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A Comparative Evaluation of Biodiesel Blends of Soapnut, Palm, and Karanja for Usage in CI Engine

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Abstract

Soapnut (Sapindus mukorossi) oil, a non edible straight vegetable oil was used to prepare soapnut biodiesel. 20% soapnut biodiesel blended with petrol with petrodiesel and 100% soapnut biodiesel ware used to evaluate performance and emission characteristics of a single cylinder direct injection constant speed diesel engine. These results were compared to the results obtained by using similar blends of palm and karanja biodiesels to establish soapnut oil as a biofuel source and also prove the superiority of soapnut oil as biofuel source compared to both karanja and palm biofuels. Brake thermal efficiency of 20% blends of Soapnut, palm and karanja biodiesel is found to be 28.7%, 28.5% and 28.2% respectively and their brake specific energy consumption is 12.90, 12.95, 13.16 MJ/kW-hr respectively. The results also show that soapnut also has advantages in terms of emissions over palm and karanja biodiesels. Soapnut 20% blend is concluded to a better option among the considered biodiesels and their blends.

Keywords: Soapnut, palm, karanja biodiesels, performance, emissions, diesel engine

INTRODUCTION

The recent interest in the production of energy from biomass has focused primarily on technologies and applications that produce liquid fuels for the use of the transportation industry. Straight vegetable oils and their biodiesels both in pure form and their blends are used as a substitute for diesel fuel and also have become widespread. Their use has the additional advantage of reducing emission of air pollutants, buildup of greenhouse gases and less dependence on fossil fuels. At the same time, the cultivation and harvesting of these biofuel sources have positive impacts on the agricultural and rural economies.

Various oils have been in use in different countries as raw materials for production SVOs and their biodiesels owing to their availability, technical feasibility, and cost of cultivation and production. Soybean oil is commonly used in United States and rapeseed oil is used in many European countries for biodiesel production, whereas, coconut oil and palm oils are used in Malaysia and Indonesia for biodiesel production [1-4]. However, non edible oils are generally preferred as a biodiesel source considering food security. In India and southeast Asia, the Jatropha [5], Karanja [3] and Mahua [2] is used as a significant fuel source. Vegetable oils are triglyceride molecules, in which three fatty acid groups are esters attached to one glycerol molecule [6]. Triglyceride vegetable oils and fats include both edible vegetable oils like palm oil, soy oil, rapeseed oil etc., and inedible vegetable oils and fats such as linseed oil, castor oil, tung oil, jatropa oil, karanja oil etc.

The objective of the present study is to establish Soapnut biodiesel and its blends as a possible CI engine fuel by comparing its engine performance and emission values with already established biodiesels like palm (PB) and karanja (KB). Soapnut biodiesel (SB) is blended with petrodiesel in predefined volumetric basis percentages of 20%, are suitably named as SB20[1], and SB100 and similarly, PB20, PB100 etc and, KB20, KB100 etc.

Characterization of biodiesels and their blends with diesel.

The physico-chemical properties of soapnut, palm and karanja biodiesels, petrodiesel, and their respective blends were determined and the results along with the test procedures are tabulated in Table1. A computerized automatic bomb calorimeter was used to measure the calorific value of various test fuels. The kinematic viscosity of the different blends of soapnut biodiesel with petrodiesel was determined by using a Redwood viscometer. Pensky Marten’s flash point apparatus was used to the determine

[1] SB, soapnut biodiesel; SB20, etc., blend of soapnutbiodiesel10% +diesel 80% etc.; KB – Karanja biodiesel; PB- Palm biodiesel; CO, carbon monoxide; HC, Hydrocarbon; NOx, nitrogen oxide; O2, oxygen; BTE, brake thermal efficiency; BSEC, brake specific energy consumption; A/F ratio, air fuel ratio; kW, kilo Watt; RPM, revolutions/minute; WC, water column; Deg, degree; TDC top dead centre; dead center; BSFC, brake specific fuel consumption; BMEP, brake mean effective pressure.

flash and fire points. The cloud and pour points of the fuel oil sample were determined by a pour and cloud point apparatus.

Performance testing of engine

Short-term engine performance tests for about 50 hrs were carried out on a small size water-cooled diesel engine with petrodiesel, and blends of all three selected biodiesels.

