Eco. Env. & Cons. 28 (December Suppl. Issue) : 2022; pp. (S17-S23)

ISSN 0971–765X

DOI No.: http://doi.org/10.53550/EEC.2022.v28i08s.003

Investigations on exhaust emissions of insulated diesel engine fuelled with algae oil blended with nano particles

P. Srinivas Reddy[1], M.V.S. Murali Krishna[2*] and Narsimhulu Sanke[3]

[1]Mechanical Engineering Department, College of Engineering, Osmania University, Hyderabad, India
[2]Mechanical Engineering Department, Chaitanya Bharathi Institute of Technology, Hyderabad, India
[3]Mechanical Engineering Department, College of Engineering, Osmania University, Hyderabad, India

(Received 26 June, 2022; Accepted 18 August, 2022)

ABSTRACT

Vegetable oils are good substitutes for diesel, as they are renewable, comparable calorific value and cetane (measure of combustion quality) number when compared with neat diesel operation. However, the disadvantages associated with vegetable oils such as high viscosity and low volatility cause combustion problems in diesel engines, which call for low heat rejection (LHR) engine, consisting of air gap insulated piston and air gap insulated liner. Particulate matter (PM), oxides of nitrogen (NO_x), carbon mono oxide (CO) levels and un-burnt hydro carbons (UBHC) are the exhaust emissions from a diesel engine. They cause health hazards, once they are inhaled in. They also cause environmental effects like Green-house effect and Global Warming. Hence control of these emissions is an immediate effect and an urgent step. The pollutants of PM, NO_x, CO and UBHC were determined at full load operation of the engine fuelled with algae oil blended with optimum quantity of diethyl ether (DEE) mixed with copper nano particles with varied injection timing with both versions of the engine such as conventional engine (CE) and LHR engine and compared with diesel operation on conventional engine. Particulate emissions were determined by AVL Smoke meter, while other emissions were measured by Netel Chromatograph multi-gas analyzer at full load operation. The pollutants of PM, CO and UBHC were drastically reduced with test fuel with advanced injection timing with both versions of the engine. However, NO_x emissions increased with LHR engine.

***Key words**: Health hazards for IC engine pollution, Alternative fuels, LHR Engine, Exhaust emissions, Effect of injection timing, Nano particles*

Introduction

The civilization of a particular country has come to be measured on the basis of the number of automotive vehicles being used by the public of the country. The tremendous rate at which population explosion is taking place imposes expansion of the cities to larger areas and common man is forced, these days to travel long distances even for their routine works. This in turn is causing an increase in vehicle population at an alarming rate thus bringing in pressure in Government to spend huge foreign currency for

([1]Research Scholar)

importing crude petroleum to meet the fuel needs of the automotive vehicles.

Rudolph diesel, the inventor of the engine that bears his name, experimented with fuels ranging from powdered coal to peanut oil (Fulekar, 2004).

The Exhaust emissions of the IC Engines, particularly Diesel Engines are the major constituents of Air-pollution around the globe. These emissions cause health hazards like tuberculosis, asthma, severe headache, vomiting sensation, dizziness, loss of haemoglobin, etc., when they are inhaled in (Sharma, 2012; Khopkar, 2012; Cummins, 1993). Government of India is imposing Bharath Stage-VII Pollution Norms to regulate and control pollutants from automobiles from April, 2021. Hence it is important to control these emissions at any const.

Various undesirable emissions are exhausted by the internal combustion (IC) engines which affect the environment and cause various problems such as ozone depletion, acid precipitation, global warming, respiratory hazards etc. Scientific results show that the contribution to global anthropogenic emissions from transportation amount to 21% of CO_2, 37% of Nox, 19% of volatile organic compounds (VOCs), 18% of CO and 14% of black carbon, the main source of carbonyls and VOCs result directly from incomplete combustion of fossil fuel such as vehicle exhausts and biomass burning (Cummins, 1993). Therefore it is very important for the researchers to arrive at the clean burning fuel to contribute in reducing the environment problems and growth of global warming.

