182. Comparative Engine Performance Analysis using Diesel fuel and Biodiesel derived from Waste cooking Oil.

M.Waseem Ahmed[a*], A.M. Liaquat [b], Khanji Harijan [a].

a Energy System Engineering, Directorate Post Graduate Studies, Mehran University of Engineering & Technology, Jamshoro, 76062, Pakistan.
[b] Department of Mechanical Engineering, Quaid-e Awam University of Engineering, Science & Technology Nawabshah, 67450, Pakistan.
E-mail address: wam.hala@gmail.com

Abstract

"Biofuels have been neglected by government policies and have not been given importance since long time. It ensures energy security through partially replacing by imported fuels. Biodiesel is mostly produced from oil-seed feed stock through transesterification process. Biodiesel can be effectively used in diesel engine without any engine modification. It has most of the properties very close to diesel fuel. Use of waste cooking oil in diesel engines is more sustainable if they can perform with similar properties as compared to petroleum diesel fuel. In this research paper, engine performance during endurance test has been analyzed using petroleum diesel (DF) as baseline and biodiesel blended fuel B20 (20% waste cooking oil biodiesel and 80% diesel fuel). However, an endurance test was carried out for 50 hours at constant speed of 1300 rpm and varied load conditions (0.1Kg-m to 2.0 Kg-m) in a single cylinder four stroke compression ignition engine. During analysis, brake specific fuel consumption (BSFC) was increased by 8.16% to 16.66% with an average of 13.79% for B20 as compared to DF, and brake thermal efficiency (BTE) was decreased by 5.17% to 12.12% with an average of 9.65% for biodiesel blend B20 as compared to DF. Moreover, analysis of some fuel properties of DF and B20 has also been discussed in this research paper"

Keywords: Waste Cooking Oil Biodiesel; Engine Performance; Fuel Properties.

1. Introduction

Since industrial revolution many forms of energy have become part of life of human being. Secondly increase in population directly proportional to energy demand. Fossil fuels, petroleum based liquid fuels, natural gas have been got importance to fulfil our energy demand. However they are non-renewable, so these fossil fuels should be exhausted in the near future [1]. This situation has occurred adverse effect with rapid increase in energy demand with significant worldwide population growth. At present the uncertainties concerning adequate and stable supply of petroleum products have renewed interest in renewable energy source. Therefore the demand for clean, reliable and economically feasible renewable energy source was needed [2]. Edible and nonedible oils are renewable energy source can be used as diesel fuel. Vegetable oil, edible oil and nonedible oil have most of the properties very close to diesel fuel [3]. However direct use of vegetable oil in diesel engine leads to problems of gum formation and smoky exhaust due to incomplete combustion [4]. It is suggested to produce biodiesel from using waste edible oil due to its low cost, disposable problems and potential contamination [5]. Biodiesel is environment friendly, non-toxic and reduces atmospheric pollution level. Biodiesel blends can be used in compression ignition diesel engine without any modification in engine parts. However its 100% use in diesel engine requires some modification [6]. Biodiesel has following advantages, carbon neutrality, potential for sustainable production, positive contribution to the energy self-sufficiency rate and prevention of air pollution [7].

Recent studies have been conducted on the physical, chemical properties and engine performance characteristics of biodiesel derived from waste cooking oil. Mofijur et al [8], studied the properties, performance of 5% and 10% palm and Moringa oleifera biodiesel blends (PB5, PB10, MB5,MB10) in a multi cylinder diesel engine at various engine speeds, PB5, MB5, PB10 and MB10 produced 1.38%, 2.27%,3.16% and 4.22% lower brake power and 0.69%, 2.56%,2.02%, and 5.13% higher BSFC, respectively than diesel fuel. Liaquat et al [9], investigated the effects of Palm oil biodiesel PB20 and diesel fuel during an endurance test, he found 3.88% higher BSFC, 11.7% lower BTE as compared to diesel fuel. Ndayishimiye and Tazerout [10], studied engine performance characteristics of palm oil biodiesel in a diesel engine and found that a high percentage of palm oil biodiesel blended with diesel fuel decreases the heating value, while increases brake thermal efficiency. In other study, Liaquat et al [11], worked on 5% and 15% blends of coconut biodiesel in a single cylinder diesel engine. A torque reduction was 0.69% and 2.58%, power reduction was 0.66% and 2.61% and higher BSFC were found 0.53% and 2.11% for 5% and 15% blended palm oil biodiesel respectively. How et al, [12] studied the effect of 10%, 30% and 50% blends of coconut biodiesel on performance in a multi cylinder diesel engine. They observed 0.4-20% higher BSFC than diesel fuel at different throttle setting. Sanjid et al, [13] evaluated the production, physiochemical properties, engine performance of jatropha, palm and combination of palm and jatropha biodiesel in a (PBJB5 and PBJB10) in an unmodified diesel engine at engine speed from 1400 rpm to 2200rpm. PBJB5 and PBJB10 biodiesel showed 7.55% and 19.82% higher BSFC, slightly lower Brake Power.