Experimental setup description

The engine setup, as shown in Fig.1, consists of single cylinder, four-stroke, water cooled CI engine having compression ratio of 17.5, constant speed of 1500 rpm, 7 bhp, and eddy current type, water cooled, dynamometer with loading unit. This type of engine is widely used in rural/agricultural applications for running the irrigation pump-sets and small capacity electrical generators. The experimental engine set-up enables study of engine performance for brake power, indicated power, frictional power, brake mean effective pressure, indicated mean effective pressure, brake thermal efficiency, indicated thermal efficiency, mechanical efficiency, volumetric efficiency, specific fuel consumption, A/F ratio and heat balance. Labview based engine performance analysis software "EnginesoftLV"is used for online performance evaluation. Setup is provided with necessary instruments for combustion pressure verses crank-angle measurements. These signals are interfaced to computer through engine for Pφ-PV diagrams. Provision is also made for interfacing airflow, fuel flow, temperatures and load measurement.

Emission testing

The experimental setup for emission measurements includes a gas analyzer and a smoke meter. Engine emissions like CO, CO2, NOx, oxygen, and HC are measured with an AVL five gas analyzer (AVL 444). Smoke opacity is measured using an AVL smoke-meter (AVL 437). The sample is drawn from the exhaust pipe after the gas analyzer sampling pipe.

RESULTS AND DISCUSSIONS

Short-term engine tests were conducted using blends of Soapnut biodiesel with diesel in order to study their effect on engine performance parameters at varying loads of 50%, 85%, and 100%. Based on the fundamental definitions, calculations were made and the CI engine performance parameters such as BSFC, BSEC, BMEP, BTE and volumetric efficiency for petroleum diesel.

Engine performance

Brake Thermal Efficiency

It is observed from Fig.2 that 20% blends all considered biodiesels perform better than their respective 100% biodiesels. The possible reason for this could be additional lubricity provided by the biodiesel and the higher oxygen availability contributing to better combustion. Biodiesels have good lubricating properties and are about 66% better in lubrication than the petrodiesel. A 1% biodiesel would increase the lubricity by 30% [7]. A combination of these two factors probably makes the 20% blends perform better. The petrodiesel has highest BTE of 28.75% and among the biodiesel blends, BTE of SB20 is found to be the highest (28.7%) followed by PB20 (28.5%) and KB20 (28.2%). When SB blends are compared with PB blends, SB blends show better BTE. This may be due to higher CV and CN of PB blends than those SB blends. The possible reason for SB20 blend having higher BTE than PB20 blend may be due to the higher CN of the PB blends. As a result of higher CN, the ignition delay of PB blends is less and hence combustion starts early resulting in higher compression power loss. When SB blends are compared with KB blends, SB blends show better BTE. The possible reason for this could be higher density and viscosity of KB blends than those of SB blends. As a result of this, KB blends have relatively poor spray pattern, air entrapment, less fuel/air mixture resulting in higher diffusion combustion as compared to SB blends. It may be concluded from BTE point of view that for all the tested biodiesel blends, SB20 blend performs better and among the considered biodiesel blends. It is well known that with the increase in blend percentages of biodiesel to 100%, the injection timing is advanced. Again, increasing blends of biodiesels have decreasing ignition delay when compared to petrodiesel. As a result of these, the combustion being initiated much before TDC. This increases compression work and heat loss and finally, resulting in reduction of BTE. Another reason could possibly be due to higher viscosity of the fuel resulting in improper spray pattern and inferior combustion overtaking the lubricity benefits gained. Biodiesel blend of 20% seems to perform better than all other blends at all loads and 100% biodiesel performance being the lowest.

Brake Specific Energy Consumption

BSEC for SB, PB, and KB blends is calculated for varying loads and are plotted in Fig.3. It is observed that BSEC is lower for 20% biodiesel blends and is higher for 100% biodiesels for all the considered biodiesels and all the blends show higher BSEC than that of petrodiesel. Further, BSEC decreases with increase in load up to about 85% loading and then increases up to 100% loading, which is in agreement with the established trend of CI engine. PB20 and KB20 are found to have the lowest BSEC among their corresponding blends. Soapnut biodiesel also follows the same trend. The petrodiesel has the lowest BSEC of 12.53 MJ/kW-hr and among the biodiesel blends, BSEC of SB20 is the lowest (12.90 MJ/kW-hr) followed by PB20 (12.95 MJ/kW-hr) and KB20 (13.16 MJ/kW-hr).

