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EFFECT OF SATURATED FATTY ACID COMPOSITION OF BIODIESEL ON OXIDES OF NITROGEN AND SMOKE EMISSIONS

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ABSTRACT

This study examine the effect of saturated fatty acid content on compression ignition engine performance and emissions. Mixtures of saturated fatty acids with a content of 55 %, 65 %, and 75 % using diesel fuel were evaluated in comparison. For each mixture, different proportions of methyl esters of palm, coconut, neem, mahua, jatropha, and pongamia oil (PONOME) were mixed. At 55 % saturation, the density of fatty acids was 878 - 885, and at 65 % saturation - 869 - 879. At 75 % saturation with fatty acids, the density was 860 - 868. It was found that the viscosity at 65% saturation is 5.04 - 5.37, whereas at 55 % saturation it is 5.13 - 5.56, and at 75 % saturation the viscosity is 4.55 - 7.88. At 75 % saturation, a higher cetane number of 57 - 61 was found. The study showed that all eleven combinations of biodiesel are unique, have excellent fuel characteristics, and emit fewer toxic emissions. It was found that as the percentage of biodiesel saturation increased, NO_x emissions decreased and smoke emissions increased.

Keywords: *engines, exhaust emissions, fatty acid esters, unsaturated double bonds.*

INTRODUCTION

Biodiesel is a liquid fuel based on fatty acid esters [1, 2]. It is known that traditionally biodiesel is used in those countries where it is necessary to have an alternative to conventional, classic diesel fuel, for example, in many countries of the European Union. In countries such as the USA, Canada, Argentina, Brazil, Chile, the Philippines, and some other countries, biological fuel is added to conventional diesel fuel to make it cheaper [3, 4]. The prospects for the development of biofuel production in the world depend on many factors, in particular, the price of oil, the availability of cheap livestock feed, government support, and a technological breakthrough that will help reduce prices for second-generation biofuels, competition from non-traditional fuels alternative to fossil fuels [5, 6]. The volume of biofuel production worldwide has grown sharply, and over the next decade, thanks to significant public investments, as stated in the published report of the Organization for Economic Cooperation and Development (OECD) and the United Nations Food and Agriculture Organization (FAO), its growth will be even greater [7].

The main used motor fuel in India is diesel, so the demand for this fuel is the main indicator of the state of the country's economy. India has a powerful oil refining complex, but the demand for oil for more than 80 % is met by imports. To meet the needs of the country's refineries for raw materials, Indian companies participate in many oil production projects abroad. India is the third-largest importer of oil in the world [3, 4, 8]. More than two-thirds of all energy used in India is obtained through the use of coal, and this gives more than three-quarters of carbon dioxide emissions from the total amount of its emissions into the atmosphere of India. The increasing demand for energy resources and India's commitments to reduce CO_2 emissions under the Kyoto Protocol to which the country has joined, encourage Indian researchers and inventors to intensively search for new energy sources, cheaper, safer and renewable [9 - 11]. Thus, the need to switch to alternative energy sources is dictated not only by the rise in the cost of fossil energy resources but also by the country's obligations to reduce the threat of global climate change. The possibility of obtaining alternative fuels based on the processing of plant raw materials is currently considered one of the most likely ways to solve this global problem [12]. India has virtually unlimited natural resources (forest and herbaceous vegetation, seaweed), and there is no doubt that the country has a certain scientific potential and can organize the production of biofuels without compromising its food production program. According to The Economic Times, Indian state oil sales and refining companies Indian Oil, Bharat Petroleum, and Hindustan Petroleum have started a program to purchase biodiesel synthesized from used vegetable oil in 100 cities across India. The program was officially approved by the Minister of Oil and Natural Gas Dharmendra Pradhan [3, 4, 13].

