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Experimental Investigation on CI Diesel Engine Using Simarouba Biodiesel, Hippe Biodiesel and Al_2O_3 Nano Additive Blended Biodiesel

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Abstract

In this present work experiments were conducted to determine performance, emissions and combustion characteristics of a single cylinder, four stroke VCR diesel engine using pure diesel , simarouba oil methyl ester(SOME) biodiesel , Hippe oil methyl ester (HpOME) biodiesel, and aluminium oxide nanoparticles were added to HpOME-20 as an additive in mass fractions of 25 ppm,50 ppm and 75 ppm with the help of a mechanical Homogenizer and ultrasonicator with cetyltrimethyl ammonium bromide (CTAB) as the cationic surfactant. It was observed from results that HpOME(B20) biodiesel at 3.5kw Brake power(BP) gives 4.7% more BTE, 3.33% reduction in BSFC, 0.437% increase in Volumetric efficiency, reduced hydro carbon (HC) emissions(7.69%),reduction in Carbon Monoxide (Co) with slightly increased in Nox emissions in comparison with SOME (B20) biodiesel. Further experiments were conducted using different aluminium oxide nanoparticles ANP-blended biodiesel fuel (HpOME20 + ANP25, HpOME20 + ANP50 and HpOME20 + ANP75) and the results obtained were compared with those of pure diesel and Hippe oil methyl ester(HpOME20). The results shows a substantial enhancement in the brake thermal efficiency and a marginal reduction in the harmful pollutants (such as CO, HC and sNox) for the nanoparticles blended biodiesel.

Keywords: *Aluminium oxide nanoparticle(ANP), Hippe oil methyl ester (HpOME), Simurouba oil methyl ester (SOME), Transesterification, Combustion, Emission, Mechanical Homogenizer.*

1. Introduction

Over a hundred years ago Rudolf Diesel, the inventor of the C.I engines that still bear his name, demonstrated at a World Fair that agriculturally produced seed oil (peanut oil) may be used as fuel . The use of these agriculturally derivative oils as a fuel was phased out by petroleum-based diesel fuels that became more widely available because they are cheaper in price as a result of government subsidies in the 1920's . In the present scenario with the depletion of the petroleum-based diesel, the demand for alternatives to petroleum-based fuels continues to increase. The increase in the awareness of these alternative biofuels is not only because of the depletion of fossil fuels, but also because these bio-energy resources have lower emissions than conventional fuels and more over they are made from renewable resources. Biofuels refer to any kind of fuel generated which is made mostly from biomass or biological material collected from living or recently living resources. Transportation sectors have shown particular interest in biofuels because of the potential for rural development. In a country like India where it is observed that biodiesel can be a viable alternative automotive fuel. Biodiesel is a fastest growing alternative fuel and India has better resources for its production.Owing to the depletion of the fossil fuels day by day, there is anecessity to find out an alternative resolution to fulfil theenergy requirement of the world. Petroleum fuels play an vitalrole in the fields of transportation, industrial development and agriculture[1,2]. Fossil fuels are fast depleting because of increased fuel consumption. Steady with the estimation ofthe International Energy Agency, by 2025 global energy utilization will increase by about 42% [3]. Many research works are going on to substitute the diesel fuel with an appropriate alternative fuel such as biodiesel. Biodiesel is one of the best available sources to fulfil the energy requirement of the world [4]. Nonedible sources such as cotton seed oil, pongamia oil, Mahua oil, Jatropha oil, and Karanja oil have been investigated for biodiesel fuel production [5]. In the modern years, severe efforts have been made by many researchers to use various sources of energy as feed in existing diesel engines. The make use of straight vegetable oils (SVO) is inadequate due to some unfavorable physical and chemical properties, particularly their viscosity and density. Because of higher viscosity, SVO causes incomplete combustion, poor fuel atomization and carbon deposition on the valve and injector seats ensuing in severe engine problems. When diesel engines are fuelled with straight vegetable oil as fuel, it leads to incomplete combustion. The potential methods to overcome the problem of higherviscosity were blending of vegetable oil with diesel fuel in the proper proportions and transesterification of vegetable oils to produce biodiesel [6–8]. The transesterification process has been established worldwide as a successful means for biodiesel production and viscosity reduction of vegetable oils [9].Transesterification is the process, by means of an alcohol (e.g. either ethanol or methanol) in the presence of catalyst to break the triglyceride molecules of the raw vegetable oil into ethyl or methyl esters (fatty acid alkyl esters) of the vegetable oil with glycerol as a by-product [10]. Ethanol is one among the chemical preferred for transesterification process when compared to methanol because it is derived from renewable sources (agricultural waste) and is biologically non-harmful for the environment. Mechanism of transesterification process is shown in Fig. 1. In general, methyl esters of vegetable oil propose the reduction of harmful exhaust emissions from the diesel engine such as CO, HC and smoke but it increased the NOx emissions [11–17]. The NOx emission is the most dangerous parameter that has an effect on the environment through acid rain, human diseases, etc. Furthermore, CO and NO are primary pollutants in the formation of atmospheric ozone, which is an important greenhouse gas [18,19] . Many researchers have found that the B20 biodiesel blend gives greater thermal efficiency and emission parameters compared with other biodiesel blends [22]. Among the different techniques accessible to reduce exhaust emissions from the diesel engine while using biodiesel, the use of fuel-borne metal catalyst is presently focused because of the advantage of an enhancement in fuel efficiency while reducing harmful exhaust emissions and healththreatening chemicals [23]. Aluminium oxide nanoparticles at high temperatures dissociate into Al2O and oxygen:

