Indian Journal of Chemical Technology
Vol. 27, September 2020, pp. 404-410

Cassia javanica biodiesel blends with SiO_2 nanoparticles for IC Engine applications

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Received 27 November 2019; accepted 14 August 2020

Crude oil production and its resources have been restricted today due to its depletion and consumption rate. Biodiesel involves less production cost, environmentally friendly, renewable, non-toxic and biodegradable. In this examination, a novel source likes *Cassia javanica* has been used as a feedstock for biodiesel utilizing the transesterification process. The impacts in biodiesel on exhaust gas emissions vary depending on the type of biodiesel and petrodiesel. Blends of biodiesel up to 20% mixed with petrodiesel fuels have been be used in all diesel engines and is more easily storage and distribution tools. The purpose of the current study investigates the analysis of biodiesel and their blends with diesel oil in four-stroke ICE applications like unburned hydrocarbons, sulfates, particulate matter, polycyclic aromatic hydrocarbon, carbon monoxide, and nitrated aromatic hydrocarbons. It ended that *Cassia javanica* methyl ester biodiesel blend (B20) with the addition of SiO_2 nanoparticles exhibits a better engine performance and emission reduced compared to fossil fuels. *Cassia javanica* methyl ester can use directly in diesel engines without requiring extensive engine changes.

Keywords: Green energy, SiO_2 nanocatalyst, Transesterification, Biodiesel, Performance, Emission.

Today most of the countries within the world are the importers of energy. The most important demand occurred within the energy system, particularly for petroleum-based products[1]. In such a state of affairs, Biodiesel is an able alternative which is an environmentally friendly, renewable supply, a nontoxic and perishable matter which might be obtained from bio-oils mainly extracted plants and their products[2]. It has monoalkyl esters of long-chain fatty matters and it's collected from oil, animal fats, algae, and non-edible oils. Biodiesel has created conversions on triglycerides in vegetable oils like soya bean, Palm, Rapeseed, Sunflowers, etc[3]. Likewise alternative sources from non-edible sources like Pongamia, Castor, Jatropha oil, Camelina, Neem oil, and Cottonseed oils. The urban waste *Cassia javanica* belongs to family Leguminosae. It's an attractive and pink blossom flower garden tree and it grows all over India. The aerial parts of these *Cassia javanica* trees are used in herbal medicine for diabetics[4]. The inferior metabolites like anthraquinones, flavones, glycosides, and sterol used as anti-inflammatory and antioxidant agents. *Cassia javanica* is one of the outstanding herbals for purpose Ayurveda medicine. Some of the chemical compounds present in *Cassia javanica* leaves used for the pharmaceutical industry[5]. Other names of *Cassia javanica* trees are a rainbow shower, pink shower, white shower and pink cassia in the existence of pink flowers. The *Cassia javanica* tree produced slim, cylindrical, with deep color. The fruit pods of *Cassia javanica* are 30 to 40 cm long and it has several seeds. This tree is native to India but traveled to other Asian countries like Sumatra, Indonesia, Malaysia[6], Southern China, and the Philippines. It's a hasty rising, semi-deciduous hierarchy able to grow 25 m. With chemicals, biodiesel is often named as FAME (fatty acid methyl esters) and the method of getting it's usually stated as Transesterification. Biodiesel has a parallel range of properties like petrodiesel and might be used for automobiles. Biodiesel and its products are less harmful to the surroundings[7]. Biodiesel has some characteristics and it causes some damages to diesel engines]. Meantime, compression engines are newly manufactured for petrodiesel have to refit and the right conditions on the blends of biodiesel with petrodiesel. Biodiesel can use directly in diesel engines with a count of their blended petrodiesel or without petrodiesel and it easily mixes with petrodiesel at any concentrations. Typical biodiesel blends are B5, B10 and B20 with 5%, 10%and 20% biodiesel content[8]. Today, the automobile sectors have to decide many of their models are suitable for biodiesel. The automobile sector prefers blended biodiesel content up to 20% for use in vehicles, because it has easy lubricity and especially of ultra-low sulfur diesel[9]. This present study aims to check the earlier studies and appearance in the emission and performance analyses of biodiesel in an enclosed combustion engine.

