Hariram et al. 2017. *Int. J. Vehicle Structures & Systems*, 9(2), 103-109
ISSN: 0975-3060 (Print), 0975-3540 (Online)
doi: 10.4273/ijvss.9.2.08

International Journal of
Vehicle Structures & Systems
Available online at www.maftree.org/eja

Effect of Metallic Nano-additives on Combustion Performance and Emissions of DI CI Engine Fuelled with Palmkernel Methyl Ester

V. Hariram[a,b], S. Seralathan[a], M. Rajasekaran[c], M. Dinesh Kumar[a] and S. Padmanabhan[d]

[a]Dept. of Mech. Engg., Hindustan Institute of Tech. & Science, Chennai, India
[b]Corresponding Author, Email: connect2hariram@gmail.com
[c]Dept. of Automobile Engg., Hindustan Institute of Tech. & Science, Chennai, India
[d]School of Mech. Engg., Sathyabama University, Chennai, India

ABSTRACT:

Compression ignition engines are widely used due to their lower energy consumption and enhanced combustion efficiency. In this experimental investigation, the feasibility of fuelling a single cylinder 4 stroke direct injection compression ignition engine with methyl esters of palmkernel (PME) oil along with various fractions of aluminium oxide nano particles (ANOP) were analysed. Two stage transesterification process was adopted to prepare PME. PME20 blend was formulated and fused using high speed homogenizer with varying proportions of AONP as 25 ppm, 50 ppm and 100 ppm in the presence of hexadecyl trimethyl ammonium bromide as surfactant. The experimental investigations were conducted at rated power of 3.5kW at 1500rpm. It was noticed that supplementation of AONP affected the ignition delay significantly favouring enhanced combustion efficiency. The rate of heat release and in-cylinder pressure was substantially increased with notable reduction in ignition delay. Addition of AONP showed an increase in brake thermal efficiency and exhaust gas temperature with diminution in brake specific energy consumption. The unburned hydrocarbons, carbon monoxide and smoke density decreased sharply with an upsurge in NOx. Increase in AONP concentration up-to 100 ppm with PME20 was found to give better combustion and performance characteristics.

KEYWORDS:

Palmkernel methyl ester; Transesterification; Nano particle; Combustion performance; Ignition delay

CITATION:

V. Hariram, S. Seralathan, M. Rajasekaran, M.D. Kumar and S. Padmanabhan. 2017. Effect of Metallic Nano-additives on Combustion Performance and Emissions of DI CI Engine Fuelled with Palmkernel Methyl Ester, *Int. J. Vehicle Structures & Systems*, 9(2), 103-109. doi:10.4273/ijvss.9.2.08.

NOMENCLATURE AND ABBREVIATIONS:

AONP	*Aluminium Oxide Nano Particle*
BDC	*Bottom Dead Centre*
BMEP	*Brake Mean Effective Pressure*
BSEC	*Brake Specific Energy Consumption*
BTE	*Brake Thermal Efficiency*
CAD	*Crank Angle degree*
CO	*Carbon Monoxide*
EGT	*Exhaust Gas temperature*
HRR	*Heat Release Rate*
HSU	*Hartridge Smoke Unit*
NO_X	*Oxides of Nitrogen*
PME	*Palmkernel Methyl Ester*
PME20	*20% PME + 80% Diesel*
PME20 25AONP	*20% PME + 80% Diesel + 25 ppm AONP*
PME20 50AONP	*20% PME + 80% Diesel + 50 ppm AONP*
PME20 100AONP	*20% PME + 80% Diesel + 100 ppm AONP*
HTAB	*Hexadecyl Trimethyl Ammonium Bromide*
SEM	*Scanning Electron Microscope*
TDC	*Top Dead Centre*
UBHC	*Unburned Hydrocarbon*

1. Introduction

Continuous degradation of conventional fossil fuel, increase in demand of energy with higher pricing and environmental pollution hazards urged the researchers to identify an alternative source of energy in liquid form to substitute commercial petro-diesel to a certain extent. Many investigations are carried out in the research world with various sources of non-edible biodiesel which could be a possible replacement of petroleum products in the transportation sector. Pongamia, jatropha, cotton seed, neem, karanja, mahua and many more are the possible non-edible oil sources which can replace the usage of petroleum products to a great extent in their esterified form because straight vegetable oil in internal combustion engine resulted in few limitations like physio-chemical properties, especially kinematic viscosity and density leading to poor combustion efficiency with increased emission. Transesterification is a process of breaking down the triglyceride molecule of vegetable oil into its respective ester in the presence of a catalyst along with an alcohol which releases glycerol as the by-product.

