HEFAT2010
7th International Conference on Heat Transfer, Fluid Mechanics and Thermodynamics
19-21 July 2010
Antalya, Turkey

THE INFLUENCE OF EGR TO PERFORMANCE AND EMISSIONS OF A CI ENGINE FUELLED WITH JATROPHA-BASED BIODIESEL BLEND

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ABSTRACT

The depletion of fossil fuel and the impact of environmental pollution from mobile vehicles have led the search for alternative fuels. Vegetable oils have very similar properties with conventional diesel fuel and therefore, they are quite promising as alternative fuels for diesel engines. Since 1900s, over 30 different types of vegetable oils have been used to fuel compressed ignition (CI) engines. Straight vegetable oils are known to pose various long-term operational and durability problems in CI engines, such as poor fuel atomization, piston ring-sticking, fuel injector coking and deposits, fuel pump failure, and lubricating oil dilution. These problems are due to the vegetable oil high viscosity, low volatility, and polyunsaturated characters. Transesterification, which produces biodiesel, is the most effective process to treat all those problems associated with vegetable oils. Biodiesel productions follow the primary country feedstock. Hence, countries like Malaysia utilize Coconut oil, Palm oil, Jatropha oil and other vegetable oils as the feedstock. Production of biodiesel from edible oil is very expensive than diesel fuel and has caused fuel-food conflicts. In the current study, the focus is on jatropha-based biodiesel (JBD) and previous studies have reported that JBD was found to emit higher nitrogen oxides (NO_X) and lower soot emissions compared to conventional diesel fuel. Other researchers have also achieved to decrease the NO_X emission from JBD by using exhaust gas recirculation (EGR), at the expense of higher soot. As a result, there exists difficulty in reducing both soot and NO_X emissions and a trade-off between them is essential. The aim of the present research was to investigate the engine performance and soot emission by using different blends of JBD with different EGR rates. A 4-cylinder, water-cooled, turbocharged, indirect injection diesel engine was used for the experiments. Data collection and analysis have been carried out on exhaust emission and other engine performance parameters such as thermal efficiency, brake specific fuel consumption (BSFC) and brake specific energy consumption (BSEC). The focal finding will verify the need of trading off between soot and NO_X emissions, for CI engine running using JBD fuel.

INTRODUCTION

Recently, diesel engines are used in transportation, electric power generation, farming, construction and in many industrial activities [1]. These wide fields of usage lead to increasing requirements of petroleum derived fuels. The depletion of world petroleum reserves and increasing demand also induce a steep rise in fuel prices therefore the diesel fuel is very important for countries economy. Besides, the combustion of petroleum based fuels causes environmental problems, which threatens human and environment. Exhaust emissions from diesel engines include CO, CO_2, SO_X, NO_X, and PM [2] cause global warming, one of the most important world problem.

Global warming is related with the GHG which are mostly emitted from the combustion of petroleum fuels. Transportation, including emissions from the production of transport fuels, is responsible for about one quarter of global-related GHG emissions, and that share is rising [3]. To solve both energy concern and environmental concern, the renewable energies with lower environmental pollution impact should be necessary.

NOMENCLATURE

Abbreviations

BESC	[MJ/kW.h]	Brake Specific Energy Consumption
BFSC	[g/kW.h]	Brake Specific Fuel Consumption
CI		Compression Ignition
CO	[%]	Carbon Monoxide
CO_2	[%]	Carbon Dioxide
DI		Direct Injection
EGR	[%]	Exhaust Gas Recirculation
GHG		Greenhouse Gases
HC		Hydrocarbon
IDI		Indirect Injection
JBD		Jatropha Biodiesel
NO_X		Nitrogen Oxides
PM		Particulate Matter
SO_X		Sulfur Oxides

Nowadays, there are many sources of renewable energy. Biofuels are just one source, but a very important one [4]. Biofuel oils can produced from plants (edible or non edible), algae, and animal fats. The use of non-edible plant oil is particularly interesting, as these are generally cheaper than edible oils. Productivity of non-edible oils tend to be higher, for *Jatropha Curcas* as example its productivity 1590 kg of oil per hectare [5]. Also, *Jatropha Curcas* has a high oil content, which has potential as a biofuel feedstock. Jatropha can be grown in dry, poor soils and is therefore less likely to compete with food production for arable land. Therefore, currently big biodiesel development countries like Malaysia focus on producing biodiesel from *Jatropha Curcas* [6]. Biodiesel is a fuel grade derived from transesterification process, which is the most effective process can be treat all problems associated with using straight plant oils directly such as poor atomization of the fuel in the combustion chamber, incomplete combustion, coking of the injectors, and accumulation of soot deposits in the piston crown, rings and lubricating oil [7,8].