Experimental Section

Preparation of *Cassia javanica* bio-oil

The extraction of oil yield has carried out using a Soxhlet glass assembly. The process was carried out in a 400 mL round bottom flask as a batch process attached to a temperature control water bath. To the top of the round neck, the flask was connected to an extractor via a reflux condenser. The dried and powdered seeds were covered with a clean cotton fabric before placing inside the Soxhlet glass assembly. In the Soxhlet apparatus, the extraction was carried out with various solvents like methanol, acetone, hexane, chloroform, isopropanol, and toluene solvent properties. The amount of % yield of bio-oil was checked at regular time intervals of the extraction process. The amount of oil extracted was estimated gravimetrically and the total oil yield is verified using the following equation,

Total yield % of bio-oil = (W2/W1) × 100

Where,

- W1 → total weight of powdered seeds in gm.
- W2 → total weight of oil extracted in gm.

Preparation of *Cassia javanica* biodiesel

Cassia javanica biodiesel was produced by the three-step method (Fig. 1). First, the *Cassia javanica* oil was esterified by acid catalyst using sulphuric acid[9]. Then it was transesterified by alkali catalyst using sodium hydroxide to convert FFAs into esters at optimum conditions of 16:1 fuel to oil ratio, 0.5 gram of NaOH for 100 mL of oil at 60°C for 45 min reaction time. Finally, the biodiesel was purified by heating at 75°C for 30 min to get rid of traces of methanol. The limits present within the *Cassia javanica* biodiesel have examined by physical and with chemicals compared with standard ASTM ways shown in Table 1.

Preparation of SiO_2 nanoparticles

Silicon dioxide (SiO_2) nanoparticles were studied by the sol-gel method. Some amount of silica tetra was isopropoxide was added to silicon dioxide nanoparticles into the mixture of ethanol and diluted with water in the ratio of 1:3 under constant stirring for 1 h. The nitric acid solution was added to the

