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NON-EDIBLE VEGETABLE OILS AS A STOCK FOR BIODIESEL IN PAKISTAN: EXPERIMENTAL INVESTIGATION

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Abstract

Suitability of Jatropha curcas and Pongamia Pinnata oils as a stock for biodiesel production in Pakistan was investigated. Biodiesels were tested in direct injection diesel engine and results were compared with those of regular diesel fuel. Result analysis was supported by an investigation of fuel injection and combustion characteristics. Engine fuelled with neat Jatropha biodiesel showed increased fuel consumption, decreased brake efficiency, increased nitrogen oxides emission and reduced unburned hydrocarbon emissions and exhaust opacity. Test results of Pongamia biodiesel showed the same trends with slight variation in values. Based on test results conclusion was made that both oils can be used for commercial production of biodiesel in Pakistan.

Key words: *Diesel engine, efficiency, emissions, biodiesel, Pongamia Pinnata, Jatropha curcas*

1. INTRODUCTION

Fatty Acid Methyl Esters (FAME), termed biodiesel, are made from vegetable oils by transesterification process and used as a conventional diesel fuel (D) substitute. The main purpose of the use of bio-fuels is to decrease the consumption of fossil fuels in internal combustion engines and reduce greenhouse effect. The use of non-edible vegetable oils as a feedstock for biodiesel is encouraged, especially in developed countries. In Pakistan Pongamia Pinnata and Jatropha curcas oils are considered as a potential source of biodiesel. Oils used for biodiesel production must satisfy several criteria. One of them is that biodiesel or biodiesel/diesel fuel blends must provide satisfactory performance and emissions of the diesel engine preferably without or with a little engine modification. Effects of biodiesel on engine performance and emissions depend on their physical and chemical properties such as viscosity, density, bulk modulus, cetane number, heating value etc. In turn, those properties are completely determined by the fatty acid composition and the properties of the individual fatty esters in biodiesel.

It was found that cetane number, heating value and viscosity of fatty compounds increase with increasing chain length and decrease with increasing unsaturation [1]. Also biodiesels with higher degree of unsaturation have lower cetane number and show increased emissions of nitrogen oxides (NO_x) [2]. Aging also changes properties of FAME. Biodiesel, having high amounts of highly unsaturated methyl ester compound such as LME, is easily oxidized. Oxidation increases biodiesel viscosity and cetane number [3]. High bulk modulus and viscosity of biodiesel change injection pressure and start of injection [4].

Extensive experimental data on the effect of biodiesels of different origin on diesel engine performance and emissions are available in literature. Most of research papers have reported up to 10% increase in NO_x emissions from diesel engines fuelled with biodiesel [5]. This fact imposes

limitation on the wide use of biodiesel, therefore impact of biodiesel on NO_x emission is the main concern of research in this area.

Some data have been published on testing Pongamia [6-9] and Jatropha [10-16] biodiesels in diesel engines. Analysis of papers revealed that published data is insufficient to make a firm conclusion on effect of Jatropha and Pongamia biodiesels on engine performance. The reasons for that are: differences in engine design, different settings of fuel delivery system and, sometimes, incorrect experimental procedure. Moreover, only in few papers data analysis was supported by an investigation of the fuel injection and combustion characteristics obtained from indicator diagrams. The absence of such analysis makes it difficult to formulate the ways for improving engine performance and emission with biodiesel.

The goal of the present research was the further investigation of the performance and emissions of diesel engine fuelled with Jatropha and Pongamia biodiesels and formulating the methods of using biodiesel without engine modification.

2. FUELS

Fatty acid compositions of Pongamia Pinnata and Jatropha curcas oils given in Table 1 were obtained by the chromatographic analysis in Laboratory of Lugansk, Ukraine.

Table 1. Fatty acid composition.

