© 2017 IJSRSET | Volume 3 | Issue 6 | Print ISSN: 2395-1990 | Online ISSN : 2394-4099
Themed Section: Engineering and Technology

Performance and Emission Parameters of CI Engine Using Karanja Oil Methyl Ester and Biogas in Dual Fuel Mode

Dr. R. Ramachandra
Principal & Professor, Department of Mechanical Engineering, SKD Engineering College, Gooty, Andhra Pradesh, India

ABSTRACT

The present study tries to investigate the possibility to absolutely replace the fossil fuel by the alternative fuel, those available near by the users. For this, an experimental investigation was carried out on a single cylinder, direct injection diesel engine operating on Karanja Oil Methyl Ester (KOME) with Biogas in dual fuel mode. During the experimentation, the engine performance and exhaust emission parameters were measured in terms of Brake Thermal Efficiency (BTE), Brake Specific Energy Consumption (BSEC), Exhaust Gas Temperature (EGT), Carbon Monoxide (CO), Carbon Dioxide (CO2), Unburent Hydrocarbon (HC), and Oxides of Nitrogen (NOx). The results indicate that the use KOME (biodiesel) and biogas produces a maximum brake thermal efficiency of 16.63% in comparison to 30.63% that produced by neat diesel. On the other hand, the measured maximum reduction in HC emissions (11.93%) was found with adding 2 gm/min biogas in to the biodiesel and NOX emissions was found 33.45% lower than that of neat diesel with adding 8 gm/min biogas in to the biodiesel. All the test results significantly improved the performance and emission parameters by using alternative fuel. Therefore the present paper provides a strong platform to entirely replace the fossil fuel.
Keywords: BSEC, Dual fuel, Biodiesel, Biogas.

I. INTRODUCTION

Energy utilization increases speedily due to increase in population. Nowadays, the energy crisis becomes one of the universal issues deal with us. It is impossible to full-fill the needs in forthcoming years with fossil fuels itself. So, there is an urgent need for appropriate substitute of fossil fuels for use in our daily life. The vegetable oils like Jatropa oil, Jojoba oil, Cottonseed oil, Karanja oil, Sunflower oil, Peanuts oil, Soya bean oil, Linseed oil, Neem oil, Mahua oil, rice bran oil are considered as alternate fuels to diesel and known as biodiesel. Biodiesel is an alternative fuel consisting of the alkyl Mono esters of fatty acids derived from vegetable oils (edible and non- edible) or animal fats. The most practical form of biodiesel is prepared with methanol and vegetable oil, known as methyl ester. Biodiesel fuels have natural character that permits for their direct utilize in diesel engines without any significant modifications. Researchers all over the world has been studied on the use of biodiesel in compression ignition (CI) engine and found that the performance of the CI engine operated with the biodiesel fuel is almost similar to that of diesel fuel. Its efficiency is found to be similar to the diesel fuel. The carbon monoxide (CO), hydrocarbon (HC) and smoke emission observed with the biodiesel is lesser than that of the diesel fuel, but the oxides of nitrogen (NOx) emission is found to be higher for the biodiesel fuel. It proves to be a major drawback in utilization of biodiesel alone for shaft power generation. Therefore to find other alternative and cheaper forms of fuel which can reduce the emissions of NOx is to be required. Biogas is one of the best available energy sources to meet this demand both in rural and urban areas. India has second ranks in the world of utilizing biogas. Among all types of renewable energy, biogas production from anaerobic digestion seems to be one of the most promising options. Biogas is produced by anaerobic digestion of various organic substances like, dry leaves of trees and crops, wood, agricultural residues, cow dung, kitchen waste, manure, sewage, municipal waste, green waste, etc. which offers low cost than any other secondary fuels. Biogas can be used in CI engine as a dual fuel mode and improves engine performance as well as reduced NOx emission. The biogas can be introduced in the engine with air during inlet stroke and diesel is injected towards the just before the end of compression stroke to initiate the combustion of gas air mixture. So, it can become a good substitute to fossil fuels.