Diesel fuel consists of hydrocarbon (HC) molecules of various lengths and shapes and does not contain oxygen atoms. Vegetable oils mainly consist of triglycerides with a complex branched molecular structure [14]. As a result, compared with the classic diesel fuel, vegetable oils have a higher viscosity. Vegetable oils have a higher content of oxygen than diesel fuel, which ultimately increases fuel economy. The presence of oxygen on the other hand, reduces the calorific value and as a result, vegetable oils have a lower calorific value than diesel fuel [15 - 17]. According to the literature [1 - 4, 18 - 20], the composition of fatty acids affects the density, viscosity, and cetane number of biodiesel. Analysis of scientific and patent literature shows that biodiesel contributes to the formation of higher NO_x emissions and lower emissions of hydrocarbons and smoke. Whereas if biodiesel is used instead of conventional diesel fuel, the thermal efficiency of the brakes is comparable. The number of research papers describing the effect of saturated fatty acids in biodiesel on diesel engine performance and emissions is very limited.

The purpose of this work is to study the effect of saturated fatty acids in biodiesel fuel on fuel properties: combustion characteristics, performance, and emissions in a compression ignition engine. For current tests, biodiesel fuel with saturation levels of 55 %, 65 %, and 75 % was taken in an engine with a power of 5.2 kW, 1500 rpm at full load.

EXPERIMENTAL

The fuels employed in this experimental investigation are represented by the following abbreviations: POME - Palm oil methyl ester, COME - Coconut oil methyl ester, NOME - Neem oil methyl ester, MOME - Mahua oil methyl ester, JOME - Jatropha oil methyl ester, PONOME -Pongamia oil methyl ester, SOME - Sunflower oil methyl ester, COTOME - Coconut oil methyl ester. For vegetable oil methyl esters, short versions are utilized throughout the results and discussion. 55 % POME + 45 % NOME, for example, is the abbreviated form for a blend of 55 % Palm oil methyl ester and 45 % Neem oil methyl ester.

The structure, cetane number, and molecular mass of different fatty acids are shown in Table 1. Stearic acid has the highest cetane number, followed by lauric acid, palmitic acid, and myristic acid. Oleic acid has the greatest cetane number of 56 among unsaturated fatty acids. It is also lower than the cetane number of saturated fatty acids usually found with biodiesel fuels. The total number of carbon atoms in a fatty acid's molecular structure increases its molecular mass [3, 21 - 23].

The experimental technique and equipment are described in our previous articles [6, 16, 21 - 23]. The

Table 1. Structural formula, cetane number and molecular weight of fatty acids present in biodiesels.

No	Acid chain and its structure	Cetane Number	Molecular mass, $g\ mol^{-1}$
1	Caprylic, (C8:0), $CH_3(CH_2)_6COOH$	34	144
2	Capric, (C10:0), $CH_3(CH_2)_8COOH$	46	172
3	Lauric, (C12:0), $CH_3(CH_2)_{10}COOH$	62	214
4	Myristic, (C14:0), $CH_3(CH_2)_{12}COOH$	74	242
5	Palmitic, (C16:0), $CH_3(CH_2)_{14}COOH$	75	270
6	Palmitoleic, (C16:1), $CH_3(CH_2)_5CH=CH(CH_2)_7COOH$	45	254
7	Stearic, (C18:0), $CH_3(CH_2)_{16}COOH$	76	298
8	Oleic, (C18:1), $CH_3(CH_2)_7CH=CH(CH_2)_7COOH$	56	296
9	Linoleic, (C18:2), $CH_3(CH_2)_4CH=CHCH_2CH=CH(CH_2)_7COOH$	38	294
10	Linolenic, (C18:3) $CH_3CH_2CH=CHCH_2CH=CHCH_2CH=CH(CH_2)_7COOH$	28	292
11	Arachidic, (C20:0), $CH_3(CH_2)_{18}COOH$	54	312
12	Eicosenoic, (C20:1), $CH_3(CH_2)_7CH=CH(CH_2)_9COOH$	32	310
13	Behenic, (C22:0), $CH_3(CH_2)_{20}COOH$	56	340
14	Erucic, (C22:1), $CH_3(CH_2)_7CH=CH(CH_2)_{11}COOH$	30	338

performance, combustion, and emission properties of vegetable oil esters with various saturated fatty acid compositions were investigated and discussed in this study. The examination of brake-specific energy consumption, brake thermal efficiency, exhaust gas temperature, and emissions, which include nitrogen oxides, hydrocarbons, carbon monoxide, carbon dioxide, and smoke, are among the experimental research. The Cylinder's peak pressure and rate of heat release and also many other combustion characteristics were investigated. The combustion, emission, and performance characteristics of employing vegetable oil esters with varying saturation levels are considered, as well as qualities like the number of cetanes, value of heat, viscosity, the density of fuel, iodine value, and saponification value.

