Performance analysis of CI engine using biodiesel from waste cooking oil

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Abstract: *As a renewable, sustainable and alternative fuel for compression ignition engine, biodiesel instead of diesel has been increasingly fueled to study its effect on engine performances and emissions recently. Biodiesel derived from the transesterification of vegetable oils or animal fats, is composed of saturated and unsaturated long-chain fatty acid alkyl esters. Present study focuses on performance analysis of waste cooking oil biodiesel and diesel. The performance of a CI engine having 4 stroke water cooled is evaluated with different blends of biodiesel prepared from waste cooking oil biodiesel and diesel. The performance tests of the engine were carried on different load conditions for different blend of biodiesel and then data obtained from the experiments were used to evaluate the performance parameters like brake thermal efficiency, brake power, brake specific fuel consumption and emission parameters such as exhaust gas temperature, carbon monoxide, Nitrogen oxide. From the results it is observed that the maximum BP is 3 Kw at 80% of load, maximum BTE is 18.33% for B20, BSFC decreases as the load increases, EGT is observed higher than diesel at full load, CO and NO emission increases with load. Overall it can be said that waste cooking oil biodiesel can be used as alternative renewable fuel which can be blended in diesel and used in CI engine without modifications as fuel.*

Keywords: **Transesterification, biodiesel, performance, emissions, CI engine**

1. Introduction

The fuel used in IC engine are made up of hydrocarbons and are derived mostly from fossil fuels. Fossil fuels include diesel fuel, gasoline and petroleum gas, and the rare use of propane. Except for the fuel delivery components, most IC engines that are designed for gasoline use can run on natural gas or liquefied petroleum gases without major modifications. Liquid and gaseous biofuels, such as ethanol and biodiesel can also be used. Engines with appropriate modifications can also run on hydrogen gas, wood gas, or charcoal gas, as well as from so called producer gas made from other convenient biomass. Most widely used modern fuels like petrol and diesel in IC engine have a maximum thermal efficiency of about 20% to 35% when used to power a car that means about 65-80% of total power is emitted as heat without being turned up into useful work. At present two-third of world energy demand is met by fossil fuels like petroleum and natural gas. Fast depletion of fossil fuels is urgently demanding an exhaustive research effort to find out the viable alternative fuels for meeting sustainable energy demand with minimum environmental impact. Today's energy system is unsustainable because of incompetent issues as well as environmental, economic and geopolitical concern that have implications far into the future. However, increase in stringent environment regulations on exhaust emissions and anticipation of the future depletion of worldwide petroleum reserves provides strong encouragement for research on alternative fuels. According to world oil meter the total oil consumption is 90 lakh barrels per day in 2015. So worlds consumption rate of oil remains same for next year than total oil reserve of the world will last for next 48 years. In this regard new alternative fuel is required for the next generation of human. Looking forward biodiesel is the best alternatives of oil specifically for IC engine. Early experiments on vegetable oil fuels included the French government and Dr Diesel himself, who envisioned that pure vegetable oils could power early diesel engines for agriculture in remote areas of the world, where petroleum was not available at the time. India is one of the largest petroleum consuming and importing country. India import about 70% approximately 35 million tones consisting about 35% of the total petro product consumption. Biodiesel derived from the oils and fats of plants like sunflower, rape seeds, Canola or Jatropha can be used as substitute or an additive to diesel. Biodiesel is a renewable liquid fuel that can be produced locally thus helping reduce the country's dependence on imported crude petroleum diesel. Biodiesel refers to a non-petroleum based diesel fuel consisting of short chain alkyl esters, made by transesterification of vegetable oil or animal fat. This biodiesel can be used alone or blend with diesel in unmodified IC engine. Biodiesel is a biofuel produced from various feedstock's including vegetable oils such as oilseed, rapeseed, soybean, animal fat or algae. Many other edible and non-edible oils available in the Indian subcontinent and across the globe are also used as feed stock for biodiesel. As edible oils are required for food its first used to satisfy that objective but after using it for food then it is waste so we can also use this waste cooking oil to produce biodiesel. Biodiesel fuel burns up to 75% cleaner than diesel fuel made from fossil fuels. Biodiesel substantially reduces unburned hydrocarbons, carbon monoxide and particulate matter in exhaust fumes. The alternative fuel is plant based and adds absolutely no carbon dioxide to the atmosphere. The importance of biodiesel is energy independence, smaller trade deficit, economic growth, cleaner air, less global warming and easy to use.

