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Investigating the Impact of Oxygenated Additives on Exhaust Emissions from Unleaded Gasoline Vehicles

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Abstract

The rapidly increasing global population, combined with a corresponding increase in power plants, factories and automobiles, has led to a significant decline in air quality. This issue first came to the forefront in the Los Angeles basin during the late 1940s, primarily due to the region's high population density and unique meteorological conditions. The combination of industrial and vehicular emissions with the prevalent fog resulted in the formation of smog. In response to this growing concern, California began implementing emission standards in the 1960s. Researchers have explored various methods to mitigate emissions from internal combustion engines. One such approach involves the utilisation of oxygen-containing additives to enhance gasoline performance and reduce harmful emissions. This study aims to determine the potential of Dimethyl Carbonate (DMC) as an additive in reducing emissions. To achieve this objective, an experimental setup was established using a multi-cylinder, four-stroke spark ignition engine to test fuel blends containing DMC.

***Major Findings:** The findings of this investigation revealed that gasoline blended with DMC exhibits lower levels of Carbon Monoxide (CO) and Hydrocarbon (HC) emissions compared to standard unleaded gasoline. However, the impact of DMC on Nitrogen Oxide (NOx) emissions appears to be negligible.*

Keywords: *Air Pollution, Dimethyl Carbonate (DMC), Emission Standards, Exhaust Emissions, Fuel Additives, Internal Combustion Engine, Oxygenated Additives, Smog*

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1.0 Introduction

For most of the 20th century, the number of Internal Combustion (IC) engines on the planet remained manageable and the pollution they produced was considered tolerable. The natural cleansing power of sunlight helped maintain a relatively clean environment. However, with a burgeoning global population, the picture began to change dramatically. The proliferation of power plants, factories and especially automobiles unleashed a wave of air pollution that reached unacceptable levels by the mid-20th century. The Los Angeles basin in California became a prime example of this growing problem. The late 1940s saw the first major recognition of air pollution as a significant environmental issue. This was primarily due to two factors: the region's high population density and its unique weather patterns. A combination of industrial and automotive emissions mingled with the prevalent fog, creating a hazardous cocktail known as smog. By the 1950s, the smog problem had intensified, with automobiles identified as the major culprit. This realisation spurred action in the 1960s, with California pioneering the implementation of emission standards. This trend continued in the subsequent decades with stricter emission regulations adopted across the United States, Europe and Japan throughout the 1970s and 1980s. These regulations, coupled with advancements in engine design and exhaust after-treatment technologies, led to a remarkable 95% reduction in emissions of Hydrocarbons (HC), Carbon Monoxide (CO), and Nitrogen Oxides (NOx) per vehicle. Another significant step in air quality improvement came in the 1980s with the phasing out of lead as a fuel additive due to its detrimental health impacts. Additionally, the development of more fuel-efficient engines throughout the 1990s resulted in the average automobile consuming less than half the fuel it did in 1970. However, this progress was overshadowed by the ever-increasing number of vehicles on the road, essentially negating the gains in fuel efficiency. As the global population continues to rise, the need for stricter emission standards becomes ever more pressing. California consistently takes the lead in this regard, with other regions often following suit. While air pollution remains a global concern, some areas of the world still lack comprehensive emission control regulations. However, many countries are progressively aligning their standards with stricter norms like Euro I, II, III and IV. Oxygenated fuels such as Methyl Tertiary Butyl Ether (MTBE) and Ethyl Tertiary Butyl Ether (ETBE) have proven effective in reducing vehicle emissions, particularly CO and HC. A Finnish study conducted in 1991 highlighted their benefits, especially at normal temperatures, with notable improvements in cold-start performance and low-temperature drivability. However, further research is necessary to evaluate their long-term effects[1]. The study compared seven late-model cars using oxygenated fuels (MTBE, Diisopropyl Ether (DIPE), Tert Amyl Methyl Ether (TAME)) with a non-oxygenated reference fuel. While the oxygenated fuels met the 1995 RFG standards, there were no significant differences in total Volatile Organic Compounds (VOCs), air toxics, or ozone-forming potential among the fuels, indicating that these oxygenates could be used interchangeably[2]. Another investigation examined the influence of methanol and ethanol blends on hydrocarbon oxidation and autoignition in a research engine. Blending these alcohols with 87 Primary Reference Fuels (PRF) and adjusting inlet conditions revealed that both alcohols reduced CO emissions and increased the temperature required for autoignition. Ethanol demonstrated greater effectiveness than methanol in suppressing autoignition, likely due to variations in their molecular structures and oxidation pathways[3]. The study examined the impact of MTBE on algae in Lake Texoma. Water samples from three marinas were tested at various MTBE concentrations. Results indicated that MTBE concentrations below 2000-3000 mg/L did not significantly affect algal growth, suggesting that MTBE is not a major threat to algal populations in the lake under normal conditions[4]. Chronic exposure to high levels of MTBE has been linked to various cancers in rodents, including kidney tumours, liver tumours and lymphomas. However, these effects were observed at very high doses and are not directly applicable to humans due to differences in metabolism and sensitivity. MTBE and its metabolites are not considered strong mutagens, suggesting tumour formation may occur through a non-genetic mechanism[5]. Oxygenated additives like ethanol and DMC can improve gasoline performance and reduce CO and HC emissions. However, they can also increase fuel consumption due

