Assessing the effects of ammonia (NH3) as the secondary fuel on the combustion and emission characteristics with nano-additives

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ABSTRACT

Ammonia is a promising alternative to replace the non-renewable fossil fuels. The present work offers the detailed evaluation of ammonia suitability in the diesel engine and how it is affecting the primary properties of the diesel engine. A series of tests was conducted on the test samples such as diesel, B20, B20N, B20A5 and B20A10 across various engine loading conditions. Two different ammonia energy ratios of 5 L/min and 10 L/min have been utilized. In addition to ammonia, the role of nanoparticles was analyzed and compared how far they can be competitive to the green ammonia fuel. 75 ppm of TiO_2 nanoparticles was dispersed with Chlorella vulgaris microalgae biodiesel blends using ultrasonication. Ammonia was injected as the secondary fuel via air intake. Based on the results, adding ammonia in the diesel engine reduced the brake thermal efficiency of the engine. There was a drastic drop in the brake thermal efficiency that has been reported across various loads. Nevertheless, biodiesel blends with nanoparticles reported peak thermal efficiency due to the enhanced cetane number and calorific value of the fuel. On contrary, the brake specific fuel consumption of B10A and B20A was decreased compared to the other blends. As the ammonia concentration increased, both the peak cylinder pressure and heat release rates were higher. Due to the addition of ammonia, NOx emission was higher due to the higher cylinder temperature. On the other hand, the emissions of

carbon dioxide, carbon monoxide and hydrocarbons were reduced for all cases compared to neat diesel.

Keywords: Chlorella vulgaris microalgae, Ammonia, Green hydrogen, Combustion, Environmental pollution

1. Introduction

Hydrocarbon fuel remains the primary energy resource to meet the major energy demand, currently. Due to the rapid use of fossil fuels, both environmental and human health are affected massively. Based on many surveys, it is predicted that the increase in air pollution increases the mortality rate [1]. Further, the pollutants such as carbon monoxide, nitrogen oxides, hydrocarbon and sulphur oxides are damaging the environment by increasing global warming [2-3]. Due to the massive upsurge of the carbon dioxide emission, the global surface temperature has been increased to 1.02 0C. Furthermore, in 2018, United Nations Intergovernmental Panel on Climate Change (IPCC) alerted the world to reduce the CO_2 emission within the next 10 years to reduce the drastic climate change and its adverse effects. Further, IPCC stressed the policy makers to develop alternate resources from the renewable resources and also stressed to explore the areas such as hydrogen (H_2), ammonia (NH3), bioethanol and other green fuels as the potential replacement for the existing fossil fuels [4-7]. Recently, several studies have been done on the usage of hydrogen as the major energy carrier for the diesel engine. From the series of findings, it is observed that hydrogen can be a potential resource to replace fossil fuels [8-10]. Addition of hydrogen to the engine increases the brake thermal efficiency (BTE) with reduced fuel consumption rates. On top of that, the emissions of carbon monoxide, hydrocarbons, and nitrogen of oxides are drastically reduced. Although hydrogen fuels have plenty of scope, the use of hydrogen is challenging owing to its volatility and high compression pressure requirement to acquire the required energy density [11-13]. Hydrogen is a highly flammable gas, which can lead to disaster due to deprived handling. Furthermore, storage of hydrogen is difficult. Hence, hydrogen can't be an attractive option in an economic point of view [14-15]. On the other hand, ammonia (NH_3) is a wise option to replace hydrogen. Ammonia exhibits higher energy density compared to hydrogen. Nevertheless, the pressure required for energy density is incredibly lower than hydrogen. Fig. 1 shows the energy density of various fuels [16-18].

Ammonia is denser than hydrogen and hence, requires only 10 times compression. Some key advantages of ammonia over hydrogen is low storage cost, wide resources for production, easy handling, higher distribution capacity and commercial feasibility. Ammonia has recently received profound interest owing to its major key benefits in the energy market [19-20]. Ammonia is a colorless and pungent gas containing high hydrogen content in terms of liquid volume. Wang et al. examined the ammonia and hydrogen mixture in the marine diesel engine. The combination of both ammonia and hydrogen has been studied at different equivalence ratios, H_2 doped ratios, pressures and intake temperatures [21]. Based on the examination, they revealed that adding hydrogen improved the laminar flame velocity. Further, the combustion temperatures were also reduced predominately with less formation of nitrogen of oxides. 30 % of hydrogen has been doped with ammonia. As the doping energy ratio increased, the pressure and temperature also increases respectively [22]. Further, cylinder pressure and ignition delay were also affected upon increase in the equivalence ratio. At 1.1 equivalence ratio, the laminar flame velocity was at its peak and the initial temperature has been increased. Besides, when the equivalence ratio increased to 1.6, the formation of NOx was negligible. Yousefi et al. examined the effect of ammonia in the diesel engine both experimentally and numerically. The effects of parameters such as start of diesel injection and ammonia energy fractions on the diesel engine have been examined. Based on the findings, ammonia reduced the flame velocity [23]. As the energy ratio of ammonia increased, the nitrogen oxide formation has been affected. The other pollutant emissions also increased upon the addition of ammonia. Similar to the above work, increasing the ammonia decreased the peak cylinder pressure and decreased the thermal efficiency of the engine. During the combustion process, the unburnt ammonia escaped through the exhaust due to the weak flame propagation [24].

