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Exhaust emission analysis of a motorcycle equipped with a Dual-Fuel Pertalite–LPG System under varying LPG flow rates and engine speeds

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Abstract

The increasing dependency on fossil-based fuels and the rise in vehicular exhaust emissions have intensified the search for environmentally friendly alternative fuels. This study aims to investigate the effect of varying liquefied petroleum gas (LPG) flow rates on the exhaust emissions of a motorcycle operating on a dual-fuel system combining Pertalite and LPG. Experimental tests were conducted on a four-stroke motorcycle with a manual transmission and a carburetor-based fuel system, under a range of engine speeds (1400–2000 rpm) and three LPG flow rates: 0.2, 0.5, and 0.8 L/min. The measured emission parameters include carbon monoxide (CO), hydrocarbons (HC), and carbon dioxide (CO_2). The results demonstrate that an LPG flow rate of 0.5 L/min yields the highest CO_2 emissions and relatively lower CO and HC levels compared to 0.2 and 0.8 L/min. In contrast, the 0.8 L/min flow rate exhibits signs of incomplete combustion, as indicated by elevated CO and HC emissions and a decline in CO_2 concentration. The findings highlight the need for an optimal LPG flow rate to achieve efficient combustion and minimal emissions. The dual-fuel Pertalite–LPG system presents practical potential, particularly when integrated with a more advanced air–fuel ratio control system.

Keywords: Dual-Fuel; Pertalite; LPG; Exhaust Emissions; Motorcycle; CO; **CO_2**; HC

1. Introduction

Indonesia's reliance on petroleum-based fuels, particularly for transportation, remains considerably high. Motorcycles, as the dominant mode of transportation for the majority of the population, contribute significantly to national fuel consumption and are a major source of air pollution, especially in densely populated urban areas. Fuels such as Pertalite (Research Octane Number 90), which are widely used by the public, produce exhaust gases containing carbon monoxide (CO), hydrocarbons (HC), and carbon dioxide (CO_2). These emissions not only impact environmental quality but also pose serious long-term health risks [1,2].

Efforts to reduce dependency on fossil fuels and lower emission levels have spurred numerous innovations in fuel technology. One promising approach is the adoption of alternative fuels that are more environmentally friendly and readily accessible. Among various available alternatives, liquefied petroleum gas (LPG) emerges as a strong candidate due to its abundant availability, relatively stable cost, and cleaner combustion characteristics compared to gasoline [3-5]. In addition, LPG possesses a high-octane rating, which theoretically improves combustion efficiency and reduces the production of harmful pollutants when used appropriately [6,7].

Several previous studies have shown that using LPG in motor vehicles can significantly reduce CO and HC emissions [8,9]. However, full conversion from gasoline to LPG poses challenges, including substantial modifications to the fuel system and safety risks associated with pressurized gas storage. As a more practical and flexible alternative, the dual-

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fuel system combining gasoline and LPG either simultaneously or alternately—offers a viable solution, particularly for motorcycles, which are widely used in the Indonesian context [10,11].

Although dual-fuel systems have been widely applied in diesel engines using compressed natural gas (CNG) or LPG, their application in gasoline-powered motorcycles remains relatively limited. One of the primary challenges is maintaining a stable and balanced air–fuel mixture to ensure optimal combustion and prevent increased emissions compared to conventional single-fuel systems. Moreover, due to LPG's distinct thermal and volatility characteristics relative to gasoline, careful regulation of the LPG flow rate is essential and warrants thorough investigation [12,13].

In this context, it is necessary to conduct research that specifically examines the impact of combining Pertalite and LPG on motorcycle exhaust emissions. Such a study is of particular importance, as it offers a low-cost, simple, and practical alternative to reducing vehicle emissions without requiring a full overhaul of the fuel system. This approach is also relevant for Indonesia, where the distribution of LPG particularly in the form of 3 kg household cylinders is widespread and readily accessible to the general population.

The objective of this study is to evaluate the effectiveness of using a Pertalite–LPG dual-fuel system in reducing exhaust emissions in gasoline-powered motorcycles. By understanding the relationship between varying fuel mixture compositions and the resulting CO, HC, and CO_2 emissions, this study aims to provide a scientific foundation for the development of cleaner dual-fuel technologies that align with typical vehicle operating conditions in Indonesia. The findings may also serve as a preliminary reference to support national energy policies that promote energy diversification and emission reduction in the transportation sector.

