Nature Environment and Pollution Technology
An International Quarterly Scientific Journal

ISSN: 0972-6268	Vol. 15	No. 4	pp. 1249-1256	2016

Original Research Paper

Effects of Low Carbon Biofuel Blends with Karanja (*Pongamia pinnata)* Oil Methyl Ester in a Single Cylinder CI Engine on CO_2 Emission and other Performance and Emission Characteristics

S. Thiyagarajan†, V. Edwin Geo, Leenus Jesu Martin and B. Nagalingam
Department of Automobile Engineering, SRM University, Kattankulathur, Kancheepuram-603 203, India
†Corresponding author: S. Thiyagarajan

Nat. Env. & Poll. Tech.
Website: www.neptjournal.com

Received: 16-12-2015
Accepted: 04-02-2016

Key Words:
Karanja oil methyl ester
Low carbon biofuel
CO_2 emission
Global warming
Orange oil

ABSTRACT

The present study investigates the effects of various low carbon biofuels on CO_2 emission and other performance and emission characteristics blended with Karanja oil methyl ester (KOME) in a single cylinder CI engine with a rated output of 5.2 KW at 1500 rpm. Carbon-di-oxide (CO_2) emission is a major threat to the environment as it causes global warming. The constant depletion of fossil fuels over the years has changed the focus of researchers towards biofuels. The number of carbon atoms in the molecular structure and carbon to hydrogen ratio of biofuel is one of the major causes for the increase in CO_2 emission. Karanja (*Pongamia pinnata*) oil is available in plenty in India, and hence it may replace conventional diesel fuel largely. However, KOME operated CI engine emits higher CO_2 emission due to higher carbon content compared to diesel. Blending of low carbon biofuel with KOME reduces CO_2 emission. Low carbon biofuels like Eucalyptus oil (EU), Pine oil (PO), Camphor oil (CMO) and Orange oil (ORG) were selected for this study and blended equally with KOME on volume basis. Performance, emission and combustion parameters for all the blends were tested at part and full load conditions and compared with neat diesel and neat KOME. CO_2 emission was lesser for all the low carbon biofuel blends with KOME. Maximum reduction of 13% was observed with KOME-ORG blend compared to neat KOME and 6% reduction of CO_2 emission for KOME-ORG blend compared to neat diesel at full load condition. A slight increase in brake thermal efficiency is observed for KOME-ORG compared to neat diesel and neat KOME with a slight increase in NO and CO emission at full load condition. With an increase in brake thermal efficiency and reduction in CO_2 emission, equal blending of KOME-ORG is the best among the various blends tested, in terms of performance, emission and combustion parameters compared to neat diesel and neat KOME.

INTRODUCTION

Global warming is a major threat to the environment. The intergovernmental panel of climate control (IPCC) has predicted an increase of 1-2°C of earth's surface temperature by 2020 and 2-5°C by 2070. The IPCC has also predicted that Asia would experience a rise in temperature, longer summer heat spell, increase in extreme rainfall and a rise in sea levels in coastal areas around the Indian Ocean, northern and southern Pacific Ocean (Christensen et al. 2007). The gases causing global warming are CO_2, CH_4 and water vapour. CO_2 is one of the major constituents for global warming. The climate change threatens the basic elements of life for people around the world-access to water, food, health and use of land and environment. Increase in temperature, sea level and storm surges will cause a substantial impact on transport infrastructure (Stern et al. 2007). In the current scenario, CO_2 emission from fossil fuels is likely to increase by 39% by 2030 (Mofijur et al. 2012).

Diesel engines are more popular prime mover because of its high thermal efficiency, reliability and handling facilities. Many studies have shown that in the current scenario, specific CO_2 emissions can be reduced by using biofuels in CI engines as they are plantation carbon neutral (Makoto et al. 2007, Thomas et al. 2008, Wagner et al. 2008, Hausberger 1998 and Stangeland 2007). Edible oil in India is deficit but non edible oils like Jatropha, Karanja, Mahua, Neem etc. are available in large scale in India (Shivkumar et al. 2013). Karanja oil being non-edible and available abundantly in India, is one of the promising renewable fuel sources considered as an alternate to diesel. Many researchers (Srivastava et al. 2008, Nabi et al. 2009, Bhupendta Singh et al. 2013, Sahoo et al. 2009, Suresh Kumar et al. 2008, Baiju et al. 2009 and Raheman et al. 2004) have studied karanja oil biodiesel utilization in a diesel engine. Chauhan et al. (2013) and Suresh Kumar et al. (2008) reported an increase in CO_2 emission while utilizing karanja oil biodiesel compared to neat diesel due to its longer carbon chain.

