ELECTRICAL ENGINEERING AND ENERGY

OPEN ACCESS

# Investigation of the Effects of $TiO_2$ and $Al_2O_3$ Nanoparticles on Exhaust Gas Temperature in Direct Injection Gasoline Engines

Mehmet Selman Gokmen[1], Hasan Aydogan[2]

[1] Necmettin Erbakan University, Seydişehir Vocational High School, Department of Motor Vehicles and Transportation Technologies., Konya Türkiye

[2] Selcuk University, Technology Faculty, Department of Mechanical Engineering, Campus, Konya Türkiye

Submitted: 10 April 2025
Accepted: 21 April 2025
Published: 30 April 2025

Corresponding author
Mehmet Selman Gokmen,
msgokmen@erbakan.edu.tr



**Abstract:**

In this study, the effects of $Al_2O_3$ and $TiO_2$ nanoparticles on exhaust gas temperature (EGT) in a direct injection gasoline engine were experimentally investigated. The $Al_2O_3$ and $TiO_2$ nanoparticles were added to fuel mixtures in concentrations of 3.5 ppm and 7 ppm, and tested at engine speeds of 1500, 2500, and 3500 rpm. The results demonstrate that nanoparticles enhance heat transfer within the combustion chamber, leading to higher combustion temperatures. This translates to greater energy production in terms of combustion efficiency and engine performance. In conclusion, the use of $Al_2O_3$ and $TiO_2$ nanoparticles as fuel additives shows potential for improving engine performance and offers a novel approach for controlling exhaust gas temperature.

**Keywords** Exhaust gas temperature, Nanoparticles, Gasoline engine

## 1. Introduction

Fossil fuels are among the most widely used energy sources for power generation, with fuels like gasoline serving as a primary energy source in internal combustion engines. However, the combustion of fossil fuels results in harmful emissions that contribute to global environmental problems and pose significant health risks (Fennell et al., 2014). Gasoline-powered engines emit harmful gases such as carbon dioxide ($CO_2$), carbon monoxide (CO), nitrogen oxides (NOx), and hydrocarbons (HC) into the atmosphere. These emissions exacerbate air pollution, contributing to global warming, ozone layer depletion, and acid rain. Considering the global environmental impacts of emissions from gasoline engines, studies on technological improvements and fuel additives aimed at reducing these emissions are of paramount importance (Acaroĝlu & Aydoĝan, 2012).

In this context, various technical solutions have been developed to achieve environmental improvements in gasoline engines. While direct injection gasoline engines have the potential to enhance engine efficiency and optimize fuel consumption, controlling harmful emissions remains challenging due to high exhaust gas temperatures. Additionally, exhaust gas temperature (EGT) is a critical parameter that directly affects engine performance, combustion efficiency, and emissions (Fushimi et al., 2016). High exhaust gas temperatures, particularly at elevated levels, lead to an increase in NOx emissions, which exacerbates environmental damage. NOx emissions are produced during high-temperature combustion and have adverse effects on both human health and ecosystems. Therefore, controlling and maintaining exhaust gas temperatures at optimal levels is a critical goal for both engine performance and environmental management in gasoline engines(Thurston et al., 2023).

Failure to regulate exhaust gas temperatures also imposes thermal stress on engine components, accelerating wear and reducing the engine's lifespan. High temperatures can affect the long-term durability of components such as exhaust valves, turbocharger systems, and exhaust manifolds. As such, temperature control is vital for optimizing engine efficiency and ensuring engine longevity. Conversely, low exhaust gas temperatures can prevent complete combustion, resulting in increased emissions of CO and HC, which are harmful to the environment. Therefore, maintaining exhaust gas temperatures within an optimal range is essential for both engine performance and emissions control(Hosseini & Chitsaz, 2023).

In recent years, nanotechnology has provided new opportunities to improve fuel efficiency and reduce emissions in the automotive industry. By adding nanoparticles to fuels, the combustion process can be optimized, allowing for better control of exhaust gas temperatures. Nanoparticles such as $Al_2O_3$ (Aluminum Oxide) and $TiO_2$ (Titanium Oxide), due to their high thermal conductivity and large surface area, promote more homogeneous fuel combustion. The use of nanoparticles as fuel additives can improve combustion efficiency(Zhang et al., 2022), particularly by achieving higher combustion temperatures, and reduce harmful emissions. $TiO_2$ contributes to more efficient combustion within the combustion chamber due to its high thermal conductivity, while $Al_2O_3$ provides more balanced and gradual temperature control(Chaimanatsakun et al., 2024). As a result, nanoparticles not only enhance engine performance but also reduce exhaust gas temperatures and protect engine components from overheating(Khameneian et al., 2022).

