Influence on diesel engine using *Chlorellea emersonii* methyl ester (CEME) biodiesel and its blend with Aluminum oxide nanoparticles

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Abstract

The impact of combining Aluminum oxide (AL₂O₃) nanoparticles in a *Chlorellea emersonii* methyl ester biodiesel is investigated in this study. Different proportions viz 10 ppm, 20 ppm and 30 ppm of AL₂O₃ nano particle were doped with B30 and blends B30 + 10 ppm, B30 + 20 ppm and B30 + 20 ppm were prepared for experimentation. Better results obtained for all 3 blends especially B30 + 20 ppm AL₂O₃ yielded 45%, 41%, 75% reduction in CO, HC and smoke. Better performance and emission was also note. The proportion of alumina nanoparticles in diesel fuel increased cylinder pressure, temperature, and heat release rate, but decreased ignition delay and combustion duration. AL₂O₃ doping in fuels also enhanced properties such as increase in calorific value and cetane number and reduction in viscosity. Hence better atomization and vapourisation were obtained. For the best benefits in the engine’s combustion, performance, and emission characteristics, the concentration of B30-20 ppm alumina nanoparticle is advised.

Keywords: Aluminum oxide, *Chlorellea emersonii*, Combustion, Performance

1. Introduction

Over past few decades the growth of world population is increasing exponentially. And hence energy consumption also increasing rapidly such as solar, thermal, wind, crude oil and nuclear power sources. Incase of transport sector the count of vehicle is increasing day to day which is the main reason for fossil fuel depletion. It is expected that these fossil fuel such as diesel and petrol obtained from crude oil is expected to deplete in next 10—15 years of time. Kowthaman *et al.* investigated the synthesis of CNT (carbon nanotube) from tailpipe suit emission. It was characterized using X-ray diffraction, Raman spectrography, scanning electron microscopy and thermogravimetric analysis. CNT with two concentrations of 25 ppm and 50 ppm were mixed ultrasonically with methyl ester of Schizochytrium (SCME). Two different blends of SCME20 (20% SCME+ 80% diesel) were used. Addition of nanoparticle improved thermal efficiency by 2.5% and decreased BSFC by 3.2%. HC,CO, NOx and smoke reduced by 14.28%,22.175,5.1% and 22.15% for 50 ppm concentration of CNT in SCME20 blend and is treated as optimum blend. Kalaimurugan *et al.* conducted experiment using copper oxide nanoparticles as nano additives in methyl ester derived from neochloris oleoabundans algae. B20 blend, B20 + 25 ppm, B20 + 50 ppm, B20 + 75 ppm and B20 + 100 ppm blends were used for testing in engine. Good performance, combustion and emission results were obtained for B20 + 50 ppm cupric oxide blend. Addition of nanoparticle enhances combustion and reduces emissions. Jayaraman *et al.* used pig fat oil methyl ester as alternative fuel in stationary diesel engine. 20% blend fuel B20 is used for present experiment. Up to 150 ppm TiO₂ nanoparticle was tested in biodiesel. B20 + 50 ppm and B20 + 100 ppm showed less BSFC
and NOx emission. With increasing nanoparticle concentration carbon emissions reduced. B20 blend with 100 ppm considered as optimum blend.

Manoj et al. investigated diesel engine using Mahua biodiesel and its blend with synthesized zinc oxide nanoparticles. Engine setup with 7 holes toroidal reentrant combustion chamber and common rail (CRDI) were used for present experiment. ZNO nanoparticle of 30 ppm strength doped with Mahua biodiesel (MOME30) blend showed better results than other with 9.65 rise in BTE. Other results such BSFC reduced by 10.9%, HC, CO smoke and NOx reduced by 15% 5% 20% and 11%. MOME30 ppm showed enhanced results than other blends.

A combination of 50% diesel, 20% by-pentanol, 20% biodiesel, and 10% sunflower oil was used in an experiment by Saimanoj et al. in a single-cylinder diesel engine. Alumina nano with 50 ppm and 100 ppm strength were used in above stated fuel. Test results showed better performance, combustion results with reduced emissions were obtained for 100 ppm doped Al2O3 blend. Thus 100 ppm Al2O3 nanoparticle in fuel chosen as optimum blended fuel.