2. Material and Methods

2.1. Research Object

This study was conducted on a two-wheeled vehicle, specifically a four-stroke, manually transmitted gasoline motorcycle Honda Supra X, a widely used model in Indonesia due to its fuel efficiency and mechanically simple configuration. The engine employs a conventional carburetor-based combustion system, which facilitates the integration of a dual-fuel configuration without the need for complex electronic control modifications. The use of this motorcycle also reflects the typical conditions experienced by most motorcycle users in Indonesia, thereby enhancing the practical relevance and applicability of the research findings.

The primary energy source in this experiment was a dual-fuel system, consisting of firstly Pertalite, a gasoline variant with a Research Octane Number (RON) of 90, officially distributed through fuel stations across Indonesia. Secondly, liquefied petroleum gas (LPG) sourced from standard household 3-kg LPG cylinders, primarily composed of a propane-butane mixture. LPG was selected in this study for its wide availability, affordability, and inherently cleaner combustion properties compared to gasoline [14].

The dual-fuel system was designed in a simplified manner to allow direct mixing of LPG into the intake manifold without disabling the original gasoline system. LPG was delivered from the cylinder through a pressure regulator and flexible tubing into the intake air manifold, which was modified minimally to accommodate the gas. In this setup, LPG did not completely replace Pertalite but rather served as a supplementary fuel, enabling observation of its influence on exhaust emissions.

Three concentrations of LPG flow rate were applied: 0.2 L/min (low), 0.5 L/min (medium), and 0.8 L/min (high). These variations were selected to systematically assess the influence of LPG proportions on the combustion process and the resulting emission characteristics. Flow adjustments were performed manually using control valves and a calibrated gas flow meter, with direct observation and documentation conducted during the testing process.

2.2. Experimental Procedure

The testing was conducted in an enclosed workspace with adequate cross-ventilation to ensure safety during LPG use and to prevent external airflow from interfering with the combustion stability and emission measurements. The motorcycle was tested in a stationary position under no-load conditions and neutral gear, such that the engine's rotation was solely driven by internal combustion without external torque or frictional resistance.

The independent variables in this experiment were: 1). Engine speed, varied incrementally across five levels: 1400, 1550, 1700, 1850, and 2000 rpm. These values represent low to moderate engine speeds commonly observed during idling and light acceleration in daily use. 2). LPG flow rate, as previously described.

For each combination of variables, measurements were conducted for the following exhaust gas emission parameters such as carbon monoxide (CO), measured in % by volume, unburned hydrocarbons (HC), measured in parts per million (ppm), carbon dioxide (CO_2), measured in % by volume.

Emissions were recorded using a portable digital exhaust gas analyzer, pre-calibrated with certified standard reference gases. The analyzer's probe was inserted directly into the tailpipe and allowed to stabilize for approximately 15 seconds prior to data acquisition to ensure measurement accuracy. Each data point was measured three times (triplicate), and the results were averaged to enhance reliability.

Prior to data collection, the engine was operated until it reached its normal operating temperature and steady-state combustion conditions at each engine speed. Throughout the testing process, environmental conditions including room temperature, humidity, and air pressure were recorded to serve as references and to account for potential corrections in the data analysis.

The experimental setup utilized in this study is illustrated in Figure 1, which provides a schematic representation of the actual configuration documented during testing. All collected data were analyzed through descriptive and comparative methods to assess how variations in LPG flow rate influence exhaust emission characteristics at different engine speed levels.