A. Jatropha Biodiesel

Jatropha Curcas is a non-edible plant, grow in waste lands and consume less water. Also, biodiesel from Jatropha has advantages compared to conventional diesel fuel such as [9]:

i. Jatropha biodiesel molecules are simple hydrocarbon chains, containing no sulfur, or aromatic substances associated with fossil fuels. They contain higher amount oxygen (up to 10%) that ensures more complete combustion of hydrocarbons.
ii. Biodiesel almost completely eliminates lifecycle carbon dioxide emissions.
iii. Jatropha biodiesel has a high flash point, or ignition temperature, of about 300 F compared to petroleum diesel fuel which has a flash point of 125 F. This means it is safer to transport. Auto ignition, fuel consumption, power output, and engine torque are relatively unaffected by Jatropha biodiesel.
iv. Jatropha biodiesel has a high cetane number. Cetane number is a measure of a fuel's ignition quality. The high cetane numbers of biodiesel contribute to easy cold starting and low idle noise.
v. It can extend the life of diesel engines because of it high lubricating properties.
vi. Jatropha biodiesel replaces the exhaust odor of petroleum diesel with a more pleasant smell of popcorn or French fries.

Although Jatropha biodiesel has many advantages, but it still has several disadvantages, one of them is higher NO_X emission. The higher NO_X emission is a common disadvantage for most of biodiesel. Previous researches achieved reduction in NO_X by using exhaust gas recirculation (EGR) technique.

B. EGR Technique

EGR has been used in recent years to reduce NO_X emissions in light duty diesel engines. EGR involves diverting a fraction of the exhaust gas into the intake manifold where the re-circulated exhaust gas mixes with the incoming air before being inducted into the combustion chamber. EGR reduces NO_X because it dilutes the intake charge and lowers the combustion temperature.

Pradeep et al. [10] investigated the effects of HOT EGR combined with pure Jatropha biodiesel (JB100) on engine performance and exhaust emissions. A single cylinder, water cooled, DI diesel engine was used for their experiments. The results showed that, at 15% EGR, the brake thermal efficiency at full load was found to be 30% and 32% for JB100 and diesel, respectively. BSEC of biodiesel was slightly higher for all levels of EGR compared to corresponding diesel values. Smoke opacity values higher than 60% were observed for EGR levels of 20% and 25% for both fuels. Higher values of CO were observed at full load for both fuels beyond 15% EGR. They concluded that HOT EGR at 15% effectively reduced NO emission without much adverse effect on the performance, smoke, and other emissions.

Mahla et al. [11] investigated the effects of COOLED EGR combined with blended Jatropha (JB20) on engine performance and exhaust emissions. Experiments were carried out to analyze the performance, emission and combustion characteristics with 14% EGR. A single cylinder, air cooled, natural aspiration, DI diesel engine was used for tests. JB20 with 14% EGR was found to be useful in improving the brake thermal efficiency, reduces the exhaust emissions and the BSEC. The study concluded that is diesel engine can be operated with JB20 along with application of EGR to reduce the NO_X emission without increasing the smoke emission.

Niranjan et al. [12] investigated the different effects between using HOT EGR and COOLED EGR on diesel engine fuelled with JB100 and JB50. The experiments carried out by using a single cylinder, natural aspiration, water cooled, DI diesel engine. The experiments result showed that EGR was increasing the emission of CO and HC. The COOLED EGR was much effective than HOT EGR for NO_X reduction even though HC emissions were slightly increased. They concluded that there is a trade-off in emissions when attempts were made to achieve very low NO_X emission by increasing the COOLED EGR rates.

A practical problem in fully exploiting EGR is that, at very high levels, EGR suppresses flame speed sufficiently that combustion becomes incomplete and unacceptable levels of PM and HC are released in the exhaust. Therefore, by using EGR there is a trade-off between reduction in NO_X emission and increase in soot, CO, and HC emissions.

The aim of the current study is to achieve reduction in soot and NO_X emissions using EGR for a CI engine fuelled with biodiesel. Therefore, the current study focused to investigate the influence of different blended Jatropha biodiesel combined with different EGR rates on the performance and exhaust emissions of a CI engine.

C. Current Study Scope

In order to achieve the aim, this study took into consideration results and conclusions of the previous studies. Three parameters are selected based on previous studies: These are biodiesel type (blended or neat), injection system and aspiration system of diesel engine.

1) *Biodiesel Type*

Previous experimental studies were conducted by Rao et al. [13] on Jatropha biodiesel and its blends. The effects of Jatropha on the performance and emissions of a single cylinder, water cooled diesel engine investigated. Experiments result showed that the engine works smoothly on JB100 with performance comparable to diesel fuel operation. JB100 results in a slightly increased thermal efficiency as compared to that of conventional diesel fuel. The exhaust gas temperature was decreased with JB100 as compared to diesel fuel. CO_2 emission was low with JB100 compared to diesel fuel. CO emission was low at higher loads for JB100 when compared to diesel. NO_X emission was slightly increased with JB100 compared to diesel fuel. There was significant difference in smoke emission when JB100 was used. Smoke emission was increased with increasing brake power. Smoke was lesser for blended Jatropha biodiesel compared to diesel fuel. When biodiesel concentration increased, smoke density decreased, but smoke density increased for JB50 and JB75 due to insufficient combustion.