Praveen et al. experimental diesel engine using waste plastic oil and honge oil. Initially transesterification was done to reduce viscosity. Alumina nano additives was synthesized and mixed with B20 (20% biodiesel with 80% diesel). These fuels were subjected to different loadings in diesel engine. Improvement in results was noted for B20 with Al2O3 nanoparticle. In comparison to diesel, BTE increased significantly but emissions of unburned hydrocarbon, carbon monoxide, carbon dioxide, smoke, and nitrous oxides decreased little. Nano additions have improved B20 blend combustion.

EL-Seesy et al. used alumina nano additives and oleic acid as additive in biodiesel obtained from seaweed biomass. Additive strength of 10 ppm, 20 ppm and 50 ppm were used for experimentation. These fuels were tested in single cylinder, stationary diesel engine. Test results showed better performance, reduced emissions of additive fuel than non-additive and diesel fuel. 50 ppm strength fuel exhibited better and chosen as optimum blend.

Hoseini et al. experimented stationary laboratory diesel engine using oenothera lamarckiana biodiesel with and without graphene oxide (GO) nano additive. Strength of GO varied to 30, 60 and 90 ppm constant speed of 2100 rpm with 0%, 25%, 50% 75% and 100% loads were varied. Significant reduction in carbon monoxide (5–22%) and unburned hydrocarbon (17–26%) were noted. Minor increase in CO2 (7–11%) and Oxides of Nitrogen (4–9%) were noted. GO strength of 60 ppm in fuel showed better results.

Jojoba biodiesel was used in an experiment by Ahmed et al. on a diesel engine. Initially transesterified fuel ie Methyl ester of jojoba biodiesel was tested in engine. Results obtained showed rise in emissions to reduce emission. TiO2 nanoparticles was added with J50D40Bu BLEND (Jojoba 50% + 40% diesel and 10% n-butane) with strengths of 25 mg/L and 50 mg/L. TiO2 addition to J50D40Bu showed rise in peak pressure and heat release rate of up to 2% and 1.45%. Reduction in BSFC, CO and UHC accounted to 17%, 31% and 52% respectively. Rise in NOx with an average of 30% occurred. TiO2 prove to be a potential technique to reduce emissions and improve performance.

Karthikeyan et al. The study investigates the effect of aluminium oxide nanoparticles as additive to pongamia 11 methyl ester (PME) blends on performance, combustion and emission characteristics of a single cylinder direct injection diesel engine operated at constant speed at different operating 13 conditions. The test fuels are indicated as B25 (75% diesel and 25% PME) and B25A50 (75% 14 diesel and 25% PME and 50 ppm Aluminium oxide nanoparticles) respectively. The results indicate that 16 the brake thermal efficiency for aluminium oxide nanoparticles blended pongamia methyl ester 17 increases slightly while brake specific fuel consumption (BSFC) decreases when compared to 18 other blends. The carbon monoxide (CO), unburnt hydrocarbon (HC) and smoke emission 19 marginally decreases as compared to mineral diesel. Oxides of nitrogen (NOx) emissions are 20 higher for aluminium oxide nanoparticles blended pongamia methyl ester.

Ramesha et al. Experiments were conducted to determine engine performance, exhaust emissions and combustion characteristics of a single cylinder, common rail direct injection (CRDI) system assisted diesel engine using diesel with 25% of ziziphus jujube methyl ester blended fuel (ZJME25). Along with this ZJME25 aluminium oxide nanoparticles were added as additive in mass fractions of 25 ppm (AONP 25) and 50 ppm (AONP 50) with the help of a mechanical Homogenizer and an ultrasonicator. It was observed that aluminium oxide nanoparticles blended fuel exhibits a significant reduction in specific fuel consumption and exhaust emissions at all operating loads.

Jayaseelan et al. used chlorella vulgaris biodiesel with Al2O3 nanoadditive in single cylinder diesel
2. Materials and methods

2.1. Test fuel and nanoadditives

The present research work aims to conduct experiments using CEME as an alternative fuel in diesel engines. Many attempts were made in fuel and engine modification to enhance performance, combustion, and emission results. This chapter shows the method used for preparing test fuel and nanoparticles, their characteristics, and comparing their properties.