$$Al_2O_3 \longrightarrow Al_2O + 2O$$

Al2O3 is unstable at high temperatures during combustion
in the combustion chamber, so it also decomposes as follows:

$$Al_2O \longrightarrow 2Al + 2O$$

Many researchers found that the combustion behaviour of methyl esters with the addition of nanosize energetic materials as an additive improves the combustion and engine performance of diesel engines. In addition, due to the small size of nanoparticles, the stability of fuel suspensions should be noticeably improved [24–26].In this investigation, aluminiumoxide nanoparticles were added in different proportions (25, 50and 75 ppm) to a biodiesel blend (HpOME20) which is found to be better than SOME20 to investigatethe performance, emission and combustion of the single cylinder, four stroke VCR diesel engine without any Modification.

2. Biodiesel production

Simarouba oil and Hippe oil which is also known as Mahua oil is heated to a temperature of 100–120 ^{0} C to remove water contents present in raw vegetable oil which is followed by filtration. The raw vegetable oil is processed by one base-catalysedtransesterification method where it is mixed with 200 ml of methanol and 7 g of potassium hydroxide (KOH) pellets per litre of vegetable oil and placed on a hot plate magnetic with stirring arrangement for 1–1.5 h up to 60 ^{0}C and then it is allowed to settle down for about 6–8 h to obtain biodiesel and glycerol. The biodiesel obtained is further washed with distilled water two to three times for the removal of acids and heated above 100 ^{0}C to remove the moisture present in the biodiesel.

2.1Process of extracting Biodiesel

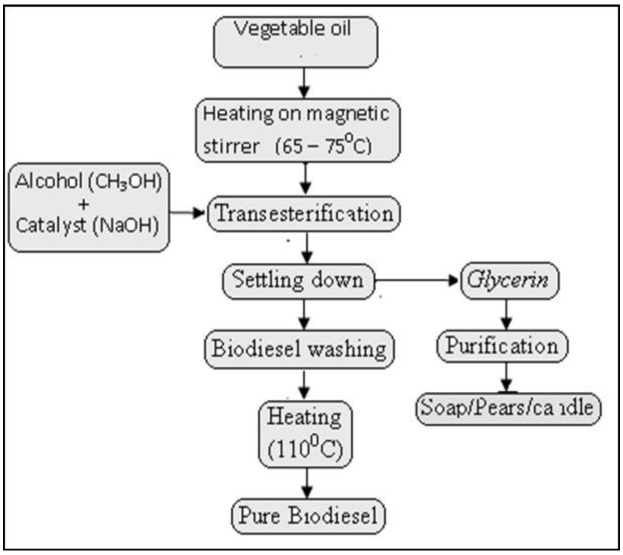


Fig.1 Flow chart ofBiodiesel production.

2.2Transesterification Process

$$\begin{array}{lcll} CH_2\text{-}OOC\text{-}R_1 & & R_1COOR' & CH_2\text{-}OH \\ | & \text{catalyst} & & | \\ CH_2\text{-}OOC\text{-}R_2 + 3R'OH & \rightleftarrows & R_2COOR' + & CH\text{-}OH \\ | & \text{Alcohol} & & | \\ CH_2\text{-}OOC\text{-}R_3 & & R_3COOR' & CH_2\text{-}OH \\ \\ \text{Glyceride} & & \text{Ester} & \text{Glycerol} \end{array}$$

Fig.2 Transesterification of triglycerides with alcohol in presence of catalyst, where R isthe alkyl group.

3. BLEND PREPARATION

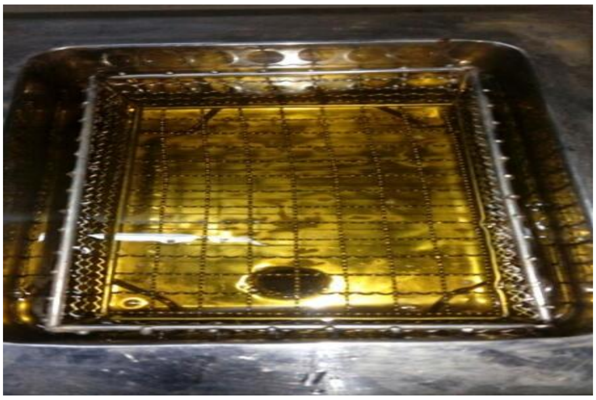
3.1. Biodiesel blends preparation.

The Simarouba oil methyl ester biodiesel obtained by transesterification is blended with neat diesel on volume basis as per the requirement to form blends like SOME10,also called as B10(10 % SOME + 90 % Diesel),B20(20% SOME +80 % Diesel),B30 and B40. Similarly blends of Hippe oil methyl ester biodiesel are prepaired (HpOME10,HpOME20,HpOME30 and HpOME40).