2. Literature Review

Jehad et. al. (2009) presented a comparative study on the use of new as well as waste oil as source of biodiesel fuel for CI engine. The result showed that there was a loss in calorific value of about 13.43% for waste oil biodiesel and 7.24% for unused oil biodiesel. The density of the fuel was found to increase by about 4.75% with respect to diesel. Biodiesel shows improvement in the torque, power and thermal efficiency and reduction in BSFC. Agrawal and Dhar (2010) used neat karanja oil and preheated karanja oil to run a diesel engine. The decrease in efficiency was observed with straight vegetable oil. The main reason behind these reductions in thermal efficiency were reported due to poor volatility and higher viscosity of oil. With preheating of karanja oil resulted in better atomization and combustion leading to less fuel consumption as compared to without preheating of oil. The increments of fuel consumption rate were found to be approximately 39% and 17% for non-preheated and preheated karanja oil respectively. K Anubumani et al (2010) observed the feasibility of using one edible plant oil mustard and one non edible plant oil neem as diesel substitute in CI engine. Oils were esterified before blending with pure diesel in the ratio of 10:90, 15:85, 20:80 and 25:75 by volume popularly known as B10, B15, B20 and B25 respectively. It was revealed that physical and chemical properties of this blends improved remarkably. Results have indicated that engine run at B20 blend of oils showed a close performance with diesel along with low smoke intensity, emission of NOx and HC. Parameters such as fuel consumption, BSFC, BTE and cylindrical peak pressure improved. This was achieved without any modification in existing CI engine. Sagar kadu et.al. (2010) performed experimental investigation on the use of preheated karanja oil as fuel in CI engine. The preheating of Karanja oil was done from 30°C to 100°C, engine speed from 1500 to 4000 rpm with varying load from no load to full load conditions. No significant change in BSFC observed for preheated and unheated vegetable oil. The heated fuel showed a marginal decrease in BTE as compared to diesel fuel during operation. The maximum power was observed at 3500 rpm and which is slightly more than that of diesel. The overall test results showed that fuel heating was not beneficial at low speed operation. Bhupendra Singh Chauhan et al. (2011) studied performance, emission and combustion characteristics of biodiesel derived from Jatropha oil using CI engine comparing it with diesel. The BTE of Jatropha biodiesel and their blends as compare to diesel were less whereas BSFC was found to be more. Emission parameters such as CO, HC, CO_2 and smoke were found less for Jatropha biodiesel whereas NOx were higher as compare to diesel. The reduction in emissions may be due to complete combustion of fuel inside the cylinder using biodiesel and its blends with diesel in engine. Pascal Ndayishimiye et al. (2011) used palm oil as fuel in IC engine. The blends of palm oil have low heating value as compared to diesel, the BTE increases with blends of palm oil in diesel with increase in CO emission. NOx emission are higher at low load but lower at full load conditions. Results shows increasing BSFC with preheated palm oil, palm oil blend diesel compared to diesel. HC emissions are significantly reduced with preheated palm oil compare to diesel while they slightly increase during blending of palm oil with diesel. Siddalingappa R Hotti et al. (2011) investigates the performance and combustion of CI engine using Karanja oil and blends with diesel like K10, K15 and K20 and the experimental results were compared with that of diesel. The higher amount of carbon residue may lead to carbon deposits on the combustion chamber and viscosity was found to be higher, the flash point enables the safe storage and transportation. The BSFC to develop the same amount of engine output power was found to be more may be due to low calorific value of all the blends. The thermal efficiency of K15 was well comparable with that of diesel. Engine ran successfully even on K100 fuel without any engine modifications. Finally based on performance and combustion characteristics it can be seen that K15 was found to be optimum blend. Sivanathan sivalaxmi et al. (2011) investigated the effect of neem oil and its methyl ester on a CI engine. A mechanical unit pump of helical plunger type made by Bosch is used to deliver the fuel to the multi hole orifice. Two separate fuel tanks with a fuel switching system are used. The thermal efficiency is lower for oil than that of biodiesel and diesel. It may be due to larger differences in viscosity, specific gravity and volatility between diesel and neem oil. Poor spray formation and reduced spray angle causes reduction in air entrainment and fuel air mixing rates. The neem biodiesel has a lower viscosity which results in better atomization that leads to complete combustion of fuel as compared to neem oil. The performance, combustion and emission characteristics of neem biodiesel is better than neem oil and hence neem biodiesel is quite suitable as an alternative fuel to diesel. Nityam Oza et al. (2012) check the performance of neem biodiesel in CI engine. B20 blend of neem biodiesel was taken and compared with diesel. BTE with B20 fuel was maximum 32.72% at BP of 9.60 kW while the maximum BTE with diesel was found to be 31.80% at BP of 9.85 kW this is due to more oxygen content in biodiesel. Minimum BSFC for diesel fuel is 0.2764 kg/kWh and minimum BSFC for B20 fuel is 0.2933 kg/kWh. EGT measured at full load which is 351.12°C and 355.56°C for B20 and diesel fuel respectively. Due to low EGT for B20 emission of NOx is less as compare to that of diesel. This is one of another reason to have higher BTE of B20 as compare to diesel. K Nantha Gopal et. al. (2014) worked on pongamia oil. Biodiesel from pongamia oil was prepared such as PME100, PME 20, PME 40, PME 60 and PME 80. Parameters such as BTE, BSFC, CO, unburned HC, smoke and NOx are evaluated and results indicate that PME can be used as an alternative fuel for diesel engine. Ankit Jani et. al (2015) studied the effect of varying load on performance and emission of diesel engine using waste plastic oil which is blended with diesel in different proportion. Experimental results show that SFC decreases with increase in load while BTE increases for all blends. Emission results shows that emission of HC, NOx and CO_2 increases with increase in load in all blend proportion. Results shows that 30% waste plastic oil diesel blend has lower SFC and higher BTE with compare to diesel. Also emission of NOx and CO_2 is less than that of diesel in 30% waste plastic oil diesel blend but HC emission is increased by small level. The results showed that waste plastic oil can be used in CI engine with diesel and 30% blend with diesel gives optimum result for performance and emission of diesel engine.

