

Cupric Oxide Nanoparticles In Diesel: Emission Impact Study

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Abstract

The escalating concerns regarding the air pollution and its impact on human health have driven extensive research into alternative fuel additives for diesel engines. The integration of Metal Oxide NanoParticles (MONPs) in diesel fuel has emerged as a promising strategy to enhance combustion efficiency and reduce harmful emissions. This study investigates the impact of MONPs additives on diesel engine emissions, focusing on key pollutants such as CO, NO_x, and HC. The present findings highlight the potential of Cupric Oxide(CuO) nanofuel as a sustainable solution for cleaner diesel engine operation, contributing to reduced environmental impact and improved energy performance. The emission characteristics of diesel fuel blended with CuO nanoparticles (at concentrations of 25 ppm, 50 ppm, and 75 ppm by weight) were initially examined. After evaluating the performance of CuO blends, the most effective results from each were compared to determine the optimal blend. Finally, the paper addresses existing challenges and future research directions related to the safe and effective application of MONPs in diesel engines. This work underscores the importance of continued innovation in nanotechnology and fuel science to develop cleaner alternatives in transportation, aligning with global efforts to combat climate change and promote sustainable energy solutions for future mobility.

Keywords : Emission Analysis, Cupric Oxide, Diesel fuel, Environmental Impact

1. INTRODUCTION

The energy demand is raising exponentially to meet the need of growing population. It is commonly recognized that the majority of energy used comes from fossil fuels, which are rapidly running out and raising serious concerns because of their harmful emissions [1,2].

Diesel engines, extensively used in transportation, power generation, and industrial sectors, are major contributors to air pollution. Their exhaust emissions comprise a complex mix of pollutants, including particulate matter (PM), nitrogen oxides (NO_x), carbon monoxide (CO), unburned hydrocarbons (UHC), and other harmful compounds. These emissions pose significant health risks, leading to respiratory disorders, cardiovascular diseases, and cancer. Biodiesel is a key alternative fuel that can help meet the growing demand for energy. By using biodiesel, environmental emissions can be reduced, although there may be a minor reduction in engine performance. However, there is potential to enhance both fuel properties and engine performance by incorporating metal oxide nanoparticles as additives [3].

Fuel additive with at least one dimension less than 100 nm is considered as nanosize fuel additive [4,5]. The nanoparticles, owing to their unique catalytic properties and high surface area-to-volume ratios, facilitate more complete fuel combustion, thereby improving engine performance and mitigating the release of pollutants.

Metallic nanoparticles are an attractive choice as fuel additives owing to high energy density and reactivity. Bergthorson et al. proposed direct burning of metallic nanoparticles for zero-carbon electricity after conducting a number of experiments on the particles. They demonstrated how, as seen in Figure 1, the flame of methane fuel in air resembles the flame of metallic particles [6].

Recent studies have demonstrated the efficacy of various metal oxide nanoparticles as fuel additives. For instance, Özgür investigated the effects of nickel iron oxide (NiFe₂O₄) and nickel zinc iron oxide (Zn_{0.5}Ni_{0.5}Fe₂O₄) nanoparticles on the exhaust emissions of a turbocharged diesel engine. The study revealed that incorporating these nanoparticles at concentrations of 15, 20, and 25 ppm led to a significant reduction in exhaust emissions, with the optimal dosage identified for maximum emission reduction [7].

Similarly, research by Fayad et al. explored the impact of titanium dioxide (TiO₂) nanoparticles blended with castor oil methyl ester (C20D) on soot nanoparticles and NO_x emissions in a common rail direct injection (CRDI) diesel engine. The findings indicated that adding TiO₂ nanoparticles at concentrations

of 25 and 40 ppm, combined with a high rate of exhaust gas recirculation (EGR), resulted in a notable decrease in NO_x emissions and a reduction in the total concentration of particulate matter (PM) [8].

Furthermore, a study by Hussain et al. examined the effects of cerium-coated zinc oxide (Ce-ZnO) nanoparticles added to soybean biodiesel blends on engine performance and emissions. The results demonstrated that a 50 ppm concentration of Ce-ZnO nanoparticles in a 25% soybean biodiesel blend led to a 20.66% increase in brake thermal efficiency and significant reductions in CO, smoke, and hydrocarbon emissions compared to the biodiesel blend without nanoparticles [9].

Previous studies revealed that addition of nanoparticle to fuel acts as combustion catalyst, improves combustion behavior and reduces pollutant emissions. Mehta et al. investigated the burning characteristics of diesel fuel blended with aluminum (Al), iron (Fe) and boron (B) nanoparticle in a diesel engine. The author reported an appreciable reduction in ignition timing for nanofuels (0.2 s), in comparison with diesel fuel (1.2 s) [10].

