Turkish Journal of Computer and Mathematics Education Vol.12 No.12 (2021), 1226-1232

Research Article

Emission studies on a direct injection diesel engine fueled with Karanja biodiesel using dimethyl carbonate as additive

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Article History: Received: 11 January 2021; Revised: 12 February 2021; Accepted: 27 March 2021; Published online: 23 May 2021

Abstract: The increasing demand for fossil fuel owing to rapid growth in civilization, industries, automobiles etc., not only deplete the conventional energy sources, but also responsible for the global climate change. In this context, biofuels in recent years have emerged as potential substitute for various conventional fuels. There are growing opportunities for the development and application of biodiesel as a promising substitute in automotive engines. The key objective of the current study is to make a comparative analysis of the performance and emissions of biodiesel synthesized from non-edible Karanja oil with an additive in a conventional diesel engine while comparing the findings with results of diesel fuel. Major physio-chemical properties of Karanja oil were experimentally evaluated after transesterification and it was found within permissible range of relevant standards. The present study primarily dealt with the key emission parameters, viz. CO, HC, NO_x and smoke emissions of a diesel engine fueled with Karanja biodiesel (KBD) using dimethyl carbonate (DMC) as an additive. The study revealed that use of DMC in KBD improves fuel properties and lowers the key emission parameters. Thus, the present work establishes the use of DMC as a suitable additive to diesel and biodiesel fuel in a diesel engine without engine modifications.

Keywords: Karanja biodiesel, transesterification, dimethyl carbonate, engine performance, NO_x emissions.

1. Introduction

Socio-economic growth and development of nation depend on energy production and its utilization. The transport sector, which is the backbone of every country, is the major consumer of energy. The increased energy demand in transport and industrial sector is fulfilled by more than half of the petroleum products. However, as the fossil fuel pools are gradually depleting, the advanced alternative fuels are projected to meet the energy crisis in future **(Appavu.P.2018)**. Amongst alternative fuels, biogas, alcohol and biodiesel are promising and encouraging fuels. As biodiesel owes the comparable properties with non-renewable fossil fuels and, shows a remarkable reduction of the emissions (HC and CO) due to some superior properties such as flash point, oxygen content and cetane number to those of petroleum-based diesel fuel **(Balan.K.N. et al.,2018 & Bharathiraja.B. et al.,2017)**. Neat biodiesel has low brake thermal efficiency (BTE) because of lower calorific value, which can be improved by blending of biodiesel with diesel **(Damodharan.D. et al.,2017)**. Commercialisation of biodiesel has some limitations due to nitrogen oxides (NO_x) emissions, poor oxidation stability as well as cold flow properties that can be set by using different types of additives, such as ignition enhancer (IE) and higher alcohols (HA) **(Rounce.P. et al.,2010)**. From investigation 20% and 10% of dimethyl carbonate (DMC) in almond biodiesel in an engine which maintains constant speed. Results of the Investigation revealed that the post-addition of DMC to almond biodiesel increased the BTE and decreased brake specific fuel consumption and all the exhaust emissions of biodiesel **(Devaraj.A. et al.,2018)**. There are so many sources of biodiesel such as Mahua, Jatropha and Karanja. Literally, Karanja seeds are considered as waste with high energy content and cheap in cost and plentily available in local market. It attracts the eyes of researcher to focus on it as the calorific value of Karanja seeds are high and make it as a potential source of biodiesel. The higher viscosity and density restrict the usage as blended fuel. The physicochemical properties including ignition property of Karanja biodiesel (KBD) can be enhanced by mixing it with DMC and HA (1-Pentadecanol). DMC additives are mixed at 10% volume with equal blends of biodiesel and diesel to improve the performance and to alter the combustion and emission pattern of the diesel engine. It is reported that Karanja oil can be a suitable substitute to fossil diesel. On experimentation, it is revealed that diesel engines running with 20% blend of biodiesel shows improved performance with reduced emissions compared to diesel fuel **(Bai.R. et al.,2011)**. This paper investigates the effect of DMC additive with KBD on the primary emissions of a diesel engine.

