International Journal of Ambient Energy

ISSN: 0143-0750 (Print) 2162-8246 (Online) Journal homepage: http://www.tandfonline.com/loi/taen20

Experimental Investigation Of The Influence Of Isobutanol Addition On Engine Performance And Emissions Of A Direct Ignition Diesel Engine Fuelled By Biodiesel Blends Derived From Waste Vegetable Oil

Jeya Jeevahan, M. Chandrasekaran, G. Britto Joseph, A. Poovannan & V. Sriram

To cite this article: Jeya Jeevahan, M. Chandrasekaran, G. Britto Joseph, A. Poovannan & V. Sriram (2017): Experimental Investigation Of The Influence Of Isobutanol Addition On Engine Performance And Emissions Of A Direct Ignition Diesel Engine Fuelled By Biodiesel Blends Derived From Waste Vegetable Oil, International Journal of Ambient Energy, DOI: 10.1080/01430750.2017.1381158

To link to this article: http://dx.doi.org/10.1080/01430750.2017.1381158

Accepted author version posted online: 19 Sep 2017.

Publisher: Taylor & Francis & Informa UK Limited, trading as Taylor & Francis Group

Journal: *International Journal of Ambient Energy*

DOI: 10.1080/01430750.2017.1381158

EXPERIMENTAL INVESTIGATION OF THE INFLUENCE OF ISOBUTANOL ADDITION ON ENGINE PERFORMANCE AND EMISSIONS OF A DIRECT IGNITION DIESEL ENGINE FUELLED BY BIODIESEL BLENDS DERIVED FROM WASTE VEGETABLE OIL

Jeya Jeevahan[1*], M.Chandrasekaran[2], G.Britto Joseph[1], A.Poovannan[1], V.Sriram[1]

[1]Assistant Professor (Mechanical Engineering), Sathyabama University, Chennai, Tamilnadu, India.
[2]Director (Mechanical Engineering), Vels University, Chennai, Tamilnadu, India.

ABSTRACT:
Biodiesel has become one of the potential alternative sources to replace diesel. Some of the limitations of biodiesel include high NOx, poor atomization, poor oxidation stability, cold flow problems, long term storage problems etc. Various strategies were discussed to overcome the limitations of biodiesels. Recent research is on effects of fuel additives or fuel composition modification to reformulate the fuel properties. This article is aimed at presenting the experimental investigation of the effects of isobutanol additive on the engine performance and emission characteristics of biodiesel blends derived from waste vegetable oils. The experimental investigation was conducted on a direct injection four stroke diesel engine with different blends, B10, B20, B30, B10 (10% ISB, B20 (10% ISB), B30 (10% ISB), (20% ISB, B20 (20% ISB) and B30 (20% ISB), and engine performance and emission characteristics are evaluated and discussed.

Keywords: alternate fuel, biodiesel, isobutanol, additive, emission, engine performance

INTRODUCTION:
Biodiesel is one of the potential alternative sources of fuel that can replace diesel one day. Biodiesel is a non-petroleum based fuel derived from vegetable oils or animal fat. Most of the biodiesel related research works show that biodiesel reduces the engine performance. On the other hand, the emissions of PM, HC, CO_2 are reduced which is considered more beneficial to the environment. Some of the limitations of biodiesel include high NOx emission, poor atomization, poor oxidation stability, cold flow problems, long term storage problems etc. High NOx emissions is one of the seriously discussed problems in bioiesel and various strategies were proposed to overcome the limitations of biodiesels, such as exhaust gas re-circulation (EGR), emulsification, after-treatments, fuel modifications, engine modifications and so on [Jeevahan et al. 2016; Kunjan et al. 2016; Szybist et al. 2005]. Out of these strategies, fuel modification has got more attention recently since they require no additional cost or engine modification. Fuel modification not only reduces NOx emissions but also has the potential to overcome other limitations of the biodiesels. Researchers have used fuel additives such as antioxidants and cetane number improvers [Zhu et al. 2016; Singh et al. 2016; Santana et al. 2006; Shahabuddin et al. 2012; Rao & Rao 2012; Velmurugan & Sathiyagnanam 2016], nanoparticles [Prabhu et al. 2015; Kannan et al. 2011; Mirzajanzadeh et al. 2015], and modified chemical composition of the biodiesel [Varatharajan & Cheralathan 2012; Moser et al. 2009; No 2014], to enhance the fuel properties. When compared to petro-diesel, the cost of biodiesel is high (1.5 times higher than petro-diesel), which may become a major barrier to large scale production. The cost of raw material (vegetable oil, algae or animal fats) itself amounts 70–95% of the total production cost of biodiesel depending on the raw material sources. Therefore, it is a good idea to explore low cost raw materials for biodiesel production [Zhang et al. 2003; Refaat et al. 2008].

The waste vegetable oil (WVO) is referred as the remaining vegetable oil after it is been used for food production and no longer fit for its further use. WVO is produced in various sources including domestic and commercial kitchens, restaurants, hotels, food processing industries. This WVO is generally poured down the drain posing many problems. It can block the pipes if the oil solidifies. The corrosive nature of the WVO is high leading corrosion on metal and concrete members of the sewage system. It can also affect the waste water treatment plants [Refaat et al. 2008; Felizardo et al. 2006]. It was reported that USA produces 10 Million Tonnes of WVO per year and China produces 4.5 Million Tonnes of WVO per year. The disposal of WCO through drainage or landfill may pollute water and soil which in turn may raise concern over the aquatic ecosystem and human health. Some recycle WCO for further cooking but the recycled WCO is believed to cause cancer due to the presence of toxic matters produced when WCO is oxidised during frying. These problems can be overcome by utilizing WCO for biodiesel production. The WVO is very cheap (2-3 times lesser compared to pure vegetable oil). This can reduce the total production cost of biodiesel to a great extend, thus reducing the price of biodiesel. Moreover, WCO does not affect the food supply since it uses the waste oil after its intended use. However the major drawback of using WCO for the biodiesel production is the presence of impurities, such as free fatty acids, water and other solid particles. The water content leads to hydrolysis; high free fatty acid content leads to saponification. These two reactions often causes low yield of biodiesel and high catalyst consumption. If the free fatty acid content is higher than 3%, transesterification process failure may even occur. Transesterification is widely used for biodiesel production. In this process, feedstock oil, methanol and a catalyst are used. Before starting transesterification of WVO, it is however necessary to pre-treat WVO before transesterification process. Some of the pre-treatments include washing step, centrifugation, and flash evaporation [Felizardo et al. 2006; Yaakob et al. 2013; Gui et al. 2008; Phan & Phan 2008]. Homogeneous/ heterogeneous acid catalyst, homogeneous/ heterogeneous base catalyst and enzyme based transesterification are proposed to convert WVO into biodiesel [Lam et al. 2010; Morais et al. 2010; Talebian-Kiakalaieh et al. 2013; Enweremadu & Mbarawa 2009]. The base catalyst and acid catalyst based transesterification processes are more attractive due to their short reaction time and low cost as compared with enzyme based transesterification process [Wang et al. 2007].