1.1. Dual Fuel Technique

All internal combustion (IC) reciprocating engines operate by the same basic principle. During the suction stroke, a combustible mixture (air and fuel) is induced in to the cylinder and then compressed during the compression stroke. The mixture is then ignited and the high-pressure combustion products push the piston through the cylinder. Generally two ignition methods are used in reciprocating IC engines, compression ignition (CI) and spark ignition (SI). In the compression ignition method, the intake air alone is compressed and at the end of the compression strokes the diesel (cetane based) fuel is directly injected at high pressure over the compressed air inside the cylinder which leads to ignite easily by virtue of its ignition temperature. Where as in the spark ignition engine air and octane based fuel mixture is induced in to the cylinder, then compressed and at the end of compression stroke a spark is developed through the spark plug which leads to ignite the mixture. Third one is newly developed ignition method known as Dual fuel ignition methods or dual fuel technique, in which both compression ignition and spark ignition concept is utilize to burn the mixture of primary octane based fuel and cetane based pilot fuel.

In the biogas-biodiesel dual fuel engine the biogas-air mixture is drawn in to the cylinder just like to spark ignition engine and this mixture is compressed in order to increase the temperature and pressure. At the end of the compression stroke the mixture is ignited by the injection of small quantity of pilot biodiesel fuel. This pilot injection acts as a source of ignition. The biogas-airmixture in the area of the injected diesel spray ignites at number of places establishing a number of flame-fronts. Thus the combustion starts smoothly and rapidly. It is interesting to note that in a dual-fuel engine the combustion starts in a fashion similar to the CI engine but it propagates by flame fronts, similar to the SI engine.

1.2. Production of Biodiesel

Biodiesel can be produced by dilution, pyrolysis, emulsion and transesterification of the vegetable oil, out of which transesterification the most commonly is used. Transesterification is a chemical reaction that occurs between triglyceride and alcohol in presence of catalyst to obtain methyl ester and glycerol as by product. atransesterification process can be done either with methanol or ethanol, which are catalyzed by potassium hydroxide. The process of transesterification removes glycerol from triglycerides and replaces it with radicals from the alcohol used for the conversion process. Methanol is more extensively used due to its low cost and physiochemical advantages with triglycerides and alkali are dissolved in it. For the production of biodiesel from the Karanja oil, raw karnja oil is to be required which is easily available in local market across the India. It extracted from the karanja seeds of karanja tree also known as *Pongamiapinnata*. . It is basically a medium size tree found in different parts of India. It is available in most of the rural areas in India. Karanja tree is a deciduous tree which grows to a height of 50-80 feet and has a life span of 80-100 years and fruits start from 4-5 years. Each of these trees produces approximately around 9-90 kg of seeds per year. The average Karanja oil yield per annum is 70,000 million tons in India. One liter of neat raw karanja oil is heated in an open beaker to a temperature of 100-110 ^{o}C to remove water particles present in oil followed by filtration of oil. The oil is processed under base catalyzed transesterification method where it is mixed with 40% (200 ml) of methanol and around 0.75% (7.5 gms) of sodium hydroxide pellets in flask on a hot plate magnetic stirring arrangement for 1-1.5 hours up to 60 ^{o}C, then poured in to separating funnel and allowed to settle down for about 6-8 hours. The two different layers of Karanja oil methyl ester and glycerol formed were then allowed to settle. Once the glycerol layer settled down, the methyl ester layer formed at the upper part of the separating funnel. Glycerol followed by Karanja oil methyl ester (KOME) separated from the bottom part of the separating funnel through a valve. The KOME obtained in the process is further washed with distilled water for 2 - 3 times for removal of acids and heated above 100^{o}C, to separate the moisture present in the KOME. Hencepure Karanjaoil biodiesel is obtained.

1.3. Production of Biogas

Biogas is produced by anaerobic digestion of cellulosic wastes. In this process organic matters like dry leaves of trees and crops, wood, agricultural residues, cow dung, kitchen waste, manure, sewage, municipal waste, green waste, ect.,decomposed bybacteria in absence of oxygen, forming gaseous by product known as biogas. This by product comprises of methane (60-70%), carbon dioxide (30-40%), nitrogen (‹1%) and hydrogen sulphide(10-2000ppm). Also, the nutrient-rich solid left after digestion can be used as fertilizer for crop growing. Biogas is about 20% lighter than air has an ignition temperature of 650 to 750^{0}C. Its calorific value is proportional to the methane concentration and found 20 - 22 MJ/m^3. It can be used lighting, cooking and shaft power for further use. In this experimental work biogas is produced by the canteen waste operating at RGPV campus. A floating drum gas holder type biogas plant is to be installed in mechanical Engineering department of Rajiv Gandhi ProudyogikiVishvavidhyalaya. This plant made of fiber material, having an inverted drum resting over the digester with gas holding capacity 1m^3 . This drum can move up and down and floating through water jacket over the digester, so that prevents the leakage of biogas from the digester. Initially 100kg of cow dung and 500 litter water mixes together into slurry form and poured in to the digester. To maintain the pH value 1kg calcium hydroxide (CaOH) also can be mixes with slurry. After one week of retention time 500 g of solid canteen waste and 20 L water is required daily to obtained biogas on regular basis for entire experimentation.