Generally, methanol is used as alcohol and KOH/NaOH is used as catalyst [4-6]. It is evident from literature survey that biodiesel extracted from vegetable oil reduces the HC and CO engine emission with a notable increase in NO_x which is due to oxygen supplement from the ester of vegetable oil leading to better combustion efficiency at higher operating temperatures. In order to control harmful exhaust emission with increased performance, metal based catalysts are used. Numerous investigations revealed that the esterified vegetable oil based fuel in the presence of nano sized metal based catalyst favoured the combustion and performance characteristics with reduced emissions. Since the nano catalyst are in the size of 30nm to 40nm, blending with diesel-biodiesel fuel using surfactants minimizes the fuel clogging, nozzle congestion and other bottle-necking problems [11]. Ozcan et al prepared mixtures of aluminium oxide and copper oxide separately with diesel fuel in varying mass fractions using ultrosonicator. They noticed that the stability of nano particle was better at pH value of 7.7 and 10 for Al_2O_3 and CuO respectively.

The addition of nano particle increased the engine torque and brake power marginally. The emission of UBHC, CO and NO_x was drastically reduced to 6% from 11% [1]. Mahua biodiesel blend was mixed with 50ppm and 100ppm of Al_2O_3 NP using ultrosonicator in the presence of cetyl trimethyl ammonium bromide as surfactant. With a minimum reduction in exhaust emission, they noticed significant increase in engine performance as the concentration of Al_2O_3 nano particle increased [3]. Selvaganapathy et al analysed the effect of adding ZnO NP with diesel fuel on combustion, performance and emission characteristics of CI engine. The tests were conducted with two different samples of 250ppm and 500ppm of NP. It was noticed that the ignition delay was reduced with an increase in rate of heat release and peak in-cylinder pressure. Increase in NOx emission was comprehended in this study [16]. Dong et al conducted series of experiments on Al_2O_3 blended fuel for thermal conductivity and sedimentation properties using 3ω method. They prepared blends of Al_2O_3 nano fluids with de-ionized water and ethylene glycol. The result exhibited that the thermal conductivity of de-ionized water and ethylene glycol was increased due to the sedimentation action of nano fluids [17].

Emulsified fuel of Jatropha methyl ester (JME), water and surfactant with the pH balance of 10 was prepared along with the addition of carbon nanotubes (CNT) at 25ppm, 50ppm and 100ppm. The experiments concluded that an increase in the CNT concentration appreciated the BTE to a great extent. At the same time, reduction in NO_x and smoke was noticed due to secondary atomization and micro-explosion phenomenon associated with CNT at elevated temperatures [8]. Ultrasonicated bath stabilization was adopted for the formulation of diesel-castor oil biodiesel-ethanol emulsified blend with cerium oxide metallic additive at 25 ppm. At higher combustion temperature, oxygen liberated from cerium oxide reduced the formation of CO and NO_x inside the combustion chamber and also aided in burning the carbon traces deposited in the cylinder walls. The BSFC was found to be higher for emulsified blends but reduced marginally with the increase in concentration of cerium oxide. The BTE and peak in-cylinder pressure was found to have significant effect with the addition of metallic NP [10]. The present experimental investigation aims at analysing the feasibility of using Al_2O_3 NP with diesel-biodiesel blends of PME at 25ppm, 50ppm and 100ppm. The physiochemical properties of AONP-biodiesel blends were noticed to be within ASTM standards. The combustion, emission and performance parameters were analysed using single cylinder direct injection compression ignition engine.

2. Biodiesel - Nano fluid preparation

Palmkernel oil was extracted from its seed procured from a local vendor in Chengalpattu, Tamil Nadu, India through crushing techniques using mortar-pestle grinder. 450ml of crude palmkernel oil was obtained with 8.5% free fatty acid content. Two stage transesterification process was adopted for deriving biodiesel. 5% of concentrated HCL and 225ml of methanol was thoroughly mixed with 100ml of crude palmkernel oil. The mixture was maintained at 480rpm, 80min and 65°C for reducing the FFA content to less than 2%. Sedimented slurry was separated for oil recovery followed by base catalysed transesterification. Molar ratio of 1:6 was maintained by adding sodium methoxide solution (2.5gms of NaOH and 200ml of methanol) in processed palmkernel oil. Biodiesel was obtained with glycerol layer formation at 85°C, 240rpm and 2hrs of reaction temperature, agitation speed and reaction temperature respectively. Careful removal of glycerol and washing of biodiesel resulted in the extraction of 74.6ml of palmkernel biodiesel at 93% of transesterification efficiency [14].

Aluminium oxide nano particle was characterized by its spherical structure obtained using SEM image as shown in Fig. 1. The average size of AONP was noticed to be between 30nm and 40nm. Amalgamated fusion of nanoparticles was processed using high speed homogenizer. Hexadecyl trimethyl ammonium bromide (HTAB-$C_{16}H_{33}$-N+$(CH_3)_3$Br-) was used as a surfactant to reduce the surface energy of AONP to prevent it from sedimentation due to macro molecule formation. Low speed agitation at 600 rpm was maintained to distribute the nano particle evenly throughout the mixture. Nano fluid solutions were prepared at 25ppm, 50ppm and 100ppm of AONP by weight along with HTAB and ethanol mixtures at 450rpm for 90 minutes following the above procedure. The nano fluid solution of 25ppm, 50ppm and 100ppm was mixed with palmkernel biodiesel separately. The mixture was steadily agitated for even distribution. A magnetic stirrer was employed at 450rpm for 60 minutes individually to ensure minimal or nil sedimentation of nano particle for the preparation of 25AONP, 50AONP and 100AONP biodiesel blends [7-10]. The physiochemical properties of these biodiesel blends are given in Table 1.