Many researchers have discussed about the synthesis of biodiesel from WVO [Demirbas 2009; Zheng et al. 2006; Chhetri et al. 2008; Hingu et al. 2010; Al-Widyan & Al-Shyoukh 2002; Issariyakul et al. 2007; Encinar et al. 2007; Lopresto et al. 2015]. However, the performance and emission characteristics of the biodiesel blends obtained from WVO were rarely discussed. In the work of Dorado et al. [Dorado et al. 2003], the emission characteristics were studied. The biodiesel was prepared from WVO and the prepared biodiesel reduced CO emissions by 58.9%, CO2 emissions by 8.6% and NO emissions by 37.5%), while increased NO_2 emissions by 81%. In the work of Utlu and Kocak [Utlu & Kocak 2008], WVO biodiesel was tested on a turbocharged DI diesel engine to evaluate the engine performance and emissions. Emissions were found to be decreased (17.14% CO, 1.45% NOx). Engine performance and specific fuel consumptions are nearly the same as that of the diesel engine. In the experiment of Cetinkaya et al. [Cetinkaya et al. 2005], The engine performance and road test performance of WVO biodiesel were investigated on a 75kW Renault Megane automobile in winter conditions for about 7500 km road tests. The results revealed that the engine performance is 3-5% less than that of petro-diesel. Fuel additives were added to improve viscosity and pour point and the results exhibited that addition of these additives showed significant improvement in the engine performance on cold-flow properties. In the work of Can [Can 2014], the combustion, performance and exhaust emission characteristics of WVO biodiesel blends were investigated. The results showed 8.7% increase in NOx emission, 5% decrease in THC, 51% decrease in CO emissions and a slight increase of CO_2 emissions.

Butanol is an biomass-based fuel produced from biomass feedstocks through alcoholic fermentation. The solubility, in diesel and biodiesel, of butanol is higher than that of ethanol at wide range of operating conditions [Liu et al. 2011]. Karabektas & Hosoz [Karabektas & Hosoz 2009] have conducted an investigation on the effects of isobutanol additives (10% and 20%) with diesel on engine performance and emissions. The results showed that the break power slightly decreased. CO, NOx emissions were found to be less as compared to petro-diesel. However, HC emissions increased considerably. In another experiment by Yilmaz et al. [Yilmaz et al. 2014], the effects of butanol–biodiesel blends on the emissions of a indirect injection diesel engine were investigated. The results showed that butanol blended fuels at higher concentrations (20%) produced less NOx emissions while higher CO and HC emissions were observed. The effects of n-butanol was studied by Atmanli et al. [Atmanli et al. 2014] on performance and emissions of vegetable oil–diesel fuel. The results showed that the cold flow properties and oxidative stability were improved while producing negative impact on NOx and CO emissions. CO2 and HC emissions were observed and the engine performance was slighly reduced. However no research work is carried out to investigate the effects of iso-butanol additive mixed with waste vegetable oil or biodiesel on engine performance and emission characteristics. In this article, the effects of isobutanol (ISB) additive on the engine performance and emission characteristics is investigated with petro-diesel, biodiesel blends and biodiesel plus ISB additive.

WVO BIODIESEL PREPARATION:

Waste vegetable oil (WVO) was collected from the domestic kitchens and restaurants in and around Sithalapakkam, Chennai City, India. At least 1 litre of WVO was collected from each place. These collected oils, that contain impurities, were stored in a container of 25 litre capacity as a homogeneous mixture. WVO was first filtered with the help of a filter to remove suspended solid particles. Two filters of mesh size 0.2 mm and 0.05 mm were used. The oil was then heated up for about 15-20 minutes while stirring continuously. This removes the water content from the oil. The purified waste vegetable oil is now ready for transesterification process. Diesel, methanol, isobutanol and a suitable catalyst (sodium hydroxide) were purchased from the local market, Chennai city, and were used to produce the biodiesel and its blends. Alkaline transesterification process was used to produce biodiesel. WVO was first transferred to a container of the transesterification setup (Research Centre at Sathyabama University, Chennai) and is heated to a temperature of about 70ºC using an electric heater, while continuously stirred by a magnetic stirrer. At this temperature, a mixture of methanol and sodium hydroxide was transferred. Now the transesterification reaction takes place. The mixture is maintained at the same temperature for about 45-60 minutes. In the experiment, the molar ratio of methanol to WVO was taken as 1:5 and the quantity of catalyst was about 1% of WVO. If the free fatty acid content is higher, the quantity of catalyst may be slightly increased. At the end of transesterification reaction, WVO biodiesel was separated from the container and purified using a decantation funnel.

PREPARATION OF WVO BIODIESEL BLENDS:

The purified WVO biodiesel was mixed with appropriate proportions of petro-diesel and isobutanol to prepare different blends. There was no need for any pre-heating or any other means to aid the mixing as both the components were miscible in diesel. No separate layers were observed in case of the mixture even after stagnation over long period of time. Thus it is clear that the components have good mixing properties. The blends were prepared on volume basis with the mixture of waste vegetable oil in 10% and 20% and 30 % and of isobutanol in 10% and 20% proportions. The properties are evaluated for each mixture and are shown in Table 1.