to lower energy content. NOx emissions remain largely unaffected by these additives[6]. DMC is an environmentally friendly alternative to harmful chemicals like phosgene and methyl halides. Depending on the reaction temperature, it can selectively methylate or methoxycarbonylate various substrates. DMC-based reactions are catalytic, using safe solid catalysts and avoiding harmful byproducts. Higher homologues of DMC also exhibit selective alkylation properties[7]. Oxygenated fuels like alcohols and ethers are increasingly used as gasoline additives. While these additives can enhance fuel performance, they require careful evaluation to ensure compatibility with existing gasoline specifications and vehicle performance. This study provides data on the performance of oxygenated fuel blends, highlighting the need for thorough understanding and formulation to avoid negative impacts on vehicle performance. Future research should focus on specific performance areas to address potential engine developments[8]. The study evaluated the impact of ethanol-blended gasoline on emissions and catalyst performance. Ethanol addition improved octane number and reduced engine-out emissions, particularly Tetrahydrocannabinol (THC). However, it increased the unburned ethanol and acetaldehyde emissions. While catalysts effectively reduced acetaldehyde, their conversion of unburned ethanol was limited. Engine-out emissions, catalyst efficiency and operating conditions influenced tailpipe emissions. Ethanol blends also improved fuel efficiency[9-10]. The study explores the use of Phase Change Materials (PCMs) for cooling electronic components, particularly in smartphones. Traditional cooling methods like natural convection, heat pipes, and forced convection often fall short for high-power applications. The proposed design integrates PCMs into mini channels surrounding the IC chips. As the components heat up, the PCM absorbs heat and undergoes a phase change, effectively dissipating heat. Among the tested PCMs, N-Eicosane demonstrated the best cooling performance, reducing temperatures significantly compared to other PCMs and the baseline without PCM. This approach offers a promising solution for improving the thermal management of high-power electronic devices[11-15]. The paper proposes a new faucet design to address hygiene and water conservation concerns in developing countries. By reviewing existing literature, the authors identified a need for such a faucet and developed a prototype to meet these specific requirements[16]. Minimum Miscibility MMCs offer superior mechanical properties and weight reduction, making them attractive for automotive and aerospace applications. However, their machining presents challenges. This review examines the machinability of HMMCs, focusing on cutting parameters, reinforcement properties, and optimisation techniques to improve surface finish, Material Receipt Report (MRR), cutting forces and tool life[17]. The provided studies explore various techniques to enhance heat transfer in different applications. These include using minijet impingement in tubular heat exchangers, employing twisted tape inserts with circular holes in forced convection, optimising biodiesel-dimethyl carbonate blends for diesel engines, and evaluating the use of nanofluids in heat exchangers. Additionally, the optimisation of aerofoil design through Computational Fluid Dynamics (CFD) simulations and wind tunnel experiments is investigated to improve aerodynamic efficiency[18-28]. The given research topics focus on enhancing heat transfer efficiency in various applications. These include optimising heat exchanger design using innovative tape inserts, improving wind turbine performance through wind analysis and sensor placement, and enhancing the thermal performance of electronic components through techniques like PCM integration and substrate material selection[29-35]. The study explored the performance of a diesel engine using a 20% mango seed methyl ester blend. Advanced injection timing improved engine efficiency and reduced emissions, but increased NOx. Adding 5% Exhaust Gas Recirculation (EGR) at advanced timing significantly reduced NOx without compromising performance[36]. To meet stricter emission norms and promote renewable energy, this study explored the performance of a diesel engine using a 20% mango seed methyl ester blend. Adjusting injection timing and EGR rates improved engine efficiency and reduced harmful emissions. Specifically, advanced injection timing and 5% EGR significantly reduced NOx without compromising overall performance[37]. The study investigated the impact of increased compression ratio and EGR on a diesel engine using a 20% mango seed methyl ester blend. A higher compression ratio significantly improved engine efficiency and reduced

emissions, but increased NOx. Adding 5% EGR at the highest compression ratio effectively reduced NOx without compromising performance[38]. The study explored the use of Mango Seed Biodiesel (MSME) as a diesel fuel alternative. MSME20 (20% MSME) showed promising results. Adding 5% Diethyl Ether (DEE) to MSME20 further improved engine performance, increasing efficiency by 3.96% and reducing emissions. This blend offers a potential solution for sustainable and efficient diesel engine operation[39]. The study explored the use of mango seed biodiesel (MSME) as a sustainable fuel for agricultural applications. MSME20 (20% MSME) showed promising results. Adding 5% decanol to MSME20 further improved engine efficiency and reduced emissions, making it a promising alternative fuel for agricultural engines[40]. The study explored the use of castor biodiesel as an alternative fuel for diesel engines. It found that castor biodiesel can significantly reduce harmful emissions like CO, HC, and NOx. While it slightly increases fuel consumption and reduces thermal efficiency, the environmental benefits and potential for job creation in the agricultural sector make it a promising renewable fuel option[41]. The study investigates the impact of EGR on reducing NOx emissions in a diesel engine fueled with biodiesel. By analysing the effects of EGR on exhaust gas temperature and emissions like NOx, CO, Underlying Hazardous Constituents (UHC) and CO_2, the study aims to optimise engine performance while minimising environmental impact[42]. The study investigated the performance of a diesel engine using castor oil biodiesel blends. B20 (20% castor oil biodiesel) showed the best performance, with higher efficiency and lower emissions compared to diesel and other blends. This suggests that castor oil biodiesel can be a promising alternative fuel for diesel engines[43]. The study investigated the performance of a diesel engine using Camelina sativa biodiesel blends. The blends reduced CO and HC emissions compared to diesel, but increased fuel consumption and decreased thermal efficiency. While promising, further optimisation is needed to improve overall engine performance[44]. These studies focus on improving the thermal performance of smartphones by incorporating PCMs. By understanding the heat transfer mechanisms and optimising PCM integration, researchers aim to enhance the cooling efficiency of electronic components, leading to improved device performance and longevity[45,46].