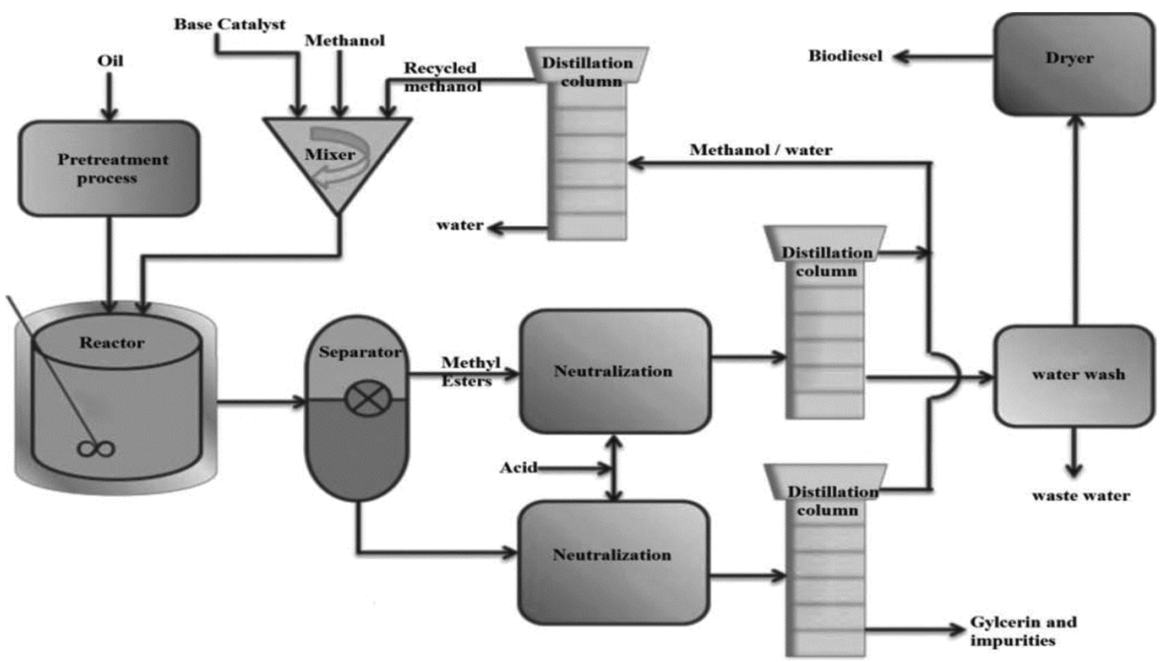

Fig. 1 — Schematic diagram for biodiesel production via a transesterification process

Table 1 — Physical and chemical properties of *Cassia javanica* methyl ester

S.No	Physicochemical properties	Units	Diesel	*Cassia javanica* methyl ester
1	Acid value	mg of KOH/g	-	0.41
2	Kinematic viscosity @ 40 ° C	mm^2/s	2.30	5.42
3	Sulfated ash	Wt%	-	0.003
4	Methanol content	Wt%	-	0.02
5	Density @ 15 ° C	Kg/m^3	824	878
6	Calorific value	MJ/kg	42.50	38.7
7	Cetane index	-	39.40	59
8	Flashpoint	° C	53	148
9	Iodine number	-	-	63

Table 2 — Properties of fuel samples

Fuel Samples	Density @ 15°C	Flashpoint °C	Fire point °C	Kinematic viscosity @ 40°C	Calorific value MJ/kg	Cetane index
B20	843.3	68	76	3.56	41690	53.85
B2040SiO_2	844.5	64	71	3.72	41935	53.94

mixture to get the sol-gel, heated at 250°C for 2 h in the furnace to evaporate the moisture in it and increase the viscosity solution. SiO_2 crystals were deposited in the substrate phase and finally, the drying process took up[10-12].

Preparation of fuel samples

Cassia javanica biodiesel blend (B20) was checked by mixing 20% of biodiesel with 80% of petrodiesel on a volumetric basis with the help magnetic stirrer are in Fig. 2. Furthermore, SiO_2 nanoparticles were added into the B20 fuel sample with a dosage of 40 ppm and it was named as B2040SiO_2 fuel sample. Instead of the sample cetyltrimethylammonium bromide (CTAB) was added to the fuel sample B2040SiO_2 to cut their deposition of nanoparticles. The properties of B20 and B2040SiO_2 nanoparticles were measured according to ASTM standard conditions and the results are reported in Table 2.

Experimental setup Kirloskar four-stroke IC Engine

The process has carried by Kirloskar single-cylinder four-stroke diesel engines with an eddy current dynamometer shows in Fig. 3. The engine develops the brake power at 6 HP (4.4 kW) and runs at a constant rated speed of 1500 rpm. The engine has a hemispherical combustion chamber with an 87.5 mm bore diameter and 110 mm of stroke length. To measure the cylinder pressure with the help of piezoelectric pressure transducers were placed at the top end of the engine cylinder[13-15]. The AVL/446N gas analyzer used to measure the emissions like HC, CO, and NO_x and AVL/437c smoke meter was used to measure smoke emissions.

Fig. 2—Biodiesel blends of *Cassia javanica* oil

Exhaust gas recirculation (EGR)

In this study, exhaust, the gas recirculation system has set up with a diesel engine. EGR is one of the finest methods to cut NOx emissions and minimize the exhaust gas from the engine. Exhaust has sent to the inner manifold of the diesel engine and mixed with incoming air circulation[6]. In this process inside the combustion chamber, specific heat is increased and oxygen has decreased. Orifice meter was used to measure the exhaust gas and exhaust rate controlled by a valve and their percentage calculated by

$$\% \text{ EGR} = CO_2 \text{ (intake / exhaust)} \times 100$$

Results and Discussion

Characterization of SiO_2

XRD pattern for SiO_2 nanoparticles has shown in Fig. 4. The main XRD pattern shows at 101, 200 and