Table 1: Properties of different blends used in the experiment

Fuel Properties	Fire Point (°C)	Flash Point (°C)	Cetane Index	Kinematic Viscosity (mm²/s)	Calorific Value (kJ/kg)	Density (kg/m³)
Diesel	65	65	45	4.7	42500	830
Waste Vegetable Oil	222	214	31	37.42	39500	910
B10	89	78	44	4.6	40000	852

B20	94	79	43	6.8	39250	860
B30	97	82	43	9.12	38500	873
Isobutanol	45	35	17	2.2	32500	809
B10+10%	86	75	44	6.8	42575	846
B20+10%	84	75	43	6.61	42978	855
B30+10%	82	70	42	6.38	42048	863
B10+20%	97	85	44	11.08	39800	840
B20+20%	95	83	43	10.64	42915	854
B30+20%	92	80	42	10.19	42978	855

EXPERIMENTAL SETUP:

The setup consists of single cylinder, four strokes, Diesel engine of power 5.2 KW at 1500rpm connected to eddy current and water cooled type dynamometer for loading. consist of four types of sensors i.e. piezo sensor of range 5000 Psi, crank shaft sensor of Resolution 1 Degree, speed 5500 RPM with TDC pulse, temperature sensor having Type K thermocouple and load sensor of range 0-50 Kg strain gauge type. The engine is first started for 10-15 minutes with diesel and then with the prepared blends (i.e. B10+10%, B20+10%, B30+10%, B10+20%, B20+20% and B30+20%) by entering the value of the calorific value and density value respectively into the engine software. Speed of the engine was kept constant at 1500 rpm under varying load conditions (i.e. 0kg, 4kg, 8kg, 12kg and 16kg) to measure the engine performance. Engine exhaust is connected with AVL DiGas 444 analyser having oxygen gas sensor of Electro Chemical type is used to measure the engine emission parameters like CO, HC, CO2, O2 and NOx. .

Figure 1: Experimental Set-up

RESULTS AND DISCUSSION:

Brake Thermal Efficiency (BTE):

Figure 2 shows the plot between the brake thermal efficiency and load in kg for a constant speed. It is observed from the figure that the BTE of biodiesel fuel is lesser than diesel. This may be due to large particle size that leading to incomplete combustion of biodiesel particles. An increasing trend of BTE is observed with increase in load was observed up to a load level of about 16 Kg. The initial increase in BTE may be attributed to the complete and high combustion of fuel, but once the load reached at full load level; the time taken for complete combustion of fuel was decreased, hence a slight drop in BTE was observed. Oxygen present in the blends perhaps also helped in complete combustion of fuel at no load and also at partial load conditions. At full load conditions, the change of state from molecule oxygen to atomic oxygen perhaps has lead to a decrease in BTE. BTE of the blend B30+20% is lowest. The addition of the waste vegetable oil decreased BTE values and thus the blends with higher content of waste vegetable oil have lower value of BTE. The same trend is also followed by addition of the additive (Isobutanol) which reduces the BTE value of the blend. This is mainly attributing to the lower calorific value of the blends.

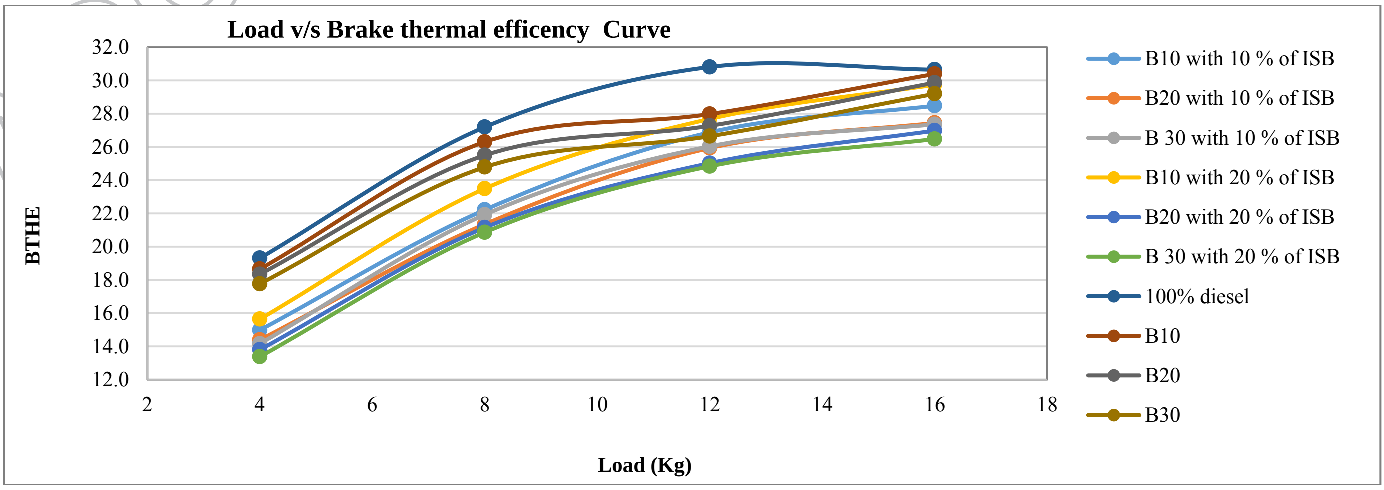

Figure 2: Load versus Brake Thermal Efficiency

Brake Specific Fuel Consumption (BSFC):

The fuel consumption characteristics of an engine are generally expressed in terms of specific fuel consumption in kilograms of fuel per kilowatt-hour. It is an important parameter that reflects how well the engine performance. It is inversely proportional to the thermal efficiency of the engine. From the figure 3, one can clearly observe that as the load increases the value of BSFC decreases showing the inverse trend of the BSFC v/s Load graph. We also observe that as we increase the amount of waste vegetable oil in the blends the BSFC decreases. This trend is also observed in the addition of theisobutanol, in this case in both the blends i.e. B30 + 20 % and B30 + 10 % shows the reflection in the graph which due to the lower calorific value of the additive. This point is already seen evidently in the corresponding BTE graph which possesses an inverse relation to the calorific value. The graph has the highest SFC for B30 + 20% blend which states that the fuel has been consumed more for the same amount of power output. The lowest value is for the blend B10 which increases the BTE of the system and can be seen that it is little high as compared to diesel.

