Role of chicken fat waste and hydrogen energy ratio as the potential alternate fuel with nano-additives: Insights into resources and atmospheric remediation process

Citation

YI-CHIA, Lin, Manigandan SEKAR, Arunachalam CHINNATHAMBI, Omaima NASIF, Beáta GAVUROVÁ, G.K. JHANANI, Kathirvel BRINDHADEVI, and Nguyen Thuy LAN CHI. Role of chicken fat waste and hydrogen energy ratio as the potential alternate fuel with nano-additives: Insights into resources and atmospheric remediation process. *Environmental Research* [online]. vol. 216, Academic Press, 2023, [cit. 2024-04-02]. ISSN 0013-9351. Available at https://www.sciencedirect.com/science/article/pii/S0013935122020692

DOI

https://doi.org/10.1016/j.envres.2022.114742

Permanent link

https://publikace.k.utb.cz/handle/10563/1011264

Role of chicken fat waste and hydrogen energy ratio as the potential alternate fuel with nano-additives: Insights into resources and atmospheric remediation proces

Lin Yi-Chia[a], Manigandan Sekar[b], Arunachalam Chinnathambi[c], Omaima Nasif[d], Beata Gavurová[e], G.K. Jhanani[f], Kathirvel Brindhadevi[g], Nguyen Thuy Lan Chi[h]

[a]*School of Innovation and Entrepreneurship Sanming University, No. 25 Jingdong Road, Sanming City, Fujian, 365004, China*

[b]*Department of Aeronautical Engineering, Sathyabama Institute of Science and Technology, Chennai, India*

[c]*Department of Botany and Microbiology, College of Science, King Saud University, PO Box -2455, Riyadh -11451, Saudi Arabia*

[d]*Department of Physiology, College of Medicine and King Khalid University Hospital, King Saud University, Medical City, PO Box-2925, Riyadh, 11461, Saudi Arabia*

[e]*Tomas Bata Univesity in Zlín, Faculty of Management and Economics, Mostní 5139, Zlín, 760 01, Czech Republic*

[f]*Center for Transdisciplinary Research (CFTR), Department of Pharmacology, Saveetha Dental College, Saveetha Institute of Medical and Technical Sciences, Saveetha University, Chennai, India*

[g]*Computational Engineering and Design Research Group, School of Engineering and Technology, Van Lang University, Ho Chi Minh City, Vietnam*

[h]*School of Engineering and Technology, Van Lang University, Ho Chi Minh City, Vietnam*

*Corresponding author: E-mail addresses: manisek87@gmail.com (M. Sekar), brindhadevi.k@vlu.edu.vn (K. Brindhadevi).

ABSTRACT

The main focus of the study was to witness the effects of chicken waste-based biodiesel blends along with constant hydrogen injection in a modified diesel engine. Furthermore, the nanoparticle multiwall carbon nanotubes ($MWCNT$) effects on the engine efficiency were also examined. A series of tests was conducted in the single cylinder, water cooled engine fuelled with diesel, CB100N, CB10N, CB30N, and CB50N. Throughout the entire run, constant hydrogen injection of 5 LPM has been maintained. The parameters such as brake thermal efficiency, brake specific fuel consumption, heat release rate and the emissions of different pollutants were determined for a variety of engine speeds. ASTM standards were applied to measure the viscosity, density and calorific value. From the reported findings, it was clear that the addition of the chicken waste biodiesel could be a sustainable substitute for the existing fossil fuels. Although the emission of the pollutants was dropped significantly, there was a massive drop in the BTE values. To compensate such shortage of power, the biodiesel was dispersed with $MWCNT$ at the concentration of 80 ppm. Compared to the regular biodiesel, MWCNT inclusion increased the BTE by 14%. Further, the consumption of the fuel was also reduced marginally. Considering the pollutants, the catalytic activity of the $MWCNT$ reduced the emissions of CO, NOx, and HC at various engine speeds. Besides, 10% reduction in NOx had been reported at lower engine

speeds and was reduced to 8% at higher speed regimes. Compiling all together, increasing the concentration of the biodiesel blends obviously reduced the performance values and however, there was a great advantage in terms of the emission magnitudes irrespective of the engine operating conditions.

Keywords: Chicken waste, Diesel engine, Waste management, Nanoparticles, Hydrogen fuel

1. Introduction

The rise in the number of automobiles corresponds to the rise in world's population. Particularly, developing countries such as China and India, which are experiencing rapid population growth, are experiencing the worst scenario in terms of air pollution due to emission of harmful air pollutants such as NOx, SOx, particulate matter, and aerosols, and the scenario appears to be deteriorating in the near future (**Basha et al., 2022**; **Maroušek, 2022a**; **Ma et al., 2022a**). Despite the fact that biodiesel is considered to be one of the environmentally beneficial options, the greater cost of manufacturing of biodiesel when compared to the fossil fuels is one of the key negatives of biodiesel, particularly in emerging nations, such as India and China (**Arunkumar et al., 2022**; **Maroušek et al., 2022**). The raw materials, primarily vegetable oil and catalysts that are used in the biodiesel manufacture are responsible for the significantly higher price. In an effort to lower the cost of producing biodiesel feedstock, more studies are being conducted on the use of animal wastes, waste oil as a feedstock for biodiesel production (**Yaa-shikaa et al., 2022**; **Zhang et al., 2022**; **Liu et al., 2022**). The world's poultry output is increasing at an accelerated rate, which has resulted in an increase in the waste generated by these industries as a result of this growth. The recycling of these poultry wastes can enhance the poultry production process and also reduces the amount of trash that ends up in landfills. The use of such residues in the production of biodiesel has the potential to lower the production costs significantly. Recently, leftover chicken fat has got a lot of interest since it can be used as a biofuel feedstock (**Mozhiarasi and Natarajan, 2022**; **Gharehghani and Fakhari, 2022**). This type of chicken fat can really be derived from poultry feather meal and trimmings generated by poultry industries and retail shops after slaughtering process. More specifically, the eating of chicken fat had not been recommended since it has been linked to a variety of health problems (**Idowu et al., 2019**; **Rosson et al., 2021**). Esterification, also known as acid treatment, is the process of lowering free fatty acids (FFA) to less than 1 percent by using a catalyst such as hydrochloric acid or sulphuric acid as a catalyst in most cases (**Guo et al., 2021**). Using a chemical reaction, transesterification converts triglyceride into biodiesel, which is then used to fuel automobiles. Using an alcohol in the presence of a heterogeneous or homogeneous catalyst, oils with triglycerides undergo transesterification reactions, which are then converted to stearic acid. For the transesterification reaction, conventional methods employ homogeneous catalysts such as KOH, NaOH, Sodium methoxide, potassium methoxide, and heterogeneous catalysts such as doped metal catalysts, metal catalysts, hydrotalcite, basic zeolites, and others (**Faruque et al., 2020**; **Nisar et al., 2021**). Transesterification is generally enhanced by the use of a homogenous base or acid as the catalyst. In recent years, much emphasis has been placed on the creation of heterogeneous catalysts, owing to its exceptional qualities, which include being environmentally benign, being simple to separate from other catalysts, and being able to be reused (**Singh and Kumar, 2018**; **Mandari and Devarai, 2021**). When it comes to biodiesel production, calcium oxide (CaO) is amongst the most commonly utilized solid catalysts. It has previously been demonstrated to be a very effective catalyst for biodiesel production (**Zamberi et al., 2018**). The utilization of leftover egg shells as a catalyst for biodiesel production has the potential to be a low cost alternative to petroleum based fuels. A substantial number of calcium derivatives ($CaCO_3$) can be found in waste egg shells, and these compounds can be easily transformed to calcium oxide by calcination at a high temperature (**Ma et al., 2022b**). Furthermore, CaO is a low cost, non-corrosive, and environmentally friendly substance that may be regenerated and reused for additional transesterification. It is also a renewable resource. Many researchers are attracted to CaO because of its advantages, and they are interested in additional researches to improve its overall features (**Ferraz et al., 2018**). Incorporating nanoparticles into a liquid will increase the thermal conductivity of biodiesel. It is possible to enhance the combustion of a fuel by increasing its thermal conductivity, which will result in an improvement in the efficiency of combustion in the process. As a result, the use of nanoparticles will boost the combustion of biofuel in the engine, hence, increasing the vehicle performance. Nanoparticles will also have a larger surface to volume ratio, which will allow for more efficient combustion to take place in the engine's cylinder head. Besides improving the ignition temperature, nanoadditives also help to shorten the ignition delay and increase the radiative mass transfer of biofuel in the combustion zone. As a result of the increased combustion caused by the addition of nanoparticles, the engine' s emissions will be reduced (**Hoang, 2021**; **Agbulut et al., 2020**). Because of this, it is evident that the addition of nanomaterials to biofuel will enhance the engine' s overall performance while also improving its emission profile. In this study, biodiesel was prepared using egg shell catalyst and chicken fat waste along with nanoparticles and the performance and emission characteristics of the blended biodiesel fuels were assessed and compared with conventional fuels.