The specific gravity of biodiesel is between 0.88 and 0.95, whereas diesel fuel has a specific gravity of 0.85. Biodiesel contains between 8 % and 11 % oxygen by weight, which accounts for its lower heating value and low emissions of soot, particle, carbon monoxide, and hydrocarbons. Biodiesel has a lower energy content of about 10 %. The heating value of bio-diesel or a bio-diesel blend influences fuel efficiency, power, and torque [23 - 26]. It is well known that the air motion and spray properties of the fuel are the primary determinants of the diesel engine's combustion. The diesel engine's performance is influenced by parameters like heat release, ignition delay, heat release, and pressure rise rate [21 - 24].

To assess the engine's performance, exhaust, and combustion characteristics, initial tests were done with diesel at rated speed and in various load situations. To investigate the engine's performance, emission, and combustion characteristics, tests were done using biodiesels with saturation levels of 55 %, 65 %, and 75 % with standard injection timing (23.4°b TDC).

RESULTS AND DISCUSSION

The fuels with 55 % and 65 % saturation levels are primarily generated from Palm oil and Pongamia oil methyl esters. Palmitic acid (16:0), stearic acid (18:0), oleic acid (18:1), and linoleic acid are the most common acids found in these fuels. Coconut oil methyl esters are the main source of fuels with a saturation level of 75 %. Lauric acid (12:0), myristic acid (14:0), and palmitic acid (16:0) are the most common acids found in these fuels [3, 4, 12, 22, 24].

Density of fuel

Fig. 1 depicts the density of biodiesel fuels utilized in the performance investigation. Fuels with 55 % and 65 % saturation levels have densities ranging from 815 to 840 kg m^{-3}, while fuels with 75 % saturation levels have densities ranging from 820 to 830 kg m^{-3}. When pongamia oil methyl esters and coconut oil esters are used in biodiesel fuels with 55 % and 65 % saturation levels, they have a lower density than fuels with palm oil methyl mixes. Because of the inclusion of myristic acid and lauric acid in their composition, they have a reduced density [25]. Lauric and myristic acids have a lower molecular mass than other acids (Table 1). Due to the high density of palm oil methyl blends, they may have a greater amount of fuel within the combustion chamber for the same volume and injection pressure.

Fuel viscosity

Various biodiesel fuel viscosity is depicted in Fig. 2. Fuels made from palm oil have a high viscosity, while

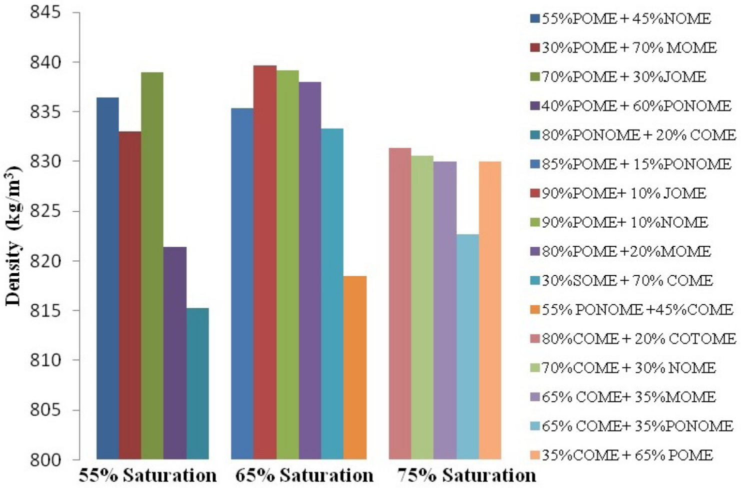

Fig. 1. Comparison of density of vegetable oil esters.