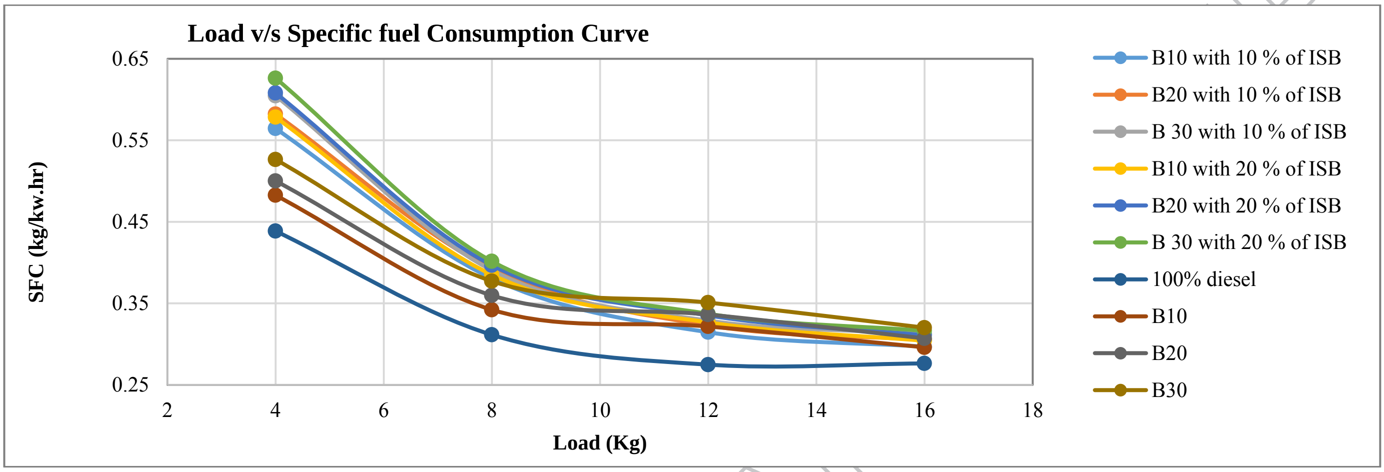

Figure 3: Load versus Brake Specific Fuel Consumption

CO_2 Emission:

The graph shown in figure 4 has a good characteristic curve which peaks at 12kg load and shows that B30 has always been at the top of the curve and B20+20% at the bottom. The other blends curve has a low value of CO_2 at different load condition when compare to diesel CO_2as the A/F ratio is lesser than diesel and there is more fuel to burn in the air, the other main reason is that the combustion doesnot take place properly at all the loads due to low cylinder temps which lead to poor atomization and thus at lower loads the carbon present in the fuel changes to CO. and not to CO_2. The waste vegetable oil blend is having higher CO_2 which means the combustion takes place properly which result in CO lesser and the CO_2 value of diesel is more are less to the waste vegetable oil blends whereas the isobutanol blends having lesser CO_2 due to higher air fuel ratio when compare to waste vegetable oil blends. The figure 4 also shows that the effect of addition of the waste vegetable oil and isobutanol has different effect on the formation of CO_2 at different loads. But looking at the graph we can conclude the effects on the basis of average values which shows that the amount of CO_2 reduces as the amount of Waste vegetable oil increases in the blend which is also reciprocated in the case of addition of isobutanol, thereby reducing the amount of CO_2 in the exhaust. Also, CO_2 formation is dependent on carbon to hydrogen ratio of the fuels. More contents of carbon in the blends causes more amount of CO_2 emissions in the exhaust gases. Compared to diesel fuel as seen in figure 4 carbon contents of other blends are relatively lower in the same volume of fuel consumed at the same engine speed, which tells us the reason for low CO_2 formation.

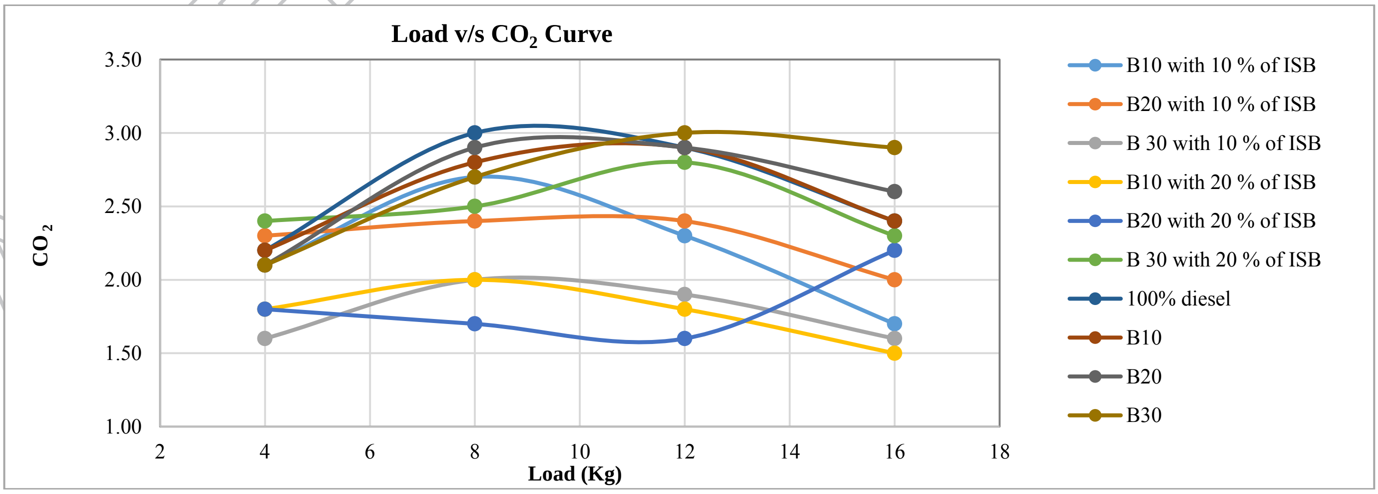

Figure 4: Load vs CO_2 Emission

HC Emissions:

The variations of HC emission for diesel and biodiesel are shown in the figure 5. The emissions of unburnt hydrocarbon for biodiesel exhaust is lower than that of diesel fuel and the reason could be the increased gas temperature and higher cetane number of biodiesel. However, HigherHC emission is found for biodiesel with isobutanol additives. As we see from the graph B30 + 20% blends have higher values of HC as compared to diesel and diesel being in the range of B10, B20 & B30 blends. By addition of Isobutanol, we see that the HC values are increasing which is an attribute to the higher viscosities leading to poor atomization hence resulting in higher HC values for B30 + 20% & B20 + 20% blends. The main reason for the higher values of HC in the exhaust is the high viscosity of the blends which inhibits the mixing of the air and fuel which takes longer and flame quenching occurs as high viscosity means poor atomization and these are left unburnt. Temperature of burnt gases in biodiesel fuel helps in preventing condensation of higher hydrocarbon reducing unburnt HC.