2. Materials and Methods

The present section enumerates different raw materials used in the current experimental study, production methodology of KBD from neat Karanja oil, fuel blend preparation, detailed fuel composition and fuel characterization and engine experimentation.

2.1. Karanja (Pongamia Pinnata) Oil

Karanja oil is usually obtained from the seeds of Karanja tree. It is an average sized evergreen tree that grows to a height of 8m but can be grown up to 15-25 m having a maximum life-span of 10-30 years and it produces fruits until 50-60 years. It is seen in mostly tropical region. In India, it is mostly found in rural areas. Each individual tree produces around 1000 kg of seeds per annum. The usual Karanja oil production is 1,35,000 million tons per annum. The colour of the raw Karanja oil is a thick yellow-orange to brown. The free fatty acid (FFA) chemical composition of Karanja oil is demonstrated in the Table 1. Commonly, the neat oil is comprised of 35-40 mg/gm acid value having 18% FFA that is greater than 1%. Hence, it is essential to process the oil using base-catalyzed transesterification to lessen its acid value **(Babu.A.V. et al.,2009)**.

TABLE. 1. Free fatty acid composition in Karanja oil **(Nayak.S.K. et al.,2017)**.

Fatty acid	Molecular formula	Carbon Number	% Composition
Lignoceric	$C_{24}H_{48}O_2$	24	1.0
Eicosanoic	$C_{20}H_{40}O_2$	20	1.1
Linolenic acid	$C_{18}H_{30}O_2$	18	2.6
Behenic acid	$C_{22}H_{44}O_2$	22	4.3
Linoleic acid	$C_{18}H_{32}O_2$	18	16.0
Arachidic acid	$C_{20}H_{40}O_2$	20	1.7
Oleic acid	$C_{18}H_{34}O_2$	18	51-52
Palmitic acid	$C_{16}H_{32}O_2$	16	11-12
Stearic acid	$C_{18}H_{36}O_2$	18	7.8

2.2. Di-methyl Carbonate (DMC)

Addition of DMC as a blend in BD increases the BTE and reduces the carcinogenic emission such as benzene and 1,3-Butadiene and particulate matter, HCs and carbon dioxide. The chemical structure of DMC ($C_3H_6O_3$) is shown in Fig. 1. It is nontoxic, transparent colourless flammable liquid by nature at room temperature. It is known as carbonate ester and found its application as methylating green reagent. Some properties of DMC are expressed is given in Table 2.

Figure. 1 Structure of DMC **(Rounce.P. et al.,2010)**.

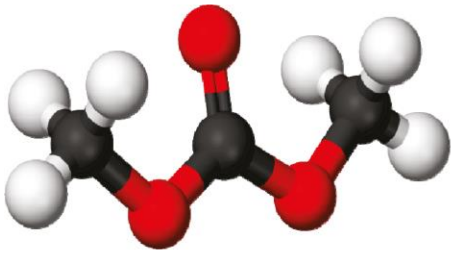


TABLE. 2. Properties of DMC **(Kim & Lee 2017)**.

Description	**Particulars**
Chemical formula	$C_3H_6O_3$
Appearance	Clear
Molar mass	90.08 g/mol
Density	1.07-1.074 g/ml
Boiling point	90°C (194° F)
Melting point	3-4°C (275-277K)
Flash point	18°C

2.3. Transesterification of Karanja oil

The present work includes preparation of Karanja methyl ester or Karanja biodiesel (KBD) from raw Karanja oil. KBD was prepared from raw Karanja oil, which was procured from the local market. A five-litre capacity biodiesel reactor was employed for the production of KBD. Initially one litre KO was fed in to reactor followed by addition of 20% v/v of reagent mixture (CH_3OH+KOH) with continuous stirring for 5-10 minutes. The temperature of the reactor was slowly increased up to 60°C. At this temperature, the transesterification reaction was performed for 90 minutes. After the reaction is over, the products were allowed to settle down for 6 hours. After completion of the settling time, glycerol was separated through the bottom release valve followed by separation of neat KBD in a clean and dried storing container. Then the obtained KBD was processed for moisture removal to get the final biodiesel to be used in engine experimentations.