In the context of fast depletion of fossil fuels, ever increase of pollution levels with fossil fuels, increase of economic burden on developing countries like India, the search for alternative fuels is necessary and inevitable.

Several researchers experimented the use of vegetable oils as fuel on conventional engines (CE) and reported that the performance was poor, citing the problems of high viscosity, low volatility and their polyunsaturated character causing the problems of piston ring sticking, injector and combustion chamber deposits, fuel system deposits, reduced power, reduced fuel economy and increased exhaust emissions (Avinash Kumar Agarwal *et al.*, 2013; Avinash Kumar Agarwal *et al.*, 2009; Agarwal *et al.*, 2010). Hence they required a hot combustion chamber which is provided by a low heat rejection (LHR) diesel engine.

Low heat rejection diesel engine or semi adiabatic diesel engine (LHR) is suitable for burning high viscous fuels like vegetable oils and plastic oils, as they provide hot combustion chamber by providing insulation in the path of heat flow to the coolant. LHR may be classified as low grade, medium grade and high grade LHR engines. Low grade LHR contains ceramic coating on inside portion of cylinder head. Medium grade LHR engine consists of air gap insulated piston and air gap insulated liner. High grade LHR contained ceramic coating plus air gap insulated engines. Several researchers conducted experiments on medium grade LHR engines and reported that performance parameters like brake thermal efficiency increased, exhaust gas temperature and coolant load decreased and pollution levels of particulate matter decreased (Chennakesava Reddy *et al.*, 2011; Janardhan *et al.*, 2012; Murali Krishna *et al.*, 2013; Srikanth *et al.*, 2013). However, main drawback with LHR engine increased NO_x emissions. Increase of NO_x emissions may be reduced by supercharging or exhaust gas recirculation or selective catalytic reduction technique. The other researchers used air gap insulated piston with superni crown and air gap insulated liner with superni insert for medium grade LHR engines. The material superni is highly expensive, tough machinability characteristics and rarely available. Pollution levels decreased with advanced injection timing, as it promotes atomization characteristics (Avinash Kumar Agarwal *et al.*, 2009; Chandrakasan Solaimuthu *et al.*, 2013; Venkateswara Rao *et al.*, 2013a; Venkateswara Rao *et al*, 2013b; Venkateswara Rao *et al.*, 2013c). By blending with nano particles of copper and aluminium, combustion will be improved in IC engines thereby reduction pollution (Gurusala *et al.*, 2015; Babu *et al.*, 2015; Basha *et al.*, 2014; Mehta *et al.*, 2014; Tyagi *et al.*, 2008; Mohammed *et al.*, 2021). However, nitrogen oxide levels increased with nano particles.

From the above literature, it is known that very few reports are available on determination of exhaust emissions from insulated diesel engine, consisted of air gap insulated piston and air gap insulated liner, fuelled with algae oil blended with nano particles. The authors worked in this direction.

Materials and Methods

The algae oil blended with diethyl ether (DEE) was injected through normal conventional system. The algae oil was also blended with copper nano particles. The exhaust emissions of Particulate matter (PM), Oxides of nitrogen (NO_x), carbon monoxide (CO) emissions and un-burnt hydro carbons (UBHC) were determined with algae oil blended with varied injection pressure and data were compared with neat diesel fuel operation on conventional engine. The nano particles are added 20 mg of the one litre solution of test fuel. The preparation of the copper nano particles was mentioned in Reference. 17. They were prepared in Indian Institute of Chemical Technology, Hyderabad.