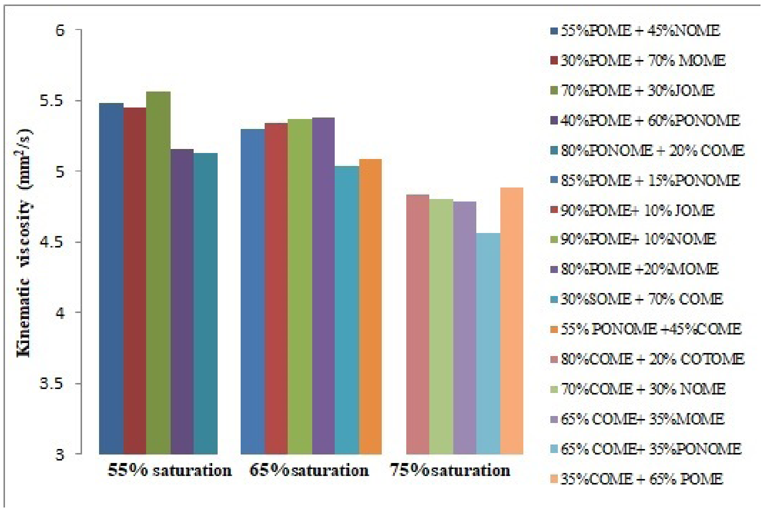

Fig. 2. Kinematic viscosity comparison of vegetable oil esters.

fuels made from coconut oil esters have a lower viscosity. At 40°C, the viscosity of fuels with a 55 % saturation level ranges from 5.13 to 5.56 centistokes, whereas the viscosity of fuels with a 65 % saturation level ranges from 5 to 5.3 centistokes. Fuel viscosity decreases as saturation levels rise. Fuel injection properties and atomization influence fuel's higher viscosity. Due to high viscosity, the spray cone angle and penetration are reduced, resulting in larger fuel droplets [11, 16, 22]. Due to insufficient fuel atomization, combustion efficiency suffers. It also influences the fuel flow rate, resulting in insufficient fueling of the engine at low loads.

Cetane number

Cetane number is a widely used and recognized indicator of the ignition quality of compression ignition fuel. Biodiesel's cetane number varies depending on the fatty acid mixture, saturation level, and chain length. With a raise in saturated fatty acids and a longer chain length, the number of cetane rises. Fig. 3 illustrates a comparison of the cetane number of different biodiesel fuels. The amount of cetane molecules increases as saturation increases [26]. For fuels with a 55 % saturation level, the number of cetane ranges between 52 and 56, while for fuels with a 65 % saturation level, the number of cetane ranges between 53 and 57.

Fuels with a 75 % saturation level have higher cetane numbers, which range from 57 to 61. When compared to palm oil methyl esters, the number of cetane of coconut oil methyl esters has been slightly larger. The maximum cetane number for the fuel 80 % COME + 20% COTOME (fuel with 75 % saturation level) is 61. The cetane number rises in proportion to the length of the carbon chain. Palm oil-based biodiesel fuels have a higher proportion of unsaturated fatty acids such as oleic acid and linoleic acid. The cetane number of palm oil-based biodiesel fuels is lower due to the existence of unsaturated fatty acids. Palmitic acid has a cetane number of 75, while palmitoleic acid has a cetane number of 45 [3, 27].

Heating value

The value of heating of a fuel is an important metric for determining how much energy it releases. The energy released by fuel combustion is converted into useful work. Fig. 4 shows the heating values of biodiesel fuels [28]. The average heating values of biodiesel based on pongamia oil methyl esters (38.5 MJ kg^{-1}) are lower than those of biodiesel based on coconut oil (39.5 MJ kg^{-1}) and palm oil (40.3 MJ kg^{-1}).

Iodine Value

The iodine value of a fuel is used to determine the degree of unsaturation. The degree to which fuel is unsaturated is directly related to its iodine content. The iodine value of biodiesel fuels is depicted in Fig. 5.

