Effect of Aluminium Oxide Nano Additive on Diesel along with Gasoline Fumigation in Single Cylinder Diesel Engine

DOI : 10.36909/jer.10479

A.Tamilvanan*, M.Bharathiraja**, K.Balamurugan***, C.Sasikumar****

*Department of Mechanical Engineering, Kongu Engineering College, Erode, Tamil Nadu, 638060, India.

**Department of Automobile Engineering, Bannari Amman Institute of Technology, Sathyamangalam, Tamil Nadu, 638401, India.

***Department of Mechanical Engineering, Institute of Road and Transport Technology, Erode, Tamil Nadu, 638316, India.

****Department of Mechanical Engineering, Bannari Amman Institute of Technology, Sathyamangalam, Tamil Nadu, 638401, India.

*Email: bharathiraja@bitsathy.ac.in; Corresponding Author.

ABSTRACT

The present investigation mainly focuses on overcoming the limitations of gasoline fumigation (GF) in diesel engines by adding up nano fuel additives. Experiments are conducted to ascertain the engine working characteristics in a single-cylinder, four-stroke diesel engine using aluminum oxide (Al_2O_3) nano additives blended diesel as the main injection fuel along with GF as an inducted fuel. GF was achieved by controlling the electronic injector fitted at the intake manifold using open ECU software. Fuel map for GF was determined based on experiments with three divergent fumigation rates of 10%, 20%, and 30% based on energy consumption and optimized using the design of experiments. The optimization results showed 10% fumigation resulted in better performance and emission characteristics and it is selected for this present investigation. Fumigation results showed a decrease in brake thermal efficiency (BTE) at low and medium loads; increase at high loads.

The two different mass fractions of 25 ppm and 50 ppm Al_2O_3 nano liquid are blended with diesel. Compared to GF with diesel, GF along with 25 and 50ppm Al_2O_3 nano additives blended diesel showed an increased BTE, maximum in-cylinder pressure, cumulative heat release rate; and reduced smoke opacity, CO, and unburned HC emissions at overall operating conditions. As the dosage level of Al_2O_3 increases from 25 to 50 ppm results in further enhancement of all working parameters except NO_x emission. Finally, the addition of an Al_2O_3 nano additive is a suitable solution to overcome the limitations of GF in the CI engine.

Key words: gasoline fumigation; electronic injection; nano additive; emissions; open ECU.

INTRODUCTION

Diesel engines or Compression ignition (CI) engines are extensively used for industrial sectors, transportation, and agricultural applications as a result of its maximum fuel conversion efficiency and negligible engine exhausts except for nitrogen oxides (NO_x) emission (Wang et al., 2021). The most harmful emissions from diesel engines are particulate matter (PM) and NO_x which has adverse effects on surroundings (Sekar et al., 2021). Fumigation is one of the dual-fuel operations which has a potential solution to reduce emissions and enhance the performance of CI engines. Here, a primary fuel called main injected fuel is injected into the combustion chamber at end of the compression stroke, and secondary fuel is called inducted fuel which is highly volatile liquid fuel injected into the intake manifold along with air stream during a suction stroke (Ayyasamy et al., 2018). Fumigation in CI engines could result in a reduction of NO_x and smoke considerably when compared to neat diesel operation. On other hand, it increases hydrocarbon (HC) emission and carbon monoxide (CO) emission (Bharathiraja et al., 2019).

The effects of GF using a simple carburetor on fuel economy, performance, combustion, and emission characteristics are studied in indirect injection automotive diesel engine (Şahin and

Durgun, 2013). The results prove that NO_x emission decreases roughly about 9.65-4.20% for 50-100% Fuel Delivery Ratio (FDR) respectively. The effect of GF on a DI diesel engine fuelled with waste cooking oil biodiesel (B20) blends and neat diesel is investigated (Hoseinpour et al., 2017). For the entire working points, the energy and exergy transfer throughout the exhaust gases reduces by an average of 2.6% and 6.4% for GF with diesel and B20 fuels respectively. Fumigation of gasoline up to 5% along with diesel and biodiesel can results in considerable raise in exhaust CO and unburned HC emissions, as well as a reduction in smoke opacity, CO_2, and NO_x emissions. The use of GF in a single-cylinder DI diesel engine results in a 4–9% enhancement of valuable power output, 1.5–4% increases of useful efficiency, and 1.5–4% reduction of specific fuel consumption. Also, the heat carried by the exhaust gas is reduced up to 4-5% for different fumigation ratios. The GF in turbo-charged an indirect injection diesel engine is investigated by (Sahin et al., 2012). NO_x concentration is reduced roughly about the levels of 5–10%. The maximum reduction ratio of 20% is achieved for 8% GF at a speed of 2500 RPM. In recent researches, the usage of nano fuel additives has received significant consideration in the combustion of fuels. The added nano fuel additives act as a catalyst that promotes combustion in a better way (Tamilvanan et al., 2021, Viswanathan and Paulraj, 2020). Investigations on a common rail direct injection system diesel engine fuelled with Al_2O_3 nanoparticles blended biodiesel was done (Aalam et al., 2015). The results exhibit a substantial improvement in heat release rate and BTE. The use of copper nanoparticles as additive along with biodiesel could result in an enhancement of 1.13-2.48%, 1.42-1.88%, and 5.02-5.79% for BTE, maximum peak pressure, and maximum heat release rate respectively (Tamilvanan et al., 2019).