2. Materials and methods

2.1. Extraction of oil from chicken waste

Initially, blood, filth, and other contaminants from the chicken waste and chicken fat were thoroughly cleaned and washed again with distilled water. To melt the fat in chicken, water bath was used for 60 min at the temperature of 98 °C to melt the waste chicken fat (WCF). Insoluble components were removed by filtering the melted fat, which was then heated to 110 °C for 30 min to extract the last remaining water molecules. During heating, the colloidal and waxy substances were removed. The extracted oil was then stored in an airtight container for future use (**Ge et al., 2021**). The oil derived from waste chicken fat was characterized using analytical chemist' s standard procedures to assess its physicochemical qualities. The free fatty acid (FFA), acid value, saponification value, density, iodine value, pH and viscosity were all used to characterize the oil.

2.2. Oil pretreatment proces

Waste chicken fat-derived oil was pretreated to prevent soap production during the transesterification process because the FFA value of WCF oil exceeded 1.0%. Two distinct alcohol molar ratios of 6:1 and 30:1 as well as two different concentrations of concentrated H_2SO_4 (2% and 35%) were used for the esterification method. Reflux condenser and magnetic stirrer were coupled to a 250 ml two-necked round bottom flask. An appropriate amount of concentrated H_2SO_4 and methanol was then injected into an oil container (**Kirubakaran and Selvan, 2021**; **Kuipa et al., 2021**) and maintained at 60 °C for 30 min with regular stirring under the same conditions. Using a separating funnel, the reaction mixture was allowed to stand for 24 h for settling. While the esterified fat settled to the bottom, methanol and acid accumulated at the top and beakers were used to transfer the mixture. After evaporation of the residual methanol and water from the esterified fat for 1 h of heating, the acid value was measured. After the extraction process, the samples were directly sent to transesterification.

2.3. Transesterification

Chicken fat was transesterified using the CaO catalyst. The round bottomed flask was used to transfer the esterified fat and CaO was vigorously agitated for 10 min at the temperature of 65 °C. The methyl alcohol was then fed in while the mixture was kept at a constant condition. The separation procedure was carried out in order to isolate the glycerol from the biodiesel. It was necessary to heat the chicken fat biodiesel in order to remove the excess glycerol which could not be recovered from the direct biodiesel (**Sangkharak et al., 2020**; **Emiroglu et al., 2018**). The distillation process was continued, and then, the water was removed by heating the mixture. The key properties of the chicken waste biodiesel has been listed in **Table 1**.

2.4. Experimental setup

A single cylinder, four stroke, IC diesel engine was used. Every test was performed at various load conditions and different engine speeds varying from 1200 rpm to 2000 rpm.

Table 1 *Test properties of the procured biodiesel.*

Property	Existing study	Literature (Wang et al., 2022 and Ge et al., 2021)
Specific gravity	0.812	0.85
Viscosity at 40 °C (mm^2/s)	4.23	4.11
Calorific value (kJ/kg)	39,700	40,200
Flash point (°C)	170–182	170
Cloud point (°C)	−5	−5
Cetane number	52	56

Table 2 represents the technical specifications for the engine. **Fig. 1** shows the typical test layout. In this engine configuration, no major changes in the specifications were made for the supply of pure diesel and biodiesel mixtures. Hydrogen has been supplied via air intake manifold. The flow rate of the hydrogen was observed by a rotameter. An eddy current dynamometer was used to measure the engine's torque and power output. An AVL Gas analyser was used to predict the exhaust gas emissions such as CO_2, CO, HC and NOx. Since the tests were performed at variable RPM, a speed sensor was required to assess the engine speed and the k-type thermocouples were used to measure the exhaust gas temperature. Testing was carried out at various speeds under full load to determine the effect of varying engine speeds on performance, combustion, and emission characteristics. After conducting the testing for each biodiesel blend independently, diesel was provided to flush the fuel lines and engine of the prior biodiesel mixes to avoid uncertainty in the determined results. The piezoelectric transducer and the AVL gas analyser were connected to the data acquisition system via LabView. All the measured values were within the limit of the literature uncertainty range. In the current study the determined uncertainty was at acceptable range i. e, below 2%.

3. Results and discussion

All tests were carried out on diesel, CB10N (10% biodiesel+80 ppm $MWCNT + 5$ LPM H_2), CB20N (20% biodiesel+80 ppm $MWCNT + 5$ LPM H_2), and CB30N ((10% biodiesel+80 ppm $MWCNT + 5$ LPM H_2) to measure the performance, combustion, and emission parameters at different engine conditions. The fuel samples were tested with $MWCNT$ and hydrogen directly instead of testing neat blends and the obtained values were compared with **Ge et al.** (**2021**), and with our previous study, **Wang et al.** (**2022**).

3.1. Engine torque

Fig. 2 explains the relationship between torque and engine speed for various test blends such as Diesel, CB10N, CB20N, and CB30N. To begin with, as the engine speed increased, the torque rates were elevated to higher levels until the maximum speed limit. The maximum torque for diesel was 24 Nm compared to 24.6 Nm, 22.4 Nm, and 20.6 Nm for the blends, CB10N, CB20N, and CB30N, respectively at 2000 rpm.

Table 2 Engine specifications.

Engine Power	6 kW
Maximum speed at maximum torque	28 Nm @ 2000 RPM
Operating fuel	Diesel and biodiesel blends
No of cylinders	Single
Stroke	Four
Cooling	Air
Injection	Direct
Bore/	85 mm
Stroke	80 mm
Compression ratio	17.5:1

Irrespective of the loading conditions, the variations between the blends were identical during the entire run. Because of the increased viscosity of the blends, the amount of torque generated decreased at higher CFB. All the blends reported the behaviour identical to one another across varied speed levels. Diesel had a higher calorific value than biofuel, which explained the torque gain indeed. There was no significant rise in the torque output with the rise of chicken fat and biodiesel concentration (**Keskin et al., 2020**; **Simsek and Uslu, 2020**). Compared to the literature, **Ge et al.** (**2021**), there was a slight improvement in the engine torque by the addition of hydrogen blends and $MWCNT$. The catalyst activity in the fuel ensured the increase in the engine torque. Similarly, based on our previous findings, **Wang et al.** (**2022**), there was 6% increase in the brake torque upon the addition of nanoparticles and hydrogen.