1.1 Economic features of Biodiesel

Pakistan is a country in acute shortage of energy. Pakistan can only progress by controlling energy shortage in swift and innovative fashion. One of the steps towards such solution is usage of Biodiesel. As discussed in earlier Biodiesel is an option which can not only be helpful in solution of the shortage of energy issue, but simultaneously can contribute heavily into the GDP of Pakistan. As the saying goes, every rupee saved is as good as rupee earned. In this section we are discussing in detail the amount of saving made in case use of biodiesel blend with Petroleum Diesel. B20 waste cooking oil biodiesel (20% waste cooking oil biodiesel and 80% Petroleum diesel) is used in single cylinder four stroke compression ignition diesel engine. The said research suggests that Biodiesel can be used in mixture with petroleum products up to 20% without any modification in the internal structure of engine. It may be noted that this use of biodiesel increasing in foreign countries. However, ratio of blend may be increased up to 40% without modification in engine parts. If the needful modification in the engine is made, the proportion of biodiesel blend in Petroleum Diesel fuel can be increased up to 100%, without compromising on engine efficiency. The cost of production of biodiesel is considerably lower than that of petroleum products; hence it will be a significant contribution to the national exchequer if its petroleum bill is reduced by a minimum of 20% (If we use 20% biodiesel with petroleum Diesel). Brief working of said calculation shows that total consumption of petroleum products was 18.68 MTOE out of 40.03 MTOE. (Pakistan Energy Yearbook 2012). However, the use of Petroleum Diesel in diesel engine is mainly in only two sectors i.e. Transport and Power sector, which consume about 90% of total petroleum products in combine, which accounts to almost 16.812 million tonnes. By using Biodiesel blend in diesel engine, if we reduce the consumption of the said energy by 20% in case of use of biodiesel up to 20% blend without modification in engine. Total consumption reduced by 20% which reduce our annual petroleum bills by 20%. Total petroleum consumption of 18.86 MTOE by 3.736 MTOE million tonnes could be saved. This lesser consumption of petroleum products will result in direct saving of Rs 315.638 Billion to GDP of Pakistan. As a matter of fact, if we can indulge in the exercise use of biodiesel which can be produced locally by planting non edible plants, like, Jatropha, moringa, etc, we can save our economy up to 20% of petroleum bills.

1.2 Biodiesel Properties

The ASTM D6751 and The European Union EN 14214 provide methods of biodiesel testing standards. The properties standards limitation of pure biodiesel B100 and biodiesel blend with diesel fuel are given in ASTM D6751. In this standard gives the quality level of biodiesel, whereas European Union EN 14214 gives the results of minimum fatty acid methyl ester. Limitation of ASTM D6751 and EN 14214 biodiesel properties are given in Table 4.1[14-16].

Table 1 Biodiesel Properties Standards ASTM D6751 and EN 12214

PROPERTIES	UNITS	TEST AST	METHODS EN	TEST LIMITS ASTM D6751	EN 12214
Kinematic Viscosity at 40	mm^2/s	D445	EN ISO 3104	1.9-6.0	3.5-5.0
Density at 15	Kg/m^3	D1298	EN ISO 3675 12185	880	860-900
Calorific Value	MJ/Kg	-	EN 14214	45.54	35
Flash Point	^0C	D93	ISO DIS 3679	Min 100-170	>120
Pour Point	^0C	D97	-	-15 to 16	-
Cloud Point	^0C	D2500	-	-3 to 12	-
Oxidation Stability	-	D675	EN 14112	Min 3	Min 6
Cetane Number	-	D613	EN ISO 5265	Min 47	Min 51
Acid Value	Mg KOH/g	D664	EN 14104	Max 0.5	Max 0.5
Water Content	%V	D2709	EN ISO 12937	Max 0.05	-
Canradsons Carbon	m/m	D4530	EN ISO 10370	Max 0.05	Max 0.03

2. Materials and Method

In this section research methodology for achieving the objectives of the study has been discussed. Overall two fuels samples were tested in compression ignition diesel engine. In connection different parameters have been discussed like, fuel properties, engine performance, brake specific fuel consumption and brake thermal efficiency in compression ignition engine.

Engine performance tests have been carried out at Mechanical Engineering laboratories, Quaid-e-Awam University of Engineering, Science and Technology Nawabshah. For this purpose a single cylinder horizontal type water cooled four stroke diesel engine is used for calculating the performance parameters. The model type of the test bed is DWE-6/10-JS-DV. This is fully equipped with different instrumentations like fuel flow meter, tachometer, dynamometer, and thermocouples etc. which are helpful for collecting data from the engine. Details of engine specification are given in table 2.1

Table 2.1 Diesel Engine Test Bed Specifications:

Cooling system	Water cooled system
Type	Horizontal
Number of cylinders	One
Bore (Piston size)	80 mm
Stroke (Piston displacement)	95 mm (477cc)
Compression Ratio	23:1
Starting Method	Manual
Output/ Rotational speed	8.5PS/ 2200RPM (Max)