Fig. 3 — Kirloskar four-stroke ICE

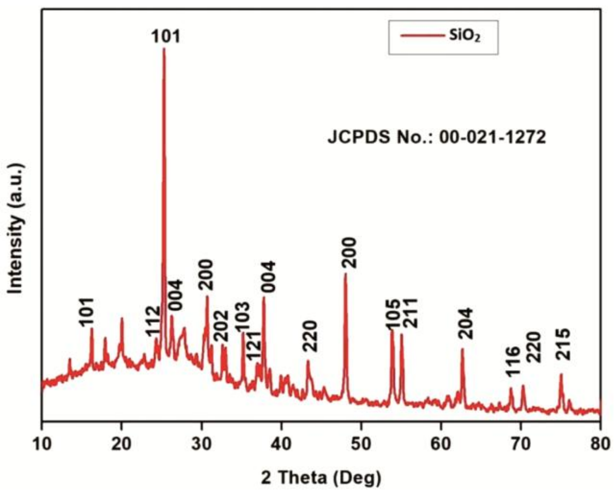

Fig. 4 — XRD pattern for SiO_2

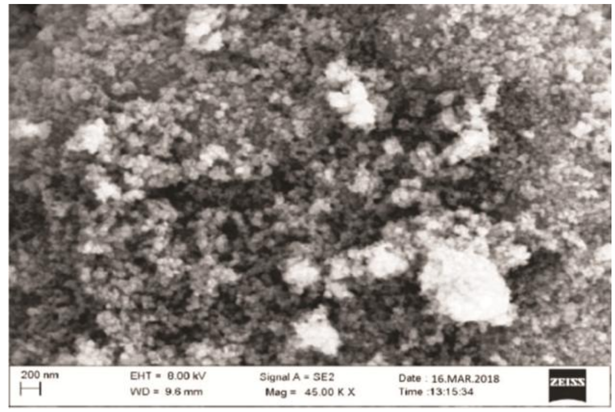

Fig. 5 — SEM analysis

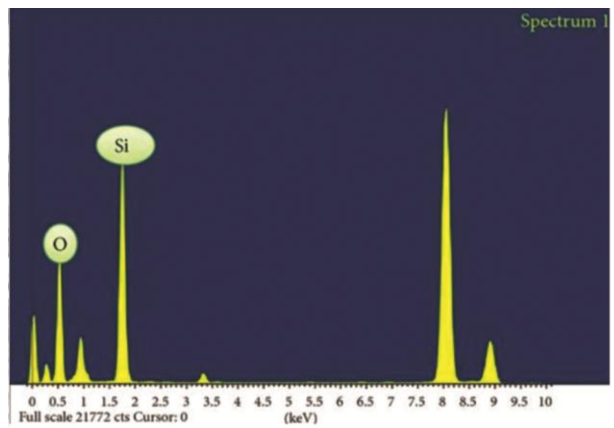

Fig. 6 — EDS spectra

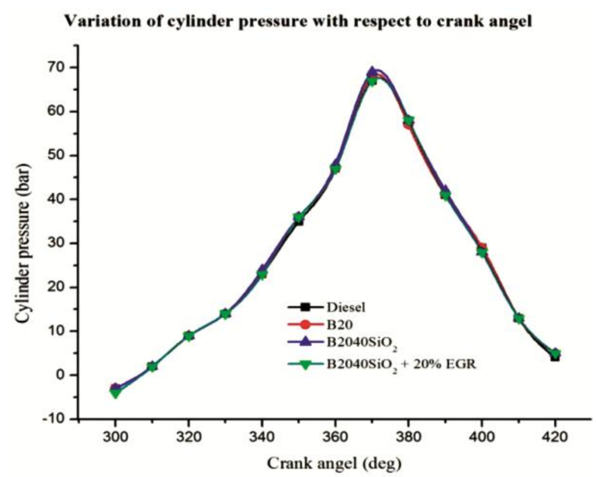

Fig. 7 — Cylindrical pressure concerning the crank angle

211 presences of SiO_2 nanoparticles and all the peaks show the anatase phase of SiO_2 nanoparticles. Surface morphology was carried out by SEM analysis using SiO_2 nanoparticles. The size of the SiO_2 nanoparticles ranges starts from 20 to 40 nm and their reputation is shown in Fig. 5. The elements present in SiO_2 nanoparticles characterized by energy dispersive spectroscopy (EDS) shown in Fig. 6. An energy dispersive spectrum confirms Si and O_2 elements in the composition.