3.2. Brake specific fuel consumption

Fig. 3 demonstrates the change in brake specific consumption relevant to the engine. The engine torque had the exact opposite effect on the $BSFC$ graph line. The brake specific fuel consumption of all the blended fuels decreased as the engine speed increased. Due to high calorific value, the brake specific fuel consumption of the blend of diesel was low compared to CB30N. Higher BSFCs were reached for CB30N biodiesel mixes due to the fuel's higher density and calorific value. Due to the relationship between the heating value and $BSFC$, the pattern of consumption of fuel depended on the flow resistance of the fuel. A direct correlation between engine performance and fuel consumption is shown by the brake specific fuel consumption (**Jamshaid et al., 2022**; **Maroušek, 2022b**). The diesel's lowest $BSFC$ was 268 g/kWh at 2000 rpm. The $BSFC$ decreased in proportion to the rising CFB percentage till 20%. The greatest $BSFC$ of 388 g/kWh was achieved at the speed of 1200 rpm. Because of the oxygenated chemicals and hydrogen presence in biofuel, fuel consumption decreased as the proportion of biofuel increased. The respective values at 2000 rpm were 253 g/kWh for CB10N, 260 g/kWh for CB20N and 275 for CB30N. From the results, it was clear that as the concentration of the blends increased, there was an increase in the amount of fuel consumed due to the shortfall in the overall calorific value of the fuel. However, the differences between diesel and the blends were not significant due to the constant hydrogen injection into the combustion chamber and the energy contribution by the MWCNT. Compared to the previously obtained results, **Wang et al.** (**2022**), the $BSFC$ rates were massively reduced upon the addition of nanoparticles.

3.3. Brake power

The engine' s output power is generally used to understand the performance quality of the blends. Brake power related to the engine speeds is shown in **Fig. 4** for the fuel mixes of Diesel, CB10N, CB20N, and CB30N. Braking power increased related to the speed of the engine. At, 2000 rpm, neat diesel clocked the highest brake power of 4.5 kW. A decreased calorific value of biofuel mixes reduced the brake power values. Having a higher heating value will generally result in a greater amount of brake power. The values of each of the blends at 2000 rpm of CB10N, CB20N and CB30N models were 4.8 kW, 4.1 kW and 3.5 kW, respectively. From the findings, it was clear that CB10N had a higher efficiency than the other mixes due to the presence of the nanoparticles (**Yaashikaa et al., 2022**).

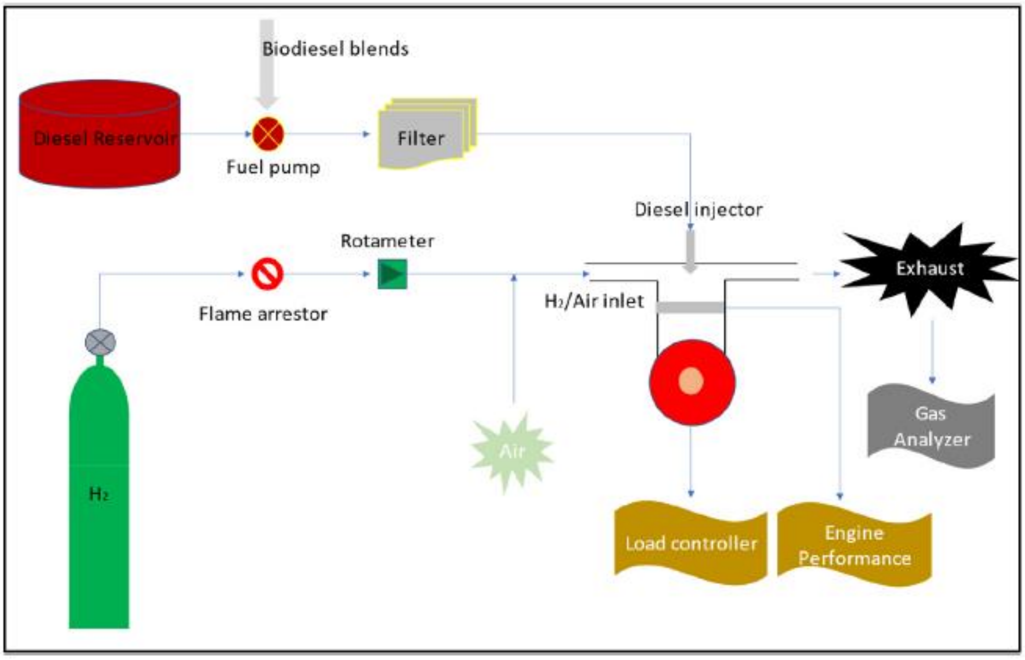

Fig. 1. Experimental layout (**Kanimozhi et al., 2021**).

CB10N had higher BTE irrespective of the engine speed, surpassing both CB20N and CB30N due to the influence of $MWCNT$. Further, hydrogen addition to the engine increased the probability of complete combustion. A massive swing in BP has been noted between biodiesel (20% and 30%) due to the higher viscosity values and poor cetane number. The same results were observed during the measurement of brake torque.

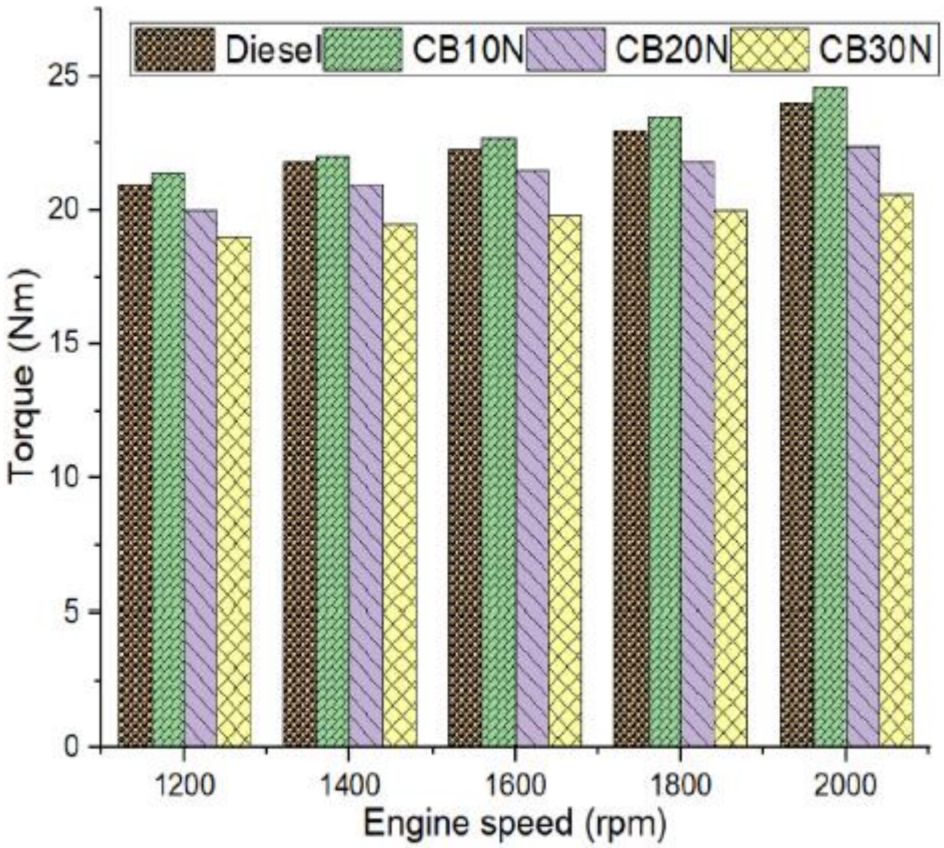

Fig. 2. Engine torque variation related to the engine speeds.

3.4. Emission characteristics

The AVL gas analyser was used to track the temperature, CO_2, CO, HC and NOx emissions from the engine's exhaust.

3.4.1. Exhaust gas temperature (EGT)

Spray penetration and atomization are the key reasons for the change in the exhaust gas temperature. Ideally, biodiesel has the least EGT compared to diesel owing to poor heating value, density and kinematic viscosity. On contrary, some of the biodiesel mixes have been reported to have higher EGT in the literature, which might have been due to the low cetane number and ignition delay. EGTs for the fuel blends of CB100N, CB10N, CB30N, and CB50N are shown in **Fig. 5**. The EGT increased corresponding to the engine speed. The net combustion rate largely related to the changes in the values of EGT. Based on the findings, it was clear that the neat diesel fuel had the lowest exhaust gas temperature across all speeds. Initially, the EGT was low at 1200 rpm.