Carbon-carbon double bonds become more prevalent when iodine value increases. Because of the high degree of unsaturation, the higher value of iodine value shows that lipid is more susceptible to oxidative

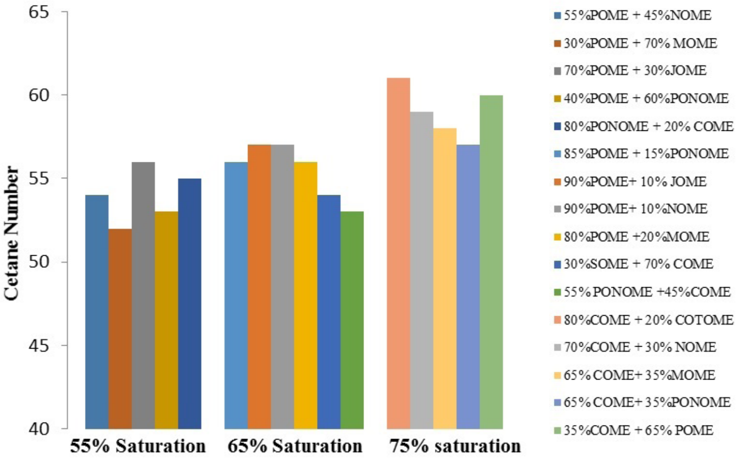

Fig. 3. Comparative analysis of cetane numbers of vegetable oil esters.

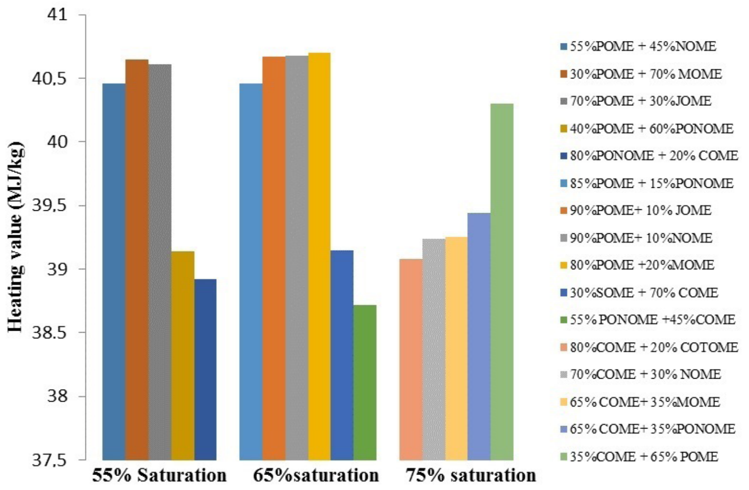

Fig. 4. Comparison of heating values of vegetable oil esters.

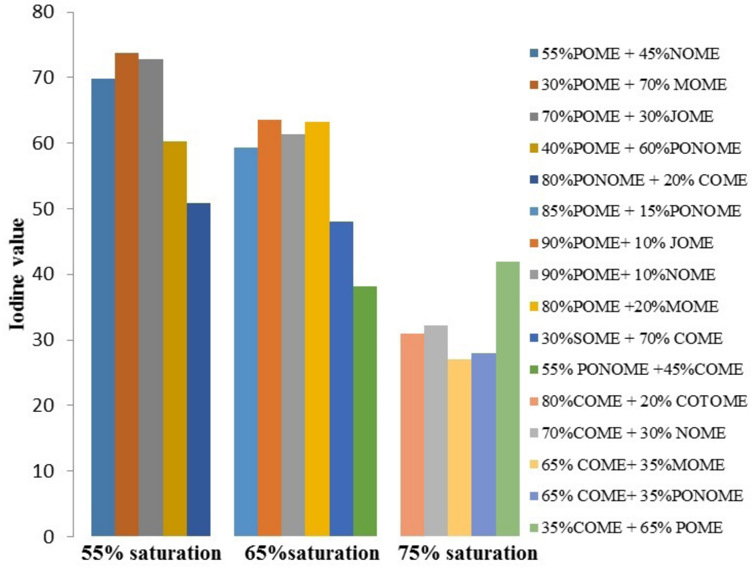

Fig. 5. Comparison of iodine value of vegetable oil esters.

rancidity. Fuels with a 55 % saturation level have iodine values ranging from 51 to 74, while fuels with a 65 % saturation level have iodine values ranging from 38 to 65. The iodine value decreases as the saturation level rises, and it is lowest for fuels with a saturation level of 75 %. The presence of oleic and linoleic acid in palm oil methyl esters causes an increase in iodine value [29]. The number of double bonds increases as oleic acid and linoleic acid levels rise.