3. Methodology

3.1 Experimental Set Up

A four stroke single cylinder Swaraj make diesel engine is used to conduct the test. The engine is coupled with electrical generator of 5 kW and operated at constant speed of 1500 rpm. The fuel used during normal engine operation were diesel, DEE and various blend of DEE biodiesel which are 20%, 40% and 60%. The detailed specification of engine is given in table 1. As shown in Figure 1 an engine is connected with an electric generator of 5 kW rating. The various measuring instrument is mounted on the engine like burette, which measures fuel consumption.

Table 1. Specification of Engine

Particular	Details
Make	Swaraj
Model	PV-4
Type	Four stroke, Water cooled
Fuel	HS Diesel
Cylinders	1
Displacement Volume	780 cm^3
Bore	95 mm
Stroke	110 mm
Compression ratio	15.5:1
Rated output (kW)	5.9 kW / 8 BHP
Specific fuel consumption	251 g/kWh
Rated speed	1600 rpm
Lubricant Oil Grade	SAE 30/40/Multigrade

Figure 1. Experimental Test Facility

There is a separate load panel consisting of 100 W two number of bulb, 200 W one number of bulb, 500 W two number of halogen and 1000 W four number of halogen to vary load on the engine. Battery is used to start an engine and also self-cranking mechanism is provided. Thermocouple are used to measure temperatures at radiator inlet and outlet, exhaust inlet and outlet. The details of experiments conducted in different modes of operation are explained. All tests were conducted at the rated speed of 1500 rpm. All readings were taken only after the engine attained stable operation. All measuring equipment are calibrated. Firstly, the blend of biodiesel like diesel, B20, B40, B60 and B100 were prepared. After the engine is started and set to no load condition the observations were taken only after the temperature become constant. The observations made during the experiment are time taken for 10 ml fuel consumption from burette, all temperatures shown by thermocouple, load on an engine, current and voltage from electric dynamometer. Once the readings are taken the load on the engine is changed by switching on bulb from the load panel and again measuring all parameters at this load condition. The different load at which observations were recorded are 300 W, 500 W, 1000 W, 2000 W, 3000 W and 4000 W respectively.

3.2 Materials

A Recycling of waste products is one of the most important issues in developing and developed countries. Waste cooking oil (WCO) is one of the prominent source for production of biodiesel by transesterification process. Normally after the use of cooking oil one discard it as waste and further it has no use as food product. However, one must consider WCO as prominent source for production of biodiesel. Transesterification of WCO not only helps in reducing the viscosity but also helps in keeping WCO to be used as biofuel in IC engine. Under normal transesterification process the reaction would accelerate with the addition of catalyst like sodium hydroxide, potassium hydroxide and sodium methoxide. WCO have no significant share of the domestic cooking oil as it directly affects the human health. WCO is a mixture of esters of long chain fatty acids its molecular weight is more than that of diesel. Fatty acids vary in carbon chain length and in the number of unsaturated bonds. The saturated fatty acid component accounts for almost 50% of total fatty acids.

