Journal Homepage: - www.journalijar.com
INTERNATIONAL JOURNAL OF ADVANCED RESEARCH (IJAR)
ISSN NO. 2320-5407
Article DOI: 10.21474/IJAR01/8421
DOI URL: http://dx.doi.org/10.21474/IJAR01/8421

RESEARCH ARTICLE

STUDY OF THE PERFORMANCE AND EMISSION CHARACTERISTICS OF DI DIESEL ENGINE FUELLED WITH BIODIESEL-DIESEL BLENDS.

Elshenawy Abd Elhamid. Elshenawy, Medhat A. M. Elkelawy, Magda Kotb El-fakharany, Hagar Alm-Eldin Bastawissi and Mohamed Mostafa Shafey.
Department of Mechanical Power Engineering, Faculty of Engineering, Tanta University, Egypt.

Manuscript Info

Manuscript History
Received: 16 November 2018
Final Accepted: 18 December 2018
Published: January 2019

Key words:-
Biodiesel; CI Diesel Engine, CO emission, NO_x emissions.

Abstract

The ever increase in global energy demand, consumption of depletable fossil fuels, exhaust emissions and global warming, all these led to search about alternative fuels. Biodiesel and its blends with diesel fuel are investigated to solve the problem of depletion of fossil fuels and environmental impact. Biodiesel was produced from waste cooking-oil by transesterification process. Blends of waste cooking-oil biodiesel and diesel oil were prepared in volume percentages of 20, 40, 60, 80 and 100% as B20, B40, B60, B80 and B100. Biodiesel blends have ASTM standards of physical and chemical characterization near to diesel fuel. Diesel engine performance and exhaust emissions were studied experimentally for burning waste cooking-oil blend with diesel fuel. This experimental was applied on a diesel engine at different engine loads from zero to full load. Thermal efficiencies for waste cooking-oil biodiesel blends were lower than diesel oil. Specific fuel consumptions of biodiesel blends were higher than diesel fuel. Higher exhaust gas temperatures were recorded for biodiesel blends compared to diesel oil. CO_2 emissions for waste cooking-oil biodiesel blends were higher than diesel oil. CO and HC emissions for biodiesel blends were lower than diesel fuel. NO_x emissions for biodiesel blends were higher than diesel fuel.

Introduction:-

The need of energy is increasing continuously due to rapid increase in the number of industries and vehicles owing to population explosion. The sources of this energy are petroleum, natural gas, coal, hydrocarbon and nuclear. The major disadvantages of using petroleum based fuels are atmospheric pollution created by the use of petroleum diesel [1]. The use of bio-fuels in place of conventional fuels would slow the progression of global warming by reducing sulfur and carbon oxides and hydrocarbon emissions [2]. A biofuel is a fuel that produced through contemporary biological processes, such as agriculture and anaerobic digestion, rather than a fuel produced by geological processes. Also those involved in the formation of fossil fuels, such as coal and petroleum, from prehistoric biological matter. Biofuels can be derived directly from plants, or indirectly from agricultural, commercial, domestic, and/or industrial wastes [3]. Biodiesel is an alternative diesel fuel derived from vegetable oils or animal fats. The main components of vegetable oils and animal fats are triglycerides or also known as ester of fatty acid attached to glycerol [4]. This renewable fuel can be produced from different feedstock containing fatty acids. Such

Corresponding Author: - Mohamed Mostafa Shafey.
Address:-Department of Mechanical Power Engineering, Faculty of Engineering, Tanta University, Egypt.

as animal fats, non-edible oils (Jatropha oil, Karanji or Pongamia oil, Neem oil, Jojoba oil, Cottonseed oil, Linseed oil, Mahua oil, Deccan hemp oil, Kusum oil, Orange oil, and Rubber seed oil), and waste cooking oils and by products of the refining vegetables oils and algae [5]. There are different processes which can be applied to synthesize biodiesel such as direct use and blending, micro emulsion process, thermal cracking process and the most conventional way is transesterification process. This because that method is relatively easy, carried out at normal conditions, and gives the best conversion efficiency and quality of the converted fuel [6]. Trans-esterification method refers to a catalyzed chemical reaction involving vegetable oil and alcohol to yield fatty acid alkyl esters (biodiesel) and glycerol. It requires a catalyst, usually a strong base, such as sodium and potassium hydroxide or sodium methylate [7]. A number of researchers have experimentally investigated the combustion, performance, and emission characteristics of vegetable oils and their esters in diesel engines. Kinoshita et al have investigated the combustion and emission characteristics of palm and rapeseed oil methyl esters and compared with gas oil in naturally aspirated water-cooled small direct injection (DI) diesel engine and swirl-chamber diesel engine. They found that the ignition delay of palm oil methyl ester was found to be lower when compared to gas oil. Similarly rapeseed methyl ester showed a longer ignition delay as compared to gas oil. The authors have also reported that the distillation temperatures of palm oil methyl ester at 5 to 90% recovery are lower than rapeseed oil methyl ester and stated that the former has a better volatility as compared to the later [8]. In comparison with conventional diesel fuels, the fuel-borne oxygen in biodiesel may promote more complete combustion. Thus reduce particulate matter (PM), carbon monoxide (CO) and total hydrocarbons (THC) in compression-ignition engine, while increase nitrogen oxides (NOx) [9]. According to a review on emission data for heavy-duty engines published by EPA (Environmental Protection Agency of USA) ,from diesel to B20 (20% biodiesel by volume), CO, HC, and PM decreased by 13%, 20% and 20% respectively, while NO_x emission increased by 4% on average [10].The aim of this study is to investigate the combustion, performance and emissions of a diesel engine operating on biodiesel blends, using biodiesel produced from waste cooking oil, and to compare these results with those obtained from diesel.

Experimental set-up and apparatus:

The experimental apparatus used for this study includes one cylinder diesel engine, coupling, water cooling coil, diesel fuel tank, load adjustment, forced air inlet, outlet exhaust, water dynamometer inlet, water dynamometer exit, water tank, water dynamometer inlet, power, torque and RPM output.

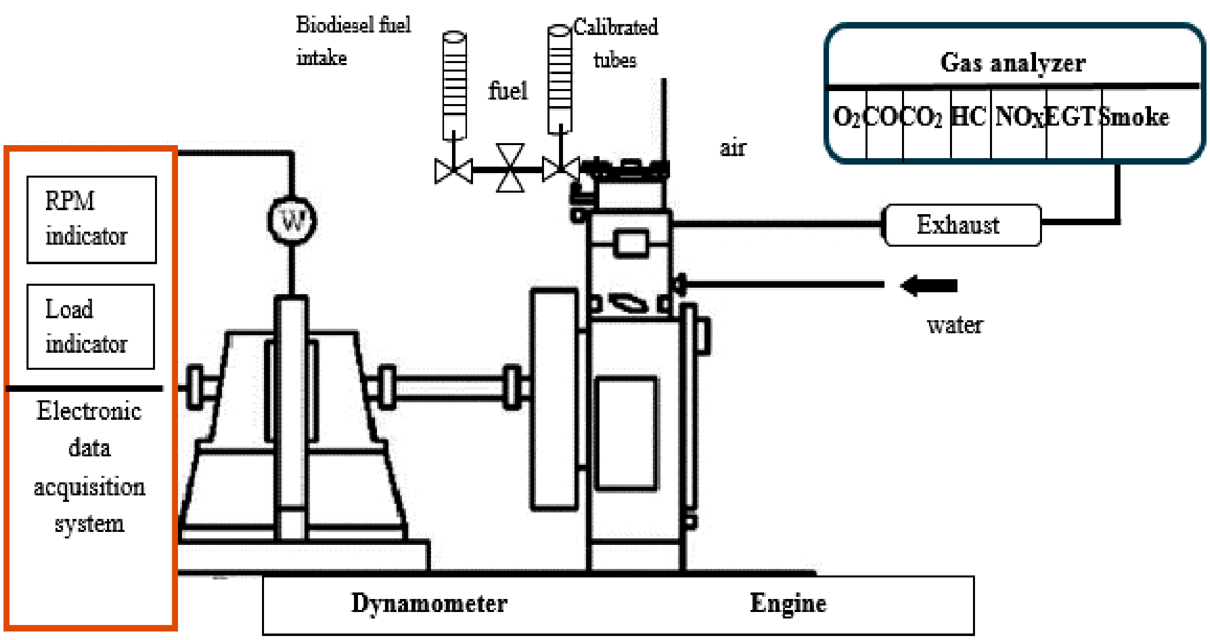

Figure 1:-schematic layout for single cylinder engine with dynamometer

The engine used in the thesis is DEUTZ FL 511/W which is a single cylinder four stroke DI diesel engine modified to partially premixed charge compression ignition engine (PPCCI) mode for running by using an intake manifold system. The diesel engine specifications are summarized in Table (1).

Table 1: Diesel engine specifications

Engine Parameter	Specification
Type	DEUTZ FL 511/W
No. of cylinder	1 cylinder
Bore	100 mm
Stroke	105 mm
Displacement	825 cm3
Compression ratio	17
Power	7.7 HP = 5.7 kW
Cooling type	Air cooling
Direction of rotation	Counter-clockwise
Weight	116 kg
Oil capacity, approx.	2.4 liter
Lubrication system	Forced circulation
Piston crown clearance	1-1.2 mm
Inlet valve opens Inlet valve closes Exhaust valve opens Exhaust valve closes	32º before TDC 59º after BDC 71º before BDC 32º after TDC
Inlet valve closes	59 after BDC
Exhaust valve opens	71 before BDC
Exhaust valve closes	32 after TDC
Injection release pressure	160 bars

Exhaust gas analyzer: The tests of NO_x, CO, CO_2 and UHC can be attempted by HPC 500/400 auto exhaust emissions analyzer which select non-dispersive infrared ray (NDIR) based on different gases absorbs infrared rays. For testing UHC, CO, CO_2 and NO_x emissions the instrument select the same light source and the detectors by advanced technologies such as AGC circuit, micro processing computing technology and automatic zeroing display the measured values.

