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Optimizing Motorcycle Combustion System for Carbon Monoxide Emission Reduction Using the Taguchi Method

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Abstract

In Indonesia, the dominance of motorcycles as the primary mode of transportation has created a significant urban air quality crisis, largely driven by exhaust emissions. Carbon monoxide (CO), a key indicator of incomplete combustion, poses a serious risk to public health and the environment. While previous studies have examined engine parameters such as spark plugs, ignition coils, or fuel quality in isolation, this study addresses a critical gap by shifting from single-factor analysis to a holistic, multi-parameter optimization. This approach is unique in its application of the Taguchi Method to identify a robust, real-world solution specifically tailored to the Indonesian context. We systematically optimized a motorcycle's combustion system by evaluating three key parameters—fuel type, spark plug type, and ignition coil—at three levels each. Using an L9 Orthogonal Array and a smaller-the-better Signal-to-Noise (S/N) ratio, we aimed to minimize CO emissions. The results identified an optimal configuration of Mobil-brand fuel, an NGK Iridium spark plug, and a Suzuki A100 coil, which achieved a 42.03% reduction in CO emissions compared to the standard setup. Analysis of Variance (ANOVA) confirmed that fuel quality is the overwhelmingly dominant factor, contributing nearly 90% to the outcome. These findings provide a practical, low-cost emission control strategy with direct policy relevance for Indonesia, offering a clear path for vehicle maintenance shops and owners to contribute to cleaner air and support sustainable transportation goals.

Keywords: Carbon Monoxide Emissions, Combustion System, Motorcycle, Taguchi Method, Optimization

1. Introduction

The global and national automotive industry is experiencing rapid growth, characterized by a high number of motor vehicles in circulation. In Indonesia, motorcycles have become the transportation backbone for the majority of the population, with ownership reaching 136.32 million units, far exceeding the number of four-wheeled vehicles [1]. Although significantly contributing to public mobility, this increase in motor vehicles also brings adverse effects, particularly on declining air quality due to exhaust emissions. Key pollutants such as carbon monoxide (CO), hydrocarbons (HC), and nitrogen oxides (NOx) released into the atmosphere not only damage the environment but also threaten human health [2], [3].

The quality of the combustion process within the engine is a primary determining factor for the resulting exhaust emissions. An ideal combustion process heavily depends on three key components: fuel quality, spark from the spark plug, and the performance of the ignition coil. A strong and consistent spark from the spark plug, supported by an ignition coil capable of generating high voltage, is crucial for ensuring a more complete combustion, thereby reducing CO emissions. Variations in these three components—such as different fuel brands, spark plug types (Standard, Iridium, Platinum), and coil types—can significantly affect combustion efficiency, engine performance, and emission levels [4–6]. Therefore, finding the optimal combination of these three parameters is a strategic step toward reducing harmful emissions from motorcycles.

Previously, several studies have investigated the influence of individual components on emissions. Study [7] analyzed the effect of spark plug type on fuel consumption and exhaust emissions, while study [8] examined the

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impact of spark plug heat range on engine performance and emissions. Study [9] also emphasized the importance of developing ignition system components, including coils and spark plugs, to optimize emissions. These studies provide a valuable foundation for understanding but they remain focused on the effects of one or two variables in isolation.

The primary novelty of this study lies in its holistic, multi-parameter optimization approach applied directly to the pressing environmental challenges in Indonesia. Unlike previous Taguchi-based engine studies that often focus on performance metrics, our work clarifies the hierarchy of influence among key combustion parameters specifically for emission reduction. By simultaneously evaluating fuel, spark plug, and ignition coil combinations, we address a critical knowledge gap concerning their synergistic effects. The practical significance is immense; identifying a low-cost, optimal configuration provides a scientifically-backed strategy for millions of motorcycle owners and maintenance shops to reduce pollution, directly impacting urban air quality and aligning with national environmental policy goals.