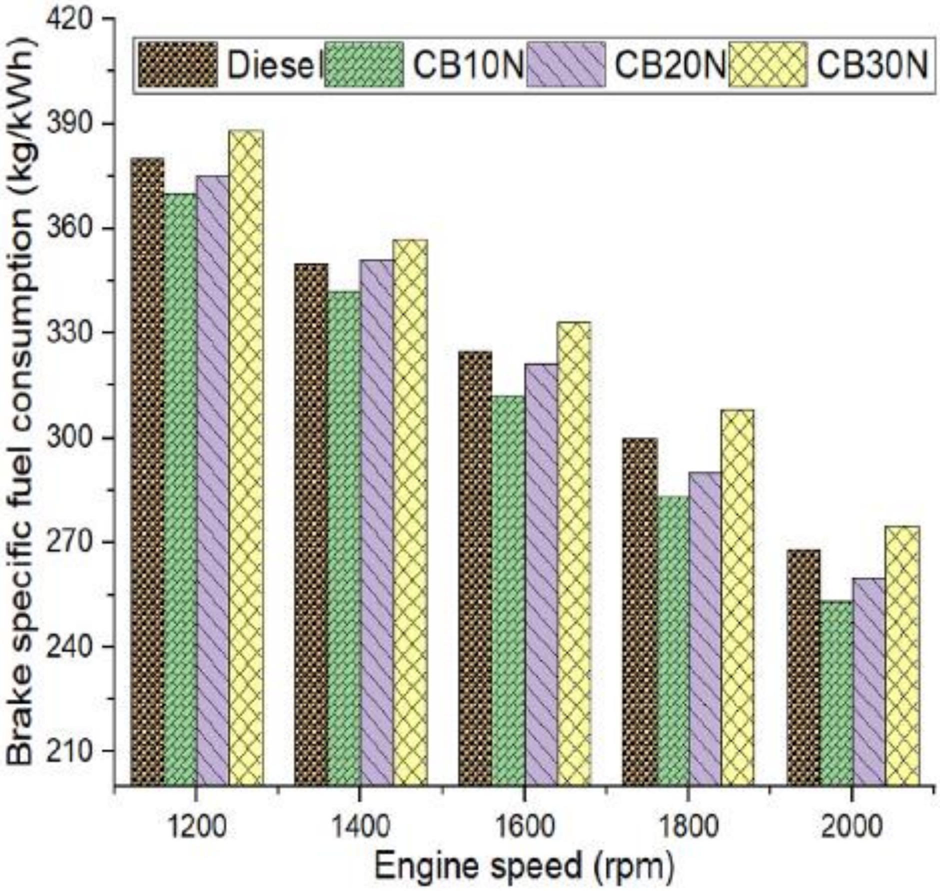

Fig. 3. Variation of brake specific fuel consumption related to the engine speeds.

There was a massive increase in the exhaust temperature by 80 K when the engine speed elevated from 1200 rpm to 1400 rpm. Fuel blends with a higher proportion of blends recorded higher EGT values because of the higher cylinder temperature that was caused by the high amount of combustion (**Shrivastava et al., 2021**; **Kanimozhi et al., 2021**; **Balaji et al., 2022**). In the 2000 rpm range, the highest EGT values were observed for CB10N, CB20N and CB30N as 890 K, 910 K and 915 K, respectively. At the beginning of the test, there was a high change in the EGT. There was no evidence of sudden spike in the EGT at a wide range of speed levels. Adding hydrogen to the combustion chamber increased the premixed combustion flame and hence, the cylinder temperatures were increased. Due to increase in the cylinder temperature, the EGT for the blends increased across wide engine speeds. On the other hand, nanoparticle addition to the blends increased the conversion of heat energy and overloaded the combustion chamber thermally. Hence, the EGT for biodiesel was higher despite the low heating and calorific values.

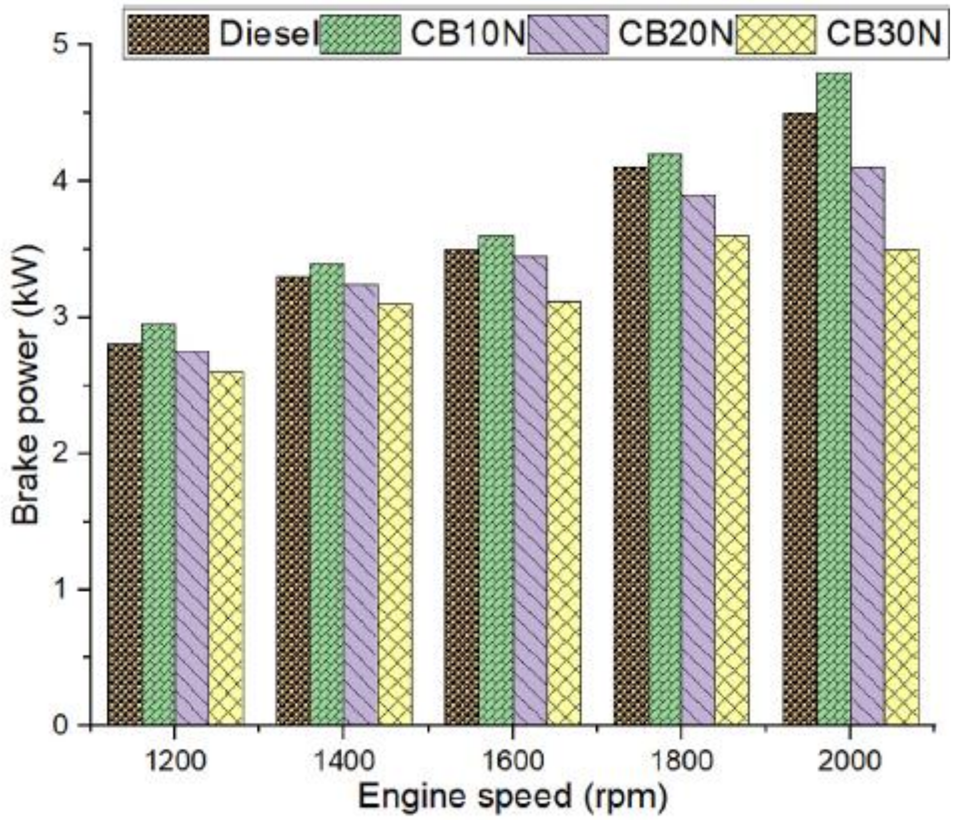

Fig. 4. Engine brake power for various engine speeds.