The exhaust analyzer can display instantaneous value and average concentration value as required by national inspection code which displayed by the front panel or printed out. An oxygen sensor is mounted for testing the oxygen concentration which its output current has linearity relationship with oxygen concentration.

In order to know the auto combustion and the exhaust has leakage or no, the instrument can display the excessive air coefficient (λ), the carbon monoxide (CO), the carbon dioxide (CO_2), the nitrogen monoxide (NO) and the nitrogen dioxide (NO_2) which are related to the nature of the combustion. The smoke opacity can be measured by using gas and smoke analyzer HPC 500/400 which measure the smoke opacity according to filter exist at lens at the back of the setup and then the smoke opacity can be measured visually according to the blackness at the filter.

Table 2:-Specifications of the standard diesel and biodiesel

SPECIFICATION	DIESEL	BIODIESEL	STANDARD
Calorific Value (MJ/KG)	42.1	93.51	ASTM D240
Density (Kg/m³)	830	875	ASTM D1298
Cetane Number	55	68	ASTM D976
Kinematic Viscosity (mm²/sec)	2.38	3.54	ASTM D445
Flash Point (°C)	45	158	ASTM 93
Specific Gravity at (15°C)	0.85	0.88	ASTM D1298
Auto Ignition Temperature (°C)	263	273	ASTM D6751
Molecular weight	200	292	ASTM D6751
Cloud Point (°C)	0	6	ASTM D2500
Oxygen (wt.%)	0	9.414	ASTM D5291
Water (vol.%)	0.05	0.05	ASTM D6751
Easter Yield (%)	-----	93.24	EN 14214

Specifications of diesel and biodiesel samples:
The specifications of the produced biodiesel are measured by the laboratories of biodiesel Alrafeek Company. The standard specifications of diesel and biodiesel, which are used for the experiments, are listed below in Table 2.

Error anaysis:-
Errors and uncertainties in the experiments can arise from instrument selection, condition, calibration, environment, observation, reading, and test planning. Errors will creep into all experiments regardless of the care which is exerted. Uncertainty analysis is needed to prove the accuracy of the experiments. In any experiment, the final result is calculated from the primary measurements. The error in the final result is equal to the maximum error in any parameter used to calculate the result (Holman) Percentage uncertainties of various parameters like total fuel consumption, brake power, brake specific fuel consumption and brake thermal efficiency was calculated using the percentage uncertainties of various instruments used in the experiment. For the typical values of errors of various parameters given in Table 4, using the principle of propagation of errors, the total percentage uncertainty of an experimental trial can be computing as the following:

Total percentage uncertainty = $\sqrt{(BP)^2 + (BSFC)^2 + (BTE)^2 + (EGT)^2 + (HC)^2 + (CO)^2 + (NOx)^2 + (CO2)^2}$

Result and discussion:-
By installing irrigation diesel engine, the injection pressure was adjusted to 140 bar and the fuel temperature was at 25°c. there was no changes for pressure and temperature for all experiments. The emission measure devise was installed at the exhaust discharge.

Figure 2 shows that by increasing the engine load, the fuel mass flow (MF)rate percentage increased at different fuel blends. After replacement diesel fuel by biodiesel blend (B20), MF increased. After increasing load by dynamometer, the MF is increasing for B20. After replacing the biodiesel fuel (B20) with biodiesel blend (B40,60,80,100) as sequence, there was direct proportion between biodiesel blend number and MF.

Figure 3 which shows the increasing rate of MF by increasing the biodiesel blend ratio, the increasing rate was calculated by considering the diesel reference to other fuel. The rate has calculated by the following equation:

$$\mathrm{R(MF)} = \frac{\mathrm{MF(Bi)} - \mathrm{MF(B0)}}{\mathrm{MF(B0)}}$$

R: is rate of increasing

MF (Bi): value of mass fuel rate at variable biodiesel fuel

MF (B0): value of MF at diesel fuel

This means that fuel consumption increases for biodiesel than diesel. The increasing change by load changing and biodiesel blend ratio. For all blends the increasing rate raises gradually by increasing load.

A diesel engine test using waste cooking-oil biodiesel fuel was run to investigate engine performance. Figure 4 shows that with increasing load by dynamometer, the Brake Specific Fuel Consumption (BSFC) value decreased with different fuel blends. By using diesel, BSFC increases with load. After replacing diesel fuel by biodiesel blends by adding 20% of waste cooking-oil biodiesel by volume, there was increase in specific fuel consumption. These were reported by many researchers [11-15]. By increasing biodiesel blend ratio, we found positive proportion between biodiesel blend number and BSFC as reported by Srithar et al (2014) [16] and Kolhe et al (2014) [17].

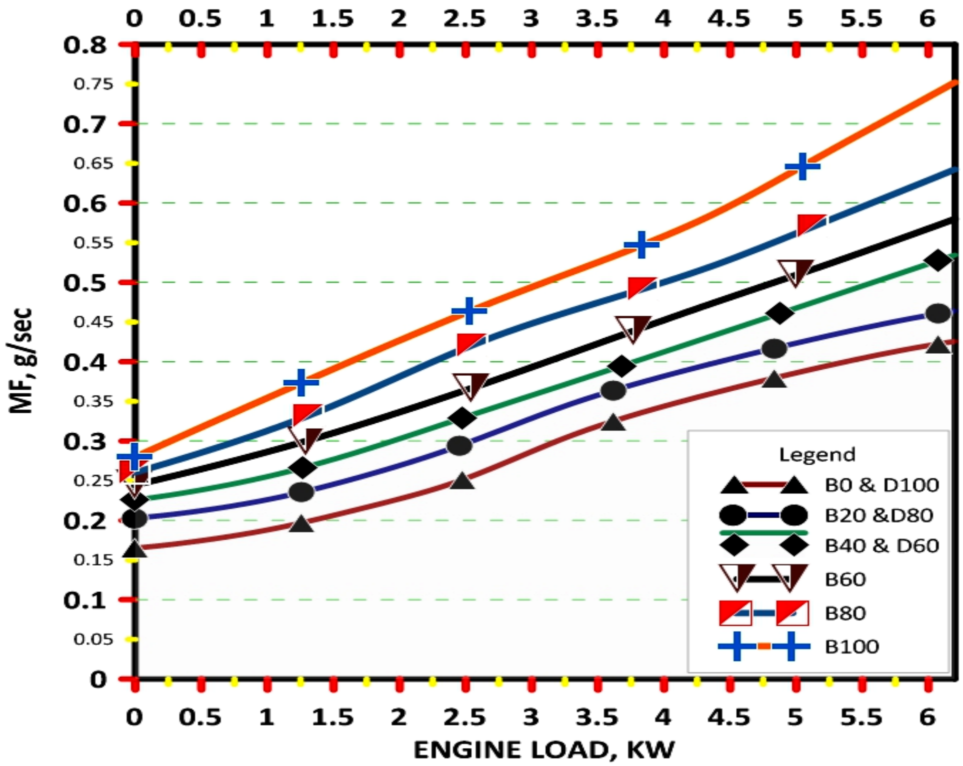

Figure 2:-Mass Flow rate variation for diesel & biodiesel blends

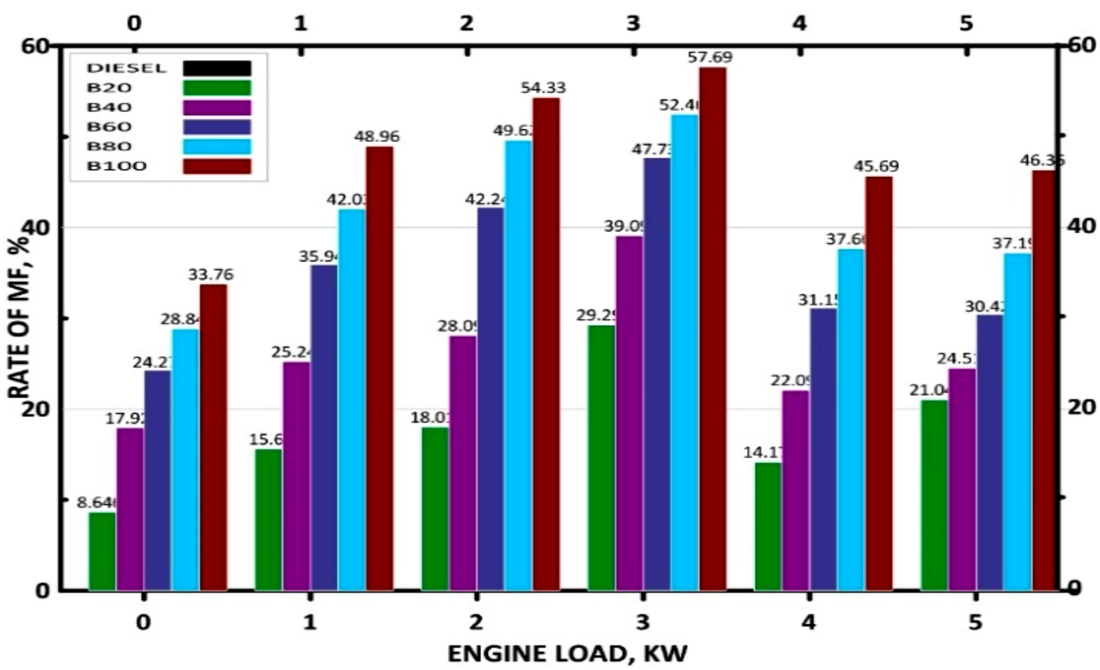

Figure 3:-Rate of MF increasing for biodiesel blends

Figure 5 shows the increased rate of BSFC by increasing the biodiesel blend ratio, which means that BSFC increases for biodiesel than diesel.