3.2. Nanofluid preparation.

The unique hybrid biodiesel-nanoparticle blends for the present study were prepared by using with the help of homogenizer and ultrasonicator.Aluninium oxide is selected as nanoparticle additives to HpOME20 because of their improved properties like higher thermal conductivity, mechanical and magnetic properties.The mean size of the nanoparticles varies from 32 to 48 nm. The nanoparticles were diffused in the solvent with the help of a homogenizer. Nanoparticles usually have a high surface contact area and therefore surface energy will be high. Nanoparticles clustered together to form a micro molecule and start to sediment. To make nanoparticles be steady in a base fluid, it should need to surface modification. Cetyltrimethyl ammonium bromide (CTAB) is a cationic surfactant and it creates an envelope on the surface of the nanoparticles and makes the surface as a negative charge. Hence the particle sedimentation was controlled. In order to disperse the nanoparticle to the base, the magnetic stirrer procedure was followed. A known quantity of aluminium oxide nanoparticles (25, 50 and 75 ppm) and CTAB (100 ml for 1Lt)was weighed and poured in the ethanol solvent and magnetically stirred for 2 h. Then it forms an even nanofluid.

3(a)



3 (b)

Fig.3 (a) & (b) Ultrasonicator setup.

3.3. Hippe oil methyl ester-nanofluid blend preparation

The aluminium oxide nanofluid was added to the Hippe oilmethyl ester blend (HpOME20) in three different proportions (25, 50 and 100 ppm). After the addition of aluminium oxide nanofluid, it is shaken well. And then it is poured into signification apparatus where it is agitated for about 30–45 min in an ultrasonic shaker, making a uniform HpOME20-ANP blend. The properties of Simuroba oil methyl ester (SOME) , Hippe oil methyl ester and ANPs blended Hippe oil methyl ester blend are determined as per ASTM standards and is listed below.

Table.1 Properties of Diesel, biodiesel and biodiesel nanoparticles blended samples.

Description	Viscosity @40^{0}c(Cst)	Density (kg/m$^{3)}$	Calorific value(MJ /kg)	Flash point (^{0}C)
Diesel	3.4	830	42.86	63
SOME 10	2.68	827	42.46	60
SOME 20	2.83	831	41.45	67
SOME 30	3.07	836	40.90	70
SOME 40	3.92	840	39.46	75
HpOME 10	3.52	831	42.43	74
HpOME 20	3.59	833	41.62	76
HpOME 30	3.79	836	41.78	77
HpOME 40	3.84	840	41.25	77.5
HpOME20 +ANP 25	3.42	825.75	41.65	74
HpOME20 +ANP 50	3.37	827.5	41.66	71
HpOME20 +ANP 75	3.34	828	41.67	68

4..Experimental set up

The experiments were conducted on fully computerized Kirloskar TV1, four stroke, single cylinder ,water cooled diesel engine. The rated power of the diesel engine was 3.7 kW. The engine was operated at a constant speed of 1500 rpm by maintaining the injection pressure from 210 to 220 bar at various load conditions. The engine was at the start fuelled with neat diesel to provide the baseline data, and then it was fuelled with SOME, HpOME biodiesel blends and then HpOME20, HpOME20 + ANP25 , HpOME20 + ANP50 and HpOME20 + ANP75. Details of the engine specification are given in Table 2. Eddy current dynamometer was used for loading the engine. HG-540 AIRREX (approved by ARAI) five-gas analyzer was used to measure HC, CO and NOx emissions.
In-cylinder pressure and heat release rate were measured by using data acquisition system interfaced with dual core processor. The experimental set-up is indicated in Fig. 4.

Table.2. Engine Specification.

Sl.No.	Parameter	Specification
1	Engine Supplier	Apex innovations Pvt. Ltd Sangli, Maharashtra, India
2	Type	TV1 (Kirloskar made) VCR
3	Software used	Engine soft
4	Nozzle Opening Pressure	200-205 bar
5	Governor type	Mechanical centrifugal
6	No. of cylinder	Single cylinder
7	No. of strokes	Four stroke
8	Fuel	H.S Diesel
9	Rated power	3.7 kw (5HP)
10	Cylinder diameter (bore dia)	87.5 mm
11	Stroke length	110 mm
12	Compression ratio	17.5
13	Speed	1500 rpm
14	Arm length	180 mm

Fig.4. Experimental Setup

5. Results and Discussions

The operation of diesel engine using Simuroba oil methyl ester, Hippe oil methyl ester blends and ANPs added Hippe oil methyl ester fuel blends was found to be very smooth throughout the rated load, without any operational trouble.

The performance characteristics such as brake specific fuel consumption (BSFC), brake thermal efficiency (BTE), volumetric efficiency and the emission characteristics such as NOx, HC, CO are plotted against the brake power. Based on the combustion data, cylinder pressure and heat release rate are plotted against crank angle.
Initially experiments were conducted with neat diesel, SOME10,SOME20,SOME30 and SOME40,and Similary for HpOME10, HpOME20, HpOME30 and HpOME40. In both the cases blend B20 (SOME20 and HpOME20) found better than their counter partners.