2.4. Test Fuel Blend Preparation and Characterization

Different fuel blends were formulated by combination of KBD and DMC in several volume fractions. In this work diesel, B100, B95 and B90 were used as test fuels, where B90 represents 90% KBD and 10% DMC. Likewise, B95 represents 95% KBD with 5% DMC and B100 represents KBD without additive. Diesel was used as the baseline fuel during the experimentation. Various fuel properties were evaluated using standard ASTM procedures and are presented in Table 3.

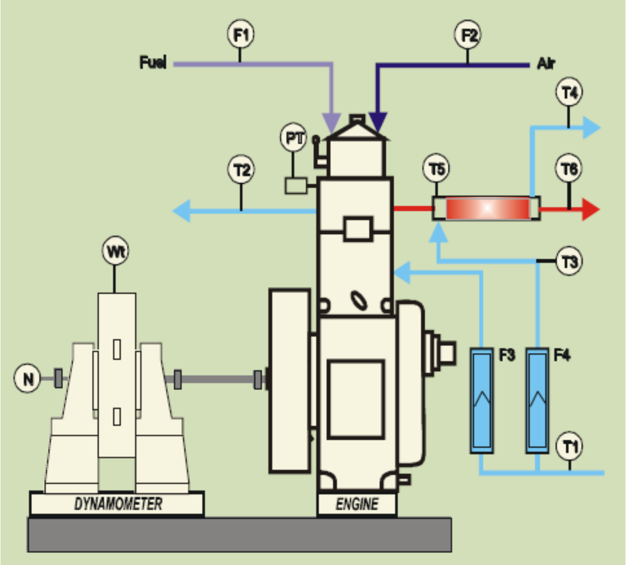
TABLE. 3. Test fuel properties.

Fuel Property	**Diesel**	**B100**	**B95**	**B90**
Density at 20°C, kg/m^3	835	844	841	832
Kinematic viscosity at 40°C, cSt	2.67	4.92	4.28	4.05
Flash point, °C	71	176	165	156
Calorific value, MJ/kg	44.58	41.1	41.2	43.8
Cloud point, °C	6.6	11.2	10.7	10.1
Pour point, °C	3.2	5.7	5.1	4.4
Cetane index	49	50.8	53.2	54.4
Ash content, %	0.001	0.0072	0.0067	0.0061

2.5. Engine Experimentation

A single-cylinder four-stroke direct injection water-cooled diesel engine was used in this work using the above formulated test fuels to investigate the behavior of the prepared biofuels and their blends. The rated power of the engine was 5.2 kW at 1500 rpm. The data encoding and handling was used through Enginesoft LV software installed in a computer connected to the engine data encoder. AVL Digas 444 and AVL Smokemeter was used for analysis of the exhaust emissions. Experiments were performed on the above engine test setup under different loading conditions between 25% load up to rated load. An eddy current dynamometer was used to apply loads on the test engine. All the observations were repeated three times in order to ensure correctness of the readings. Figure 2 shows the test engine setup used in the present experimentation.

Figure. 2 Experimental engine setup.



F1: Fuel injection pressure sensor F2: Airflow measuring, T1: Cooling water inlet temperature to engine and calorimeter, T2: Cooling water outlet temperature from engine, T3: Cooling water inlet temperature to calorimeter, T4: Cooling water outlet temperature from calorimeter, T5: Exhaust gas inlet temperature to calorimeter, PT: Piezo sensor, N: rpm pick up and TDC encoder.

