

An Experimental Study on the Effect of a Water Injection System on Performance, Specific Fuel Consumption, and Exhaust Gas Emissions in a 110 cc Gasoline Engine

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ABSTRACT

The increase in motor vehicle numbers in developing countries has driven higher fuel demand and increased exhaust emissions, requiring technologies to optimise combustion and reduce environmental impact. This study aims to evaluate the effects of injection systems on engine performance, fuel consumption, and exhaust emissions in 110 cc gasoline engines. The experiment was conducted by comparing two configurations: standard operation (STD) and water injection (H₂O). In the latter, distilled water was sprayed at 15% of the fuel volume at 1700 rpm, under 400 kPa, and activated at 4000 rpm, controlled by an Arduino-based PWM system. Exhaust emissions were measured using an HG-520 gas analyser; performance was tested on a dynamometer; and fuel consumption was evaluated through a 15 km road test. The results showed that water injection significantly reduced HC and CO emissions by 49.4% and 90%, respectively, while CO₂ remained stable and O₂ decreased by 74.60%, indicating more effective combustion. Engine performance improved, with power and torque increasing by 6.26%. However, fuel consumption increased by 18.75%. Overall, water injection can improve combustion quality and engine output, but further optimisation is needed to improve fuel efficiency.

Keywords: Water Injection; Small Engine; Cleaner Combustion; Emission Control; Fuel Consumption

1. INTRODUCTION

The increase in motor vehicle population, especially in urban areas, shows a strong correlation with increased consumption of fossil fuels and a decline in environmental quality. This phenomenon is mainly driven by motorcycles as the primary mode of transportation, especially in developing countries. Sales data show that in 2024, approximately 6.2 million motorcycles were sold, bringing the total population of two-wheeled vehicles to more than 130 million units during the 2023–2024 period (Central Statistics Agency,

2024). This situation confirms that motorcycles no longer function solely as a means of personal transportation but have evolved into the backbone of daily mobility, logistics, and urban economic activities.

This increase in the number of motorcycles has a direct impact on two fundamental problems: increased consumption of fossil fuels and increased exhaust emissions. The transportation sector, which remains heavily dependent on hydrocarbon-based fuels, is a major contributor to air pollution (Thakur, Singh, and Kumar, 2025). Exhaust emissions from motor vehicles contribute to

global warming by increasing greenhouse gas emissions and pose serious public health risks from exposure to pollutants such as carbon monoxide (CO), nitrogen oxides (NO_x), and fine particulate matter (Bhoite, Gitay, and Patil, 2025).

This requires urgent technological innovation to reduce environmental impact without compromising vehicle performance. At the same time, government policies and regulations, such as the implementation of increasingly stringent emission tests and standards, are driving the development of more efficient and environmentally friendly vehicle technologies. As a result, technical approaches that focus on improving combustion efficiency have become the primary strategy for reducing emissions and saving fuel (Novella, García, and Gomez-Soriano, 2024).

One technology that has regained attention in this context is the water injection system. Also known as an anti-knock system, this technology has been around since World War II and operates on the principle of spraying water in the form of mist into the combustion chamber or intake manifold (Mingrui et al., 2023). This process cools the air-fuel mixture, thereby reducing combustion temperature, suppressing knocking tendencies, and enabling higher compression ratios and greater engine thermal efficiency (Sittichompoo, Buntek, & Theinnoi, 2025; Tang, Deng, & Li, 2024).

Recent research shows significant benefits from the application of water injection systems. Several studies indicate that this technology can improve fuel

efficiency, reduce brake-specific fuel consumption (BSFC), and significantly reduce NO_x and CO₂ emissions (Gullino, Millo, & Rolando, 2023; Wu, Zhang, & Wu, 2022; Marbun, 2020). Furthermore, commercial applications in high-performance vehicles and experimental studies indicate that water injection not only has a positive impact on environmental aspects but can also increase engine power output (Zhang et al., 2024; Purwanto, Liu, and Nasir, 2024). These findings confirm the potential of water injection systems as a promising technical solution for developing low-emission vehicles.

However, the literature and application of water injection technology are currently dominated by research on four-wheeled vehicles or large-capacity engines (Kaleemuddin et al., 2025; Wei, Qian, and Wang, 2024). Its application and performance evaluation on motorcycles, especially small-capacity engines, which constitute a large population, are still relatively limited (Nguyen & Dong, 2022). The characteristics of motorcycle engines differ significantly from those of motor vehicle engines, particularly in terms of cylinder capacity, cooling system, and operating mode, requiring specific studies to understand the actual impact of this technology (Piras et al., 2021). This indicates a significant research gap, particularly regarding the quantitative evaluation of the effect of water injection on the performance, efficiency, and emissions of motorcycles.