Table 1 shows the properties of algae fuel are shown as below

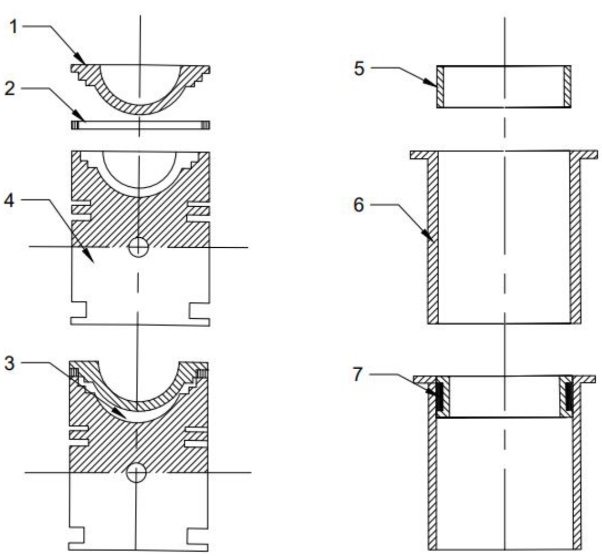
Table 1. Properties of Algae Oil

	Algae Oil	Diesel
Specific Gravity at 40 °C	0.91	0.84
Cetane Number	51	55
Viscosity at 40 °C	4.84 mm²/s	3.0mm²/s
Calorific Value	41MJ/kg	42MJ/kg

Fabrication of Combustion Chamber of Medium grade LHR engine

Fig.1 shows assembly details of combustion chamber of medium degree insulated engine.

It contained a two-part piston; the top crown (1) made of low thermal conductivity material, stainless steel (A-304 Grade-B) screwed to aluminum body of the piston by keeping a gasket made of stainless steel (2), providing an optimum air gap (3) 2.8 mm in between the crown and the body of the piston. The optimum thickness of air gap in the air gap piston was found to be 2.8 mm for improved performance of the engine with stainless steel insert and diesel as fuel A stainless steel insert (5) was screwed to the top portion of the liner in such a manner that an optimum air gap (7) of 2.8 mm was maintained between the insert and the liner body (6). At 500 °C the thermal conductivity of stainless steel (A 304 Grade-B) and air are 16.0 and 0.057 W/m-K respectively. Stainless steel employed by the authors is plenty available, good machinability characteristics and less expensive.



1. Stainless steel crown, 2. Stainless steel gasket, 3. Air gap in the piston, 4 Body of the piston. 5. Stainless steel insert for liner, 6. Body of the liner and 8. Air gap in the liner

Fig. 1. Combustion chamber of the medium grade insulated diesel engine

Experimental set up

Fig. 2 shows that the test engine (1) and the details of the engine are given in Table 1. 2 shows the specification of the experimental engine. It was located at Applied Thermo Dynamics Laboratory of MED, CBIT, Hyderabad. The engine was connected to power measuring device (2). The engine had computerized test bed. There was facility of loading the engine by means of variable rheostat. (3). The mass flow rate of air was measured by an orifice meter (4), U-tube water manometer (5) and air box (6). Air box will reduce pressure oscillations in intake manifold. Fuel circuit consisted of components, fuel tank (7), three way valve (8) and burette (9).

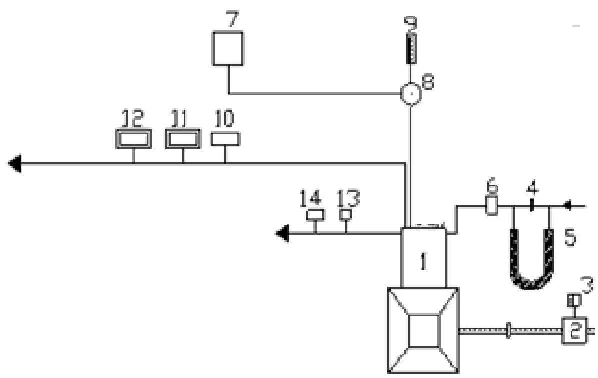
Table 2 gives the details of the engine.

The temperature of the exhaust gas was indicated with exhaust gas temperature sensor (10).The particulate levels were determined with AVL Smoke meter (11) at full load operation. The pollutants of

Table 2. Details of the Engine

Description	Specification
Make	Kirloskar
Number of cylinders	01
Number of Strokes	04
Ratio of bore to stroke	80 mm/110 mm
Power	3.68 kW (5 HP) at the rated speed of 1500 rpm
Compression Ratio	16.5:1
Type of cooling Arrangement	Water cooling
Recommended Injection Pressure	190 bar
Recommended Injection Timing	27 degrees before top dead centre

CO and UBHC were determined by Netel Chromatograph multi gas analyzer (12) at full load operation. The range and accuracy of the analyzers in multi gas analyzer are shown in Table 3. Outlet jacket water temperature was indicated with temperature sensor (13). The flow of the coolant was measured with flow meter (14). The engine was provided with gravity lubrication system. Algae oil blended with optimum quantity of 15% by DEE, which in turn mixed with nano particles of copper. There was facility to increase injection pressure by means of nozzle testing device.