Combustion characteristics IC Engine using *Cassia javanica* biodiesel blends

Figure 7 shows variations of cylindrical pressure concerning the crank angle for all loads at full conditions in the engine. Inside the engine cylinder pressure of pure petrodiesel was higher than biodiesel. The various proportions of biodiesel blends with petrodiesel fuel inside the cylinder the pressure decreased with the increase of biodiesel added. Even though the Cetane number of biodiesel is higher than diesel, the power of heat of vaporization at lower loads leads to more evaporation time for rapid combustion. The maximum cylinder pressure B2040SiO_2 fuel sample values observed as 69.72 bar[16].

Heat release

The heat release rate has calculated from the in-cylinder pressure with the help of the first law of thermodynamics. *Cassia javanica* methyl ester biodiesel peak heat release rate is found to be less than compared to petrodiesel fuel. Because the lower heat release rate consumes shorter ignition delay of biodiesel due to higher Cetane number. Furthermore, surface tension and high viscosity also lead role in a lower heat release rate in biodiesel. The heat rate of *Cassia javanica* methyl ester B2040SiO_2 and B2040SiO_2 + 20% EGR decrease when compared to B20 fuel due to its ignition delay. The heat release rate for B20, B2040SiO_2 and B2040SiO_2 + 20% EGR fuel have observed at 69.97, 68.83 and 68.45 kJ/m^3 deg respectively at full load conditions and the results are in Fig. 8.

Performance characteristics

Break thermal efficiency

Figure 9 shows that the variations placed in brake thermal efficiency of the biodiesel blend for all fuels. The BTE increases with increases in different loads of biodiesel for all fuel samples in the diesel engine at full load conditions. Due to the process condition, evaluation of the engine capacity can produce heat energy which converts into mechanical energy and SiO_2 nanoparticles added with B20 fuel, will increase the brake thermal efficiency compared to normal B20 fuel because of the high surface area to volume ratio which causes to improve the amount of fuel to reach the engine performance[17]. The brake thermal efficiency was decreased in the EGR method for biodiesel and biodiesel blend with nano-additives because the exhaust gas recirculation leads to delay in the combustion and shorter the burning rate of the fuel.

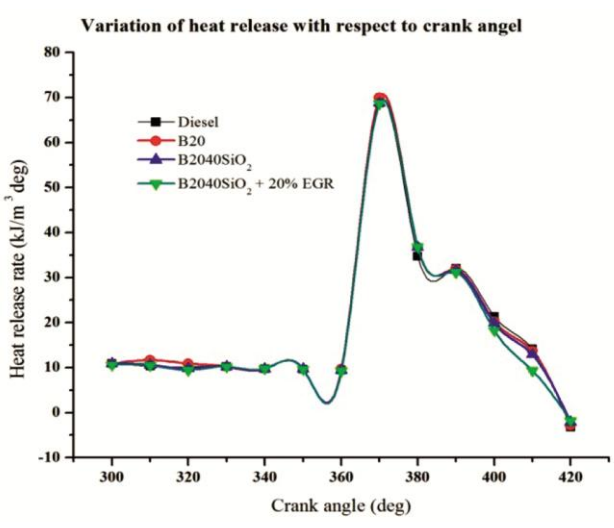

Fig. 8 — Heat release rate concerning the crank angle

Brake specific fuel consumption

Cassia javanica methyl ester biodiesel consumes low calorific value and the changes taken in combustion characteristics lead to slight increase in the brake specific fuel consumption of petrodiesel. The variations of brake specific fuel consumption with brake power for all fuels at full load conditions and their results are given in Fig.10. It was observed that the *Cassia javanica* methyl ester biodiesel mixed with a small amount of SiO_2 nanoparticles to their blends with petrodiesel fuel in engine leads to decrease in brake specific fuel consumption compared to petrodiesel and reduced the ignition delay.