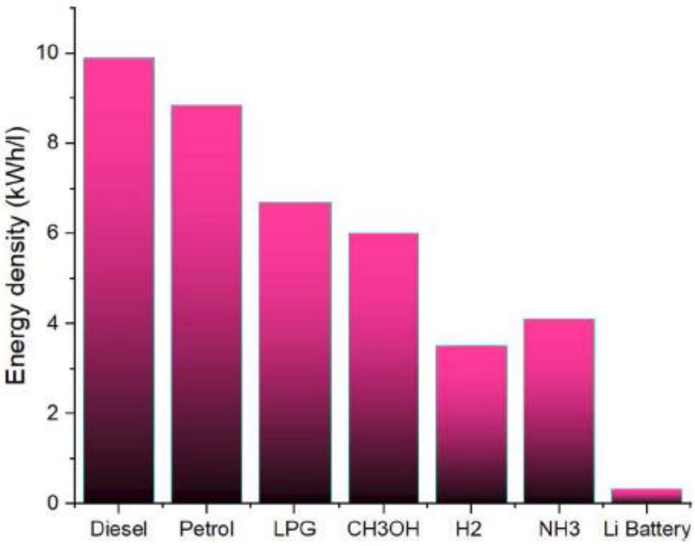

Fig. 1. Energy density of various resources.

As the ammonia ratio increased compared to diesel, the NOx has dropped significantly. Overall greenhouse gas contribution has been decreased by 12 % by introducing the dual fuel mode concept. Kurien et al. reviewed the advantages and disadvantages of ammonia as the primary fuel in the diesel engine. The above study revealed that the presence of hydrogen in ammonia increased the NOx formation in the combustion zone due to the pyrolysis process [25]. Due to the increased combustion duration, the combustion resulted in partial oxidation and ammonia in the combustion chamber are unburned which leads to formation of higher concentration of pollutants in the exhaust. Hence, the ammonia fuel engine required a selective catalytic reduction system to pretreat the exhaust. Ammonia in the combustion chamber affected the ignition temperature and the flame velocity, and poor kinematic reactions were a threat to the engine [26-27]. Hence, blending ammonia with existing diesel fuels can be a promising one. Blending diesel with ammonia reduced the limitation of flame velocity and improved the chemical kinetics. In addition to the above, supplying ammonia via the intake manifold required certain modifications to tackle corrosion. Supplying high concentrations of ammonia to the engine affected the thermal efficiency of the engine. Based on the above studies, it was understood that the use of 100 % ammonia in the diesel engine was not a viable option due to the reduced thermal efficiency and combustion characteristics [28]. Hence, the current study focused on using ammonia as the secondary fuel to the diesel engine. Further, the effectiveness of the nanoparticles was also examined and compared to ammonia.

2. Experimental setup

A series of tests was conducted in the single cylinder diesel engine, Kirloskar TV1 made. The engine is a natural aspired four stoke water cooled engine. The current study used chhrella vulgaris microalgae biodiesel blends acquired from local market and their properties are listed out in Table 1. The fuels such as diesel, B20 (20 % biodiesel), B20N (20 % biodiesel + 75 ppm TiO_2), B20A5 (20 % biodiesel + 5 L/min NH_3), and B20A10 (20 % biodiesel + 10 L/min NH_3) were tested across different engine loads. Ammonia and biodiesel have been tested for their performance, combustion and emission characteristics at various loading conditions. Table 2 shows the specifications of the test setup. Load cell was connected with the engine coupled with eddy current dynamometer. In order to cool the engine, water has been used and the flow rate of water while applying the load has been controlled using flowmeter. Ideally, water was passed from the storage tank to the engine via rotameters to avoid excess heat production by the dynamometer. Electronic control unit has been used to vary the engine loads. Fuel consumption rates were determined using simple burette. Ammonia has been passed through the air intake manifold [29]. The sample projection has been made in the inlet pipe and it was connected to the flash back arrestor through which ammonia has been supplied. The pressure of ammonia was controlled using the pressure regular attached to the cylinder.

Table 1 Test fuel properties.

Properties	Diesel	B20
Density kg/m^3	828	835
Kinematic viscosity mm^{2}/s	2.45	3.45
Calorific Value (MJ/K)	44.2	42.16
Cetane Number	48–49	53–54
Flash point °C	68	160

Table 2 Test engine specifications.

Model	TV1
Cylinder	Single
Stoke	Four
Injection	Direct
Coolant	Water
Bore	87.5 (mm)
Stroke	110 (mm)
Engine Speed	1500 rpm
Rated power	5.2 kW
Compression ratio	17.5:1
Injection pressure	210 bar
Load cell	Eddy current dynamometer

Two measurements have been done in order to avoid uncertainty in the mass flow rate of ammonia. Rotameter and flow meter were attached in the ammonia pipelines. Airflow rate has been measured using the inclined manometer. Pressure, heat release rate and temperature have been found using piezo transducer, calorimeter and k-type thermocouple, respectively [30]. AVL Di gas analyzer has been used to measure the pollutants such as carbon monoxide (CO), carbon dioxide (CO_2), hydrocarbons (HC) and nitrogen of oxides (NOx). All the sensors were connected to the data acquisition system and the procured data were filtered and averaged for 10 cycles. The measured uncertainty for all the instruments ranged below 2 %. Fig. 2 shows the typical layout of the test engine.