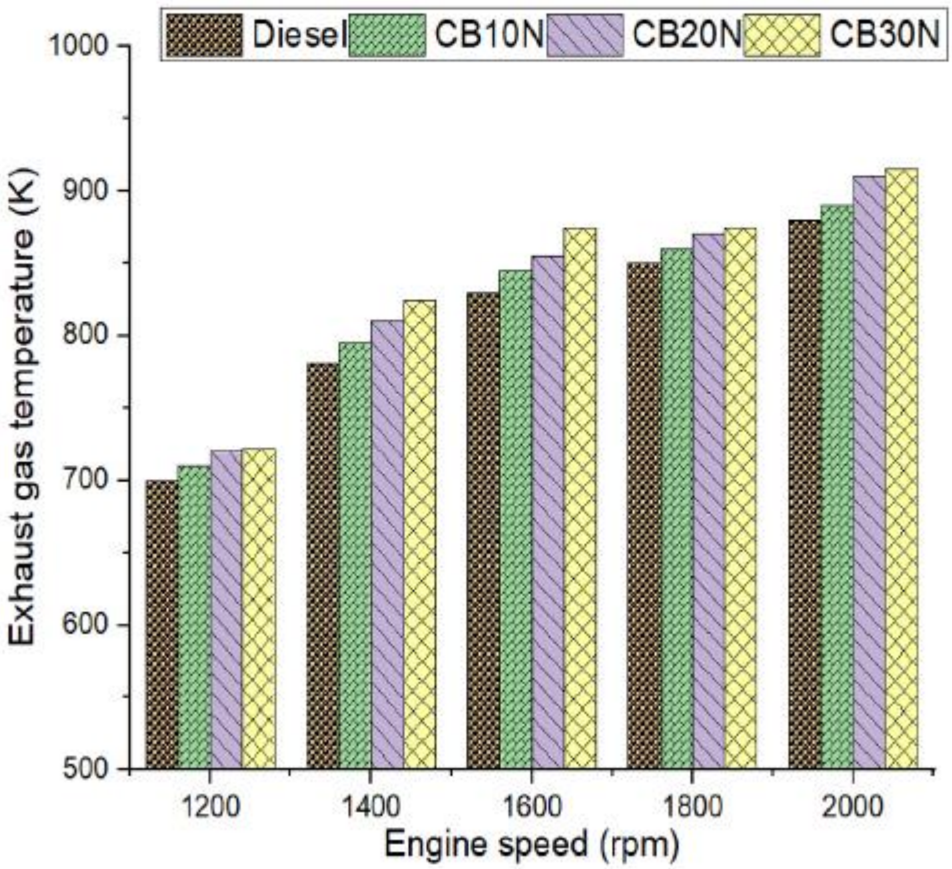

Fig. 5. Exhaust gas temperature changes for the different blends.

3.4.2. CO emission

Fig. 6 depicts the CO emission levels for CB10N, CB20N, and CB30N as a function of speed. Due to the CFB's oxygen molecules, CO emissions were minimized in all the biodiesel blends. The CO emission decreased as the CFB concentration had increased. In all the biodiesel mixes, more oxygen aided in the burning of missing or escaping carbon, reducing CO emissions (**Razak et al., 2021**; **Yesilyurt and Cakmak, 2021**; **Hao, 2022**). For diesel, CB10N, CB20N, and CB30N fuel blends at 1200 rpm, the CO emissions were 5.2 %vol, 4.9 %vol, 4.4 %vol, and 3.75 %vol, respectively. At full load, the same order fuel blends produced CO emissions of 2.35 %vol, 2.1 %vol, 1.7 %vol and 1.4%vol, respectively. Compared to the initial speed, the blend CB30N reported 90% decrease in CO emission at higher engine speeds. All the biodiesel blends contained less unburnt carbon due to the addition of hydrogen and nanoparticles.

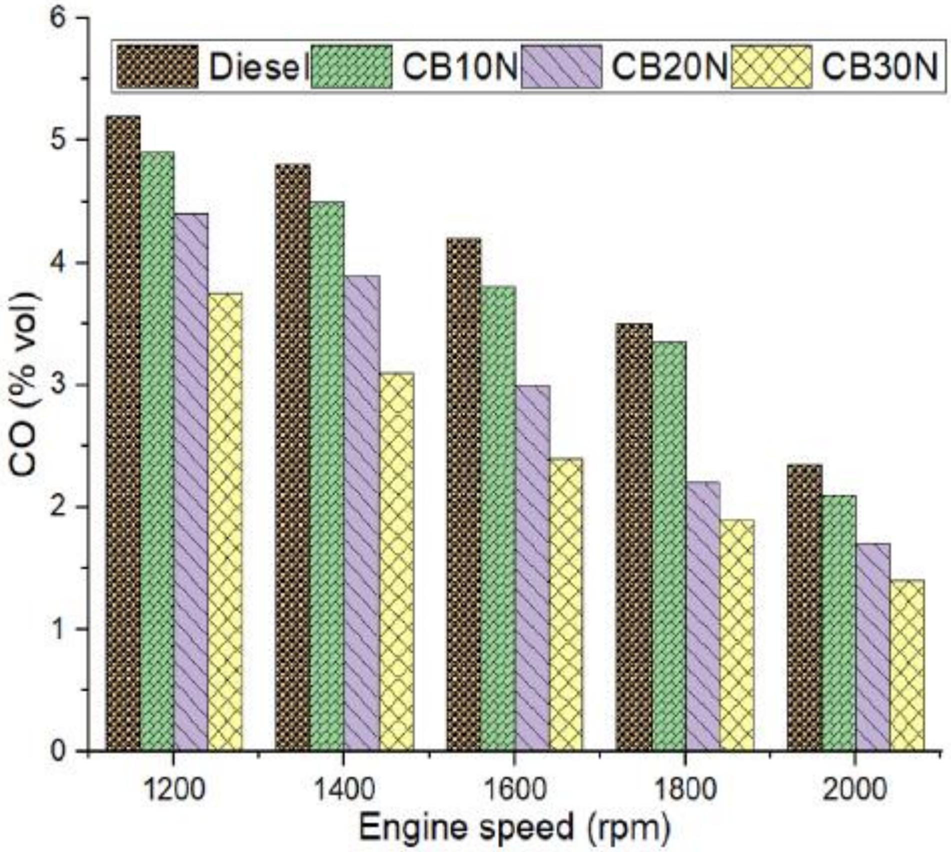

Fig. 6. CO emission of the various blends.

Blends CB10N, CB20N, and CB30N stated 11%, 32% and 50% decrease in CO production at 2000 rpm. Higher combustion was possible by the addition of hydrogen blends to the engine. Further, adding blends increased the rate of combustion due to the lower heating values (**Senthil Kumar et al., 2022**). The exhaust temperature was high for all the blends, which directly denoted full combustion. If the blends were subjected to complete combustion, then, the emissions would be lower.

3.4.3. CO_2 emission

CO_2 emissions from various biodiesel blends at varying speeds are depicted in **Fig. 7**. With each increase in speed, the amount of CO_2 generated by all the fuel blends increased, especially, when the biofuel content was increased. CO_2 is the product of combustion of carbon dioxide (CO) and oxygen (O_2). CO or CO_2 can be made from oxygen and carbon combination in the exhaust gas. The more CO_2 is produced, the more oxygen is used. At greater speeds, the CO2 emissions from all the gasoline blends increased dramatically (**Zare et al., 2021**). Compared to 1200 rpm, the average reduction in CO_2 was 40%. For instance, diesel, CB10N, CB20N and CB30N recorded 42%, 41%, 44% and 34% lower emission rates, respectively. Higher CO_2 also emphasized the rate of combustion. If the combustion is complete, the emission rate will be higher due to the interaction of oxygen atoms with carbon. It has been noted that there was only slight increase in CO_2 generation between diesel, CB10N and CB20N. On the other hand, there was a massive increase in CO_2 formation for the blends CB30N irrespective of the engine speeds; this ensured the blend CB30N depicting the highest fuel combustion rates. Higher viscosity levels and oxygen content in the fuel ensured effective combustion compared to other blends. The results were well augmented with **Wang et al.**, (**2022**) and **Ge et al.** (**2021**). Thus, by the addition of nanoparticles, the combustion efficiency can be improved.