Building on previous research that demonstrated the effectiveness of metal oxide nanoparticles in enhancing combustion and reducing emissions, this study aims to investigate the impact of CuO and Al_2O_3 nanoparticles on emission characteristics in detail.

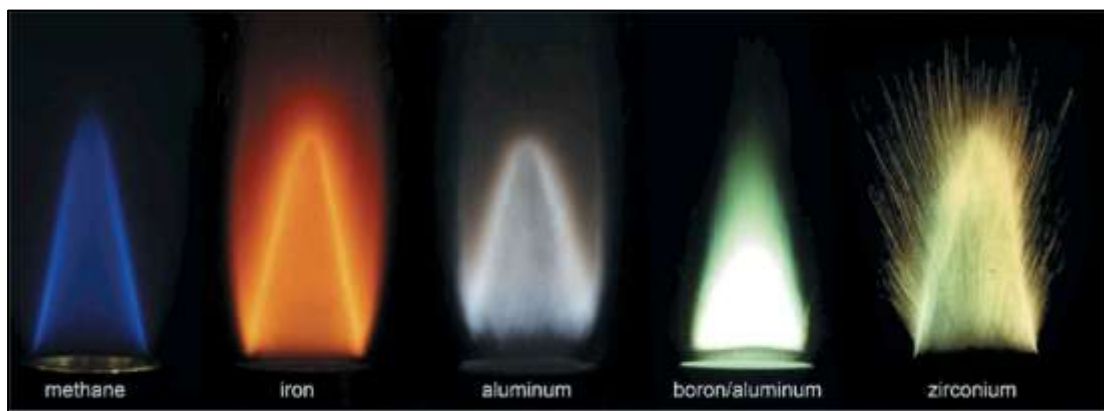


Fig. 1 Burning of various metallic fuels in a Bunsen burner and compared to a methane flame [10]

2. MATERIALS AND METHODS

2.1 Materials

CuO Nanoparticles with a specific surface area of approximately $30\text{-}50\text{ m}^2/\text{g}$ and an average particle size of $20\text{-}30\text{ nm}$ were used.

Commercially available Diesel was used as the base fuel.

2.2 Preparation of Fuel Blends

The fuel blends were formulated by dispersing the nanoparticles into the diesel fuel with the aid of a magnetic stirrer. The nanoparticles concentration used was 25, 50, and 75 ppm (parts per million) by weight in the diesel fuel.

From hereon, the fuel blends will be denoted as follows :

Table 1 : Fuel Blends and corresponding run

Neat Diesel	Run 0
Diesel + 25 ppm CuO	Run 1
Diesel + 50 ppm CuO	Run 2
Diesel + 75 ppm CuO	Run 3

Engine Setup and Testing:

A single-cylinder, four-stroke, direct-injection diesel engine was used for the emission tests. The engine was coupled to a dynamometer to control the load and speed. Engine operating conditions were carefully controlled. The engine was run at various load conditions (0 %, 25%, 50%, 75%, and 100% of rated load) at a constant speed of 1500 rpm.

Exhaust Emission Measurement:

Carbon dioxide (CO₂), carbon monoxide (CO), nitrous oxide (NO_x), sulfuric compounds, particulate matter (PM), and unburned hydrocarbons (UHCs) are the most prevalent emissions from fossil fuels [11,12].

The high temperature in the combustion chamber and the surplus availability of oxygen are the causes of formation for NO_x emission [13].

The CO₂ is formed by complete combustion of fuel and adequate availability of oxygen, whereas CO emissions are formed due to incomplete combustion or deficiency of oxygen [14,15].

Due to environmental issues, PM emissions are a major concern. PM is usually a complex mixture of sulfur compounds, various HCs, elemental carbon, and other species [16,17]. UHCs, considered as a main pollutant and significantly affecting the environment, are the result of incomplete combustion [11]. In the present study, an Exhaust Gas Analyzer(AVL444N) was used to measure the concentrations of gaseous pollutants, including CO, HC, CO₂, O₂ & NO_x; Smoke meter (AVL437) was used to measure the smoke emission.