Many researchers have reported that low carbon-hydrogen ratio and low carbon content of fuel reduces CO_2 emission (Devan et al. 2009a, Lulaji et al. 2011, Tarabet et al. 2014, Atmanl et al. 2014, An et al. 2012, Coronado et al. 2009, Swaminathan et al. 2012, Ahmet et al. 2009, Dorado et al. 2003, Atmanl et al. 2013, Kasiraman et al. 2012). Lujaji et al. (2011) investigated the fuel properties, engine performance, emission and combustion characteristics of a four cylinder turbo charged DI diesel engine using croton oil, butanol and diesel blends. They noted that CO_2 emission is less, as butanol content increases in the blends compared to neat diesel due to less carbon to hydrogen ratio. Coronado et al. (2009) analysed various fuels like gasoline, diesel ethanol, soybean biodiesel and used frying oil to calculate CO_2 emissions per cubic meter of fuel, based on fuel structure at stoichiometric ratio. They estimated that 1 m^3 of gasoline emits 2.316 ton of CO_2, 1 m^3 of diesel emits 2.683 tons of CO_2, 1 m^3 of ethanol emits 1.511 tons of CO_2, 1 m^3 of soybean biodiesel emits 2.48 ton CO_2 and 1 m^3 of used frying oil emits 2.492 ton CO_2. Among the various fuels analysed, ethanol emits less CO_2 emission due to low carbon content in the fuel. Ahmet et al. (2009) studied the performance and emission characteristics of a six cylinder DI diesel engine using waste palm oil and canola oil methyl ester. They concluded that CO_2 emission for waste palm oil was 1.8% less compared to diesel and 3.6% less compared to canola oil methyl ester which is due to lower carbon-hydrogen ratio of waste palm oil compared to canola oil methyl ester and diesel fuel. The literature study indicated that combustion of low carbon fuels reduces CO_2 emission. Higher CO_2 emission from karanja oil methyl ester can be reduced by blending low carbon biofuels which will reduce the CO_2 emission and also increases the net negative CO_2 effect considering well to wheel analysis.

Four low carbon biofuels, Eucalyptus oil, camphor oil, pine oil and orange oil were identified as potential fuels for reducing CO_2 emission based on the molecular structure from the literature study. Tarabet et al. (2014) investigated the performance and emission characteristics of a single cylinder DI diesel engine using Eucalyptus oil biodiesel and natural gas in dual fuel mode. They concluded that CO_2 emission was less for Eucalyptus oil biodiesel compared to diesel and CO_2 emission was further reduced with natural gas due to lower carbon-hydrogen ratio. Similar results were reported by Devan et al. (2009b) while studying performance, emission and combustion characteristics of CI engine using methyl ester of paradise oil-Eucalyptus oil blends. They stated that blending paradise oil with Eucalyptus oil reduces viscosity and increases volatility. They concluded with their observations of reduction in smoke, HC and CO emission and slight increase in NO emission and brake thermal efficiency that, methyl ester of paradise oil (50%)-Eucalyptus oil (50%) is optimum blend. Kasiraman et al. (2012) conducted experiments using camphor oil-cashew nut shell oil blend and compared performance, emission and combustion parameters with diesel. They reported an improvement in performance and emission characteristics of cashew nut shell oil and camphor oil blend. Vallinayagam et al. (2013) conducted experiments using kapok oil biodiesel, pine oil blends in a single cylinder CI engine, and compared the performance and emission characteristics. They concluded that increase in pine oil in the blend, causes knocking due to low cetane number of pine oil. Their results indicated that kapok oil biodiesel (50%) -pine oil (50%) blend is optimum in terms of performance and emission characteristics. Purushothaman et al. (2009) investigated the performance and emission characteristics of CI engine with neat orange oil and compared it with diesel. They observed an increase in brake thermal efficiency and reduction in HC, CO and smoke emission for neat orange oil compared to diesel and slight increase in NO emission for neat orange oil. The experimental results from the literature corresponding to Eucalyptus oil, camphor oil, pine oil and orange oil lack detailed discussion of CO_2 emission due to the low carbon content of the fuels which is addressed in this experimental work.

In the present work, KOME was tested as an alternate to diesel in a single cylinder CI engine. KOME emits more CO_2 compared to diesel. The main aim of the work is to reduce the CO_2 emission produced from KOME operation in a CI engine by blending low carbon secondary biofuels. Experimental tests were conducted using 50% KOME and 50% Eucalyptus oil (KOME-EU), 50% KOME and 50% pine oil (KOME-PO), 50% KOME and 50% camphor oil (KOME-CMO) and 50% KOME and 50% orange oil (KOME-ORG) blends in equal proportion on volume basis, in order to study the reduction in CO_2 emission and its implication on performance, emission and combustion parameters compared to neat diesel and KOME. The well to wheel analysis for KOME and the optimized blend based on minimum CO_2

Table 1: Properties of neat diesel and neat karanja oil methyl ester (KOME).