3. Results and discussion

A series of tests was conducted in the diesel engine by utilizing the various ammonia blends such as diesel, B20 (20 % biodiesel), B20N (20 % biodiesel + 75 ppm TiO_2), B20A5 (20 % biodiesel + 5 L/min NH_3), and B20A10 (20 % biodiesel + 10 L/min NH_3). Each blend was examined for the brake thermal efficiency (BTE), brake specific fuel consumption (BSFC), exhaust gas temperature (EGT), In-cylinder pressure, heat release rate (HRR), carbon monoxide (CO), carbon dioxide (CO_2), hydrocarbon emissions (HC) and nitrogen of oxides (NOx). Based on the findings, comparative analysis has been done to ensure the effectiveness of ammonia over nanoparticles. All the tests were conducted under different engine loading conditions varying from 25 % to 100 %.

3.1. Engine performance

3.1.1. Brake thermal efficiency

Fig. 3 shows the brake thermal efficiency of the test blends at various engine loading conditions. All the blends reported a significant increase in the BTE according to the engine load elevation. Irrespective of fuel combinations, BTE increased with regard to the engine loads.

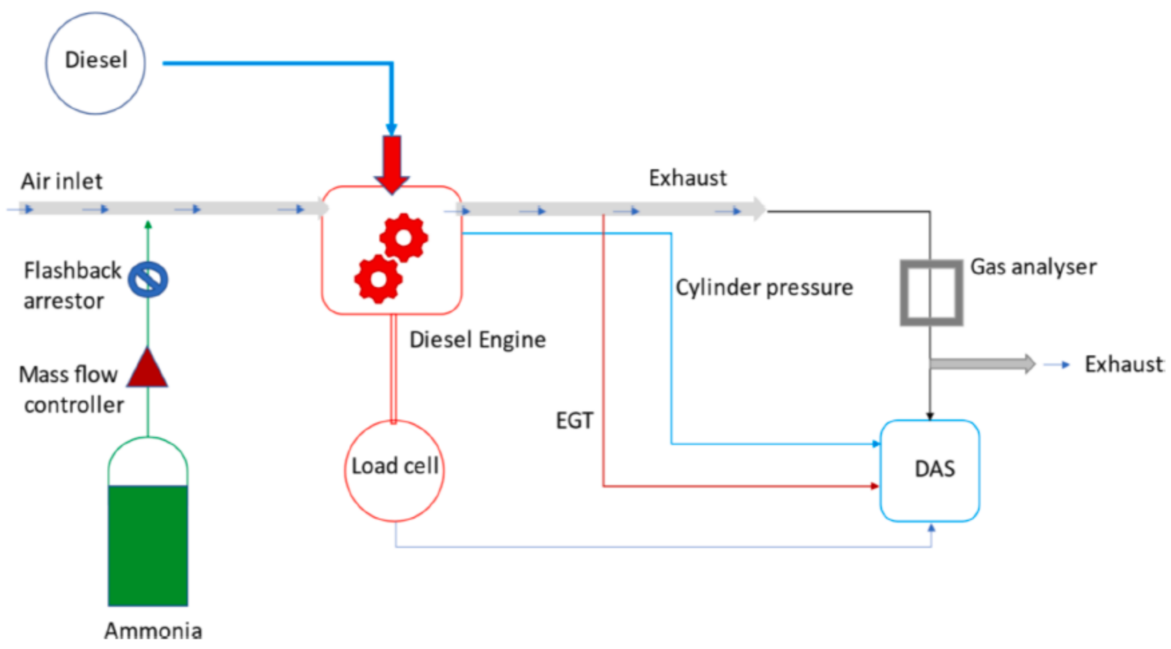

Fig. 2. Experimental layout.

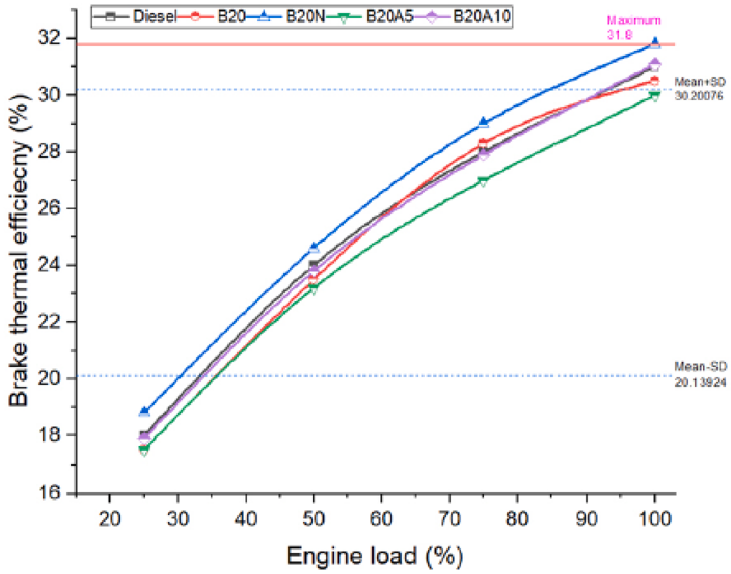

Fig. 3. Rate of change of BTE for various test conditions.