Based on this background, this study aims to comprehensively

analyse the impact of water injection systems on motorcycles, focusing on engine performance, specific fuel consumption, and exhaust emission characteristics. It is hoped that this study will contribute to scientific understanding by providing a deeper technical understanding of the effectiveness of water injection systems in motorcycle engines, as well as laying the foundation for the development of more efficient and environmentally friendly two-wheeled motor vehicle technology in the future.

2. METHODS AND MATERIALS

2.1 Research Design

This study aims to evaluate the effect of water injection on fuel consumption, exhaust emissions, and motorcycle engine performance. A controlled experiment design was used, in which the variables tested were systematically controlled to obtain more valid and reliable data. In this experiment, water injection was applied using two similar injectors, each with six injector holes. The injected water volume was 15% of the injected fuel volume at 1700 rpm, and the system was activated at 4000 rpm.

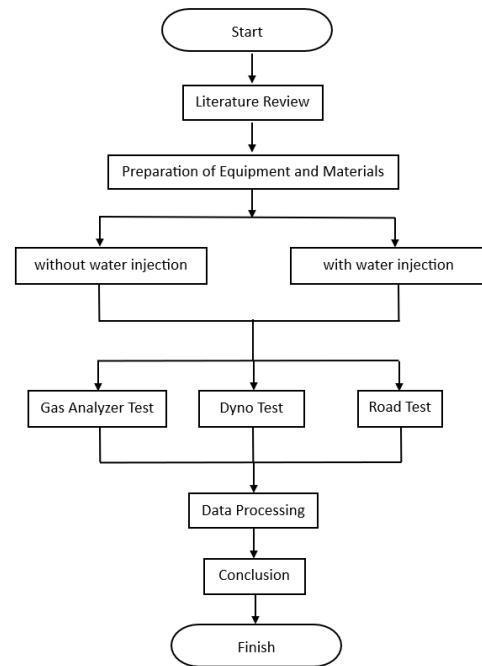


Figure 1. Research Scheme

To support the interpretation of cause-and-effect relationships, strict controls were implemented to minimise confounding effects (Wu, Zhang, and Wu, 2022). Controlled factors included fuel type and source, engine operating temperature, environmental conditions, and standardised data collection procedures.

2.2 Test Object and Engine Specifications

The test object was a 110 cc motorcycle engine with the following specifications: single-cylinder, four-stroke, fuel-injected system, and V-Matic automatic transmission. All experiments were performed with the engine in factory-standard condition, with no internal modifications.

2.3 Materials

Materials used in this study were as follows: Fuel: Commercial gasoline with a consistent octane rating throughout all test runs, namely RON 90 (Pertalite),

obtained from the same source/lot to maintain uniformity. Injection water: Distilled/deionised water, selected to reduce risks of mineral scaling, corrosion, and injector nozzle blockage.

2.4 Equipment and Instruments

The primary instruments used in this research included a Dynamometer: an eddy-current or hydraulic dynamometer (chassis dyno or engine dyno) to measure torque and brake power across engine operating conditions. Exhaust gas analyser: An HG-520 gas analyser capable of measuring key exhaust components. The system was equipped with an exhaust probe and operated according to standard warm-up procedures to ensure stable readings. • Fuel consumption measurement: A real-road driving test method, conducted at a vehicle speed of 40–60 km/h over a travel distance of 15 km, followed by volumetric fuel measurement using a graduated cylinder.

2.5 Water Injection System Configuration

The water injection system applied in this study used a port water injection configuration, in which water is atomised into a fine mist and introduced into the intake manifold upstream of the intake valve/combustion chamber. This configuration aligns with recent methodologies exploring intake-based injection for optimising mixture formation (Bhoite, Syed and Reddy, 2025; Yuan, Lin and Li, 2025).