Fig. 1: Al_2O_3 nano particle and its SEM image

Table 1: Comparison of physio-chemical properties

Fuel / Properties	Diesel	Palmkernel biodiesel	PME20 25AONP	PME20 50AONP	PME20 100AONP
Density @ 15°C (kg/m^3)	834	880	838	839	843
Kinematic viscosity @ 40°C (cSt)	3.7	3.68	3.54	3.49	3.42
Calorific value (kJ/kg)	42200	38400	41440	41680	41890
Cetane number	47	48	49.5	50	51.2
Flash point (°C)	52	162	68	64	62
Fire point (°C)	59	176	71	69	67
Acid number (mg KOH/g)	0.01	0.03	0.032	0.031	0.033

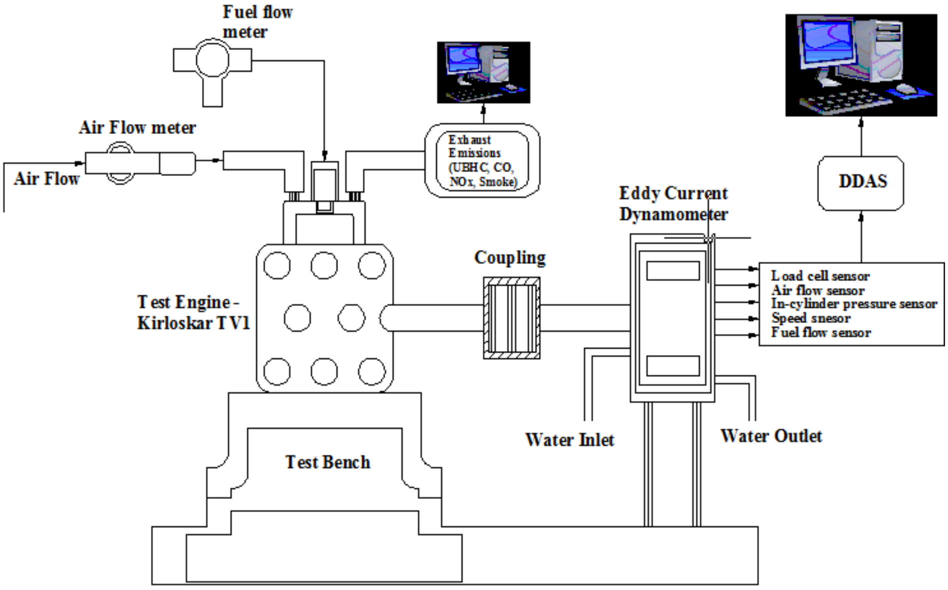

Fig. 2: Schematic diagram of experimental setup

3. Experimentation

A single cylinder, four stroke, water cooled, direct injection compression ignition engine of Kirloskar make (Kirloskar 240PE) was experimented in this investigation with a bore diameter and stroke length of 87.5mm and 110mm respectively. The schematic experimental set up is shown in Fig. 1. The cubic capacity was noticed to be 661.45cc with a rated power of 3.5kW at 1500rpm. The loading was carried out using eddy current dynamometer with stain gauge type load cell. The in-cylinder pressure was measured using piezoelectric transducer ranging between 0 and 350 bar along with RTD thermocouple for temperature measurement. The detailed specification of test engine setup is given in Table 2. Kistler made piezoelectric transducer was used to measure the in-cylinder pressure rise. AVL 5 gas analyser and AVL smoke meter were employed for analysing the emission data. Straight diesel was primarily used to derive the base data of the engine averaging 10 cycles which was followed by fuelling blend of PME 20. Biodiesel emulsified with metallic nano additive (PME20 25AONP, PME20 50AONP and PME20 100AONP) were investigated experimentally to analyse the performance, combustion and emission parameters. All the experiments were carried out at rated power of 3.5kW @1500rpm rated speed across all loading conditions.