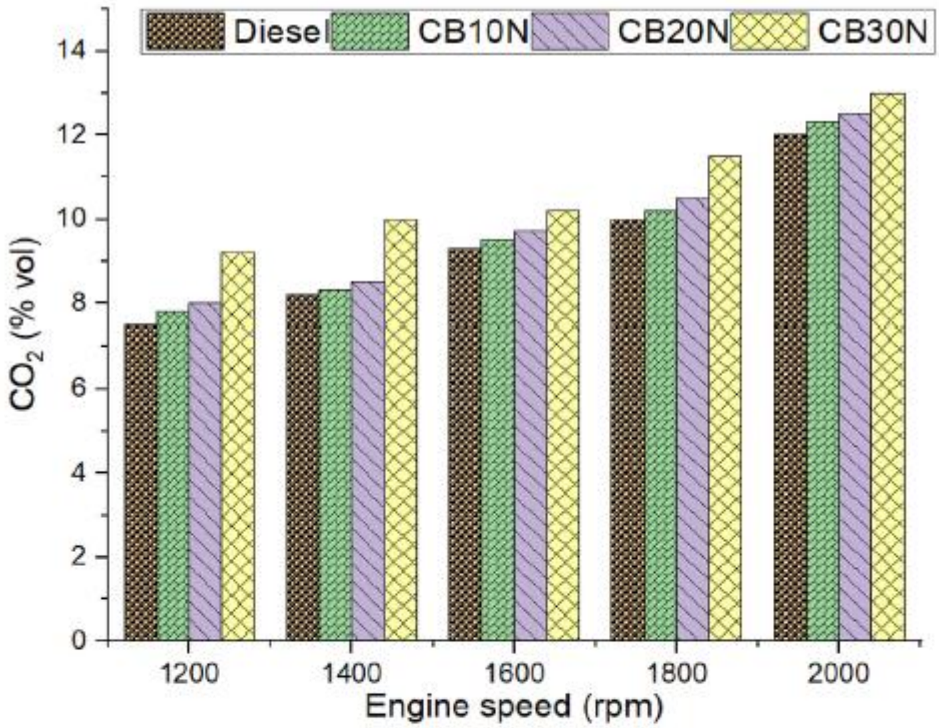

Fig. 7. Variation of CO_2 for different engine speeds.

3.4.4. NOx emission

Variations in nitric oxide emission values as a function of speed are shown in **Fig. 8** for various fuel mixes of D100, CB10N, CB20N, and CB30N. All the fuel blends emitted more NOx as the vehicle speeds increased. There was an increase in NOx production because of the increased combustion levels in the cylinder, which in turn increased the cylinder temperatures. The amount of NOx emitted increased in direct proportion to the temperature of the cylinder. As the engine speed increased, the concentration of the nitrogen oxides increased (**Sittichompoo et al., 2022**; **Sogbesan et al., 2021**). For example, there was a massive increase in the nitrogen of oxides such as, 940 ppm, 980 ppm, 995 ppm and 1005 ppm, respectively. At 1200 rpm, the NOx emission was 722 ppm, 710 ppm, 720 ppm and 735 ppm, respectively for diesel, CB10N, CB20N and CB30N. Although the $MWCNT$s were included, there was no trace of reduction in the NOx due to the density of the blends and poor flow rate to the combustion chamber. It was typical the NOx was higher due to the addition of hydrogen. The similar trend has been reported previously by **Kanimozhi et al.** (**2021**). Hydrogen is the key reason for the increase in the cylinder temperature. As the cylinder temperature increased, the production of NOx still increased. However, this massive upsurge in NOx production can be suppressed by the addition of the $MWCNT$s.

3.4.5. HC emission

Fig. 9 represents the changes in the hydrocarbons irrespective of the engine speeds. All the blends reported lower HC levels compared to neat diesel. Further, as the engine speed increased, there was a massive drop in the HC emissions (**Wang et al., 2022**; **Thanh et al., 2021**). At 1200 rpm, the HC levels were 58 ppm, 53 ppm, 45 ppm and 41 ppm, respectively. When the engine speed increased to 2000 rpm, there was a drop in the HC emission.

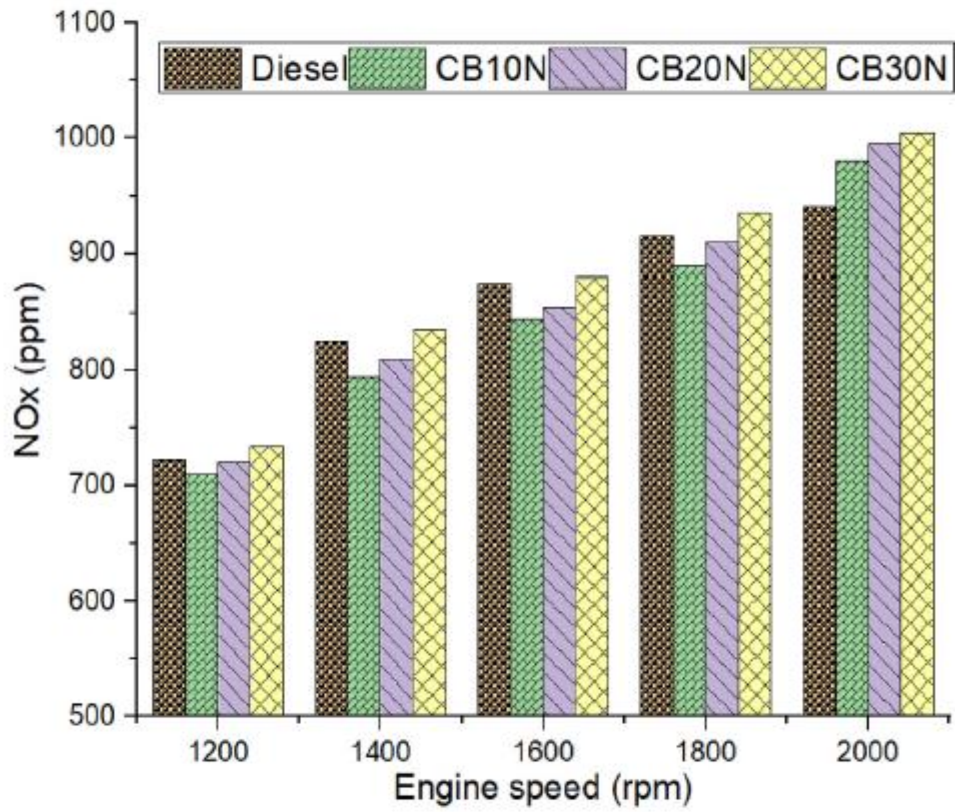

Fig. 8. Variation of the NOx related to the engine speed.

Compared to 1200 rpm, 2000 rpm reported 28 ppm, 25 ppm, 22 ppm and 18 ppm, respectively. Until 1600 rpm, the reduction in HC was gradual, which was decreased massively later than 1800 rpm. Adding the hydrogen blends reduced the carbon content, which drastically reduced the formation of the hydrocarbons. Compared to the previous findings by **Wang et al.**,(**2022**) and **Ge et al.** (**2021**) the formation of the hydrocarbons in the cylinders has been decreased upon adding hydrogen and nanoparticles. Inclusion of hydrogen decreased the presence of carbon atoms and hence, the hydrocarbon emission. Supplying extra amount of oxygen to the combustion chamber via biodiesel mixes decreased the HC levels.