II. EXPERIMENTAL SET-UP

The experimental set-up was installed in Mechanical Engineering department of University institute of Technology, RGPV, Bhopal. Figure 1 shows the photographs of experimental set-up and schematic diagram of experimental set-up is shown in Figure 2. It contains a complete system for measuring the performance parameters such as engine load by rope brake dynamometer, air consumption by box method, diesel and biodiesel consumption by U-tube manometer, biogas consumption by anemometer and electronic weighing machine, temperature of inlet air, exhaust gas and cooling water by K-type thermocouples. For the analysis of the exhaust, Eurotron green line gas analyzer was used. The CO and HC were measured by the principle of Non dispersive infra-red (NDIR) detection and NOx by electrochemical sensors. The test engine specifications are given in Table 1.

2.1. Test Procedure

The test was carried out at a constant speed of 1500 rpm byvarying the load. The engine speed was kept constant so that the quantity of the injected liquid fuel (pilot fuel) varied depending on the engine load, and the flow rate of the biogas was kept nearly constant. The biogas were mixes with fresh air through the convergent divergent nozzle mixer (venturimeter) and sucked by the engine during suction stroke than, this mixer is compressed during compression stroke and at the just before of the compression stroke pilot fuel (diesel/biodiesel) was injected through the injector likewise combustion were takes place. In this technique partial energy were added by the biogas and partial energy were added by the pilot fuel. The quantity of pilot fuel were control automatically according to load by the governor. Initially engine was run by the pure diesel at zero load for 20 minutes so that the engine can achieved its steady state and take all required readings which is used as a base reading for the analysis. After that pilot fuel supply is shifted to biodiesel mode and engine was run for 15 min at zero load to achieve steady state condition. Thereafter, loads were increases gradually 3, 6, 9 and 12 kg and taken all the required readings for the observation. Similar readings were takes place with supplying different proportions 2, 4, 6 and 8 gm/min of biogas and examine the effect on Performance and emissions. These are the combination of fuel sets those were used for observations, neat diesel (D+BG0), neat biodiesel (BD+BG0), biodiesel with 2 gm/min supplying of biogas (BD+BG2), biodiesel with 4 gm/min supplying of biogas (BD+BG4), biodiesel with 6 gm/min supplying of biogas (BD+BG6) and biodiesel with 8 gm/min supplying of biogas (BD+BG8).

Figure 2. Schematic diagram of experimental set-up

Make	Kirloskar
No. of Cylinders	1
Bore X Stroke (mm)	80X110
Compression Ratio	16.5:1
Rated Output (kW)	3.7
Rated Speed (rpm)	1500

III. RESULTS AND DISCUSSION

All the results were calculated, tabulated and then plotted in the terms of line graphs thus for the determination and analysis the proper ratio of Air, biogas and biodiesel to get optimum performance and emissions of the engine.

3.1. Brake-Specific Energy Consumption

Brake specific energy consumption (BSEC) can be defined as fuel energy utilized to produce unit brake power and it is the appropriate terms for the dual fuel operation to obtained the performance of test engine where two different type of fuels octane &cetane based that having different calorific values and density are to be used. Specific energy consumption is calculated based on fuel consumption and calorific value to the brake power of both diesel and biogas. It was found that the specific energy consumption in dual fuel mode operation is higher in all combination of fuel set than that of neat diesel in all operating conditions as shown in Figure3. The values of BSEC were decreases with increasing the load, it could be happened due to reduction in losses at higher loads. The values of BSEC were found to increase with an increase the quantity of biogas. The possible reason of higher energy consumption for higher mass flow rate of biogas could be the lower calorific value in the biogas. Due to the low calorific value of biogas the BSEC increases with the increasing the quantity of biogas in neat diesel as well as biodiesel at various load conditions. When the engine loads were increases from no load to 12 kg load, the reduction of specific fuel consumption is about 50.32% in case of diesel fuel mode and this Percentage reduction were increases with increasing the quantity of biogas and found 71.06% at 8 gm/min supplying of biogas.