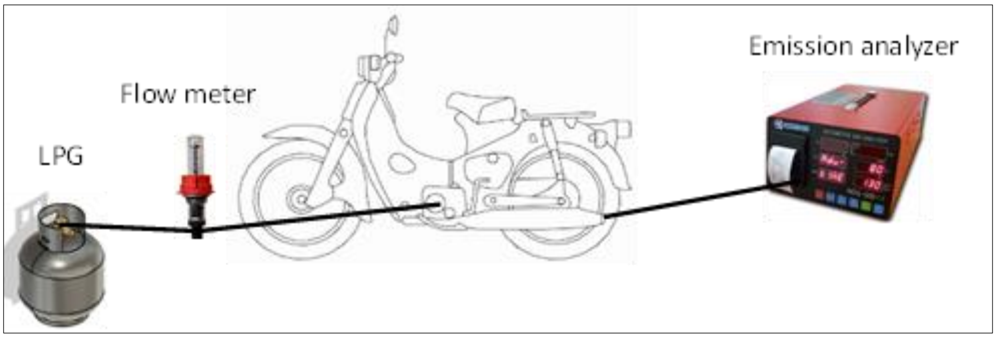


Figure 1 Schematic diagram of the experimental setup

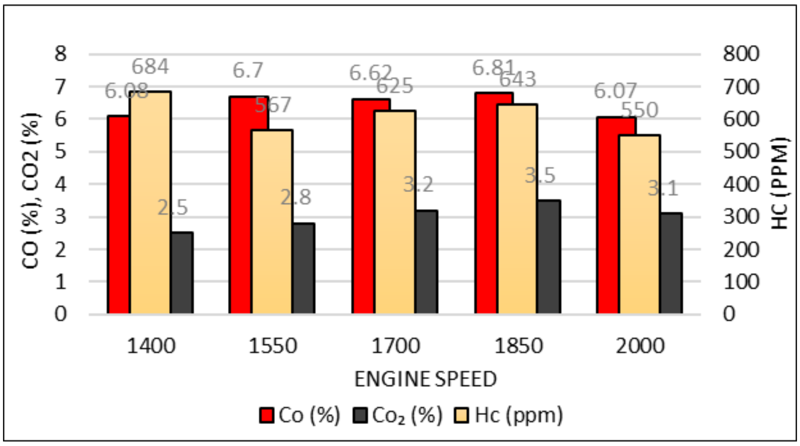
3. Result and Discussion

This study investigates the impact of varying LPG flow rates on the exhaust emission characteristics of a dual-fuel Pertalite–LPG motorcycle at different engine speeds. The measured emission parameters include carbon monoxide (CO), carbon dioxide (CO_2), and hydrocarbons (HC), representing incomplete combustion, complete combustion, and unburned fuel residues, respectively. The experimental results are presented in Figures 2A, 2B, and 2C for each LPG flow rate: 0.2, 0.5, and 0.8 L/min.

3.1. Carbon Monoxide (CO) Emissions

CO emissions displayed a relatively consistent trend across engine speeds for each LPG flow rate. At a flow rate of 0.2 L/min, CO concentrations ranged from 6.08% to 6.07%, with the peak observed at 1700 rpm and the minimum at 1400 rpm. As the LPG flow increased to 0.5 L/min, CO concentrations also rose slightly at all rpm levels, ranging between 6.09% and 6.88%. A similar trend was observed at 0.8 L/min, with CO levels ranging from 6.09% to 6.89%.

This general increase in CO levels with higher LPG flow rates suggests a tendency toward rich combustion, where excess fuel is not fully oxidized due to insufficient air supply. Such a condition results in incomplete combustion, thereby increasing CO emissions, which are both toxic and environmentally harmful [15]. These results are consistent with previous studies indicating that an overly rich LPG mixture in the combustion process can result in increased carbon monoxide emissions due to incomplete fuel oxidation [16].



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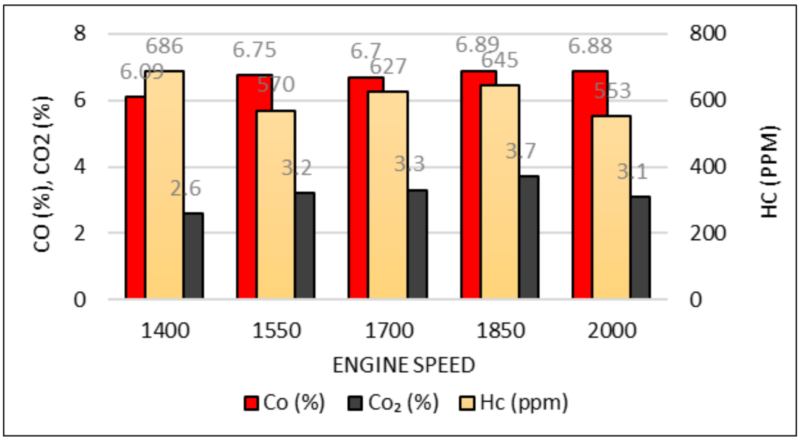

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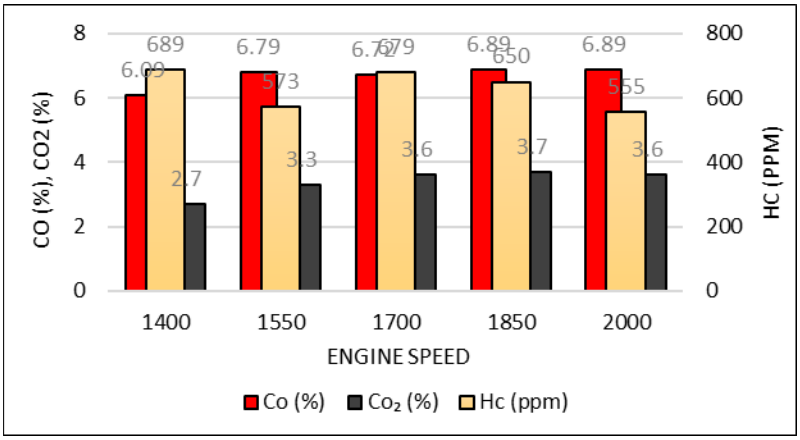