Figure 2. Waste cooking oil and its biodiesel

Table 2. Properties of WCO at different blends

Blends	Density (kg/m^3)	Calorific Value (MJ/kg)
Diesel	830	44.20
B20	833	44.80
B40	829	44.60
B60	840	44.90
B80	836	44.70
B100 (WCO)	832	38.33

The development of alternative fuel from WCO can meet several demands of our country and can partially substitute fossil fuel. The glycerine byproduct has thousands of industrial chemical uses in common household products and foods. Biodiesel is one of the alternative fuels that are environmentally friendly because biodiesel can reduce emissions. Important properties of WCO biodiesel blends used in this study are compared with petro diesel in Table 2.

4. Results and Discussion

As shown in Figure 3 BTE increases as load on engine increases. For 80% of loading condition we get maximum BTE. There is not much variation in BTE for all blends of biodiesel up to 1000 W of load on engine. At 80% load we get highest BTE for 20% of blending which is 18.33% and the lowest BTE is of B80 which is 13.87%. Diesel has lower BTE compared to B20, B40 and B60. BTE decrease as percentage of biodiesel increase in diesel.

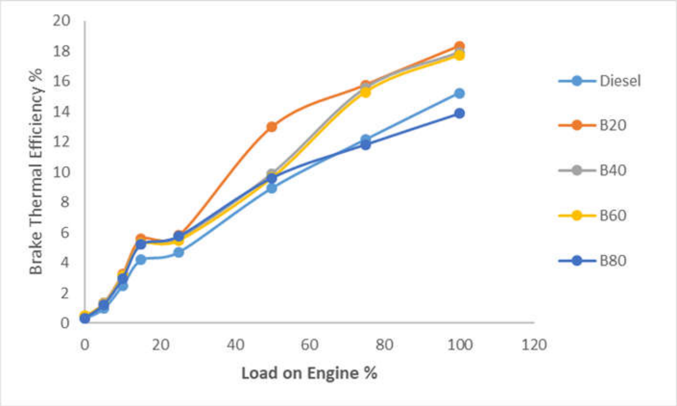

Figure 3. Variation of BTE with Load on Engine

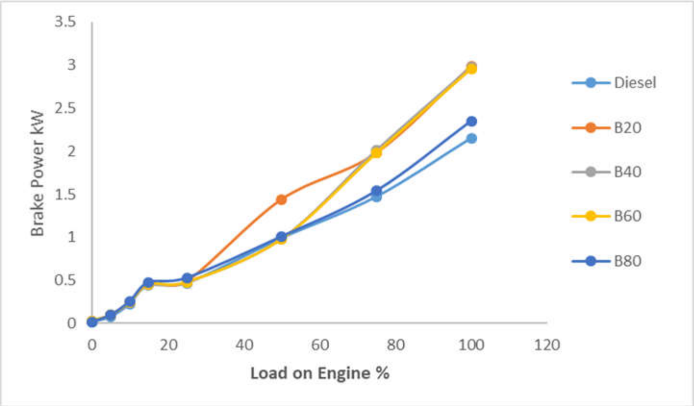

Figure 4. Variation of BP with Load on Engine

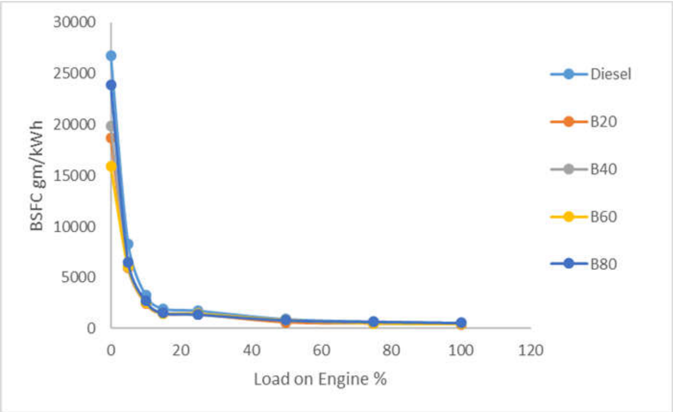

Figure 5. Variation of BSFC with Load on Engine

As shown in Figure 4 the graph of Brake power with variation of load, it can be observed that BP increases with increasing the load on engine. BP is almost equal up to 0.5 kW for all blends. BP is maximum at 80% loading condition of engine. Maximum BP is observed for B20 which is 3 kW at maximum load. There is rapid increase in BP for B60 after 40% of loading. B80 has lower BP than other blends. Hence with increasing percentage of blend in diesel BP is decreasing. It is observed that diesel has lower BP compared to biodiesel at full load.