Value of saponification

The average molecular mass of triglycerides in fuel has been calculated by the value of saponification. The process of breaking down a neutral lipid into fatty acids and glycerol using an alkali is called saponification. The lower the saponification value, the larger the average molecular masses of triglycerides present in the fuel. The value of saponification is indirectly proportional to the molecular mass of fatty acids and the length of the fuel chain [30]. Fig. 6 shows the saponification values of the biodiesel fuels used in the study. Values of saponification for 75 % saturation fuels range from 221 to 241. As the percentage of saturation decreases, the saponification value decreases. For fuels with a 65 % saturation level, saponification values range from 201 to 235. Fuels with a 55 % saturation level have minimum values ranging

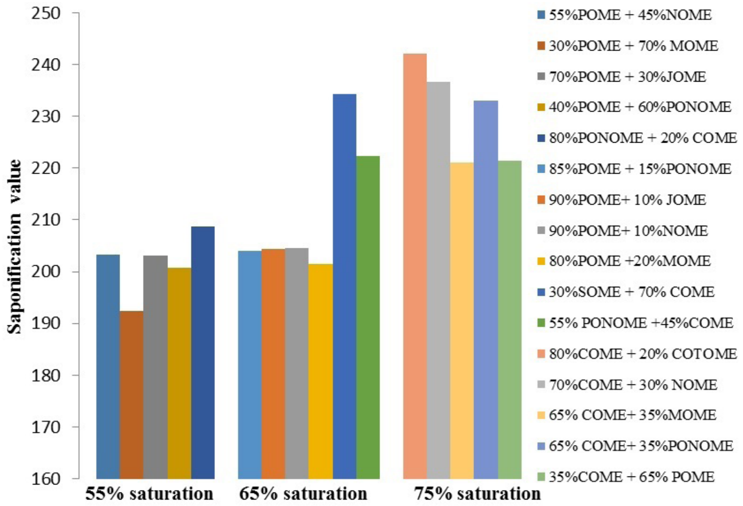

Fig. 6. Comparative analysis of vegetable oil esters' saponification values.

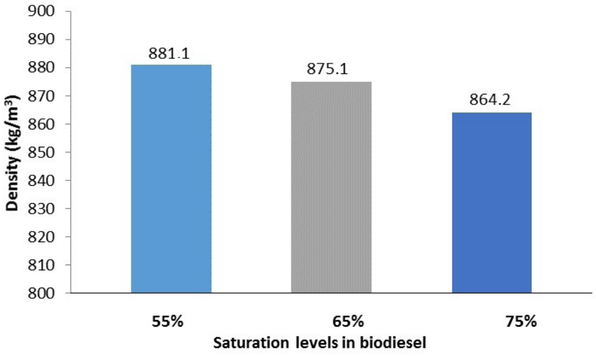

Fig. 7. Comparison of average density of vegetable oil esters.

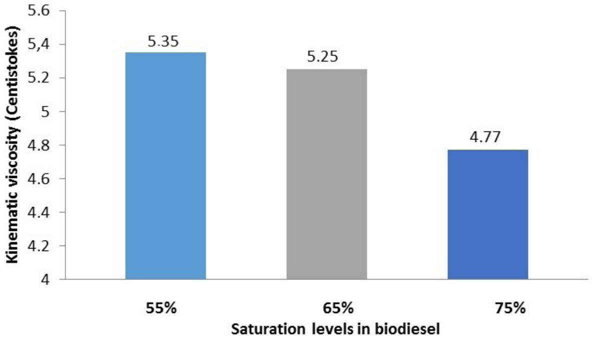

Fig. 8. Comparison of average viscosity of vegetable oil esters.

from 192 to 208.