Brake Specific Energy Consumption (BSEC) can be defined as fuel energy utilized to produce unit Brake Power and it is the appropriate terms for the dual fuel operation to obtained the performance of test engine where two different type of fuels octane &cetane based that having different calorific values and density are to be used. Specific energy consumption is calculated based on fuel consumption and calorific value to the brake power of both diesel and biogas. It was found that the specific energy consumption in dual fuel mode operation is higher in all combination of fuel sets than that of neat diesel in all operating conditions as shown in Figure 3. The value of BSEC decreases with increasing load, it may be because of reduction in losses at higher loads. The values of BSEC were found to increase with an increasing the quantity of biogas. The possible reason of higher energy consumption for higher mass flow rate of biogas could be the lower calorific value in the biogas. Due to the low calorific value of biogas the BSEC increases with the increasing the quantity of biogas in neat diesel as well as biodiesel at various load conditions. When the engine loads were increased from no load to 12 kg load, the reduction of specific fuel consumption was about 50.32% and 58.40% in case of diesel and Biodiesel fuel mode. This percentage reduction increases with increasing the quantity of biogas and found 71.19% at 8 gm/min supplying of biogas with biodiesel.

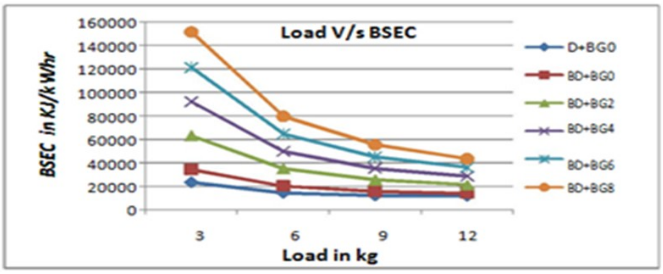

Figure 3. Variation in BSEC with the Engine Load.

3.2. Brake Thermal Efficiency

Thermal efficiency is the ratio of engines shaft power output to the input fuel energy. The fuel energy is the product of mass flow rate of fuel and calorific value of fuel. BTE indicates the inverse of BSEC. Figure 4 shows the variation in BTE with the Load for neat diesel, neat biodiesel and different combination of fuel sets. BTE increases with increasing the load which can be due to reduction in heat losses at higher load. The values of BTE were found to increase with an increasing the load in all combination of fuel sets and higher in case of neat diesel than the other fuel combination and goes continuously decreases with increasing the quantity of biogas. Maximum BTE (30.63%) was found in neat diesel fuel mode whereas 25.16% in neat biodiesel fuel mode at 2 gm/min supplying of biogas, and continuously decreases with increasing the quantity of biogas. The possible reason of higher BTE for neat diesel than the other combinations of fuel sets could be the higher calorific value in the neat diesel.

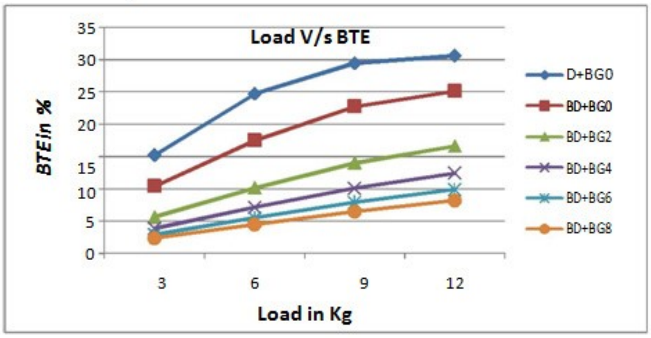

Figure 4. Variation in BTE with the Engine Load

3.3. Exhaust gas Temperature

Figure 5 shows the variation of the exhaust gas temperature with engine load for all combinations of fuel sets. The exhaust gas temperature increases linearly as the engine load is increased, it was found slightly higher in case of dual fuel mode and goes lower down with increasing the quantity of biogas than the single fuel mode. It could be happened due to Oxygen present in biodiesel and Carbon Dioxide (CO_2) present in biogas which reduces the combustible contents in to the engine cylinder and consequently reduces the flame propagation speed and increases the ignition delay which leads to improper combustion and therefore the exhaust gases come out at higher temperature. Test results shows the maximum increments of EGT (33.33%) in neat diesel mode whereas minimum increments of EGT (29.56%) in neat biodiesel mode.