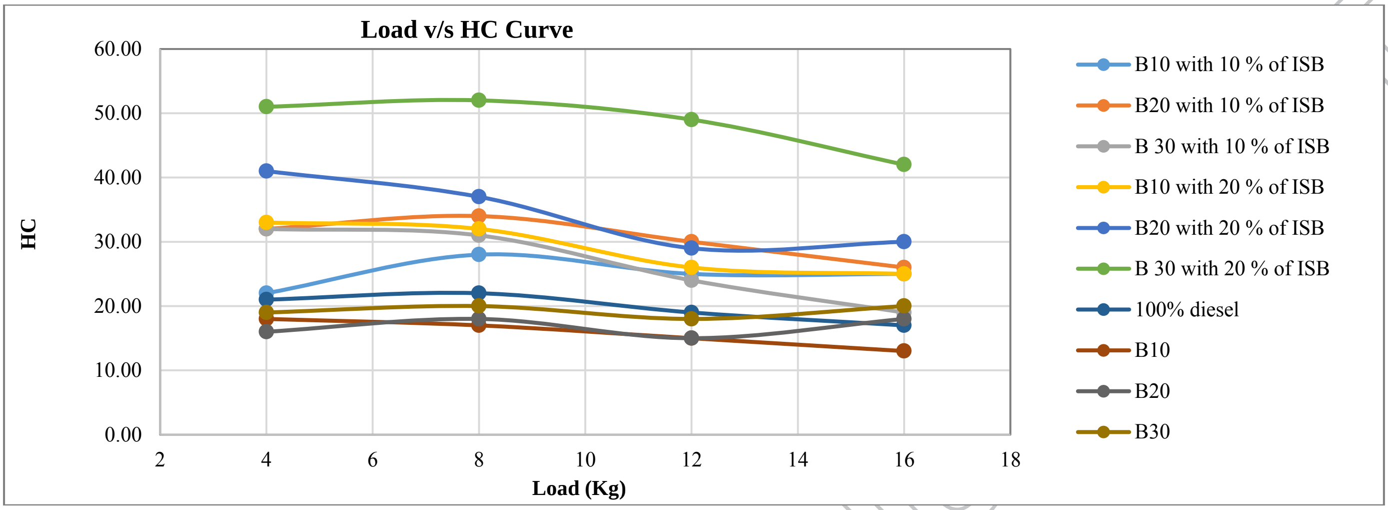

Figure 5: HC Emissions

NOx Emissions:
The figure 6 shows the NO_X curve which is increasing with load and thus the temp in the cylinder increases this produces more NO_X. But the value of NO_X of biodiesel blends is always higher than the diesel engines. As seen in the graph above, the highest value for NOx emission is B30 and lowest is for B10+20% for higher loads. B30+10% has lower NOx values at lower loads and also lower NOx values at higher loads,when compare the other blends the NOx values are lesser than diesel NOx. Within the engine cylinder, there is several of high temperature regions corresponded to oxygen contents. Meanwhile, the great reduction of the cetane number moves the whole combustion process forward during expansion stroke limiting the resident time of the gases at highest temperature, leading to higher NOx emissions.

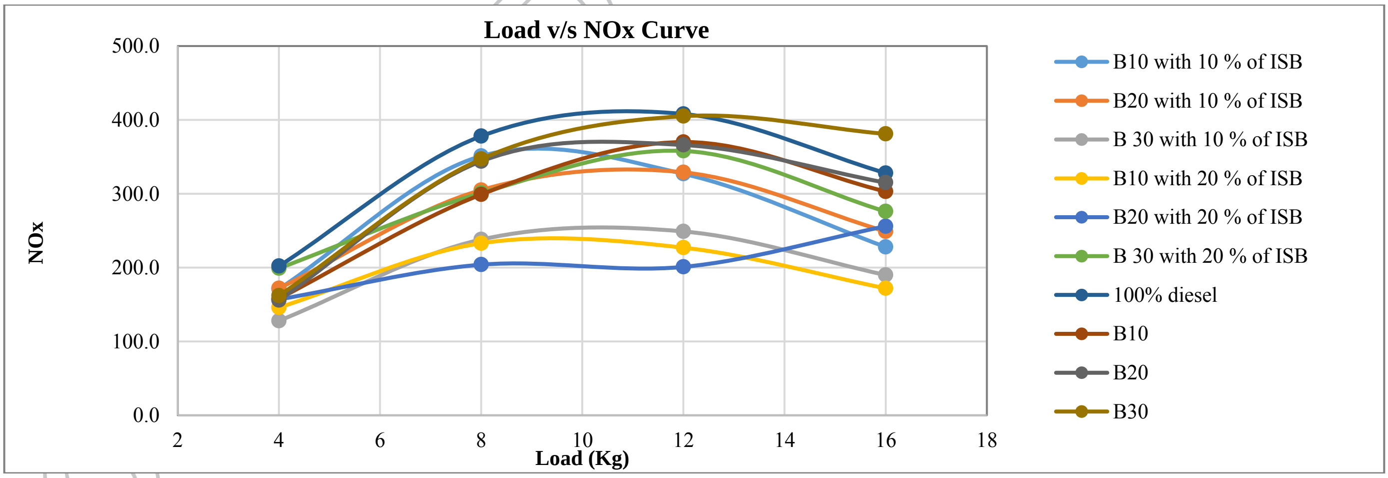

Figure 6: Load vs NOx emissions

Oxygen Content at the Exhaust:
The figure 7 shows the values of O_2 plotted against load for different blends of varying ratios. As we see in the figure, the values of O_2 in the exhaust are in direct relations with the above graph of oxides such as CO, CO_2, NO_X. The highest value of O_2 is for B10+20% at lower loads and B30+20% at higher loads. The lower values of O_2 in the graph tells us that the O_2 has been used up in the combustion process , thereby giving higher values of other gases. So in terms of O_2 content we find the B10+20% should have least performance characteristics but which is not the case. This is mainly due to the highest inherent O_2 content of the fuel due to waste vegetable oil and Isobutanol thereby giving better performance characteristics. All oxygen values are lower than diesel, because all have higher NOx & CO_2 content in exact proportions.