5.1 Engine performance

5.1.1Brake thermal efficiency

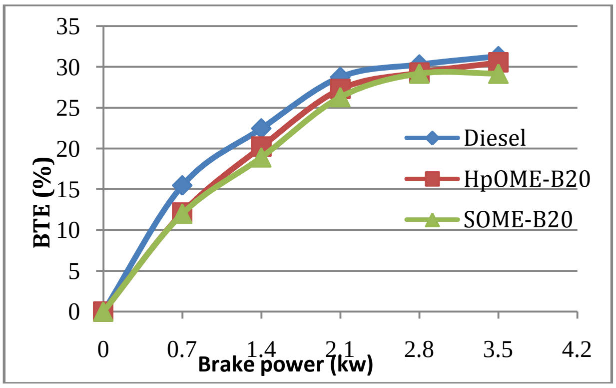


Fig. 5(a)BTE (%) against Bp (kw) for Diesel,SOME20 and HpOME20

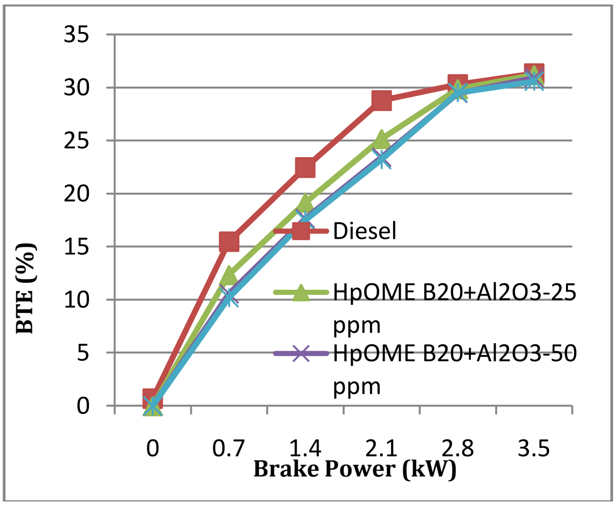


Fig. 5(b)BTE(%) against Bp (kw) for Diesel, HpOME20 +ANP25,HpOME20+ANP50 and HpOME20 + ANP75.

From Fig. 5(a), it can be observed that the brake thermal efficiency (BTE) increases with the load for diesel, SOME and HpOME biodiesel. The BTE of HpOME20 (30.54 %) is better than that of SOME20 (29.16 %) at full load.From Fig. 5(b),it is observed that BTE is further improved with addition of ANP25 PPM to HpOME20 (31.2 %) this could be attributed to the better combustion characteristics of ANP. The catalytic activity of ANP might have improved because of the existence of high active surfaces.

5.1.2 Brake Specific fuel consumption (BSFC)

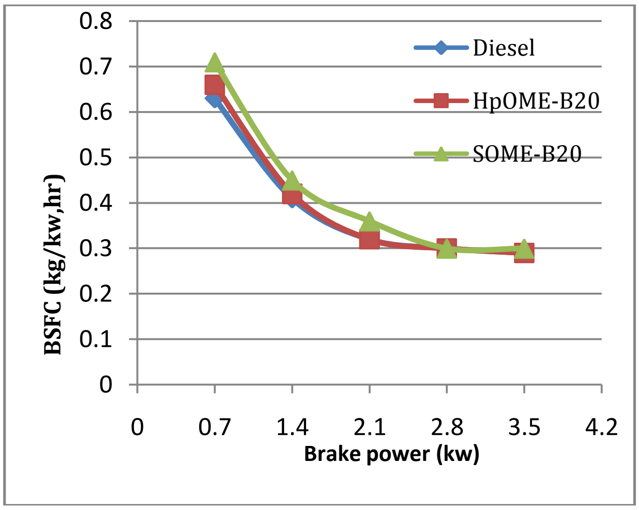


Fig. 6(a) BSFC against BP for Diesel,HpOME20 and SOME20 biodiesel.

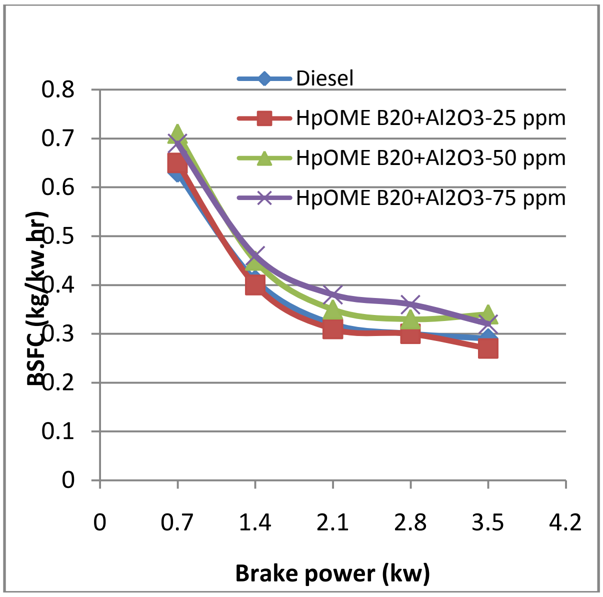


Fig. 6(b) BSFC against BP for Diesel, HpOME20 + ANP 25,HpOME20 + ANP 50 and HpOME20 + ANP 75

It is observed from the above Fig. 6(a) the BSFC for HpOME20 is less than SOME20 and same as that of Diesel at full load condition.
It is observed from Fig. 6(b) that with addition of ANP to HpOME20 there is marginal decrease in BSFC. For ANP25 BSFC is less compared to ANP50 and ANP75 at full condition.