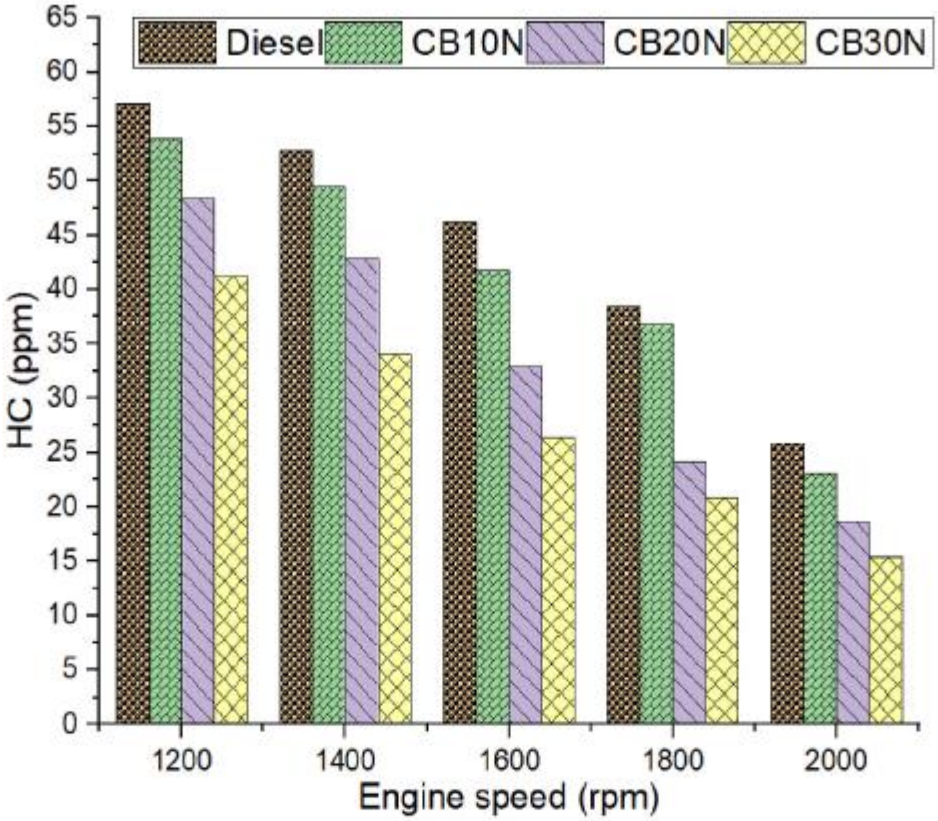

Fig. 9. Change in the HC emission for various engine speed.

4. Conclusion

In this study, biodiesel was extracted from the chicken waste through the transesterification process. Further, the $MWCNT$ nanoparticles were added to biodiesel to enhance the calorific value of the fuel using son-ication. The diesel engine equipped with single cylinder, four stroke layout, was used to determine the performance, emission, and combustion characteristics. Based on the acquired results, it was noticeable that adding hydrogen and $MWCNT$ nanoparticles increased the engine performance by enhancing the overall calorific value of the blends. As the engine speed increased, there was a marginal increase in the engine torque. The maximum torque was reported at higher engine speeds. Compared to the other blends, CB10N recorded the maximum torque of 24 Nm at 2000 rpm. In general, the $BSFC$s of the biodiesel blends were low when the concentration of the blends was between 10% and 20%. Higher concentration led to lower heating value of the fuel. The lowest fuel consumption was observed at 2000 rpm irrespective of the test blends. Brake power and EGT of the engine also reported identical behaviour similar to the torque. The maximum temperature, EGT was reported for CB30N as 910 K, which was 23 K higher than neat diesel. With regard to the emission, NOx and CO_2 formation were increased to the engine loading conditions and CB30N reported maximum emission. On contrary, CB30N recorded lower emission levels of HC and CO. CB30N test blend has shown, 12 ppm and 1.4 %vol of HC and CO. Formation of HC and CO was reduced upon reduction of the carbon atoms in the combustion chamber following the addition of hydrogen. From the above findings, it was clear that utilization of both hydrogen and $MWCNT$ on the chicken blends was sustainable when the concentration was below 20%. In the end, by optimizing the nanoparticle utilization and the process of extraction, biodiesel production can be increased.

References

Agbulut, U., Karagdz, M., Saridemir, S., O zturk, A., 2020. Impact of various metal-oxide based nanoparticles and biodiesel blends on the combustion, performance, emission, vibration and noise characteristics of a CI engine. Fuel 270, 117521. **https://doi.org/ 10.1016/j.fuel.2020.117521**.

Arunkumar, G., Dhavare, P., Alharbi, S.A., Nasif, O., Strunecky, O., Subramani, N., 2022. Effect of injection pressure on spray cone and penetration angle for enhanced fuel atomization of various blended viscous fluid: A numerical modeling. J. Energy Resour. Technol. 145 (1), 010901 **https://doi.org/10.m5/L4054562**.

Balaji, V., Kaliappan, S., Madhuvanesan, D.M., Ezhumalai, D.S., Boopathi, S., Mani, S., 2022. Combustion analysis of biodiesel-powered propeller engine for least environmental concerns in aviation industry. Aircraft Eng. Aero. Technol. **https:// doi.org/10.1108/AEAT-11-2021-0344**.

Basha, J.S., Al Balushi, M., Soudagar, M.E., Safaei, M.R., Mujtaba, M.A., Khan, T.M., Hossain, N., Elfasakhany, A., 2022. Applications of nano-additives in internal combustion engines: A critical review. J. Therm. Anal. Calorim. 1-21. **https://doi. org/10.1007/s10973-022-11199-6**.

Emiroglu, A.O., Keskin, A., Sen, M., 2018. Experimental investigation of the effects of Turkey rendering fat biodiesel on combustion, performance and exhaust emissions of a diesel engine. Fuel 216, 266-273. **https://doi.org/10.1016/j.fuel.2017.12.026**.

Faruque, M.O., Razzak, S.A., Hossain, M.M., 2020. Application of heterogeneous catalysts for biodiesel production from microalgal oil—A review. Catalysts 10 (9), 1025. **https://doi.org/10.3390/catal10091025**.

Ferraz, E., Gamelas, J.A., Coroado, J., Monteiro, C., Rocha, F., 2018. Eggshell waste to produce building lime: Calcium oxide reactivity, industrial, environmental and economic implications. Mater. Struct. 51 (5), 1-4. **https://doi.org/10.1617/s11527-018-1243-7**.

Ge, S., Brindhadevi, K., Xia, C., Elesawy, B.H., Elfasakhany, A., Unpaprom, Y., Van Doan, H., 2021. Egg shell catalyst and chicken waste biodiesel blends for improved performance, combustion and emission characteristics. Fuel 306, 121633. **https:// doi.org/10.1016/j.fuel.2021.121633**.

Zhang, J., Wang, Y., Muldoon, V.L., Deng, S., 2022. Crude glycerol and glycerol as fuels and fuel additives in combustion applications. Renew. Sustain. Energy Rev. 159, 112206 **https://doi.org/10.1016/j.rser.2022.112206**.

Gharehghani A, Fakhari AH. Biodiesel as a clean fuel for mobility. InClean Fuels for Mobility 2022 (pp. 141-168). Springer, Singapore.

Guo, M., Jiang, W., Chen, C., Qu, S., Lu, J., Yi, W., Ding, J., 2021. Process optimization of biodiesel production from waste cooking oil by esterification of free fatty acids using La3+/ZnO-TiO2 photocatalyst. Energy Convers. Manag. 229, 113745 **https://doi. org/10.1016/j.enconman.2020.113745**.

Hao, Y., 2022. Numerical simulation of regional air pollution characteristics based on meteorological factors and improved Elman neural network algorithm. Appl. Nanosci. 1-9. **https://doi.org/10.1007/s13204-021-02201-y**.

Hoang, A.T., 2021. Combustion behavior, performance and emission characteristics of diesel engine fuelled with biodiesel containing cerium oxide nanoparticles: A review. Fuel Process. Technol. 218, 106840 **https://doi.org/10.1016/j.fuproc.2021.106840**.

Idowu, I., Pedrola, M.O., Wylie, S., Teng, K.H., Kot, P., Phipps, D., Shaw, A., 2019. Improving biodiesel yield of animal waste fats by combination of a pre-treatment technique and microwave technology. Renew. Energy 142, 535-542. **https://doi. org/10.1016/j.renene.2019.04.103**.

Jamshaid, M., Masjuki, H.H., Kalam, M.A., Zulkifli, N.W., Arslan, A., Qureshi, A.A., 2022. Experimental investigation of performance, emissions and tribological characteristics of B20 blend from cottonseed and palm oil biodiesels. Energy 239, 121894. **https://doi.org/10.1016/j.energy.2021.121894**.

Kanimozhi, B., Alsehli, M., Elfasakhany, A., Veeman, D., Balaji, S., Kumar, T.P., Sekar, M., 2021. Effects of oxyhydrogen on the CI engine fueled with the biodiesel blends: A performance, combustion and emission characteristics study. Int. J. Hydrogen Energy 47 (88), 37668-37676. **https://doi.org/10.1016/j. ijhydene.2021.08.054. Sep 10**.