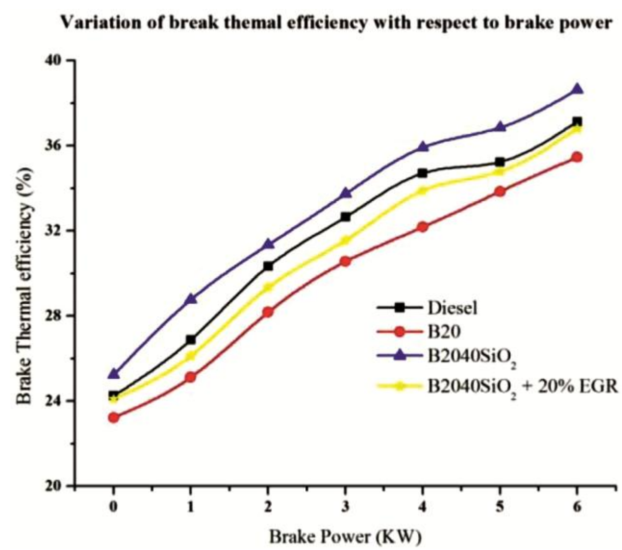

Fig. 9 — Brake thermal efficiency

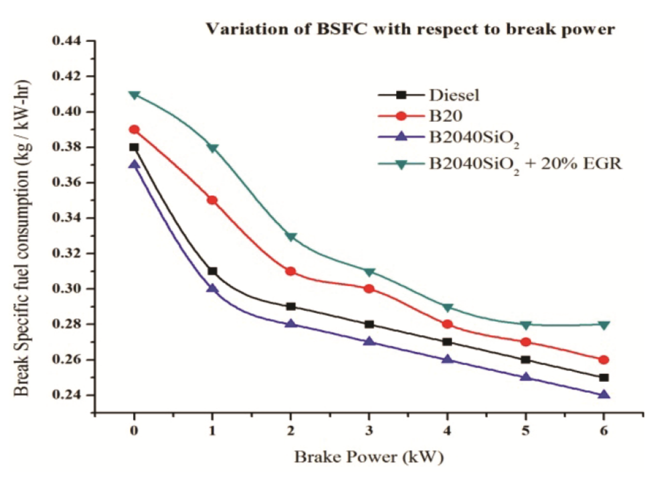

Fig. 10 — Brake specific fuel consumption

Emissions analysis

CO emissions

Figure 11 shows CO emission variations that occurred in blends of biodiesel as compared to petrodiesel fuel for full load conditions. CO emissions decrease with increases in biodiesel blends in all fuel samples except for the fuels which are in full load conditions. It was notified that CO emission decrease when the additives SiO_2 added into the fuel sample compared to B20 fuel. The SiO_2 nanoparticle was blended with a fuel sample lead to improving shorter ignition delay and higher combustion and improves air-fuel mixing leads to complete combustion inside the engine[18]. It has observed that CO emissions reduced by 26% for the B2040SiO_2 fuel sample than the B20 fuel sample. CO emissions increases by 16.3%, 19.7% for B20 + 20% EGR, B2040SiO_2 + 20% EGR fuel samples compared to B20 fuel sample.

HC emissions

Figure 12 shows the variations of HC emissions in different blends concerning load at full conditions. All the fuel samples lead the HC emissions increase to increase in load, but the HC emission decrease with SiO_2 nanoparticles added to the B20 blend. HC emission decreases by 13% for the B2040SiO_2 fuel sample than B20 fuel. The main reasons are biodiesel contains rich oxygen content with nanoparticles add and leads to improve lower HC emission. With the help of the EGR technique the deficiency of oxygen content present in HC emissions increases by 14%, 7% for B20 + 20% EGR, B2040SiO_2 + 20% EGR fuel samples compared to B20 fuel sample.