Fatty acid	*Structure*	*Formula*	*Mass fraction, %*	
			Jatropha curcas	*Pongamia Pinnata*
Miristic	C 14:0	$C_{14}H_{28}O_2$	0.076	0.039
Palmitic	C 16:0	$C_{16}H_{32}O_2$	13.424	7.894
Palmitoleic	C 16:1	$C_{16}H_{30}O_2$	0.824	0.063
Stearic	C 18:0	$C_{18}H_{36}O_2$	6.777	4.405
Oleic	C 18:1	$C_{18}H_{34}O_2$	42.242	49.030
Linoleic	C 18:2	$C_{18}H_{32}O_2$	35.883	17.222
Alpha-Linolenic	C 18:3	$C_{18}H_{30}O_2$	0.244	4.040
Arachidic	C 20:0	$C_{20}H_{40}O_2$	0.214	1.111
Eicosenoic	C 20:1	$C_{20}H_{38}O_2$	-	2.388
Heneicosanoic	C 21:0	$C_{21}H_{42}O_2$	0.033	-
Behenic	C 22:0	$C_{22}H_{44}O_2$	-	3.007
Erucic	C 22:1	$C_{22}H_{42}O_2$	0.098	9.272
Docosadienoic	C 22:2	$C_{22}H_{32}O_2$	0.034	0.174
Lignoceric	C 24:0	$C_{24}H_{48}O_2$	-	0.904
Nervonic	C 24:1	$C_{24}H_{46}O_2$	-	0.301

Pongamia seeds were collected from the trees growing on GIK Institute campus and oil was extracted in the local mill. Pongamia biodiesel was prepared by transesterification with methanol in a device designed and fabricated by undergraduate students of GIK Institute.

Jatropha biodiesel was provided by PSO. The diesel fuel was obtained from local fuel station. Properties of fuels tested are given in Table 2.

Table 2. Fuel properties.

Property	***Method***	***B100 Spec***	***D***	***J100***	***P100***
Density @ 15ºC, kg/m^3	ASTM D1298	Report	831.9	881.8	893.7
Kinematic viscosity @ 40ºC, cSt	ASTM D445	1.9-6.0	3.348	4.62	5.14
Flash point, ºC	ASTM D93	130 min	65.0	148.0	138.0
Total acid No., mg KOH/gm	ASTM D664	0.80 max	NA	0.44	0.23
Cloud point, ºC	ASTM D2500	Report	NA	+3	+15
Pour point, ºC	ASTM D97	-	-6	NA	NA
Distillation @ 90% recovery, ºC	ASTM D86	360 max	355	250	NA
Lower heating value, MJ/kg	ASTM D240	-	42.41	38.3	37.74
Cetane index	ASTM D976	47 min	50	47	NA
Free glycerine, %wt	ASTM D128	0.020	NA	0.006	0.08
Total glycerine, %wt	ASTM D128	0.24	NA	0.086	0.17

3. EXPERIMENTAL

Experiments were conducted in FME Heat Engine Lab of GIK Institute. Fuels were tested in the single cylinder four-stroke naturally aspirated direct-injection diesel engine. Engine specification is given in Table 3.

Table 3. Engine specification.

Rated power, kW	5.0
Rated speed, rpm	3600
Maximum torque, Nm	15.6 at 2650 rpm
Minimum stable speed, rpm	1000
Combustion system	Direct injection
Bore/Stroke, mm	76.2/66.67
Engine displacement, l	0.304
Compression ratio	18.5
Injection timing (static), degree BTDC	26

To load the engine a swinging field dc machine was used. When biodiesel was used the fuel delivery was increased by adjusting governor rod in order to achieve the same power output as with diesel oil.

To avoid mixing of biodiesel with diesel fuel in the leak-off and return pipes fuels was changed using following procedure. Engine was stopped, fuel system was drained and then primed with another fuel. Nitrogen oxides, carbon monoxide (CO), and unburned hydrocarbons (THC, as Hexane) concentrations and exhaust opacity were measured dry by AVL DiCom 4000 gas analyzer with resolution of 1 ppm for NO_x and THC, 0.01% for CO, and 0.1% for exhaust opacity. Gas analyzer was calibrated using certified calibrating gas mixtures. Brake specific emission was calculated in accordance with ISO 8178-1:2006(E).