Two fuel tanks are attached to a diesel engine test bed. Both fuel tanks connected with common line; however flow can be controlled with two separate valves. One tank is filled with Petroleum diesel (D100) and other is filled with B20 Biodiesel (20% waste Cooking oil Biodiesel and 80% Petroleum Diesel). An endurance test was carried out for 50hours at constant speed and varying load conditions. As concerned with the Performance of the engine, engine Torque, Brake Power, Brake Specific Fuel Consumption (BSFC), Brake Thermal Efficiency (BTE) were analysed. The varying load is changed from 0.1 Kg-m to 2.0 Kg-m at the constant speed of 1300 rpm. Waste cooking oil biodiesel was collected from Syntech Biofuels Private Limited, SITE Area Hyderabad. Engine performance can be calculating by using following basic internal combustion engine equations:

$$BP = \frac{2\pi NT}{60} \tag{1}$$

$$BSFC = \frac{\dot{m}}{BP} \tag{2}$$

$$BTE = \frac{3600}{BSFC} \times HHV \times 100\% \tag{3}$$

Where N is the engine speed in rpm, $\dot{m}$ is the fuel flow in g/h, and HHV is the higher heating value of fuel in MJ/Kg.

Fig. 2.1 Pictorial view of four stroke Diesel Engine Test bed

3. Results and Discussion

In this research work an endurance test was carried out on two different fuel samples. One Petroleum Diesel D100 and secondly B20 Waste cooking oil biodiesel tested in single cylinder CI diesel engine. Endurance test was carried out for 50 hours on each fuel samples. In which engine performance parameters observed at various load condition and at various engine speeds. Engine Power, Engine Torque, Specific fuel consumption, Brake thermal efficiency was observed.

3.1 Fuel Properties

Fuel properties of waste cooking oil biodiesel are very close to Petroleum Diesel. For example kinematic viscosity of B20 Biodiesel is 3.61 mm ^{2}/s, whereas kinematic viscosity of Petroleum Diesel is 2.91 mm ^{2}/s. Density of Biodiesel is 880 Kg/m^3, whereas density of Petroleum diesel is 839 Kg/m^3. The biodiesel has higher density than diesel fuel, due to its affected property on compression [21]. The higher density also effect fuel atomization. Higher density leads poor atomization and lean combustion which increase the engine temperature [22-23]. Further more detailed properties of B20 Biodiesel are given in Table 3.1

Table 3.1 Properties of Prepared Biodiesel samples.

Properties	Diesel	Biodiesel B20	Standards
Kinematic Viscosity @ 40^{0}C(mm^2/s or cSt)	2.5-5.7	3.61	(1.9-6.0) ASTM D445
Density Kg/m^3	816-840	880	(860-900) ASTM D127
Cetane Number	45-55	48	(45-55) ASTM D6890
Flash Point (^{0}C)	50-98	110	(100-170) ASTM D93
Fire Point (^{0}C)	112	121	(120-140) ASTM D93
Calorific Value MJ/Kg	45.9	43.78	(45.54) ASTM D240
Specific Gravity	0.835	0.846	ASTM D891

