the combination of low grade and medium grade LHR combustion chambers.

Experiments were conducted on conventional engine with low grade LHR combustion chamber, consisting of ceramic coated cylinder head with neat diesel. [17–19]. They reported an increase of brake specific fuel consumption (BSFC) by 4% at full load operation with LHR engine in comparison with standard engine. Experiments were extended to LHR-1 engine with crude vegetable oil with varied injection timing and pressure. [20–22]. They reported marginal increase of BTE and particulate emissions with LHR-1 engine. The optimum injection timing was observed to be 31° bTDC with low grade semi adiabatic diesel engine with crude vegetable oil operation. They reported from their investigations, that thermal efficiency increased by 2–4%, volumetric efficiency decreased by 4–6%, particulate emissions decreased by 25–30%, NO_x levels increased by 5–8%, peak pressure increased by 8–12% and maximum rate of pressure increased by 6–8% with engine with low LHR combustion chamber with crude vegetable oil at optimum injection timing when compared with neat diesel operation at 30° bTDC.

Little literature was available on studies on exhaust emissions with crude rice bran oil with low grade LHR engine. Hence an attempt was made here to determine exhaust emissions with crude rice bran oil with LHR-1 engine consisting of ceramic coated cylinder head at different operating conditions with varied injection timing and injector opening pressure and compared with CE with crude rice bran oil.

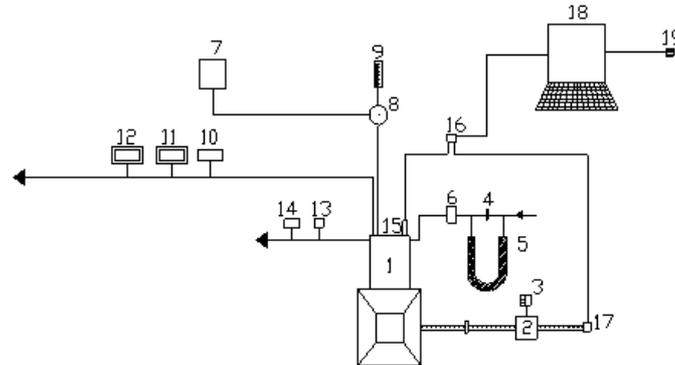
II. MATERIALS AND METHODS

The properties of the Test fuels used in the experiment were presented in Table-1.

Table.1. Properties of Test Fuels

| Fuel | Specific Gravity at 40° C (cSt) | Cetane Number | Kinematic Viscosity at 40° C (cSt) | Lower Calorific value (kJ/kg) |
|----------------------------|---------------------------------|---------------|------------------------------------|-------------------------------|
| Diesel (DF) | 0.84 | 52 | 2.25 | 42000 |
| Crude rice bran oil (CRBO) | 0.90 | 45 | 4.5 | 39000 |
| ASTM Standard | ASTM D 4809 | ASTM D 4809 | ASTM D 445 | ASTM D 7314 |

Engine with LHR-1 combustion chamber contained ceramic coating of thickness 500 microns sprayed on cylinder head. Schematic diagram of experimental setup used for the investigations on compression ignition diesel engine with crude rice bran oil is shown in Fig.1. The test fuels used in the experimentation were neat diesel and crude vegetable oil. The experimental engine was four-stroke, water cooled, single cylinder, 3.68 kW at the speed of 1500 rpm. The manufacturer's recommended injection timing and pressure were 27° bTDC and 190 bar. The bore of the engine was 80 mm, while stroke was 110 mm. The combustion chamber consisted of a direct injection type with no special arrangement for swirling motion of air. The engine was connected to an electric dynamometer for measuring its brake power. Burette method was used for finding fuel consumption of the engine.



1.Engine, 2.Electical Dynamometer, 3.Load Box, 4.Orifice flow meter, 5.U-tube water manometer, 6.Air box, 7.Fuel tank, 8, Pre-heater, 9.Burette, 10. Exhaust gas temperature indicator, 11.AVL Smoke meter, 12.Netel Chromatograph NO_x Analyzer, 13.Outlet jacket water temperature indicator, 14. Outlet-jacket water flow meter, 15.Piezo-electric pressure transducer, 16.Console, 17.TDC encoder, 18.Pentium Personal Computer and 19. Printer.