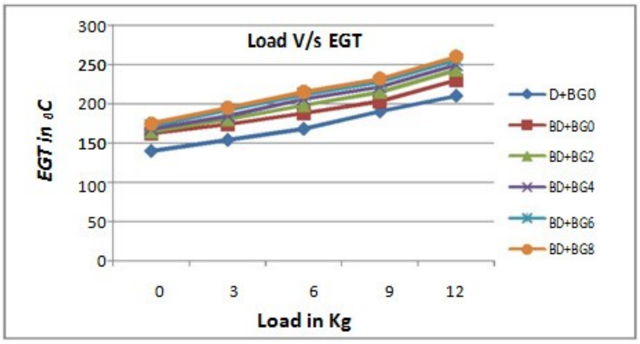

Figure 5. Variation in EGT with the Engine Load

3.4. CO Emission

Figure 6 shows the variation of CO emission in percentage volume with the load. Result showed CO emissions increases with the increasing load and found lower in case of neat diesel than the other fuel combination and increases with increasing the quantity of biogas. The test results shows that the when the engine loads were increases from no load to 12 kg load, the increments of CO emission was maximum 93.44% in case of neat Biodiesel fuel mode and this percentage increments were decreases with increasing the quantity of biogas and found 82.39% at 8 gm/min supplying of biogas with biodiesel. The CO emission depends on the air fuel ratio while adding the biogas, BSEC increases and air fuel ratio decreases, which in turn increases CO emission. Other probable causes for higher CO emission are due to high carbon content that adversely affects the combustion efficiency. In incomplete combustion CO_2 is not converted in to CO.

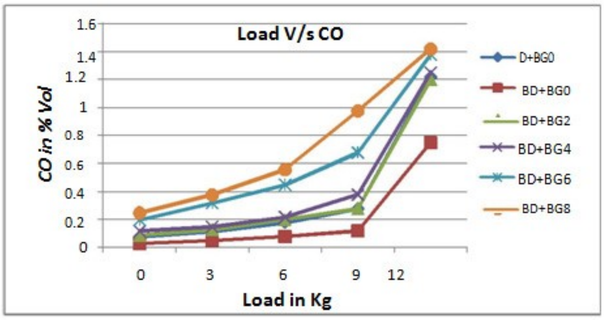

Figure 6. Variation in CO emission with the Engine Load

3.5. CO_2 Emission

Figure 7 shows the variation of CO_2 emission in % volume with the load. Result showed CO_2 emissions increases linearly with the increasing load and found lower in case of neat diesel than the other fuel combination and decreases with increasing the quantity of biogas. At no load condition CO_2 emissions were almost same for all combinations of fuel sets and increases with increasing the load at different rate. The test results shows that the rate of increasing of CO_2 emissions for neat diesel and neat biodiesel are 68.84% and 68.34% respectively, it continuously decreases with adding the quantity of biogas and found minimum (52.89%) at 8 gm/min supply of biogas. The probable causes could be that the amount of fuel consumptions were increases for high loading conditions and biogas contains large amount around 40% by volume of CO_2, and combustion efficiency were also increases at higher load.