1. Engine, 2. Electical Dynamometer, 3. Load Box, 4. Orifice flow meter, 5. U-tube water manometer, 6.Air box, 7. Fuel tank, 8, Preheater, 9. Burette, 10. Exhaust gas temperature indicator, 11. AVL Smoke meter, 12. Netel Chromatograph NOx Analyzer, 13. Outlet jacket water temperature indicator, 14. Outlet-jacket water flow meter.

Fig. 2. Schematic diagram of experimental set-up

The test fuels of the investigations were i) neat diesel and ii) Algae oil blended with 15% diethyl ether and copper nano particles. The pollutants of PM, NO_x, CO and UBHC emissions were determined at full load of the engine, at recommended injection timing (RIT) and optimum injection timing (OIT) with algae fuel blended with an optimum quantity of 15% diethyl ether (DEE) and copper nano particles.

Results and Discussion

Fig. 3 shows the variation of brake thermal efficiency (BTE) with brake mean effective pressure for conventional engine (CE) for algae oil blended with 15% DEE and nano particles.

BTE increased up to 80% of the load and beyond that load, it decreased with test fuels. This is due to increase of fuel conversion efficiency, mechanical efficiency and oxygen-fuel ratio up to 80% of the full load and reduction of the same beyond 80% of the load. The optimum injection timing (OIT) is the timing, at which the efficiency of the engine with test fuels is greater or equal to diesel operation on conventional engine. The recommended injection timing (RIT) is the timing specified by the manufacturer. (27°bTDC). At RIT, the performance of algae oil (AO) with CE deteriorated due to lower calorific value and high viscosity of the fuel. However, at 30°bTDC, performance improved due to atomization characteristics of the test fuel. Hence the optimum

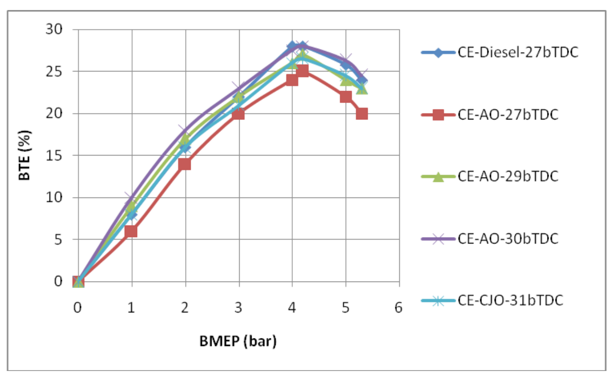


Fig. 3. Variation of BTE with BMEP for conventional engine (CE) with algae oil (AO)

Table 3. Range and accuracy of Analyzers

S.No	Name of the Analyzer	Principle adopted	Range	Accuracy
1	AVL Smoke Analyzer	Opacity	0-100 HSU(Hartridge Smoke Unit)	±1 HSU
2	Netel Chromatograph CO analyzer	Infrared absorption spectrograph	0-10%	± 0.1%
3	Netel Chromatograph UBHC analyzer	NDIR	0-1000 ppm	±5 ppm
4	Netel Chromatograph NO_x analyzer	Chemiluminiscence	0-5000pm	±5 ppm

injection timing for CE with algae oil was found to be 30°bTDC.

Fig. 4 shows the variation of brake thermal efficiency (BTE) with brake mean effective pressure for LHR engine for algae oil (AO) blended with 15% DEE and nano particles. The optimum injection timing for LHR engine was observed to be 29°b TDC, which was lower than CE due to hot combustion chamber provided by LHR engine.