Fig.1. Experimental Set-up

Air-consumption of the engine was measured by an air-box method (Air box was provided with an orifice flow meter and U-tube water manometer). The naturally aspirated engine was provided with water-cooling system in which outlet temperature of water was maintained at 80°C by adjusting the water flow rate.

Engine oil was provided with a pressure feed system. No temperature control was incorporated, for measuring the lube oil temperature. Copper shims of suitable size were provided in between the pump body and the engine frame, to vary the injection timing and its effect on the performance of the engine was studied, along with the change of injector opening pressure from 190 bar to 270 bar (in steps of 40 bar) using nozzle testing device. The maximum injector opening pressure was restricted to 270 bar due to practical difficulties involved. Exhaust gas temperature was measured with thermocouples made of iron and iron-constantan.

Exhaust emissions of smoke and NO_x were recorded by AVL (A company trade name) smoke meter and Netel Chromatograph (A company trade name) NO_x analyzer respectively at full load operation of the engine. Various test fuels used in experiment were neat diesel and Different operating conditions of the crude vegetable oil were normal temperature and preheated temperature (95° C). Different injector opening pressures attempted in this experimentation were 190 bar, 230 bar and 270 bar. Various injection timings attempted in the investigations were 27–34° bTDC.

III. RESULTS AND DICUSSION

The optimum injection timing with CE with diesel was 31° bTDC, while it was 30° bTDC with LHR–1 engine. [23]. Similarly with crude vegetable oil operation, the optimum injection timing with CE was 32° bTDC [24]. Fig.2 shows variation of brake thermal efficiency with brake mean effective pressure (BMEP) with crude vegetable oil at various injection timings with LHR–1 engine

International Journal of Innovative Research in Science, Engineering and Technology

(An ISO 3297: 2007 Certified Organization)

Vol. 5, Issue 5, May 2016

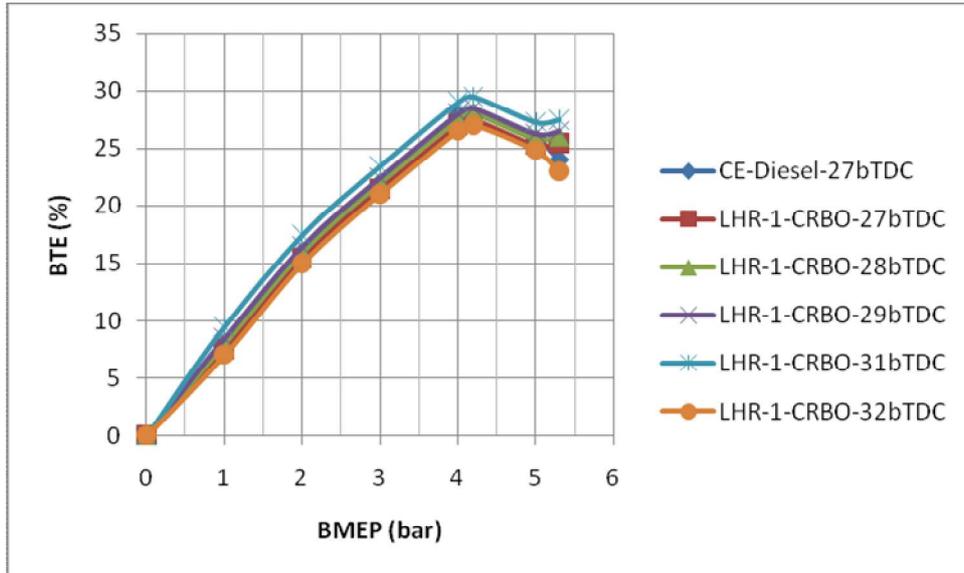


Fig.2 Variation of brake thermal efficiency with brake mean effective pressure (BMEP) with crude vegetable oil at various injection timings with LHR–1 engine.