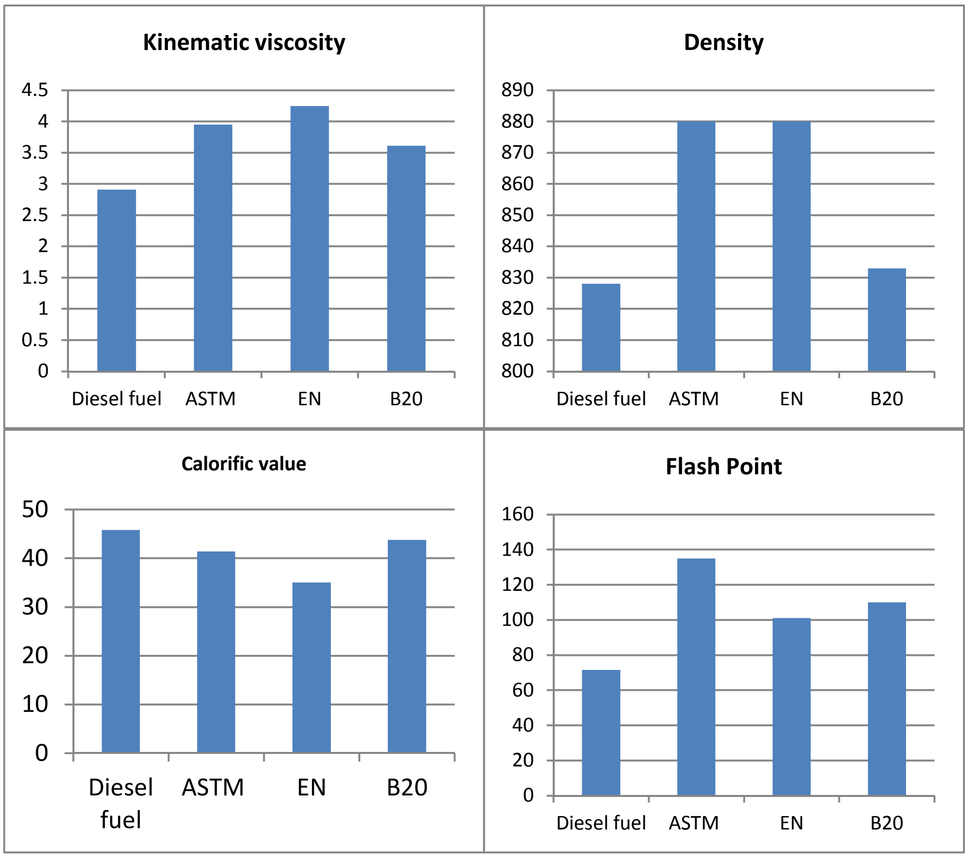


Fig.3.1 Properties of Diesel Fuel, Biodiesel B20 and Standards of Biodiesel

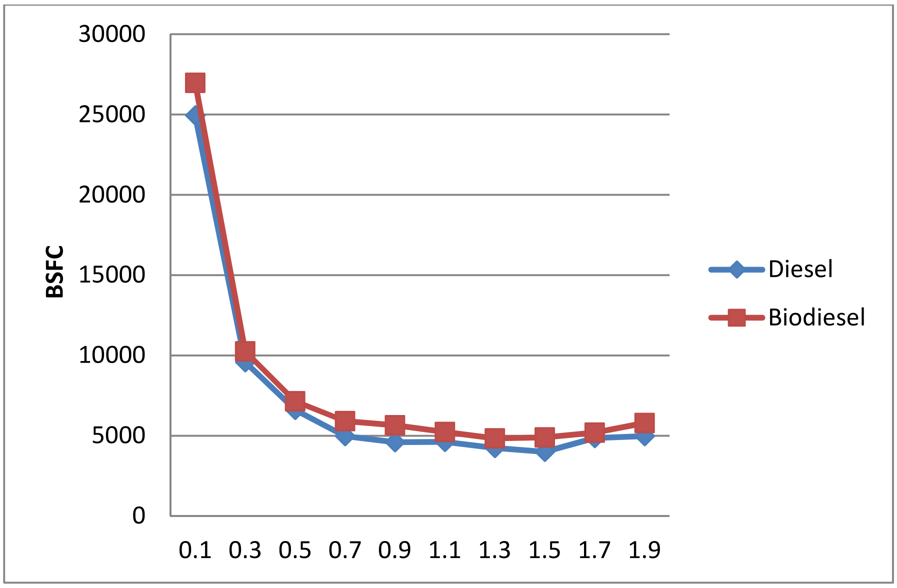
3.2 Engine Performance Analysis

The engine performance tests were carried on a single cylinder four stroke compression ignition diesel engine. The horizontal type water cooled diesel engine was mounted on the structure of the test bed. On the same structure dynamometer has also mounted which is also directly coupled with a diesel engine. It can control the brake load on the engine. The dynamometer controlled is attached to the panel of the test bed. In this work two different fuel samples were tested firstly Petroleum Diesel D100 and B20 Waste Cooking oil Biodiesel (include 20% Waste Cooking oil Biodiesel and 80% Petroleum Diesel blended). The engine performance parameters have been calculated on variable load and at constant speed 1300 RPM. The applied load on CI diesel engine is divided into 10 different point ranges from 0.1 Kg-m to 2.0 Kg-m. The performance parameters measured during the research work are, brake power, Torque, brake specific fuel consumption, brake thermal efficiency and mass flow rate. Two fuel tanks have been connected with a common single line separated with control valve attached with diesel engine. One tank is filled with diesel fuel, whereas other tank is filled with biodiesel blended fuel.

3.2.1 Brake Specific Fuel Consumption (BSFC)

The brake specific fuel consumption (BSFC) is a function of diesel engine at test bed. The variation in brake specific fuel consumption of a compression ignition engine is depends on engine speed, applied load and blending ratios of biodiesel blend. In this research work brake specific fuel consumption was analysed with three different cases. BSFC is firstly compared with engine torque, Brake Power and Engine Speed. It is observed that BSFC graph line firstly slightly decreased then goes in straight line in all three cases. BSFC is increased by 7.56% to 14.28% using biodiesel B20 as compared to Petroleum Diesel D100 with an average of 11.93% increase in BSFC using Biodiesel as compared to Petroleum Diesel.

The BSFC is an engine performance parameter that reflects how good engine is performing. The brake specific fuel consumption of an engine expressed in terms of Kg/Kwh. The BSFC values of Cooking oil Biodiesel is greater than Diesel fuel, it is just because of higher contents of oxygen in the fuel which results lower heating value. The lower density and lower heating value of the fuel requires higher mass flow rate for the same energy output from the engine.