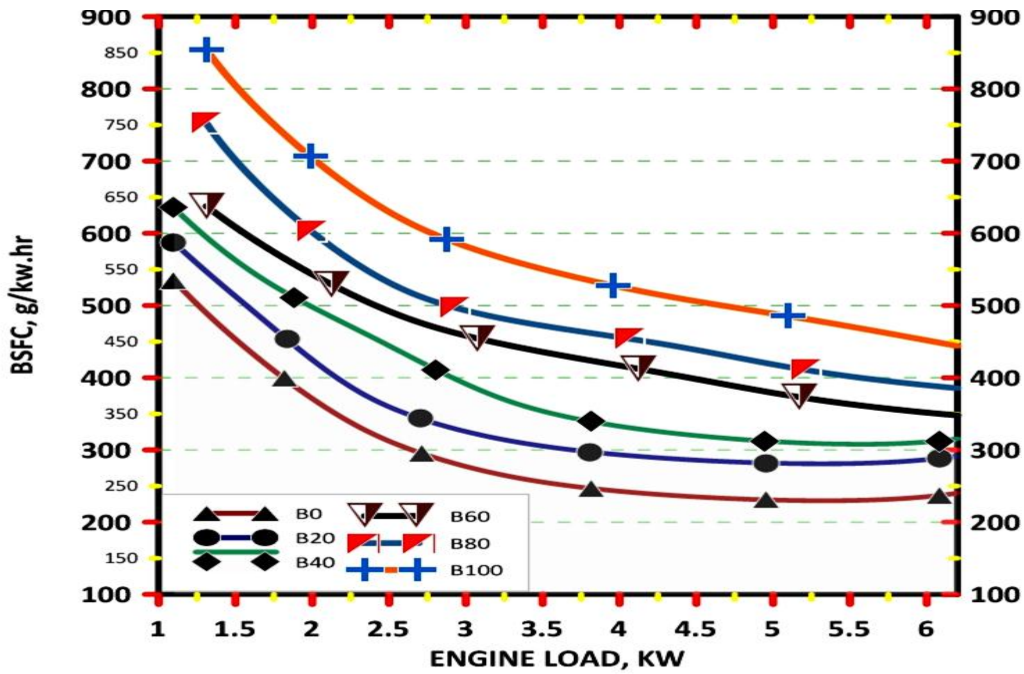

Figure 4:-BSFC variation for diesel& biodiesel blends

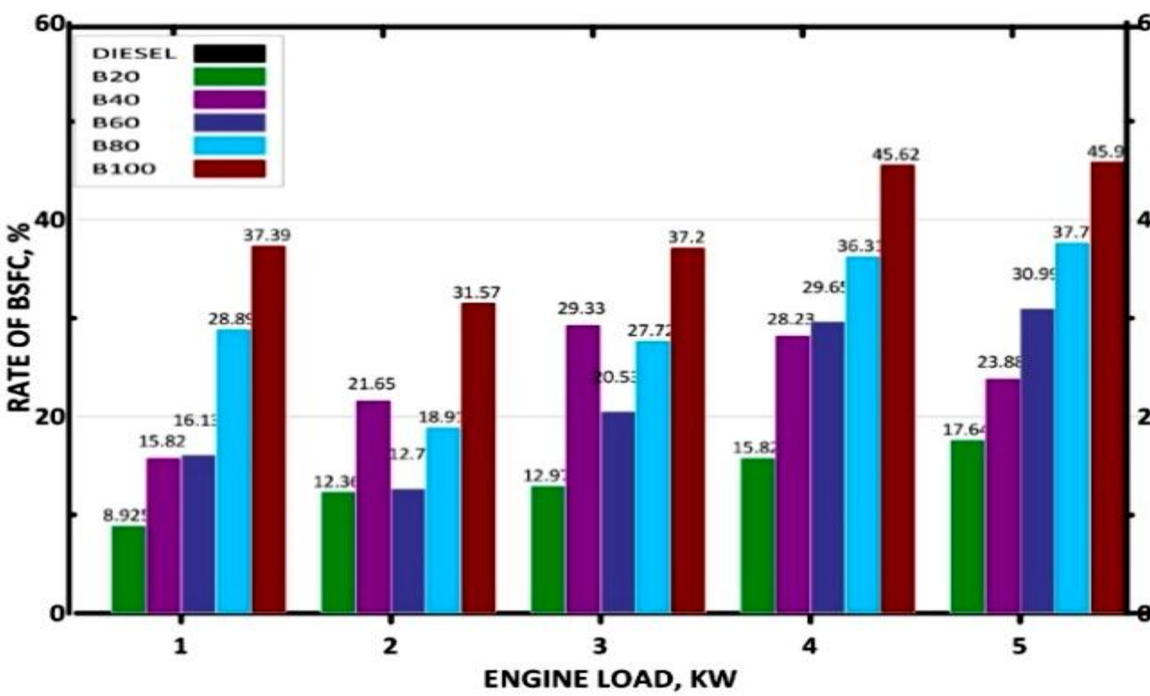

Figure 5:-Rate of BSFC increasing for biodiesel blends

Figure 6 shows break thermal Efficiency (BTE), which means the capacity of mechanical energy conversion by engine from heat released by the explosion of fuel inside the cylinder volume. BTE was directly proportional to brake power developed and inversely proportional to mass fuel injection and calorific value. These results obtained were similar to results reported by many researchers [18, 19, 20, 21, 22, 23]. Figure 7 shows the decreasing rate of BTE by increasing the biodiesel blend ratio, which means that BTE decreases for biodiesel than diesel. the increasing change by load changing and biodiesel blend ratio.