Fig. 2 Smoke meter (AVL437) & Exhaust gas analyzer(AVL444N)

3. RESULTS & DISCUSSION

The detailed interpretation of the individual runs along with its experimental data (represented graphically) is as follows :

1) Run 0 (Neat Diesel)

Carbon monoxide (CO) levels initially drop from 0.08% at no load to 0.03% at 9 kg, suggesting improved combustion efficiency. However, at 12 kg, CO slightly increases to 0.04%, pointing to incomplete combustion under peak load conditions. Hydrocarbon (HC) emissions show a steady rise, climbing from 1 ppm at no load to 9 ppm at 12 kg, indicating higher levels of unburned fuel residues as the load increases. Carbon dioxide (CO₂) levels consistently grow, from 1.3% at no load to 6.1% at 12 kg, reflecting more complete combustion. Simultaneously, oxygen (O₂) levels decline from 18.93% to 12.18%, demonstrating greater oxygen consumption with higher loads. Nitric oxide (NO) emissions surge significantly, from 80 ppm to 1068 ppm, likely due to elevated combustion temperatures at increased loads. Smoke emissions, which remain low at lower loads, experience a sharp rise from 0.2 at no load to 33.2 at 12 kg, suggesting heightened particulate formation and incomplete combustion at higher loads. These trends highlight that while higher loads enhance combustion efficiency, they also lead to a substantial increase in NO and smoke emissions, which can adversely affect both environmental quality and engine performance.

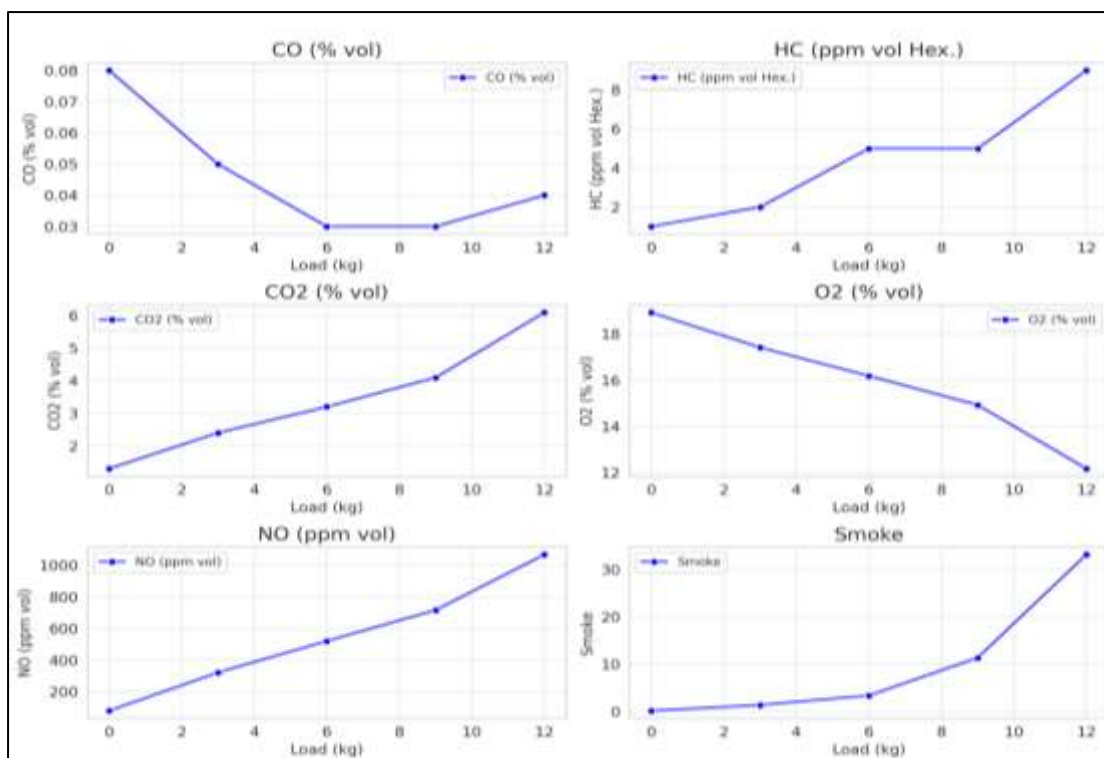


Fig. 3 Graphical Representation - Run 0

2) Run 1 (Diesel + 25 ppm CuO)

Carbon monoxide (CO) content reduces from 0.12% at no load to 0.04% at 9 kg, reflecting improved combustion efficiency. But at 12 kg, CO increases marginally to 0.05%, which may be a result of incomplete combustion at maximum load. Hydrocarbon (HC) emissions gradually increase from 6 ppm at no load to 15 ppm at 12 kg, reflecting increased unburned fuel content with rising load. Carbon dioxide (CO₂) content increases steadily from 1.4% no load to 6.6% at 12 kg, indicating better combustion. On the other hand, oxygen (O₂) content decreases from 18.9% to 11.62%, showing more oxygen consumption. Nitric oxide (NO) emissions rise sharply from 38 pm no load to 1244 ppm at 12 kg, probably due to increased combustion temperatures. Smoke emissions also trend in the same way, increasing from 0.9 to 22.9, reflecting greater particulate formation at greater loads.