C

Figure 2 Emissions characteristics, A). pertalite and LPG 0.2 L/min, B). pertalite and LPG 0,5 L/min, C) pertalite and LPG 0.8 L/min

3.2. Carbon Dioxide (CO_2) Emissions

CO_2 emissions are a key indicator of combustion efficiency. At an LPG flow rate of 0.2 L/min, CO_2 levels declined as engine speed increased, peaking at 6.72% at 1550 rpm and decreasing to 6.07% at 2000 rpm. At 0.5 L/min, CO_2 levels were generally higher and more stable (6.75%–6.88%), indicating improved combustion efficiency compared to the lower flow rate.

However, at 0.8 L/min, CO_2 levels showed a slight decline again, though still marginally higher than at 0.2 L/min. The highest recorded value was 6.79% at 1550 rpm and the lowest was 6.68% at 2000 rpm. This decline implies that although LPG offers the potential for cleaner combustion, excessive flow rates may disrupt the air–fuel balance, resulting in reduced combustion efficiency [17].

3.3. Hydrocarbon (HC) Emissions

Elevated HC concentrations indicate unburned fuel due to incomplete combustion [18]. At 0.2 L/min, HC emissions ranged from 550 ppm to 684 ppm, with a general downward trend as engine speed increased. At 0.5 L/min, HC levels ranged from 553 ppm to 686 ppm—slightly higher than at 0.2 L/min, particularly at lower rpm.

At the highest LPG flow rate of 0.8 L/min, HC emissions remained high with minimal reduction, ranging from 555 ppm to 689 ppm. This suggests inefficient combustion, especially at lower engine speeds where air–fuel mixing may be suboptimal, resulting in increased unburned hydrocarbons.

3.4. Comparative Analysis and Interpretation

Overall, increasing the LPG flow rate yields mixed effects on emission characteristics. On one hand, a moderate flow rate of 0.5 L/min improves combustion efficiency, as indicated by increased CO_2 emissions and relatively stable CO levels. On the other hand, at the highest flow rate (0.8 L/min), combustion efficiency decreases, as evidenced by rising CO and HC levels and a slight drop in CO_2 emissions.

These results highlight the importance of maintaining an optimal air–fuel ratio in dual-fuel systems. Without a feedback control mechanism—such as a closed-loop oxygen sensor—manual adjustment of LPG flow may disrupt combustion performance and increase pollutant output. In this study, the 0.5 L/min flow rate demonstrated the most balanced performance, with the highest CO_2 emissions and decreasing HC levels, indicating an optimal compromise between efficiency and emissions.

4. Conclusion

This study demonstrates that the application of a Pertalite–LPG dual-fuel system in a four-stroke motorcycle significantly influences the exhaust emission characteristics, particularly CO, CO_2, and HC concentrations. Variations in LPG flow rate directly affect the combustion quality within the engine. An LPG flow rate of 0.5 L/min was shown to provide the most favorable balance between combustion efficiency and emission output. Under these conditions, CO_2 emissions reached their highest values—indicating more complete combustion—while CO and HC levels remained within manageable limits. Conversely, at an LPG flow rate of 0.8 L/min, CO and HC emissions increased and CO_2 emissions decreased slightly, indicating fuel-rich conditions and less efficient combustion. These findings confirm that without precise control of the air–fuel ratio, excessive LPG flow can impair combustion efficiency and increase pollutant emissions. Therefore, the dual-fuel Pertalite–LPG system holds practical potential for reducing motorcycle exhaust emissions, provided that LPG flow is carefully regulated. Future studies are recommended to incorporate electronic control systems—such as O2 sensors and fuel valve actuators—to stabilize the fuel–air mixture and evaluate engine performance under dynamic load conditions that more closely represent real-world usage.

Compliance with ethical standards

Disclosure of conflict of interest

The authors declare that there are no conflicts of interest regarding the publication of this paper. No financial, personal, or professional relationships with individuals or organizations have influenced the outcome or content of this manuscript.

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