The addition of nanoparticles to fuels presents a significant opportunity to lower exhaust gas temperatures, improving engine performance and reducing emissions(G M et al., 2023). While high temperatures are indicative of efficient combustion, excessive temperatures can increase NOx emissions, leading to environmental damage(Kim et al., 2017). Nanoparticles can be utilized to balance temperature increases, thereby enhancing combustion efficiency while keeping harmful emissions under control. $Al_2O_3$ and $TiO_2$ nanoparticles, in this context, hold great potential in terms of thermal management and engine performance.

The aim of this study is to investigate the effects of $Al_2O_3$ and $TiO_2$ nanoparticles on exhaust gas temperature in direct injection gasoline engines and to experimentally analyze the effects of different nanoparticle concentrations on engine performance. This study seeks to contribute to the literature by revealing the potential impacts of nanoparticles on engine efficiency and emissions control. Specifically, analyzing the effects of $Al_2O_3$ and $TiO_2$ nanoparticles on exhaust gas temperature at different engine speeds highlights the potential of fuel additives to improve engine performance. Additionally, evaluating the effects of nanoparticles on the combustion process represents an important step toward enhancing environmental sustainability in engine technologies.

## 2. Material and Method

The fuel mixtures were prepared using 12 nm-sized $Al_2O_3$ and $TiO_2$ nanoparticles with similar properties. Preliminary screening tests were conducted to determine the appropriate fuel ratios, and it was observed that agglomeration occurred when the total particle concentration exceeded 15 ppm. Therefore, the total particle concentration was limited to a maximum of 14 ppm. During the preparation of the mixtures, an ultrasonic homogenizer and a mechanical stirrer were used to ensure the homogeneous dispersion of the nanoparticles within the fuel. As shown in Table 1, a three-level factorial design method was applied for each nanoparticle, resulting in eight different mixtures containing nanoparticles. FuelSave unleaded gasoline, supplied by Shell, was used as the base fuel for preparing the mixtures and for comparison.

**Table 1.** Particle Mixture Ratios

| Factors | Levels | | |
|---|---|---|---|
| $Al_2O_3$ (ppm) | 0 | 3.5 | 7 |
| $TiO_2$ (ppm) | 0 | 3.5 | 7 |

In the tests, a Volkswagen gasoline engine, whose specifications are provided in Table 2, was used. The exhaust gas outlet temperatures were measured using a CEM DT8820 compact device with a tolerance of ±1 °C. The measurements were taken when the engine coolant temperature reached 90 °C, using a metal probe placed at the midpoint of the exhaust pipe to minimize the influence of external factors. Five measurements were taken for each engine speed, and the averages of these measurements were calculated.

**Table 2.** Test Engine Specifications

| Property | Specifications |
|---|---|
| Model | 1.2 TSI, Direct Injection |
| Engine Volume | 1197 $cm^3$ |
| Cylinder Number | 4 |
| Compression Ratio | 10:1 |
| Engine Power | 77 kW |
| Engine Torque | 175 Nm |

## 3. Results

The test results presented in Table 3 were subjected to variance analysis, resulting in an $R^2$ value of 98.35% and a Mean Absolute Error (MAE) of 12.40. In Figure 1, the response surface graph related to $TiO_2$ is provided, while in Figure 2, the graph for $Al_2O_3$ is displayed. Additionally, in the mathematical expression of the response surface function shown in Equation 1, "$TiO_2$" and "$Al_2O_3$" represent the particle quantities in ppm, and "ES" denotes the engine speed in rpm.

$$EGT = -21{,}8704 + 0{,}265042 * ES + 1{,}3869 * Al_2O_3 + 25{,}746 * TiO_2 - 0{,}0000233056 * ES^2 - 0{,}000869048 * MH * Al_2O_3 - 0{,}0177024 * ES * TiO_2 - 0{,}218821 * {Al_2O_3}^2 + 2{,}0085 * Al_2O_3 * TiO_2 + 1{,}0941 * {TiO_2}^2 + 0{,}0 * ES^2 * TiO_2 + 0{,}000278912 * ES * {Al_2O_3}^2 - 0{,}0532796 * ES * Al_2O_3 * TiO_2 - 0{,}000945578 * ES * {TiO_2}^2 \quad (1)$$

According to the data presented in the table, the changes in exhaust gas temperature (EGT) at different engine speeds (1500, 2500, 3500 rpm) and nanoparticle concentrations ($Al_2O_3$ and $TiO_2$) are significant. In tests conducted with standard gasoline fuel, a noticeable increase in EGT was observed as the engine speed increased. Specifically, the temperature rose from 314°C at 1500 rpm to 598°C at 3500 rpm. These values serve as control data obtained without the addition of nanoparticles and provide a fundamental reference for comparing other fuel mixtures. When $Al_2O_3$ nanoparticles were added to the fuel at a concentration of 3.5 ppm, EGT increased across all engine speeds compared to the control values. At 1500 rpm, the temperature rose to 327°C, and at 3500 rpm, it reached 614°C. These results indicate that even at low concentrations, $Al_2O_3$ enhances combustion efficiency, leading to a gradual and stable temperature increase.