AVL 488 TDC sensor was used to determine position of the Top Dead Center. Cylinder pressure was measured by the AVL quartz pressure transducer QC34D, fuel line pressure was measured by the AVL SL31D-3000 strain gauge sensor. Both sensors were used along with the AVL MicroIFEM Combi 4CH SDC amplifier. Lift of needle valve of injector was measured by an inductive sensor along with the Bridge Amplifier 3010A01.

Pressures and injector needle lift data were recorded by the AVL IndiModul 621 indicating system used along with a high resolution (0.1 cad) AVL angle encoder 365CC.

Recorded pressure and needle lift data were processed by IndiCom software for calculation of an indicating mean effective pressure, rate of heat release and other important fuel injection and combustion characteristics.

Engine was tested on type G2 cycle in accordance with ISO 8178-1, ISO 8178-3, and ISO 8178-4 standards. The measurements of load, air and fuel flow rates, temperatures, exhaust gas composition and exhaust opacity were made simultaneously.

4. RESULTS AND DISCUSSION

Neat Jatropha biodiesel (J100) and its blends with diesel oil (J80 and J20) were tested in diesel engine and results were compared with regular diesel fuel (D). It should be noted, that J20 was prepared by authors, but J80 was provided by PSO. Engine performance characteristics at engine speed of 3600 rpm over range of load are shown in Fig. 1. As seen from Fig.1a, brake specific fuel consumption (bsfc) at all loads is lowest for diesel fuel and highest for J100, that of J20 and J80 lying in-between. Also, increase in bsfc for blends is approximately proportional to their composition. Brake efficiency (Fig. 1c) shows the opposite but still proportional trends (decreases from D to J100) except of J80, which falls out of proportionality. The reason for that may be different properties (most probably heating values) of Jatropha biodiesel and diesel fuel used to prepare J80 blend. These results cannot be simply explained by difference in viscosity, bulk modulus etc. of biodiesel and diesel fuel. Discussion must be supported by fuel injection and combustion analysis.

Indicator diagram, rate of heat release, fuel line pressure and injector needle lift vs. crank angle are shown in Fig. 2 a, b, c and d correspondingly. Higher values of bulk modulus and viscosity of biodiesel resulted in higher fuel pressure (Fig. 2c) and earlier start of fuel injection (Fig. 2d). The earlier start of injection would increase ignition delay period, since fuels were injected in a lower temperature cylinder charge. But as seen from Fig. 2b combustion of diesel fuel starts earlier than that of biodiesel, which is indication of better biodiesel ignition quality. At the same time, cetane index (determined by PSO) of Table 2 is higher for diesel fuel than for Jatropha biodiesel. This discrepancy may be explained by following. Cetane index is just an approximation of cetane number and its calculation is based on API gravity and mid-boiling point [17]. Cetane index is a close approximation of cetane number of regular diesel oil, but cannot be used for biodiesel as proved by data of Fig. 2.