Rao et al. [14] used single cylinder, water cooled, DI diesel engine to investigate the performance and emission characteristics of Jatropha and other two types of non-edible oils on diesel engine. They observed slight drop in thermal efficiency with methyl esters when compared to diesel fuel. Biodiesel gave less smoke density compared to petroleum diesel. When percentage of blend biodiesel increases, smoke density decreases, but smoke density increased for B80 and B100 due to insufficient combustion. Smoke, HC, and CO emissions at different loads were found to be higher for diesel, compared to B10, B20 and B40. In conclusion, good mixture formation and lower smoke emission were the key factors for good CI engine performance. These factors are highly influenced by viscosity, density, and volatility of the fuel. For biodiesels, these factors are mainly decided by the effectiveness of the transesterification process.

Banapurmath et al. [15] carried out experiments by using a single cylinder, air cooled, DI diesel engine fuelled with JB100. The experiments result presented that was JB100 had a thermal efficiency lower than diesel fuel. Also observed, JB100 had slightly higher smoke emission than diesel fuel.

Therefore, current study decided to use blended Jatropha biodiesel because the blended biodiesel is better than the pure biodiesel. Blended biodiesel has high durability with the engine because its properties close to conventional diesel fuel. The brake thermal efficiency is higher than pure biodiesel. It has smoke emission and BSFC lower than pure biodiesel. The blended percentages were selected in this study are JB20 denoted by (20% Jatropha biodiesel by volume blended with 80% diesel fuel) and JB30. These are lower than B50 to avoid high smoke emissions.

2) *Injection System*

From previous studies, Rao & Mohan [16] investigated the performance and exhaust emissions of DI and IDI diesel engines fuelled with Jatropha biodiesel. The experiments result showed that the exhaust of IDI engine was less smoky when compared to DI engine. The lower pollution levels were achieved in IDI engine with biodiesel and IDI engine operation with biodiesel can be regarded as eco-friendly performance. Also, IDI engine operation with biodiesel not only improves the performance but also tremendously reduces the gummy deposits.

Therefore, the current study also used an IDI diesel engine due to the low production of smoke emission.

3) *Aspiration System*

Karabektas [17] investigated the effect of turbocharger application with biodiesel. The experiments result showed that the application of turbocharger provides increased air to the diesel engine and enables mixing of fuel-air easily in the combustion chamber, hence improving the performance and reducing the exhaust emissions.

Therefore, this study also will use turbocharger with the test engine to achieve good performance and low emissions.

EXPERIMENTAL SETUP AND TEST PROCEDURES

A. *Experimental Facilities*

The properties of JB20 and JB30 relative to diesel fuel are detailed in Table I. The experimental installation used in the present work consists of a 4-cylinder, water cooled, turbocharged, IDI diesel engine (see Table II). This engine was connected to hydraulic dynamometer Go-Power System model DA316. The fuel supply system was connected in two fuel tanks, one for diesel fuel and another for blended Jatropha biodiesel, two control valves which allowed rapid switching between the diesel fuel used as a standard and the test alternative fuel, and fuel flow detector Ono Sokki model FZ-2100 was fitted between the fuel filter and the fuel pump. Square edge orifice plate was used for measuring air intake mass flow rate. A digital manometer was used for measuring pressure drop across the orifice plate. EGR was controlled by poppet valve and the rates were determined by using the following equation:

$$\%\text{EGR} = \frac{\text{Mass of air admitted without EGR} - \text{Mass of air admitted with EGR}}{\text{Mass of air admitted without EGR}} \qquad (1)$$

Air temperature, exhaust temperature and coolant temperature were measured using K-type thermocouples. The wires from thermocouples were connected with thermocouple data logger which connected to USB cable connected with PC.

Based on measurements of intake air temperature and pressure drop across orifice plate, convenient software by LabVIEW was designed to instantly calculate the air mass flow rate, the percentage of EGR and display. By controlling the EGR valve, the percentage of EGR can be adjusted to the desired value.

Soot emission was measured using AUTOCHECK soot meter. NO_X, CO and CO_2 emissions were measured using AUTOCHECK gas analyzer. The experimental setup is shown schematically in Figure 1.

B. Experimental Procedures

The test engine was started until it achieved the stable idling condition. Then the engine speed was increased gradually up to 2000 rpm. At the same time, the dynamometer, all analyzers and meters for measurements were switched on and the proper preparations and settings for measurements were carried out as the recommended methods by the manufacturer's instruction manuals. When the test engine got stable condition and preparations and settings for the measurements were finished the experiments were started. The type of experiments is a steady state with high load conditions. Engine speed was maintained constant at 2000 rpm and fuel flow was set to obtain 85% full load at 0% EGR condition.