Emission Analysis

The variations of CO, HC, and NOx emissions with respect to the load for various blends of SB, PB, and KB are shown in Fig.4, 5, and 6 respectively. It is observed that with the increase in blend percentage the CO emissions reduce, the same for petrodiesel is the highest. This is possibly because biodiesels contain about 10% oxygen by weight. There will be extra oxygen to react with the fuel during the combustion process facilitating better combustion. Further, biodiesel has a lower carbon to hydrogen ratio. Thus, with less carbon in the fuel, there is a better chance that each carbon atom will find two oxygen atoms to bind to. However, established trends are observed only at higher loading, i.e., 85% and higher. PB100 and KB100 have the lowest CO emissions among the corresponding blends which match with the published literature.

Soapnut biodiesel also follows the same trend. The CO emission of PB100 is the lowest, followed by SB100 and KB100. The CO emission of PB blends is probably lower than SB blends as the start of combustion in PB blends is early. Hence, more time for complete combustion. Whereas the CO emissions of KB blends is higher than SB blends possibly due to their higher viscosity and density. The available literature [8-10] shows that the HC emissions of various types of engines running on biodiesels and their blends result in lesser HC emissions than that run on petrodiesel. Over mixing, also known as over leaning, is a major source of HC emissions. The extent of over leaning is strongly associated with ignition delay as well as with the mixing of air and fuel during this period. Shorter ignition delays can decrease HC emissions. Again, better atomization leads towards complete combustion resulting in improved HC emissions.

Table 1 Physiochemical Properties of soapnut, palm and karanja biodiesels

Property	SB20	SB 100	PB 20	PB 100	KB20	KB100	Petrodiesel
Density, kg/m^3	844	870	842	865	847	877	835
Calorific value, MJ/kg	42.48	38. 24	42. 58	38.61	41.66	38.02	44.62
Kinematic Viscosity @ 40^{0}C	3.17	4.86	3.16	4.64	3.47	5.02	2.83
Flash point, ^{0}C	106	175	94	160	91	152	70
Cloud point, ^{0}C	8.5	13.5	9.5	14	7.8	12.2	6.4
Pour point, ^{0}C	4.0	5.1	5.5	4.5	3.7	5.4	3.0
Cetane index		49.5		55.8		47.5	48

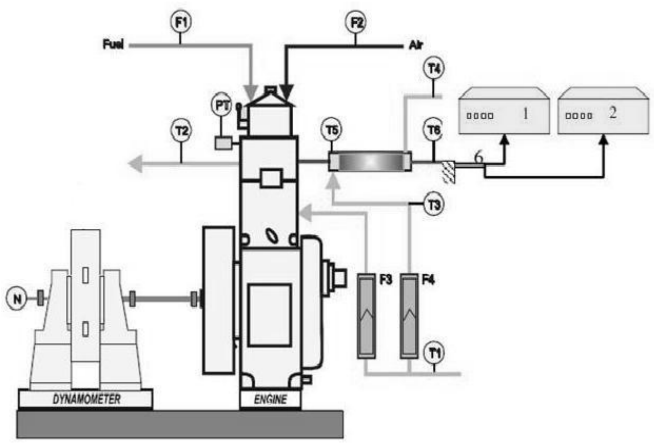

Figure 1. Schematic diagram of experimental set up of engine test rig

F1	Fuel injection pressure sensor	T3	Cooling water inlet temp to calorimeter
F2	Air flow measuring	T4	Cooling water outlet temp from calorimeter
PT	Piezo sensor	T5	Exh . gas inlet temp to calorimeter
N	Rpm pick up &TDC encoder	T6	Exh . gas outlet temp from calorimeter
T1	Cooling water inlet temp to engine	1	AVL 5 gas analyser
T2	Cooling water outlet temp from engine	2	AVL 437 Smoke meter

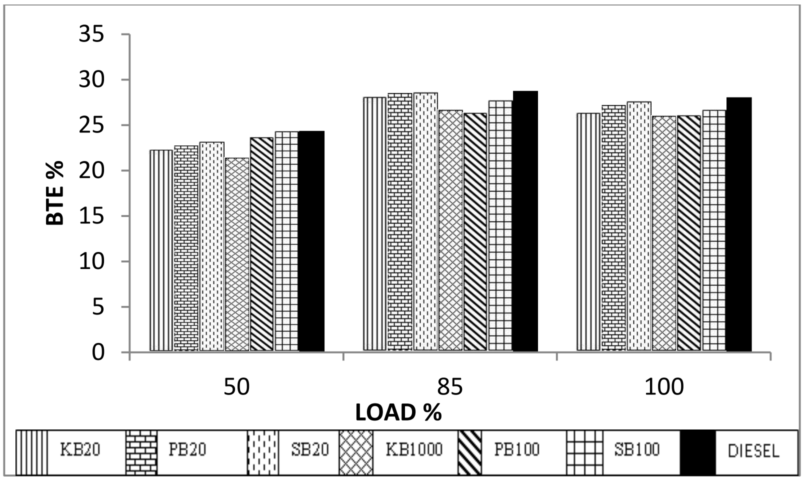

Figure 2 BTE vs. Load for various biodiesel blends.