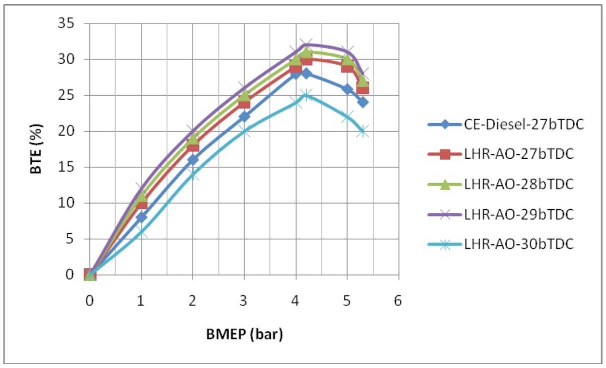


Fig. 4. Variation of BTE with BMEP for LHR engine with algae oil (AO)

Exhaust Emissions

Fig. 5 presents the bar chart showing the variation of particulate emissions in Hartridge Smoke Unit (HSU) at full load with algae oil at RIT and OIT with both versions of the engine.

Particulate emissions at full load decreased with advanced injection timing with both versions of the engine due to improved atomization characteristic of the fuel. Particulate emissions at full load decreased with LHR engine in comparison with CE at RIT and OIT. This is due to improved combustion with high heat release rate by LHR engine. As the fuel was blended with DEE and nano particles combustion improved with reduction in viscosity of the fuel, improved cetane number with both versions of the engine leading to reduce particulate emissions in comparison with CE with diesel operation..

Fig. 6 presents the bar chart showing the variation of NO_x levels at full load with algae oil at RIT and OIT. NO_x levels decreased with CE, while it increased with LHR engine at RIT. Combustion deteriorated with CE, while gas temperatures increased with LHR engine at RIT. NO_x levels increased with CE, while they decreased with LHR engine with advanced injection timing. This is due to increase of gas temperatures with CE, while decrease of same with LHR engine. NO_x levels were found to be higher with LHR engine than CE with test fuel at RIT and OIT. This is due to increase of heat release rate and faster rate of combustion with LHR engine.

Fig. 7 presents the bar chart showing the variation of carbon monoxide (CO) emissions at full load with both versions of the engine. CO emissions reduced with blend of nanoparticles due to efficient combustion of fuel with high thermal conductivity of copper nano particles. CO emissions at full load deceased with advanced injection timing with both versions of the engine due to improved atomization characteristics of the fuel. LHR engine reduced CO emissions considerably than CE at full load. This is due to improved combustion with high heat release rate and faster rate of combustion with LHR engine.

Fig. 8 presents the bar chart showing the variation of un-burnt hydro carbon (UBHC) emissions at full load with both versions of the engine with test fuel of algae oil (AO).

The UBHC emissions at full load followed similar trends with CO emissions. CO is formed due to in-

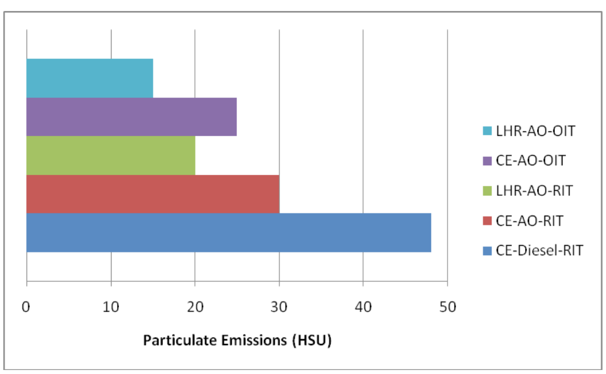


Fig. 5. Variation of particulate emissions in Hartridge Smoke Unit (HSU) at full load with both versions of the engine with algae oil (AO).