BTE increased up to 80% of the full load and beyond that load, it decreased with crude vegetable oil operation on LHR–1 engine. Increase of fuel conversion efficiency, mechanical efficiency up to 80% of the full load might have improved performance of the engine; Reduction of fuel conversion efficiency, air fuel ratio and volumetric efficiency might have deteriorated the performance of the engine beyond 80% of the full load with crude vegetable oil operation. At recommended injection timing, the performance of the LHR–1 engine was comparable with crude vegetable oil operation. Improved heat release rates might have improved combustion reaction with crude vegetable oil operation on LHR–1 engine. When the injection timing was advanced, the performance of the LHR–1 engine increased due to increase of atomization and resident time of fuel with air. Initiation of combustion at early period increased the performance of the LHR–1 engine with crude vegetable oil operation. The optimum injection timing was found to be 31° bTDC with LHR–1 engine with crude vegetable oil operation.

3.2 Exhaust Emissions

Particulate emissions and NOx are the emissions from diesel engine cause health hazards like inhaling of these pollutants cause severe headache, tuberculosis, lung cancer, nausea, respiratory problems, skin cancer, hemorrhage, etc. [25–26]. The contaminated air containing carbon dioxide released from automobiles reaches ocean in the form of acid rain, there by polluting water. Hence control of these emissions is an immediate task and important. Fig.3 presents bar charts showing the variation of particulate emissions with both versions of the engine at recommended and optimum injection timing with test fuels at injection pressure of 190 bar.

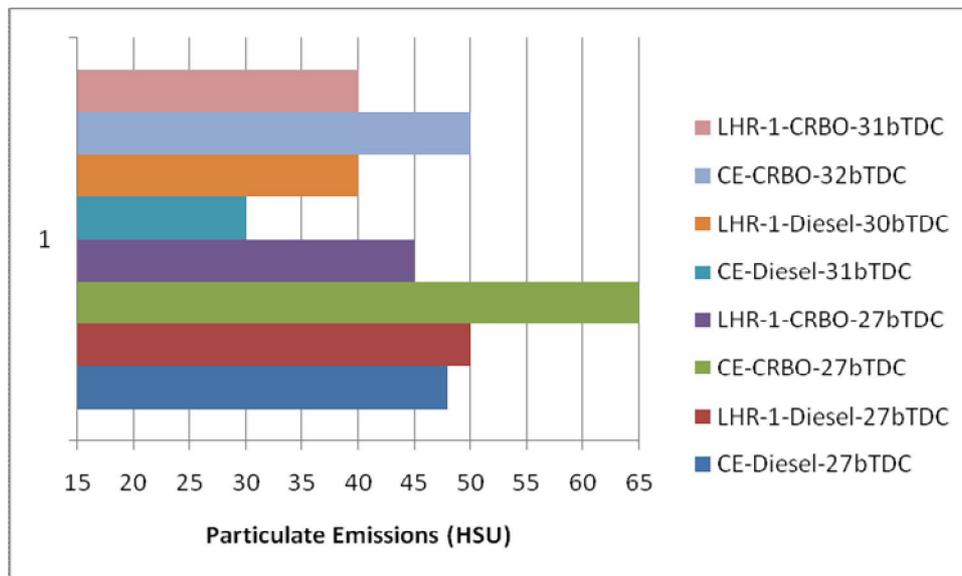


Fig.3.Bar charts showing the variation of particulate emissions in Hartridge smoke unit (HSU) at full load.

Particulate emissions at full load increased by 35% at recommended injection timing and 67% at optimum injection timing with crude vegetable oil operation on CE in comparison with neat diesel (DF) operation. Presence of fatty acids, high value of C/H ratio (C= Number of carbon atoms and H=Number of hydrogen atoms in fuel composition) and high value of density of vegetable oil drastically increased particulate emissions.

LHR-1 engine with crude vegetable oil reduced particulate emissions by 31% at recommended injection timing and 20% at optimum injection timing in comparison with CE with crude vegetable oil operation, which showed that combustion improved with LHR-1 engine with vegetable oil operation.