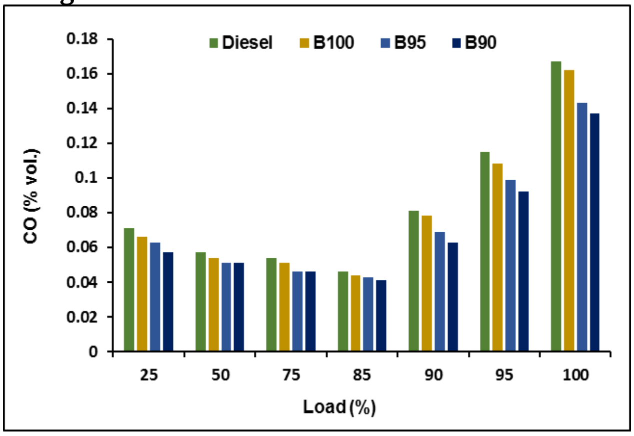
3. Results and Discussion

Results were achieved following the above-mentioned experimental procedure for all considered test fuels. The primary emissions of the test engine, viz. CO, HC, NO_x and smoke were investigated with all the test fuels and are discussed in the below sections.

3.1. CO Emissions

The variation of CO emissions with load for all the test fuels are presented in Fig. 3. It is detected that CO emissions decline with rise in load up to 85% load and then sharply increases until full load for all test fuels. The same may be due to incomplete combustion at higher loads leading to higher CO emissions. Again, increase in DME percentage exhibited lower CO emissions at all loads. This may be because of greater calorific value and cetane index of B95 and B90 that led to improved combustion and lower CO emissions **(Pattanaik.B.P. et al.,2021)**. Lowest CO emissions were observed for B90 at all loads. At full load, the CO emissions with B90 was found to be 15% and 18% lower compared to B100 and diesel, respectively.

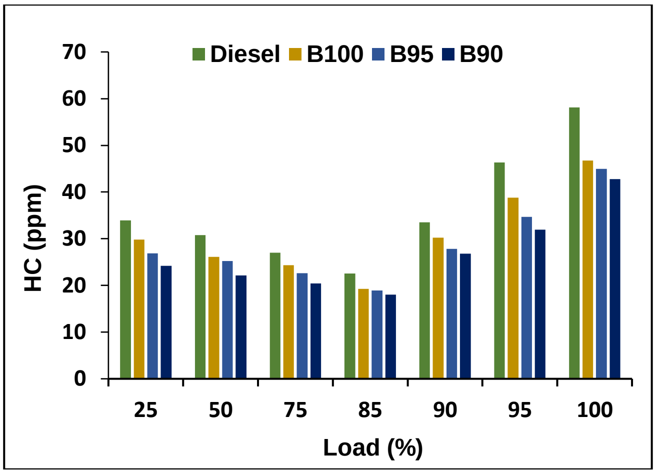
Figure. 3 Variation of CO emissions with load.



3.2. HC Emissions

Figure 4 shows the deviation of HC emissions with load for all selected fuels. It was noted that HC emissions are lowest at 85% load and then sharply increases. This may be attributed to incomplete combustion at higher loads due to less availability of oxygen and higher injection pressures **(Nayak & Pattanaik 2014)**. HC emissions with diesel was found to be highest at all loads. The same are lowest for B90 at all loads. At full load, the HC emissions with B90 was observed to be lower by 8.5% and 26.4% respectively, compared to B100 and diesel. This may be owing to the greater cetane index and calorific value of B90 compared to other fuels that led to enhanced combustion and reduced HC emissions **(Nayak.C. et al.,2014)**.