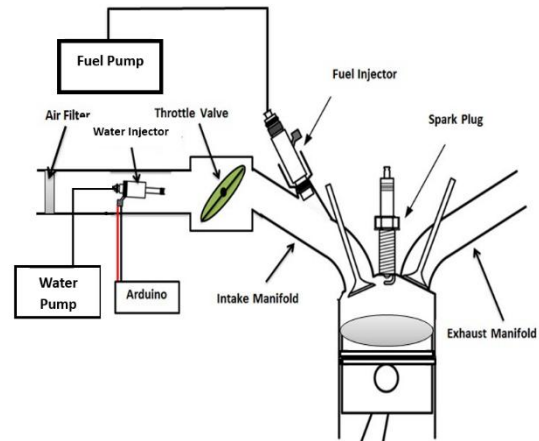


Figure 2. Water Injection System Installation Schematic

An atomising nozzle was installed on the intake manifold with an orientation aligned with the intake airflow to promote stable atomization. Water was supplied from an auxiliary reservoir using a pump capable of delivering a line pressure of 400 kPa. The injection process was controlled by an Arduino Uno, which regulated injector operation through PWM signalling according to a predefined injection duration (Wei, Qian and Wang, 2024). To reduce the likelihood of misfire at low engine speeds, the water injection system was configured to activate only when engine speed reached 4000 RPM. Additionally, to mitigate the risk of hydrolock, injection was constrained within a safe operating range characterised by fine mist formation, absence of liquid droplets, and no prolonged misfire symptoms. Prior to the main trials, a preliminary validation test was conducted to confirm spray stability, the absence of leakage, and steady engine operation at the intended test points (Kaleemuddin *et al.*, 2025).

2.7 Research Variables

The variables in this study were defined as follows: Independent variable: Water injection ratio of 15%, quantified based on injector volumetric delivery at 1700 RPM. Dependent variables: Engine performance: torque (Nm), brake power (kW/HP), Fuel efficiency: brake specific fuel consumption (BSFC, L/km), Exhaust emissions: CO (%vol), HC (ppm), CO₂ (%vol), and O₂ (%vol). Control variables: fuel type and source, steady-state engine operating temperature, ambient temperature/humidity (recorded), throttle position/load, engine speed, air filter condition, spark plug condition, engine oil condition, and tyre pressure (when using a chassis dynamometer).

2.8 Testing Procedure

Data collection consisted of three main stages: exhaust emission testing, performance testing, and fuel consumption testing. Exhaust emissions were measured using the HG-520 gas analyser, while engine performance data were obtained using a dynamometer. Fuel consumption was evaluated during an on-road test at controlled speeds. The operational sequence began with distilled water stored in an auxiliary tank equipped with a pump installed in the motorcycle luggage compartment. When the ignition switch was turned ON, the pump increased system pressure to 400 kPa. Water was subsequently delivered to the intake-mounted injector, which was actuated by the Arduino Uno via PWM control signals. The injector used in this study had six outlet holes, each 0.13 mm in diameter. The water injection system was configured to initiate at 4000 RPM, supplying water equivalent to 15% of the primary fuel delivery into the combustion process. The injected water mixed with the baseline fuel (Pertalite) prior to entering the combustion chamber. To improve reliability and repeatability, both emission and performance

measurements were repeated three times under two test conditions: with and without water injection. For fuel consumption testing, the motorcycle was operated at a steady speed range of 40–60 km/h for 15 km under both test conditions. The consumed fuel volume was then measured using a graduated cylinder and recorded as the fuel consumption dataset.

3. RESULTS AND DISCUSSION

Exhaust gas emission testing, fuel consumption, and performance measurements were processed using a computerised system and converted into tabular and graphical data to facilitate analysis.

3.1 Results of Exhaust Gas, Fuel Consumption, and Performance Data Analysis

Analysis of CO, CO₂, HC, and O₂ Exhaust Emissions. The following are the test results of HC, CO, O₂, and H₂O exhaust emissions:

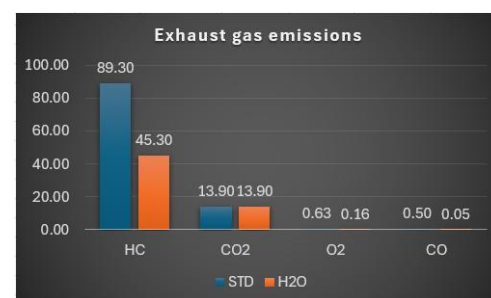


Figure 3. Exhaust gas emission test results

Based on Figure 3, the exhaust emission test results show a significant difference between standard conditions (STD) and water-injection conditions (H₂O). In the HC (hydrocarbon) parameter, a substantial decrease was observed, from 89 ppm in STD conditions to 45 ppm in H₂O conditions,

corresponding to approximately 49.4%. This decrease indicates that water injection improves combustion efficiency in the engine combustion chamber. The reduction in hydrocarbon emissions can be explained by the way water injection acts as a coolant during combustion. Water injection can lower the combustion temperature and reduce the formation of incomplete combustion products, such as hydrocarbons. When water is injected into the combustion chamber, it converts some of the heat energy into steam, which reduces the peak combustion temperature. This process lowers combustion temperature, thereby reducing the formation of harmful compounds, such as unburned hydrocarbons.