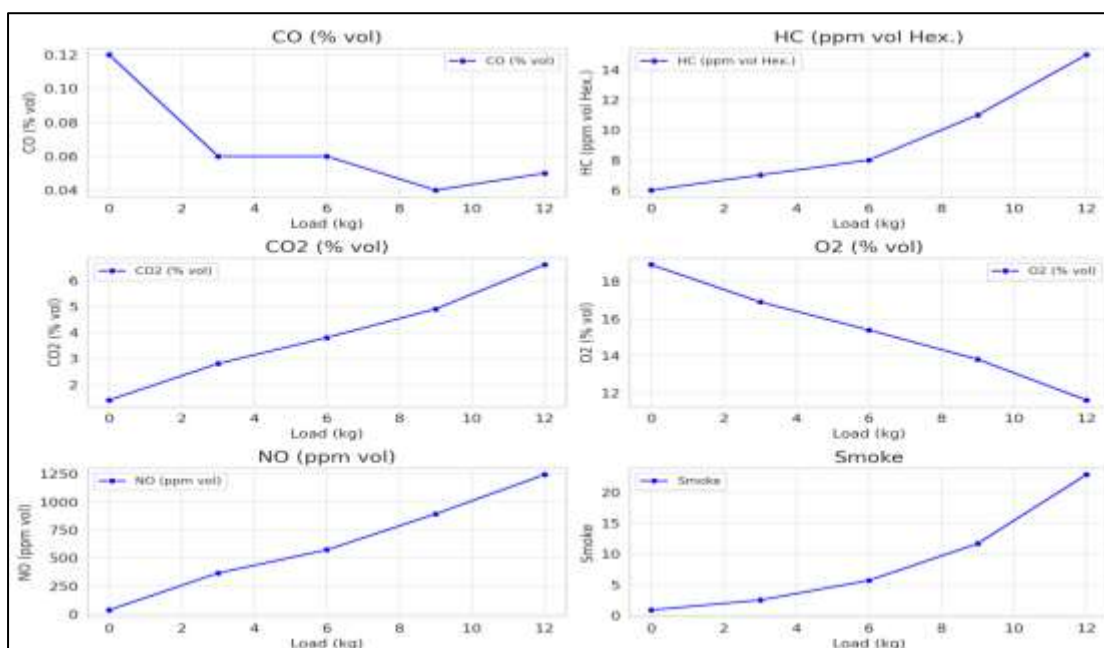


Fig. 4 Graphical Representation - Run 1

3) Run 2 (Diesel + 50 ppm CuO)

CO emissions fall with load, beginning at 0.13% at no load and dropping to 0.06% at 12 kg, showing better combustion efficiency. HC emissions are fairly constant but grow slightly higher with increasing loads, reaching 12 ppm vol Hex. at 12 kg, which can be attributed to incomplete combustion at extreme loads. CO₂ emissions increase from 1.4% no load to 6.5% at 12 kg, verifying increased fuel oxidation and improved combustion. O₂ decreases with increasing load, from 18.73% to 11.68%, indicating more oxygen is consumed for combustion. NO emissions increase substantially with load, from 39 ppm no load to 1207 ppm at 12 kg, as would be expected with increased combustion temperatures with CuO. Smoke emissions also increase steeply from 0.5 to 26.2, reflecting elevated particulate matter generation at high loads.