Initially, chlorella emersonii methyl ester is prepared using the transterification process. Different blends of CEME are prepared using a magnetic stirrer arrangement to maintain the homogeneity of the blend. Blends like B10, B20, and B30 were created, and each one’s attributes were determined using ASTM criteria (Table 1). Diesel was used to compare various qualities.

The following inferences were obtained from the fuel properties table.

(1) The viscosity of the blend was close to diesel, so better atomization is expected.

<table>
<thead>
<tr>
<th>Properties</th>
<th>Diesel</th>
<th>B10-CEME</th>
<th>B20-CEME</th>
<th>B30-CEME</th>
<th>B100-CEME</th>
</tr>
</thead>
<tbody>
<tr>
<td>Density @ 15 °C, kg m⁻³</td>
<td>838</td>
<td>842</td>
<td>854</td>
<td>862</td>
<td>887</td>
</tr>
<tr>
<td>Kinematic viscosity @ 40 °C, cSt</td>
<td>1.82</td>
<td>2.12</td>
<td>2.25</td>
<td>2.36</td>
<td>3.96</td>
</tr>
<tr>
<td>Calorific value, MJ/kg</td>
<td>42.7</td>
<td>41.56</td>
<td>41.56</td>
<td>41.56</td>
<td>38.9</td>
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<tr>
<td>Flash point, °C</td>
<td>68</td>
<td>72</td>
<td>77</td>
<td>88</td>
<td>201</td>
</tr>
<tr>
<td>Cetane number</td>
<td>48</td>
<td>47</td>
<td>48.2</td>
<td>49.65</td>
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<tr>
<td>Water content</td>
<td>0.02</td>
<td>0.03</td>
<td>0.03</td>
<td>0.035</td>
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</table>

(2) The calorific value is slightly lower but close to that of diesel. Hence, better BTE and BSFC results can be expected.

(3) The cetane number also increased with an increase in CEME biodiesel concentration in diesel.

(4) A marginal rise in flashpoint is observed in diesel; hence, good combustion quality is said to occur.

2.2. Preparation of alumina nanoparticles

A solution of aluminium nitrate with 0.5 M strength is added to water at a temperature of 50 °C and stirred using a magnetic stirrer setup. Urea (0.05 M strength) is added to the solution and kept to react for 30 min until a pH value of 2 is obtained. The obtained solution is titrated with NaOH of 0.1 M strength. The thus obtained sample is dried at 300 °C and kept idle in the furnace for 2 h. Finally, an Al₂O₃ nanoparticle is obtained.

Synthesized Al₂O₃ nanoparticles with 10 ppm, 20 ppm, and 30 ppm strength are doped with a B30 fuel blend. To avoid the accumulation of nanoparticles in fuel, ultrasonication is used for 30 s. After that, blend fuel is stored in a clear test tube for a considerable amount of time without forming any sediment or phase separation (Fig. 1).

The properties of these blends were determined using ASTM standards and tabulated.

(1) A marginal rise in density was observed.
(2) Reduced kinematic viscosity is noted.
(3) Calorific value and Cetane number are also enhanced.

It was commonly observed that the enhanced properties were observed up to 20 ppm and the inferior properties were obtained beyond 20 ppm, i.e., 30 ppm.

A precursor solution of 0.6 M was prepared using AlCl₃.6H₂O dissolved in ethanol (95%). The precipitating agent, liquid ammonia (1.0 M) was added dropwise to the ethanol solution with continuous stirring and this resulted in formation of a gelatinous white precipitate of Al(OH)₃.
resultant precipitate was filtered and washed with ethanol followed by oven drying at 90 °C for 6 h. The dried white gel was calcined in a muffle furnace at 600 °C for 3 h in the presence of air at a heating rate of 10 °C/min, thus transforming Al(OH)3 into Al2O3 powder (Table 2). After calcination, the calcined powder was milled and sieved. A yield of 91% was obtained.

2.3. Experimental setup

A single-cylinder, air-cooled, four-stroke direct injection stationary research engine was employed for the current experiment. Using a smoke metre, the Avl437C detects smoke. In Fig. 2, the full experimental setup is depicted. Within an engine, SAE100 lubricating oil is used to lessen friction between moving elements (Table 3).