Water injection can improve the homogeneity of the fuel-air mixture, leading to more complete combustion and reduced exhaust emissions. The resulting reduction in hydrocarbon emissions also shows that, with water injection, the combustion process of motorcycle engines becomes more efficient, thereby reducing air pollution and improving overall engine performance. Meanwhile, CO₂ emissions remained relatively stable at 13.93 (STD) and 13.90 (H₂O), indicating that the system modification did not significantly affect CO₂ production. For the O₂ parameter, the value decreases from 0.63 (STD) to 0.16 (H₂O), indicating a significant reduction in residual oxygen in the exhaust gas and more complete combustion. If combustion is incomplete, oxygen often remains because it does not have time to react, or high levels of CO are formed. If combustion is close to complete, O₂ will approach zero because everything has been converted to CO₂. In addition, CO emissions decreased significantly from 0.50 (STD) to 0.05 (H₂O), corresponding to a reduction of about 90%, further supporting the indication that water injection can

suppress the formation of gases from incomplete combustion.

3.2 Fuel Consumption Test Results

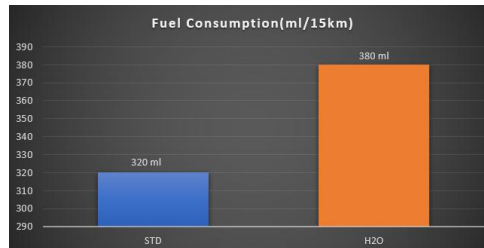


Figure 4. Fuel consumption test results

Based on Figure 4, the fuel consumption test results show that under the standard condition (STD), fuel usage was 320 ml per 15 km, whereas under the water injection condition (H₂O), consumption increased to 380 ml per 15 km. This means that applying water injection increased fuel consumption by 60 ml, or approximately 18.75%, compared to the standard condition. This finding indicates that, under the same tuning and testing conditions, adding water injection tends to increase fuel demand. Therefore, its influence on efficiency and specific fuel consumption should be considered in the overall analysis of the research results.

3.3 Performance Test Results



Figure 5. Performance test results

Based on Figure 5, the engine performance test results show that implementing the water injection system (H₂O) increased both power (HP) and torque (Nm) compared to the standard

condition (STD). In terms of power output, the STD condition produced 5.27 HP, while the H₂O condition increased to 5.60 HP, an improvement of 0.33 HP (approximately 6.26%). Meanwhile, torque under STD conditions was 5.43 Nm and increased to 5.77 Nm with water injection, representing an increase of 0.34 Nm (approximately 6.26%). Overall, these data indicate that the water injection system can improve engine performance, both in power and torque, suggesting that the combustion process and engine operating efficiency are optimised under the tested conditions.

4. CONCLUSION

The application of a water injection system (H₂O) in a 110 cc gasoline engine was proven to produce varied effects. In terms of engine performance, water injection increased power from 5.27 HP (STD) to 5.60 HP (H₂O) and increased torque from 5.43 Nm (STD) to 5.77 Nm (H₂O), indicating improved performance. Regarding exhaust emissions, water injection significantly reduced HC emissions from 89 to 45 and reduced CO emissions from 0.50 to 0.05, indicating cleaner combustion, while CO₂ remained relatively stable (13.93 to 13.90) and O₂ decreased from 0.63 to 0.16. However, in terms of fuel consumption, water injection increased fuel usage from 320 ml (STD) to 380 ml (H₂O), or approximately 18.75%. Therefore, under the conditions of this test, the water injection system was more effective at improving performance and reducing harmful emissions (HC and CO), but it also increased fuel consumption. Further optimisation is needed so that performance and emission benefits can be achieved without compromising fuel efficiency

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REFERENCES

- Badan Pusat Statistik (2024). *Perkembangan Jumlah Kendaraan Bermotor Menurut Jenis (Unit), 2022-2024*. Available at: <https://www.bps.go.id/> (Accessed: 23 January 2026).
- Bhoite, R., Gitay, M.J. and Patil, V. (2025). 'Comparative evaluation of multi-port fuel injection petrol engine powered using gasoline-ethanol-methanol blend on performance and emission parameters', *Journal of Mines, Metals and Fuels*. doi: 10.18311/jmmf/2025/49024.
- Gullino, F., Millo, F. and Rolando, L. (2023) 'Numerical assessment of port water injection capabilities to reduce CO₂ emissions of a lambda 1 turbocharged spark ignition engine', *SAE Technical Paper Series*. doi: 10.4271/2023-01-0181.
- Hsueh, M.H. *et al.* (2021). 'Effect of water vapor injection on the performance and emissions characteristics of a spark-