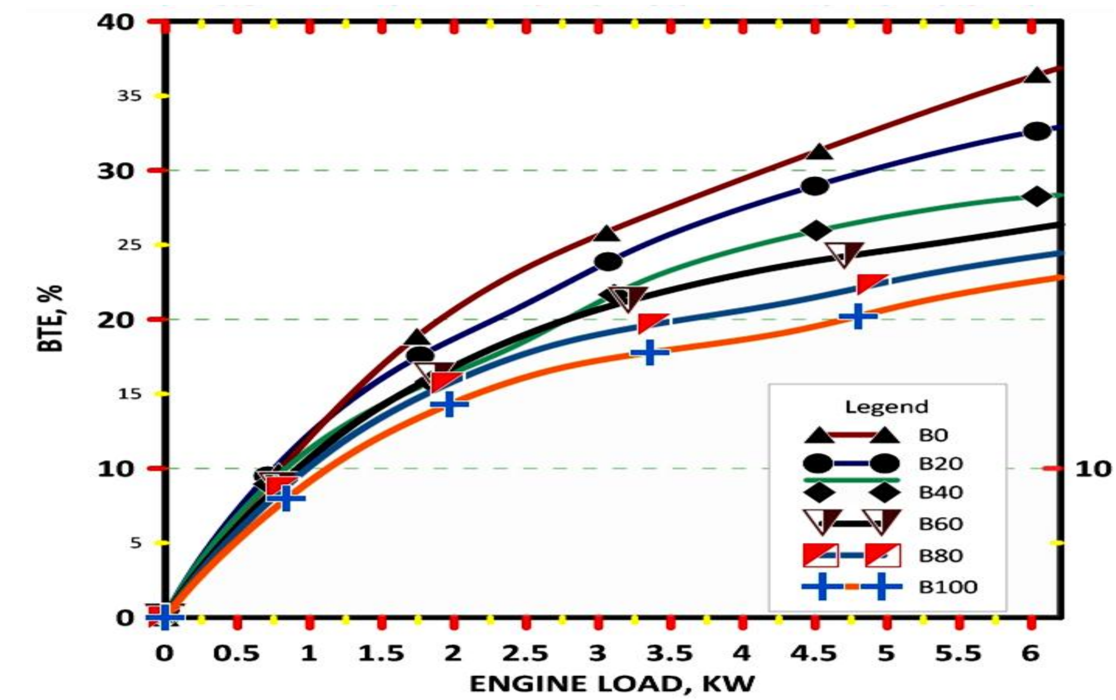

Figure 6:-Brake Thermal Efficiency variation for diesel & biodiesel blends

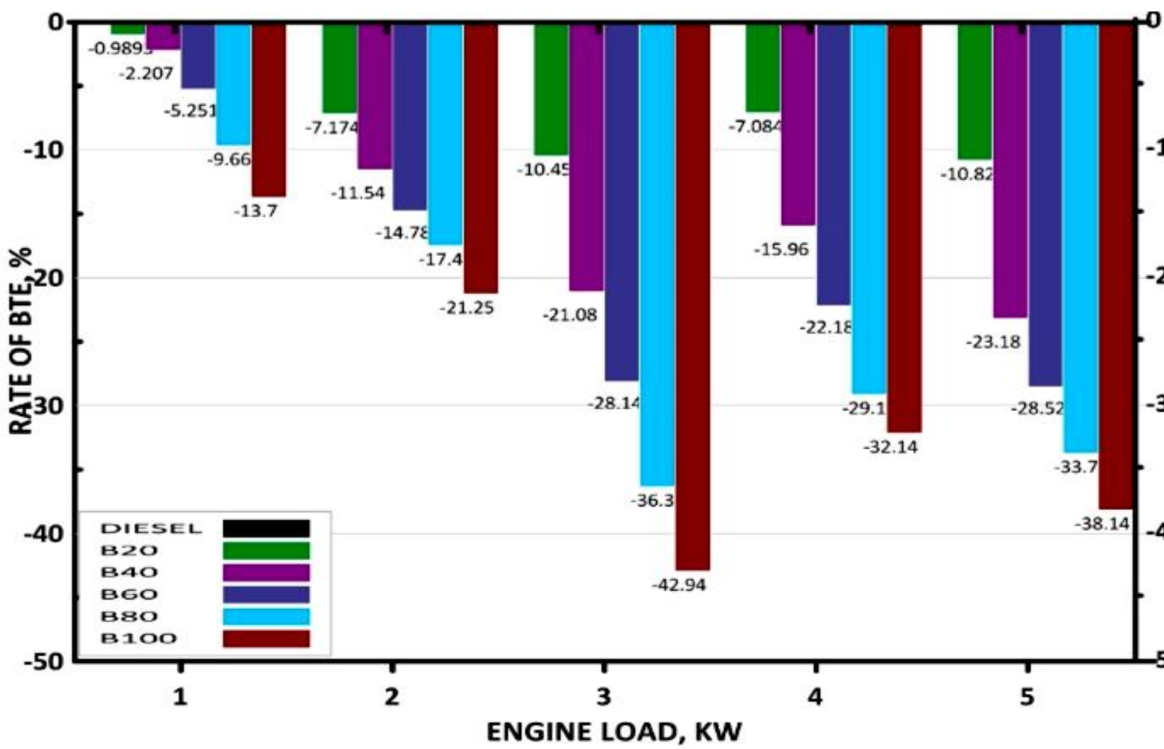

Figure 7:-Rate of BTE decreasing for biodiesel blends

Figure 8 shows by increasing engine load, the Exhaust Gas Temperature (EGT) value increased with different fuel blends. By using diesel EGT increases with load. By replacing diesel fuel with biodiesel blends, EGT decreased. After increasing load by dynamometer, the EGT increased. For B20, EGT decreased compared to diesel After replacing biodiesel fuel (B20) with biodiesel blend (B40,60,80,100) as sequence, we found opposite proportion between biodiesel blend number and EGT.

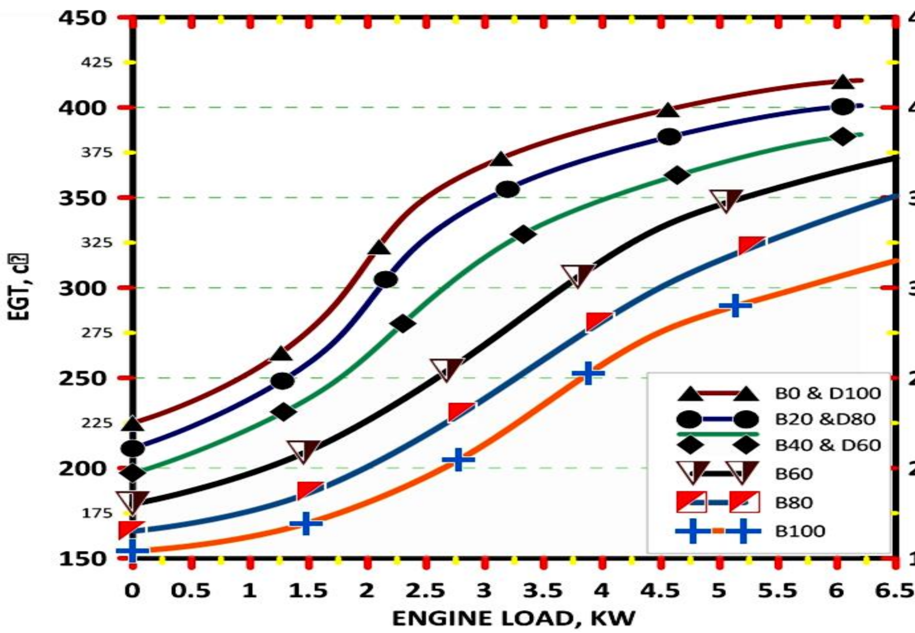

Figure 8:-Exhaust Gas Temperature for diesel & biodiesel blends

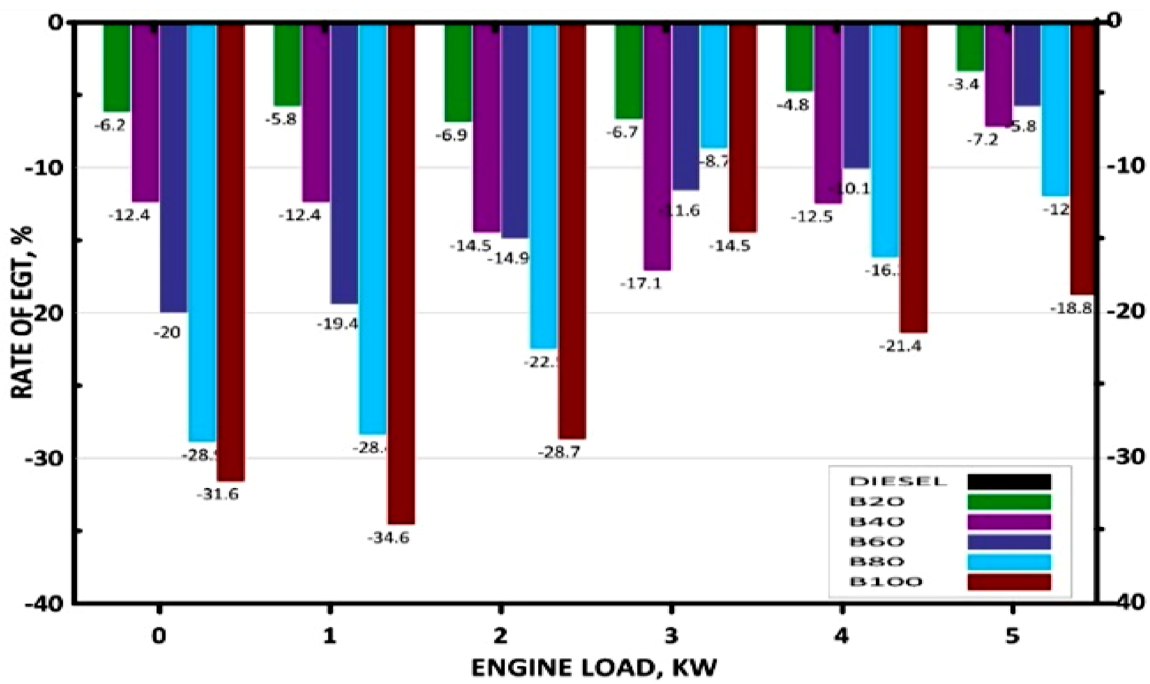

Figure 9:-Rate of EGT decreasing for biodiesel blends

Figure 9 shows the decreasing rate of EGT by increasing the biodiesel blend ratio, which means that EGT decreases for biodiesel than diesel. Figure 10 shows that by increasing engine load, the NO_x increased with different fuel blends. By using diesel, NO_x increased with load. After replacement diesel fuel with biodiesel, blend (B20) which consists of 20% waste cock oil biodiesel and 80% diesel. The NO_x increased compared to diesel. After increasing load by dynamometer, the NO_x increased for B20. After replacing biodiesel fuel (B20) with biodiesel blends (B40,60,80,100) as sequence, there was a direct proportion between biodiesel blend percentage and NO_X emission as shown by R.KARTHIK M.E. and PRABHAKARN M.E. (2016) [24]. Figure 11 shows the increasing rate of NO_x by increasing the biodiesel blend ratio