Fig, 3.2 Torque relationships with BSFC

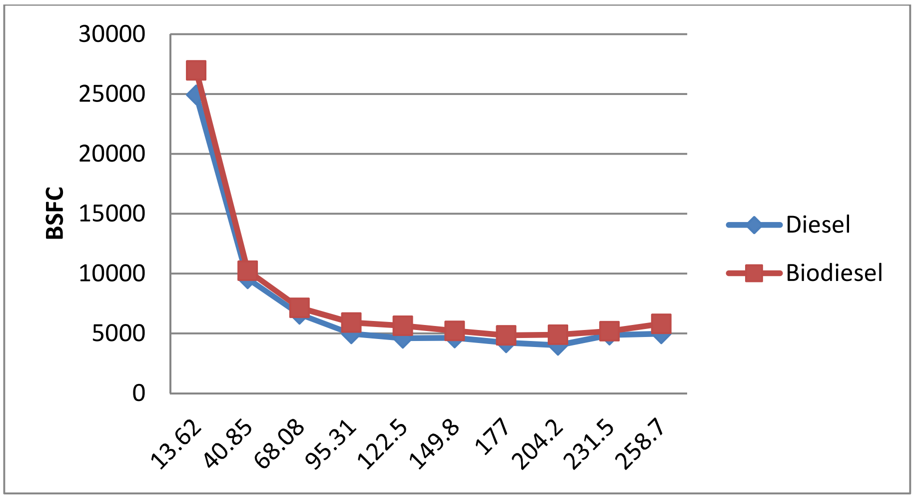


Fig. 3.3 Brake Power relationship with BSFC

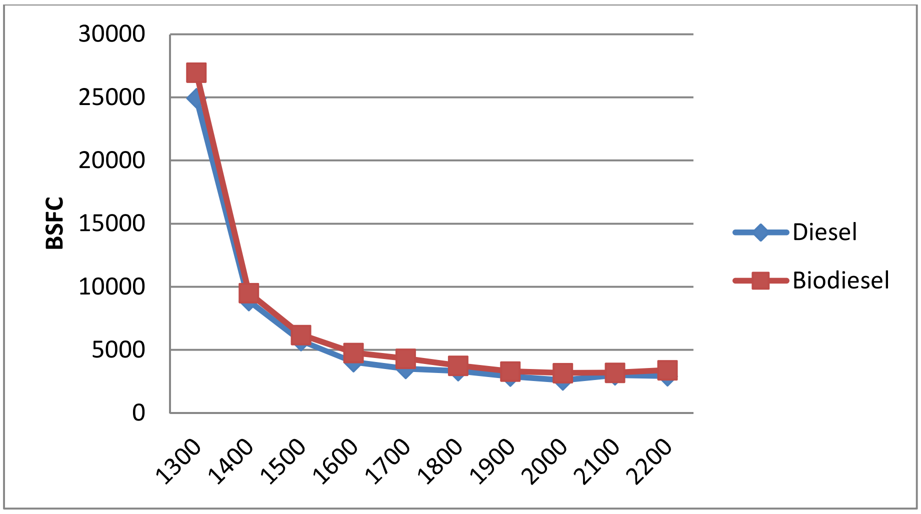


Fig. 3.4 Speed relationship with BSFC

3.2.2 Brake Thermal Efficiency (BTE)

Brake thermal efficiency is defined as brake power of CI engine as a part of heat supplied by the fuel. Brake thermal efficiency is used to determine the energy is extracted from fuel to convert into mechanical energy.

It has been observed that by using waste cooking oil biodiesel in CI diesel engine, the mass flow rate also increases which affect brake thermal efficiency. In this research work variation in BTE is observed in three different cases. Firstly BTE relationship with Engine Torque, Brake Power and Engine Speed. BTE is slightly increased up to 40% it is directly proportional with Torque and Brake Power, and then goes down with increase in Power and Torque. Brake thermal efficiency is decreased by 5.53% to 13.72% while using Biodiesel B20 as compared to Petroleum Diesel D100, with an average of 10.75% decreases BTE using biodiesel as compared to Petroleum Diesel. It is due to the reason of increment in percentage of oxygen contents which helps to improve the combustion process therefore due to a higher percentage of oxygen content it may produce faster combustion process.