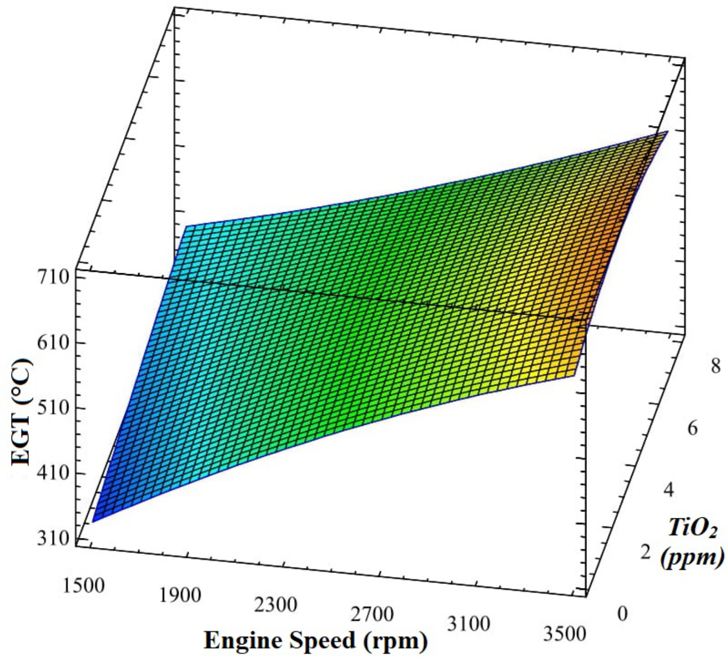


**Figure 1.** Response surface plot of $TiO_2$ nanoparticles for EGT

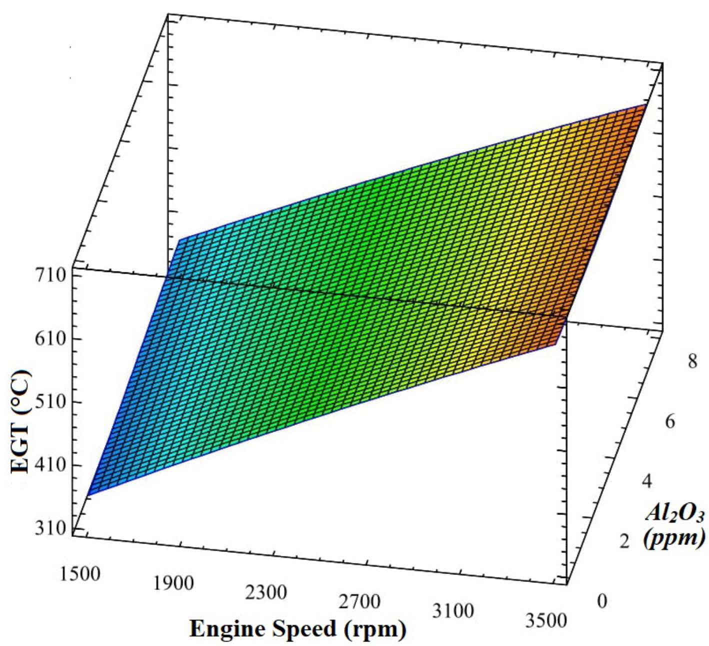


**Figure 2.** Response surface plot of $Al_2O_3$ nanoparticles for EGT

**Table 3.** Measurement Results for EGT

| Fuel | ES (rpm) | $Al_2O_3$ (ppm) | $TiO_2$ (ppm) | EGT (°C) |
|---|---|---|---|---|
| Gasoline | 1500 | 0 | 0 | 314 |
| | 2500 | 0 | 0 | 503 |
| | 3500 | 0 | 0 | 598 |
| Fuel 1 | 1500 | 3,5 | 0 | 327 |
| | 2500 | 3,5 | 0 | 518 |
| | 3500 | 3,5 | 0 | 614 |
| Fuel 2 | 1500 | 7 | 0 | 339 |
| | 2500 | 7 | 0 | 491 |
| | 3500 | 7 | 0 | 675 |
| Fuel 3 | 1500 | 0 | 3,5 | 355 |
| | 2500 | 0 | 3,5 | 532 |
| | 3500 | 0 | 3,5 | 695 |
| Fuel 4 | 1500 | 3,5 | 3,5 | 346 |
| | 2500 | 3,5 | 3,5 | 511 |
| | 3500 | 3,5 | 3,5 | 658 |
| Fuel 5 | 1500 | 7 | 3,5 | 395 |
| | 2500 | 7 | 3,5 | 504 |
| | 3500 | 7 | 3,5 | 637 |
| Fuel 6 | 1500 | 0 | 7 | 375 |
| | 2500 | 0 | 7 | 497 |
| | 3500 | 0 | 7 | 642 |
| Fuel 7 | 1500 | 3,5 | 7 | 397 |
| | 2500 | 3,5 | 7 | 515 |
| | 3500 | 3,5 | 7 | 632 |
| Fuel 8 | 1500 | 7 | 7 | 399 |
| | 2500 | 7 | 7 | 511 |
| | 3500 | 7 | 7 | 639 |

When the $Al_2O_3$ concentration was raised to 7 ppm, a temperature of 339°C was recorded at 1500 rpm, and it further increased to 675°C at 3500 rpm. Interestingly, at 2500 rpm, the EGT dropped to 491°C, falling below the control value. This suggests that using higher concentrations of $Al_2O_3$ may disrupt homogeneity in the combustion chamber, negatively affecting efficiency. Therefore, it is evident that maintaining an optimal nanoparticle concentration is critical for effective performance. In the case of $TiO_2$ nanoparticles added at a concentration of 3.5 ppm, there was a notable increase in EGT. The temperature rose to 355°C at 1500 rpm and reached 695°C at 3500 rpm. Due to $TiO_2$'s high thermal conductivity, it enabled faster heat transfer, particularly at higher engine speeds, significantly improving combustion efficiency. This demonstrates that $TiO_2$ is more effective at increasing temperatures compared to $Al_2O_3$, and it has a positive impact on engine performance.

When $Al_2O_3$ and $TiO_2$ were combined at a concentration of 3.5 ppm, a more balanced temperature increase was observed at both low and medium engine speeds. The temperature rose to 346°C at 1500 rpm and 658°C at 3500 rpm. These findings suggest that the combined use of both nanoparticles provides a balanced thermal effect, helping to control excessive temperature increases and preventing