Coconut oil-based fuel's saponification value is higher. The composition of coconut oil-based fuel has been higher in lauric acid and myristic acid. When compared to palmitic acid and stearic acid, lauric acid and myristic acid have fewer carbon atoms. The carbon chain's length is reduced as the number of. carbon atoms decrease. Lauric acid and myristic acid have lower molecular masses than palmitic acid and stearic acid.

Comparison of different saturation levels

Fig. 7 depicts a comparison of the test fuels' average density at various saturation levels. It has been observed that as saturation levels rise, the density decreases [31]. It is because of the lower molecular mass of myristic and lauric acid found in fuels with a saturation level of 75 %. The higher molecular mass of oleic and linolenic acid raises the density of vegetable oil esters to a saturation level of 55 %. Using a 65 % saturated fatty acid as a baseline, a 15 % increase in fatty acid content reduces density by 1.2 %, while a 15 % decrease in fatty acid content increases density by 0.6 %. For every 15 % increase in saturated fatty acid content, the density changes by 0.6 to 1.2 %.

Fig. 8 illustrates the comparability of the average viscosities of the test fuels. The viscosities of the test fuels decrease as saturation increases. When fuels with a 75 % saturation level are compared to fuels with a 55 percent saturation level, the kinematic viscosity values drop by 10 %. The presence of saturated fatty acids with a lower molecular mass is responsible for the decrease in viscosity [32]. Raising the fatty acid content by 15 % lowers the viscosity by 9 % while decreasing the fatty acid content by 15 % increases the viscosity by 2 %. For every 15 % increase in saturated fatty acid content, the viscosity changes by 2 to 9%. The average values of cetane numbers of vegetable oil esters are compared in Fig. 9. Fuels with 55 and 65 % saturation levels have average cetane numbers of 54 and 55.5, respectively. The presence of saturated fatty acids like myristic acid, lauric acid, and stearic acid in their composition results in an increase in cetane number for fuels with a 75 % saturation level. When compared to other unsaturated acids, these acids have a larger number of cetane [33]. The number of cetane raises by 6 % while the content of fatty acid is raised by 15 %, the cetane number decreases by 3% while the content of fatty acid is decreased by 15 %. It can be seen that a 15 % rise in saturated fatty acid content results in a 3 % to 6 % increase in cetane number.

Fig. 9 shows a comparison of the average heating values of vegetable oil esters. Vegetable oil esters with different saturation levels have similar heating values. The average iodine values of vegetable oil esters are compared in Fig. 9. With increasing saturation, a decrease in iodine values is observed. The iodine value rises with the count of double bonds in unsaturated fatty acids rises, as discussed in [34]. When compared to fuels with a 75 % saturation level, fuels with 55 % and 65 % saturation levels have a higher percentage of oleic and linoleic acid in their composition. A 15 % increase in fatty acid content lowers iodine value by 43 %, while a 15 % decrease in fatty acid content raises iodine value by 17 %. For every 15% change in saturated fatty acid content, the iodine value changes by 17 to 43 %.

Fig. 9 shows a comparison of the average saponification values of vegetable oil esters. The molecular mass of fatty acids is inversely proportional to the saponification value. As the saturation level rises, the saponification value rises as well [35 - 40]. Because saturated fatty acids have a lower molecular mass than unsaturated fatty acids, their saponification value rises. It can be seen that increasing fatty acid content by 15 % increases saponification value by 9 % while decreasing fatty acid content by 15 % decreases saponification value by 5 %. For every 15 % change in saturated fatty acid content, the saponification value changes by 5 % to 9 %.

The average values of the smoke emissions are 1.28, 1.333, and 1.42 BSU for the fuels with 55 %, 65 %, and 75 % saturation levels as shown in Fig. 10. It can be observed that increasing the fatty acid content by 15 % increases the smoke emission by 6 % and by decreasing the fatty acid content by 15 % the smoke emission decreases by 4 %. There is a ± 4 - 6 % change in smoke emission for a ± 15 % change in saturated fatty acid content. The higher emission of smoke for fuels with higher saturation levels may be due to the affinity of oxygen towards hydrogen in the case of fuels with higher saturated fatty acid levels.