Table.2 shows data of particulate emissions varied with injector opening pressure at different operating conditions of the crude vegetable oil. Data from Table 2 shows a decrease in particulate emissions with different operating conditions of the crude vegetable oil with both versions of the engine with increase of injector opening pressure. Improvement in spray characteristics might have reduced particulate emissions. Preheating of the crude vegetable oil reduced particulate emissions, when compared with normal temperature of the test fuels. This was due to i) the reduction of density the crude vegetable oil, as density was directly related to particulate emissions, ii) the reduction of the diffusion combustion proportion with the preheated crude vegetable oil iii) the reduction of the viscosity of the test fuels, with which the fuel spray does not impinge on the combustion chamber walls of lower temperatures rather than it directed into the combustion chamber.

Temperature and availability of oxygen are two favorable conditions to form NO_x levels. Fig.4 presents bar charts showing the variation of nitrogen oxide levels at full load with crude vegetable oil and diesel (DF) at recommended injection timing and optimum injection timing with both versions of the engine. From Fig.4, it is noticed that NO_x levels were lower with crude vegetable oil at full load with CE when compared with diesel operation on CE. Combustion deteriorated with crude vegetable oil in CE causing lower heat release rate and thus causing lower NO_x levels in CE. However, LHR engine with crude vegetable oil gave higher NO_x levels in comparison with CE with neat diesel operation. Higher heat release rate in hot environment might have produced higher NO_x levels in LHR engine with vegetable oil operation.

NO_x levels increased with test fuels with CE, while marginal reduction of NO_x levels with LHR-1 engine was observed with advanced injection timing. Residence time and availability of oxygen had increased, when the injection timing was advanced with test fuels, which caused higher NO_x levels in CE, while improved combustion with improved air fuel ratios were responsible for reduction of NO_x levels in LHR-1 engine with crude vegetable oil operation.

From Fig.4, it is noticed that NO_x levels decreased by 18% at recommended injection timing and 18% at optimum injection timing with CE with crude vegetable oil operation in comparison with neat diesel operation. LHR-1 engine

International Journal of Innovative Research in Science, Engineering and Technology

(An ISO 3297: 2007 Certified Organization)

Vol. 5, Issue 5, May 2016

with crude vegetable oil increased NO_x levels by 71% at recommended injection timing and 28% at optimum injection timing in comparison with CE with crude vegetable oil operation.

From the Table 2, it is noted that NO_x levels increased in CE, while they decreased marginally in LHR-1 engine with increase of injector opening pressure with different operating conditions of crude vegetable oil. NO_x slightly increased with test fuels as injector opening pressure increased. This was because of improved combustion causes higher peak brake thermal efficiency due to higher combustion chamber pressure and temperature, which leads to higher NO_x formation

Table.2 Data of exhaust emissions at full load operation

| Injection Timing (° bTDC) | Test Fuel | Engine version | Particulate emissions (Hartridge Smoke Unit) | | | | | | NO _x Levels (ppm) | | | | | |
|---------------------------|-----------|----------------|--|-----|-----|-----|-----|-----|---------------------------------|------|------|------|------|------|
| | | | Injector Opening Pressure (Bar) | | | | | | Injector Opening Pressure (Bar) | | | | | |
| | | | 190 | | 230 | | 270 | | 190 | | 230 | | 270 | |
| | | | NT | PT | NT | PT | NT | PT | NT | PT | NT | PT | NT | PT |
| 27 | DF | CE | 48 | -- | 38 | -- | 34 | -- | 850 | ---- | 900 | ---- | 950 | --- |
| | CRBO | CE | 65 | 60 | 60 | 55 | 55 | 50 | 700 | 650 | 750 | 700 | 800 | 750 |
| | DF | LHR-1 | 50 | -- | 45 | -- | 40 | -- | 1200 | -- | 1150 | -- | 1100 | -- |
| | CRBO | LHR-1 | 45 | 40 | 40 | 35 | 35 | 30 | 1200 | 1150 | 1150 | 1100 | 1100 | 1050 |
| 30 | DF | LHR-1 | 40 | --- | 35 | --- | 30 | --- | 1050 | --- | 1000 | --- | 950 | --- |
| 31 | CRBO | LHR-1 | 40 | 35 | 35 | 30 | 30 | 25 | 1150 | 1100 | 1100 | 1050 | 1050 | 1000 |
| | DF | CE | 30 | -- | 35 | -- | 40 | -- | 1100 | -- | 1150 | -- | 1200 | -- |
| 32 | CRBO | CE | 50 | 45 | 55 | 50 | 60 | 55 | 900 | 850 | 950 | 900 | 1000 | 950 |