thermal stress on engine components. The effects of using higher concentrations of nanoparticles are also noteworthy. When $Al_2O_3$ and $TiO_2$ were combined at a concentration of 7 ppm, the EGT reached 399°C at 1500 rpm, showing a significant increase. However, at 2500 and 3500 rpm, the temperature increases were more limited. This suggests that higher nanoparticle concentrations may enhance efficiency at lower engine speeds but may be less effective at higher speeds than expected.

Overall, $Al_2O_3$ and $TiO_2$ nanoparticles have demonstrated positive effects in controlling EGT and improving engine performance. However, exceeding a certain concentration of nanoparticles can disrupt homogeneity in the combustion chamber, limiting the temperature increase and reducing efficiency. Therefore, adding nanoparticles to fuel at optimal concentrations is crucial for enhancing engine performance and maintaining control over EGT.

## 4. Conclusions

In this study, the effects of $Al_2O_3$ and $TiO_2$ nanoparticles on the exhaust gas temperature of a direct injection gasoline engine were experimentally investigated. Tests conducted with nanoparticles at different concentrations (3.5 ppm and 7 ppm) revealed that exhaust gas temperature varied depending on both engine speed and the type and concentration of the nanoparticles. The results showed that $TiO_2$ nanoparticles, in particular, led to significant increases in exhaust gas temperature in relation to engine speed. In contrast, $Al_2O_3$ nanoparticles, with their lower thermal conductivity, exhibited a more balanced and gradual effect on exhaust gas temperature. However, the lower-than-expected temperature values observed with 7 ppm $TiO_2$ indicated that excessive nanoparticle loading may disrupt combustion homogeneity, thereby reducing efficiency. In conclusion, both $Al_2O_3$ and $TiO_2$ nanoparticles show potential as additives to enhance engine performance and combustion efficiency. Due to its high thermal conductivity, $TiO_2$ facilitates faster heat transfer and thus improves combustion efficiency, while $Al_2O_3$ provides a more balanced temperature increase, contributing to the engine's longevity. Increasing the nanoparticle concentration can improve efficiency up to a certain point, but excessive nanoparticle loading may adversely affect the combustion process and limit the temperature rise. Therefore, the potential of nanoparticles to enhance engine performance and reduce harmful emissions must be optimized through careful use.