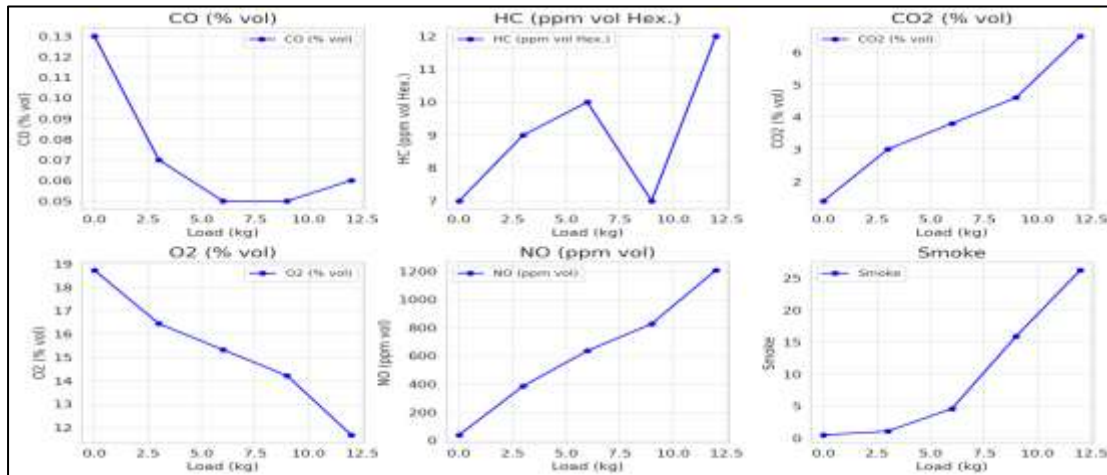


Fig. 5 Graphical Representation - Run 2

4) Run 3 (Diesel + 75 ppm CuO)

CO emissions initially start high at 0.17% at zero load but significantly reduce as the load increases, stabilizing at 0.05%–0.06% beyond 6 kg. This indicates better oxidation of CO at higher loads. HC emissions remain relatively stable at lower loads (7–9 ppm) but rise slightly to 11 ppm at 12 kg, suggesting some incomplete combustion at higher loads. CO₂ levels increase steadily from 1.6% at 0 kg to 6% at 12 kg, reflecting better combustion efficiency with increasing load. O₂ levels show a consistent decline from 18.35% to 12.32%, signifying higher oxygen consumption for combustion. NO emissions rise significantly from 34 ppm to 1117 ppm as load increases, due to the higher combustion temperature. Lastly, smoke emissions rise from 0.6 at no load to 28.3 at full load, which suggests higher soot formation at increased load due to rich fuel-air mixture.

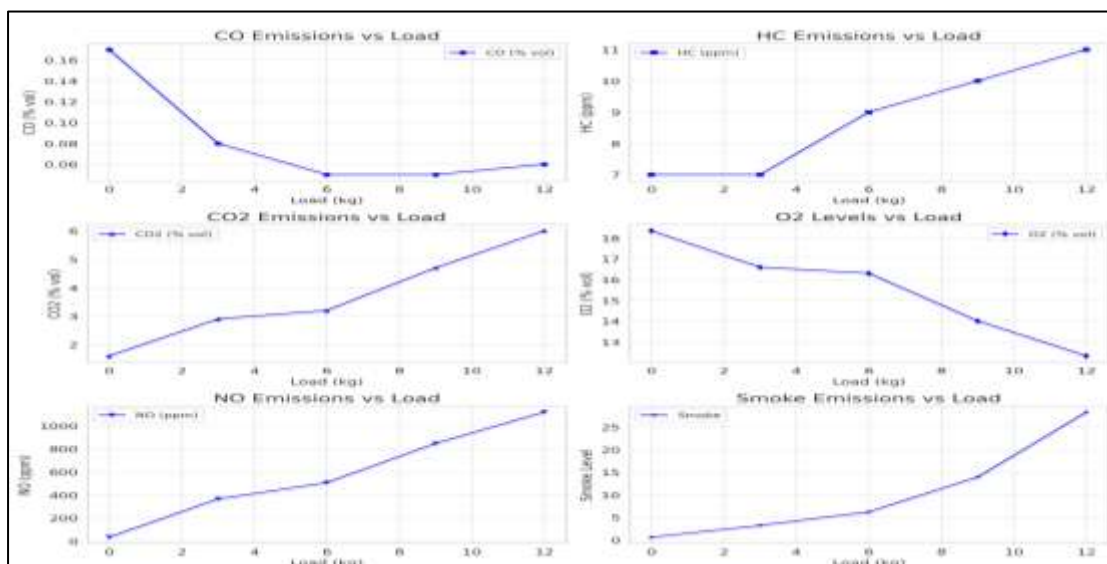


Fig. 6 Graphical Representation - Run 3

Comparative Analysis of Emission Trends: Run 0 vs. Run 1 (CuO 25 ppm) vs. Run 2 (CuO 50 ppm) vs. Run 3 (CuO 75 ppm)

CO Emissions: Run 3 (CuO 75 ppm) shows slightly higher CO emissions at low loads compared to the other runs, especially at 0 kg load (0.17% vol). However, at higher loads, CO levels remain similar to Runs 1 and 2, suggesting CuO improves oxidation at higher temperatures.