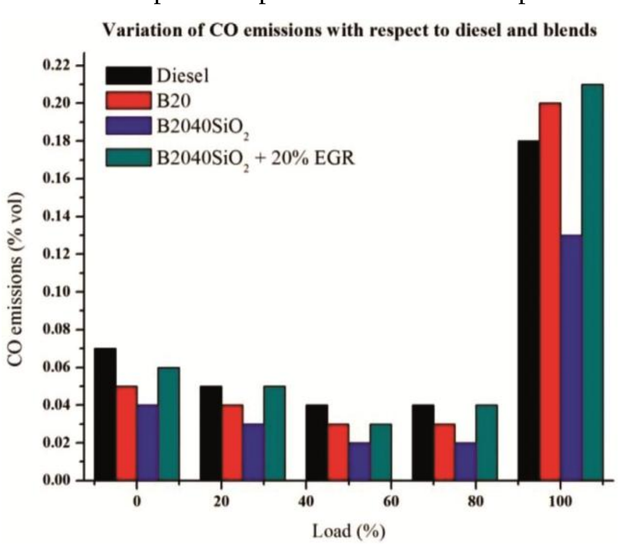

Fig. 11 — CO emissions

NO_x emissions

The variations of NOx emissions to load and their results are in Figure 13. While adding the additives of nanoparticles with B20 fuel leads to an increase in NO_x emission compared to B20 fuel. It has noticed that NO_x emissions are higher in B2040SiO_2 fuel 63 ppm compared to B20 fuel. This is due to the sudden increase of heat present inside the combustion chamber. It has observed those NOx emissions for B20 + 20% EGR, B2040SiO_2 + 20% EGR were 124 ppm and 23 ppm lesser than B20 fuel sample. Oxygen concentration and the flame have reduced inside the combustion chamber due to the EGR method.