From the previous literature, it is revealed that the diesel engines are suitable for many power train applications but the only limitation is only higher exhaust NO_x emissions. This limitation can be overcome by fumigation with simple modifications in the existing CI engine. Gasoline is found as the most suited fumigation fuel because of its properties like calorific value and volatility and also it has better combustion characteristics when compared with remaining fumigation fuels. However, the disadvantages of fumigation are elevated CO and HC emissions. On other hand, a nano fuel additive is also called a combustion inhibitor or catalyst which promotes the oxidation of HC resulted in enhanced combustion. Compared to so many nano fuel additives, Al_2O_3 received so much attention because of the existence of oxygen molecules that enriches combustion. Based on the inferences obtained from previous literature, the main objective of this investigation is to reduce elevated CO and HC emissions of GF along with diesel in a single-cylinder diesel engine. This can be achieved by blending Al_2O_3 nano additive liquid with 25 and 50ppm concentrations.

MATERIALS AND METHODS

Preparation of nanoadditive fuels and its properties

The adding nano-additives in base fuel progress in the improvement of thermophysical properties (Tamilvanan et al., 2016). Numerous varieties of nanoparticle metal additives were used as fuel additives to diesel/biodiesel. Compared to other metal additives, Al_2O_3 showed excellent thermophysical properties such as heat transfer rate and thermal conductivity. In this research work, Al_2O_3 nano liquid was selected because it would blend more easily with diesel fuel and also the existence of oxygen in Al_2O_3. The required concentration of Al_2O_3 is mixed with diesel and placed in an ultrasonicator for proper blending of the liquids. To avoid the phase separation of the liquids, the surfactant SPAN 80 is used here. The properties were tested in the laboratory as per the standard. The fuel properties of gasoline, diesel with 25 ppm of Al_2O_3 (25AONP-D), and diesel with 50 ppm of Al_2O_3 (50AONP-D) are compared with diesel are presented in Table 1.

Table 1 Fuel Properties.

Particulars	D	Gasoline	25ANOP-D	50ANOP-D

Density at 15ºC (kg/m^3)	815	737	816.5	819
Flash point (°C)	56	45	51	45
Calorific value (kJ/kg)	42000	43400	42100	42150
Cetane number	47	5	47.5	49

Experimental Setup for gasoline fumigation with fuel map table

Generally, the control of fumigation is done by the carburetor or electronic injector with ECU. Four-stroke water-cooled CI engine with single cylinder and 17.5 compression ratio is modified for fumigation, including microcomputer control, modified air intake system with open ECU and secondary fuel tank with pump. In this research work, PE3, an open ECU from Apex Innovations Inc is used for controlling fuel injection parameters. Here, the injection duration can be altered in the fuel map table, based on the different input values like throttle position and speed. The representation of the experimental setup is shown in Figure 1. The AVL 444 exhaust gas and AVL 435 smoke meter analyzer are used to measure the smoke and emission values respectively. The experiment is repeated for different loads of the engine and open ECU software would control the fumigation rates according to the fuel map table. The GF is done for three different rates of 10%, 20%, and 30% based on energy. The results of the fumigation are optimized and the optimized fumigation rate is calculated for various loads. Based on the optimal results, 10% fumigation is best for obtaining better performance and emission (Bharathiraja et al., 2017). The modified fuel map of 10% fumigation is used for GF for further research.