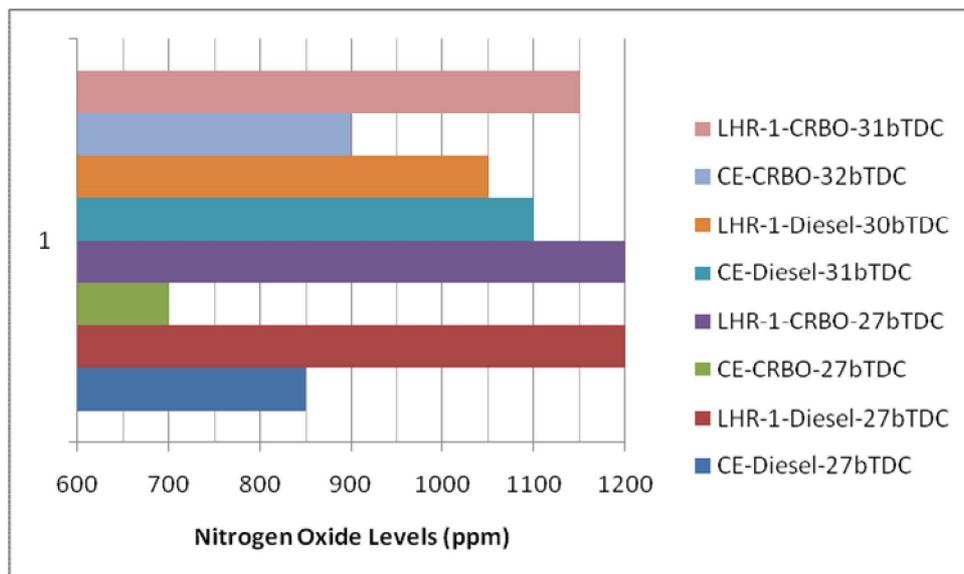


Fig.4. Bar charts showing the variation of nitrogen oxide levels (NO_x) at full load operation with test fuels

This is an evident proof of enhanced spray characteristics, thus improving fuel air mixture preparation and evaporation process. Improved combustion with improved air fuel ratios with an increase of injection pressure decreased NO_x levels in LHR-1 engine with test fuels. NO_x levels decreased with preheating of the crude vegetable oil as noticed from the Table.2 The fuel spray properties may be altered due to differences in viscosity and surface tension. The spray properties affected may include droplet size, droplet momentum, degree of mixing, penetration, and evaporation. The change in any of these properties may lead to different relative duration of premixed and diffusive combustion regimes.

International Journal of Innovative Research in Science, Engineering and Technology

(An ISO 3297: 2007 Certified Organization)

Vol. 5, Issue 5, May 2016

Since the two burning processes (premixed and diffused) have different emission formation characteristics, the change in spray properties due to preheating of the test fuels are lead to reduction in NO_x formation. As fuel temperature increased, there was an improvement in the ignition quality, which will cause shortening of ignition delay.