1.1 The Power of the Petrol Engine and the Challenges it Presents

The invention of the petrol engine revolutionised transportation, providing reliable, compact power units for personal mobility. Petrol-powered vehicles became a symbol of modern society, offering unprecedented freedom and convenience. However, the convenience came at a cost. In recent years, the internal combustion engine has faced criticism due to the various environmental problems it creates, air pollution being a major concern.

1.2 Sources of Air Pollution from Petrol Engines

There are four primary sources of atmospheric pollution from a petrol-engine-powered vehicle:

- **Evaporative Losses:** This accounts for 15-25 % of unburned HC escaping from the fuel tank and carburettor.
- **Crankcase Blowby:** This contributes 20-35 % of unburned HC leaking past the piston rings into the crankcase and eventually venting out.
- **Tailpipe Exhaust:** This is the main source, releasing 50-60 % of unburned HC and nearly all the CO and NOx emissions.
- **Refuelling Emissions:** This refers to Volatile Organic Compounds (VOCs) released during the refuelling process.

1.3 Harmful Pollutants Emitted by Spark Ignition Engines

- **Unburned Hydrocarbons (HC):** These contribute to smog formation and pose health risks.
- **Oxides of Carbon (CO and CO_2):** CO is a colourless, odourless gas that displaces oxygen in the blood, leading to health problems. CO_2 is a greenhouse gas contributing to climate change.
- **Oxides of Nitrogen (NO and NO_2):** NOx emissions contribute to smog formation and acid rain.

- **Oxides of Sulphur (SO_2 and SO_3):** These primarily originate from fuel with high sulphur content and contribute to acid rain.

2.0 Strategies for Controlling SI Engine Emissions

To reduce harmful emissions from Spark Ignition (SI) engines, several strategies are employed:

2.1 Engine Design Modifications

- Optimised Combustion Chamber Design: Improved combustion efficiency can significantly reduce emissions.
- Variable Valve Timing (VVT): Optimising valve timing for different engine operating conditions can enhance combustion and reduce emissions.
- Direct Injection: Precise fuel injection directly into the combustion chamber can improve fuel atomisation and combustion efficiency.

2.2 Exhaust Gas Treatment Systems

- Catalytic Converters: These devices use a catalyst to convert harmful pollutants (HC, CO, NOx) into less harmful substances.
- Three-Way Catalytic Converter (TWC): A type of catalytic converter that simultaneously reduces emissions of HC, CO and NOx.
- Selective Catalytic Reduction (SCR): This system injects a reducing agent (urea) into the exhaust stream to convert NOx into harmless nitrogen and water vapour.

2.3 Fuel Modifications

- Oxygenated Fuels: Blending gasoline with oxygenated compounds (e.g., ethanol, methanol) can improve combustion efficiency and reduce emissions.
- Reformulated Gasoline: Gasoline blended with additives to reduce emissions, such as benzene and other harmful compounds.

2.4 Other Strategies

- Exhaust Gas Recirculation (EGR): Introducing a portion of the exhaust gas back into the intake manifold reduces peak combustion temperatures, leading to lower NOx emissions.
- Lean Burn Combustion: Operating the engine with a lean air-fuel mixture can reduce NOx emissions but requires careful control to avoid misfire and incomplete combustion.
- Water Injection: Injecting water into the intake manifold can lower combustion temperatures and reduce NOx emissions.
- By combining these strategies, significant reductions in emissions from SI engines can be achieved, contributing to improved air quality and environmental sustainability.

3.0 Fuel Modification: The Role of Oxygenates

3.1 The Emergence of Oxygenates

The mid-to-late 1970s marked a turning point in the automotive industry, as concerns over dwindling crude oil supplies and the need for alternative fuels intensified. Methanol, derived from coal, and bioethanol, produced from agricultural feedstocks, were extensively explored as potential replacements for petroleum-based gasoline. However, the logistical challenges associated with separate fuel distribution systems and the need for specially designed vehicles hindered the widespread adoption of these fuels.

To address these limitations, a more practical approach emerged: blending alcohol directly with gasoline. This practice gained momentum in the late 1970s and early 1980s, with West Germany and the United States leading the way. Notably, Brazil embarked on an ambitious program to convert its entire motor fuel supply to either pure ethanol or a 20% ethanol-gasoline blend.

3.2 Oxygenates as Octane Boosters

Today, oxygenates are primarily employed by refiners not as a substitute for crude oil but as a crucial source of octane. The removal of lead anti-knock compounds from gasoline to mitigate health risks has significantly increased the demand for octane-enhancing additives. Oxygenates effectively fulfil this need, improving fuel performance and reducing engine knock.

3.3 Common Oxygenates

Several oxygenated compounds are commonly used to enhance gasoline performance:

- Methanol: A simple alcohol that can be derived from various sources, including natural gas, coal and biomass.
- Ethanol: Produced from agricultural feedstocks like corn and sugarcane, ethanol is a popular oxygenate and renewable fuel.
- Methyl Tertiary Butyl Ether (MTBE): A high-octane ether that was widely used but has faced environmental concerns due to groundwater contamination.
- Ethyl Tert-Butyl Ether (ETBE): A less environmentally harmful alternative to MTBE.
- Dimethyl Carbonate (DMC): A promising oxygenate with the potential to improve fuel performance and reduce emissions.