Property	Diesel	Karanja Oil Methyl Ester (KOME)
Average Molecular Formula	$C_{14}H_{28}$	$C_{20}H_{36}O_2$
Kinematic viscosity,cST @ 40°C	3.6	4.9
Density @ 15°C, g/cm3	0.840	0.858
Lower Heating value kJ/kg	42700	41200
Cetane index	52	49
Flash point,°C	74	135

emission was also done to calculate the overall negative CO_2 emission (Table 5).

Test fuels: The blends of 50% KOME and 50% Eucalyptus oil (KOME-EU), 50% KOME and 50% pine oil (KOME-PO), 50% KOME and 50% camphor oil (KOME-CMO) and 50% KOME and 50% orange oil (KOME-ORG) were prepared on volume basis and observed for any phase separation. There were no phase separations observed in the blends. Table 1 shows the physicochemical properties of neat KOME and neat diesel.

Table 2 shows the comparison of physicochemical properties of Eucalyptus oil, pine oil, camphor oil and orange oil. Table 2 indicates that low carbon biofuels have low viscosity and low cetane number except for orange oil. Hence, Eucalyptus oil, camphor oil and pine oil operation as a single fuel in CI engine is not feasible. The carbon content of all the biofuels is low as evident with the molecular formula.

Table 3 shows the important properties for blends of KOME-EU, KOME-PO, KOME-CMO and KOME-ORG.

Experimental setup and test procedure: A single cylinder water-cooled four-stroke direct injection compression ignition engine which runs at 1500 rpm and develops 5.2 kW power coupled with eddy current dynamometer was used for experimentation. Table 4 highlights the test engine specifications. The engine has a hemispherical combustion chamber with overhead valves. Cylinder head of the engine was modified to mount a piezoelectric pressure transducer flush with the cylinder to measure the pressure and a TDC pulse pick up was used to measure the crank angle. The cylinder pressure and TDC signals were acquired and stored on a high speed computer based Digital Data Acquisition System (PCDDS). Data from 100 consecutive cycles were recorded and the signals were processed with "Engine Soft" software to obtain the combustion parameters such as pressure-crank angle and the heat release rate. The CO, HC, NO and CO_2 emission was measured using AVL five gas analyser and smoke emission was measured using AVL 432c smoke meter. The experimental setup is shown in Fig. 1.

Initially, the engine was tested with neat diesel and KOME at 1500 rpm for full and part load conditions as base data. Experiments were conducted with biofuel blends of 50% KOME and 50% Eucalyptus oil (KOME-EU), 50% KOME and 50% pine oil (KOME-PO), 50% KOME and 50% camphor oil (KOME-CMO) and 50% KOME and 50% orange oil (KOME-ORG) at 1500 rpm for full and part load conditions. The performance, emission and combustion characteristics were obtained for various blends and compared with base data.

RESULTS AND DISCUSSION

CO_2 emission: Fig. 2 shows the variation of CO_2 emission for various blends with KOME compared to diesel and KOME at part load and full load conditions. CO_2 emission is directly proportional to the number of carbon atoms present in the fuel. Another important reason for CO_2 emission is carbon to hydrogen ratio in the fuel. At full load, CO_2 emission for diesel is 810.17 g/kW-h and for KOME is 1098.84 g/kW-h. Higher CO_2 emission for KOME compared to neat diesel is due to higher number of carbon atoms present in KOME. Another possible reason may be due to higher density of KOME compared to diesel and hence overall fuel mass is increased during KOME operation. Biofuels

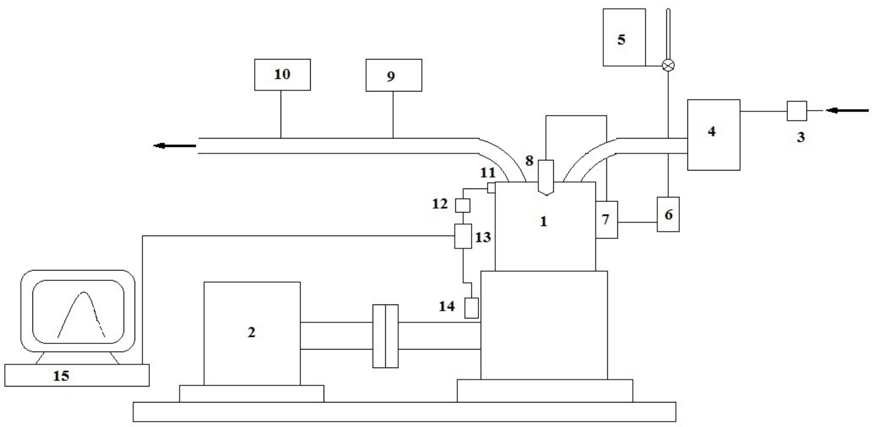

Fig. 1: Schematic diagram of experimental setup.
1. Engine 2. Eddy current dynamometer 3. Air filter 4. Air box 5. Fuel tank 6. Fuel filter 7. Fuel pump 8. Fuel injector 9. AVL exhaust gas analyzer 10. AVL smoke meter 11. Pressure transducer 12. Charge Amplifier 13. Analog to digital converter 14. TDC pickup 15. Data acquisition system

Table 2: Properties of various low carbon biofuels.