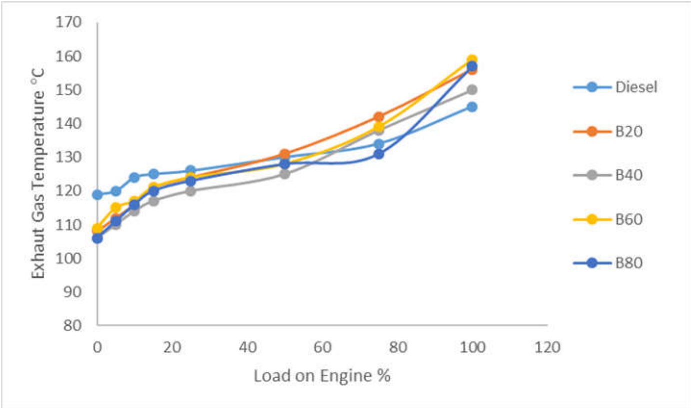

Figure 6. Variation of EGT with Load on Engine

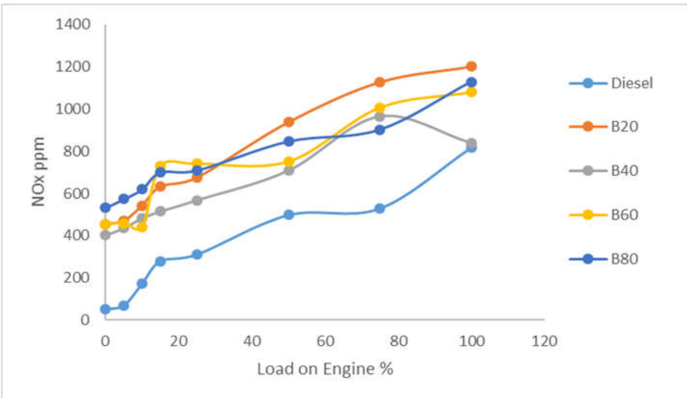

Figure 7. Variation of NOx with Load on Engine

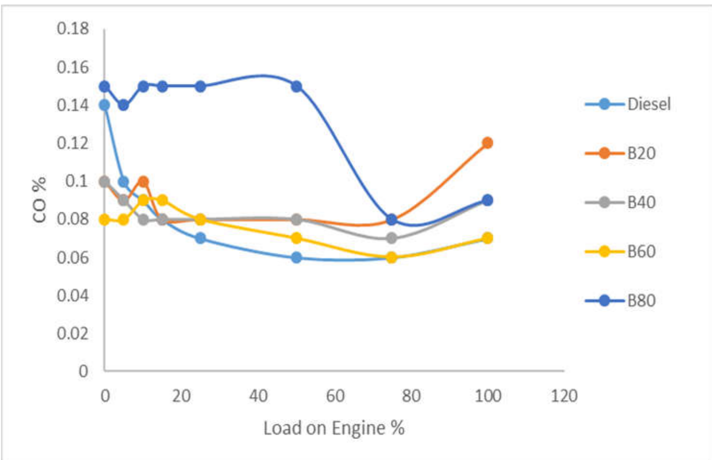

Figure 8. Variation of CO with Load on Engine

As shown in Figure 5 we can find that there is decrease in BSFC for all different blending of biodiesel as the load on engine increases. There is maximum BSFC for lower load on engine. Minimum BSFC is 438 gm/kWh for 80% of load. As shown in Figure 6 with increasing load on engine there is increase in exhaust gas temperature. With the increase of load more fuel is burned inside the cylinder and more temperature is generated and so the exhaust gas temperature increases. There will be higher fuel consumption at higher load and highest temperature is observed for B60 at 80% of engine load. Maximum exhaust gas temperature is 160°C of B60. As shown in Figure 7 NOx emission increases with increasing loading conditions. It is observed initially emission increases but it starts decreasing after 500 W of load. Overall minimum emission is observed for B40. B80 has more emission than other blends but NOx emission observed for diesel is minimum at all loading conditions compared to different blends. Figure 8 shows variation of CO emission with different blends of biodiesel at varying load. There is highest CO emission for B20 at 80% of the loading condition. Highest CO emission is emitted by B80 at 40% load on engine. At 60% of load B60 has less emission compared to diesel.