Table 2: 240PE/Kirloskar single cylinder engine specifications

Description	Specification
Bore	87.5mm
Stroke length	110 mm
Compression ratio	17.5:1
Rated power	3.5 kW
Rated Speed	1500 rpm
Injection timing	23°bTDC
Connecting rod length	234 mm
Cubic capacity	661.45 cc
Orifice diameter	20 mm
Orifice co-efficient discharge	0.60
Dynamometer arm length	185 mm
Fuel pipe diameter	12.40 mm
Nature of cooling	Water cooling
Type of loading	Eddy current dynamometer
Load cell	Stain gauge type
Pressure sensor range	0-350 bar
Temperature sensor	RTD thermo-couple

Table 3: Uncertainties of instruments and parameters

Instrument / Parameters	Uncertainty (%)
Pressure transducer	± 1.04
Speed	± 1.2
Crank angle encoder	± 0.6
Thermocouple	± 0.85
BTE	± 1.8
Load	± 0.6
Temperature	± 0.4
BSEC	± 1.4

3.1. Estimation of uncertainty

The measurement of combustion, performance and emission parameters by instruments of different manufacturers and technologies were used in this investigation. The accuracy of measurement also depends on the environmental condition and human aspects along with instrumental errors. Therefore it is necessary to analyse the fraction of errors and uncertainties in the experimental investigation [15]. The total uncertainties of this investigation was calculated based on 2σ root mean square method and found to be 2.08% considering the Eqns. (1) and (2).

$$\Delta X_a = \left(2\sigma_a / \overline{X_a}\right) \times 100 \qquad (1)$$

$$\Delta A = \sqrt{\left(\partial A/\partial X_a(\Delta X_a)\right)^2 + \left(\partial A/\partial X_b(\Delta X_b)\right)^2 + \ldots.\left(\partial A/\partial X_n(\Delta X_n)\right)^2} \qquad (2)$$

4. Result and discussions

The variations of in-cylinder pressure with respect to crank angle for straight diesel, PME blends with metallic nano additives at full load condition is shown in Fig. 3(a). It can be noticed that, pressure rise at 8° before TDC for straight diesel and 6° before TDC for PME blended with AONP signifies the importance of premixed combustion period. The peak in-cylinder pressure was found to have favourable effect with the increase in concentration of aluminium oxide nano additive up-to 100 ppm with the reduction in the period of rapid combustion. This may be due to the increase in surface contact area and liberation of enhanced oxygen molecule at high concentration of aluminium oxide nano particle. It was also observed that, with increase in engine load, PME20 100AONP enhanced the combustion performance by shortening the ignition delay which in-turn increased the cylinder was temperature and residual gas temperature to a great extent. From Fig. 3(a), it can be noticed that, the in-cylinder pressure for straight diesel, PME20, PME20 25AONP, PME20 50AONP and PME20 100AONP was 63.97 bar, 61 bar, 63.8 bar, 65.46 bar and 67.5 bar respectively at full load condition [2].

Fig. 3(b) exhibits the variation of heat release rate for straight diesel, PME20, PME20 25AONP, PME20 50AONP and PME20 100AONP fuel blends for a combustion cycle at full load operation. The HRR indicates the amount of useful work considering the heat energy released during the combustion cycle. It can be noticed that reduction in flash point and increase in calorific value with the increase in concentration of AONP favours the shortening of ignition delay with prolonged premixed combustion period leading to higher rate of heat release. Higher temperature reactions for converting methyl ester of palmkernel biodiesel (diglycerides to monoglycerides) liberates gaseous hydrocarbon compounds acting as pre-igniters also helps in reduction of ignition delay to a great extent. It can be noticed from Fig. 3(b) that heat release rate for straight diesel, PME20, PME20 25AONP, PME20 50AONP and PME20 100AONP was 48.43 J/CAD, 45.54 J/CAD, 51.58 J/CAD, 54.89 J/CAD and 58.2 J/CAD respectively at full load condition [12].

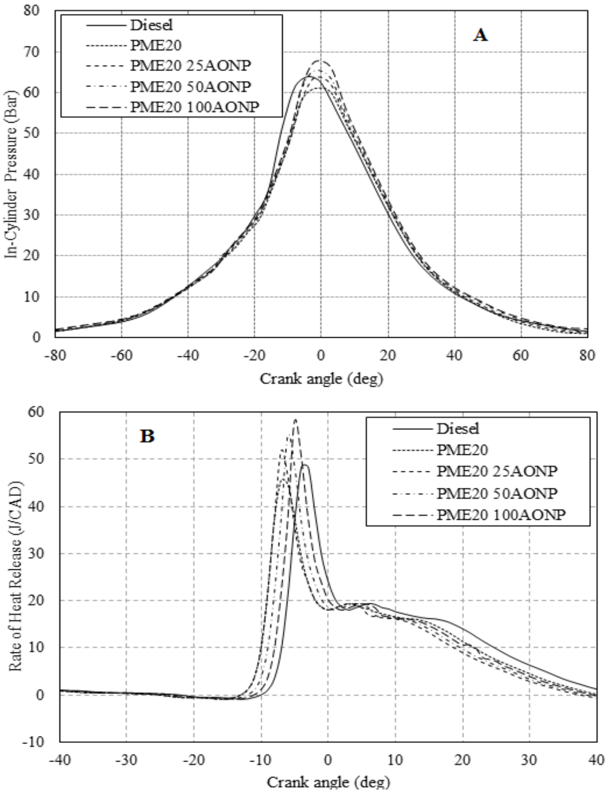

Fig. 3: Variation of in-cylinder pressure and HRR with diesel, biodiesel and metallic nano-particle additive at full load