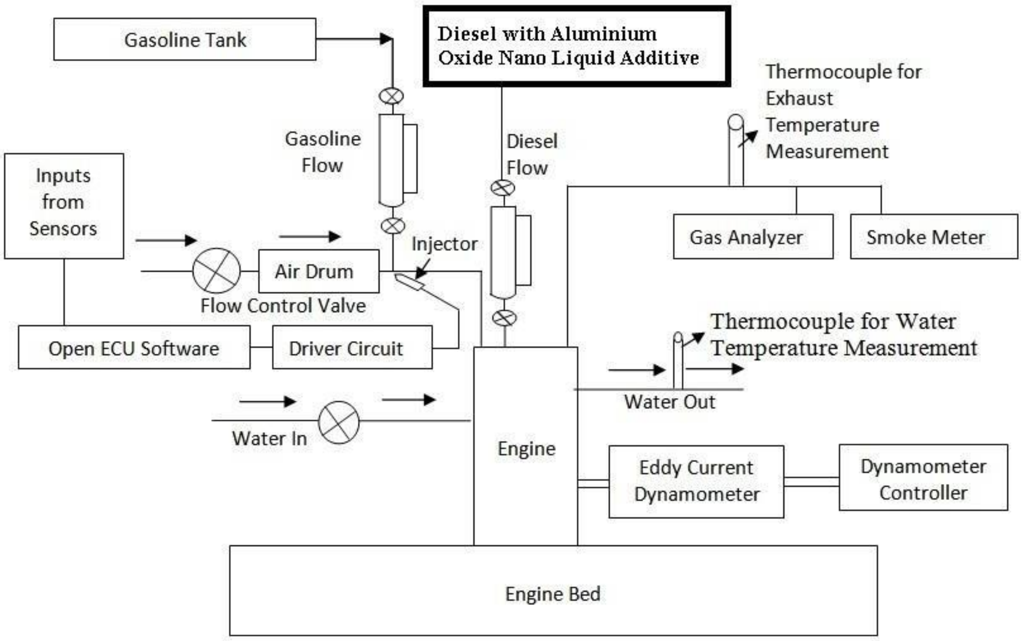

Figure 1 Experimental setup

RESULTS AND DISCUSSION

In this present investigation, the experiments were conducted on four modes of operation (mentioned below) under similar operating conditions such five different loads (0, 25, 50, 75 and 100%) and constant speed.

1. Diesel (D) only
2. Diesel with Gasoline Fumigation (D+GF)
3. 25ppm Al_2O_3 nano additive blended diesel along with Gasoline Fumigation (25ppmAONP-D+GF)
4. 50ppm Al_2O_3 nano additive blended diesel along with Gasoline Fumigation (25ppmAONP-D+GF)

Performance Characteristics

Brake Thermal efficiency

BTE was decreased about 3.1-4.12% for GF along with diesel at lower loads whereas it was increased about 0.86-1.09% at higher loads when compared to neat diesel mode which is exposed in Figure 2. The cooling effect of gasoline and leaner air -gasoline mixture (because fumigated gasoline at inlet manifold replaces considerable amount of air entered into the combustion chamber) resulted in longer ignition delay (ID) and poorer combustion which tends to lower BTE at low loads. Whereas at high loads, the higher cylinder temperature and shorter ID makes the combustion better which resulted in higher BTE compared to diesel (Hoseinpour et al., 2018, Viswanathan et al., 2020). Compared to diesel along with GF, there was an improvement of 0.18-5.41%, and 1.60-7.85% is obtained for GF along with 25 ppm and 50 ppm Al_2O_3 blended diesel respectively. Also, an average improvement of 1.98% was obtained for GF along with 50ppm Al_2O_3 blended diesel when compared to the same with 25ppm additive. This was due to the thermal conductivity and larger surface area to volume ratio of Al_2O_3 nano additives which enhanced the fuel droplets evaporation rate and better air-fuel mixing. The above factors ensuing in improved combustion for GF with AONP diesel mode when compared to gasoline with neat diesel. Similar improvements in BTE is obtained in previous literature using Al_2O_3 nano additive (El-Seesy et al., 2018, Aalam et al., 2015)