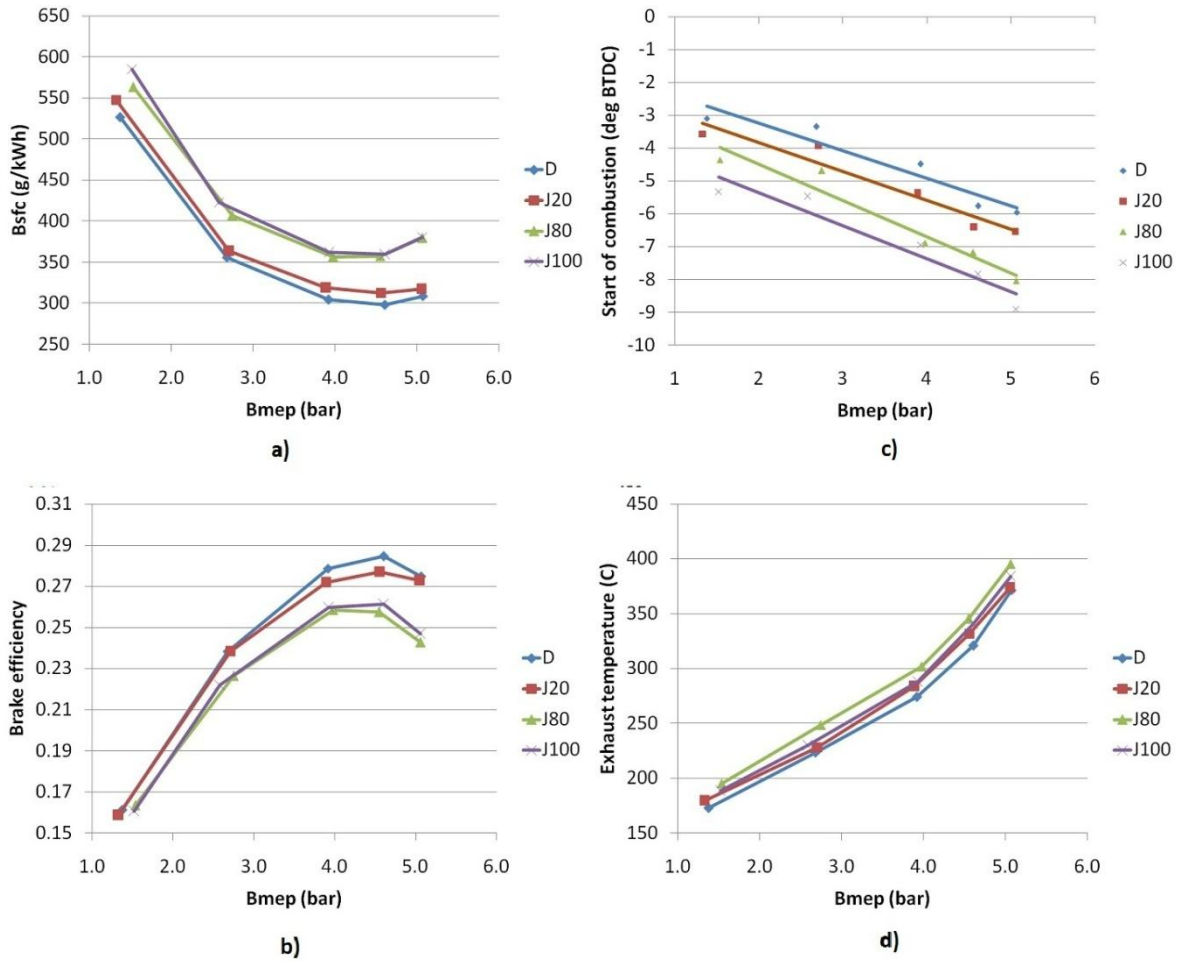


Fig. 1. Engine performance characteristics. N = 3600 rpm.

Combustion start earlier for biodiesel at all loads, as seen from Fig. 1c. Regardless of earlier start of combustion the exhaust temperature is higher for biodiesel. This is the result of the increased consumption of biodiesel needed to maintain the same load as with diesel fuel. Increased amount of biodiesel injection is evident from the increased injection pressure (Fig. 2c) and longer injection duration (Fig. 2d).

Closer inspection of data of Table 2 and Fig. 1a and 1b shows that only part (10 %) of the increased by about 20% consumption of J100 above that of diesel fuel may be explained by lesser by 10% heating value of J100, but the rest should be attributed to the reduced by 10% brake efficiency.