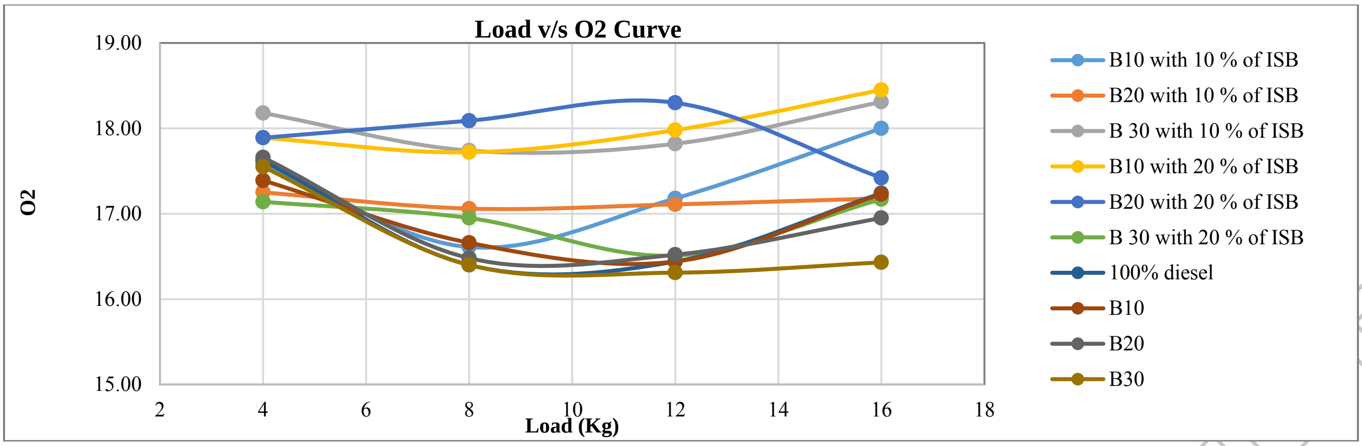

Figure 7: Oxygen Content at the Exhaust

Air-Fuel Ratio:

From the figure 8, we observed that, the waste vegetable oil blends have high air-fuel ratio than isobutanol blends and to diesel curve. B30+ 20% of isobutanol blend have lesser air fuel ratio and this low air-fuel ratio made low brake thermal efficiency and also high HC emission and when the load is increasing, the amount of air fuel ratio is getting reduced due to the density changes of fuel which reduces the air flow to the cylinder. The other blends air fuel ratio value is less than diesel air fuel ratio due to density and viscosity changes on fuel. B10 & B20 blends have more air fuel ratio when compare to other blends and also it have more relevant value to diesel.

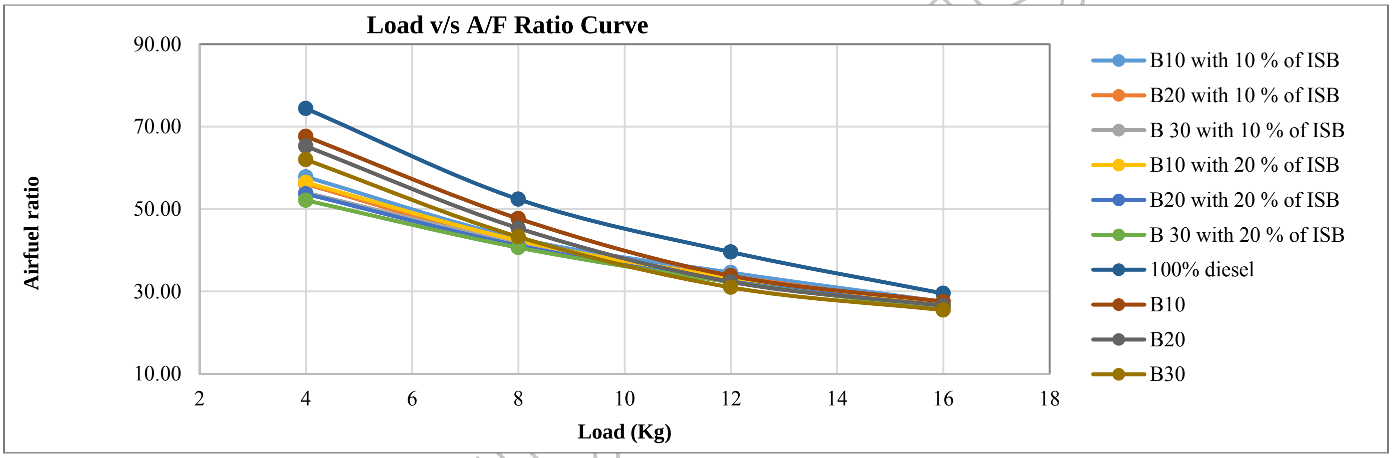

Figure 8: Air-Fuel Ratio

From the above discussions, The addition of waste vegetable oil in diesel increases its density viscosity but decreases its calorific value. The brake thermal efficiency of the fuel goes on increasing as the amount of Waste vegetable oil increases in the blend and at the same time reduces its specific fuel consumption with a decrease in the air fuel ratio. The emissions were also likely improved with B10 & B20 Blends as the values for the CO, HC, NOX and O2 reduced but CO2 value also have some improvement in higher loads whereas in lower loads the CO2 is increased as reduction of air fuel ratio at lower loads. with the addition of the Waste vegetable oil in the blend due to various factors and mechanism affecting the reasons for the obtained variations, there is an increase in the value of HC which is undesirable but mainly due to its high viscosity. The combustion characteristics are better at lower loads but same at higher loads. The addition of isobutanol in diesel blended with Waste vegetable oil increases its oxygen content but decreases its density, calorific value and viscosity. The addition of isobutanol has satisfactory effects on the performance characteristics of the fuel such as the increases in the amount of isobutanol increases the brake thermal efficiency of the fuel and thus having the revers effect on the specific fuel consumption i.e. lowers it, the exhaust gas temperature also reduces. The emission curves show the same effects as that of addition of Waste vegetable oil which is reduction in CO, CO2, NOX and O2 and an increase in the amount of HC. The combustion characteristics are good at lower loads but become better as the load increase.