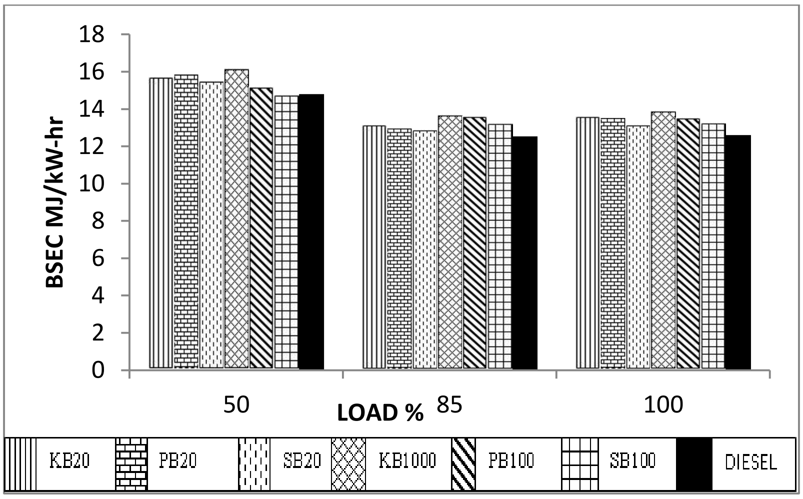

Figure 3 BSEC vs Load for various biodiesel blends.