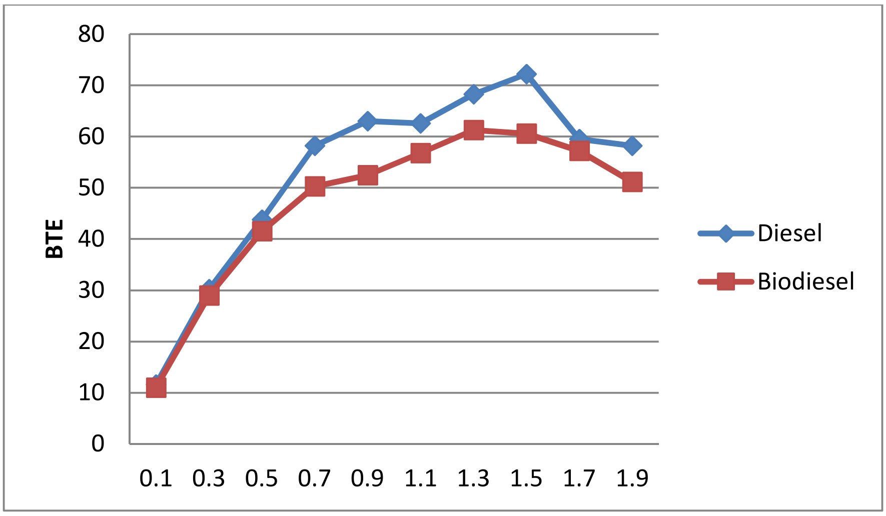


Fig. 3.5 Torque relationship with BTE

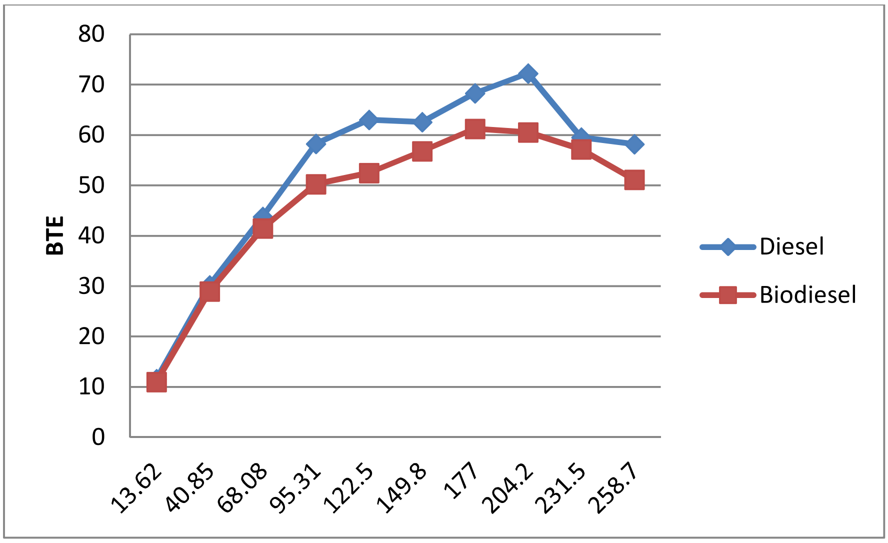


Fig. 3.6 Brake Power relationship with BTE

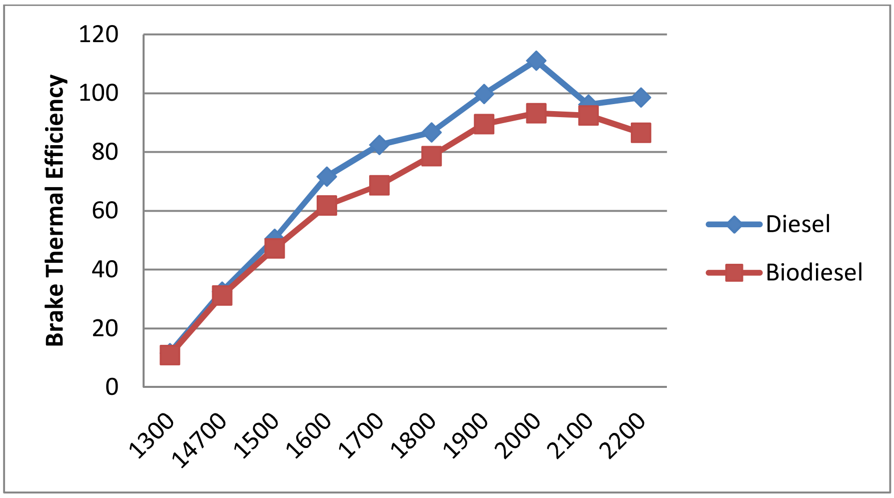


Fig. 3.7 Speed relationship with BTE

4. Conclusion and Recommendations

In this study, the effects of Diesel fuel as a baseline and the B20 Waste cooking oil biodiesel blend on performance of single cylinder four stroke diesel engine was analysed during short term endurance test. Following conclusion were drawn from present investigation:

1. Waste cooking oil biodiesel blended fuel has very close physical and chemical properties to that of Diesel fuel.
2. During varying load from 0.1to 2.0Kg-m and at constant speed 1300rpm, BSFC was increased by 8.16% to 16.66% , while using B20 biodiesel as compared to diesel fuel.
3. At same condition BTE were decreased by 5.17% to 12.12% as compared to diesel fuel.
4. During varying load from 0.1 to 1.9 Kg-m and with varying speed from 1300 to 2200 rpm, BSFC is increased by an average of 13.78%, while using B20 biodiesel as compared to Diesel fuel.
5. At varying load and varying speed BTE is decreased by an average of 9.8% as compared to diesel fuel.

For the future work it is recommended that unregulated exhaust emissions may be determined.
As concerned about suggestion, Government should take steps to enhance for production of non-edible seeds for usage of biodiesel. Government should announce packages for growers and should purchase seeds from them. Chemical plants should be installed for tests of oils and for transesterification process. Also Government inform public through print media and social media for encouraging farmers to grow seeds for biodiesel purpose.