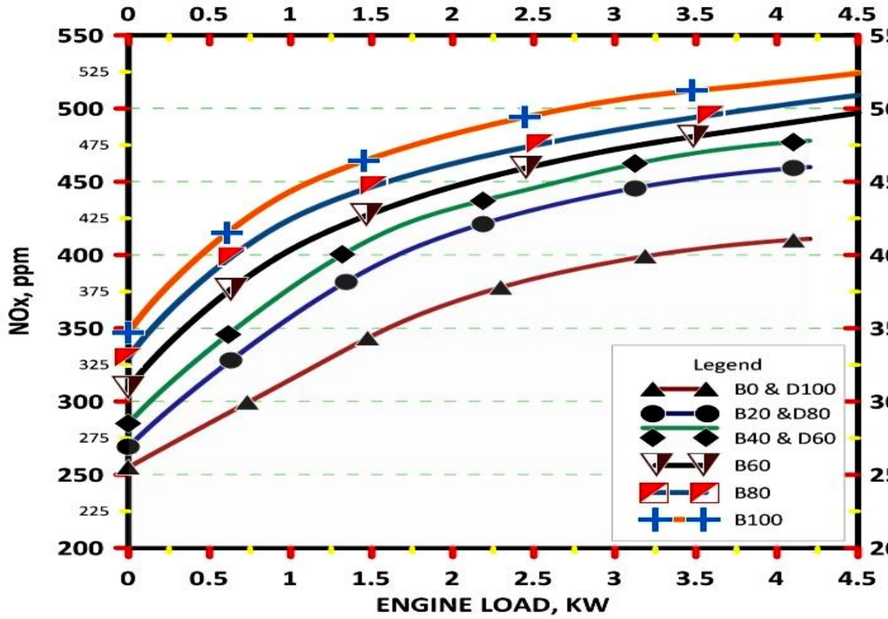

Figure 10:-NOx variation for diesel & biodiesel blends

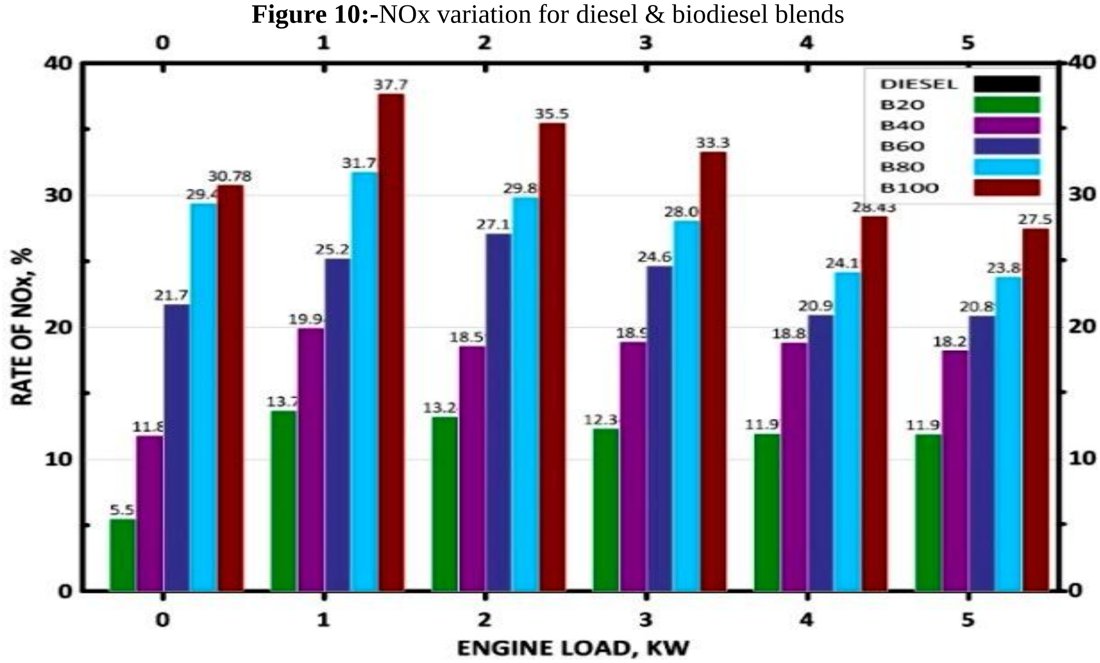

Figure 11:-Rate of NOx increasing for biodiesel blends

For all blends the increasing rate reduces by increasing load, which means that it can be overcome the increasing of NOx in biodiesel by increasing load at biodiesel fuel, this was also showed by M.N. Nabi et al (2009) [25].

Figure 12 shows the variation of CO_2 emission with different engine load for waste cooking-oil biodiesel blends. CO_2 emission is more for biodiesel and its blends than that for diesel fuel. The rising trend of CO_2 emission with engine load was due to the higher fuel entry as the load increased. CO_2 emissions for diesel-biodiesel blends were higher than diesel oil and it increased with the increase in blend proportion. CO_2 emission increase was due to higher oxygen content in biodiesel blends.

Figure 13 shows the increasing rate of CO_2 by increasing the biodiesel blend ratio. the rate of increase varies by load changing and biodiesel blend ratio. For all blends the increasing rate raises to the maximum at zero load then reduced gradually by increasing load.

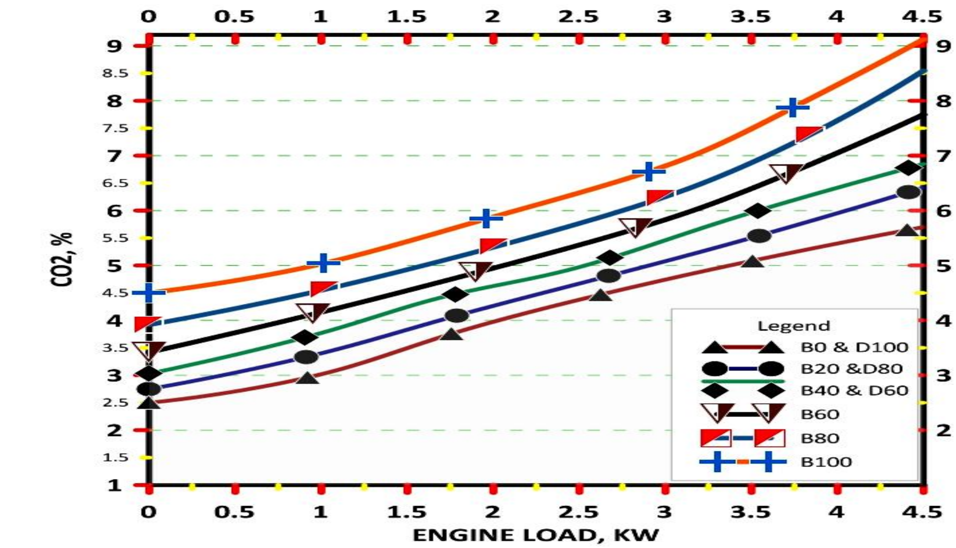

Figure 12:-CO_2 variation for diesel & biodiesel blends

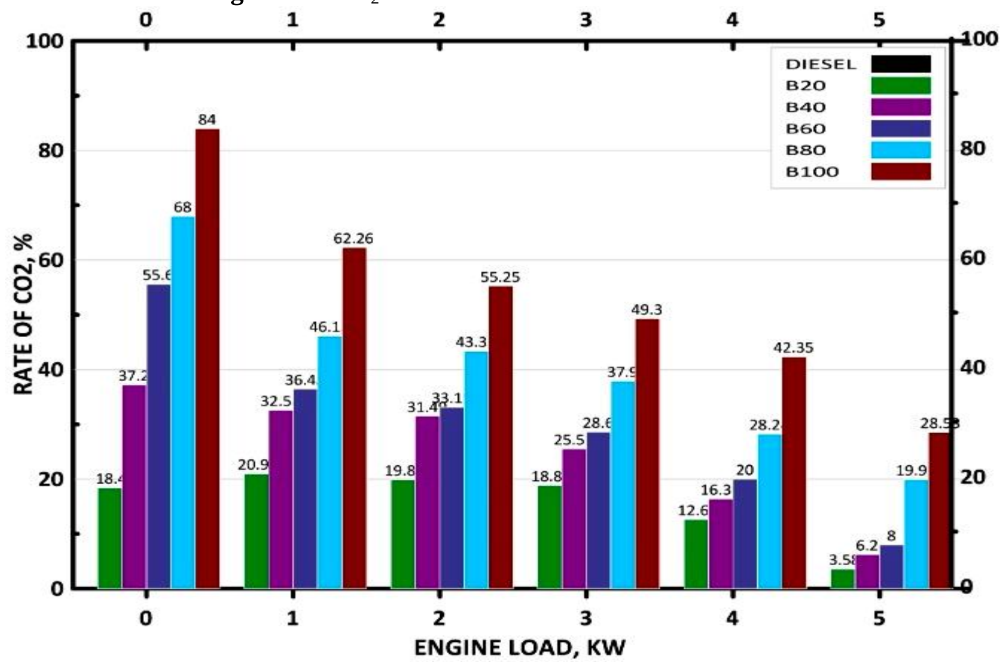

Figure 13:-Rate of CO_2 increasing for biodiesel blends

Figure 14 shows a decrease in carbon monoxide emission for biodiesel blends was due to more oxygen molecules and lower carbon content in biodiesel blends as compared to diesel fuel, which lead to better combustion. The presence of oxygen in waste cooking-oil biodiesel blends is helpful for better combustion and reduction of CO emissions. Suryawanshi [26] found that 100% biodiesel experienced lower CO.

Figure 15 shows the decreasing rate of CO emission by increasing the biodiesel blend ratio, which means that CO decreases for biodiesel than diesel. The increasing change by load changing and biodiesel blend ratio.

Figure 16 shows that by increasing engine load by dynamometer, the unburned hydrocarbon HC values increased with different fuel blends. By using diesel, HC increased with load. After replacement diesel fuel by biodiesel blend (B20), HC decreased compared to diesel. In case of B20 with increasing load by dynamometer, the HC increased. With replacing biodiesel fuel (B20) with biodiesel blend (B40,60,80,100) as sequence , there was negative correlation between biodiesel blend number and HC as shown by Adaileh and AlQdah (2012) [27, 28].