4.0 Dimethyl Carbonate (DMC): A Promising Biofuel Additive

4.1 Beyond Methylation: A Versatile Green Option

DMC emerges as a multifaceted compound with applications extending beyond its role as a catalyst in methylation and carbonylation reactions. It presents itself as an attractive and environmentally friendly alternative to traditional options like methyl halides (dimethyl sulphate) and phosgene. This "green" reputation stems from several key characteristics:

- Non-toxic and Biodegradable: Unlike its predecessors, DMC is not produced using harmful phosgene. Instead, it is synthesised through a clean and sustainable process involving the catalytic oxidative carbonylation of methanol with oxygen. Additionally, DMC is biodegradable, minimising its environmental footprint.
- Safe Handling: Classified as a flammable liquid, DMC possesses a pleasant odour similar to methanol. It lacks irritating or mutagenic properties, allowing for safer handling without the need for extensive safety precautions typically required for more hazardous chemicals.
- Tuneable Reactivity: DMC exhibits versatile and adaptable chemical reactivity, making it valuable in various applications.

4.2 Unlocking Potential in Gasoline Blends

- DMC's true potential lies in its role as an oxygenated renewable fuel. It is frequently used as an additive blended with fossil fuels, particularly gasoline. This approach serves two key purposes:
- Enhanced Combustion: By incorporating DMC into the fuel blend, the combustion process within the engine becomes more efficient. This translates to improved engine performance and potentially higher fuel economy.
- Reduced Emissions: DMC's oxygen content plays a crucial role in reducing harmful exhaust emissions produced by gasoline engines. This makes it a valuable tool in combating air pollution and contributing to a cleaner environment.

4.3 Key Physical and Chemical Properties of DMC

- **Molecular Formula:** $C_3H_6O_3$
- **Molecular Weight:** 90.08 g/mol
- **Appearance:** Colorless liquid
- **Odor:** Mild, ethereal
- **Density:** 1.069 g/cm^3 at 20°C
- **Boiling Point:** 90°C
- **Melting Point:** -5°C
- **Solubility in Water:** Miscible
- **Refractive Index:** 1.381
- **Flash Point:** 15°C

This information highlights the multifaceted nature of DMC, showcasing its potential as a safe, environmentally friendly fuel additive capable of enhancing engine performance and reducing emissions.

5.0 Experimental Setup

This study utilised DMC as an oxygenated additive to investigate its potential to improve engine performance and reduce emissions. The experimental setup comprised a computerised Internal Combustion Engine Test Rig coupled with an NP Electronics five-gas analyser. A visual representation of this setup is presented in Figure 1.



Figure 1. Actual setup.

Unleaded gasoline, sourced from Bharane Petroleum, was used as the base fuel. DMC, obtained from Alpha Chemika, was blended with the base fuel in various volumetric ratios to create gasoline-DMC blends. Before testing each new fuel blend, the engine was run to ensure the complete consumption of any residual fuel. The experiments were conducted on a four-stroke, four-cylinder spark ignition engine manufactured by Maruti Suzuki India for Wagon R cars. This engine, with a total stroke volume of 4932mm^3 per cylinder, was operated under a constant load of 3 N. Key engine specifications are detailed in Table 1. A series of tests were performed at different engine speeds: idle, 3500rpm, 5000rpm and 6500rpm. Fuel consumption was measured using a calibrated burette and stopwatch, while exhaust emissions were analysed with a gas analyser. The experimental results were compared to those obtained using pure unleaded gasoline as a baseline.

5.1 Engine Specifications

6.0 Experimental Procedure

The experimental setup was configured as outlined in the block diagram. Initially, the engine was operated using 100% unleaded gasoline. The gas analyser probe was inserted into the exhaust pipe to monitor emissions. Once the engine reached steady-state conditions, readings were taken from the analyser's display, and fuel consumption was measured using a stopwatch and calibrated burette. Real-time air-fuel ratio values were obtained from the engine's control software. After collecting baseline data at idle speed, the engine speed was progressively increased to 3500rpm, 5000rpm, and 6500rpm, and readings were recorded at each speed. Following the completion of the initial test cycle, the engine was run to consume any remaining gasoline. Subsequently, the first fuel blend, consisting of 95% gasoline and 5% DMC, was prepared volumetrically. The experimental procedure was then repeated for this blend at various engine speeds (idle, 3000rpm, 5000rpm and 6500rpm) while maintaining a constant load. This process was replicated for two additional fuel blends: 90% gasoline-10% DMC and 85% gasoline-15% DMC. The experimental data collected for each fuel blend was compared to the baseline data obtained with 100% gasoline to assess the impact of DMC addition on engine performance and emissions.

7.0 Results and Discussion

7.1 Emission of Carbon Monoxide (CO)

Figure 2 shows that adding DMC to gasoline reduced CO emissions at lower engine speeds (3500 and 5000rpm).