3. Result and discussion

Thus B30-CEME is an optimum fuel blend. In order to improve the performance, emission and combustion characteristics of B30 fuel further, alumina nanoparticle is doped with fuel with different strength viz 10 ppm, 20 ppm and 30 ppm. Several researches in past resulted in better outcome while doping Al2O3 nano particles with fuel. Hence this strategies is adopted to reduce emission and improve performance and combustion aspects of B30-CEME fuel. B30 with different strength is doped and mixed by ultrasonication

<table>
<thead>
<tr>
<th>Properties</th>
<th>Diesel</th>
<th>B30-CEME</th>
<th>B30 + 10 ppm Al2O3</th>
<th>B30 + 20 ppm Al2O3</th>
<th>B30 + 30 ppm Al2O3</th>
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<tr>
<td>Density @ 15 °C, kg m⁻³</td>
<td>838</td>
<td>862</td>
<td>868</td>
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<td>876</td>
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<tr>
<td>Kinematic viscosity @ 40 °C, cSt</td>
<td>1.82</td>
<td>2.36</td>
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<tr>
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<tr>
<td>Cetane number</td>
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<td>53.4</td>
<td>52.2</td>
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<td>Water content</td>
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<td>0.035</td>
<td>0.035</td>
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</tbody>
</table>
process to avoid agglomeration of nanoparticles. Fuels are tested and results were obtained.

3.1. Performance characteristics

Fig. 3 portrays the variation of BTE of B30 and Al2O3 nano doped blends with varying load condition. Properties of B30 + 10 ppm, B30 + 20 ppm, B30 + 30 ppm blends were found and it was noted that all blends showed similar and close properties in which B30-20 ppm exhibited better properties. From graph it is clear that these blends showing close results. B30 + 20 ppm blend exhibiting better BTE around 30%. Better combustion properties of B30 along with 20 ppm Al2O3 nanoparticle exhibited improved and enhanced combustion. Reduction in viscosity also attributed for better spray characteristics such as high degree of atomization and
thereby reducing delay period and improving combustion. Other enhanced properties such as cetane number and flash point of B30 + 20 ppm blend also attributed for high BTE. For B30 + 30 ppm inferior fuel properties occurred which caused it to exhibit less BTE than B30 + 20 ppm blend. Few researchers in past such as Hoseini et al., experienced similar results.

Fig. 4 shows variation of BSFC of alumina doped blends in B30 with respect to engine load. B30 + 20 ppm showed lower fuel consumption because of its improved calorific value and good combustion properties. Thus fuel with lower calorific value exhibited high BSFC and vice versa so as to maintain engine speed and brake power constant. Inverse profile of BTE stays in good agreement. These factors caused B30 + 20 ppm to exhibit lower BSFC. Additionally low viscosity and high calorific value supported indirectly for lower BSFC. These results are in line with Manoj et al.

3.2. Combustion characteristics

Fig. 5 illustrates rise in pressure trend with respect to engine load. It can be noted that peak cylinder pressure of 73.24 bar is obtained for B30 + 20 ppm fuel and minimum peak pressure is obtained for B30 of 70 bar. Improved results is obtained for all alumina blends especially for B20 + 20 ppm. Addition of alumina nanoparticle has enhanced the combustion process and also supplied additional oxygen molecules for enhancing the combustion. High surface to volume ratio of Al2O3 in fuel also improved combustion characteristics of fuel which also improved combustion phase. Hence better results obtained. Up to 20 ppm strength the catalytic activity was good and on further increase, the catalytic activity did not support for combustion. Thus high peak value is exhibited for B30 + 20 ppm fuel. Few other researchers obtained same kind of results.13

Fig. 6 depicts the variation of HRR with respect to varying engine load. Highest value of HRR is obtained for diesel (89.86 J/°CA) followed by B30 + 20 ppm, B30 + 30 ppm and B30 + 10 ppm fuel with 79.30 J/°CA, 70.2 J/°CA and 68.7 J/°CA because of reduced fuel viscosity of alumina blend. Accumulated fuel in premixed combustion phase also supported for high HRR. Presence of more O2 molecules with enhanced fuel properties along with catalytic activity of fuel attributed for higher performance of fuel. Reduction in delay period is also noted for these nanoparticle blends because of improved combustion properties such as viscosity and cetane number on
addition of Al\textsubscript{2}O\textsubscript{3} nano particle. Few other researchers in past such as Kowthaman et al., also experienced similar kind of results.