5.1.3Volumetric efficiency

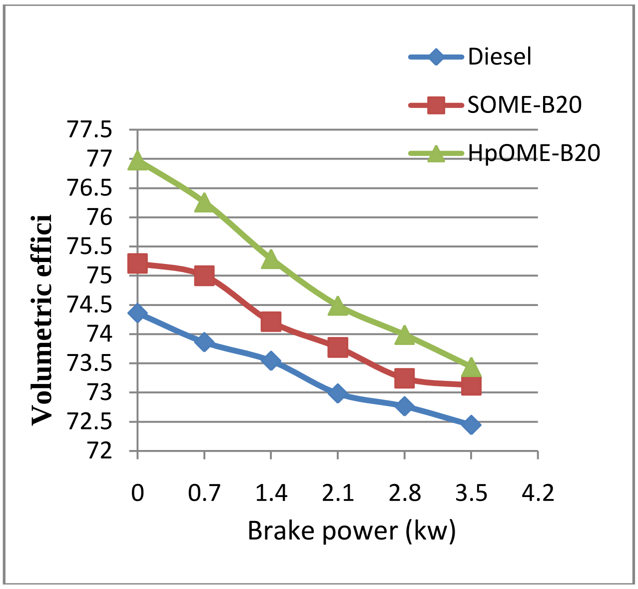


Fig. 7(a) Vol.efficiency against BP for Diesel,SOME20 and HpOME20 biodiesel.

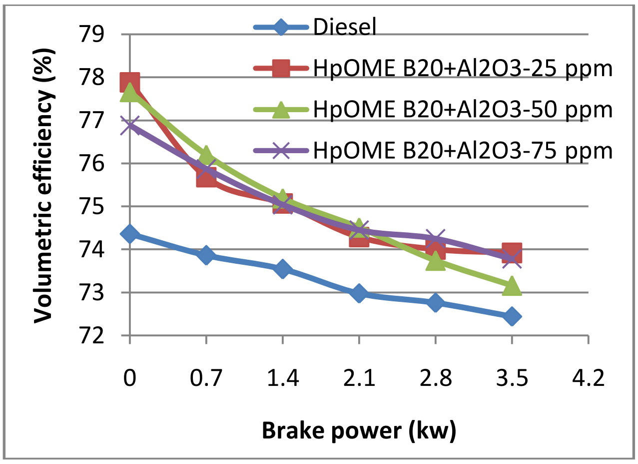


Fig. 7(b) Vol.efficiency against BP for Diesel,HpOME20 + ANP25,HpOME20 + ANP50 and HpOME20 +ANP75 ppm.

It is observed from Fig. 7(a) and Fig. 7(b) that the Volumetric efficiency for HpOME20 is more than SOME20 and also HpOME20 + ANP25 ppm has efficiency compared to other blends.

5.2Emission parameters

5.2.1Hydrocarbon (HC)

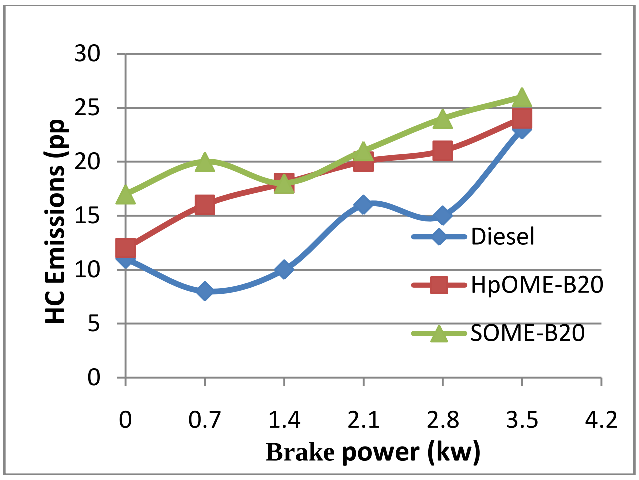


Fig. 8(a) HC emissions against BP for Diesel,SOME20 and HpOME20 biodiesel.

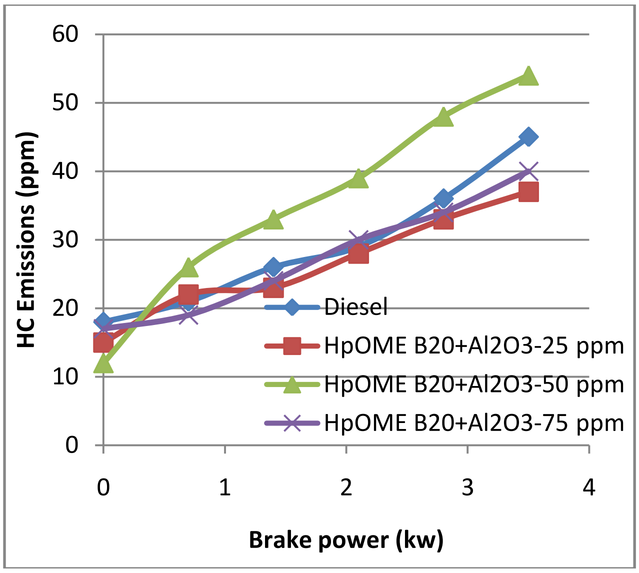


Fig. 8(b) HC emissions against BP for Diesel,HpOME20 + ANP25, HpOME20 + ANP50 and HpOME20 + ANP75 ppm blended biodiesel.

It is observed from Fig. 8(a) and Fig. 8(b) that as the load increases the HC emissions steadily increases for all cases. Many authors' results show a significant reduction in HCemissions when replacing diesel fuel with biodiesel [17,31]. The higher cetane number of biodiesel blend (HpOME20) reduces the combustion delay period and the reduction has been connected to decreases in the HC emissions. Further addition of aluminium oxide nanoparticles reduces the hydrocarbon emissions, because ANP supplies the oxygen for the oxidation of hydrocarbon and CO during combustion.