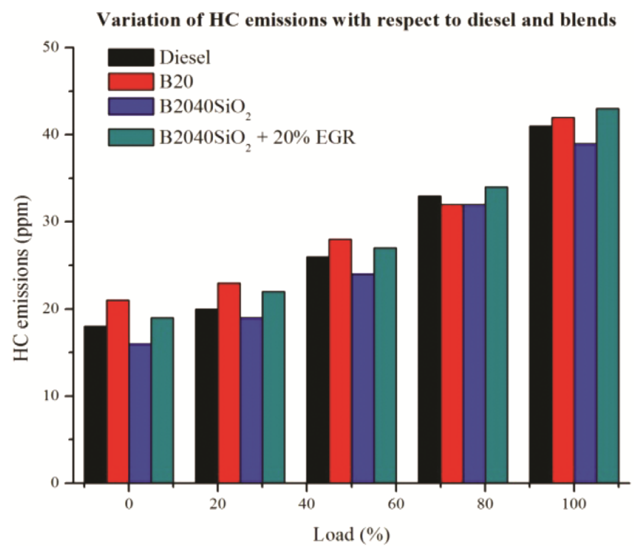

Fig. 12 — HC emissions

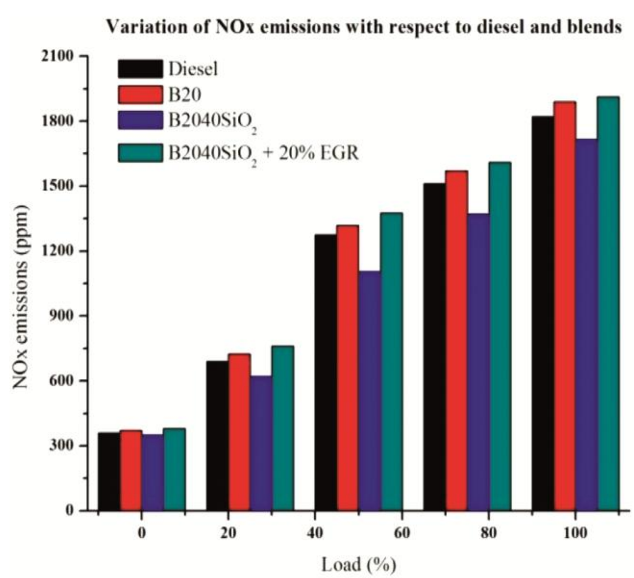

Fig. 13 — NO_x emissions

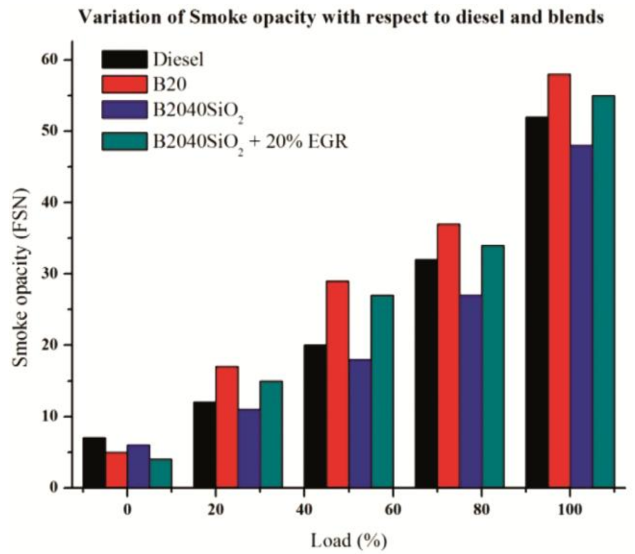

Fig. 14 — Smoke opacity

Smoke opacity

Figure 14 shows the variations get in smoke for a load. Instead of adding nanoparticles in the B20 fuel sample leads to lower smoke emission compared to B20 fuel. This is due to the presence of nanoparticles blended with fuel which leads to slower ignition delay and improved ignition conditions. Presence of incomplete combustion inside the chamber and soot formation at full load conditions smoke opacity for B20 + 20% EGR, B2040SiO_2 + 20% EGR were increased by 18.23% and 14% compared to B20 fuel sample.

Conclusion

Today there is an enormous demand for crude petroleum and its derivatives which drive the global economy. However, a contribution of fresh energy just like biodiesel will cut the stress on oil reserves. *Cassia javanica* biodiesel gives prominent results using single-cylinder four-stroke diesel engines for emission and efficiency performance of biodiesel with various blends. Compare to any or all blends, B2040SiO_2 blends give prominent results and get closer to the diesel properties. Among these results from our research, *Cassia javanica* biodiesel will act as a better replacement for diesel in diesel engine applications like industrial and automobile sectors. Biodiesel from *Cassia javanica* seeds is a humble yet ambitious attempt to make the alternative fuel work and saves our environment from harmful effects. The following results are present in diesel engine applications, brake thermal efficiency has reduced by 3.1% and basic specific fuel consumption has increased due to the heat released was higher in B2040SiO_2. The emission characteristics are present in diesel blends with biodiesel, carbon monoxide reduces 26%, hydrocarbon emits decrease by 13% and an oxide of nitrogen increased by 63 ppm for B2040SiO_2 fuel sample and compares the fuel sample in full load conditions. Finally, the smoke has measured by a photoelectric measuring head and the result was analyzed by a microprocessor the value determined value is the Filter Smoke Number (FSN), which is decreasing while adding the nano-additives in fuel sample compared to B20 fuel.

Nomenclature

ASTM-American Society for Testing and Materials	**SiO_2**- Silicon Dioxide
B20- *Cassia javanica* Biodiesel 20% + 80% of Diesel Fuel	**CO**- Carbon monoxide
HC-Hydrocarbon	**NO_x**- Oxides of Nitrogen
EGT-Exhaust Gas Temperature	**EGR**- Exhaust Gas Recirculation
EDS- Energy Dispersive Spectrum	**SEM**- Scanning Electron Microscopy
BTE-Brake Thermal Efficiency	**BSFC**-Brake Specific Fuel Consumption

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