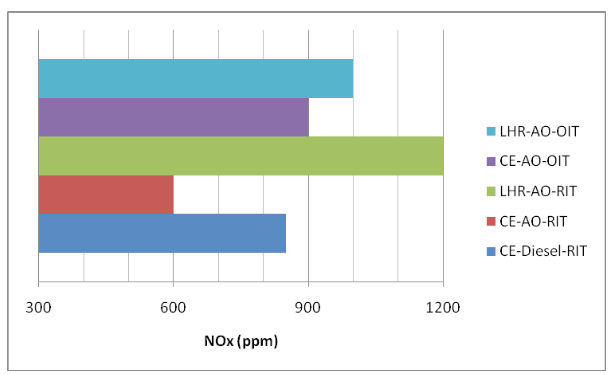


Fig. 6. Variation of Nitrogen Oxide emissions at full load with both versions of the engine with algae oil (AO).

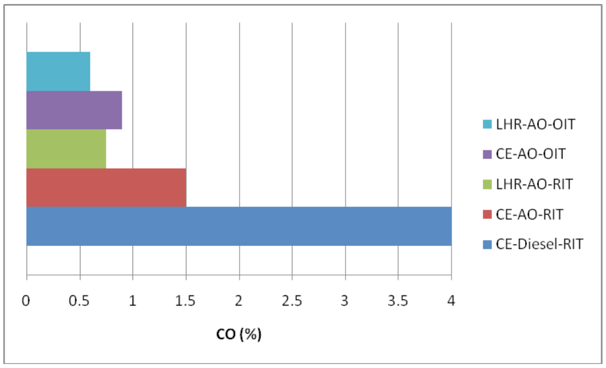


Fig. 7. Variation of CO emissions at full load with injection pressure, with both versions of the engine with algae oil (AO).

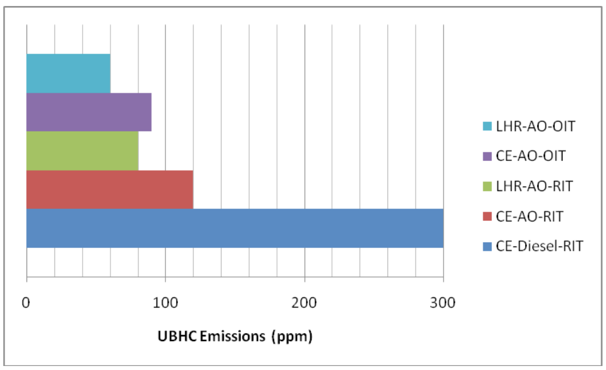


Fig. 8. Variation of UBHC emissions at full load with two configurations of the engine.

complete combustion of the fuel, while UBHC emissions are formed due to accumulation of the fuel in the crevice volume. UBHC emissions decreased with advanced injection timing with both versions of the engine. This is due to improved oxidation reaction of the fuel with improved atomization characteristics of the fuel. LHR engine reduced UBHC emissions considerably than CE at RIT and OIT. This is due to reduction of ignition delay with LHR engine, leading to reduce UBHC emissions.

Conclusion

The optimum injection timing for CE was 30^{o}b TDC, (before top dead centre) while, it was 29^{o}b TDC with LHR engine. Particulate emissions, carbon monoxide levels and un-burnt hydro carbons drastically decreased with advanced injection timing, in comparison with diesel operation on conventional engine. However, nitrogen oxide levels at full load increased with CE, with advanced injection timing. LHR reduced all pollutants except NO_x levels in comparison with CE with vegetable oil operation.

Acknowledgements

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

References

Avinash Kumar Agarwal and Atul Dhar, 2009. Performance, emission and combustion characteristics of jatropha oil Blends in a direct injection CI engine, *SAE International*. 2009.

Agarwal, A.K. and Dhar, A. 2010. 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 : 064503.1 - 064503.4

Avinash Kumar Agarwal and Atul Dhar. 2013. Experimental investigations of performance, emission and combustion characteristics of Karanja oil blends fuelled DICI engine. *Renewable Energy.* 52 : 283-291.

Avinash Kumar Agarwal, Dhananjay Kumar Srivastava, and Atul Dhar, 2013. Effect of fuel injection timing and pressure on combustion, emissions and performance characteristics of a single cylinder diesel engine. *Fuel.* 111 : 374-383.