Property	Eucalyptus oil (EU)	Pine oil (PO)	Camphor oil (CMO)	Orange oil (ORG)
Molecular Formula	$C_{10}H_{18}O$	$C_{11}H_{10}BrN_5$	$C_{10}H_{16}O$	$C_{10}H_{20}O$
Kinematic viscosity,cST @ 40°C	2.0	1.3	1.9	3.52
Density @ 15°C, g/cm³	0.895	0.875	0.894	0.816
Lower Heating value kJ/kg	43270	42800	38200	34650
Cetane index	28	11	5	47
Flash point, °C	54	52	50	74
Molar mass g/mole	154	292	152	156
Carbon content (%)	78	45	79	77
Hydrogen content (%)	12	3	11	13
Oxygen content (%)	10	0	10	10
Carbon-Hydrogen ratio	0.55	1.1	0.62	0.5
Stoichiometric A/F ratio	13.80	7.04	13.53	14.16

Table 3: Properties of blends of various low carbonbiofuels with neat KOME.

Property	KOME–EU (50-50) (% volume)	KOME-PO (50-50) (% volume)	KOME-CMO (50-50) (% volume)	KOME-ORG (50-50) (% volume)
Kinematic viscosity,cST @ 40°C	3.5	3.1	3.4	4.2
Density @ 15°C, g/cm3	0.876	0.866	0.876	0.837
Lower Heating value kJ/kg	42235	42000	39700	37925
Calculated cetane index	39	30	27	48

Table 4: Engine specifications.

Make and Model	Kirloskar AV1
Engine Type	Single cylinder, water cooled, direct injection constant speed
Bore (mm)	87.5
Stroke (mm)	110
Compression Ratio	17.5:1
Rated power @ 1500rpm	5.2 kW
Injection Pressure (bar)	200
Injection timing	23°bTDC

like Eucalyptus oil, camphor oil, pine oil and orange oil have low number of carbon atoms in their molecular structure as shown in Table 2 and hence blending these biofuels with KOME may result in overall reduction of carbon atoms. CO_2 emission for KOME-EU blend is 1015.92 g/kW-h, KOME-CMO blend is 999.68 g/kW-h and KOME-PO blend is 995.46 g/kW-h, which is less as compared to neat diesel and KOME because of lower carbon hydrogen ratio. The minimum CO_2 emission is observed for KOME-ORG blend which is 797.46 g/kW-h because of reduced carbon content and lower carbon to hydrogen ratio compared to other low carbon biofuel blends with KOME, neat diesel and KOME. Density of fuel plays a major role in CO_2 emission formation. KOME-ORG blend has minimum density compared to other low carbon biofuel blends. Maximum percentage reduction of CO_2 emission is 13% with KOME-ORG blend compared to neat KOME and 6% with KOME-ORG blend compared to diesel. Similar trends were observed in part load conditions also.

Performance Characteristics

Brake thermal efficiency: The variation of brake thermal efficiency for various low carbon biofuel blends with KOME compared with neat KOME and diesel at part load and full load conditions are shown in Fig. 3. The brake thermal efficiency of KOME is similar to that of diesel at part load and full load conditions. This is because of similar properties like lower heating value and cetane index as shown in Table 1 for both diesel and KOME. At full load, brake thermal efficiency of diesel is 29.9 % and for KOME is 28.8 %. The

Table 5: Well to wheel analysis for diesel, KOME and KOME-ORG.

	Diesel	KOME	KOME-ORG
CO_2 emission (kg) per kg of fuel burnt	2.88	3.37	2.7
Well to wheel analysis for 1 kg of fuel	0	25	21
Negative CO_2 impact	0	-21.63	-18.3

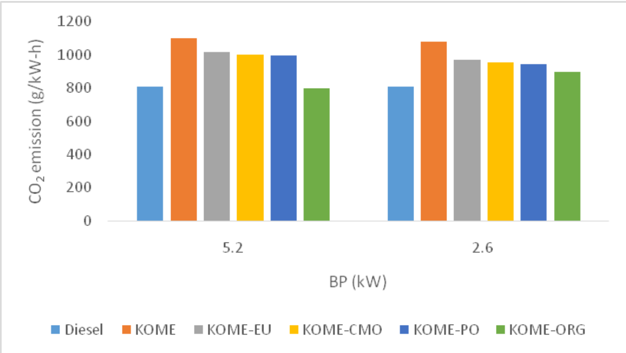

Fig. 2: Variation of CO_2 emission for various blends at full load and part load condition.