5. Conclusions

In this experimentation, performance of single cylinder, four stroke diesel engine is evaluated using WCO biodiesel The experiment was performed with various blend of biodiesel measuring various performance parameters such as BP, BTE, BSFC and emission parameters like EGT, CO and NOx which are compared with diesel. It was observed that BP was maximum for B20 blend at 80% load which is 3 kW. It is 39.4% higher than diesel at full load condition. BTE is maximum for B20 blend at 80% of load which is 18.33%. The maximum variation in BTE is observed at 40% of load which is 4.05% higher than diesel. BSFC for B20 is lowest among all blend. In case of B20 the BSFC is around 17% less than diesel fuel at full load. EGT is increases with increasing load on engine. There is 8% increase in temperature compared to diesel at full load. Carbon monoxide emission is observed minimum for B20 than all other blends minimum emission is observed at 20% of load on engine. NOx emission increases with increasing load on engine. It is observed that B40 has lowest emission than other at full load. NOx emission observed for diesel is minimum compared to different blends of biodiesel. From said experiment engine’s best suitable conditions for performance and lowest emission is derived. The optimum condition for performance of engine using biodiesel is blend of 20% biodiesel and 40% load on engine. Whereas desiring lowest emission, optimum condition is to use B40 blend.

REFERENCES

[1] *Yamin, Jehad & Sakhnini, dr.nina & Hamdan, Mohammad. (2009). Performance of CI engines using Biodiesel as fuel.*

[2] *Agrawal A K and Dhar A, "Karanja oil utilization in a direct injection engine by preheating part 1", Journal of Automobile Engineering, vol. 224,* ***(2010),*** *pp. 73-84.*

[3] *K Anbumani and Ajit Pal Singh, "Performance of mustard and neem oil blends with diesel fuel in CI engine", ARPN Journal of Engineering and Applied Sciences, vol. 4, no. 4,* ***(2010).***

[4] *Sagar Kadu and Rajendra Sarda, "Experimental investigations on the use of preheated neat Karanja oil as fuel in a Compression Ignition engine", International Journal of Mechanical and Mechatronics Engineering, vol. 4, no. 12,* ***(2010).***

[5] *Bhupendra singh Chauhan, Naveen Kumar, Haeng Muk Cho, "A study on the performance and emission of a diesel engine fueled with Jatropha biodiesel oil and its blends", Energy, vol. 37, no. 1,* ***(2012)****, pp. 612-626.*

[6] *Pascal Ndayshimiye and Mohand Tazerout, "Use of palm oil based biofuel in the internal combustion engine: Performance and emission characteristics", Energy, vol. 33, no. 3,* ***(2011)****, pp. 1790-1796.*

[7] *Siddalingappa R Hoti and Omprakash Hebbal, "Performance and combustion characteristics of single cylinder diesel engine running on Karanja Oil diesel fuel blends", Engineering, vol. 3,* ***(2011),*** *pp. 371-375.*

[8] *Sivanathan Sivalakshmi and Thangavel Balusamy, "Experimental investigation on a diesel engine fueled with need oil and its methyl ester", Thermal Science, vol. 15, no. 4,* ***(2011)****, pp. 1193-1204.*

[9] *Nityam P Oza, Nikul K Patel, Pravin Rathod, "Performance comparison of 4stroke multicylinder Ci engine using neem biodiesel and diesel as fuel", Proceedings of National Conference on Emerging Vistas of Technology in 21st century, Vadodara, Gujarat, India,* ***(2012),*** *April 8-9.*

[10] *K Nantha Gopal, R Thundi Karupparaj, "Effect of pongamia biodiesel on emission and combustion characterisitics of DI compression ignition engine", Engineering Journal, vol. 6,* ***(2015),*** *pp. 297-305.*

[11] *Ankit Jani, Tushar Patel, Gaurav Rathod, "Effect of varying load on performance and emission of CI engine using WPO diesel blend", Journal of Mechanical and Civil Engineering, vol. 12, no. 2,* ***(2015)****, pp. 37-44.*