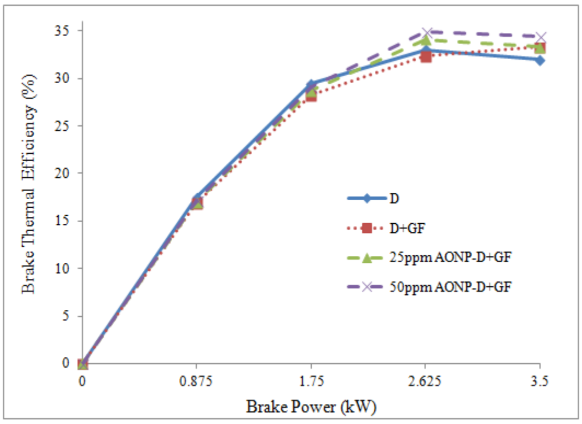

Figure 2 Variations of BTE

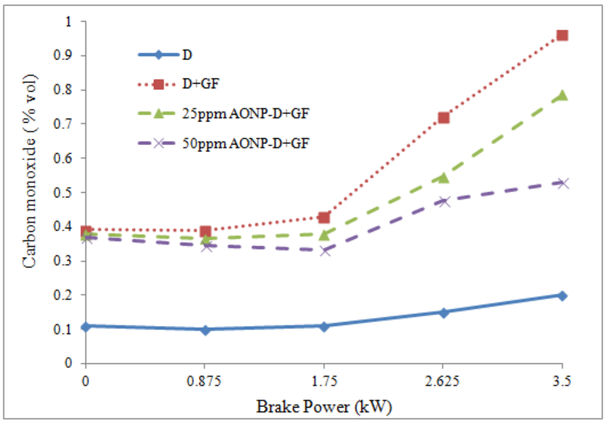

Figure 3 Variations of CO emission

Emission Characteristics

CO Emissions

CO emissions are significantly higher for GF operation when compared to neat diesel and also GF with 25&50ppm Al_2O_3 nano additive diesel blends which are exposed in Figure 3.

The increase in CO is lesser at low and medium loads, but it is significantly larger at higher loads. The reason for the higher CO emission of fumigation mode was mainly due to longer ID and cooling effect of gasoline inside the cylinder which could lead to partial oxidation of the CO to CO_2. And also, the lowered air/fuel ratio related to premixed gasoline would result in elevated CO emission (Hoseinpour et al., 2018). The CO emissions GF with 25&50ppm Al_2O_3 nano additive diesel blends were significantly higher than neat diesel and considerably lower than GF along with non-additive diesel. The presence of Al_2O_3 nano additive in diesel along with GF resulted in an average reduction of CO emissions about 12.5% and 23.6% for 25ppm and 50ppm respectively when compared to fuel without additive. The reasons for the reduction of CO emissions of GF with Al_2O_3 nano additive were mainly due to catalytic activity of nano fuel additive and existence of oxygen molecule in nano fuel additive which took part in the oxidation of CO to CO_2 resulted in enhanced combustion. Moreover, the CO emissions were further reduced to 3-32% when the concentration of Al_2O_3 nano additive was increased from 25ppm to 50ppm. Thus, it has been proved that the catalytic action of nano fuel additive which took part in the combustion of fuel.

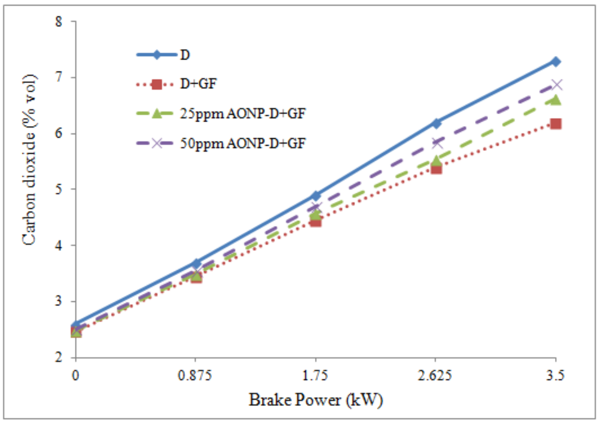

Figure 4 Variations of CO_2 emission

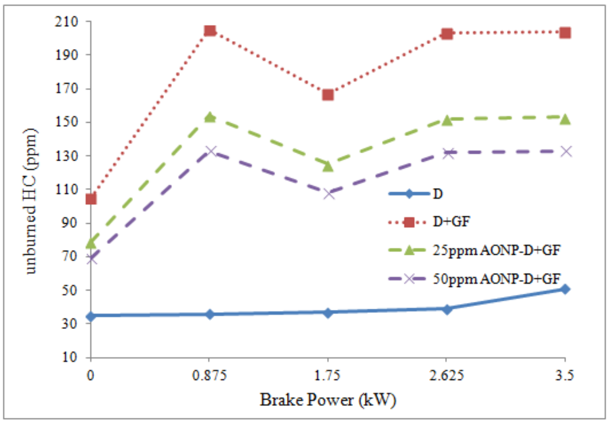

Figure 5 Variations of UBHC emission

CO_2 Emissions

CO_2 emission is decreased by about 3.65-5.76% for GF with diesel when compared with neat diesel at overall working conditions. At every load, CO_2 emission was reduced to some extent for GF when compared to diesel which is depicted in Figure 4. The existence of gasoline in a premixed air-fuel mixture in an intake manifold offers a smaller quantity of oxygen into a combustion chamber which resulted in incomplete combustion and thus diminishes CO_2 formation. The cooling effect of gasoline reduces in-cylinder combustion temperature that leads to incomplete combustion and it resulted in lower CO_2 emission (Hoseinpour et al., 2018). The addition of Al_2O_3 nano additives to diesel along with GF could further increase CO_2 emissions. The result also showed that an increase of CO_2 emissions about 0.40-6.95% and 1.21-11.1% is obtained for GF along with 25ppm and 50ppm Al_2O_3 nano additives respectively when compared to same without additive. It was noticed that the Al_2O_3 nano additives had a significant constructive effect on CO_2 emissions, that was probably attributable to the presence of oxygen molecule in Al_2O_3 nano additive, better air-fuel mixing of premixed gasoline, shorter ID, superior catalytic activity the higher surface-to-volume ratio resulted in enhanced combustion. These above factors promoted the effective conversion of CO to CO_2 and thus resulted in higher CO_2 emission for nano additives blended fuels (El-Seesy et al., 2018).