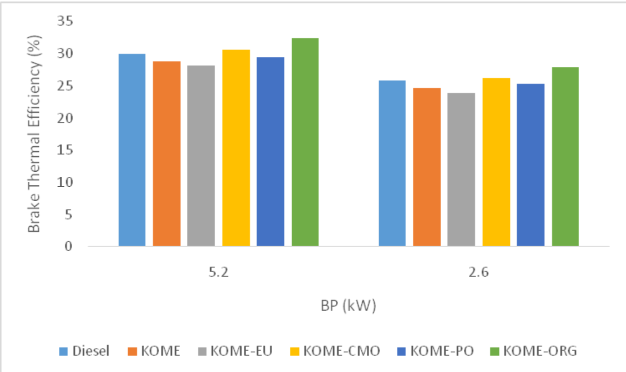

Fig. 3: Variation of brake thermal efficiency for various blends at full load and part load conditions.

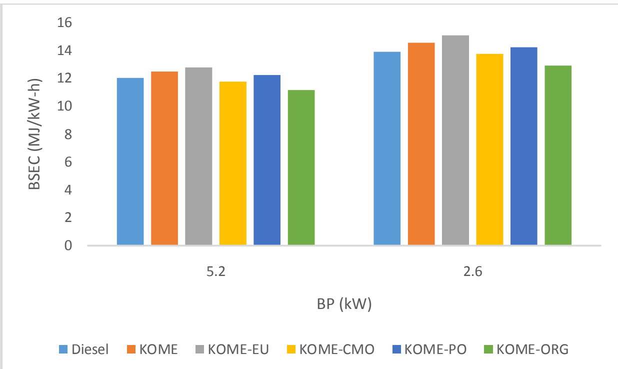

Fig.4 Variation of BSEC for various blends at part load and full load conditions

maximum brake thermal efficiency is observed for KOME-ORG blend (32.36 %) compared to all other low carbon biofuel blends, diesel and neat KOME at full load.

This is due to less number of double bonds present in the structure, higher cetane number, low density, high volatility, shorter chain length and more saturated carbon bond in KOME-ORG blend, compared to other low carbon biofuel blends. Higher hydrogen content in KOME-ORG blend is also another reason for improvement in combustion. KOME-CMO blend has almost same brake thermal efficiency compared to neat diesel and KOME. KOME-EU and KOME-PO blends have lower brake thermal efficiency compared to the other fuels. At part load, similar trends are observed for all low carbon biofuel blends compared to neat diesel and KOME.

Brake Specific Energy Consumption (BSEC): The variation of brake specific energy consumption (BSEC) for various low carbon bio fuel blends with KOME is compared with neat KOME and diesel at part and full load conditions in Fig. 4. There is minimal change observed in BSEC of neat diesel and KOME because of similar properties like density, viscosity possessed by both the fuels. The BSEC for neat diesel is 12.03 MJ/kWh and for KOME is 12.48 MJ/kWh at full load. BSEC for KOME-ORG blend is 11.16 MJ/kWh which is less compared to diesel and neat KOME at full load. This may be due to lower density and better volatility of KOME-ORG blend compared to neat diesel and KOME resulting in better mixing of fuel and air. The BSEC for KOME-CMO is similar to neat diesel and KOME. BSEC for KOME-EU and KOME-PO are higher compared to other fuels tested.

Emission Characteristics

NO emission: The variation of NO emission for various low carbon biofuel blends with KOME is compared with neat diesel and KOME at part and full load conditions are shown in Fig. 5. Longer ignition delay, higher combustion temperature, availability of oxygen and resident time are major causes of NO emission. At full load, NO emission for neat diesel is 9.06 g/kW-h and neat KOME is 10.25 g/kW-h. Increase in NO emission for neat KOME compared to neat diesel is due to oxygen atoms present in KOME. NO emission for KOME-ORG is 10.35 g/kW-h which is higher compared to neat diesel and KOME. This may be due to low density and better volatility of KOME-ORG blend which resulted in an improvement in premixed combustion. Another probable reason for increase in NO emission for KOME-ORG blend may be due to higher incylinder temperature, hence less heat is released in later part of combustion which reduces the EGT. NO emission for KOME-EU is 9.84 /kW-h, KOME-CMO is 10.30 g/kW-h and KOME-PO is 10.32 g/kW-h at full load condition. NO emission is more for all low carbon biofuel blends with KOME compared to diesel .

Smoke emission: Fig. 6 shows the variation of smoke emission for various biofuel blends with KOME compared to diesel and KOME. At part load, maximum smoke emission is for KOME compared to diesel and other KOME-low carbon biofuel blends due to longer hydrocarbon chain and

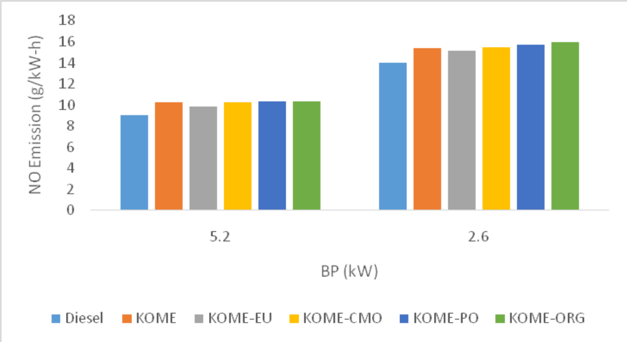

Fig. 5: Variation of NO emission for various blends at full load and part load conditions.