Heating value of biodiesel is determined by its composition and cannot be increased. But negative effect of biodiesel properties on fuel consumption can be mitigated by improving engine efficiency. Fuel conversion efficiency equals the ratio of power to fuel energy content (fuel mass flow rate multiplied by fuel heating value). Fuel conversion efficiency is a normalized parameter and does not depend on fuel heating value. It is solely determined by the shape of indicator diagram, in particular peak pressure and its position with respect to TDC. For fuels tested in this experiment, decreasing cetane number of Jatropha biodiesel (and its blends with diesel oil) would result in the retarded start of

combustion, decreased negative compression work and, as a result, increase in brake efficiency. So, formulation of biodiesel by additives can be used to mitigate the negative effect of biodiesel on engine performance by increasing the fuel conversion efficiency.

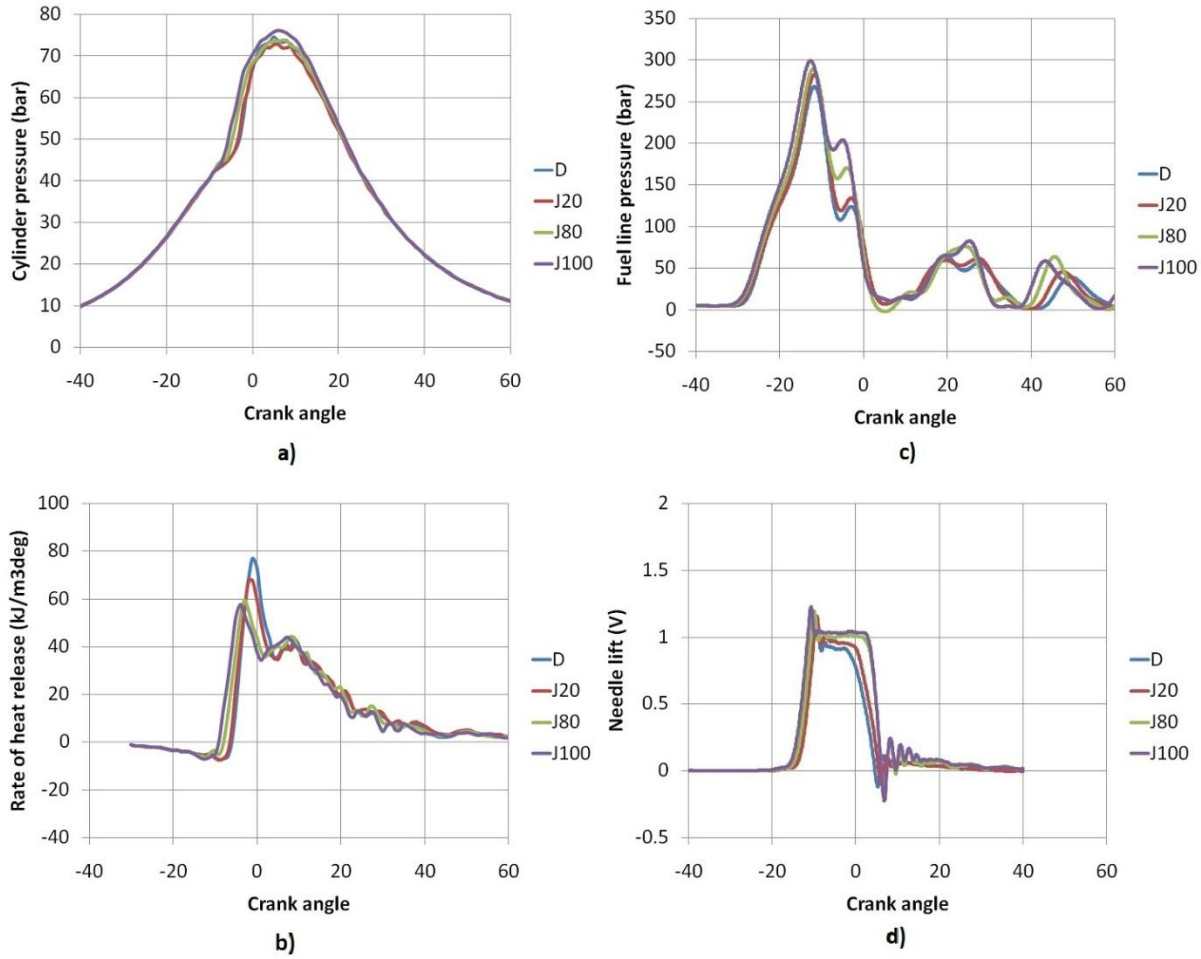


Fig. 2. Fuel injection and combustion characteristics. Bmep = 5.1 bar, N = 3600 rpm.