Unburned HC Emissions

GF operation showed higher HC emissions when compared to neat diesel operation which is depicted in Figure 5. During GF mode operation, the air/gasoline mixture absorbed in crevices and cylinder wall and rich air-gasoline fuel mixture might be the reason for the formation of unburned HC. Additionally, at low engine loads, there was a possibility of inferior combustion due to lean air/fuel mixture, longer ID, and its cooling effect resulted in higher unburned HC emissions (Bharathiraja et al., 2017). The addition of nano Al_2O_3 additive with diesel and GF led to a reduction in the HC emission as compared to GF without additive. The result showed that an average reduction of unburned HC emissions of about 25.04% and 35.04% was obtained for 25ppm and 50 ppm of Al_2O_3 nano additive blended diesel along with GF respectively when compared to GF without Al_2O_3 nano additive. And the same was again reduced to an average of 13.37% when the concentration of Al_2O_3 nano additive was increased from 25ppn to 50ppm. These results are revealed positive effects on the enhanced combustion process which led to the reduction of unburned HC emissions as a result of the existence of oxygen molecules in Al_2O_3 nano additives (El-Seesy et al., 2018).

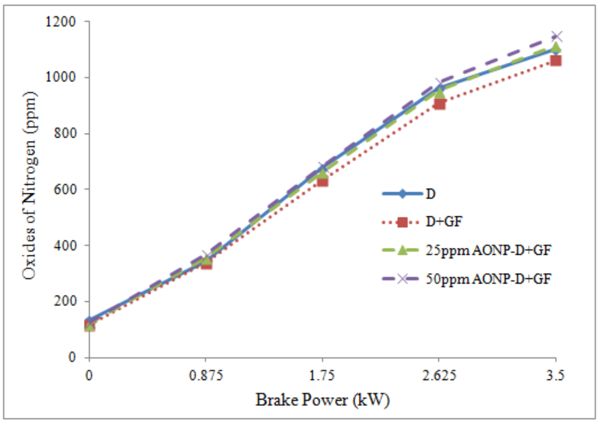

Figure 6 Variations of NO_x emission

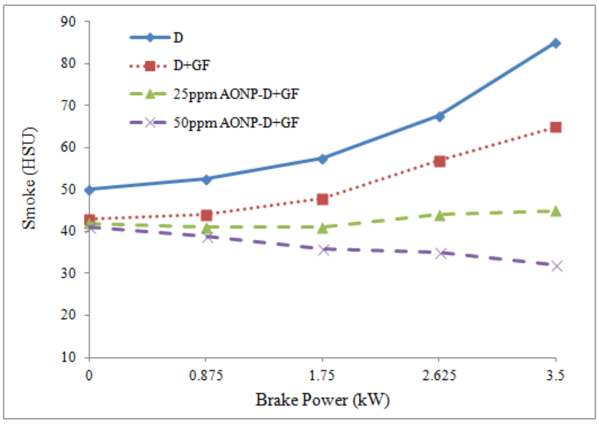

Figure 7 Variations of Smoke Opacity

NO_x Emissions

NO_x emissions decrease about 1.1-14.6% for GF with diesel when compared to diesel at all loads is exposed in Figure 6. This is owing to the higher specific heat of the gasoline-air mixture than that of the air inside the combustion chamber, where the gasoline consumed a larger amount of heat energy and thus resulted in longer ID and reduced in-cylinder temperature (Ou et al., 2012, Hoseinpour et al., 2018). The addition of nano Al_2O_3 additive with diesel and GF led to an increase of NOx emission as compared to neat diesel and GF without Al_2O_3 nano additive diesel. An increase of NO_x emissions of about 1.18-3.49% and 0.84-6.72% for GF along with 25ppm and 50ppm Al_2O_3 nano additive diesel respectively when compared to neat diesel are also observed. The existence of oxygen molecule in Al_2O_3 nano additive blended fuel would provide sufficient oxygen during the combustion process which may raise the maximum in-cylinder temperature that would affect additional NO_x formation. There was a small difference of about 3.05% exist in NO_x emissions concerning the dose level of nanoparticles from 25ppm to 50ppm in the diesel fuel along with GF. This consequence might be due to superior combustion fuel blends as a result further shorter ID with 50ppm nano additive (El-Seesy et al., 2018).