The variation in BSEC for straight diesel, PME20, PME20 25AONP, PME20 50AONP and PME20 100AONP at all load against BMEP is shown in Fig. 4(a). It can be seen that PME20 exhibit higher BSEC than diesel fuel due to lower calorific value of 38400 kJ/kg throughout the entire operation to obtain the same power as an output. Addition of AONP to PME20 blend decreases the BSEC marginally leading to better combustion. Increase in the concentration of AONP up-to 100ppm reduces the BSEC significantly at all loads due to oxidation of deposited HC molecules on the crevice volume and other in-cylinder parts. Decrease in the BSEC may also be due to increase in fuel density and reduction in kinematic viscosity. It can be noted from the graph that, at low load, the BSEC of all fuel was nearly same but part and full load exhibited significant reduction in BSEC especially PME20 100AONP showed 8% to 10% lower BSEC than straight diesel.

Fig. 4(b) shows the variations of BTE of straight diesel, PME20 as well as AONP blends of PME20 against BMEP at all loading condition. It is observed that, the BTE increased steadily for all fuel blends especially PME20 50AONP and PME20 100AONP showed significant rise in BTE at full load condition which may be due to super heating temperature prevailing in the cylinder causes the oxidizing of AONP leading to micro explosion and minor droplet formation in the combustion chamber leading to ancillary atomization. This ancillary atomization increases the active surface area to volume ratio which in-turn admits enhanced fuel reaction leading to better combustion efficiency at higher loads. From the Fig. 4(b), it can be noticed that the BTE for straight diesel, PME20, PME20 ANOP25, PME20 50AONP and PME20 100AONP was 26.8%, 26%, 27.5%, 28.5% and 29.1% respectively.

The variations of exhaust gas temperature with brake mean effective pressure for straight diesel, PME20 and a blend of PME20 with AONP at all loads is shown in Fig. 4(c). It can be noticed that, there is a gradual increase in EGT across all fuel blends with increasing load. The EGT of straight diesel was found to be 490°C at full load whereas PME20 exhibited 485°C which was 8% to 10% lesser than diesel fuel may be instigated due to significant reduction in calorific value. Addition of AONP with PME20 gradually increased the EGT as shown in Fig. 4(c). PME20 25AONP, PME20 50AONP and PME20 AONP100 exhibited 510°C, 530°C and 552°C of EGT at full load condition. This may be due to supplement of additional oxygen by AONP at higher concentration leading to enhanced premixed combustion period. Ignition delay is primarily responsible for premixed and diffusive combustion period releasing the amount of heat energy. Fig. 4(d) depicts the variation of ignition delay for straight diesel, PME20 and PME20 blended with AONP against BMEP at all loads. It can be seen that PME20 exhibits higher ignition delay on comparison with straight diesel. The ignition delay period was gradually reduced with the increase in concentration of nano particle with diesel-biodiesel blends which was also revealed by J. Sadhik Basha and R.B. Anand in their study [13]. PME20 50AONP and PME20 100AONP exhibited nearly 15% to 17% reduction in ignition delay as shown in Fig. 4(d) may be due to increase in active surface area encouraging early chemical reactions during the admittance of fuel particles. It is clear that increase in AONP concentration significantly reduces the ignition delay resulting in enhanced combustion reactions.