3.3. Emission characteristics

Fig. 7 illustrates variation of HC emission along with varying load for alumina doped blends of B30 along with diesel and B30. It is clear that all blends showing tremendous reduction of HC emission than diesel. With increase in Chlorella emersonii methyl ester concentration and alumina nano particle the reduced emission trends were noted and is limited to 20 ppm of Al\textsubscript{2}O\textsubscript{3} nano particle. Over concentration of Al\textsubscript{2}O\textsubscript{3} in B30 + 30 ppm and less concentration of B30 + 10 ppm of Al\textsubscript{2}O\textsubscript{3} caused slight increase in HC than B30 + 20 ppm blend. Effect of Al\textsubscript{2}O\textsubscript{3} nanoparticle became inactive (ie) catalytic activity of Al\textsubscript{2}O\textsubscript{3} is bit poor when compared to B30 + 20 ppm but is better than B30 blend. Additionally presence of additional oxygen molecule in alumina blends supported for complete combustion thus mitigating HC emission. Similar kind of results were identified with Aalam et al.\textsuperscript{14}

Fig. 8 shows variation of CO of alumina fuel blends with respect to engine load. At full load condition almost all CEME fuels exhibited same value of CO. AT high load because of high incylinder pressure and temperature along with lower viscosity facilitated better combustion and hence CO emission is reduced. Tremendous reduction in CO when compared to diesel is noted for all load conditions. Availability of O\textsubscript{2} and good oxidation of B30 + 20 ppm fuel led to reduction of CO. Thus because of complete combustion less CO is obtained. Few literatures such as Kowthaman et al., obtained same kind of results.

Fig. 9 portrays the NO\textsubscript{x} emission of Alumina fuels with respect to engine load. All blends of B30 with Al\textsubscript{2}O\textsubscript{3} nanoparticle showed higher NO\textsubscript{x} than B30 fuel. Low viscosity along with good ignition characteristics of fuels caused better (ie) complete combustion which resulted in high incylinder temperature to form NO\textsubscript{x} emission. Particularly B30 + 30 ppm showed high NO\textsubscript{x} at all load condition because of presence of more oxygen molecules in fuel as well as Al\textsubscript{2}O\textsubscript{3} nanoparticles. Thus because of better combustion which led to rise in adiabatic flame temperature of fuel especially B2 + 30 ppm to give more rise to NO\textsubscript{x} emission. These results are in line with findings of Mohamed Nour et al.,
4. Conclusion

(1) B30-20 ppm Al2O3 blend proved to be optimum and reliable fuel on performance, combustion and emission aspects.

(2) Alumina nano additive was adopted to reduce emission and improve performance. Emission such as HC, CO and smoke reduced considerably with increase in NOx. These results highlights the role of Al2O3 usage in fuel blends.

(3) Al2O3 doping in fuels also enhanced properties such as increase in calorific value and cetane number and reduction in viscosity. Hence better atomization and vapourisation were obtained.

(4) BTE was high for B30-20 ppm Al2O3. HC, CO, NOx and smoke reduced.

(5) Thus 20 ppm dosage of Al2O3 nano particle is decided as optimum blend and fuel B20-20 ppm is named as Best fuel (BF) for next experimentation.

Fig. 10 shows variation of smoke trend with respect to varying engine load of blends in comparison to diesel. Smoke emission is an indication of incomplete combustion. It is formed because of less retention time for fuel to burn especially at full load condition as time for combustion to complete is very less at that condition. Hence high smoke is noted for all fuel at 100% load condition. All biofuels exhibited reduced smoke than diesel at all load condition because of better combustion due to oxygen content inside cylinder for combustion. Thus mitigation product of incomplete combustion (ie) smoke emission reduced. Similar work findings were noted in studies from Nour et al.15

Conflict of interest

The author(s) of this study disclosed no potential conflicts of interest with regard to the research, authorship, and/or publication of this work.

CRediT authorship contribution statement

Krishnan Rangasamy: (Research Scholar) - Fuel Preparation, fuel Property analysis and Writing-Original draft, Investigation. Naveen Chandran Panchacharam: Supervision and Methodology.

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