At 25 % engine load, the accumulated BTE for the test blends was 18.1 %, 17.6 %, 18.9 %, 17.8 % and 17.95 %, respectively. Biodiesel blends reported the lowest BTE among various blends since the neat biodiesel blends exhibited poor fuel atomization and lower boiling point. Adding ammonia to the blends reduced the thermal efficiency of the engine owing to the flame temperature, and flame speed. Ammonia combustion in the diesel engine reduced the flame speed due to high auto ignition temperature. Further, high latent heat of vaporization was also another reason for the reduction in the BTE across various engine loading conditions for ammonia. However, compared to 5 L/min, 10 L/min showed a slight increase in the BTE. As the concentration of ammonia increased, the marginal increase in the engine efficiency has been noted due to the slight improvement in the premixed ammonia-air mixing. There was no massive reduction in the flame speed or temperature by increasing the ammonia concentration [31-32]. The maximum BTE has been reported at 100 % engine load. Among the various blends, B20 blend with nanoparticles reported the peak BTE of 31.8 % as depicted. Compared to B20N, other blends reported a slight reduction in the BTE including diesel. When the oxygenated additives were added to the biodiesel, the overall calorific value and heating value of the blends increased. Excess oxygen molecule presence in the B20N blends was the other reason for the enhanced BTE [33]. The maximum BTE for the blend's diesel, B20, B20N, B20A5 and B20A10 was shown as, 31.05 %, 30.3 %, 31.8 %, 29.8 % and 30.9 %, respectively. Compared to ammonia, nanoparticles reported a better flame speed and successful combustion at the premixed phase.

3.1.2. Brake specific fuel consumption

Fig. 4 records the change in the brake specific fuel consumption for various blends under different engine loadings. According to the literature study of the biodiesel and hydrogen gases in the diesel engine, the BSFC of the test fuel decreased in line with the engine loads. It is typical that ammonia blends reported reduced BSFC due to the high energy ratio. Among the procured results, the maximum BSFC was observed for the biodiesel blends. As we know, higher viscosity of the fuel is the main reason for fuel consumption. When the blend has higher viscosity with a poor heating value, the rate of fuel consumption will be increased to match the power required by the engine [34-35]. Hence, in general, the diesel engine consumed higher biodiesel than neat diesel. This was maintained for the entire engine load. Blends such as diesel, B20, B20N, B20A5 and B20A10 reported 0.60 kg/kWh, 0.68 kg/kWh, 0.675 kg/ kWh, 0.61 kg/kWh and 0.585 kg/kWh. There was a drastic reduction in the consumption of the fuel when the engine load dropped to 50 %. Based on the understanding, there was a 45 % reduction in the overall fuel consumption of various blends. However, there was no change in the BSFC reported for the later engine loading cases. In fact, there was a slight increase in the BSFC once the engine was operated at high loading compared to 75 % and 50 % engine loads. This was due to higher cylinder temperatures. Highest cylinder temperature surged the rate of unburnt hydrocarbon in the combustion chamber. Ammonia test blends showed reduced consumption owing to the decreased brake thermal efficiency and thermal efficiency [36-37]. Increase of ammonia in the blends retarded the combustion phase owing to low burnt rates. The observed BSFC for the blends at 100 % engine load was 0.37 kg/kWh, 0.41 kg/kWh, 0.38 kg/kWh, 0.375 kg/kWh and 0.370 kg/kWh, respectively. Compared to nanoparticles, the ammonia blends reported the least fuel consumption. Besides, the difference between the two samples was not massive.

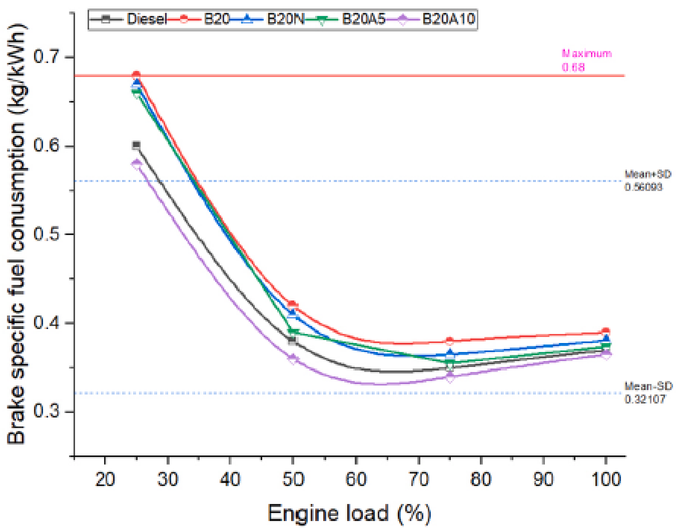

Fig. 4. Rate of change of BSFC for various test conditions

3.1.3. Exhaust gas temperature

Fig. 5 illustrates the variations of EGT for various blends under different loading conditions. As the engine load increased, the EGT for all the blends increased. This typical behavior was due to the increased brake thermal efficiency that resulted in a higher cylinder temperature and consequently, the EGT as well. At the initial loading conditions, the blends reported identical EGT for all cases. Only slight changes in the EGT between the samples were observed. As the engine load increased, there was a slight deviation, which was examined only at higher loads. The minimum EGT for the samples such as diesel, B20, B20N, B20A5 and B20A10 was 205 °C, 220 °C, 245 °C, 239 °C and 217 ° C as witnessed at 25 % engine load. When the engine loads were at peak, there was an increase in the EGT. Among the various blends, B20N was reported to generate higher EGT owing to the higher combustion levels [38]. Basically, adding the nanoparticles to the cylinder enhanced combustion by increasing the thermal conductivity of the fuel. When the titanium dioxide was dispersed with the biodiesel blends, the parameters such as viscosity, thermal conductivity and calorific value of the blend were increased leading to the improved combustion phase and the flame temperatures. On the other hand, the addition of ammonia reduced the EGT slightly owing to the increase in the premixed combustion phase. Furthermore, net heat release at the expansion stroke was low due the addition of ammonia, which resulted in a reduced EGT [39-41]. The highest EGT reported at 100 % engine load for diesel, B20, B20N, B20A5 and B20A10 was as follows, 625 °C, 660 °C, 695 °C, 684 °C and 640 °C. From the ignition process, it was identified that the nanoparticles enhanced combustion far better than ammonia addition to the diesel engine.