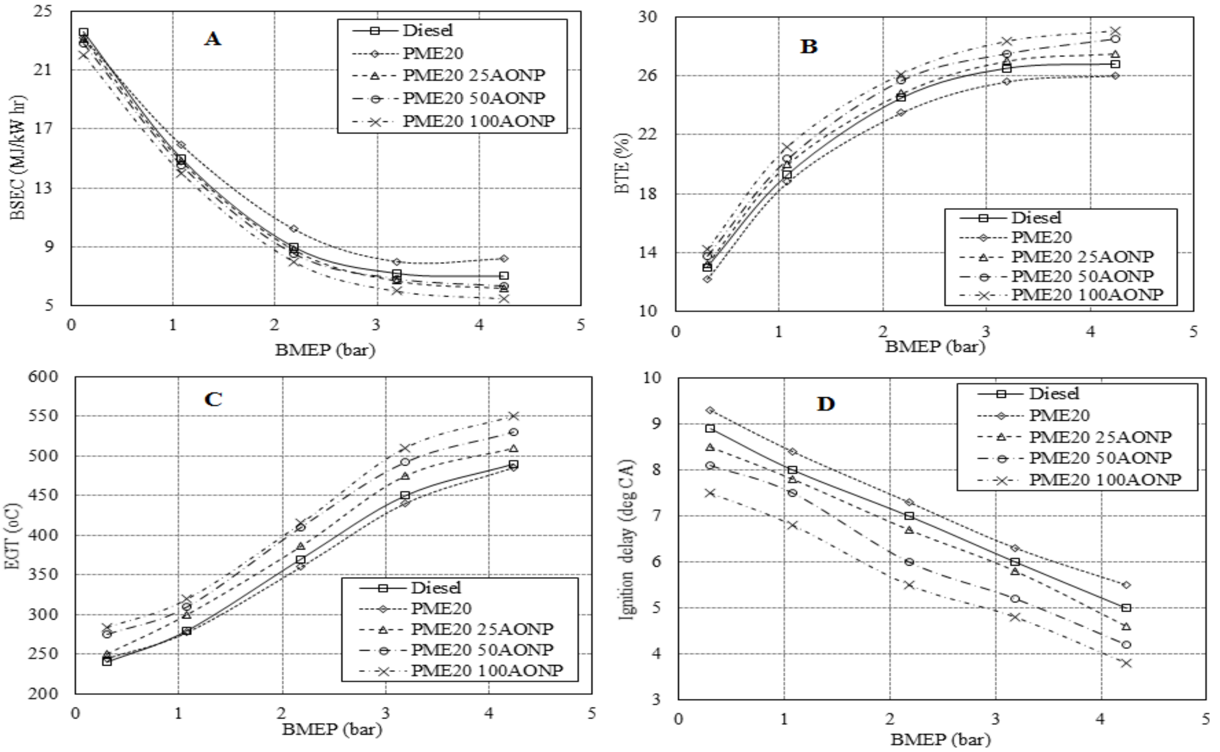

Fig. 4: Variations of BSEC (a), BTE (b), EGT (c) and Ignition delay (d) with diesel, biodiesel and Metallic nano-particle additive at all loads

Fig. 5(a) depicts the comparison of UBHC emission with respect to straight diesel, PME20 and blends of PME20 with AONP at 25, 50 and 100ppm at all loads. It can be seen that, the UBHC emission reduces with the increase in concentration of AONP but marginal increase was noticed with PME20 blend at part load condition. Since oxygen supplement during combustion plays a vital role in the formation of UBHC, the addition of AONP increase the quantity of oxygen lessening the formation and emission of unburned hydrocarbons. The UBHC emission was noticed to be 0.212 g/kWhr, 0.184 g/kWhr, 0.173 g/kWhr, 0.142 g/kWhr and 0.118 g/kWhr for straight diesel, PME20, PME20 25AONP, PME20 50AONP and PME20 100AONP respectively. This gradual decrease in UBHC may also be due to catalysed ignition improvement of AONP, augmented fuel air mixing and ancillary atomization of fuel blend preventing the formation of UBHC to a large extent.

Oxides of nitrogen being the most important emission of CI engine, depends mainly on the in-cylinder temperature, fuel atomization characteristics and premixed combustion period. Fig. 5(b) exhibits the NO_x emission variation for straight diesel, PME20 and PME20 AONP blends at all loading condition. It can be noticed that NO_x emission increases gradually across all fuel blends with escalation of load. Straight diesel, PME20, PME20 25AONP, PME20 50AONP and PME20 100AONP exhibited 5.152g/kWhr, 5.375g/kWhr, 5.992g/kWhr, 6.215g/kWhr and 6.472g/kWhr of NO_x respectively. With the increase in nanoparticle concentration, the ignition delay was largely reduced resulting in deprived premixed combustion period and thereby intensifying the diffusive combustion phase emitting more NO_x. The increase in adiabatic flame temperature at higher load for AONP blended fuel also supported the formation of NO_x.

The variation in carbon-monoxide emission for straight diesel, PME20 and PME20-AONP blends with BMEP is shown in Fig. 5(c). The emission of CO was almost similar and lower across all the fuel blends at low load condition, but with increase in load, straight diesel and PME20 showed drastic increase in CO emission. From the Fig., it can be noticed that at full load condition, straight diesel, PME20 25AONP, PME20 50AONP and PME20 100AONP exhibited 7.584g/kWhr, 6.972g/kWhr, 5.762g/kWhr, 4.987g/kWhr and 3.876g/kWhr respectively. It is clear from the Fig. that absence of nano particle aggravated the formation and emission of CO whereas PME20 25AONP, PME20 50AONP and PME20 100AONP fuel blends showed lower CO emission which may be due to catalytic action in supplementing oxygen during combustion by AONP, reduction in ignition delay period and augmented active surface area of AONP resulting in complete combustion. The main reason behind the emission of smoke is incomplete combustion of fuel in the period of diffusive combustion.

Addition of nanoparticle reduced the ignition delay significantly enhancing the diffusive combustion phase and thereby smoke emissions are reduced. Fig. 5(d) depicts the variation of smoke density of all fuel blends with BMEP across all loads. It can be noticed that straight diesel, PME20 25AONP, PME20 50AONP and PME20 100AONP emitted 68HSU, 65HSU, 59HSU, 61HSU and 52HSU of smoke respectively. This deterioration in smoke density could be possibly caused due to higher supplementation of oxygen by AONP during diffusive combustion phase. On the other hand, AONP being ignition activists reduces ignition delay thereby providing more time period for oxidizing the hydrocarbon fuel particle accumulated during the combustion cycle.