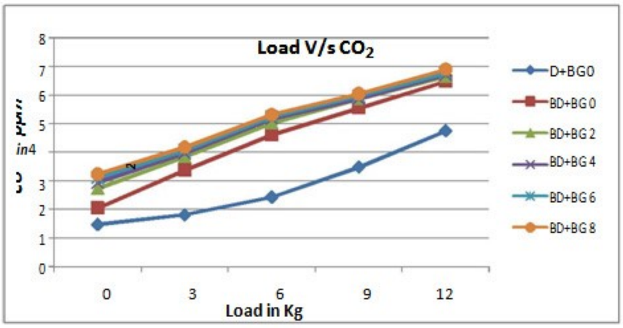

Figure 7. Variation in CO_2 emission with the Engine Load

3.6. HC Emission

Unburnt Hydrocarbon (HC) emissions are the direct result of incomplete combustion. Figure 8 shows the variations of unburnt hydrocarbons emission in parts per million (ppm) with engine Load for neat diesel, neat biodiesel and biodiesel with various quantity of biogas. The HC emissions increases with increasing the engine load. Test results shows that the percentage increments higher (62.5%) for the neat biodiesel and continuous decreasing with adding the quantity of biogas and found minimum (50.64%) at 8 gm/min supply of biogas. It may be because of more induction of biogas into the engine, the CO_2 content in the mixture increases which reduces the air–fuel ratio and combustion temperature therefore incomplete combustion takes place which results increase in HC emissions.

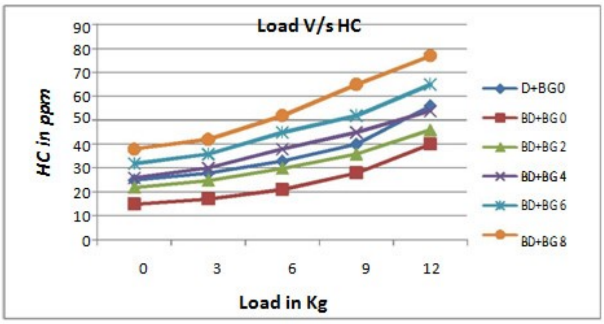

Figure 8. Variation in HC emission with the Engine Load

3.7. NOx Emission

Oxides of Nitrogen (NO_X) are composed by NO and small amount of NO_2 . The NO_X formation depends on high temperature and availability of Oxygen, it is formed by the high temperature combustion gases generate inside the cylinder through the oxidation of nitrogen present in the inducted air. Figure 9 shows the variation of NO_x emissions in parts per million (ppm) with engine Load for neat diesel, neat biodiesel and biodiesel with various quantity of biogas. Result shows NO_x emissions increases linearly with increasing the engine load. It may happened due to need of more fuel at higher loads, which results in slightly higher maximum combustion pressure and temperature, therefore increases the formation of NOx emission. However, the NO_X emission in the neat biodiesel is much higher in comparison to neat diesel and other combination of fuel sets and continuously decreases with increasing the quantity of biogas. On an average a drop of 22.86% and 33.45% NO_x emission were found from neat diesel and neat biodiesel respectively at8 gm/min supply of biogas with biodiesel. This is because of oxygenated fuel, biodiesel has 10–11% oxygen by weight, which may promote Combustion than the neat diesel, and results generate much more temperature in the engine cylinder. Whereas probable causes for more reduction in NO_x emission in dual fuel mode could be presence of CO_2 in the biogas, CO_2contents dilutes the oxygen concentration of the intake mixture which reduced the engine cylinder temperature therefore lowering the formation of NOx.

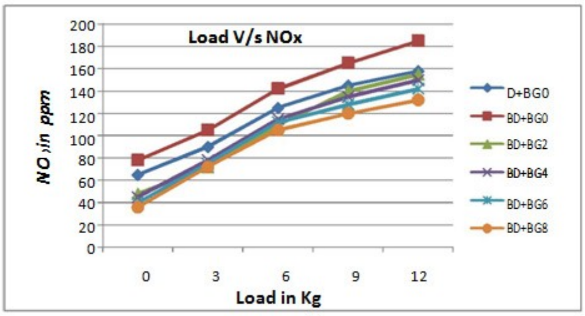

Figure 9. Variation in NO_X emission with the Engine Load

IV. CONCLUSION

The present study investigated the possibility of using alternative fuels for the shaft power particularly in rural areas of developing countries like India. The Biodiesel and Biogas are the renewable fuel and easily available in rural areas that, can be used with inconsequential modification in to a diesel engine, it can make a good substitute for petroleum diesel fuel. This is an easy and low cost technique of running a Compression ignition engine with Biodiesel and Biogas in dual fuel mode, this technique could be suitable for applications where the engine load does not vary frequently and widely. This required minimal modification of the engine and all the diesel settings were kept unchanged to retain instant interchangeability to "mono fuel-only" (either petroleum diesel or biodiesel) operation. At medium load around 50% (7.5 kg) performance and emission parameters were found at optimum level.

Future studies are required to investigate the use of biodiesel and its blends in place of biodiesel with varying quantity of raw biogas as well as purified biogas.