IV. CONCLUSIONS

1. Particulate emissions at full load increased by 35% at recommended injection timing and 67% at optimum injection timing with crude vegetable oil operation on CE in comparison with neat diesel (DF) operation. LHR-1 engine reduced particulate emissions at full load by 10% at recommended injection timing and comparable at optimum injection timing with crude vegetable oil operation in comparison with same version of the engine with diesel operation.
2. NO_x levels decreased by 18% at recommended injection timing and 18% at optimum injection timing with CE with crude vegetable oil operation in comparison with neat diesel operation .LHR-1 engine showed comparable nitrogen oxide levels at full load at recommended injection timing and 10% at optimum injection timing with crude vegetable oil operation in comparison with same version of the engine with diesel operation.
3. With increase of injector opening pressure, particulate emissions decreased, while NO_x levels increased in CE, while in LHR engine, particulate emissions and NO_x levels decreased with crude vegetable oil operation. With preheating, decrease of particulate emissions and NO_x levels were observed with crude vegetable oil operation with both versions of the engine.

4.1.Future Scope of Studies

In order to reduce nitrogen oxide levels from LHR engine with crude vegetable oil, selective catalytic reduction technique can be employed.[27]

ACKNOWLEDGMENTS

Authors thank authorities of Chaitanya Bharathi Institute of Technology, Hyderabad for providing facilities for carrying out this research work. Financial assistance provided by All India Council for Technical Education (AICTE), New Delhi, was greatly acknowledged.

REFERENCES

1. Matthias Lamping, Thomas Körfer, Thorsten Schnorbus, Stefan Pischinger, Yunji Chen, "Tomorrows Diesel Fuel Diversity – Challenges and Solutions", SAE 2008-01—1731,2008.
2. Deepak Agarwal., Lokesh Kumar., and Avinash Kumar Agarwal., "Performance evaluation of a vegetable oil fuelled compression ignition engine", Renewable Energy, 33(6), 1147–1156, 2008.
3. S.K. Acharya, R.K. Swain, and M.K. Mohanti, "The use of rice bran oil as a fuel for a small horse-power diesel engine", Energy Sources, Part A: Recovery, Utilization, and Environmental Effects, 33(1), pp 80-88, 2009.
4. P.K. Devan, and N.V. Mahalakshmi, "Performance, emission and combustion characteristics of poon oil and its blends in a DI diesel engine", Fuel, 88, pp 861-870, 2009.
5. A.K. Agarwal, and A. Dhar, A., "Comparative performance, emission and combustion characteristics of rice-bran oil and its biodiesel in a transportation diesel engine", Journal of Engineering for Gas Turbines and Power, Transactions of ASME, 132: pp 064503.1 -064503.4, 2010.
6. R.D. Misra, and M.S. Murthy, "Straight vegetable oils usage in a compression ignition engine—A review", Renewable and Sustainable Energy Reviews, 14, pp 3005–3013, 2010.
7. N. Venkateswara Rao, M.V.S. Murali Krishna, and P.V.K. Murthy, "Comparative studies on exhaust emissions and combustion characteristics of tobacco seed oil in crude form and biodiesel form in direct injection diesel engine", International Journal of Mechanical and Production Engineering Research and Development, 3(4), pp 125-138, 2013.
8. Avinash Kumar Agarwal, and Atul Dhar, "Experimental investigations of performance, emission and combustion characteristics of Karanja oil blends fuelled DIC engine", Renewable Energy, 52, pp 283–291, 2013.
9. S. Bari, T.H. Lim, and C.W. Yu, "Effect of preheating of crude palm oil on injection system, performance and emission of a diesel engine, Renewable Energy," 27(3), pp 339-351, 2002
10. O.M.L. Nwafor, "The effect of elevated fuel inlet temperature on the performance of diesel engine running on a neat vegetable oil at constant speed conditions", Renewable energy, 28, pp 171-180, 2003.
11. M. Senthil Kumar, A. Kerihuel, J. Belletre, and M. Tazerout, "Experimental investigations on the use of preheated animal fat as fuel in a compression ignition engine", Renewable Energy, 30, pp 2314-2323, 2005.