Acknowledgement:

The authors acknowledge the support extended by the Directorate of Post Graduate Studies, Mehran University of Engineering & Technology Jamshoro, and Mechanical Engineering Department, Quaid-e-Awam University of Engineering, Science and Technology, Nawabshah.

References:

[1] A.M. Ashraful, H.H. Masjuki, M.A. Kalam, I.M. Rizwanul Fattah, S. Imtenan, S.A. Shahir and H.M. Mobarak, "Production and comparison of fuel properties, engine performance, and emission characteristics of biodiesel from various non-edible vegetable oil, A review," Energy conversion and Management, Volume 80, pp. 202-228, 2014.

[2] M. Habibullah, H.H. Masjuki, M.A. Kalam, I.M. Rizwanul Fattah, A.M. Ashraful, and H.M. Mobarak, "Biodiesel production and performance evaluation of coconut, palm and their combined blend with diesel in a single cylinder diesel engine", Energy conversion and Management, Volume 87, pp. 250-257, 2014.

[3] M. Senthil Kumar and M. Jaikumar, "A comprehensive study on performance, emission and combustion behaviour of a compression ignition engine fuelled with WCO (waste cooking oil) emulsion as fuel", Journal of the Energy Institute, Volume 87, pp. 263-271, 2014.

[4] Ali M.A. Attia and Ahmad E. Hassaneen, " Influence of diesel fuel blended with biodiesel produced from waste cooking oil on diesel engine performance", Fuel, Volume 167, pp. 316-328, 2016.

[5] Bhupendra Singh Chauhan, Naveen Kumar and Haeng Muk Cho," A study on the performance and emission of a diesel engine fuelled with Jatropha biodiesel oil and its blends", Energy, Volume 37, pp. 616-622, 2012.

[6] H. An, W.M. Yang, A. Maghbouli, S.K. Chou and K.J. Chua, "Performance, combustion and emission characteristics of biodiesel derived from waste cooking oils", Applied Energy, Volume 112, pp. 493-499, 2013.

[7] Shogo Eguchi, Shigemi Kagawa and Shunsuke Okamoto, " Environmental and economic performance of a biodiesel plant using waste cooking oil", Journal of Cleaner Production, Volume 101, pp. 245-250, 2015.

[8] Mofijur M, Masjuki HH, Kalam MA, Atabani AE, Fattah IMR, and Mobarak HM, "Comparative evaluation of performance and evaluation characteristics of Moringa oleifera and palm oil based biodiesel in a diesel engine," Ind crops production, Volume 53, pp. 78-84, 2014.

[9] Liaquat AM, Masjuki HH, Kalam MA, Fazal MA, Khan AF, and Fayaz H et al, "Impact of palm biodiesel blend on injector deposit formation", Applied Energy, Volume 111, pp. 882-893, 2013

[10] Ndayishimiye P, and Tazerout M, "Use of palm oil based biofuel in the internal combustion engine performance and emissions characteristics," Energy, Volume 36, pp. 1790-1796, 2011.

[11] Liaquat AM, Masjuki HH, Kalam MA, Fattah IMR, Hazrat MA, and Varman M, et al, "Effect of coconut biodiesel blended fuels on engine performance and emission characteristics," Procedia Engineering, Volume 56, pp.583-590, 2013.

[12] How HG, Teoh YH, Masjuki HH, and Kalam MA, " Impact of coconut oil blends on particulate phase PAHs and regulated emission from a light duty diesel engine", Energy, Volume 48, pp. 500-509, 2012.

[13] Sanjid A, Masjuki HH, Kalam MA, Rahman SMA, Abedin MJ, and Palash SM, "Production of palm and jatropha based biodiesel and investigation of palm-jatropha combined blend properties, performance, exhaust emission and noise in an unmodified diesel engine," Journal of Cleaner Production, Volume 65, pp.295-303, 2014.

[14] Silitonga, A.S., Masjuki H.H, Mahila TMI, Ong HC, Chong WT, and Boosroh MH, "Overview properties of biodiesel blends from edible and non-edible feedstock", Renewable and Sustainable Energy Reviews, Volume 22,pp. 346-360, 2013.

[15] Atabani AE, Silitonga AS, Ong HC, Mahila TMI, Masjuki HH, Badruddin IA, and Fayaz H, " Non edible vegetable oils: a critical evaluation of oil extraction, fatty acid compositions, biodiesel production, characteristics, engine performance and emissions production", Renewable and Sustainable Energy Reviews, Volume 18, pp. 211-245, 2013.

[16] Sanford SD, White JM, Shah PS, Wee C, Valverde, MA, and Meier GR, " Feed stock and biodiesel characteristics report", Renewable Energy Group, Volume 416, pp. 1-136, 2009.

[17] Raj FRMS, and Sahayaraj JW, "A comparative study over alternative fuel for environmental friendly emission", In Recent Advances in Space Technology Services and Climate change (RSTSCC), pp. 80-86, 2010.