V. REFERENCES

[1]. Sadiq Y. Ragadia and Dr. Rajesh C. Iyer, A Review Paper on Theoretical &Experimental Investigations of a Biogas Engine Technology. International Journal for Scientific Research & Development (IJSRD) Vol. 3, Issue 06, 2015, ISSN (online): 2321-0613.

[2]. N.H.S.Ray, P.R.Swain and M.K.Mohanty, An Investigation On Performance Characteristics Of C.I Engine Using Biogas And Diesel In Dual Fuel Mode. International Journal of Science, Engineering and Technology Research (IJSETR), Volume 3, Issue 6, June 2014.

[3]. N.H.S.Ray, M.K.Mohanty and R.C.Mohanty, Anaerobic Digestion of Kitchen Wastes: "Biogas Production, Purification and Application in I.C Engines." International Journal of Latest Trends in Engineering and Technology (IJLTET), Vol. 3 Issue 3 January 2014, ISSN: 2278-621X.

[4]. C. Sundar Raj, S. Arul, S. Sendilvelan and C.G. Saravanan, Bio Gas from Textile Cotton Waste - An Alternate Fuel for Diesel Engines. The Open Waste Management Journal, Vol. 2, 2009, ISSN: 1876-4002.

[5]. Shaik Magbul Hussain, B. Sudheerpremkumar and K .Vijaya Kumar Reddy, Biogas – Diesel Dual Fuel Engine Exhaust Gas Emissions. International Journal Of Advanced Research In Engineering And Technology (IJARET), Volume 4, Issue 3, April 2013, pp. 211-216, ISSN 0976 – 6480.

[6]. Bhaskor J. Bora and Ujjwal K. Saha, Comparative assessment of a biogas run dual fuel diesel engine with rice bran oil methyl ester, pongamia oil methyl ester and palm oil methyl ester as pilot fuels, Renewable Energy, 81 (2015) 490-498.

[7]. Hasan Koten, Mustafa Yilmaz, and M. Zafer Gul, Compressed Biogas-Diesel Dual-Fuel Engine Optimization Study for Ultralow Emission. Hindawi Publishing Corporation, Advances in Mechanical Engineering Volume 2014.

[8]. Juan Guillermo Lira Cacho , Alfredo Oliveros & Jhordann Barrera (2011): Development of a Biogas Fuel Supply System for an Internal Combustion Engine, Distributed Generation& Alternative Energy Journal, 26:3, 6-19

[9]. Hawi, M., Kiplimo, R. and Ndiritu, H. (2015) Effect of Exhaust Gas Recirculation on Performance and