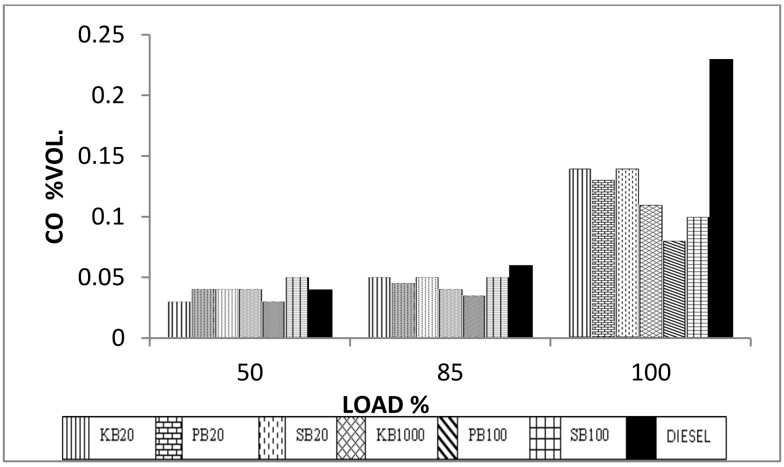

Figure 4 carbon monoxide emissions vs. load for different blends

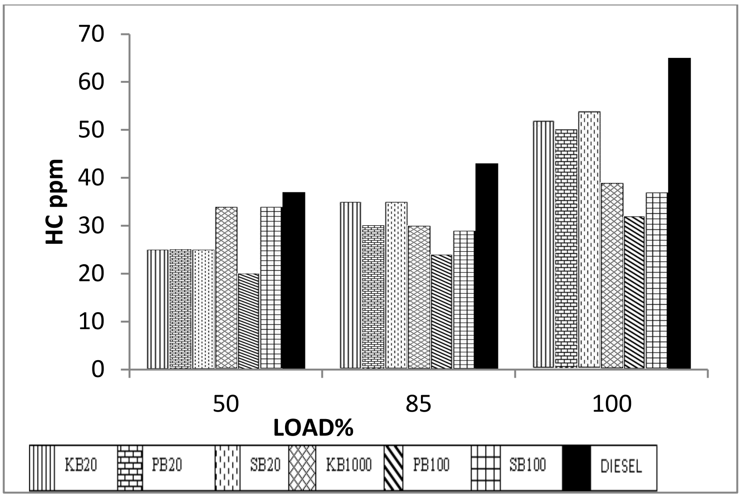

Figure 5 Unburnt hydrocarbon emissions vs. load for different blends

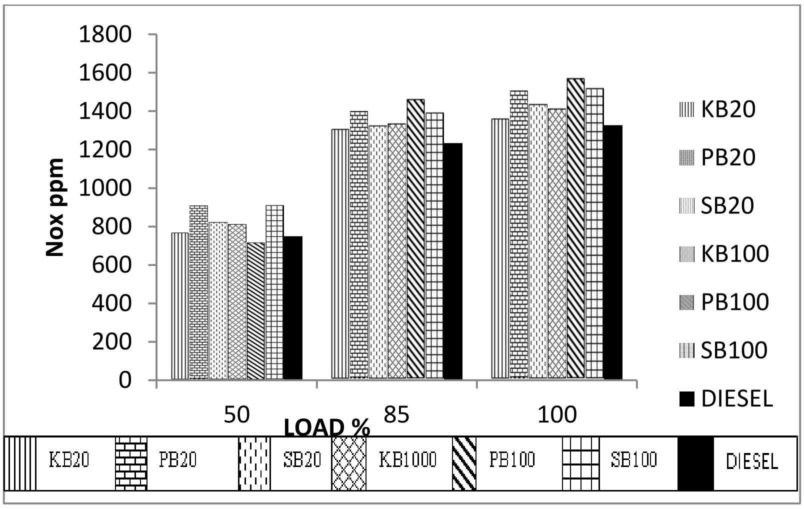

Figure 6. NOx Emissions vs. load for different blends

It is observed that as the biodiesel percentage is increased in the blend, the HC emissions decrease; which may possibly be due to the two factors controlling the magnitude of over leaning as mentioned above. The biodiesel has a higher CN and has 10-11 percent oxygen content by weight, the combination of which reduces ignition delay [11]. However, biodiesel has higher kinematic viscosity and surface tension. The significance of these two properties can be explained in terms of atomization which varies with fuel injection velocity and the Weber number. Higher kinematic viscosity reduces injection velocity of the fuel jet due to increased friction effects. Increased surface tension properties are related to a decrease in Weber numbers. Both lower Weber number and lower injection velocity lead to larger fuel droplets and poor atomization [12]. The lower HC emissions that arose from using 100% biodiesel over 20% biodiesel blend represents the region where biodiesel's oxygen content and higher cetane number contribute greater in reducing HC emissions. It is observed that the HC emissions from lower to higher blends, for all the considered biodiesels, are similar to that of CO variations. The HC emission of PB100 is the lowest, followed by SB100 and KB100.

It is observed from Fig.6 that NOx emissions increase with increase in load and also they increase with increase in percentage of biodiesel in the blend. With the increase in load, the in cylinder temperature is increased and hence, increased NOx emissions. The possible reasons for increasing NOx emissions with biodiesels, compared to that of petrodiesel, could be advancing of injection timing and hence advancing the start of combustion. This may result in a higher peak temperature inside the cylinder which further may increase the rate of NOX production. This also results in a longer residence time, allowing NOX production to continue for more time. This has been confirmed in a study by Szibist and Boehman, who found a linear trend between injection timing and NOX emissions [13]. In addition to the injection timing, ignition delay also affects the combustion timing.

Because biodiesel has a higher CN, it will have a shorter ignition delay, which advances the start of combustion. This results in a significantly longer residence time of higher temperature in the cylinder, causing higher NOX emissions [11]. This result has also been corroborated by Szybist et al. [13]. The NOx emissions of KB20, SB20, and PB20 are higher than that of petrodiesel. Palm biodiesel has highest CN among the considered biodiesels, hence lowest ignition delay. As result of this, the start of combustion is early and hence longer residence time of higher temperature gases in the cylinder. This contributes to the higher NOx emissions. similar explanation may be given for slightly higher NOx emissions of soapnut biodiesel over karanja biodiesel.

Heat Release Analysis

The variation net heat release for SB, PB and KB blends are presented in Figs. 7, 8 and 9 Respectively. It is observed that the peak heat release rate show a decreasing trend with increasing biodiesel percentage in the blend from 20% to 100%. This may be explained from combustion point of view which takes place primarily in two phases: premixed combustion and diffusion combustion. The factors that govern the relative amounts of these two phases of combustion are engine load, injection timing, and CN of the fuel [14]. Increased CN reduces the ignition delay resulting in lesser intense premixed combustion phase [15]. However, the higher heat release rate of petrodiesel is due to the increased accumulation of the fuel during relatively longer delay period. Because of shorter ignition delay, the maximum heat release rate occurs early for biodiesels than when compared with petrodiesel [16]. As a result of improved combustion during the main combustion phase due to the higher oxygen content of the fuel, the heat release rate for biodiesel blends is less during the late combustion phase. The values of peak heat release rates for petrodiesel, SB20, SB100 PB20, PB100, KB20 and KB100 are found to be 84.42, 73.01, 67.33, 72.70, 65.50, 70.86, and 63.50 J/CA respectively, as seen from Figs 7 to 9. The SB blends are preferable over PB blends as they have higher heat release rates. This is probably due to higher CN of PB blends, resulting in early peaking characteristics. When SB blends are compared with KB blends, KB blends have slightly higher diffusion combustion as a result of their higher viscosity. Hence, SB blends are a better choice.