The NO_x emissions were reduced with an increase in saturation levels. It is observed that the average values of NO_x emissions for 55 %, 65 %, and 75 % are 13.6, 12.6, and 12.3 g kWh^{-1}, respectively as shown in Fig. 10.

It can be observed that increasing the fatty acid content by 15 %, decreases the NO_x emission by 2 %, and by decreasing the fatty acid content by 15 % the NO_x emission increases by 7 %. There is a ± 2-7 % change in NO_x emission for a ± 15 % change in saturated fatty acid content. Fuels with lesser saturation have linoleic

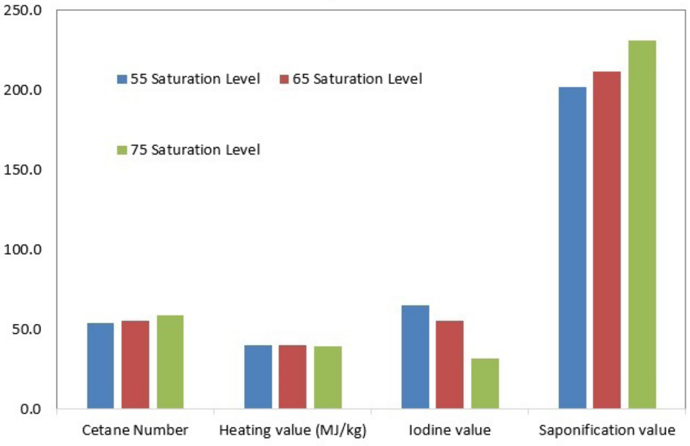

Fig. 9. Comparison of average cetane number, heating value, iodine value and saponification value of vegetable oil esters.

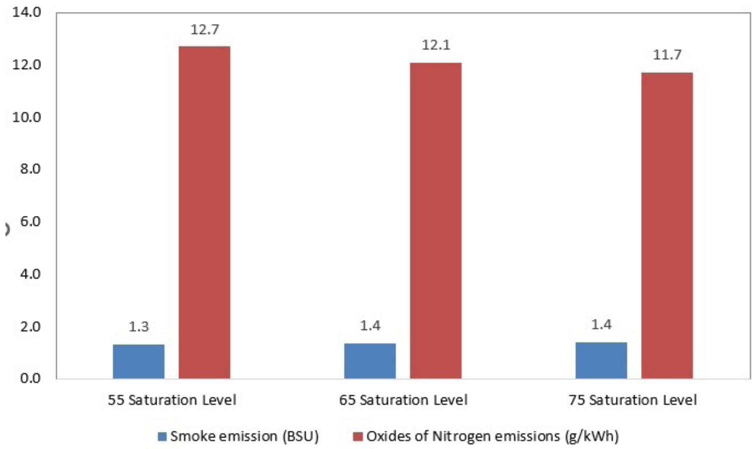

Fig. 10. Comparison of smoke emission and nitrogen oxide emissions with 55%, 65% and 75% saturation levels in biodiesel.

acid, oleic acid, and unsaturated fatty acids in their composition. These unsaturated fatty acids have a lesser cetane number which causes ignition delay and higher premixed combustion. This increases the in-cylinder temperature which increases the NO_x emissions.

CONCLUSIONS

In this research, the emission, performance, and combustion characteristics of biodiesels at saturation levels of 55 %, 65 % and 75 % were studied in a 5.2-kilowatt engine running with 1500 rpm at full load. It was discovered that as the saturation percentage in biodiesel increased, NO_x emissions decreased while smoke emissions increased. Esters containing 75 % saturated fatty acids, that are mainly sourced from coconut oil, emitted less NO_x. This could be owing to the presence of saturated fatty acids like lauric acid, myristic acid, palmitic acid, and stearic acid in their composition. The cetane number of fuels with high saturated fatty acids is higher. The ignition delay, pressure, and temperature are all reduced when the cetane number is high, lowering NO_x emissions. The findings of the experiments show that biodiesel with a high-saturated fatty acid composition could be used as the CI engine's fuel with modest engine changes. The higher emission of smoke for fuels with higher saturation levels may be due to the affinity of oxygen towards hydrogen in the case of fuels with higher saturated fatty acid levels.

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