The air intake mass flow rate, fuel consumption, intake air temperature, exhaust gas temperature, engine coolant temperature, CO_2, CO, NO_X, and soot emissions were measured and recorded.

A system was devised to vary EGR by manually controlling the EGR valve. The EGR valve was opened step by step until the EGR rates were started from 5% until 40% and the increment was 5%. The same conditions, methods and procedures were used for JB20, JB30 and diesel fuel (baseline).

TABLE I
FUELS PROPERTIES

Properties	Diesel	JB20	JB30
Density (kg/m^3)	840	847.1	851.2
Kinematic viscosity @ 40°C (mm^2/s)	3.6	4.1	6
Calorific value (MJ/kg)	45.70	41.90	41.20
Ash (%)	0.01	0.04	0.06
Carbon residue (%)	0.14	0.16	0.14
Water content (%)	0.05	0.010	0.008

TABLE II
ENGINE SPECIFICATIONS

Displacement	1998 CC
Maximum net power	69.14 kW @ 4500 rpm
No. of cylinder	4
Aspiration system	Turbocharged with intercooler
Fuelling system	Indirect injection
Compression ratio	22.4

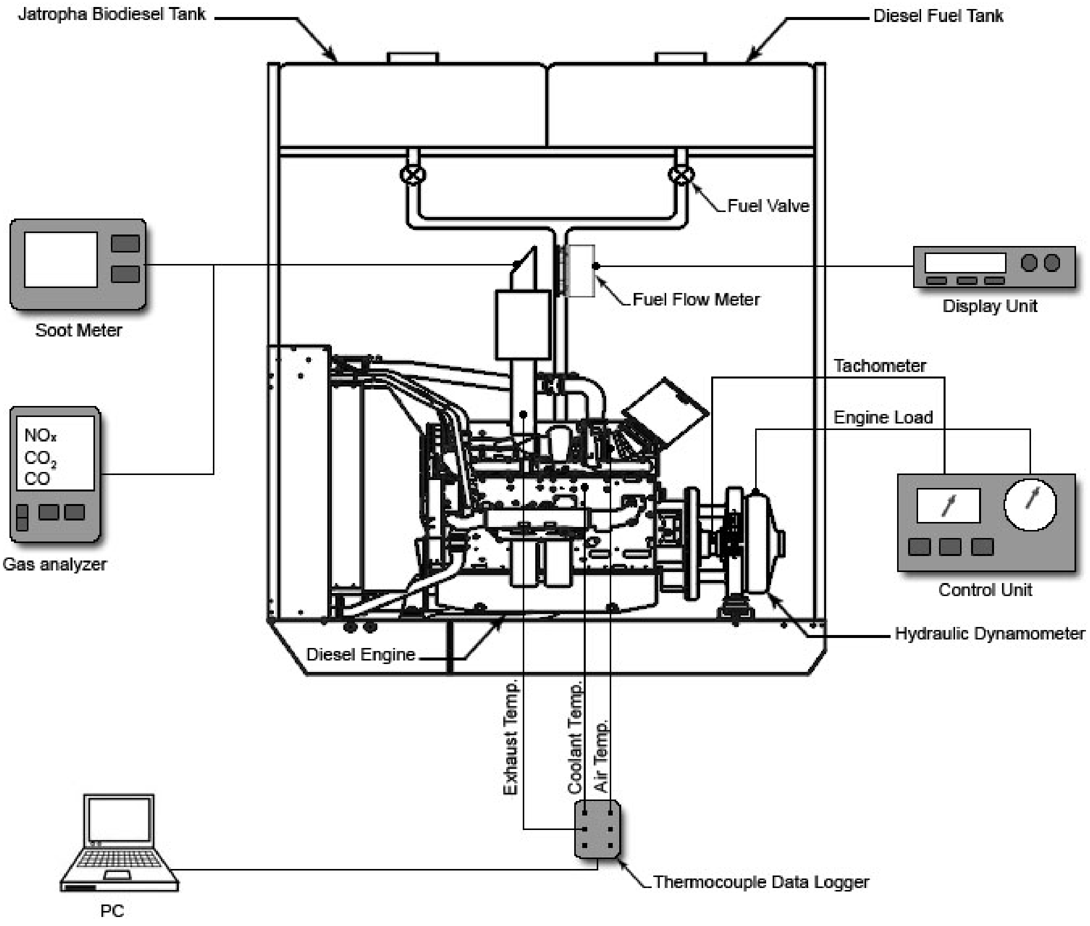

Figure 1 Experimental setup diagram

RESULTS AND DISCUSSION

The experiments were performed to investigate the effect of EGR combined with blended Jatropha biodiesel on engine performance and emissions compared to diesel fuel. During experiments noted that the torque decreased with increasing EGR rates. For both JB20 and JB30, torque decreased approximately 20% from the lowest to the highest EGR rating, while for diesel fuel the torque decreased 30% with the same EGR rates. All gaseous emissions and data measured with and without EGR for all fuels.