3.2. Combustion characteristics

Fig. 6 represents the in-cylinder pressure profile for various engine loads. The pressure readings were calculated only for the 100 % engine load conditions. Only at 100 % engine load conditions, the BTE and EGT were maximum, hence, the calibration for the full load conditions was more than enough to understand the variations in the cylinder pressure and heat release rate. Higher concentration of ammonia in the fuel increased the cylinder pressure. The peak in-cylinder pressure has been observed for both B20A5 and B20A10. When the concentration of ammonia increased, the cylinder pressure also increased due to ignition duration, ignition delay and premixed ratio of the ammonia based samples. Peak in-cylinder pressure for diesel, B20, B20N, B20A5 and B20A10 was 66 bar, 69.5 bar, 69.45 bar, 73 bar and 74.5 bar respectively. Fig. 7 shows the changes in the heat release rate for the various blends at different crank angles. Preferably, the HRR of the engine depends on the ignition delay, combustion duration, premixed combustion phase and diffusion. Based on the above variables, the HRR of each test sample differed.

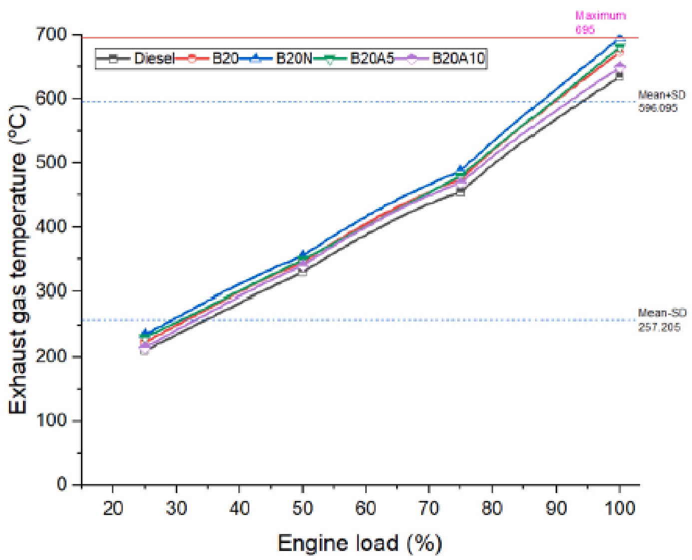

Fig. 5. Rate of change of EGT for various test conditions

Ammonia blends reported the peak HRR values compared to the biodiesel and diesel blends. Higher concentration of ammonia produced higher HRR due to the heat release in the premixed combustion phase [42]. As the ammonia mixed with diesel in the combustion chamber, the presence of high ammonia in the combustion chamber led to poor flame speed.

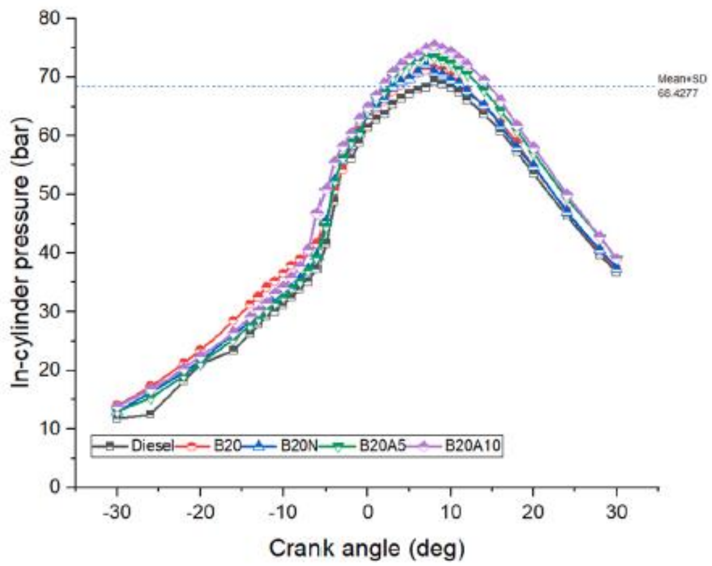

Fig. 6. Rate of change of in cylinder pressure at full load condition.

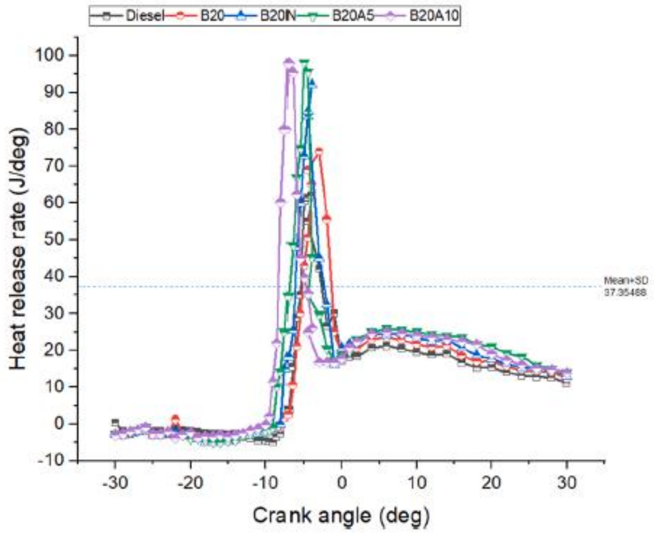

Fig. 7. Rate of change of HRR at full engine load.