5.2.2 Carbon monoxide (CO)

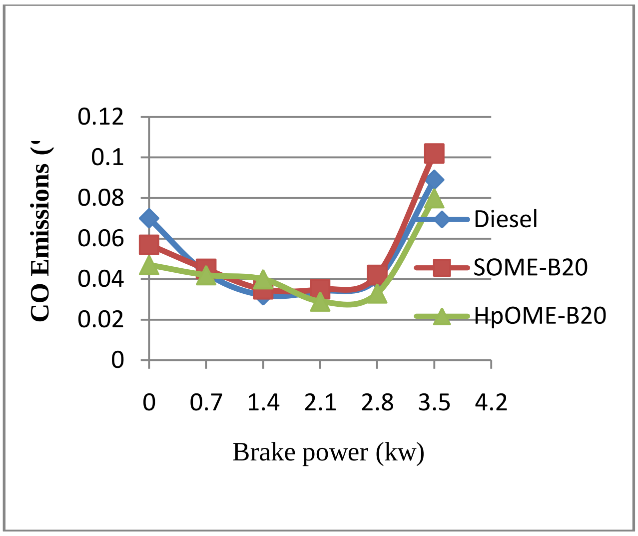


Fig. 9(a) CO emissions against BP for Diesel, SOME20 and HpOME20

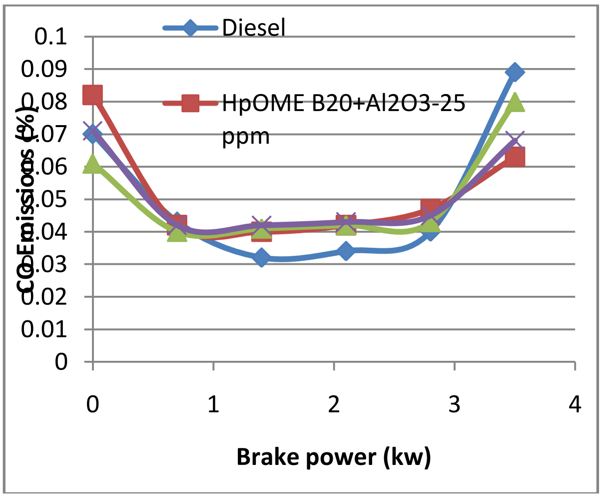


Fig. 9(b) CO emissions against BP for Diesel, HpOME20 + ANP25, HpOME20 + ANP50 and HpOME20 + ANP75 ppm blended biodiesel.

It is observed from from Fig. 9(a) the CO emissions of HpOME20 is less than SOME20 and is almost same as diesel at full load. The effects of ANP with a biodiesel blend (HpOME20) on thecarbon monoxide emission at various engine loads have beenshown in Fig. 9(b) ANPs have high surface contact areas which raise the chemical reactivity which consecutively shortened the ignition delay period. From Fig. 9(b) it shown that CO emission found marginally less than diesel for HpOME20 + ANP25 ppm.

5.2.3 Oxides of nitrogen (NOx)

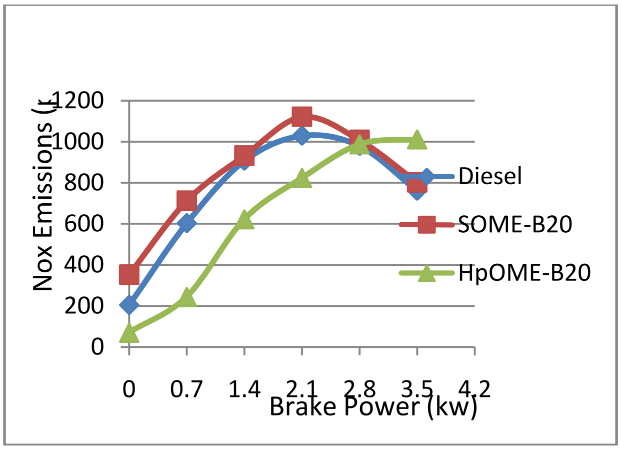


Fig. 10(a) NO_X emissions against BP for Diesel, SOME20 and HpOME20

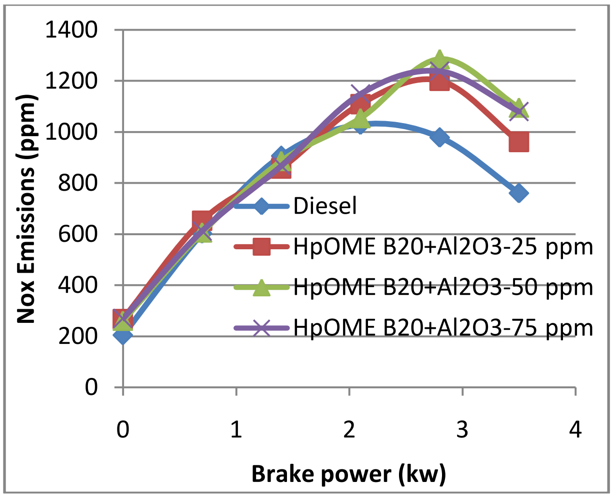


Fig. 10(b) NO_X emission against BP for Diesel, HpOME20 + ANP25, HpOME20 + ANP50 and HpOME20+ANP75 ppm.