Table 2: Overall result

Performance		**Emissions**			
BTE	SFC	NOx	HC	CO_2	O_2
B10	B10	B10+20%	B10	B10	B30+10%
B20	B20	B30 +10%	B20	B30+20%	B10+20%
B10 + 20%	B10 + 20%	B20+20%	B10+20%	B10+20%	B20+20%

The test result reveal that waste vegetable oil and isobutanol can be used as fuel additive and the blend perform better as both the blending material increase in the blends thus stating that B10+20% blend is the most suitable blend which can be used in place of pure diesel without making any changes in the engine system.

CONCLUSION:

Waste vegetable oil seems to be a good renewable source of feed stocks for biodiesel production. However collecting WVO requires integrated waste management and awareness about the ill effects of the used oil. In this article, the effects of isobutanol as an additive to enhance the properties of biodiesel blends derived from waste vegetable oil was discussed. The biodiesel blends of B10, B20 and B30 were prepared first. The blends are mixed with isobutanol in two concentratios 10% and 20% to make another six blends (B10 (10% ISB, B20 (10% ISB), B30 (10% ISB), (20% ISB, B20 (20% ISB) and B30 (20% ISB). The experimental investigation was then conducted on a direct injection diesel engine to determine engine performance and emission characteristics. From the obtained results, it is observed that engine performance is improved with the addition of isobutanol with reduced emissions of HC, CO_2. However, addition of isobutanol has no effect on reduction of NOx emissions. Further research is required in the aspect of other properties such as cold flow properties, oxidative stability and NOx reductions.

REFERENCES:

[1] Al-Widyan, M.I. and Al-Shyoukh, A.O. 2002. "Experimental evaluation of the transesterification of waste palm oil into biodiesel." Bioresource Technology, 85: 253–256.

[2] Atmanli, A., Ileri, E. and Yuksel, B. 2014. "Experimental investigation of engine performance and exhaust emissions of a diesel engine fueled with diesel–n-butanol–vegetable oil blends." Energy Conversion and Management, 81: 312–321.

[3] Can, O. 2014. "Combustion characteristics, performance and exhaust emissions of a diesel engine fueled with a waste cooking oil biodiesel mixture." Energy Conversion and Management, 87: 676–686.

[4] Cetinkaya, M., Ulusoy, Y., Tekin, Y. and Karaosmanoglu, F. 2005. "Engine and winter road test performances of used cooking oil originated biodiesel." Energy Conversion and Management, 46: 1279–1291.

[5] Chhetri, A.B., Watts, K.C. and Islam, M.R. 2008. "Waste Cooking Oil as an Alternate Feedstock for Biodiesel Production." Energies, 1(1): 3-18.

[6] Demirbas, A. 2009. "Biodiesel from waste cooking oil via base-catalytic and supercritical methanol transesterification" Energy Conversion and Management, 50: 923–927.

[7] Dorado, M.P., Ballesteros, E., Arnal, J.M., Gomez, J. and Lopez, F.J. 2003. "Exhaust emissions from a Diesel engine fueled with transesterified waste olive oil" Fuel, 82: 1311–1315.

[8] Encinar, J.M., González, J.F. and Rodríguez-Reinares, A. 2007. "Ethanolysis of used frying oil. Biodiesel preparation and characterization" Fuel Processing Technology, 88: 513–522.

[9] Enweremadu, C.C. and Mbarawa, M.M. 2009. "Technical aspects of production and analysis of biodiesel from used cooking oil—A review." Renewable and Sustainable Energy Reviews, 13: 2205–2224.

[10] Felizardo, P., Correia, M.J.N., Raposo, I., Mendes, J.F., Berkemeier, R. and Bordado, J.M. 2006. “Production of biodiesel from waste frying oils” Waste Management, 26: 487–494.

[11] Gui, M.M., Lee, K.T. and Bhatia, S. 2008. "Feasibility of edible oil vs. non-edible oil vs. waste edible oil as biodiesel feedstock" Energy, 33: 1646–1653.

[12] Hingu, S.M., Gogate, P.R. and Rathod, V.K. 2010. "Synthesis of biodiesel from waste cooking oil using sonochemical reactors" Ultrasonics Sonochemistry, 17: 827–832.

[13] Issariyakul, T., Kulkarni, M.G., Dalai, A.K. and Bakhshi, N.N. 2007. "Production of biodiesel from waste fryer grease using mixed methanol/ethanol system." Fuel Processing Technology, 88: 429–436.

[14] Jeevahan, J. Chandrasekaran, M., Mageshwaran, G., Joseph, G. B. and Staline, S. 2016, “Investigation of Engine Performance and Emissions of B20 Biodiesel Blend and Effect of EGR on NOx Emissions Reduction.” Journal of Chemical and Pharmaceutical Sciences, 9(4): 2469-2473.

[15] Kannan, G.R., Karvembu, R. and Anand, R. 2011. “Effect of metal based additive on performance emission and combustion characteristics of diesel engine fuelled with biodiesel.” Applied Energy, 88: 3694–3703.

[16] Karabektas, M. and Hosoz, M. 2009. "Performance and emission characteristics of a diesel engine using isobutanol–diesel fuel blends." Renewable Energy, 34: 1554–1559.

[17] Kunjan, M., Jeevahan, J., Joseph, J.B., Mageshwaran. G., Raj, R.B.D. and Poovannan, A. 2016. “Biodiesel Derived from Mango Seed Oil as An Alternative Fuel for Diesel Engines.” Research Journal of Pharmaceutical, Biological and Chemical Sciences, 7(6): 2137-2143.

[18] Lam, M.K., Lee, K.T. and Mohamed, A.R. 2010. "Homogeneous, heterogeneous and enzymatic catalysis for transesterification of high free fatty acid oil (waste cooking oil) to biodiesel: A review" Biotechnology Advances, 28: 500–518.