HC Emissions: Hydrocarbon (HC) emissions remain relatively stable across all CuO-doped runs, with Run 3 showing an average of 8.8 ppm. This is slightly lower than Run 1 (9.4 ppm) and Run 2 (9 ppm), suggesting moderate effectiveness in reducing unburned hydrocarbons.

CO₂ Emissions: CO₂ emissions increase with load in all runs, indicating better combustion efficiency with CuO addition. Run 3 shows slightly lower CO₂ levels than Run 2, but still higher than Run 0, suggesting the combustion efficiency gain starts to saturate at higher CuO concentrations.

O₂ Levels: Oxygen levels decrease with increasing load, as expected. Run 3 maintains an average O₂ of 15.516%, which is slightly higher than Run 2 but lower than Run 0, indicating that more oxygen is being utilized in combustion but at a diminishing rate beyond 50 ppm CuO.

NO Emissions: NO levels rise significantly with increasing CuO concentration. Run 3 records an average of 573.4 ppm, which is slightly lower than Run 2 (619 ppm) but still much higher than Run 0. This suggests that excessive CuO concentrations may reach a threshold where additional oxidation does not further increase NO formation.

Smoke Emissions: Smoke emissions continue to increase at higher loads, with Run 3 showing an average of 10.44, which is higher than Runs 1 and 2. The high smoke levels at full load (28.3) suggest that 75 ppm CuO may cause incomplete combustion due to excessive nanoparticle agglomeration.

CONCLUDING REMARK:

While CuO additives improve combustion efficiency by increasing CO₂ production and reducing unburned HC and O₂ levels, the diminishing returns beyond 50 ppm suggest that excessive CuO does not further enhance performance. Instead, it increases NO emissions and smoke levels at higher loads. Run 1 (CuO 25 ppm) remains the most balanced option, providing a good trade-off between efficiency and emissions control.

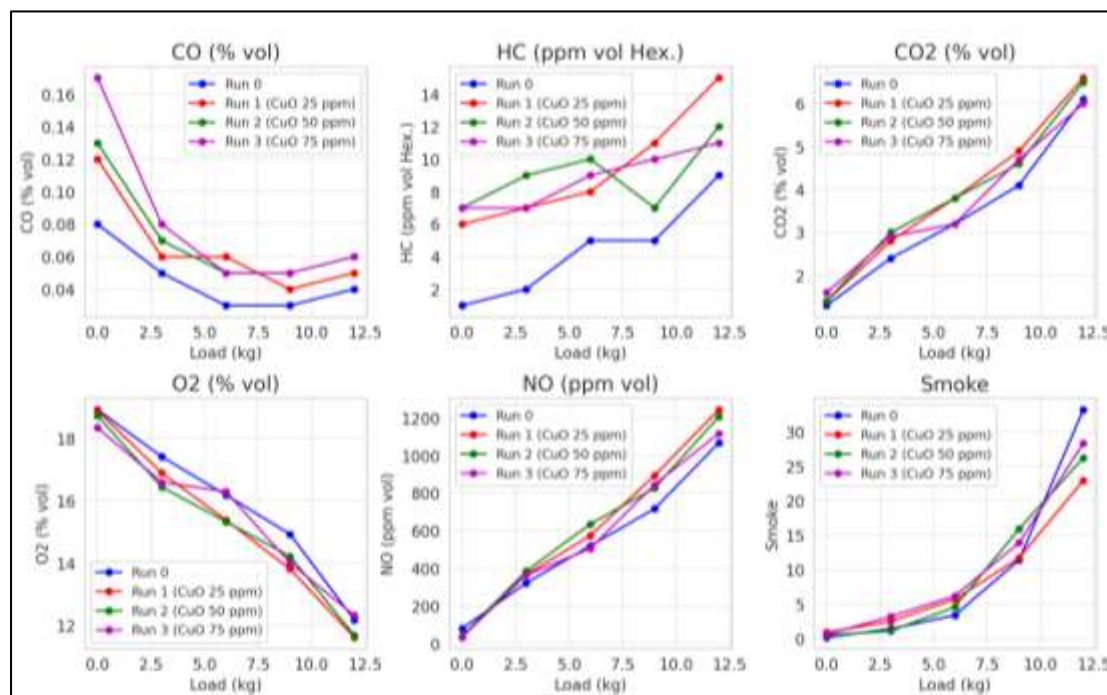


Fig. 7 Comparative Emission Trends : Neat Diesel and CuO Blends

4. CHALLENGES & FUTURE SCOPE

Undoubtedly the nanoparticle additives in diesel fuel reduces the engine emissions significantly. Further experimental efforts are needed to fill the knowledge gap about the type of nanoparticle used and its optimum dosage in fuel so that it serves the purpose of Complete Combustion as well as Lower Emissions

and Environmental Impact. In addition, the stability characteristics of nanofluid fuels under different operating conditions should be addressed technically.