The reduced ignition delay and combustion timing are obtained when using the biodiesel blend. It is widely accepted that the shorter ignition delay may contribute to slightly increased NOx emissions with biodiesel blend (HpOME20). The addition of nano metal oxide particles leads to complete combustion because of the aluminium oxide nanoparticles acting as an oxygen-donating catalyst. NOx emissions increased for ANP blend due to maximum heat release rate and high peak pressure during the combustion. NOx emissions of the engine at different nanoparticle concentrations with a biodiesel blend with engine loads are shown in Fig. 10(b). From the figure, it is clear that the NOx emission noticeably increases by means of aluminium oxide nanoparticle additives.

5.3Combustion characteristics

5.3.1 Cylinder pressure

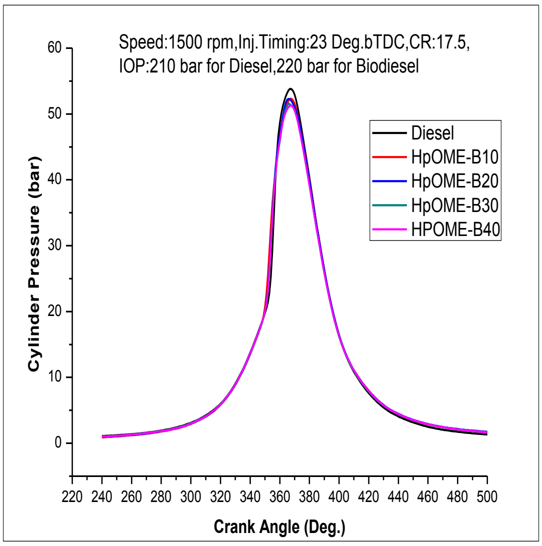


Fig.11(a) Cylinder pressure against crank Angle for Diesel and HpOME biodiesel.

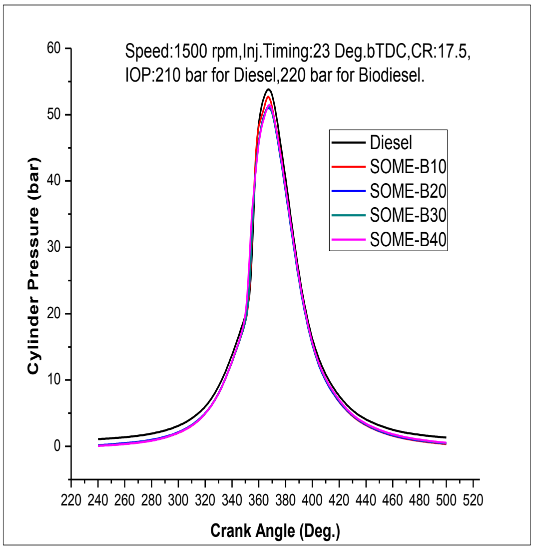


Fig.11(b) Cylinder pressure against crank Angle for Diesel and SOME biodiesel.

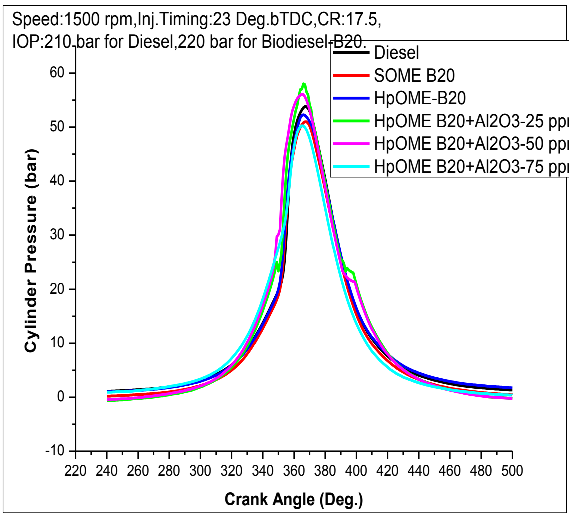


Fig. 11(c) Cylinder pressure against crank Angle for Diesel and HpOME20 with different blends of ANP(25, 50 and 75 ppm) biodiesel.

Fig. shows the variation of the in-cylinder pressure of the
engine with crank angle. From the figure 11(a), it is seen that the maximum pressure at 366º crank angle is 52.18 bar is obtained for HpOME20.
From the figure 11(b), it is seen that the maximum pressure at 366º crank angle is 51 bar is obtained for SOME20.
From the figure 11(c), it is seen that the maximum pressure at 366º crank angle is 58.0275 bar is obtained for HpOME20 + ANP25 ppm.

5.3.2 Heat release rate

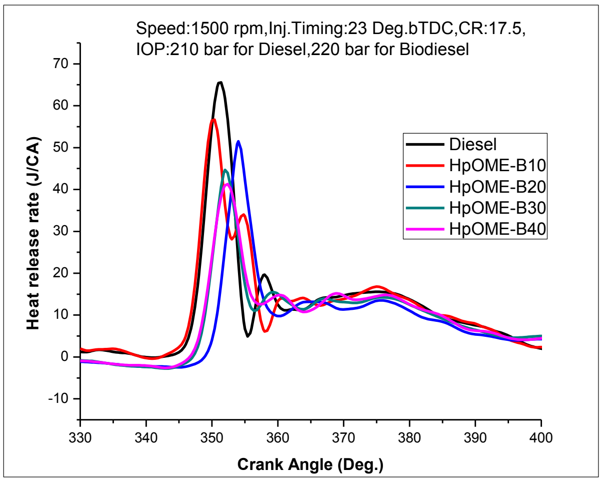


Fig. 12(a) Heat release rate against crank Angle for Diesel and HpOME biodiesel.