Babu, K.R. and Raja, R.B. 2015. Theoretical and experimental validation of performance and emission characteristics of nano additive blended diesel engine. *Int J Res Aeronaut Mech Eng*. 3 : 18–31.

Basha, J.S. and Anand, R.B. 2014. Performance, emission and combustion characteristics of a diesel engine using carbon nanotubes blended Jatropha methyl ester emulsions. *Alexandria Eng J*. 53: 259-273.

Cummins, C. Lyle, Jr. 1993. *Diesel's Engine, Volume 1: From Conception To 1918.* Wilsonville, OR, USA: Carnot Press.

Chennakesava Reddy, Murali Krishna, M.V.S., Murthy, P.V.K. and Ratna Reddy, T. 2011. Potential of low heat rejection diesel engine with crude pongamia oil. *International Journal of Modern Engineering Research.* 1(1) : 210-224.

Chandrakasan Solaimuthu and Palani Swamy Govindaraju, 2013. Effect of injection timing on performance, combustion and emission characteristics of diesel engine using mahua oil methyl ester. *Journal of Scientific and Industrial Research*. 71: 69-74.

Gurusala, N.K. and Selvan, V.A. 2015. Effects of alumina nanoparticles in waste chicken fat biodiesel on the operating characteristics of a compression ignition engine. *Clean Tech Env Policy*. 17 : 681-692.

Janardhan, N., Murali Krishna, M.V.S., Usha Sri, P. and Murthy, P.V.K. 2012. Potential of a medium low heat rejection diesel engine with crude jatropha oil. *International Journal of Automotive Engineering and Technologies.* 1(2): 1-16.

Khopkar, S.M. 2012. *Environmental Pollution Analysis*. [New Age International (P) Ltd, Publishers, New Delhi] : 180-190.

Fulekar, M.H. 2004. Chemical pollution – a threat to human life. *Indian J Environmental Protection.* 1 : 353-359.

Murali Krishna, M.V.S., Durga Prasada Rao, N., Anjeneya Prasad, A. and Murthy, P.V.K. 2013. Improving of emissions and performance of rice brawn oil in medium grade low heat rejection diesel engine. *International Journal of Renewable Energy Research.* 3(1): 98-108.

Mehta, R.N., Chakraborty, M. and Parikh, P.A. 2014. Nanofuels: combustion, engine performance and emission. *Fuel.* 120 : 91–97.

Mohammed, S. Gad, Sayed M. Abdel Razek, P.V. Manu and Simon Jayara, 2021. Experimental investigations on diesel engine using alumina nanoparticle fuel additive. *Advances in Mechanical Engineering*. 13(2) : 1-16.

Sharma, B.K. *Engineering Chemistry,* [Pragathi Prakashan (P) Ltd, Meerut]: 50-160

Srikanth, D., Murali Krishna, M.V.S., Usha Sri, P. and Krishna Murthy, P.V. 2013. Comparative studies on medium grade low heat rejection diesel engine and conventional diesel engine with crude cotton seed oil. *International Journal of Innovative Research in Science, Engineering and Technology.* 2(10) : 5809-5228.

Tyagi, H., Phelan, P.E. and Prasher, R. 2008. Increased hot plate ignition probability for nanoparticle-laden diesel fuel. *Nano Lett*. 8 : 1410–1416.

Venkateswara Rao, N., Murali Krishna, M.V.S. and Murthy, P.V.K. 2013. aEffect of injector opening pressure and injection timing on performance parameters of high grade low heat rejection diesel engine with tobacco seed oil based biodiesel. *International Journal of Current Engineering &Technology.* 3(4): 1401-1411.

Venkateswara Rao, N., Murali Krishna, M.V.S. and Murthy, P.V.K. 2013b. Effect of injector opening pressure and injection timing on exhaust emissions and combustion characteristics of high grade low heat rejection diesel engine with tobacco seed oil based biodiesel. *International Journal of Recent Technology and Engineering.* 2(4) : 70-79.

Venkateswara Rao, N., Murali Krishna, M.V.S. and Murthy, P.V.K. 2013c. 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) : 125-138.