Keskin, A., Sen, M., Emiroglu, A.O., 2020. Experimental studies on biodiesel production from leather industry waste fat and its effect on diesel engine characteristics. Fuel 276, 118000. **https://doi.org/10.1016/j.fuel.2020.118000**.

Kirubakaran, M., Selvan, V.A., 2021. Experimental investigation on the effects of micro eggshell and nano-eggshell catalysts on biodiesel optimization from waste chicken fat. Bioresource Technology Reports 14, 100658. **https://doi.org/10.1016/). biteb.2021.100658**.

Kuipa, O., Marwizi, T.S., Kuipa, P.K., 2021. Optimisation of biodiesel production from dairy effluent scum using calcined egg shell as a transesterification catalyst. SN Appl. Sci. 3 (2), 1-5. **https://doi.org/10.1007/s42452-021-04223-1**.

Liu, Y., Meenakshi, V., Karthikeyan, L., Marousek, J., Krishnamoorthy, N.R., Sekar, M., Nasif, O., Alharbi, S.A., Wu, Y., Xia, C., 2022. Machine learning based predictive modelling of micro gas turbine engine fuelled with microalgae blends on using LSTM networks: An experimental approach. Fuel 322, 124183. **https://doi.org/10.1016/j. fuel.2022.124183**.

Ma, H., Zhang, Z., Fan, Y., Cao, B., Liu, Z., Feng, G., 2022a. Directional fast drilling technology in Yanchang gas field with quartz sandstone geology. Appl. Nanosci. 1. Feb 3.

Ma, Y., Li, H., Yang, H., Zhu, Y., Zhao, L., Li, M., 2022b. Calcium oxide derived from eggshells supported on titanium oxide green catalysts for lignin hydrogenolysis under supercritical alcohol solvents. J. Energy Inst. 101, 160-167. Apr 1.

Mandari, V., Devarai, S.K., 2021. Biodiesel production using homogeneous, heterogeneous, and enzyme catalysts via transesterification and esterification reactions: A critical review. Bioenergy Research 1-27. **https://doi.org/10.1007/ s12155-021-10333-w**.

Maroušek, J., 2022a. Nanoparticles can change (bio) hydrogen competitiveness. Fuel 328, 125318. Nov 15.

Maroušek, J., 2022b. Aluminum nanoparticles from liquid packaging board improve the competitiveness of (bio) diesel. Clean Technol. Environ. Policy 1-9. Oct 3.

Maroušek, J., Strunecký, O., Bartoš, V., Vochozka, M., 2022. Revisiting competitiveness of hydrogen and algae biodiesel. Fuel 328, 125317. **https://doi.org/10.1016/j. fuel.2022.125317**.

Mozhiarasi, V., Natarajan, T.S., 2022. Slaughterhouse and poultry wastes: management practices, feedstocks for renewable energy production, and recovery of value added products. Biomass Conversion and Biorefinery 1-24. **https://doi.org/10.1007/s13399-022-02352-0**.

Nisar, S., Hanif, M.A., Rashid, U., Hanif, A., Akhtar, M.N., Ngamcharussrivichai, C., 2021. Trends in widely used catalysts for fatty acid methyl esters (Fame) production: a review. Catalysts 11 (9), 1085. **https://doi.org/10.3390/catal11091085**.

Razak, N.H., Hashim, H., Yunus, N.A., Klemes, J.J., 2021. Reducing diesel exhaust emissions by optimisation of alcohol oxygenates blend with diesel/biodiesel. J. Clean. Prod. 316, 128090 **https://doi.org/10.1016/j.jclepro.2021.128090**.

Rosson, E., Sgarbossa, P., Pedrielli, F., Mozzon, M., Bertani, R., 2021. Bioliquids from raw waste animal fats: An alternative renewable energy source. Biomass Conversion and Biorefinery 11 (5), 1475-1490. **https://doi.org/10.1007/s13399-020-00634-z**.

Sangkharak, K., Mhaisawat, S., Rakkan, T., Paichid, N., Yunu, T., 2020. Utilization of mixed chicken waste for biodiesel production using single and combination of immobilized lipase as a catalyst. Biomass Conversion and Biorefinery 1-4. **https:// doi.org/10.1007/s13399-020-00842-7**.

Senthil Kumar, A., Karthikeyan, L., Alharbi, S.A., Salmen, S.H., 2022. Assessment of the engine vibration and noise characteristics of an unmodified direct injection engine powered with non-feedstock Citrullus lanatus seed oil. J. Energy Resour. Technol. 145 (1) **https://doi.org/10.1115/L4054563**.

Shrivastava, K., Thipse, S.S., Patil, I.D., 2021. Optimization of diesel engine performance and emission parameters of Karanja biodiesel-ethanol-diesel blends at optimized operating conditions. Fuel 293, 120451. **https://doi.org/10.1016/j. fuel.2021.120451**.

Simsek, S., Uslu, S., 2020. Comparative evaluation of the influence of waste vegetable oil and waste animal oil-based biodiesel on diesel engine performance and emissions. Fuel 280, 118613. **https://doi.org/10.1016/j.fuel.2020.118613**.

Singh, A., Kumar, G., 2018. Advancement in catalysts for transesterification in the production of biodiesel: A review. J. Biochem. Technol. 9 (1), 17.

Sittichompoo, S., Theinnoi, K., Sawatmongkhon, B., Wongchang, T., Iamcheerangkoon, T., Phugot, S., 2022. Promotion effect of hydrogen addition in selective catalytic reduction of nitrogen oxide emissions from diesel engines fuelled with diesel-biodiesel-ethanol blends. Alex. Eng. J. 61 (7), 5383-5395.

Sogbesan, O., Garner, C.P., Davy, M.H., 2021. The effects of increasing FAME biodiesel content on combustion characteristics and HC emissions in high-EGR low temperature combustion. Fuel 302, 121055. **https://doi.org/10.1016/j. fuel.2021.121055**.

Thanh, N.C., Askary, A.E., Elfasakhany, A., Nithya, S., 2021. Exergy and energy analyses of the spirulina microalgae blends in a direct injection engine at variable engine loads. J. Energy Resour. Technol. (12), 143. **https://doi.org/10.1115/L4052180**.

Wang, C., Bhatia, S.K., Manigandan, S., Yang, R., Alharbi, S.A., Nasif, O., Brindhadevi, K., Zhou, B., 2022. Comparative assessment of waste cooking, chicken waste and waste tire biodiesel blends on performance and emission characteristics. Fuel 320, 123859. **https://doi.org/10.1016/j.fuel.2022.123859**.

Yaashikaa, P.R., Kumar, P.S., Karishma, S., 2022. Bio-derived catalysts for production of biodiesel: A review on feedstock, oil extraction methodologies, reactors and lifecycle assessment of biodiesel. Fuel 316, 123379. May 15.

Yesilyurt, M.K., Cakmak, A., 2021. An extensive investigation of utilization of a C8 type long-chain alcohol as a sustainable next-generation biofuel and diesel fuel blends in a CI engine-The effects of alcohol infusion ratio on the performance, exhaust emissions, and combustion characteristics. Fuel 305, 121453. **https://doi.org/ 10.1016/j.fuel.2021.121453**.

Zamberi, M.M., Ani, F.N., Abdollah, M.F., 2018. The application of calcium oxide from waste cockle for biodiesel production from used cooking oil via microwave heating system. Journal of Advanced Research in Fluid Mechanics and Thermal Sciences 49 (2), 92-100.

Zare, A., Stevanovic, S., Jafari, M., Verma, P., Babaie, M., Yang, L., Rahman, M.M., Ristovski, Z.D., Brown, R.J., Bodisco, T.A., 2021. Analysis of cold-start NO2 and NOx emissions, and the NO2/NOx ratio in a diesel engine powered with different diesel-biodiesel blends. Environ. Pollut. 290, 118052 **https://doi.org/10.1016/j. envpol.2021.118052**.