A. Thermal Efficiency

Figure 2 shows the thermal efficiency of JB20, JB30 and diesel fuel at various EGR rates. Both of JB20, JB30 have high thermal efficiency than the baseline data with and without EGR, the improvement in brake thermal efficiency was due to the higher oxygen present in biodiesel [7,18]. Observed a slight increase in thermal efficiency for blended Jatropha biodiesel from 5% until 15% EGR rates may be this due to the inbuilt oxygen and dilution. While over 15% EGR the thermal efficiency decreased with increasing the EGR rates with JB20, JB30 and diesel fuel. The reduction in thermal efficiency with increase EGR rates is due to the dilution of the fresh charge with the exhaust gas which results in lower flame velocity and hence deterioration of the combustion [12].

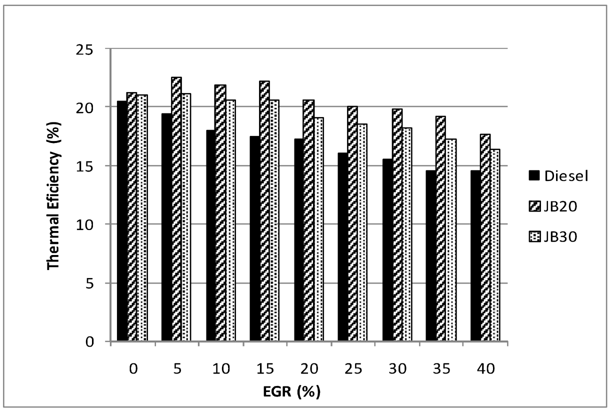

Figure 2 Variation of thermal efficiency with various EGR

B. Brake Specific Fuel Consumption (BSFC)

Figure 3 shows the BSFC of JB20, JB30 and diesel fuel at various EGR rates. When engine was operated on blended Jatropha biodiesel, observed a slightly increase in BSFC compared to diesel fuel without EGR application. Also, the BSFC increased with increasing biodiesel concentration. This increase in BSFC was due to lower calorific value of blended jatropha biodiesel compared to diesel, with highest thermal efficiency found the lowest BSFC [7,18]. BSFC increased with increase EGR rates it is due to dilution of the charge. Upon sending exhaust gas along with the intake air, the amount of intake air will be decreased and lead to high fuel consumption [19]. An important observation is that with EGR application, JB20 and JB30 have lower BSFC than the baseline data. The possible reason is that the torque drop with increase EGR rates for diesel fuel was higher than blended Jatropha biodiesel hence, the power output from diesel fuel is lower than blended biodiesel. Therefore the BSFC of JB20 and JB30 were lower than diesel fuel.

BSFC is not a very reliable parameter to compare fuels of different calorific values and densities. BSEC is more reliable parameter for comparison. This energy consumption is the energy input required to develop unit power [7,20].

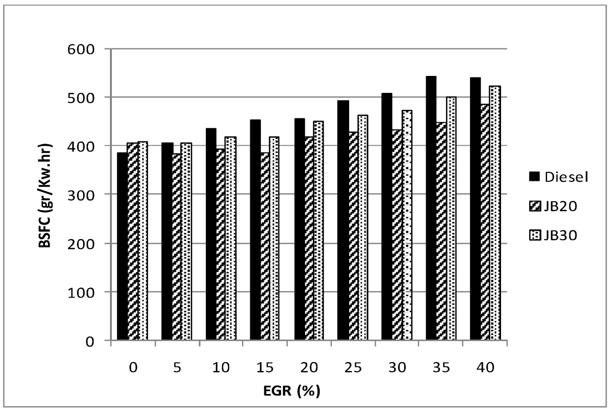

Figure 3 Variation of BSFC with various EGR

C. Brake Specific Energy Consumption (BSEC)

Figure 4 shows the BSEC of JB20, JB30 and diesel fuel at various EGR rates. When engine was operated on blended Jatropha biodiesel, noted that the BSEC was lower than diesel fuel in all cases. The possible reason for lower BSEC may be better thermal efficiency. JB20 gave the lowest BSEC in all cases [7].