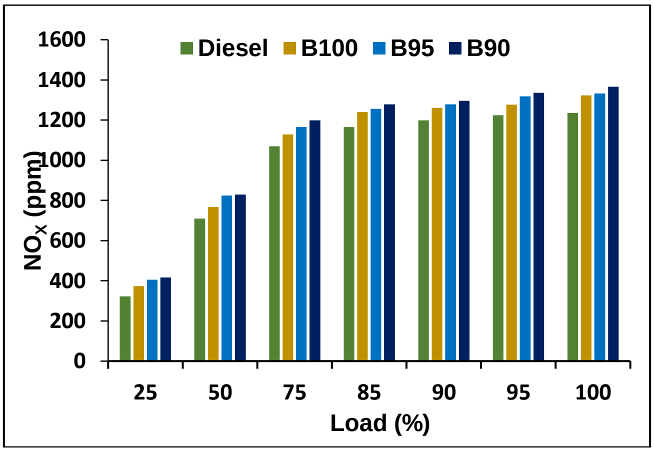
Figure. 4 Variation of HC emissions with load.



3.3. NO_X Emissions

The behavior of NO_x emissions with load for all the test fuels are presented in Fig. 5. Results revealed that NO_x emissions rise with increase in engine load and highest at full load for all the test fuels. The same is in agreement with the published literature **(Pattanaik & Misra 2017)**. However, the same was found to be lowest with diesel and highest with B90 at all loads. It was observed that B90 exhibited 3.3% and 10% higher NO_x emissions compared to B100 and diesel respectively, at full load. This shows increased NO_x emissions with use of DMC. The same may be due to the enhanced cetane index and calorific value of the blends with use of DMC. Another reason to this may be the higher oxygen content of biodiesels that led to increased NO_x emissions **(Pattanaik.B.P. et al.,2017; Pattanaik & Misra 2018)**.

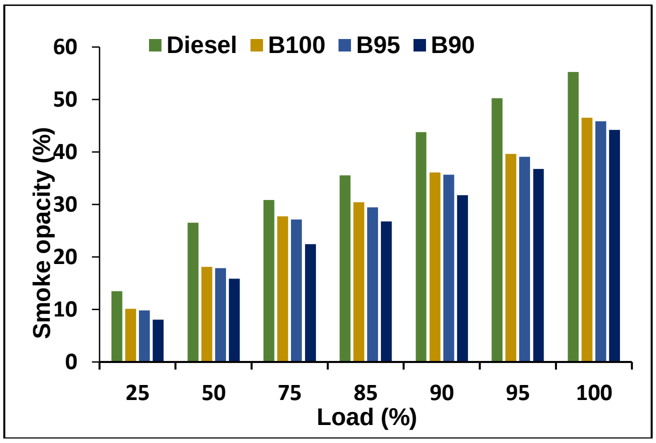
Figure. 5 Variation of NO_x emissions with load.



3.4. Smoke Opacity

Figure 6 presents the deviations of smoke opacity with engine load for all selected fuels. It is detected that smoke opacity rises with increase in engine load and is highest for diesel at all loads. Again, the same decreases with upsurge in DMC fraction in the blends. This shows better combustion in presence of DMC in the blends owing to its greater cetane index and calorific value **(Nayak & Pattanaik 2014)**. The smoke opacity was found to be lowest with B90, in comparison to all other selected test fuels. At full load, B90 produced 5% and 20% lower smoke opacity compared to B100 and diesel, respectively.

Figure. 6 Variation of smoke opacity with load.



4. Conclusions

The present experimental investigation shows that DMC can be successfully used as an additive to biodiesel fuels in a diesel engine. Use of DMC as an additive enhances the fuel properties as well as lowers key emission parameters, such as CO, HC and smoke opacity. However, the NO_x emissions tend to increase to a little extent with the use of DMC additive. Apart from this, DMC as an additive was found to be successful in diesel engine, especially in lowering the exhaust emissions. Further research may be carried out to lower the NO_x emissions of a diesel engine using DMC additives along with conventional and biodiesel fuels.

Acknowledgement

The authors express their sincere thanks to the management of KMBB College of Engineering and Technology, Bhubaneswar for extending their valuable support in carrying out the present research. The authors also extend their gratitude to Prof. R. D. Misra, Department of Mechanical Engineering, NIT Silchar, India and Prof. G. R. K. Sastry, Department of Mechanical Engineering, NIT Andhra Pradesh, India for their valuable guidance in the present research.

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