Engine emission characteristics are given in Fig. 3. It should be noted that brake specific emissions of gaseous species are given rather than volume concentration. Dry gas concentrations are not representative of engine emissions because they depend on the fuel composition and air mass flow rate. In this experiment, for example, dry gas analysis showed increased NOx concentration with J100 at some loads, whereas, as follows from Fig. 1a, brake specific NO_x emissions ($bsNO_x$) are higher for biodiesel. General observation concludes maximum 25% increase in NOx emission with J100 as compared to D and decrease in exhaust opacity and unburned hydrocarbons emissions. Brake specific emission of carbon monoxide increases at high load and decreases at low load.

Such a change in engine emissions is in line with most of papers published for testing Jatropha biodiesel. The natural question arises, can engine emissions be controlled (to some extent) by fuel

additives as it is suggested for efficiency? The answer is yes for NOx emissions and hardly ever for others.

Oxides of nitrogen, mainly nitric oxide (NO), form in high-temperature burned gas from atmospheric nitrogen and oxygen [18]. In IC engines, the NO formation process is kinetically controlled and the amount of NO emitted is determined by a trade-off between NO formation and decomposition and, eventually, by the temperature history. In diesel engines NO_x emission is very sensitive to dynamic injection timing, ignition delay period and start of combustion. Thus, changing properties of biodiesel by additive it will be possible to control NO_x emission along with efficiency.