The blends with ammonia exhibited slower flame propagation in lean mixture conditions compared to stoichiometry. The peak HRR reported for the samples such as diesel, B20, B20N, B20A5 and B20A10 was 66 J/deg, 75 J/deg, 94.5 J/deg, 97.3 J/deg, and 98 J/deg, respectively. From the results, it was identified that more ammonia to the combustion chamber increases the in-cylinder pressure and heat release rate. Although the flame speed of ammonia was poor, at higher loads, the flame propagated faster than the other blends with the aid of a higher premixed ratio.

3.3. *Emission characteristics*

The exhaust gas emission of hydrocarbons, carbon monoxide, carbon dioxide and nitrogen of oxides was examined for various engine loading conditions obtained from the ammonia and biodiesel blends. Further, a comparative analysis was also made to analyze the effect of nanoparticles and ammonia on the accumulation of the pollutants.

3.3.1. Hydrocarbon emission

The primary source for the production of hydrocarbons is incomplete combustion. Hydrocarbons are emitted during the combustion of the fuel particles owing to the poor air fuel ratio and fuel atomization. In addition, the flame temperature and flame speed are the other vital reasons for the increase in the hydrocarbon [43,44]. At the initial loading conditions, the accumulation of the hydrocarbons in the exhaust was low due to the lower engine efficiency and lower cylinder temperatures. Fig. 8 represents the variations of the HC across various engine loads. Among the blends, ammonia reported the least hydrocarbon emissions. As discussed earlier, ammonia inclusion in the combustion chamber reduced the flame speed and the flame temperature due to which, the formation of the hydrocarbons has been reduced. Furthermore, the carbon content in the fuel was massively dropped, which typically affected the accumulation of the carbon in the exhaust [42]. At 25 % engine load, the test samples diesel, B20, B20N, B20A5 and B20A10 reported 35 ppm, 26 ppm, 24 ppm, 20 ppm and 18.25 ppm, respectively. From the findings, it was clear that when the ammonia concentration in the combustion chamber increased, there was a drastic reduction in hydrocarbon formation. In precise, by increasing the ammonia content from 5 L/min to 10 L/min, the HC dropped by 9.1 %. This massive reduction was possible only by retarding the total carbon content in the fuel. Beyond the ammonia blends, the addition of nanoparticles to the biodiesel also reduced the HC formation by 6.5 % and 29 % compared to regular biodiesel and diesel. Adding nanoparticles to the biodiesel increased the oxygen content in the fuel, which assured complete combustion of the fuel. Ideally, the mass burnt by the nanoparticle blends was higher than biodiesel [44]. The maximum HC has been witnessed at 100 % engine load for diesel, B20, B20N, B20A5 and B20A10 as 52 pm, 40.5 ppm, 38 ppm, 28.5 ppm and 24 ppm, respectively. Hence, it was evident that all except diesel reported drastic reduction in HC formation owing to the higher oxygen content and lower cetane number [40]. In addition, the latent heat of vaporization and behavior of the blends at the combustion chamber were the vital reasons for the biodiesel to report less HC. With regard to ammonia, HC decreased as ammonia increased due to the homogenous premixed combustion with less carbon content.

3.3.2. Carbon monoxide

Among the different pollutants, CO is the most poisonous gas, which affects both human health and the environment on a large scale. Hence, the reduction of CO formation during burning of the fossil fuels is crucial. Several emission norms are placed by different government policies to control the formation of carbon monoxide in the exhaust. The main reason for the formation of CO was the presence of carbon atoms in the fuel. Furthermore, the unburnt gas after combustion also increased the CO content [44]. As the engine speed increased, CO emission also increased. Fig. 9 shows the changes in CO at various engine loads. As noticed in the Fig. 9, the biodiesel blends and ammonia blends reported drastic reduction in CO emissions. Adding ammonia in the diesel fuel enhanced the combustion rates by controlling the fuel injection, combustion duration and oxygen deficiency in the combustion chamber. Further, lower temperatures in the combustion chamber were also responsible for the reduction in the emission of CO.