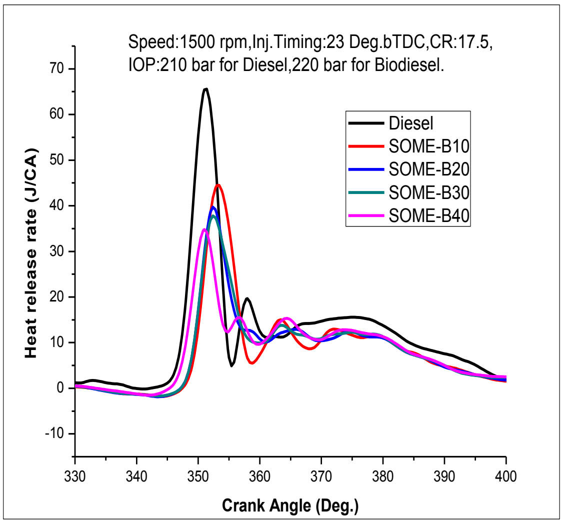


Fig. 12(b) Heat release rate against crank Angle for Diesel and SOME biodiesel.

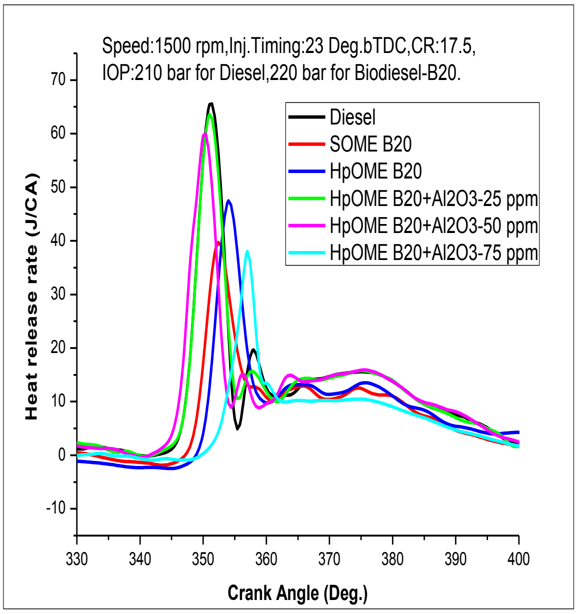


Fig. 12(c) Heat release rate against crank Angle for Diesel and HpOME20 + ANP(25,50 and 75 ppm) blends biodiesel.

Fig. 12(a, b and c) shows the heat release rate for diesel, Hippe oil methyl ester, Simarouba oil methyl ester biodiesel and HpOME20 + ANP(25, 50 and 75 ppm) blended biodiesel.It is seen that heat release rate is maximum for neat diesel this is due to high CV.
The heat release rate curves indicate the available heat energy, which can be rehabilitated into useful work. Hippe Oil methyl ester (HpOME) includes a small amount of diglycerides having high boiling points compared with the diesel fuel. The chemical reactions during the injection of the Hippe oil methyl ester blend (HpOME20) at very high temperature resulted in the breaking of the diglycerides. These chemical reactions produce the gases of monoglycerides. Gasification of these monoglycerides in the tassel of the spray spreads out the fuel jet, and the volatile combustion compounds

present in the fuel are ignited in advance and reduced the ignition delay period. The heat release rate in the combustion chamber during the starting of combustion is not enough to entirely combust the fatty acids.. The addition of ANP considerably increases the heat release rate of HPOME20

6. Conclusions

In this present investigation work, ANP-mixed Hippe oil methyl ester blend fuelled diesel engine performance, emission and combustion characteristics were studied, and based on the experiments the following conclusions were drawn:

- ANP-blended biodiesel (HpOME20+ANP25 HpOME20+ ANP50 and HpOME20+ ANP75) showed an improvement in the calorific value and a reduction in the flash point compared to HpOME20.
- Biodiesel has higher fuel consumption, because of its inferior heating value. With the addition of aluminium oxide nanoparticles, there is a considerable reduction in fuel consumption compared to biodiesel operation and for HpOME20+ANP25 ppm BSFC is found to be 6.896% reduction to Diesel.
- A minor reduction in BTE was observed in all the cases with minimum of 0.38 % (HpOME20 + ANP 25 ppm) w.r.t diesel.
- ANP reduced HC and CO emissions up to 17.77% and 29.21% compared with a biodiesel blend (HpOME20+ANP25), because ANP acts as an oxygen buffer catalyst and donates surface lattice oxygen for the oxidation of HC and CO. NOx emissions increase with the use of ANP and biodiesel blend compared to the diesel fuel.
- The peak pressure increases with the addition of ANP. The addition of ANP reduces the ignition delay period. The heat release rate also increases with the addition of ANP. The addition of ANP accelerates the hydrocarbon combustion and is the reason for the higher heat release rate when compared with neat diesel and biodiesel blend (HpOME20 and SOME2).

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