It is worth noting that, besides the engine emissions, performance, and combustion characteristics, most of the existing reviews have only focused on the dispersion stability, wear and friction loss, corrosion, and cost-related issues with nanoparticles, with limited discussion on a very important aspect of these nano-additives, which is their toxicity and health impacts when they come into contact with humans and animals over a period of exposure. There is numerous evidence supporting how toxic these nanoparticles are and how detrimental they could be to an individual's health [18,19,20,21,22]. Harmful effect of exhaust emissions becomes more concerning when nanosize fuel additives are used [23]. The most probable entrance sites for nanoparticles are the skin, gastrointestinal system, and lungs [24]. Nanoparticles that are released or naturally occurring can infiltrate and move about inside living organisms. Nanoparticles can penetrate physiological barriers and enter the living organism system because of their minuscule size [25]. According to reports, the nanoparticles interacted with a number of bodily systems, including the skin, brain, lungs, liver, kidneys, and blood, and may have disrupted their regular functions [26]. Mauro et al. demonstrated in a study that skin is a negligible route of penetration and permeation of nanoparticles. However, they found that Al_2O_3 nanoparticles slightly permeate the skin [27].

5. CONCLUSION

The concept of blending Cupric Oxide Nanoparticles into neat diesel on the emission patterns were investigated in this study, and the results obtained during the trails are summarized.

- 1) Significant reduction in all the emissions was observed by doping additives to diesel since metal oxide nanoparticles provide extra oxygen during combustion and hence complete combustion was achieved.
- 2) It was observed that the NO_x emissions were increased with the usage of metal oxide nanoparticles due to liberation of extra oxygen.
- 3) Run 1 (CuO 25 ppm), is cleaner overall, with lower HC, NO, and smoke emissions, making it a better option for minimizing pollution, especially at higher loads. While its CO and CO_2 emissions are slightly higher, it represents a more environmentally friendly choice.

REFERENCES

- 1) E. Khalife, M. Tabatabaei, A. Demirbas and M. Aghbashlo, *Prog. Energy Combust. Sci.* 59, 32 (2017). doi:10.1016/j.pecs.2016.10.001.
- 2) V. Saxena, N. Kumar and V.K. Saxena, *Renew. Sust. Energ. Rev.* 70, 563 (2017). doi:10.1016/j.rser.2016.11.067.
- 3) Dewangan, A., Mallick, A., Yadav, A. K., & Richhariya, A. K. (2020). Effect of metal oxide nanoparticles and engine parameters on the performance of a diesel engine: A review. *Materials Today Proceedings*, 21, 1722–1727. <https://doi.org/10.1016/j.matpr.2019.12.117>
- 4) Khan, Y. Dewang, J. Raghuwanshi and V. Sharma, *AIP Conf. Proc.* 2100, 020146 (2019).
- 5) Ü. Ağbulut and S. Sarıdemir, *Int. J. Ambient Energy*, in press, 1, (2020). doi:10.1080/01430750.2018.1563822
- 6) J.M. Bergthorson, S. Goroshin, M.J. Soo, P. Julien, J. Palecka, D.L. Frost and D.J. Jarvis, *Appl. Energy* 160, 368 (2015). doi:10.1016/j.apenergy.2015.09.037.
- 7) Özgür, C. (2021). Influence of $NiFe_2O_4$ and $Zn_0.5Ni_0.5Fe_2O_4$ nanoparticles on exhaust emissions of 4 stroke-6 cylinders turbocharged diesel engine. *International Journal of Automotive Engineering and Technologies*, 10(1), 42–49. <https://doi.org/10.18245/ijaet.781493>
- 8) Fayad, M. A., Sobhi, M., Chaichan, M. T., Badawy, T., Abdul-Lateef, W. E., Dhahad, H. A., Yusaf, T., Isahak, W. N. R. W., Takriff, M. S., & Al-Amiery, A. A. (2023). Reducing Soot Nanoparticles and NO_x Emissions in CRDI Diesel Engine by Incorporating TiO_2 Nano-Additives into Biodiesel Blends and Using High Rate of EGR. *Energies*, 16(9), 3921. <https://doi.org/10.3390/en16093921>
- 9) Hussain, F., Soudagar, M. E. M., Afzal, A., Mujtaba, M., Fattah, I. R., Naik, B., Mulla, M. H., Badruddin, I. A., Khan, T. M. Y., Raju, V. D., Gavhane, R. S., & Rahman, S. A. (2020). Enhancement in Combustion, Performance, and Emission Characteristics of a Diesel Engine Fueled with Ce-ZnO Nanoparticle Additive Added to Soybean Biodiesel Blends. *Energies*, 13(17), 4578. <https://doi.org/10.3390/en13174578>
- 10) Mehta RN, Chakraborty M, Parikh PA. Nanofuels: combustion, engine performance and emissions. *Fuel* 2014;120, [91-7]
- 11) İ.A. Reşitoğlu, K. Altinişik and A. Keskin, *Clean Technol. Environ. Policy* 17, 15 (2015). doi:10.1007/s10098-014-0793-9.
- 12) P. Geng, E. Cao, Q. Tan and L. Wei, *Renew. Sust. Energ. Rev.* 71, 523 (2017). doi:10.1016/j.rser.2016.12.080.
- 13) Sudalaimuthu G, Rathinam S, Munuswamy DB, Thirugnanasambandam A (2018) Testing and evaluation of performance and emissions characteristics of water- biodiesel aspirated research engine. *J Test Eval* 48(5):20180306. <https://doi.org/10.1520/jte20180306>
- 14) S. Dey and G.C. Dhal, *Mater. Sci. Energy Technol.* 2, 575 (2019). doi:10.1016/j.mset.2019.06.003.
- 15) K.S. Bradley, D.H. Stedman and G.A. Bishop, *Chemosphere Global Change Sci.* 1, 65 (1999). doi:10.1016/S1465-9972(99)00017-3.
- 16) Y. Wang, H. Liu and C.F.F. Lee, *Renew. Sust. Energ. Rev.* 64, 569 (2016).
- 17) L. Wei and P. Geng, *Fuel Process Technol.* 142, 264 (2016). doi:10.1016/j.fuproc.2015.09.018.