In this study, we apply the Taguchi Method to optimize the motorcycle combustion system in a systematic and efficient manner. We demonstrate how the optimal combination of fuel type, spark plug type, and ignition coil type can be determined to significantly reduce carbon monoxide (CO) emissions. The Taguchi Method was selected for its ability to identify parameter configurations that not only minimize the average response but also make it robust against noise variation, all with a reduced number of experiments. Our findings provide a practical engineering approach to the problem of air pollution from motorcycles, while also contributing to the literature by applying a multi-parameter optimization approach that has been relatively unexplored in this context.

2. Experimental Method

This section details the materials, equipment, and experimental procedure used in the study. The experimental section shall provide necessary information for reproducing the results. This study is an experimental study aimed at optimizing the combustion system parameters to reduce motorcycle exhaust emissions. The approach employed is the Taguchi Method, selected for its ability to determine the optimal parameter combination with a minimal number of experiments while producing a configuration that is robust against variations in conditions. The research focuses on minimizing exhaust emissions, with primary emphasis on the analysis of carbon monoxide (CO) emissions as the main parameter. The selection of CO is based on several considerations: (1) CO is a direct indicator of combustion efficiency, where high values indicate incomplete combustion due to suboptimal air-fuel ratio; (2) CO is toxic and hazardous to human health and the environment; (3) from a regulatory perspective, CO is a mandatory parameter in motor vehicle emission testing.

2.1. Optimization Problem Formulation

The objective was to minimize the concentration of CO emissions (%). The experiment involved three controllable factors, each set at three levels, as detailed in Table 1. This table outlines the three controllable factors and their respective levels investigated in this study to optimize the motorcycle's combustion system.

2.2. Experimental Design

The experimental design was arranged using an L9 Orthogonal Array, which is suitable for investigating three factors each with three levels. This design allows for the testing of 9 of the 27 possible combinations, making it highly efficient in terms of time and cost. Table 2 shows the layout of the experimental combinations to be conducted.

An L9 Orthogonal Array was used to structure the experiment, efficiently evaluating the parameter combinations in just nine runs instead of the 27 required for a full factorial design. Each experimental run was replicated three times to ensure data reliability. The experimental layout is shown in Table 2.

Table 1. Factors and Levels of the Design Variables

No	Factor	Code	Level 1	Level 2	Level 3
1	Fuel Type	BB	Pertamax	AKR	Mobil
2	Spark Plug Type	BS	NGK Standard	NGK Iridium	NGK Platinum
3	Ignition Coil Type	KL	Standard	KTC	Suzuki A100

Table 2. Experimental Runs and Factor Combinations

Run	Fuel Type	Spark Plug Type	Ignition Coil Type
1	Pertamax	Standard	Standard
2	Pertamax	Iridium	KTC
3	Pertamax	Platinum	A100
4	AKR	Standard	Standard
5	AKR	Iridium	KTC
6	AKR	Platinum	A100
7	Mobil	Standard	KTC
8	Mobil	Iridium	A100
9	Mobil	Platinum	Standard

Table 3. Main Research Instruments

No	Instrument	Brand & Model	Technical Specifications
1	Gas Analyzer	Heshbon HG-510	CO Range: 0–10% vol HC Range: 0–2000 ppm Resolution: 0.01% vol (CO), 1 ppm (HC)
2	Tachometer	IMAX BRT	Range: 0.0001–20,000 RPM Voltage: AC 220V 50/60 Hz Sensor cable: 400 cm
3	Blower	Benz BZ 8714	Airflow: 6,500 m^3/h Power: 750 watts Outlet: 14 inch