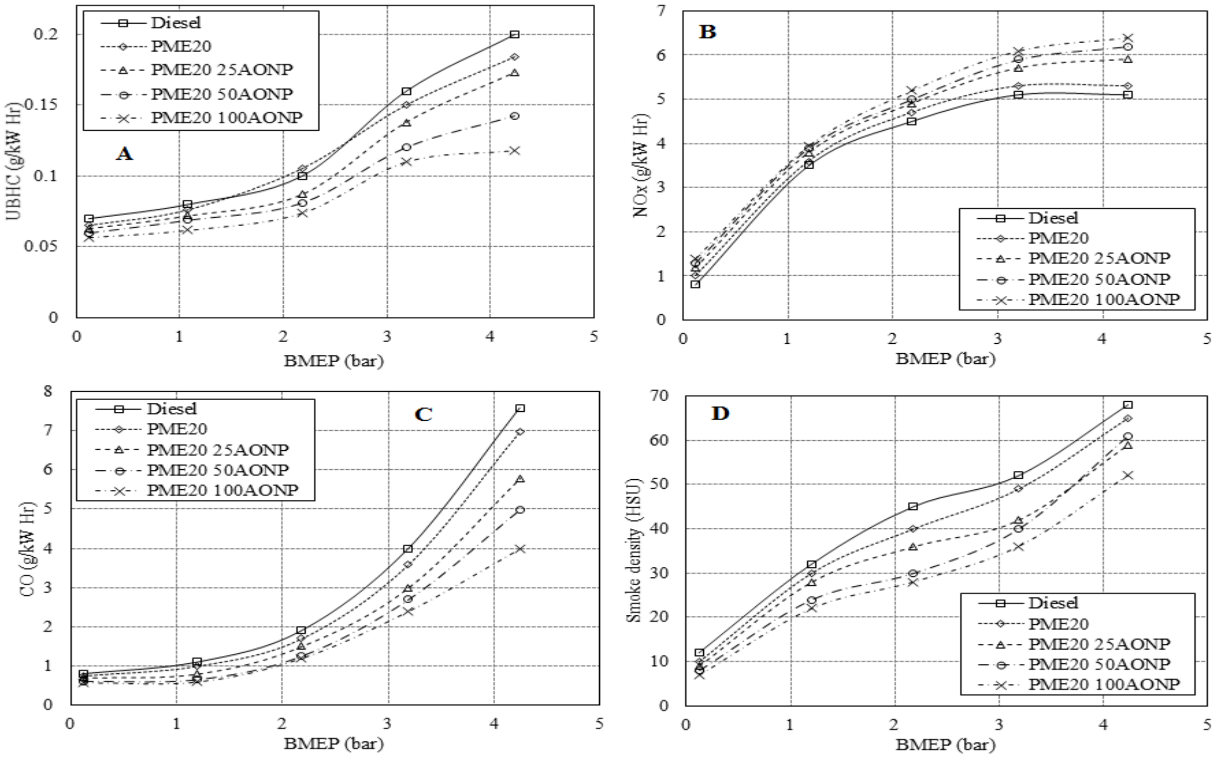

Fig. 5: Variations of UBHC (a), NOx (b), CO (c) and Smoke (d) Emissions with diesel, biodiesel and metallic nano-particle additive at all load

5. Conclusions

In the present experimental investigation, the feasibility of amalgamating the methyl esters of palmkernel oil with aluminium oxide nanoparticle was carried out and the following conclusions were drawn.

- Palmkernel biodiesel was produced through two stage transesterification with NaOH as catalyst at molar ratio of 1:6 and the esterification efficiency was noticed to be 93%.
- High speed homogenizing technique successfully fused AONP with palmkernel biodiesel at fractions of 25ppm, 50ppm and 100ppm using hexadecyl trimethyl ammonium bromide (HTAB).
- Addition of AONP showed significant increase in density, calorific value and cetane number with a marginal decrease in kinematic viscosity.
- Increase in concentration of AONP greatly influenced the ignition delay resulting in enhanced combustion efficiency. Higher in-cylinder pressure was observed for PME20 100AONP at full load condition.
- Augmented diffusive combustion phase resulted in higher heat release rate with increase in AONP concentration.
- PME20 exhibited higher BSEC than straight diesel but found to be diminishing significantly at higher load with more AONP supplement.
- The BTE and EGT was found to be higher with increasing load for all blends of fuel, especially higher AONP concentration exhibited better BTE and higher EGT.
- Smoke and UBHC emission was found to decrease with escalation in AONP concentration. At part

load condition, PME20 showed higher BSEC emission than straight diesel.

- NO_x emission was noticed to be continuously escalating with the addition of AONP due to prolonged diffusive combustion phase leading to better combustion.
- Higher CO emission was noticed for PME20 and straight diesel. Addition of AONP suppressed the formation and emission of CO to a large extent.