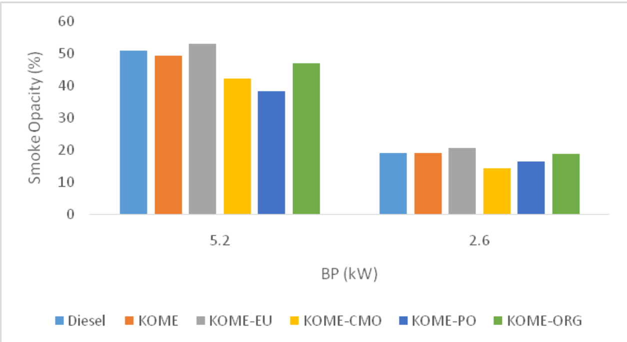

Fig. 6: Variation of smoke emission for various blends at full load and part load conditions.

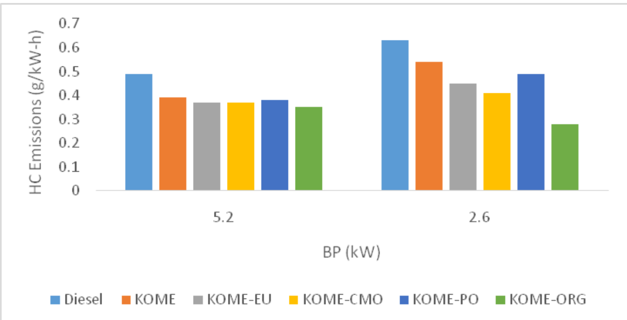

Fig. 7: Variation of HC emissions for various blends at part load and full load conditions.

high viscosity of KOME. At full load, smoke emission for diesel is 51% and KOME is 49.4 %. Reduction in smoke emission for KOME may be due to presence of oxygen atoms in its structure. Smoke emission for KOME-ORG blend is 47% which is less as compared to neat diesel and KOME. This may be due to low viscosity, low density and better volatility of the blend compared to neat diesel and KOME, which resulted in proper atomization and mixture formation. Another possible reason may be due to availability of oxygen atoms and higher incylinder temperature which reduces smoke formation. Minimum smoke emission of 38.2 % is observed for KOME-PO blend, this may be due to low viscosity of pine oil which improves the atomization.

HC emissions: Fig. 7 shows the variation of HC emissions for various low carbon biofuel blends with KOME at part load and full load conditions. At full load, HC emission for diesel is 0.49 g/kW-h which is high compared to 0.39 g/kW-h for KOME. This is due to inherent oxygen availability in KOME which oxidizes HC to CO_2 and H_2O. HC emission is less for all the biofuel blends with KOME compared to diesel and KOME. At full load, HC emissions are 0.37 g/kW-h for KOME-EU blend, 0.37 g/kW-h for KOME-CMO and 0.38 g/kW-h for KOME-PO blend. The minimum HC emissions is found to be 0.35 g/kW-h for KOME-ORG blend. The reason for reduction in HC emission for all low carbon biofuel blends with KOME compared to neat diesel and KOME is due to lower C-H ratio in the molecular structure of the fuel. KOME-ORG is having minimum C-H ratio which may lead to better combustion compared to other low carbon biofuel blends with KOME, hence minimum HC emissions.

Combustion Characteristics

Heat release rate: Fig. 8 shows the variation of heat release rate with crank angle at full load condition for KOME-ORG blend, diesel and KOME. The maximum heat release rate for KOME is less compared to diesel and it is occurring in advance. The maximum heat release rate for diesel fuel is 34 J/°CA and for KOME 30 J/°CA. This is due to the consequence of shorter ignition delay and lower premixed combustion phase of KOME compared to diesel fuel. Higher ignition delay for diesel compared to KOME increases the accumulation of diesel fuel which increases the maximum heat release rate. The occurrence of maximum heat release rate for KOME-ORG is advanced compared to diesel maximum heat release rate point, which is due to shorter ignition delay of the blends.

The maximum heat release rate obtained for KOME-ORG blend is 42.77 J/°CA which is less as compared to diesel but higher than KOME. Heat release at later part of combustion is low for KOME and KOME-ORG blend compared to neat diesel, this may be due to the presence of oxygen atoms which aids in complete combustion of remaining fuels which is not burnt in main combustion phase.