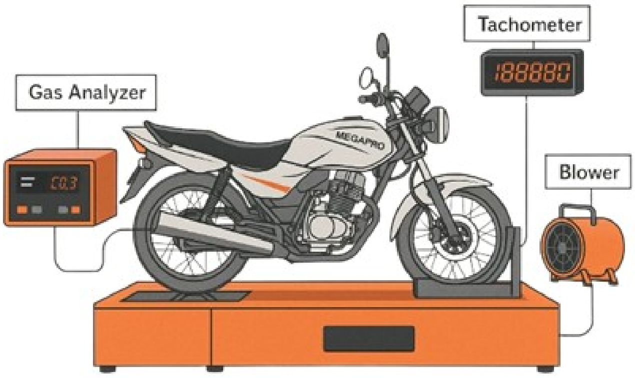

Figure 1. Schemaric of the Experimental Setup

2.3. Research Instruments

The experiment was conducted on a standard Honda Megapro motorcycle. Calibrated instruments were used for all measurements, as listed in Table 3. The experimental setup is illustrated in Figure 1. This diagram illustrates the test motorcycle on a dynamometer. Key instruments include the Gas Analyzer for measuring exhaust emissions, the Tachometer for monitoring engine speed, and the Blower for engine cooling to simulate real-world driving conditions.

2.4. Data Analyst

The data analysis in this study is based on the Taguchi Method, utilizing the Smaller-the-Better (STB) type Signal-to-Noise (S/N) ratio as the primary optimization indicator. This approach was selected because it not only focuses on achieving the lowest average emission value but also ensures the robustness of the results by minimizing variation caused by noise factors. The S/N ratio is calculated using the following equation:

$$\frac{S}{N} = -10\log_{10}\left(\frac{1}{n}\sum_{i=1}^{n} y_i^2\right) \tag{1}$$

where y_i represents the measured CO emission value in the i replication, and n is the number of replications (in this study, n = 3).

Once the S/N ratio for each experimental combination is obtained, an Analysis of Means (ANOM) is performed on these S/N values. ANOM is used to identify the effect of each factor level (fuel type, spark plug, and coil) on the response. The factor level with the highest average S/N ratio indicates the best contribution to reducing emissions with maximum stability. Based on the ANOM results, the optimal parameter combination that yields the minimal emissions and maximum robustness is predicted. This prediction is then validated through a follow-up confirmation experiment to verify the superiority of the optimal combination over the initial configuration.

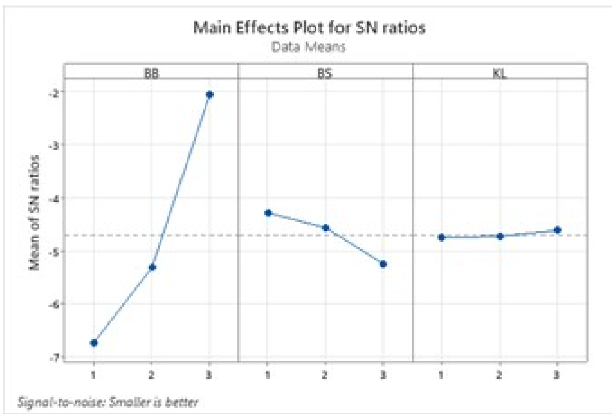

Figure 2. Main Effects Plot for S/N Ratios

Table 4. Experimental Results for CO Emissions and Calculated S/N Ratios

Run	Fuel Type	Spark Plug	Ignition Coil	Mean CO (%)	STDEV	S/N Ratio (dB)
1	Pertamax	Standard	Standard	2.07	0.48	-6.55
2	Pertamax	Iridium	KTC	2.31	0.32	-7.34
3	Pertamax	Platinum	A100	2.02	0.47	-6.34
4	AKR	Standard	Standard	1.69	0.03	-4.58
5	AKR	Iridium	KTC	1.80	0.01	-5.12
6	AKR	Platinum	A100	2.05	0.11	-6.26
7	Mobil	Standard	KTC	1.22	0.13	-1.75
8	Mobil	Iridium	A100	1.15	0.01	-1.24
9	Mobil	Platinum	Standard	1.44	0.02	-3.16

3. Results and Discussion

3.1. Experimental Results and S/N Ratio Analysis

The results from the nine experimental runs, including the calculated S/N ratios, are presented in Table 4. The S/N ratio was calculated using the Taguchi Smaller-the-Better (STB) equation, aiming to optimize the response by minimizing CO emission values while reducing variation [10].