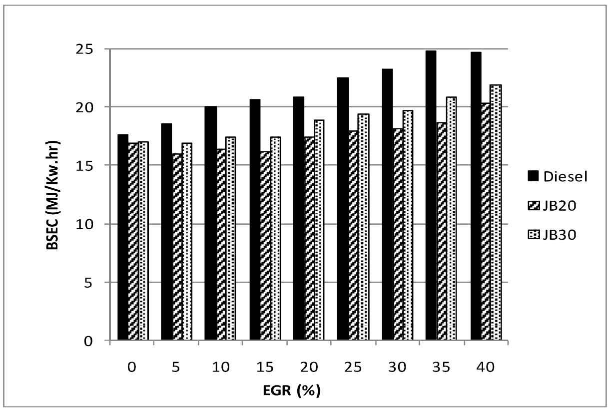

Figure 4 Variation of BSEC with various EGR

D. Exhaust Temperature

Figure 5 shows the exhaust temperature of JB20, JB30 and diesel fuel at various EGR rates. without EGR application, observed that the exhaust temperatures of blended Jatropha biodiesel were lower compared to diesel fuel. Also, observed that with increase biodiesel concentration the exhaust gas temperature decrease [18]. The exhaust gas temperature has increased with increasing EGR rates. The reason associated with after combustion or late combustion or late combustion phase (burning of un-burnt and partial burnt fuel particles in the expansion stroke) with EGR [19].

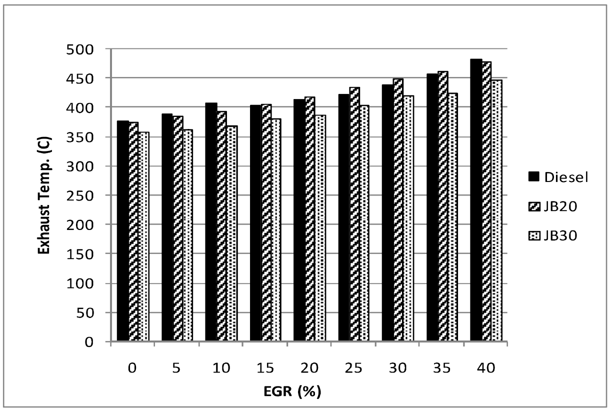

Figure 5 Variation of exhaust temperature with various EGR

E. Carbon Dioxide (CO_2)

Figure 6 shows the variation of CO_2 with various EGR rates. With using EGR application the CO_2 emission increased with increasing EGR rates. Maybe this is due to replace some of the oxygen concentration in combustion chamber by CO_2 because the principal constituents of EGR are CO_2 and water vapour (H_2O) [21].

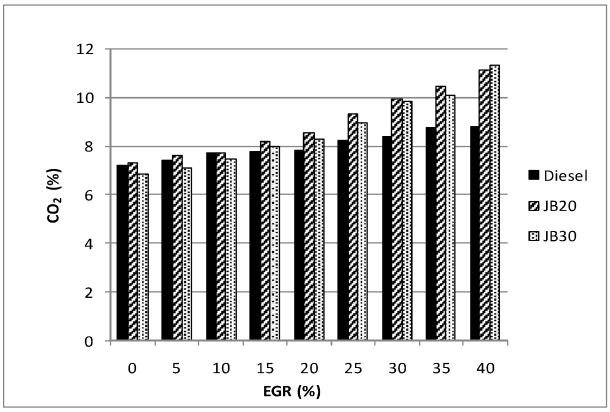

Figure 6 Variation of CO_2 emission with various EGR

F. Carbon Monoxide (CO)

Figure 7 shows the variation CO emission with various EGR rates for JB20, JB30 and diesel fuels. The Effect of EGR on CO emission, CO was increased with increasing EGR rates. The possible reason may be lower excess of oxygen available for combustion. Lower excess oxygen concentration results in rich air-fuel mixture at different locations inside the combustion chamber. With EGR, the air-fuel ratio decrease and CO eventually increase [7,19]. CO emissions of JB20 and JB30 were comparatively lower than diesel fuel with EGR application. For blended Jatropha biodiesel the excess oxygen content is believed to have partially compensated for oxygen deficient operation under EGR. Dissociation CO_2 to CO at peak loads where high combustion temperatures and comparatively fuel rich operation exists, can also contribute to higher CO emissions [11,18].