Table 1. Engine specifications

Sr. No	Item	Specifications
1	Make	Maruti Suzuki Wagon – R Engine
2	Type	4 Stroke / Water Cooled
3	Number of Cylinders	Four
4	Maximum Power	47.7KW at 6200RPM
5	Fuel System	MPFI
6	Cylinder Bore x Stroke	68.5mm X 72mm
7	Compression Ratio	9.2:1

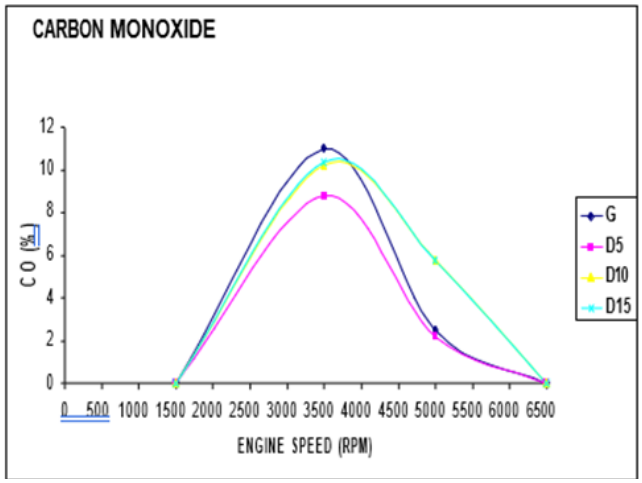


Figure 2. Carbon monoxide emissions at various speeds.

This is because DMC's oxygen content improves combustion. However, at higher speeds (6500rpm), the effect was less noticeable due to shorter combustion time.

7.2 Emission of Unburnt Hydrocarbon (HC)

Figure 3 shows that adding DMC to gasoline reduced HC emissions at 5000 rpm. This is because DMC's oxygen content improves combustion. However, at higher speeds (6500 rpm), the effect was less noticeable due to shorter combustion time. Among the blends, D5 showed the most significant HC reduction (35%) compared to gasoline at 5000 rpm.

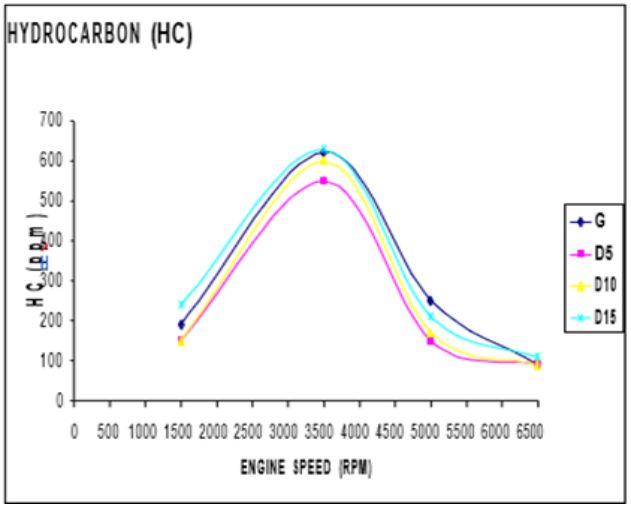


Figure 3. Unburnt hydrocarbon emissions at various speeds.

7.3 Emission of Carbon Dioxide (CO_2)

Figure 4 shows CO_2 emissions increase with some DMC blends (D5, D10) at 5000rpm due to more complete combustion. However, at higher speeds (6500rpm), the lower heating value of the blends with more DMC (D10, D15) leads to incomplete combustion and lower CO_2.

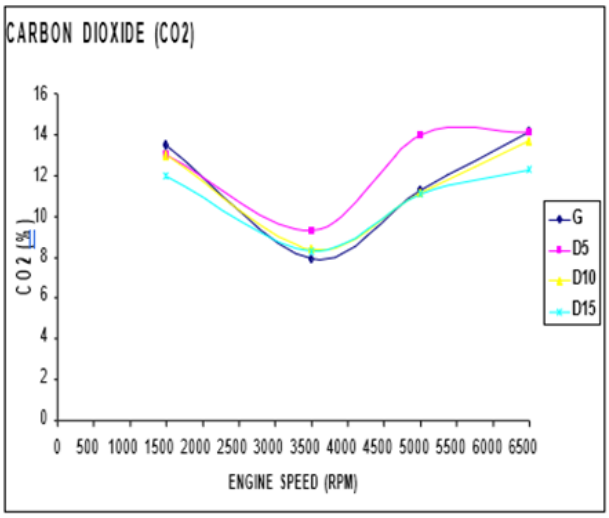


Figure 4. Carbon dioxide emissions at various speeds.

7.4 Emission of Nitrogen Oxides (NOX)

Figure 5 shows NOx emissions are highest at idle speed and 6500rpm due to higher flame temperatures. Adding

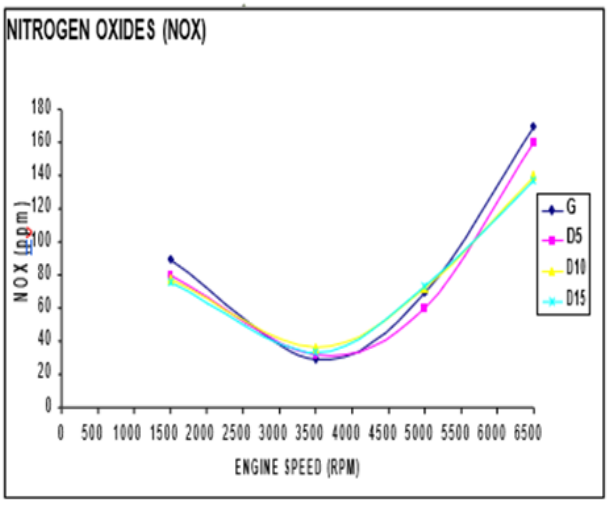


Figure 5. Nitrogen oxide emissions at various speeds.