Smoke Opacity

The smoke opacity decreases about 12.1-23.4% for GF with diesel when compared to neat diesel at overall operating conditions which is exposed in Figure 7. The addition of 25ppm and 50ppm Al_2O_3 nano additive to diesel along with GF could result in further reduction of smoke opacity about 15.4-46.4% and 17.6- 61.7% respectively when compared to neat diesel. It is also noticed that a reduction of smoke opacity about 2.3-30.7% and 4.6-50.7% was obtained for 25ppm and 50 ppm of Al_2O_3 nano additive blended diesel along with GF respectively when compared to GF without Al_2O_3 nano additive. The increase in the concentration of Al_2O_3 from 25ppm to 50ppm resulted in further reduction of smoke opacity about 2-28% over entire operating region. At low load, there was no substantial reduction in the smoke opacity for Al_2O_3 blended fuels. However, at medium to high loads, there were considerable large reductions above 30%. GF lowered the relative fuel-air ratio inside the combustion chamber of the cylinder which decreases the amount of diesel contribute to the diffusion combustion phase that resulted in the reduction of soot formation (Karthickeyan et al., 2019). Also, the existence of Al_2O_3 in diesel fuels could act as a catalyst that promotes better combustion.

Combustion Characteristics

In-cylinder Pressure with Crank Angle

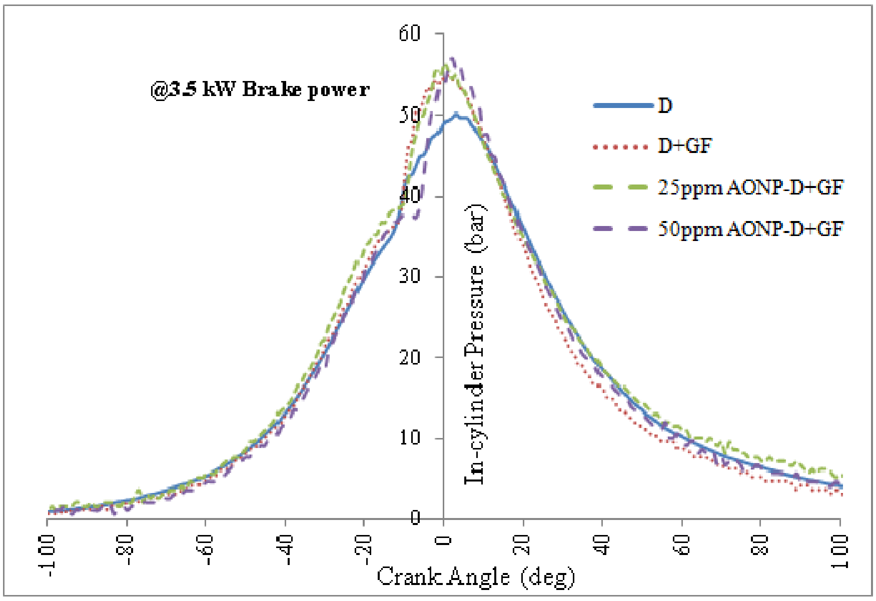

Figure 8 Variations of In-cylinder Pressure with Crank Angle for different fuel blends

The GF with diesel has a 9.86% higher peak pressure value than neat diesel which is exposed in Figure 8. The fumigation of the gasoline could increase the quantity of the premixed fuel inside the combustion chamber (Ou et al., 2012). This resulted in an increased ID period which provides more time to make a homogeneous mixture before start of combustion (Wang et al., 2020). Consequently, this led to a higher pre-mixed combustion phase and a shorter diffusion phase of combustion. (Jamrozik et al., 2018). The GF along with 25ppm and 50ppm Al_2O_3 nano additive diesel has 12.78% and 13.98% respectively higher peak pressure value when compared to that of neat diesel. Also, the GF along with 25ppm and 50ppm Al_2O_3 nano additive diesel has 2.12% and 3.77% respectively higher peak pressure value than GF without Al_2O_3 nano additive diesel. Conversely, the addition of Al_2O_3 nano additive to diesel along with GF reduced the ignition delay period to minimum extent when compared to neat diesel with fumigation. The concentration of nano fuel additive is increased from 25ppm to 50ppm resulted in a slight improvement about 1.07% higher pressure. This was owing to the more catalytic action of Al_2O_3 nano additive (Aalam et al., 2015).