International Journal of Innovative Research in Science, Engineering and Technology

(An ISO 3297: 2007 Certified Organization)

Vol. 5, Issue 5, May 2016

12. D. Agarwal, and A.K. Agarwal, "Performance and emissions characteristics of jatropha oil (preheated and blends) in a direct injection compression ignition engine", *Int. J. Applied Thermal Engineering*, 27, pp 2314-23, 2007.
13. J.B. Heywood, "Fundamentals of Internal Combustion Engines," Tata McGraw Hills, New York, 1988.
14. I. Celikten, "An experimental investigation of the effect of the injection pressure on the engine performance and exhaust emission in indirect injection diesel engines", *Applied Thermal Engineering*, 23, pp 2051–2060, 2003.
15. Y. Cingur, and D. Altiparmak, "Effect of cetane number and injection pressure on a DI diesel engine performance and emissions," *Energy Conversion and Management*, 44, pp 389–397, 2003.
16. D.T. Hountalas, D.A. Kouremenos, K.B. Binder, V. Schwarz, and G.C Mavropoulos, "Effect of injection pressure on the performance and exhaust emissions of a heavy duty DI diesel engine," *SAE Technical Paper No. 2003-01-0340. Warrendale, PA, 2003.*
17. A. Parlak, H. Yasar, O. Idogan, "The effect of thermal barrier coating on a turbocharged Diesel engine performance and exergy potential of the exhaust gas", *Energy Conversion and Management*, 46(3), pp 489–499, 2005.
18. B. Ekrem, E. Tahsin, and C. Muhammet, "Effects of thermal barrier coating on gas emissions and performance of a LHR engine with different injection timings and valve adjustments", *Journal of Energy Conversion and Management*, 47, pp 1298-1310, 2006.
19. M. Ciniviz, C. Hasimoglu, F. Sahin, and S. Salman, "Impact of thermal barrier coating application on the performance and emissions of a turbocharged diesel engine", *Proceedings of The Institution of Mechanical Engineers Part D-Journal Of Automobile Eng.*, 222 (D12), pp 2447–2455, 2008.
20. M.V.S Murali Krishna, R.P. Chowdary, T. Kishen Kumar Reddy, and P.V.K. Murthy, "Performance evaluation of waste fried vegetable oil in a low grade low heat rejection diesel engine", *International Journal of Research in Mechanical Engineering and Technology*, 2(2), pp 35-43, 2012.
21. Ch. Kesava Reddy, M.V.S. Murali Krishna, P.V.K. Murthy, and T. Ratna Reddy, "Performance evaluation of a low grade low heat rejection diesel engine with crude Pongamia oil", *International Scholarly Research Network (ISRN) Renewable Energy*, 2012, Article ID 489605, pp 1-10, 2012.
22. T. Ratna Reddy, M.V.S. Murali Krishna, Ch. Kesava Reddy, and P.V.K. Murthy, "Studies on performance of ceramic coated diesel engine fuelled with crude mohr oil", *International Journal of Engineering Sciences*, 2(4), pp 119-129, 2013.
23. M.V.S. Murali Krishna, N. Janardhan, Ch. Kesava Reddy, and P.V. Krishna Murthy, "Experimental investigations on DI diesel engine with different combustion chambers", *British Journal of Applied Science & Technology*, 6(3), 239–260, 2014.
24. M.V.S. Murali Krishna, N. Durga Prasada Rao, B. Anjenaya Prasad, and P.V.K. Murthy, "Comparative studies on exhaust emissions and combustion characteristic of direct injection diesel engine with different combustion chamber with rice bran oil based biodiesel", *International Journal of Engineering and Innovative Technology*, 3(6), pp 163-173, 2014.
25. S.M. Khopkar, "Environmental Pollution Analysis", [New Age International (P) Ltd, Publishers, New Delhi], pp 180-190, 2010.
26. B.K. Sharma, "Engineering Chemistry", [Pragathi Prakashan (P) Ltd, Meerut], pp 150-160, 2010.
27. N. Janardhan, P. Usha Sri, M.V.S. Murali Krishna, and P.V.K. Murthy, "Performance of biodiesel in low heat rejection diesel engine with catalytic converter," *International Journal of Engineering and Advanced Technology*, 2(2), 97-109, 2012