DMC to gasoline had a negligible effect on NOx emissions. At idle speed and 6500 rpm, the DMC blends slightly reduced NOx emissions due to lower flame temperatures caused by lower heating value.

7.5 Exhaust Temperature Variations at Various Speeds

Figure 6 shows that exhaust temperature increases with engine speed. At 6500 rpm, both exhaust temperature and NOx emissions are highest, indicating higher flame temperatures. Adding DMC to gasoline reduces exhaust temperature at all speeds due to lower heating value and reduced flame temperature.

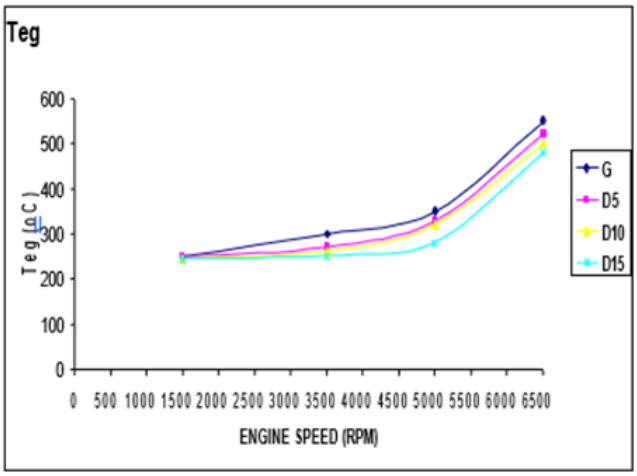


Figure 6. Exhaust gas temperatures at various speeds.

8.0 Conclusion

In summary, while oxygenated additives offer benefits in reducing certain pollutants, they also increase fuel consumption. This trade-off highlights the need for a balanced approach when considering the use of such additives. Future research may explore optimising able blend ratios and engine settings to mitigate the negative impact on fuel economy while maximising emission reduction.

8.2 Emission Reduction

Oxygenated additives, such as DMC, can significantly reduce harmful exhaust emissions, particularly HC and carbon monoxide CO.

- The D5 blend (5% DMC) demonstrated the most significant reduction in HC and CO emissions compared to pure gasoline, with reductions of approximately 24% and 65%, respectively.
- However, the impact of these additives on NOx emissions was negligible, as the air-fuel ratio had a more substantial influence on NOx formation.

8.2 Fuel Consumption

- The addition of oxygenated additives led to increased fuel consumption.
- This is primarily due to the lower heating value of these blended fuels compared to pure gasoline.
- To maintain the same engine power and operating conditions, the engine required more fuel to compensate for the reduced energy content.

9.0 References

1. Kivi J, Niemi A, Nylund NO, Kytö M, Orre K. Use of MTBE and ETBE as gasoline reformulation components. SAE Tech Pap. 1992; https://doi.org/10.4271/922379 PMid:36061401.
2. Noorman MT. The effect of MTBE, DIPE and TAME on vehicle emissions. SAE Tech Pap. 1993; https://doi.org/10.4271/932668 PMid:24702491.
3. Li H, Prabhu SK, Miller DL, Cernansky NP. The effects of methanol and ethanol on the oxidation of a primary reference fuel blend in a motored engine. SAE Trans. 1995; 1:1190-1201. https://doi.org/10.4271/950682 PMid: 36274848.
4. Kampbell DH, An YJ, Williams VR. Influence of methyl tert-butyl ether on lake water algae. Bull Environ Contamin Toxicol. 2001; 67(4). https://doi.org/10.1007/s001280162 PMid:11779074.
5. Mennear JH. Carcinogenicity studies on MTBE: Critical review and interpretation. Risk Anal. 1997; 17(6):673-681. https://doi.org/10.1111/j.1539-6924.1997.tb01274.x PMid:9463924.
6. Wen LB, Xin CY, Yang SC. The effect of adding Dimethyl Carbonate (DMC) and ethanol to unleaded gasoline on exhaust emission. Appl Energy. 2010; 87(1):115-121. https://doi.org/10.1016/j.apenergy.2009.06.005
7. Tundo P, Selva M. The chemistry of dimethyl carbonate. Accounts of chemical research. 2002; 35(9):706-716. https://doi.org/10.1021/ar010076f PMid:12234200.