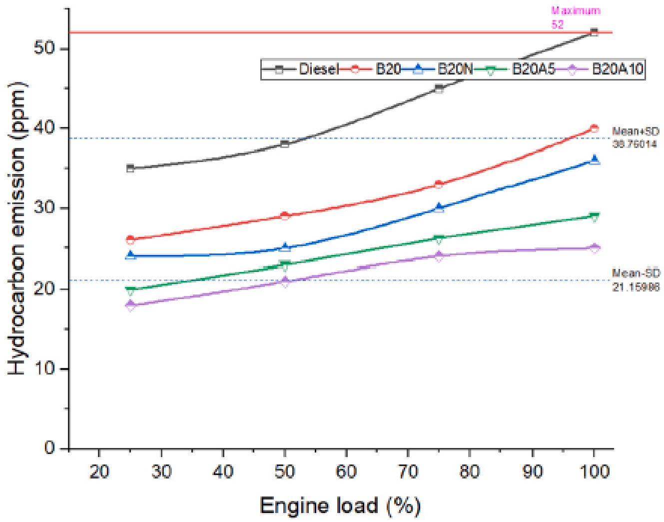

Fig. 8. Rate of change of HC emissions for various test conditions

Besides, the role of nanoparticles in the biodiesel blends was immense. Adding nanoparticles to the blends enhanced the combustion by increasing the oxygen content in the fuel. The presence of excess oxygen molecules in the cylinder generated higher combustion and lower formation of CO. At lower engine loads, CO for diesel, B20, B20N, B20A5 and B20A10 was 4.65%vol, 3.42%vol, 3.2%vol, 2.5%vol, and 2.1%vol, respectively. Increasing the energy ratio of ammonia decreased the emission of CO by 16.6%. Further, compared to diesel, the nanoparticle based biodiesel reported 35.6% reduction in CO formation, which was impeccable. The maximum CO formation was witnessed at 100 % engine loading conditions as 8.35%vol, 6.98%vol, 6.01%vol, 5.35%vol, and 4.15%vol respectively. All the biodiesel blends exhibited lower CO due to the decreased ignition delay and the delay period [38]. Ammonia in diesel enhanced the rate of combustion and resulted in complete combustion to yield the lowest emission compared to other blends.

3.3.3. Carbon dioxide emission

Carbon dioxide is not a poisonous gas like carbon monoxide; however, higher CO_2 emission contributes to global warming. Ideally, CO emission was due to the oxidation of the carbon molecules [45]. Replacing the carbon molecules in the fuel decreases the emission of CO_2. On the other hand, stimulating the combustion process also decreases CO_2 production [46]. Fig. 10 shows the production of CO2 for different test blends at various engine loads. At lower engine loads, CO_2 for diesel, B20, B20N, B20A5 and B20A10 was 0.95%vol, 0.75%vol, 0.7%vol, 0.8%vol, and 0.78%vol, respectively. Increasing the energy ratio of ammonia decreased the emission of CO_2 by 2.6%. Further, compared to diesel, the nanoparticle-based biodiesel reported 30 % reduction in CO_2 formation. As the engine load increased, CO_2 emission has been reduced steadily. These reductions were due to the lack of availability of carbon atoms in the combustion chamber. Total CO_2 emission resulting in 100 % loading was 0.62%vol, 0.49%vol, 0.3%vol, 0.2%vol and 0.18%vol, respectively.

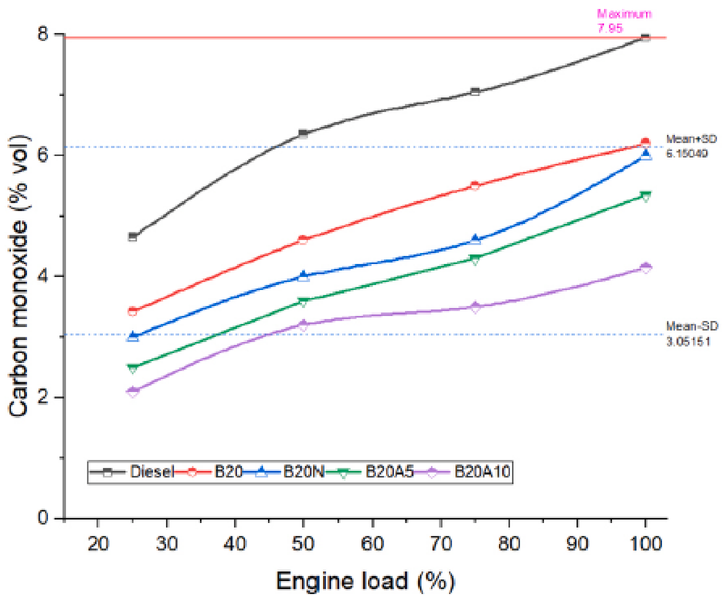

Fig. 9. Rate of change of CO emission for various test conditions

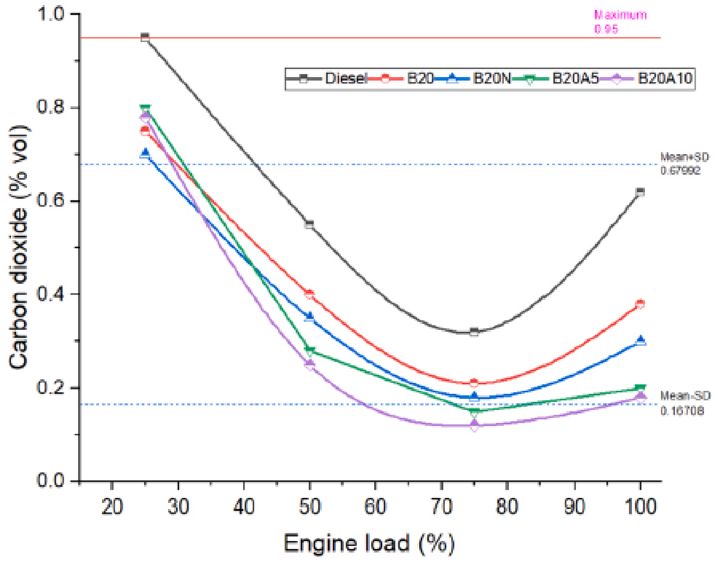

Fig. 10. Rate of change of CO_2 emission for various test conditions.