- 18) Doshi, R.; Braida, W.; Christodoulatos, C.; Wazne, M.; O'Connor, G. Nano-aluminum: Transport through sand columns and environmental effects on plants and soil communities. *Environ. Res.* 2008, 106, 296–303. [Google Scholar] [CrossRef]
- 19) Karlsson, H.L.; Cronholm, P.; Gustafsson, J.; Möller, L. Copper Oxide Nanoparticles Are Highly Toxic: A Comparison between Metal Oxide Nanoparticles and Carbon Nanotubes. *Chem. Res. Toxicol.* 2008, 21, 1726–1732. [Google Scholar] [CrossRef] [PubMed]
- 20) Lin, D.; Xing, B. Phytotoxicity of nanoparticles: Inhibition of seed germination and root growth. *Environ. Pollut.* 2007, 150, 243–250. [Google Scholar] [CrossRef]
- 21) Long, T.C.; Saleh, N.; Tilton, R.D.; Lowry, G.V.; Veronesi, B. Titanium dioxide (P25) produces reactive oxygen species in immortalized brain microglia (BV2): Implications for nanoparticle neurotoxicity. *Environ. Sci Technol.* 2006, 40, 4346–4352. [Google Scholar] [CrossRef]
- 22) Soutter, W. Nanoparticles as Fuel Additives. Available online: <https://www.azonano.com/article.aspx?ArticleID=3085> (accessed on 25 August 2021).
- 23) Z.H. Zhang and R. Balasubramanian, *Appl. Energy* 146, 270 (2015). doi:10.1016/j.apenergy.2015.02.029.
- 24) C. Buzea, I.I. Pacheco and K. Robbie, *Biointerphases* 2, MR17 (2007).doi:10.1116/1.2815690.
- 25) E. Kabir, V. Kumar, K.H. Kim, A.C. Yip and J.R. Sohn, *J. Environ. Manage.* 225, 261 (2018). doi:10.1016/j.jenvman.2018.07.087.
- 26) A.M. Schrand, M.F. Rahman, S.M. Hussain, J.J. Schlager, D.A. Smith and A.F. Syed, *Wiley Interdiscip. Rev.* 2, 544 (2010). doi:10.1002/wics.106.
- 27) M. Mauro, M. Crosera, M. Bovenzi, G. Adami, G. Maina, E. Baracchini and F.L. Filon, *Toxicol. In Vitro* 59, 275 (2019). doi:10.1016/j.tiv.2019.04.015.