8. Palmer FH. Vehicle performance of gasoline containing oxygenates. in an international conference on petroleum-based fuels and automotive applications. IMechE Conf Trans. 1986; 11:c319/86.
9. He BQ, Wang JX, Hao JM, Yan XG, Xiao JH. A study on emission characteristics of an EFI engine with ethanol blended gasoline fuels. Atmospheric Environ. 2003; 37(7):949-957. https://doi.org/10.1016/S1352-2310(02)00973-1
10. Huang ZH, Lu HB, Jiang DM, Zeng K, Liu B, Zhang JQ, Wang XB. Combustion characteristics and heat release analysis of a compression ignition engine operating on a diesel/methanol blend. Proceedings of the institution of mechanical engineers, Part D: J Automob Eng Appl. 2004; 218(9):1011-1024. https://doi.org/10.1243/0954407041856818
11. Kurhade AS, Rao TV, Mathew VK, G. Patil N. Effect of thermal conductivity of substrate board for temperature control of electronic components: A numerical study. Int J Mod Phys C. 2021; 32(10):2150132. https://doi.org/10.1142/S0129183121501321
12. Kurhade A, Talele V, Rao TV, Chandak A, Mathew VK. Computational study of PCM cooling for electronic circuit of smartphone. Mater Today: Proceedings. 2021; 47:3171-3176. https://doi.org/10.1016/j.matpr.2021.06.284
13. Kurhade AS, Murali G. Thermal control of IC chips using phase change material: A CFD investigation. Int J Mod Phys C. 2022; 33(12):2250159. https://doi.org/10.1142/S0129183122501595
14. Kurhade AS, Murali G, Rao TV. CFD Approach for thermal management to enhance the reliability of IC chips.
15. Kurhade AS, Biradar R, Yadav RS, Patil P, Kardekar NB, Waware SY, Munde KH, Nimbalkar AG, Murali G. Predictive placement of IC chips using ANN-GA approach for efficient thermal cooling. J Adv Res Fluid Mech Therm Sci. 2024; 118(2):137-147. https://doi.org/10.37934/arfmts.118.2.137147
16. Upadhe SN, Mhamane SC, Kurhade AS, Bapat PV, Dhavale DB, Kore LJ. Water-saving and hygienic faucet for public places in developing countries. InTechno-Societal 2018: Proceedings of the 2nd International Conference on Adv Tech Soc Appl. 2020; 1:617-624. Springer International Publishing. https://doi.org/10.1007/978-3-030-16848-3_56
17. Patil SP, Kore SS, Chinchanikar SS, Waware SY. Characterization and machinability studies of aluminium-based hybrid metal matrix composites-A Critical Review. J Adv Res Fluid Mech Therm Sci. 2023; 101(2):137-163. https://doi.org/10.37934/arfmts.101.2.137163
18. Waware SY, Kore SS, Patil SP. Heat transfer enhancement in tubular heat exchanger with jet impingement: A review. J Ad Res in Fluid Mech and Thermal Sciences. 2023; 101(2):8-25. https://doi.org/10.37934/arfmts.101.2.825
19. Waware SY, Kore SS, Kurhade AS, Patil SP. Innovative Heat Transfer Enhancement in Tubular Heat Exchanger: An Experimental Investigation with Minijet Impingement. Journal of Advanced Research in Fluid Mechanics and Thermal Sciences. 2024; 116(2):51-8. https://doi.org/10.37934/arfmts.116.2.5158
20. Sidhappa KA, Hande MS, Patil MS, Mask MV. Heat Transfer enhancement by using twisted tape inserts with circular holes in forced convection. Int J Innov Eng Res Technol. 2016; 3(3):1-7.
21. Kurhade AS, Waware SY, Bhambare PS, Biradar R, Yadav RS, Patil VN. A comprehensive study on Calophyllum inophyllum biodiesel and dimethyl carbonate blends: Performance optimization and emission control in diesel engines. J Mines Met Fuels. 2024; 72(5):499-507. https://doi.org/10.18311/jmmf/2024/45188
22. Kurhade AS, Waware SY, Munde KH, Biradar R, Yadav RS, Patil P, Patil VN, Dalvi SA. Performance of solar collector using recycled aluminium cans for drying. J Mines Met Fuels. 2024; 72(5):455-61. https://doi.org/10.18311/jmmf/2024/44643
23. Waware SY, Chougule SM, Yadav RS, Biradar R, Patil P, Munde KH, Kardekar NB, Nimbalkar AG, Kurhade AS, Murali G, Kore SS. A comprehensive evaluation of recent studies investigating nanofluids utilization in heat exchangers. J Adv Res Fluid Mech Therm Sci. 2024; 119(2):160-172. https://doi.org/10.37934/arfmts.119.2.160172
24. Patil P, Kardekar N, Yadav R, Kurhade A, Kamble D. Al_2O_3 nanofluids: An experimental study for MQL grinding. J Mines Met Fuels. 2023; 2751-6. https://doi.org/10.18311/jmmf/2023/41766
25. Kurhade AS, Siraskar GD, Bhambare PS, Dixit SM, Waware SY. Numerical investigation on the influence of substrate board thermal conductivity on electronic

component temperature regulation. J Adv Res Numer Heat Transf. 2024; 23(1):28-37. https://doi.org/10.37934/arnht.23.1.2837