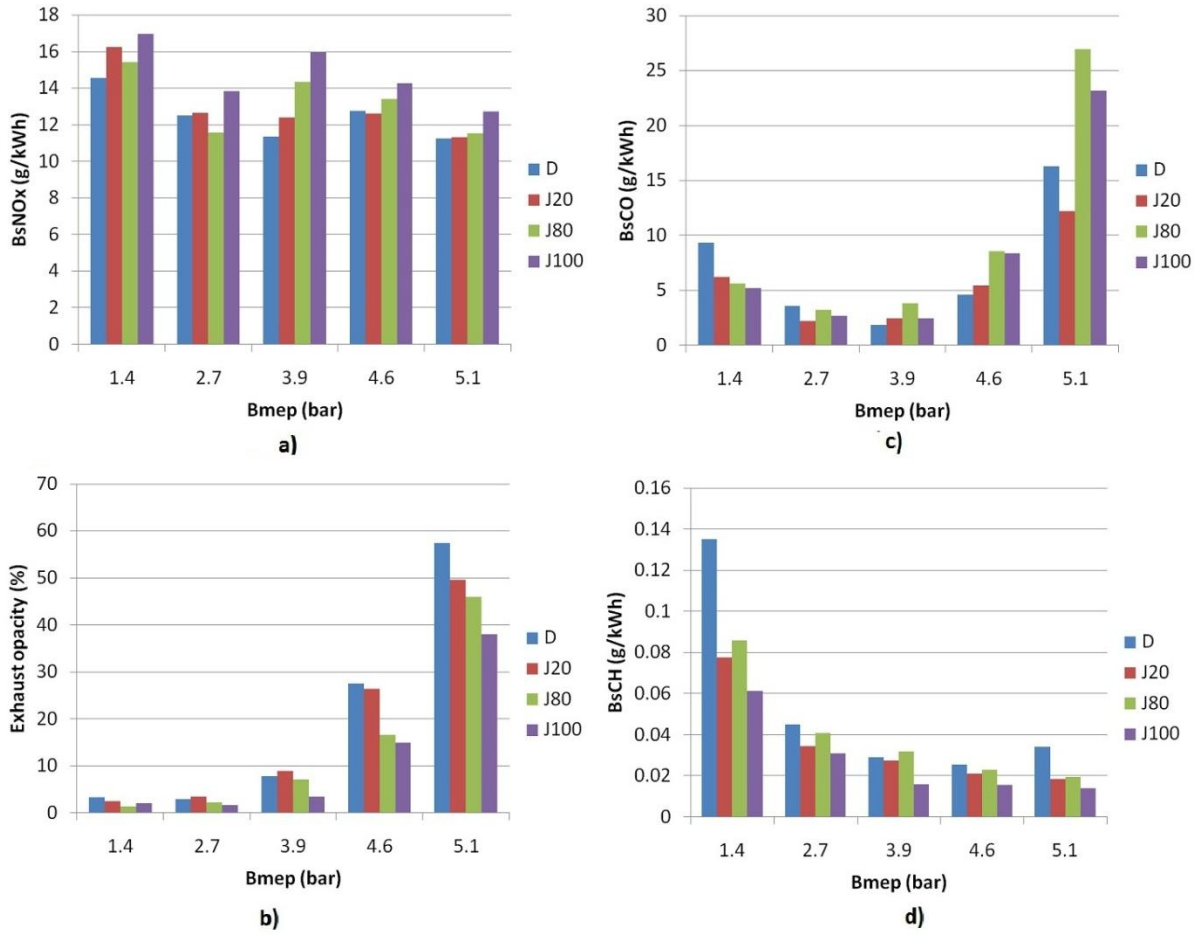


Fig. 2. Engine emissions characteristics. N = 3600 rpm.

Decreased emissions of smoke and unburned hydrocarbons are due to oxygen content in biodiesel and cannot be changed significantly by start of combustion. At the same time decreasing combustion duration would be beneficial for their emission. Unexpectedly increased at high loads carbon monoxide emission requires further investigation. One of the reasons for that may be the poor atomization of biodiesel and fuel-air mixing of biodiesel.

Test results of Pongamia biodiesel showed the same trends as those with Jatropha with a slight variation in values [19]. This is not surprising, since both Jatropha and Pongamia biodiesels have close composition and properties (Table 1, Table 2). Thus, discussion of test results of Jatropha biodiesel may be extended to Pongamia biodiesel.

5. CONCLUSIONS

Jatropha and Pongamia biodiesels and their blends with diesel oil were tested in direct injection diesel engine. Results were compared with those of regular diesel engine. Result analysis was supported by an investigation of fuel injection and combustion characteristics. Based on results following conclusion have been made.

1. Use of biodiesels and their blends with diesel oil results in reduced engine efficiency and increased fuel consumption.

2. Emission of nitrogen oxides increases at all loads, whereas slight increase in carbon monoxide was observed at high load. Unburned hydrocarbons emission and exhaust opacity have been reduced.

3. Blends of both biodiesel with diesel fuel (J20, P20) can be used in diesel engine to provide satisfactory performance and emissions without engine modification.

3. Engine efficiency with biodiesel can be optimized by using additives, and this matter requires further investigation.

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REFERENCES

1. G. Knothe, “Dependence of biodiesel fuel properties on the structure of fatty acid alkyl esters”, Fuel Processing Technology, vol.86, p.p. 1059-1070, 2005.

2. M.S. Graboski, R.L. BcCormick, T.L. Alleman, and A.M. Herring, “The Effect of Biodiesel Composition on Engine Emissions from a DDC Series 60 Diesel Engine”, Final Report, NREL/SR-510-31461, 2003.

3. K. Yamane, K. Kawasaki, K. Sone, T. Hara, and T. Prakoso, “Oxidation stability of biodiesel and its effects on diesel combustion and emission characteristics,” Int. J. Engine Res., vol. 8, p.p. 307-319, 2007.

4. M. G. Bannikov, S. I. Tyrlovoy, I. P. Vasilev, and J. A. Chattha, “Investigation of the characteristics of the fuel injection pump of a diesel engine fuelled with viscous vegetable oil–diesel oil blends,” Proc. Instn Mech. Engrs, Part D: J. Automobile Engineering, vol. 220, 787-792, 2006.