Emission Characteristics of a Diesel-Piloted Biogas Engine. Smart Grid and Renewable Energy, 6, 49-58.
[10]. Hitesh N Prajapati, Tushar M Patel and Gaurav P Rathod, Emission analysis of biogas premixed charge diesel dual fuelled engine. International organization of Scientific Research, Journal of Engineering (IOSRJEN) Vol. 04, Issue 05 (May. ISSN (e): 2250-3021, ISSN (p): 2278-8719), PP 54-60.
[11]. Harilal S. Sorathia and Hitesh J.Yadav, Energy Analyses To A Ci-Engine Using Diesel And Bio-Gas Dual Fuel- A Review Study, International Journal of Advanced Engineering Research and Studies (IJAERS) Vol. 1 Issue 2 (2012) pp 212-217 ISSN 2249–8974
[12]. M.Ravi, KCK.Vijayakumar, M.Ashok Kumar and T.Gunaseelan, Experimental Investigation on Emission and Performance Charecteristics of Single Cylinder Diesel Engine using Lime Treated Biogas. International Journal of ChemTech Research (IJCRGG) Vol.7, No.4, pp 1720-1728, 2014-2015. ISSN 0974-4290.
[13]. K. Senthilkumar and S. Vivekanandan, Investigating the Biogas as Secondary Fuel for CI Engine. International Journal of Applied Environmental Sciences Vol. 11, No. 1 pp. 155-163, 2016. ISSN 0973-6077
[14]. Bhabani Prasanna Pattanaik, Chandrakanta Nayak and Basanta Kumar Nanda, Investigation on utilization of biogas & Karanja oil biodiesel in dual fuel mode in a single cylinder DI diesel engine. International Journal Of Energy And Environment, Vo.l 4,Issue2, pp.279-290(2013). ISSN 2076-2895 (Print), ISSN 2076-2909.
[15]. Vijayaprabhakaran.P, Ravi.M, Periyasamy. Nand Kannan.C, Performance and Emission Characteristics of a Four Stroke Diesel Engine Using Biogas. International Journal of Engineering Research-Online A Peer Reviewed International Journal, Vol.3, Issue 2, 2015. ISSN: 2321-7758.
[16]. R. Chandra, V.K. Vijay, P.M.V. Subbarao and T.K. Khura, Performance evaluation of a constant speed IC engine on CNG, methane enriched biogas and biogas. Applied Energy 88 (2011) 3969–3977.
[17]. Harilal S. Sorathia, Bhagirathsinh H. Zala, Dinesh L. Suthar and Vashant K. Pipaliya, Performance of Biogas Premixed Charge Constant Speed Diesel Engines Used in an Agricultural field. International Journal of Advanced Engineering Technology, Vol. 5 Issue 1, pp 33-40, 2014.ISSN 0976-3945.
[18]. A. Bilcan , O. Le Corre& A. Delebarre (2003): Thermal efficiency and environmental performances of a biogas-diesel stationary engine, Environmental Technology, 24:9, 1165-1173.
[19]. Gaurav Paul, Ambarish Datta and Bijan Kumar Mandal, An Experimental and Numerical Investigation of the Performance, Combustion and Emission Characteristics of a Diesel Engine fueled with Jatropha Biodiesel, Energy Procedia 54 (2014) 455 – 467
[20]. Avinash Kumar Agarwal, Biofuels (alcohols and biodiesel) applications as fuels for internal combustion engines, Progress in Energy and Combustion Science 33 (2007) 233– 271
[21]. C. Vijayakuma, A.Murugesan, B.Aishwarya, A.Jeyaram, G.Gogul, P.Abinash Nayak, Experimental Investigation of Mahua Methyl Ester as an Alternative Fuel for Diesel Engine, International Journal of Pharm Tech Research, CODEN (USA): IJPRIF, ISSN: 0974-4304,Vol.8, No.2, pp 193-199, 2015.
[22]. Swarup Kumar Nayak, Bhabani Prasanna Pattanaik, Experimental Investigation on Performance and Emission Characteristics of a Diesel Engine Fuelled with Mah Biodiesel Using Additive, Energy Procedia 54 (2014) 569 – 579
[23]. R. Suresh and S. Vivekanandan. Investigation on Edible De-Oiled and Non Edible De-Oiled Cakes in Anaerobic Co-Digestion for Biogas Production. International Journal of Mechanical Engineering and Technology, 8(1), 2017, pp. 249–255.
[24]. Bhaskor J. Bora, Ujjwal K. Saha, Comparative assessment of a biogas run dual fuel diesel engine with rice bran oil methyl ester, pongamia oil methyl ester and palm oil methyl ester as pilot fuels, Renewable Energy 81 (2015) 490-498
[25]. Yudai Yamasaki, Masanobu Kanno, Yoshitaka Suzuki, Shigehiko Kaneko, Development of an engine control system using city gas and biogas fuel mixture Applied Energy 101 (2013) 465–474
[26]. Bhabani Prasanna Pattanaik, Chandrakanta Nayak, Basanta Kumar Nanda, Investigation on utilization of biogas & Karanja oil biodiesel in dual fuel mode in a single cylinder D diesel engine, International Journal Of Energy And Environment, Volume 4, Issue 2, 2013 pp.279-290
[27]. V. Venugopalan, Dr. N. Balasundaram and S. Hemalatha, Comparative Study on Biogas Production from Cow Dung, Food Waste and Organic Wastes. International Journal of Civil Engineering and Technology, 8(2), 2017, pp. 100–106
[28]. Nitin Shrivastava , S. N. Varma & Mukesh Pandey (2012): Experimental investigation of diesel engine using EGR and fuelled with Karanja oil methyl ester, International Journal of Sustainable Engineering, DOI:10.1080/19397038.2012.749310
[29]. Manjiri Ayade and Dr. A.A. Latey, Performance and Emission Characteristics of Biogas – Petrol Dual Fuel in Si Engine, International Journal of Mechanical Engineering and Technology, 7(2), 2016, pp. 45-54