This table summarizes the measured CO emissions for each of the nine configurations, including the mean, standard deviation, and the calculated S/N ratio used for optimization. Combination 8 (Mobil fuel, NGK Iridium spark plug, Suzuki A100 coil) emerged as the best performer, yielding the lowest average CO emissions (1.15%) and the highest S/N ratio (-1.24 dB). This indicates that this configuration is both effective and highly stable. In contrast, Combination 2 was the least effective.

3.2. Analysis of Factor Effects and Optimal Combination

The Analysis of Mean (ANOM) for the S/N ratios (Figure 2) quantifies the effect of each factor level.

This plot shows the mean S/N ratio for each factor level. The steep slope for factor BB (Fuel Type) demonstrates its dominant effect on CO emissions compared to the other factors. The plot clearly shows that Fuel Type (BB) has the most dominant influence on CO emissions, with Mobil fuel (Level 3) being the optimal choice. The effects of the spark plug (BS) and ignition coil (KL) are significantly smaller. Based on this analysis, the predicted optimal combination is BB3-BS2-KL3: Mobil fuel, NGK Iridium spark plug, and Suzuki A100 coil, corresponding to Combination 8 from the experimental array, which yielded the optimal result.

Table 5. Validation Experiment Results: Optimal vs Standard Configuration

Configuration	Mean CO (%Vol)	STDEV	S/N Ratio (dB)
Standard	2.07	0.48	-6.55
Optimal	1.20	0.01	-1.61

Table 6. Analysis of Variance (ANOVA) Results for S/N Ratio

Source	DF	Seq SS	Adj SS	Adj MS	F	P
BB	2	34,873	34,873	174,366	25,60	0,038
BS	2	1,481	2,591	12,956	1,90	0,345
KL	2	1,144	1,144	0,5721	0,84	0,543
Residual Error	2	1,362	1,362	0,6810		
Total	8	38,861				

3.3. Validation Experiment and Analysis of Variance (ANOVA)

The validation results for. The optimal combination compared to the standard combination (combination 1) are presented in Table 5, which demonstrates a significant performance improvement.

Based on Table 5, the optimal combination reduced average CO emissions by 42.0% and drastically lowered the standard deviation from 0.48 to 0.01, demonstrating enhanced stability. To statistically validate these findings, an Analysis of Variance (ANOVA) was performed (Table 6).

Based on Table 6, the Fuel Type factor (BB) has a significant influence on CO emissions, with a p-value of 0.038 (< 0.05) and a contribution of 89.73%. Meanwhile, the Spark Plug (BS) and Ignition Coil (KL) factors are not statistically significant (p-value > 0.05), with relatively small contributions. The R-Sq value of 96.49% indicates that the constructed model has an excellent ability to explain the variation in the data.

4. Discussion

This study successfully demonstrates that the Taguchi method can effectively optimize a motorcycle's combustion system to reduce CO emissions. The overwhelming dominance of fuel quality, which contributed 89.73% to the emission variation, can be explained by fundamental combustion chemistry. Fuel is the primary reactant; its composition and characteristics directly govern the efficiency of the energy conversion process. A higher quality fuel enables a more complete combustion, naturally producing less CO. In contrast, the spark plug and ignition coil are merely the initiators of this process. While a strong spark is necessary, even the most advanced ignition system cannot compensate for poor quality fuel, as it can only optimize the start of the combustion, not alter the fuel's inherent properties. This finding is consistent with research by [11, 12], which also used ANOVA and identified fuel type as the most significant factor affecting emissions in diesel engines, suggesting this principle holds across different combustion types. Our approach, which achieved a 42.03% CO reduction, builds upon the work of [13], confirming the Taguchi method's robustness for optimizing fuel parameters to reduce emissions in light engines. Furthermore, the high reliability of our predictive model, evidenced by an R-Sq value of 96.49%, aligns with similar optimization studies like [14], , which also reported high prediction accuracy using a Taguchi-based approach. The use of ANOVA to successfully isolate fuel as the critical factor is a method supported by findings from [15], which validates its effectiveness in identifying key parameters that affect engine performance. Ultimately, this research provides a clear, hierarchical understanding of parameter influence, emphasizing that addressing fuel quality is the most impactful strategy for emission control in this context.