5. M. Lapuerta, O. Armas, J. Rodrıguez-Fernandez, “Effect of biodiesel fuels on diesel engine emissions”, Progress in Energy and Combustion Science, 34 (2008), 198–223.

6. P. Mahanta, S. C. Mishra, and Y. S. Kushwah, "An experimental study of Pongamia pinnata L. oil as a diesel substitute," Proc. Instn Mech. Engrs, Part A: J. Power and energy, 220(A7), pp. 803–808, 2006.

7. P. K. Srivastava, and M. Verma, "Methyl ester of karanja oil as an alternative renewable source energy," Fuel, vol. 87, pp. 1673–1677, 2008.

8. N. R. Banapurmatha, P. G. Tewaria, and R. S Hosmath, "Performance and emission characteristics of a DI compression ignition engine operated on Honge, Jatropha and sesame oil methyl esters," Renewable Energy, vol. 33, p.p. 1982–1988, 2008.

9. K. Sureshkumara, R. Velrajb, and R. Ganesan, "Performance and exhaust emission characteristics of a CI engine fueled with Pongamia pinnata methyl ester (PPME) and its blends with diesel," Renewable Energy, vol. 33, p.p. 2294–2302, 2008.

10. C.M.V. Prasad, M.V.S.M. Krishna, C.P. Reddy, and K.R. Mohan. "Performance evaluation of non-edible vegetable oils as substitute fuels in low heat rejection diesel engines", 2000.

11. S Jindal, B.P. Nandwana, N.S. Rathore, and V. Vashistha. "Experimental investigation of the effect of compression ratio and injection pressure in a direct injection diesel engine running on Jatropha methyl ester". Applied Thermal Engineering 30: 442–448, 2010.

12. V. Pradeep, and R.P. Sharma. "Use of hot EGR for NO_x control in a compression ignition engine fuelled with bio-diesel from Jatropha oil". Renewable Energy 32: 1136–1154, 2007.

13. N.R. Banapurmath, P.G. Tewari, and R.S. Hosmath. "Performance and emission characteristics of a DI compression ignition engine operated on Honge, Jatropha and sesame oil methyl esters". Renewable Energy 33: 1982–1988, 2008.

14. M.S. Kumar, A. Ramesh, and B. Nagalingam. "An experimental comparison of methods to use methanol and Jatropha oil in a compression ignition engine". Biomass and Bioenergy 25: 309 – 318, 2003.

15. I.K. Reksowardojo, T.P. Brodjonegoro, T.H. Soerawidjaja, W. Arismunandar, N.N. Dung, R. Sopheak, T.Q. Tuyen, and H. Ogawa. "The Study of Combustion of Jatropha Curcas Linn.Oil (Crude; Degummed; Fatty Acid Methyl Ester) as a Fuel on a Direct Injection Diesel Engine". COMODIA 2008, July 28-31, Sapporo, Japan, 2008.

16. K. Anand, R.P. Sharma, and P.S. Mehta. "Experimental investigations on combustion of jatropha methyl ester in a turbocharged direct-injection diesel engine". Proc. Instn Mech. Engrs, Part D: J. Automobile Engineering 222 (D): 1865-1877, 2008.

17. J. B. Heywood, Internal Combustion Engines fundamentals. McGraw-Hill, 1988.

18. J.B. Zeldovich and Y.P. Rizer. Physics of shock waves and high temperature hydrodynamic phenomena, Moscow: Nauka, 1966.

19. M.G. Bannikov, J.A. Chattha, Ahmed Faraz Khan, and I.P. Vasilev. Test results of Pongamia Pinnata Methyl Esters with direct injection diesel engine. International Conference on Power Generation Systems & Renewable Energy Technologies (PGSRET), Pakistan, Islamabad, November 29 – December 2, 2010, 333-336.