To fully optimize the positive effects of nanoparticles on engine performance and emissions control, the optimal nanoparticle concentration must be carefully determined, and excessive loading should be avoided. The effects of nanoparticles on harmful emissions, especially NOx, should be evaluated through more comprehensive studies. In the long term, the effects of nanoparticles on engine component wear and thermal stress should be investigated, and new-generation nanotechnologies should be developed to create more efficient and sustainable engines.

**Declaration of Ethical Standards**
As the authors of this study, we declare that he complies with all ethical standards.

**Credit Authorship Contribution Statement**
M.S. Gokmen: Investigation, Experimentation, Writing, Review & Editing.
H. Aydogan: Investigation, Writing, Review & Editing, Supervision.

**Declaration of Competing Interest**

The authors declared that they have no conflict of interest.

**Funding / Acknowledgements**

The authors were supported within the scope of the research by the Selcuk University Scientific Research Projects Unit with Project No: 21211039.

**Data Availability**

No datasets were generated or analyzed during the current study.

## References

Acaroĝlu, M., & Aydoĝan, H. (2012). Biofuels energy sources and future of biofuels energy in Turkey. Biomass and Bioenergy, 36, 69–76. https://doi.org/10.1016/j.biombioe.2011.10.004

Chaimanatsakun, A., Sawatmongkhon, B., Sittichompoo, S., & Theinnoi, K. (2024). Effects of reformed exhaust gas recirculation (REGR) of ethanol-gasoline fuel blends on the combustion and emissions of gasoline direct injection (GDI) engine. Fuel, 355. https://doi.org/10.1016/j.fuel.2023.129506

Fennell, D., Herreros, J., & Tsolakis, A. (2014). Improving gasoline direct injection (GDI) engine efficiency and emissions with hydrogen from exhaust gas fuel reforming. International Journal of Hydrogen Energy, 39(10), 5153–5162. https://doi.org/10.1016/j.ijhydene.2014.01.065

Fushimi, A., Kondo, Y., Kobayashi, S., Fujitani, Y., Saitoh, K., Takami, A., & Tanabe, K. (2016). Chemical composition and source of fine and nanoparticles from recent direct injection gasoline passenger cars: Effects of fuel and ambient temperature. Atmospheric Environment, 124, 77–84. https://doi.org/10.1016/j.atmosenv.2015.11.017

G M, L. L., M, C. Das, Jayabal, R., S, M., D, S., & N, M. (2023). Experimental evaluation and neural network modelling of reactivity-controlled compression ignition engine using cashew nut shell oil biodiesel-alumina nanoparticle blend and gasoline injection. Energy, 282. https://doi.org/10.1016/j.energy.2023.128923

Hosseini, M., & Chitsaz, I. (2023). Knock probability determination in a turbocharged gasoline engine through exhaust gas temperature and artificial neural network. Applied Thermal Engineering, 225. https://doi.org/10.1016/j.applthermaleng.2023.120217

Khameneian, A., Wang, X., Dice, P., Naber, J. D., Shahbakhti, M., Archer, C., Moilanen, P., Glugla, C., & Huberts, G. (2022). A real-time control-oriented discrete nonlinear model development for in-cylinder air charge, residual gas and temperature prediction of a Gasoline Direct Injection engine using cylinder, intake and exhaust pressures. Control Engineering Practice, 119. https://doi.org/10.1016/j.conengprac.2021.104978

Kim, J., Chun, K. M., Song, S., Baek, H. K., & Lee, S. W. (2017). The effects of hydrogen on the combustion, performance and emissions of a turbo gasoline direct-injection engine with exhaust gas recirculation. International Journal of Hydrogen Energy, 42(39), 25074–25087. https://doi.org/10.1016/j.ijhydene.2017.08.097

Thurston, M. G., Sullivan, M. R., & McConky, S. P. (2023). Exhaust-gas temperature model and prognostic feature for diesel engines. Applied Thermal Engineering, 229. https://doi.org/10.1016/j.applthermaleng.2023.120578

Zhang, X., Song, C., Lyu, G., Li, Y., Qiao, Y., & Li, Z. (2022). Physicochemical analysis of the exhaust soot from a gasoline direct injection (GDI) engine and the carbon black. Fuel, 322. https://doi.org/10.1016/j.fuel.2022.124262