ACKNOWLEDGEMENTS:

The authors acknowledge the Centre of Nano Energy and Convergence (CENCON), Hindustan Institute of Technology and Science, Padur for providing support to characterizing the nano particle.

REFERENCES:

[1] S. Gumus, H. Ozcan, M. Ozbey and B. Topaloglu. 2016. Aluminum oxide and copper oxide nanodiesel fuel properties and usage in a compression ignition engine, *Fuel*, 163, 80-87. https://doi.org/10.1016/j.fuel.2015.09.048.

[2] Y. Gan and L. Qiao. 2011. Combustion characteristics of fuel droplets with addition of nano and micron-sized aluminium particles, *Combustion and Flame*, 158, 354-368. https://doi.org/10.1016/j.combustflame.2010.09.005.

[3] C.S. Aalam and C.G. Saravanan. 2015. Effects of nano metal oxide blended Mahua biodiesel on CRDI diesel engine, *Ain Shams Engg. J.*. https://doi.org/10.1016/j.asej.2015.09.013.

[4] C.S. Aalam, C.G. Saravanan and M. Kannan. 2015. Experimental investigations on a CRDI system assisted diesel engine fuelled with aluminium oxide nanoparticles blended biodiesel, *Alexandria Engg. J.*, 54, 351-358. https://doi.org/10.1016/j.aej.2015.04.009.

[5] Anbarasu, A. Karthikeyan and M. Balaji. 2016. Performance and emission characteristics of diesel engine using alumina nanoparticle blended biodiesel emulsion fuel, *ASME Trans. J. Energy Resources Tech.*, 138, 022203-6.

[6] R. Bharathiraja, N. Praveenkumar, K.S. Amirthagadeswaran, S. Periyasamy and K. Rameshbabu. 2015. Study on characteristics of CI engine using nano additive blended diesel fuel, *Int. J. Applied Engg. Research*, 10(67), 328-334.

[7] J.S. Basha and R.B. Anand. 2013. The influence of nano additive blended biodiesel fuels on the working characteristics of a diesel engine, *J. Braz. Soc. Mech. Sci. Engg.*, 35, 257-264. https://doi.org/10.1007/s40430-013-0023-0.

[8] J.S. Basha and R.B. Anand. 2014. Performance, emission and combustion characteristics of a diesel engine using carbon nanotubes blended jatropha methyl ester emulsions, *Alexandria Engg. J.*, 53, 259-273. https://doi.org/10.1016/j.aej.2014.04.001.

[9] A. Selvaganapthy, A Sundar, B. Kumaragurubaran and P. Gopal. 2013. An experimental investigation to study the effects of various nano particles with diesel on DI diesel engine, *ARPN J. Sci. and Tech.*, 3 (1), 112-115.

[10] V.A.M. Selvan, R.B. Anand and M. Udayakumar. 2008. effects of cerium oxide nanoparticle addition in diesel and diesel-biodiesel-ethanol blends on the performance and emission characteristics of a CI engine, *ARPN J. Engg. and Applied Sci.*, 4(7), 1-6.

[11] A.A.T. Bafghi, H. Bakhoda and F.K. Chegeni. Effects of cerium oxide nanoparticle addition in diesel and diesel-biodiesel blends on the performance characteristics of a CI engine, *Int. J. Mech., Aerospace, Industrial, Mechatronic and Manufacturing Engg.*, 9(8), 1415-1420.

[12] S. Tajudeen and R. Velraj. 2014. Nanoadditives: enhancement of combustion and performance characteristics of a CI diesel engine, *Int. J. Applied Environmental Sci.*, 9(4), 1727-1741.

[13] J.S. Basha and R.B. Anand. 2011. Role of nanoadditive blended biodiesel emulsion fuel on the working characteristics of a diesel engine, *J. Renewable and Sustainable Energy*, 3, 1-6. https://doi.org/10.1063/1.3575169.

[14] V. Hariram, S. Seralathan, M. Dineshkumar, S. Vasanthaseelan and M. Sabareesh. 2016. Analyzing the fatty acid methyl esters profile of palmkernel biodiesel using GC/MS, *NMR and FTIR techniques*, 9(4), 3122-3128.

[15] V. Hariram and R.V. Shangar. 2015. Influence of compression ratio on combustion and performance characteristics of direct injection compression ignition engine, *Alexandria Engg. J.*, 54, 807-814. https://doi.org/10.1016/j.aej.2015.06.007.

[16] A. Selvaganapthy, B. Sundar, P. Kumaragurubaran and Gopal. 2013. An experimental investigation to study the effects of various nanoparticles with diesel on DI diesel engine, *APRN J. Sci. Tech.*, 3(1), 112-115.

[17] D. Wook Oh, A. Jain, J.K. Eaton, K.E. Goodson and J.S. Lee. 2008. Thermal conductivity measurement and sedimentation detection of aluminium oxide nanofluids by using the 3ω method, *Int. J. Heat & Fluid Flow*, 29, 1456-1461. https://doi.org/10.1016/j.ijheatfluidflow.2008.04.007.