All ammonia blends reported the least emission of CO_2. As the ammonia concentration increased, there was a significant drop in CO_2. Compared to B20A5, the blend B20A10 reported 10.5% reduction in the formation of carbon dioxide [42]. Adding the oxygenated additives to the combustion chamber stimulated the process of oxidation by supplying extra molecules of oxygen.

3.3.4. Nitrogen of oxides emission

The emission of nitrogen of oxides depends on the operating cylinder temperature and the heat value of the fuel. Oxidation of the NOx increased due to the presence of excess molecules of oxygen in the combustion chamber. Both BTE and the NOx were directly related to one another. Regarding BTE, NOx also increased as the engine load increased. Fig. 11 exhibits the variations of the NOx at several engine loads. As the engine load increased, the apex cylinder temperature increased [47,48]. Biodiesel blends reported higher NOx due to the presence of oxygen molecules in the fuel. Further, ammonia addition increased the total NOx due to the presence of nitrogen in ammonia. The NOx reported at 25% engine load for diesel, B20, B20N, B20A5 and B20A10 was 165 ppm, 178 ppm, 160 ppm, 180 ppm, and 200 ppm, respectively. B20 blend increased the NOx by 7.5% owing to the high oxygen content and cetane number. However, adding the nanoparticles to the blends reported reduction in NOx. To summarize, the blend B20N reported 3.1% reduction in NOx compared to diesel due to the increase in latent heat of vaporization of the blend [49,50].

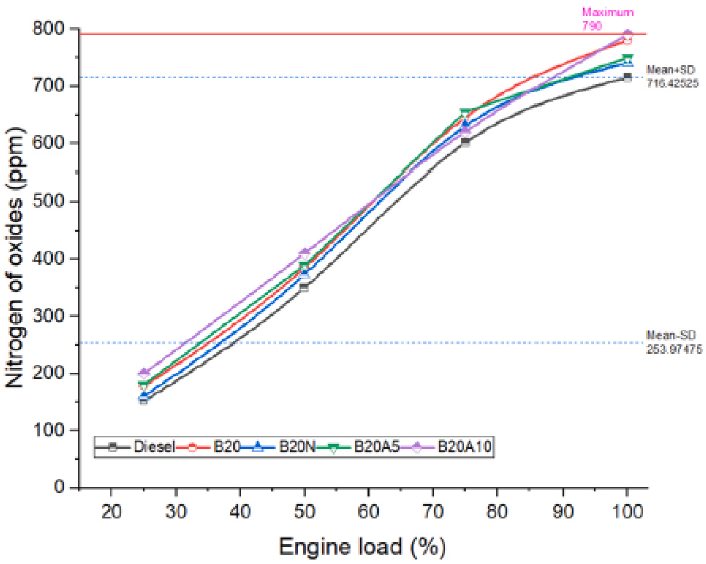

Fig. 11. Rate of change of CO emission for various test conditions

Further, the addition of nanoparticles enhanced the cetane number and heating value of the fuel. The maximum NOx was reported at 100% engine load and the respective values wre 720 ppm, 780 ppm, 710 ppm, 730 ppm and 750 ppm. In all conditions, NOx was increased as the ammonia content has been raised to higher levels. When the ammonia concentration increased, the N atom increased due to the molecular behavior [42]. From the obtained results, it was clear that ammonia addition increased the NOx, which could be compensated slightly by applying nanoparticles to the fuel blends.

4. Conclusion

The current study demonstrated the sustainability of ammonia in the diesel engines compared to biodiesel and biodiesel with nanoparticles blends. In this study, a series of tests was conducted to measure the performance, combustion and emission characteristics across various engine loads. The acquired results were compared and analyzed to prove the use of ammonia in the diesel engine without any major modifications. Ammonia blends in the diesel engine reduced the BTE irrespective of the engine loads. As the concentration of ammonia increased, there was a slight increase in the BTE. Ammonia blends exhibited poor BTE owing to poor flame speed and flame temperature compared to the biodiesel blends. On the other hand, ammonia did not support complete combustion of the fuel products supplied to the engine. The maximum BTE has been reported for the blend with nanoparticles due to superior cetane number and latent heat of evaporation. In addition, the increased oxygen content in the fuel led to higher combustion rates. On contrary, BSFC for the ammonia blends was lower than biodiesel. Biodiesel consumed a higher amount of fuel due to larger viscosity values. As the engine load increased, BSFC dropped; yet, BTE and EGT values increased. The maximum EGT was reported for B20A10 owing to the higher in-cylinder pressure and heat release rate. Upon increasing ammonia in the blends, cylinder pressure and heat release rate elevated to peak magnitudes, which led to higher NOx emissions. Higher cylinder temperature is one of the key reasons for the higher production of NOx. With regard to other pollutants such as CO, CO_2 and HC, all the blends reduced the formation of carbonbased pollutants due to the increased oxygen and decreased carbon in the fuel. By adding the nanoparticles, the rate of combustion increased that led to significant reduction in the formation of pollutants. Based on the measured results, it was clear that the addition of ammonia was not sustainable owing to the reduced BTE and increased NOx emission. This drawback can be overcome by adding some of the oxygenated additives along with diesel. Further, hydrogen can be used as the secondary fuel to assist with ammonia since the flame temperature and auto ignition temperature of hydrogen were higher than ammonia.

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