Cumulative Heat Release Rate

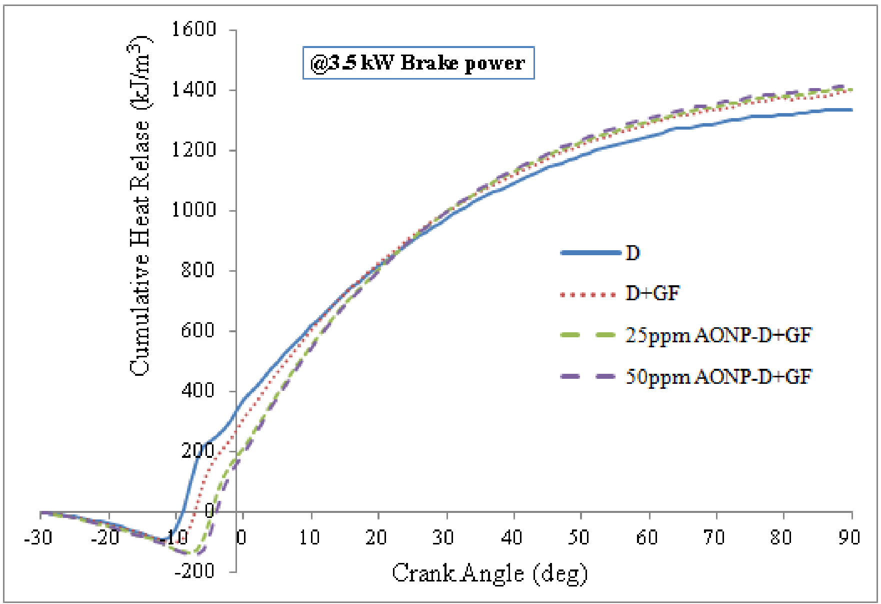

Figure 9 Variations of Cumulative heat release with Crank Angle for different fuel blends

Figure 9 shows that the maximum cumulative heat release rate (CHRR) of GF with diesel was 4.54% higher than neat diesel. It is observed that the maximum CHRR of 25 and 50ppm of Al_2O_3 nano additive to diesel along with GF is 5.04% and 5.79% higher than neat diesel respectively. Also, it is noticed that maximum CHRR of 25 and 50ppm of Al_2O_3 nano additive to diesel along with GF was 0.21% and 0.92% respectively higher than GF along with nano additive diesel. The concentration of nano fuel additive was increased from 25ppm to 50 ppm resulted in a slight enhancement of maximum CHRR which is about 0.71%. The CHRR rate for GF with Al_2O_3 nano additive is lower before TDC as compared to those of neat diesel and diesel with GF. This is mainly due to the higher thermal conductivity of Al_2O_3 nano additive which absorbs a larger amount of heat from the combustion chamber (El-Seesy et al., 2018). The concentration was increased from 25ppm to 50ppm resulted in a slightly higher cumulative heat release rate which was happened due to the presence of additional oxygen and superior catalytic activity of nano additive in fuel blends (Karthickeyan, 2019).

CONCLUSION

The following conclusions are obtained from the results of testing the GF in open ECU with Al_2O_3 nano liquid blended diesel in DI diesel engine. GF up to 10% with Al_2O_3 nano liquid blended diesel has significantly higher BTE about 0.86-1.09% and 0.18-5.41% compared to diesel mode and diesel with GF mode respectively. The AONP diesel fuel with GF could show lower CO and unburned HC emissions throughout engine loading conditions when compared to a diesel with GF mode. This was due to improved combustion of Al_2O_3 nano liquid blended fuel.

The smoke opacity of AONP diesel with GF was considerably reduced when compared to neat diesel and diesel with GF at medium to high loads. While AONP diesel with GF has elevated NO_x emission compare to all other modes except GF with neat diesel. CO, HC, and NO_x emissions of AONP diesel fuel with GF mode were decreased considerably and BTE was slightly increased as the dosage level was increased from 25ppm to 50 ppm. This is evident that the drawbacks of using GF in conventional CI engine were eliminated by adding Al_2O_3 nano liquid additive to diesel fuel.

ACKNOWLEDGMENT

Authors would like to thank the Management and Administration of Kongu Engineering College for providing the “Seed Grant Research Scheme- KEC/R&D/SGRS/01/2020”.

REFERENCES

Aalam, C. S., Saravanan, C. & Kannan, M. 2015. Experimental investigations on a CRDI system assisted diesel engine fuelled with aluminium oxide nanoparticles blended biodiesel. Alexandria Engineering Journal, 54: 351-358.

Ayyasamy, T., Balamurugan, K. & Duraisamy, S. 2018. Production, performance and emission analysis of Tamanu oil-diesel blends along with biogas in a diesel engine in dual cycle mode. International Journal of Energy Technology and Policy, 14: 4-19.

Bharathiraja, M., Venkatachalam, R., Murugesan, A. & Tiruvenkadam, N. 2017. Experimental investigation of a novel alcohol fumigation in a single-cylinder constant speed diesel engine. International Journal of Ambient Energy, 38: 794-802.