CONCLUSIONS

The effect of low carbon biofuel fuel blending with KOME on CO_2 emissions and its impacts on other performance, emissions and combustion parameters was studied in a single cylinder CI engine and compared with neat diesel and KOME. The following are the major conclusions obtained based on experimental results:

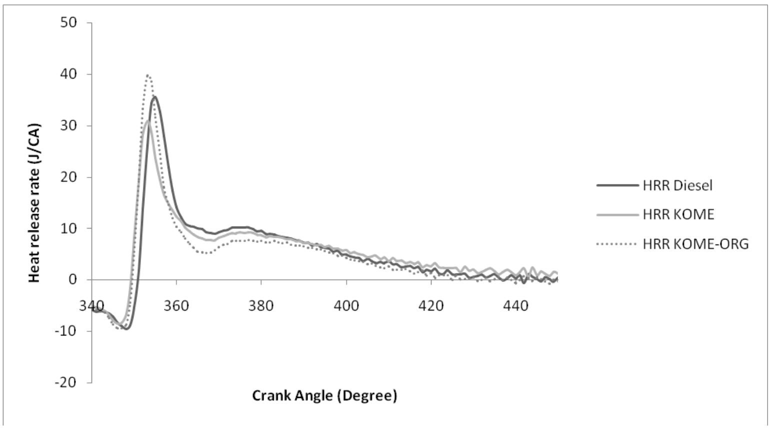

Fig. 8: Variation of heat release rate with crank angle at full load for diesel, KOME and KOME-ORG blend.

1. The maximum CO_2 emission reduction is observed with KOME-ORG when compared to other low carbon biofuel blends with KOME. CO_2 emission for KOME-ORG blend is reduced by 13% and 6% when compared to neat KOME and diesel, respectively. The reduction in CO_2 emission is due to lower carbon atoms present in the blend KOME-ORG compared to other low carbon biofuel blends with KOME.
2. The maximum brake thermal efficiency is observed for KOME-ORG when compared to other low carbon biofuel blends, neat diesel and neat KOME. Brake thermal efficiency of KOME-ORG is 32.66 %, neat diesel is 29.9 % and KOME is 28.8 %.
3. NO emission is higher for KOME compared to diesel due to presence of oxygen atoms. NO emission for KOME-ORG is 4 % higher compared to neat KOME.
4. Smoke emission for KOME-ORG is 22 % less compared to KOME, because of improved combustion.

With higher brake thermal efficiency, reduced CO, HC, smoke, CO_2 emissions and marginally increased NO emission, KOME-ORG blend is considered as optimum blend among other low carbon biofuel blend with KOME for reducing CO_2 emission.

Karanja oil is called as 'second generation fuel' because of its nitrogen fixing capabilities, it can grow in any land with minimum water requirement. Considering well to wheel analysis, negative CO_2 effect of KOME-ORG is -18.3 kg. The eco recycling of karanja oil and orange oil makes it a better fuel for reducing the overall CO_2 sequestration.

REFERENCES

Ahmet, Necati Ozsezen, Mustafa Canakci, Ali Turkcan and Cenk Sayin 2009. Performance and combustion characteristics of a DI diesel engine fueled with waste palm oil and canola oil methyl esters. Fuel, 88(4): 629-636.

An, H., Yang, W.M., Chou, S.K. and Chua, K.J. 2012. Combustion and emissions characteristics of diesel engine fueled by biodiesel at partial load conditions. Applied Energy, 99: 363-371.

Atmanl, Alpaslan, Bedri Yüksel and Erol Ileri 2013. Experimental investigation of the effect of diesel-cotton oil-n-butanol ternary blends on phase stability, engine performance and exhaust emission parameters in a diesel engine. Fuel, 109: 503-511.

Atmanl, Alpaslan, Erol Ileri and Bedri Yuksel 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.

Baiju, B., Naik, M.K. and Das, L.M. 2009. A comparative evaluation of compression ignition engine characteristics using methyl and ethyl esters of Karanja oil. Renewable energy, 34(6): 1616-1621.

Chauhan, Bhupendra Singh, Naveen Kumar, Haeng Muk Cho and Hee Chang Lim 2013. A study on the performance and emission of a diesel engine fueled with Karanja biodiesel and its blends. Energy, 56: 1-7.

Christensen, J. H., Hewitson, B., Busuioc, A., Chen, A., Gao, X., Held, I., Jones, R., Kolli, R. K., Kwon, W.T., Laprise, R., Magaña Rueda, V., Mearns, L., Menéndez, C.G., Räisänen, J., Rinke, A., Sarr, A. and Whetton, P. 2007. Regional climate projections. In: Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change [Solomon, S., Qin, D., Manning, M., Chen, Z., Marquis, M., Averyt, K. B., Tignor, M. and Miller, H. L. (eds)]. Cambridge University Press. Cambridge, United Kingdom and New York, NY, USA.

Coronado, Christian Rodriguez, João Andrade de Carvalho Jr. and José Luz Silveira 2009. Biodiesel CO_2 emissions: a comparison with the main fuels in the Brazilian market. Fuel Processing Technology, 90(2): 204-211.