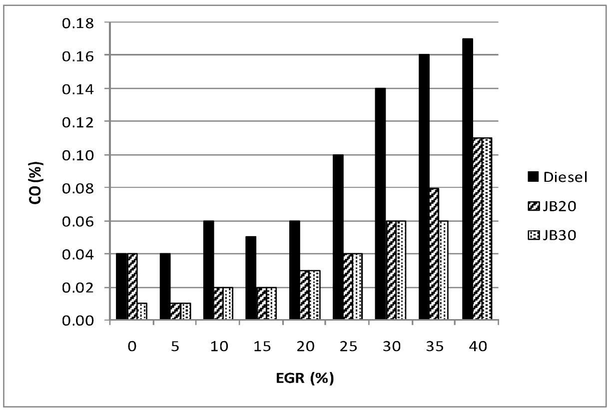

Figure 7 Variation of CO emission with various EGR

G. Nitrogen Oxides (NO_X)

Figure 8 shows the variation of normalized NO_X emission with various EGR rates. When engine was operated without EGR application on blended Jatropha biodiesel, observed that the NOx emission was slightly lower compared to diesel fuel. The possible reason for lower NOx emission may be because the higher cetane number (shorter premixed combustion part) and the absence of aromatics tend to contribute to less NOx production, which seems to more than offset the possible increase caused by the presence of the fuel bound oxygen even in locally rich zones (more zones nearer to stoichiometry) [22]. With EGR induction in blended biodiesel and diesel fuel, the NOx is reduced because of oxygen depletion and reducing maximum flame temperature consequently NO_2 is reduced [11]. NO_X emission in case of blended biodiesel with EGR was higher than diesel fuel due to higher temperature prevalent in the combustion chamber [7,18].

H. Soot Emission

Figure 9 shows the plots of soot emission variation with various EGR rates. an important observation is that the soot emissions of JB20 and JB30 are noticed to be generally lower than that of diesel fuel. The molecule of biodiesel contains some oxygen that takes part in combustion and this may be a possible reason for lower soot emission [7]. The soot emission decreased with increasing biodiesel concenteration. This is due to the complete and stable combustion of the biodiesel, which contain the more number of oxygen atoms [22,23,24]. By using higher EGR ratio there was sharp increase in soot emission level due to reduction oxygen available for combustion [7,11].

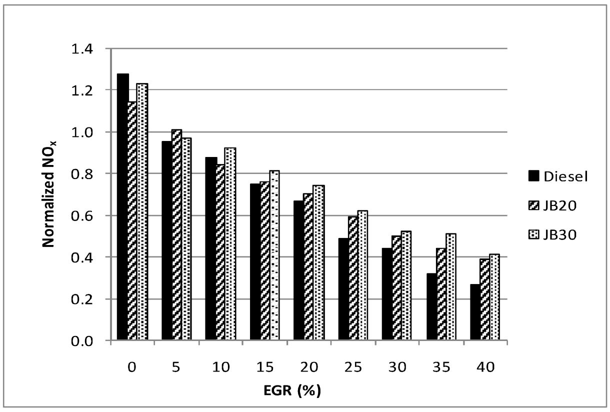

Figure 8 Variation of normalized NO_X with various EGR

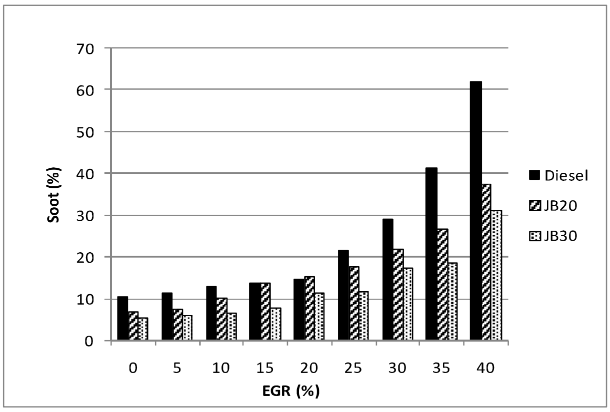

Figure 9 Variation of soot emission with various EGR

I. The difference between JB20 and JB30 compared to diesel

With using EGR application, the torque loss about 3% for both JB20 and JB30 from no EGR to 15% EGR, while for diesel fuel was 17.5% under the same EGR rates. JB20 with 15% EGR shows 9% increase in thermal efficiency, BSEC decreased about 8%, 40% decreased in NO_X emission, and soot emission increased about 30% compared to diesel fuel without EGR. While JB30 with 15% EGR shows 37% decreased in NO_X emission and 26.5% decreased in soot emission, without adverse effects on the engine performance compared to diesel fuel without EGR. therefore, in the performance as well as in the enviromental protection aspects, 15% EGR with JB30 is preferable.

CONCLUSION

On the basis of experimental data, it was found that blended Jatropha biodiesel and EGR technique both can be used in compression ignition engine to simultaneously reduce NO_X and soot emissions. For all blends biodiesel operating conditions, a better trade-off between NO_X and soot emissions can be attained within a limited EGR rate of 5-15% without adverse effects on the performance. 15% EGR with JB30 effectively to reduced NO_X (37%) and soot (26.5%) emissions compared to diesel fuel without EGR.

ACKNOWLEDGMENT

Appreciation and acknowledgement to Ministry of Higher Education of Malaysia for providing financial support under fundamental research grant schemes (FRGS): Vote 0362 and 0364.

REFERENCES

[1] Alan C. Lloyd and Thomas A. Cackette, "Diesel Engines: Environmental Impact and Control," *Air & Waste Management Association*, vol. 51, June 2001, pp. 809-847.

[2] Cherng-Yuan Lin and Hsiu-An Lin, "Diesel engine performance and emission characteristics of biodiesel produced by the peroxidation process," *Fuel*, vol. 85, 2006, pp. 298–305.