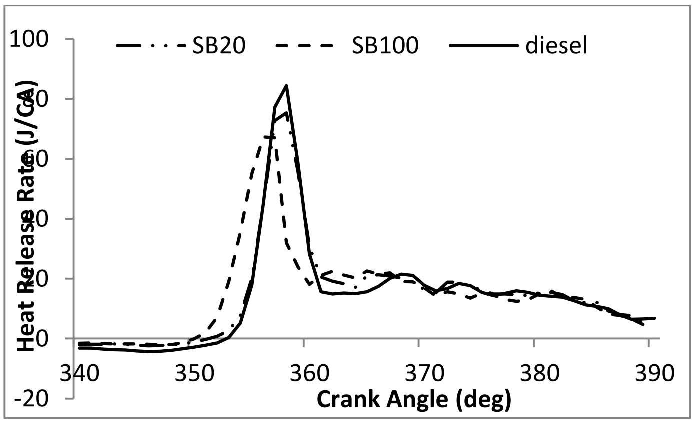

Figure 7. Variation of heat release rate with crank angle at 85% load for SB blends

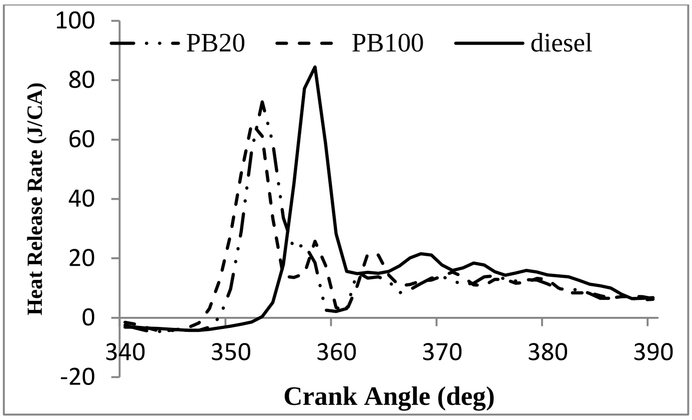

Figure 8. Variation of heat release rate with crank angle at 85% load for PB blends

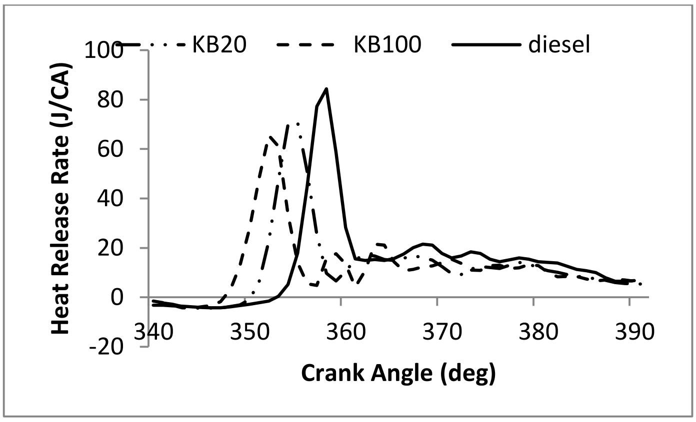

Figure 9. Variation of heat release rate with crank angle at 85% load for KB blends

CONCLUSIONS

It has been found that the SB20 blend performed better than PB20 blend in terms of BTE and BSEC. The NOx emission of SB20 blend is found to be the lower than PB20 blend, but the HC and CO emissions of SB20 blend are higher than PB20 blend. The palm oil being edible, the SB20 blend is preferred over PB20. The SB20 blend is preferred over the KB20 as its BTE and BSEC are better and the HC and CO emissions are lower than KB20 blend. However, the NOx emissions of SB20 blend is higher than KB20 blend. Hence, the SB20 blend is concluded to be a better choice over PB20 and KB20 blends.

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