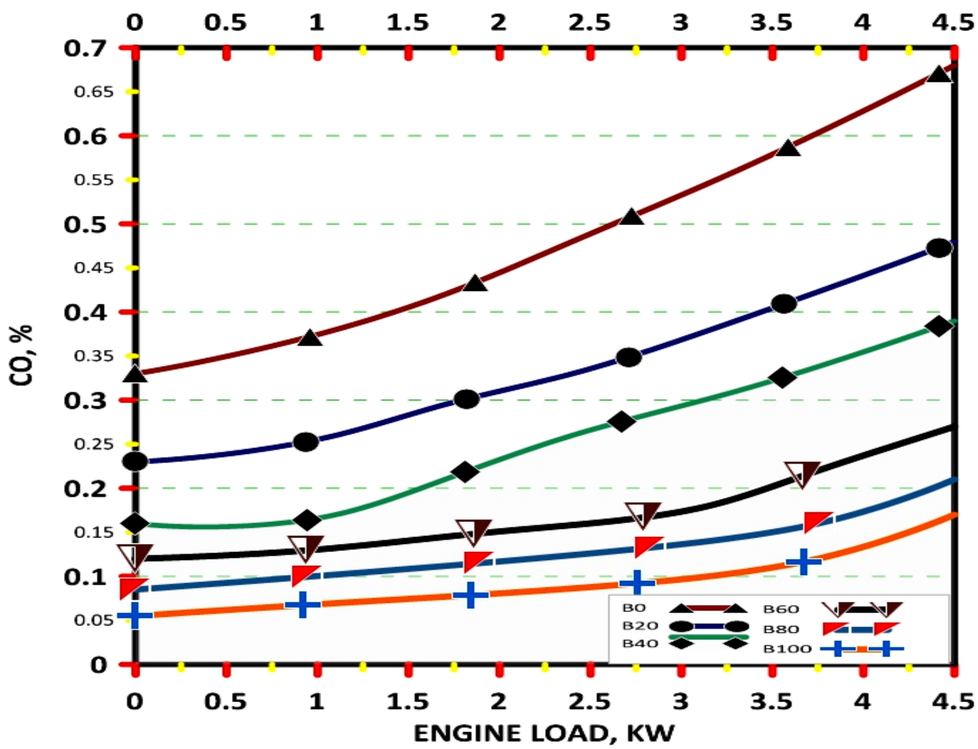

Figure 14:-Mass Flow rate variation for diesel & biodiesel blends

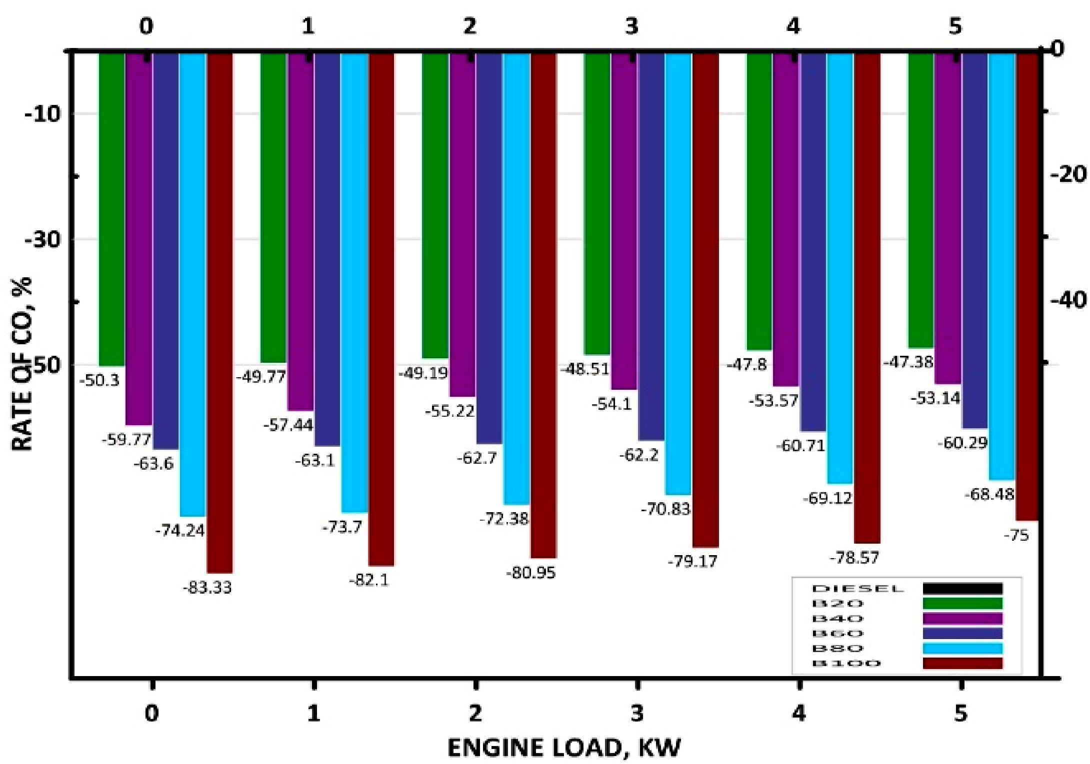

Figure 15:-Rate of MF decreasing for biodiesel blends

Figure 17 shows the decreasing rate of HC by increasing the biodiesel blend ratio, which means that HC decreases for biodiesel than diesel. The increasing change by load changing and biodiesel blend ratio.

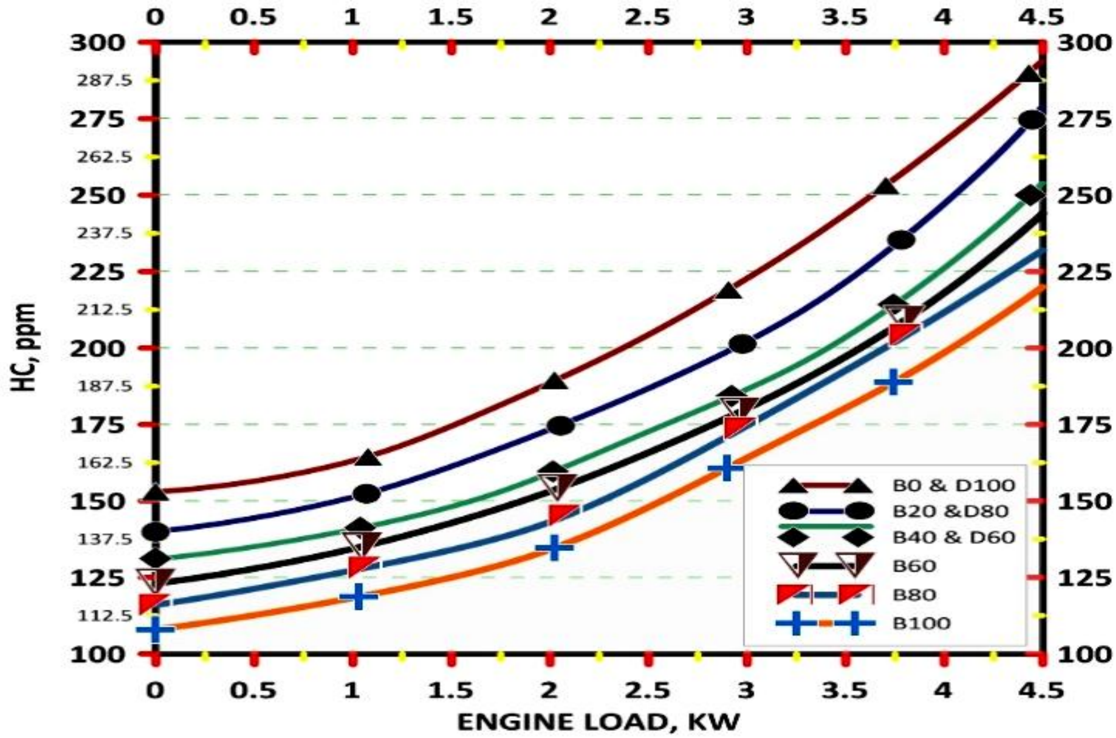

Figure 16:-unburned Hydrocarbon variation for diesel & biodiesel blends

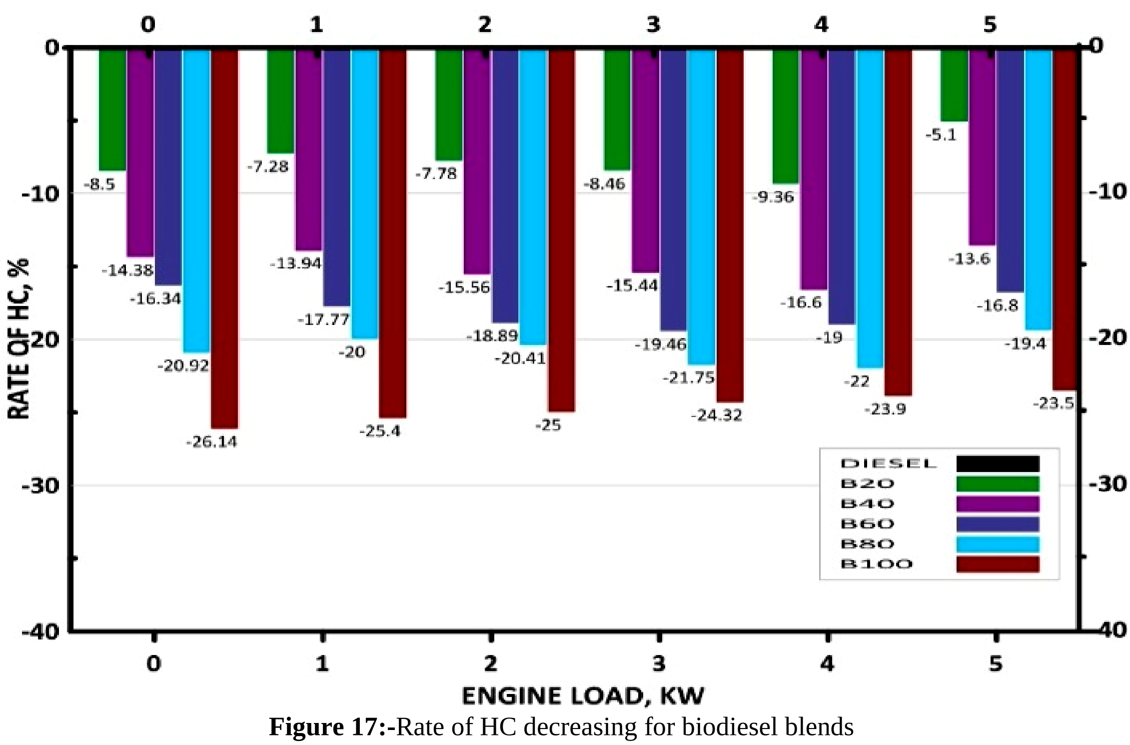

Figure 17:-Rate of HC decreasing for biodiesel blends

Figure 18 shows that by increasing engine load by dynamometer, the residual oxygen (O_2) value decreased with different fuel blends. By using diesel, O_2 decreases with load. After replacement diesel fuel by biodiesel blends, O_2 decreases than diesel. After increasing load by dynamometer, the O_2 decreased. For B20, O_2 decreased compared to diesel. After changing biodiesel fuel (B20) by biodiesel blend (B40, 60, 80,100) as sequence we found negative correlation between biodiesel blend number and O_2.