[18] Sarin R, Sharma M, Sinharay S, and Malhotra RK, "Jatropha palm biodiesel blends, an optimum mix for Asia", Fuel, Volume 86(10), pp.1365-1371, 2007.

[19] Ong HC, Mahila TMI, Masjuki HH, and Norhasyima RS, "Comparison of palm oil, jatropha curcas and Calophyllum inophyllum for biodiesel: a review", Renewable and Sustainable Energy Reviews, Volume 15(8), pp. 3501-3515, 2011.

[20] Veruzco LFR, "Density and viscosity of biodiesel as a function of temperature: empirical models", Renewable and Sustainable Energy Reviews, Volume 19, pp. 652-665, 2013.

[21] Canakci M, and Sanli H, "Biodiesel production from various feed stocks and their effects on the fuel properties", Journal of Industrial microbiology & biotechnology, Volume 35(5), pp.431-441, 2008.

[22] De La KTDS, Meneghetti SMP, de La Salles WF, Meneghetti MR, Dos Santos ICF, Da Silva JPV, De Carvlho SHV, and Soletti JI, " Characterization of Syagrus coronata (Mart) Becc, Oil and properties of methyl esters for use as biodiesel", Industrial crops and products, Volume 32(3), pp.518-521, 2010.

[23] Yoon SH, Park SH, and Lees CS, "Experimental investigation on the fuel properties of biodiesel and its blends at various temperature", Energy and Fuels, Volume 22(1), pp. 652-656, 2007.

[24] Singh SP, and Singh D," Biodiesel production through the use of different sources and characterization of oils and their esters as the substitute of diesel: a review", Renewable and Sustainable Energy Reviews, Volume 14(1), pp.200-216, 2010.

[25] Sanford SD, White JM, Shah PS, Wee C, Valverde MA, and Meier GR, "Feed stock and biodiesel characteristics report", Renewable Energy Group, Volume 416, pp. 1-136, 2009.

[26] Ramadhas AS, Jayaraj S and Muraleedharan C, "Biodiesel production from high FFA rubber seed oil", Fuel, Volume 84(4), pp. 335-340, 2005.

[27] Harington KJ, "Chemical and physical properties of vegetable oil esters and their effect on diesel fuel performance", Biomass, Volume 9(1), pp.1-17, 1986.

[28] Knothe G, "Fuel properties, cetane numbers, heat of combustion-why vegetable oils and their derivatives are suitable as a diesel fuel", The biodiesel Handbook AOCS Press, Champaign, Illinois, pp.84-88, 2005.

[29] Md. Arbab Iqbal, Mahendra Varman, Masjuki HJ Hassan, and Md. Abul kalam, "Tailoring fuel properties using jatropha, palm, and coconut biodiesel to improve CI engine performance and emission characteristics", Journal of Cleaner Production, Volume XXX,pp.1-9, 2015.

[30] X.J. Man, C.S. Cheung, Z. Ning, L. Wei, and Z.H. Haung, "Influence of engine load and speed on regulated and unregulated emissions of a diesel engine fuelled with diesel fuel blended with waste cooking oil blended", Fuel, Volume 180, pp. 41-49, 2016.

[31] Shogo Eguchi, Shigemi Kagawa, and Shunsuke Okamoto, " Environmental and economic performance of a biodiesel plant using waste cooking oil," Journal of Cleaner Production, Volume 101, pp. 245-250, 2015.

[32] Anh N. Phan, and Tan M. Phan, " Biodiesel production from waste cooking oils", Fuel, Volume 87, pp. 3490-3496, 2008.

[33] Ashok Kumar Yadav, Mohd Emran khan, Alok Manas Dubey, and Amit Pat, "Performance and emission characteristics of a transportation diesel engine operated with non-edible vegetable oils", Case Studies in Thermal Engineering, Volume 8, pp.236-244, 2016.

[34] Jinlin Xue, Tony E. Grift, and Alan C. Hansen, "Effect of biodiesel on engine performance and emissions", Renewable and Sustainable Energy Reviews, Volume 15, pp. 1098-116, 2011.

[35] Jinlin Xue, "Combustion characteristics, engine performance and emissions of waste edible oil biodiesel in diesel engine", Renewable and Sustainable Energy Reviews, Volume 23, pp. 350-365, 2013

[36] M.A. Kalam, H.H. Masjuki, M.H. Javed, and A.M. Liaquat, "Emission and performance characteristics of an indirect ignition diesel engine fuelled with waste cooking oil", Energy, Volume 36, pp.397-402, 2011.

[37] Md. Mofijur Rahman, Masjuki Hj. Hassan, Md. Abul Kalam, Abdelaziz Emad Atabani, and Liaquat Ali Memon et al, " Performance and emission analysis of Jatropha curcas and Moringa oleifera methyl ester fuel blends in a multi-cylinder diesel engine", Journal of Cleaner Production, Volume 65, pp. 304-310, 2014.