[19] Liu, H., Lee, C., Huo, M. and Yao, M. 2011. "Comparison of Ethanol and Butanol as Additives in Soybean Biodiesel Using a Constant Volume Combustion Chamber." Energy & Fuels, 25: 1837–1846.

[20] Lopresto, C.G., Naccarato, S., Albo, L., Paola, M.G.D., Chakraborty, S., Curcio, S. and Calabro, V. 2015. "Enzymatic transesterification of waste vegetable oil to produce biodiesel." Ecotoxicology and Environmental Safety, 121: 229–235.

[21] Mirzajanzadeh, M., Tabatabaei, M., Ardjmand, M., Rashidi, A., Ghobadian, B., Barkhi, M. and Pazouki, M. 2015. “A novel soluble nano-catalysts in diesel–biodiesel fuel blends to improve diesel engines performance and reduce exhaust emissions.” Fuel, 139: 374–382.

[22] Morais, S., Mata, T.M., Martins, A.A., Pinto, G.A. and , Costa, C.A.V. 2010. "Simulation and life cycle assessment of process design alternatives for biodiesel production from waste vegetable oils." Journal of Cleaner Production, 18: 1251-1259.

[23] Moser, B.R., Williams, A., Haas, M.J. and McCormick, R.L. 2009. “Exhaust emissions and fuel properties of partially hydrogenated soybean oil methyl esters blended with ultra low sulfur diesel fuel.” Fuel Processing Technology, 90: 1122–1128.
[24] No, S.Y. 2014. “Application of hydrotreated vegetable oil from triglyceride based biomass to CI engines – A review.” Fuel, 115: 88–96.
[25] Phan, A.N. and Phan, T.N. 2008. "Biodiesel production from waste cooking oils" Fuel, 87: 3490–3496.
[26] Prabhu, L., Satish Kumar, S., Anderson, A. and Rajan, K. 2015. “Investigation on Performance and Emission Analysis of TiO2 Nanoparticle as an Additive for Bio-diesel Blends.” National Conf. on Recent Trends And Developments In Sustainable Green Technologies, Published in Journal of Chemical and Pharmaceutical Sciences, Special Issue 7: 408-412.
[27] Rao, P.V. and Rao, B.V.A. 2012. “Performance and emission characteristics of diesel engine with COME-Triacetin additive blends as fuel.” Int. J. of Energy and Environment, 3(4): 629-638.
[28] Refaat, A.A., Attia, N.K., Sibak, H.A., Sheltawy, S.T.E., ElDiwani, G.I. 2008. "Production optimization and quality assessment of biodiesel from waste vegetable oil" International Journal of Environmental Science and Technology, 5(1): 75-82.
[29] Santana, R.C., Do, P.T., Santikunaporn, M., Alvarez, W.E., Taylor, J.D., Sughrue, E.L. and Resasco, D.E. 2006. “Evaluation of different reaction strategies for the improvement of cetane number in diesel fuels.” Fuel, 85: 643–656.
[30] Shahabuddin, M., Masjuki, H.H., Kalam, M.A., Mofijur, M., Hazrat, M.A. and Liaquat, A.M. 2012. “Effect of Additive on Performance of C.I. Engine Fuelled with Bio Diesel.” 2nd Int. Conf. on Advances in Energy Engineering (ICAEE 2011), Energy Procedia, 14: 1624-1629.
[31] Singh, D., Subramanian, K.A., Juneja, M., Singh, K., Singh, S., Badola, R., and Singh, N. 2016. “Investigating the Effect of Fuel Cetane Number, Oxygen Content, Fuel Density, and Engine Operating Variables on NOx Emissions of a Heavy Duty Diesel Engine”, Environmental Progress & Sustainable Energy.
[32] Szybist, J.P., Boehman, A.L., Taylor, J.D. and McCormick, R.L. 2005. “Evaluation of formulation strategies to eliminate the biodiesel NOx effect.” Fuel Processing Technology, 86, 1109–1126.
[33] Talebian-Kiakalaieh, A., Amin, N.A.S. and Mazaheri, H. 2013. "A review on novel processes of biodiesel production from waste cooking oil." Applied Energy, 104: 683–710.
[34] Utlu, Z. and Kocak, M.S. 2008. "The effect of biodiesel fuel obtained from waste frying oil on direct injection diesel engine performance and exhaust emissions." Renewable Energy, 33: 1936–1941.
[35] Varatharajan, K. and Cheralathan, M. 2012. “Influence of fuel properties and composition on NOx emissions from biodiesel powered diesel engines: A review.” Renewable and Sustainable Energy Reviews, 16: 3702–3710.
[36] Velmurugan, K. and Sathiyagnanam, A.P. 2016. “Impact of antioxidants on NOx emissions from a mango seed biodiesel powered DI diesel engine.” Alexandria Engineering Journal, 55: 715–722.
[37] Wang, Y., Ou, S., Liu, P. and Zhang, Z. 2007. "Preparation of biodiesel from waste cooking oil via two-step catalyzed process" Energy Conversion and Management, 48: 184–188.
[38] Yaakob, Z., Mohammad, M., Alherbawi, M., Alam, Z. and Sopian, K. 2013. "Overview of the production of biodiesel from Waste cooking oil" Renewable and Sustainable Energy Reviews, 18: 184–193.
[39] Yilmaz, N., Vigil, F.M., Benalil, K., Davis, S.M. and Calva, A. 2014. "Effect of biodiesel–butanol fuel blends on emissions and performance characteristics of a diesel engine." Fuel, 135: 46–50.
[40] Zhang, Y., Dube, M.A., McLean, D.D., Kates, M. 2003. "Biodiesel production from waste cooking oil: 2. Economic assessment and sensitivity analysis" Bioresource Technology, 90: 229–240.
[41] Zheng, S., Kates, M., Dube, M.A. and McLean, D.D. 2006. "Acid-catalyzed production of biodiesel from waste frying oil" Biomass and Bioenergy, 30: 267–272.
[42] Zhu, Z., Guo, H.J., Zhou, A.P., Li, D.K. and Liu, S.H. 2016. “One way to reduce the NOX Emission of biodiesels: The increase of cetane number.” International Journal of Green Energy, 13(9): 957-962.