[3] IEO, "International Energy Outlook 2009," Washington, DC 20585, 2009.

[4] Caye M. Drapcho, Nghiem Phu Nhuan, and Terry H. Walker, *Biofuels engineering process technology*. New York: McGraw-Hill, 2008.

[5] A.K. Hossain and P.A. Davies, "Plant oils as fuels for compression ignition engines: A technical review and life-cycle analysis," *Renewable Energy*, vol. 35, 2010, pp. 1–13.

[6] G.P. Lopez and L. Tara, "BIOFUELS - AT WHAT COST ?," 2008.

[7] D. Agarwal, S. Sinha, and A. Kumar Agarwal, "Experimental investigation of control of NOx emissions in biodiesel-fueled comperssion ignition engine," *Renewable Energy*, vol. 31, 2006, pp. 2356-2369.

[8] Institute World Dwatch, *Biofuels For Transport*. London: EARTHSCAN, 2007.

[9] jookaplee. (2007, January) Jatropha Curcas L. Web Blog. [Online]. http://jatropha-blog.blogspot.com/2007/01/what-is-jatropha-biodiesel.html

[10] V. Pradeep and R.P. Sharma, "Use of HOT EGR for NOx control in a compression ignition engine fuelled with bio-diesel from Jatropha oil," *Renewable Energy* , vol. 32, 2007, pp. 1136–1154.

[11] S.K. Mahla, L.M. Das, and M.K.G. Babu, "Effect of cooled EGR on performance and exhaust emission characteristics of biodiesel fueled engine," in *International Conference on Thermal Engineering: Theory and Applications*, vol. 3, Amman, Jordan, 2007.

[12] L.Niranjan, Shijo Thomas, and V.Sajith, "Experimental investigation on the effects of cold and hot EGR using diesel and bio-diesel as Fuel," in *Energy and Environment*, 2006.

[13] Y.V.H. Rao, R. S. Voleti, A.V.S. Raju, and P.N. Reddy, "Experimental investigations on jatropha biodiesel and additive in diesel engine," *Indian Journal of Science and Technology*, vol. 2, April 2009, pp. 25-31.

[14] T.Venkateswara Rao, G.Prabhakar Rao, Principal, and K.Hema Chandra Reddy, "EXPERIMENTAL INVESTIGATION OF METHYL ESTERS OF NON-EDIBLE OILS AS BIODIESEL ON C.I ENGINE," *International Journal of Meterials Sciences*, vol. 3, 2008.

[15] 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* , vol. 33, 2008, pp. 1982–1988.

[16] G. Amba Prasad Rao and P. Rama Mohan, "Performance Evaluation of DI and IDI engines with Jatropha Oil based Biodiesel," *IE Journal - MC*, vol. I, 2005, pp. 72-76.

[17] M. Karabektas, "The effects of turbocharger on the performance and exhaust emissions of a diesel engine fuelled with biodiesel," *Renewable Energy*, vol. 34, April 2009, pp. 989-993.

[18] K. Rajan and K. R. Senthilkumar, "Effect of Exhaust Gas Recirculation (EGR) on the Performance and Emission Characteristics of Diesel Engine with Sunflower Oil Methyl Ester," *Jordan Journal of Mechanical and Industrial Engineering*, vol. 3, December 2009, pp. 306 - 311.

[19] V. J. J. Prasad, N. Hari Babu, and B. V. Appa Rao, "Reduction of NOx in the exhaust gas of DI- diesel engine fueled with mahua methyl ester along with exhaust gas recirculation," *JOURNAL OF RENEWABLE AND SUSTAINABLE ENERGY* , vol. 1, 2009.

[20] D.H. Qi et al., "Combustion and performance evaluation of a diesel engine fueled with biodiesel produced from soybean crude oil," *Renewable Energy* , vol. 34, 2009, pp. 2706–2713.

[21] G.H. Abd-Alla, "Using exhaust gas recirculation in internal combustion engines: a review," *EnergyConversion and Management* , vol. 43, 2002, pp. 1027–1042.

[22] C.D. Rakopoulos, K.A. Antonopoulos, D.C. Rakopoulos, D.T. Hountalas, and E.G. Giakoumis, "Comparative performance and emissions study of a direct injection Diesel engine using blends of Diesel fuel with vegetable oils or bio-diesels of various origins," *Energy Conversion and Management* , vol. 47, 2006, pp. 3272–3287.

[23] Shiwu Li et al., "Biodiesel production from Eruca Sativa Gars vegetable oil and motor, emissions properties," *Renewable Energy* , vol. 34, 2009, pp. 1871–1876.

[24] Cengiz Öner and Sehmus Altun, "Biodiesel production from inedible animal tallow and an experimental investigation of its use as alternative fuel in a direct injection diesel engine," *Applied Energy* , vol. 86, 2009, pp. 2114–2120.