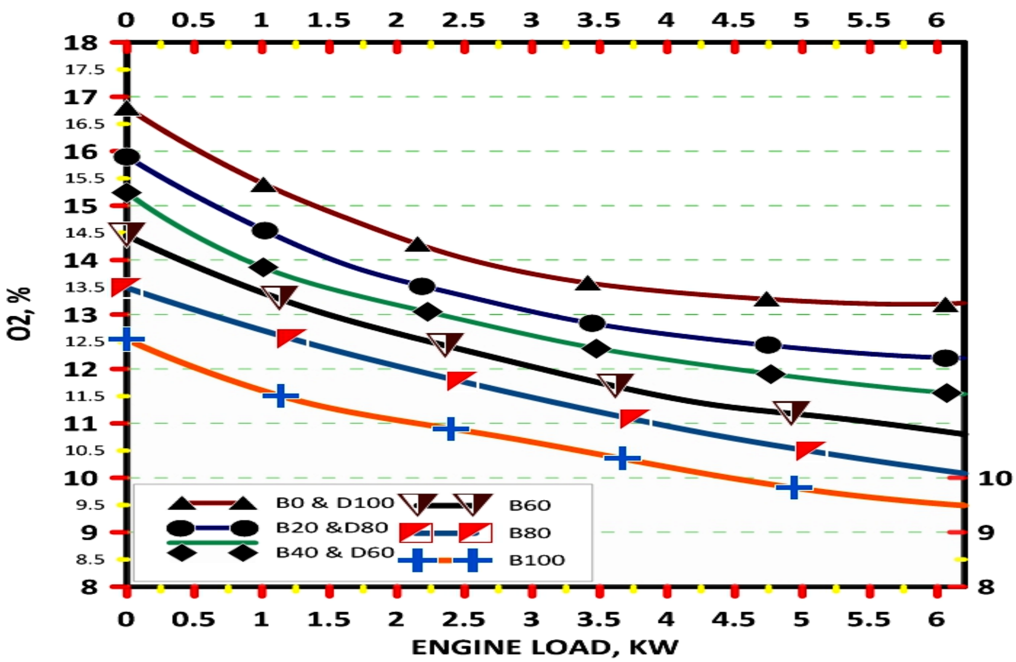

Figure 18:-O_2 variation for diesel & biodiesel blends

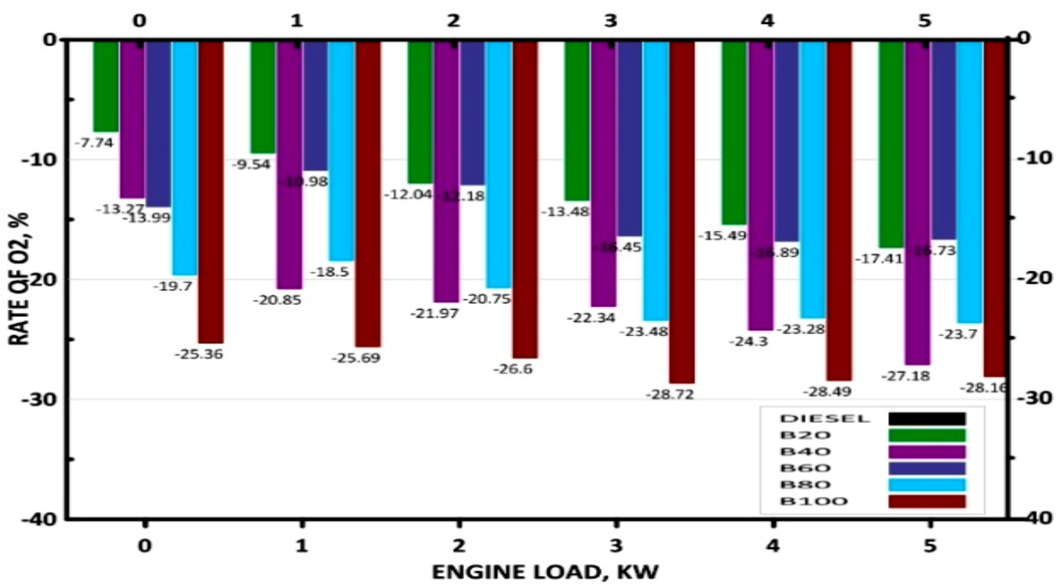

Figure 19:-Rate of O_2 decreasing for biodiesel blends

Figure 19 shows the decreasing rate of O_2 by increasing the biodiesel blend ratio, which means that O_2 decreased for biodiesel than diesel fuel. Variations of waste cooking-oil emissions for different biodiesel blends with respect to engine load are shown in figure 20. Smoke emission increased with engine power output for all fuels. The increased pattern of emissions is due to the increase of fuel consumption with engine output power. Presence of branched and ring structures in diesel fuel increases the emission levels. Smoke emissions of biodiesel blends were lower than diesel fuel under similar operating conditions. This inbuilt oxygen in biodiesel blends led to better combustion and smoke emission reduction. Smoke emission decreased with increase in biodiesel percentage in biodiesel blends [29].

Figure 21 shows the decreasing rate of smoke by increasing the biodiesel blend ratio, which means that smoke decreases for biodiesel than diesel. The increasing change by load changing and biodiesel blend ratio was also reported by K.A. Abed et al (2018) [30].

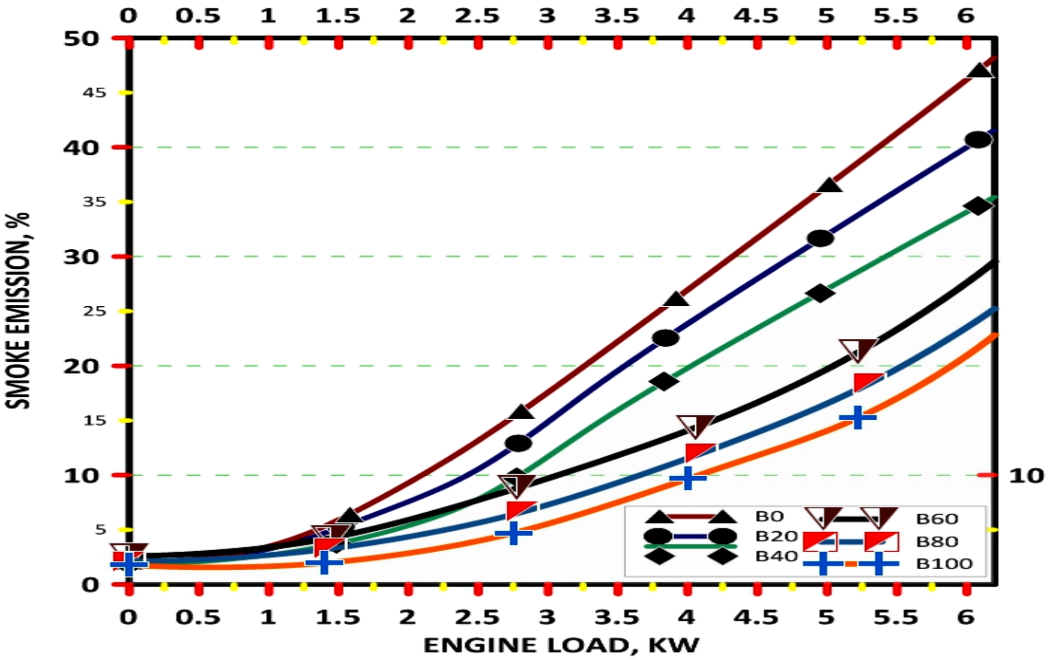

Figure 20:-Smoke variation for diesel & biodiesel blends

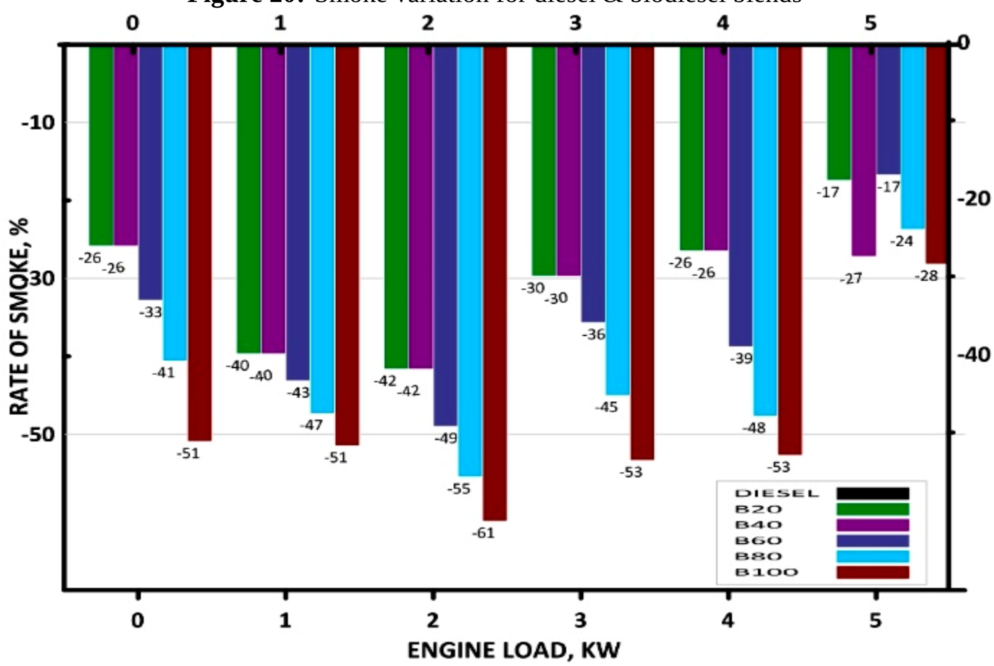

Figure 21:-Rate of Smoke decreasing for biodiesel blends

Conclusion:-

A single cylinder diesel engine was run using waste cooking-oil biodiesel blends B20, B40, B60, B80 and B100. Performance and exhaust emissions were measured at different engine loads of 1, 2, 3,4 and 5 kW at constant engine speed of 1500 rpm. Specific fuel consumption, thermal efficiency, exhaust gas temperature and mechanical efficiency were measured. CO, CO_2, NOx, HC and the emissions were measured and compared with diesel fuel. The following conclusions could be summarized as:

1. Thermal efficiencies of waste cooking-oil biodiesel blends were lower compared to diesel fuel
2. It was found that brake specific fuel consumptions were higher in biodiesel than diesel and the increasing is approximately 50g/kw.hr for 20% increasing in blend ratio.