Devan, P.K. and Mahalakshmi, N.V. 2009a. Performance, emission and combustion characteristics of poon oil and its diesel blends in a DI diesel engine. Fuel, 88(5): 861-867.

Devan, P.K. and Mahalakshmi, N.V. 2009b. A study of the performance, emission and combustion characteristics of a compression ignition engine using methyl ester of paradise oil-Eucalyptus oil blends. Applied Energy, 86(5): 675-680.

Dorado, M.P., Ballesteros, E., Arnal, J.M., Go´mez, J. and Lo´pez, F.J. 2003. Exhaust emissions from a diesel engine fueled with transesterified waste olive oil. Fuel, 82:1311-5.

Hausberger, Stefan 1998. Scenarios for the future energy demand and CO_2-emissions from the global transport sector. SAE Technical Paper, No: 982216, 1998.

Kasiraman, K., Nagalingam, B. and Balakrishnan, M. 2012. Performance, emission and combustion improvements in a direct injection diesel engine using cashew nut shell oil as fuel with camphor oil blending. Energy, 47(1): 116-124.

Lujaji, Frank, Lukács Kristóf, Akos Bereczky and Makame Mbarawa. 2011. Experimental investigation of fuel properties, engine performance, combustion and emissions of blends containing croton oil, butanol, and diesel on a CI engine. Fuel, 90(2): 505-510.

Makoto, Hasegawa, Yoshihito Sakurai, Yoshikazu Kobayashi, Nobuo Oyama, Masanori Sekimoto and Hisashi Watanabe 2007. Effects of fuel properties (content of FAME or GTL) on diesel emissions under various driving modes. SAE Technical Paper, No: 2007-01-4041.

Mofijur, M., Masjuki, H., Kalam, M. A., Hazrat, M. A., Liaquat, A. M. and Shahabuddin, M. et al. 2012. Prospects of biodiesel from jatropha in Malaysia. Renewable and Sustainable Energy Reviews, 16(7): 5007-5020.

Nabi, Nurun Md., Hoque, S.M. and Shamim Akhter. Md. 2009. Karanja (*Pongamia pinnata*) biodiesel production in Bangladesh, characterization of karanja biodiesel and its effect on diesel emissions. Fuel Processing Technology, 90(9): 1080-1086.

Purushothaman, K. and Nagarajan, G. 2009. Performance, emission and combustion characteristics of a compression ignition engine operating on neat orange oil. Renewable Energy, 34(1): 242-245.

Raheman, H. and Phadatare, A.G. 2004. Diesel engine emissions and performance from blends of karanja methyl ester and diesel. Biomass & Bioenergy, 27(4): 393-397.

Sahoo, P.K. and Das, L.M. 2009. Combustion analysis of jatropha, karanja and polanga based biodiesel as fuel in a diesel engine. Fuel, 88(6): 994-999.

Shivkumar, Lohan, Ram, T., Mukesh, S., Ali, M. and Arya, S. 2013. Sustainability of biodiesel production as vehicular fuel in Indian perspective. Renewable and Sustainable Energy Reviews, 25: 251-259.

Srivastava, P.K. and Madhumita Verma 2008. Methyl ester of karanja oil as an alternative renewable source energy. Fuel, 87(8-9): 1673-1677.

Stangeland, Aage 2007. A model for the CO_2 capture potential. International Journal of Greenhouse Gas Control, 1(4): 418-429.

Stern, N. et al. 2007. Stern Review on the Economics of Climate Change. Cambridge, UK: Cambridge University Press.

Suresh Kumar, K., Velraj, R. and Ganesan, R. 2008. Performance and exhaust emission characteristics of a CI engine fueled with *Pongamia pinnata* methyl ester (PPME) and its blends with diesel. Renewable Energy, 33(10): 2294-2302.

Swaminathan, C. and Sarangan, J. 2012. Performance and exhaust emission characteristics of a CI engine fueled with biodiesel (fish oil) with DEE as additive. Biomass and Bio Energy, 39: 168-174.

Tarabet, L., Loubar, K., Lounici, M.S., Khiari, K., Belmrabet, T. and Tazerout, M. 2014. Experimental investigation of DI diesel engine operating with Eucalyptus biodiesel/natural gas under dual fuel mode. Fuel, 133: 129-138.

Thomas, L. Darlington and Dennis Kahlbaum, 2008. Evaluation of California greenhouse gas standards and federal energy independence and security act-part 2: CO_2 and GHG impacts. SAE Technical Paper, No: 2008-01-1853.

Vallinayagam, R., Vedharaj, S., Yang, W.M., Lee, P.S., Chua, K.J.E. and Chou, S.K. 2013. Pine oil-biodiesel blends: A double bio fuel strategy to completely eliminate the use of diesel in a diesel engine. Applied Energy, 130:466-473.

Wagner, Jens, Bernhard Mencher and Stefan Keller, 2008. Bosch system solutions for reduction of CO_2 and emissions. SAE Technical Paper, No: 2008-28-0005.