Bharathiraja, M., Venkatachalam, R. & Senthilmurugan, V. 2019. Performance, emission, energy and exergy analyses of gasoline fumigated DI diesel engine. Journal of Thermal Analysis and Calorimetry, 136: 281-293.

El-Seesy, A. I., Attia, A. M. & El-Batsh, H. M. 2018. The effect of Aluminum oxide nanoparticles addition with Jojoba methyl ester-diesel fuel blend on a diesel engine performance, combustion and emission characteristics. Fuel, 224: 147-166.

Hoseinpour, M., Sadrnia, H., Tabasizadeh, M. & Ghobadian, B. 2017. Energy and exergy analyses of a diesel engine fueled with diesel, biodiesel-diesel blend and gasoline fumigation. Energy, 141: 2408-2420.

Hoseinpour, M., Sadrnia, H., Tabasizadeh, M. & Ghobadian, B. 2018. Evaluation of the effect of gasoline fumigation on performance and emission characteristics of a diesel engine fueled with B20 using an experimental investigation and TOPSIS method. Fuel, 223: 277-285.

Jamrozik, A., Tutak, W., Gruca, M. & Pyrc, M. 2018. Performance, emission and combustion characteristics of CI dual fuel engine powered by diesel/ethanol and diesel/gasoline fuels. Journal of Mechanical Science and Technology, 32: 2947-2957.

Karthickeyan, V. 2019. Effect of combustion chamber bowl geometry modification on engine performance, combustion and emission characteristics of biodiesel fuelled diesel engine with its energy and exergy analysis. Energy, 176: 830-852.

Karthickeyan, V., Ashok, B., Nanthagopal, K., Thiyagarajan, S. & Geo, V. E. 2019. Investigation of novel Pistacia khinjuk biodiesel in DI diesel engine with post combustion capture system. Applied Thermal Engineering, 159: 113969.

Ou, L. J., Wang, C. M., Qian, Y. J., Huang, W., Zhu, S. W. & Sun, J. **2012.** Effect of gasoline fumigation on diesel engine performance and emissions. Applied Mechanics and Materials, Trans Tech Publ: 1744-1748.

Şahin, Z. & Durgun, O. 2013. Improving of diesel combustion-pollution-fuel economy and performance by gasoline fumigation. Energy conversion and management, 76: 620-633.

Sahin, Z., Durgun, O. & Bayram, C. 2012. Experimental investigation of gasoline fumigation in a turbocharged IDI diesel engine. Fuel, 95: 113-121.

Sekar, D., Venkadesan, G. & Viswanathan, K. 2021. Experimental evaluation of orange oil biodiesel in compression ignition engine with various bowl geometries. Energy Sources, Part A: Recovery, Utilization, Environmental Effects: 1-12.

Tamilvanan, A., Balamurugan, K., Mohanraj, T., Selvakumar, P. & Madhankumar, B. 2021. Parameter optimization of copper nanoparticle synthesis by electrodeposition process using RSM and CS. Materials Today: Proceedings, 45: 751-756.

Tamilvanan, A., Balamurugan, K., Ponappa, K. & Madhan Kumar, B. 2016. Using response surface methodology in synthesis of ultrafine copper nanoparticles by electrolysis. International Journal of Nanoscience, 15: 1650001.

Tamilvanan, A., Balamurugan, K. & Vijayakumar, M. 2019. Effects of nano-copper additive on performance, combustion and emission characteristics of Calophyllum inophyllum biodiesel in CI engine. Journal of Thermal Analysis and Calorimetry, 136: 317-330.

Viswanathan, K. & Paulraj, A. 2020. A comprehensive study on the performance and emission characteristics of a diesel engine with the blends of diesel, jojoba oil biodiesel, and butylated hydroxyl anisole as an alternative fuel. Energy Sources, Part A: Recovery, Utilization, Environmental Effects: 1-15.

Viswanathan, K., Wang, S. & Esakkimuthu, S. 2020. Impact of yttria stabilized zirconia coating on diesel engine performance and emission characteristics fuelled by lemon grass oil biofuel. Journal of Thermal Analysis Calorimetry: 1-13.

Wang, S., Karthickeyan, V., Sivakumar, E. & Lakshmikandan, M. 2020. Experimental investigation on pumpkin seed oil methyl ester blend in diesel engine with various injection pressure, injection timing and compression ratio. Fuel, 264: 116868.

Wang, S., Viswanathan, K., Esakkimuthu, S. & Azad, K. 2021. Experimental investigation of high alcohol low viscous renewable fuel in DI diesel engine. Environmental Science Pollution Research, 28: 12026-12040.