26. Kurhade AS, Kadam AA, Biradar R, Bhambare PS, Gadekar T, Patil P, Yadav RS, Waware SY. Experimental investigation of heat transfer from symmetric and asymmetric IC chips mounted on the SMPS board with and without PCM. J Adv Res Fluid Mech Therm Sci. 2024; 121(1):137-147. https://doi.org/10.37934/arfmts.121.1.137147
27. Kurhade AS, Kardekar NB, Bhambare PS, Waware SY, Yadav RS, Pawar P, Kirpekar S. A comprehensive review of electronic cooling technologies in harsh field environments: Obstacles, progress and prospects. J Mines Met Fuels. 2024; 72 (6):557-579. https://doi.org/10.18311/jmmf/2024/45212
28. Kurhade AS, Siraskar GD, Kondhalkar GE, Darade MM, Yadav RS, Biradar R, Waware SY, Charwad GA. Optimizing aerofoil design: A comprehensive analysis of aerodynamic efficiency through CFD simulations and wind tunnel experiments. J Mines Met Fuels. 2024; 713-724. https://doi.org/10.18311/jmmf/2024/45361
29. Kurhade AS, Siraskar GD, Darade MM, Dhumal JR, Kardile CS, Biradar R, Patil SP, Waware SY. Predicting heat transfer enhancement with twisted tape inserts using fuzzy logic techniques in heat exchangers. J Mines, Met Fuels. 2024; 743-750. https://doi.org/10.18311/jmmf/2024/45348
30. Kurhade AS, Bhambare PS, Desai VP, Murali G, Yadav RS, Patil P, Gadekar T, Biradar R, Kirpekar S, Charwad GA, Waware SY. Investigating the effect of heat transfer influenced by the application of wavy corrugated twisted tape inserts in double pipe heat exchangers. J Adv Res Fluid Mechs and Therm Sci. 2024; 122(2):146-155. https://doi.org/10.37934/arfmts.122.2.146155
31. Kurhade AS, Warke P, Maniyar K, Bhambare PS, Waware SY, Deshpande S, Harsur S, Ingle M, Kolhe P, Patil PA, Jadhav P. Wind Rose Analysis of temperature variation with sensor implantation technique for wind turbine. J Adv Res Fluid Mech Therm Sci. 2024; 122(1):1-8. https://doi.org/10.37934/arfmts.122.1.118
32. Kurhade AS, Murali G, Jadhav PA, Bhambare PS, Waware SY, Gadekar T, Yadav RS, Biradar R, Patil P. Performance Analysis of corrugated twisted tape inserts for heat transfer augmentation. J Adv Res Fluid Mech Therm Sci. 2024; 121(2):192-200. https://doi.org/10.37934/arfmts.121.2.192200
33. Kurhade AS, Kadam AA, Biradar R, Bhambare PS, Gadekar T, Patil P, Yadav RS, Waware SY. Experimental investigation of heat transfer from symmetric and asymmetric IC chips mounted on the SMPS board with and without PCM. J Adv Res Fluid Mech Therm Sci. 2024; 121(1):137-147. https://doi.org/10.37934/arfmts.121.1.137147
34. Kurhade AS, Siraskar GD, Jawalkar SS, Gadekar T, Bhambare PS, Biradar R, Yadav RS, Waware SY, Mali CN. The impact of circular holes in twisted tape inserts on forced convection heat transfer. J Mines Met Fuels. 2024; 1005-1012. https://doi.org/10.18311/jmmf/2024/45505
35. Kurhade AS, Gadekar T, Siraskar GD, Jawalkar SS, Biradar R, Kadam AA, Yadav RS, Dalvi SA, Waware SY, Mali CN. Thermal performance analysis of electronic components on different substrate materials. J Mines Met Fuels. 2024; 1093-1098. https://doi.org/10.18311/jmmf/2024/45569
36. Reddy SR, Murali G, Shaik AA, Raju VD, Reddy MS. Experimental evaluation of diesel engine powered with waste mango seed biodiesel at different injection timings and EGR rates. Fuel. 2021; 285:119047. https://doi.org/10.1016/j.fuel.2020.119047
37. Reddy SR, Murali G, Shaik AA, Raju VD, Reddy MS. Experimental evaluation of diesel engine powered with waste mango seed biodiesel at different injection timings and EGR rates. Fuel. 2021; 285:119047. https://doi.org/10.1016/j.fuel.2020.119047
38. Ahamad Shaik A, Rami Reddy S, Dhana Raju V, Govindarajan M. Combined influence of compression ratio and EGR on diverse characteristics of a research diesel engine fueled with waste mango seed biodiesel blend. Energ Source, Part A: Recovery, Utilisation, and Environmental Effects. 2020; 1-24. https://doi.org/10.1080/15567036.2020.1811809
39. Reddy RS, Murali G, Raju DV. Assessment of diethyl ether as a fuel additive on the diverse characteristics of diesel engine powered with waste mango seed biodiesel blend. Int J Ambient Energy. 2022; 43(1):3365-3376. https://doi.org/10.1080/01430750.2020.1824944
41. Reddy RS, Murali G, Dhana Raju V. Influence of decanol as fuel additive on the diverse characteristics of the diesel engine powered with mango seed biodiesel

blend. Int J Ambient Energy. 2022; 43(1):2875-2888. https://doi.org/10.1080/01430750.2020.1783356

41. Arunkumar M, Kannan M, Murali G. Experimental studies on engine performance and emission characteristics using castor biodiesel as fuel in CI engine. Renew Energ. 2019; 131:737-744. https://doi.org/10.1016/j.renene.2018.07.096
42. Arunkumar M, Murali G, Vikky S, Thangadurai R, Tamilarasi M. Performance study of a diesel engine with Exhaust Gas Recirculation (EGR) system fuelled with palm biodiésel. Int J Therm Eng. 2018; 6(1):1-9.
43. ArunKumar M, Murali G. Research on performance and emission on compression ignition engine fuelled with blends of neem bio-diesel. Int J Adv Eng Technol. (IJEAT). 2019; 8(6):3732-3735. https://doi.org/10.35940/ijeat.F9382.088619
44. Murali G, Anusha M, Arunkumar M. Performance study of a single cylinder diesel engine using diesel with Pongamia pinnata and Camelina sativa seed oil blends. Mater Today: Proceedings. 2020; 21:206-211. https://doi.org/10.1016/j.matpr.2019.04.222
45. Kurhade AS, Siraskar GD, Bhambare PS, Kaithari DK, Dixit SM, Waware SY. Enhancing smartphone circuit cooling: A computational study of PCM integration. J Adv Res Numer Heat Trans [Internet]. 2024; 27(1):132-145. https://doi.org/10.37934/arnht.27.1.132145
46. Kurhade AS, Bhambare PS, Siraskar GD, Dixit SM, Purandare PS, Shital Yashwant Waware SY x.. J Adv Res Numer Heat Trans. [Internet]. 2024; 26(1):34-43. https://doi.org/10.37934/arnht.26.1.3443