3. CO were lower for waste cooking-oil biodiesel blends compared to diesel fuel, the CO reduction was 0.1% for b20 than diesel and that reduction reduces by higher biodiesel blend ratio.
4. There was significant negative correlation between unburned hydrocarbon (HC) and waste cooking-oil biodiesel blends concentration.
5. Higher biodiesel fuel blends increase NO_x emission. The increasing between diesel and B20 was 50ppm for NO_x, while the increasing seems to be constant with 15ppm for 20% excess biodiesel blend ratio from B40 to B100.
6. O_2 were lower for waste cooking-oil biodiesel blends compared to diesel fuel. Dcreasing in O_2 was 0.5% for diesel, B20 and B40, although decreasing reach to 1% from B60 to B80 and B100.
7. There was significant negative correlation between exhaust gas temperature (EGT) and waste cooking-oil biodiesel blends concentration.
8. Higher biodiesel fuel blends increase CO_2 emission. Increasing in CO_2 was 0.25% for diesel, B20 and B40, although increasing reach to 0.5% from B60 to B80 and B100.
9. Smoke of waste cooking-oil biodiesel blends was lower compared to diesel fuel.

References:-

1. Kannahi, P.M., Arulmozhi, R. (2013): Production of biodiesel from edible and non-edible oils using Rhizopus oryzae and Aspergillus niger. Asian Journal of Plant Science and Research, 3(5): 60-64.
2. Ghaly, A.E., Dave, D., Brooks, M.S., Budge, S. (2010): Production of Biodiesel by Enzymatic Transesterification: Review. American Journal of Biochemistry and Biotechnology, 6 (2): 54-76.
3. "What is biofuel? definition and meaning". Business Dictionary.com. Retrieved 30 May 2015
4. Abdullah, N.H., Hasan, S.H., Yusoff, N.R.M. (2013): Biodiesel Production Based on Waste Cooking Oil (WCO). International Journal of Materials Science and Engineering, 1(2): 94-99.
5. Gude,V.G., Patil, P. D., Grant, G. E., Deng S.(2012): Sustainable Biodiesel Production. Second world Sustainable forum,1-14.
6. Shahid, E.M., Jamal, Y., Shah, A.N., Rumzan, N., Munsha, M. (2012): effect of used cooking oil methyl ester on compression ignition engine. Journal of Quality and Technology Management, 8(2) : 91–104.
7. Sarbyk,O.Y., Özcan, M., Serin, H., Serin, S., Aydın, K. (2012): Biodiesel Production from Ricinus Communis Oil and Its Blends with Soybean Biodiesel. Journal of Mechanical Engineering, 56: 811-816.
8. Kinoshita E, Hamasaki K, Jaqin C (2003): Diesel combustion of palm oil methyl ester. SAE Paper No. 2003-01-1929: 1-7.
9. Zheng M, Mulenga MC, Reader GT, Wang M, Ting DSK, Tjong J.(2008): Biodiesel engine performance and emissions in low temperature combustion. Fuel; 87:714–22.
10. Environmental Protection Agency of USA. A comprehensive analysis of biodiesel impacts on exhaust emissions, Draft tech. report.; 2002. EPA420-P- 02-001.
11. R.B. Sharma, Amit Pal, Juhi Sharaf (2013): Production of bio-diesel from waste cooking-oil. J. Eng. Res,4 (6) :1629–1636.
12. E.M. Shahid, Shah A.N. Jamal, N. Rumzan, M. Munsha (2012): Effect of used cooking-oil methyl ester on compression ignition engine. J. Quality Technol. Manage, 8(2):91–104.
13. Pedro Felizardo, M. Joana Neiva Correia, Idalina Raposo, Joao F. Mendes, Rui Berkemeier, Joao Moura Bordado (2006):Production of biodiesel from waste frying oils.Waste Manage. J, 26 (3) :487–494.
14. Osmano Souza Valente, Vanya Marcia Duarte Pasa, Carlos Rodrigues Pereira Belchior, Jose Ricardo Sodre (2012):Exhaust emissions from a diesel power generator fuelled by waste cooking-oil biodiesel.Sci. Total Environ. J, 431:57–61.
15. K. Nantha Gopal, Arindam Pal, Sumit Sharma, Charan Samanchi, K. Sathyanarayanan, T. Elango, (2014):Investigation of emission and combustion characteristics of a CI engine fueled with waste cooking-oil methyl ester and diesel blends .Alex. Eng. J, 53:281–287.
16. K. Srithar a, K. Arun Balasubramanian b, V. Pavendan a , B. Ashok Kumar. (2014): Experimental investigations on mixing of two biodiesels blended with diesel as alternative fuel for diesel engines. Journal of King Saud University – Engineering Sciences,29:50–56.
17. Ajay V. Kolhe, R. E. Shelke, S. S. Khandare (2014): Performance, Emission and Combustion Characteristics of a Variable Compression Ratio Diesel Engine Fueled with Karanj Biodiesel and Its Blends. World Academy of Science, Engineering and Technology International Journal of Mechanical and Mechatronics Engineering,8:4, 2014.
18. Wail M. Adaileh and Khaled S. AlQdah (2012): Performance of Diesel Engine Fuelled by a Biodiesel Extracted From A Waste Cocking Oil. Energy Procedia ,1317 – 1334.

19. L.C. Meher, D. Vidya Sagar, S.N. Naik (2006): Technical aspects of biodiesel production by transesterification – a review, Renew. Sustain. Energy Rev, 10: 248–268.
20. M. Kannan, C.G. Saravanan, S. Prasanna Raj Yadav(2014):Experimental investigation of compression ignition engine fuelled by a catalytic fuel reformer.International Journal of Ambient Energy, Taylor and Francis, 2014.
21. A. Selvaganapthy, A. Sundar, B. Kumaragurubaran, P. Gopal (2013):An experimental investigation to study the effects of various nanoparticles with diesel on DI diesel engine .ARPN J. Sci. Technol, 3 (1).
22. H. Jung, D.B. Kittelson, M.R. Zachariah (2005):The influence of a Cerium additive on ultra fine diesel particle emissions and kinetics of oxidation. Combust. Flame, 142:276–288.
23. Elkelawy, M., Bastawissi, H., Sathyamurthy, R., Chandra Sekar, S. et al (2018): Numerical and Experimental Investigation of Ethyl Alcohol as Oxygenator on the Combustion, Performance, and Emission Characteristics of Diesel/Cotton Seed Oil Blends in Homogenous Charge Compression Ignition Engine, SAE Technical Paper 2018-01-1680.
24. R.KARTHIK M.E. and PRABHAKARN M.E. (2016): performance and emission characteristics of di diesel engine using ziziphus jujuba oil as biodiesel. International conference on Current Research in Engineering Science and Technology, (E-ISSN :2348 – 8360.
25. Md. Nurun Nabi, Md. Mustafizur Rahman, Md. Shamim Akhter (2009): Biodiesel from cottonseed oil and its effect on engine performance and exhaust emissions. Applied Thermal Engineering, 29 :2265–2270.
26. J.G. Suryawanshi.(2006):Performance and emission characteristics of CI engine fueled by coconut oil methyl ester.SAE Paper. Paper Number 2006-32-0077.
27. J. Sadikbasha, R.B. Anand (2010): Application of nanoparticles/nanofluid in compression ignition engines: a case study. Int. J. Appl. Eng. Res. 5 : 697–708.
28. Karuppasamy K., Sathyamurthy R., Elkelawy M., Bastawissi H.,Paramasivan P., Sathiyamoorthy K. and Edison P.(2018): Emission analysis on compression ignition engine fueled with lower concentrations of Pithecellobium dulce biodiesel-diesel blends, Heat Transfer—Asian Res. 2019;48:254-269.
29. Chandra Sekhar, S., Karuppasamy, K., Vedaraman, N., Kabeel, A. E., Sathyamurthy, R., Elkelawy, M., & Alm ElDin Bastawissi, H. (2018). Biodiesel production process optimization from Pithecellobium dulce seed oil: Performance, combustion, and emission analysis on compression ignition engine fuelled with diesel/biodiesel blends. Energy Conversion and Management, 161, 141–154.
30. K.A. Abed a, A.K. El Morsi b, M.M. Sayed c, A.A. El Shaib d, M.S. Gad (2018): Effect of waste cooking-oil biodiesel on performance and exhaust emissions of a diesel engine. Egyptian Journal of Petroleum.