- ignition engine', *Sustainability*.
- Kadhim, N.S. (2024). 'Effect of fuel temperature on some performance indicators and exhaust gas emissions of a four-cylinder diesel engine', *Iraqi Journal of Agricultural Sciences*. doi: 10.36103/eby7fs22.
- Kaleemuddin, S. *et al.* (2025). 'Experimental study of port water injection system on single cylinder diesel engine performance and exhaust emission', *SAE Technical Paper Series*. doi: 10.4271/2024-32-0025.
- Marbun, J. (2020). 'Analisis Sistem Injeksi Air/Metanol dan Air/Etanol Terhadap Konsumsi Bahan Bakar dan Emisi Gas buang', *Jurnal Teknik Mesin ITI*, 4(3), pp. 88-95.
- Mingrui, W. *et al.* (2023). 'Water injection for higher engine performance and lower emissions', *Applied Thermal Engineering*.
- Nguyen, T.T. and Dong, N.P. (2022). 'Improving performance and reducing emissions from a gasoline and LPG bi-fuel system based on a motorcycle engine fuel injection system', *Journal of the Institution of Engineers (India): Series C*.
- Novella, R., García, A. and Gomez-Soriano, J. (2024) 'Numerical assessment of water injection for improved thermal efficiency and emissions control in a hydrogen engine for transportation applications', *Fuel*.
- Piras, M. *et al.* (2021). 'Exploring the potentials of water injection to improve fuel consumption and torque in a small displacement PFI spark-ignition engine', *Energy Conversion and Management*, 245, p. 114611. doi: 10.1016/j.enconman.2021.114611.
- Purwanto, W., Liu, T.-K. & Nasir, M. (2024). 'The fuel system modification to strengthen achievement and the prospect of utilizing gasoline ethanol blended with water injection', *Journal of Applied Engineering and Technology Sciences*. doi: 10.37385/jaets.v5i2.3249.
- Sittichompoo, S., Buntek, N. & Theinnoi, K. (2025). 'The effect of port water injection on knocking and emission characteristics of natural-aspirated GDI engine operated under cruising condition', *International Journal of*

- Environmental Science and Engineering*. doi: 10.1177/14680874251329596
- Tang, Y., Deng, J. & Li, L. (2024). 'Effect of port water injection on the knock and combustion characteristics for an argon power cycle hydrogen engine', *SAE Technical Paper Series*. doi: 10.4271/2024-01-2612.
- Thakur, N., Singh, B. & Kumar, P. (2025). 'Advancements in renewable energy: a sustainable solution for global energy demands', *Journal Renewable Energy & Mechanics (REM)*, 8(2). doi: 10.25299/rem.2025.vol8(02). 22087.
- Wei, X.-x., Qian, Y. and Wang, T. (2024) 'Investigation on the combined influence mechanism of port water injection timing, injection pressure and ignition timing on natural gas engine performance based on the Taguchi method', *Fuel*. doi: 10.1016/j.fuel.2023.130064.
- Wu, J., Zhang, Z., & Wu, Z. (2022). 'An assessment methodology for fuel/water consumption co-optimization of a gasoline engine with port water injection', *Applied Energy*. doi: 10.1016/j.apenergy.2022.118567.
- Yuan, Z., Lin, Z. and Li, Y. (2025). 'A study on the effect of spark plug micro-hole hydrogen injection on the spray and combustion processes of a gasoline engine with intake port water injection', *Energy*. doi: 10.1016/j.energy.2025.134366.
- Zareei, J. and Ghadamkheir, K. (2023). 'The effects of variable excess air ratio and ignition timing on the performance and exhaust emissions in a direct injection hydrogen-CNG fueled engine', *International Journal of Environmental Science and Engineering*. doi: 10.1177/14680874221107141
- Zembi, J., Battistoni, M. & Merola, S. (2023). 'Investigations on the impact of port water injection on soot formation in a DISI engine through CFD simulations and optical methods', *Fuel*. doi: 10.1016/j.fuel.2022.127170.
- Zhang, Q. *et al.* (2024). 'Experimental study of port water injection on GDI engine fuel economics and emissions', *ACS Omega*. doi: 10.1021/acsomega.3c06859.