5. Conclusions

The application of the Taguchi method proved highly effective in optimizing a motorcycle's combustion system for reduced CO emissions. The optimal combination of Mobil fuel, an NGK Iridium spark plug, and a Suzuki A100 ignition coil reduced CO emissions by 42.03% compared to the standard configuration, while also significantly improving operational robustness. The key takeaway from this study is that fuel quality is the most influential factor in controlling CO emissions, with ignition system components playing a secondary, supporting role. This has significant practical implications, offering a low-cost, high-impact strategy for emission reduction that can be easily implemented by vehicle maintenance workshops and individual owners without requiring major engine modifications. These findings contribute directly to efforts to improve urban air quality and support the enforcement of stricter emission regulations.

Future research should expand on these findings by including additional parameters, such as air-fuel ratio and engine speed, or by testing on different engine types to enhance the generalizability of the results.

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References

[1] Indonesian Central Statistics Agency, "The growth of motor vehicles in indonesia." `https://www.bps.go.id/linkTableDinamis/view/id/1133`, 2021. Accessed: 2020-04-11.

[2] E. Amboro and W. Warju, "The effect of using metallic catalytic converter made from brass and application of sass technology on emissions of the honda new mega pro motorcycle," *J. Tek. Mesin*, vol. 01, no. 02, pp. 102–109, 2013.

[3] D. N. Aini, H., and H. Puspitawati, "Ketimpangan dan faktor-faktor yang mempengaruhi kualitas pembangunan manusia di kota depok," *Jurnal Manajemen Pembangunan Daerah*, vol. 8, no. 1, 2019.

[4] E. Julianto and S. Sunaryo, "Analisis pengaruh putaran mesin pada efisiensi bahan bakar mesin diesel 2dg-ftv," *Jurnal Penelitian dan Pengabdian Kepada Masyarakat UNSIQ*, vol. 7, pp. 225–231, 09 2020.

[5] I. P. Chaniago, W. Purwanto, Rifdarmon, and A. Arif, "Optimasi sistem pengapian terhadap emisi gas buang sepeda motor 4 langkah dengan metode taguchi," *JTPVI: Jurnal Teknologi dan Pendidikan Vokasi Indonesia*, vol. 1, p. 181–190, Jun. 2022.

[6] B. Budiyono, “Pengaruh catalytic converter berbahan tembaga 0,6 mm berbentuk sirip terhadap hasil emisi gas buang pada honda beat tahun 2015,” *Jurnal Teknik Mesin UNISKA*, vol. 5, no. 2, pp. 34–39, 2020.

[7] W. T. Putra, “Pengaruh jenis busi terhadap konsumsi bahan bakar dan emisi gas buang pada sepeda motor honda revo fit 110cc,” *Jurnal Teknik Mesin Universitas Muhammadiyah Metro*, vol. 5, no. 2, pp. 88–94, 2016.

[8] I. Nurdianto, “Pengaruh variasi tingkat panas busi terhadap performa mesin dan emisi gas buang sepeda motor 4 tak,” *Jurnal Teknik Mesin*, vol. 3, no. 3, pp. 119–127, 2015.

[9] R. C. Putra and A. Rosyidin, “Pengaruh nilai oktan terhadap unjuk kerja motor bensin dan konsumsi bahan bakar dengan busi-koil standar-racing,” *Jurnal POLIMESIN*, vol. 18, no. 1, pp. 7–15, 2020.

[10] K. Rashid, “Optimize the taguchi method, the signal-to-noise ratio, and the sensitivity,” *International Journal of Statistics and Applied Mathematics*, vol. 8, pp. 64–70, 12 2023.

[11] I. Suryati, I. Indrawan, J. Lubis, M. Tanjung, and L. Setyowaty, “Analysis of exhaust gas emission of motor vehicles with variations of fuel types,” *Jurnal Presipitasi : Media Komunikasi dan Pengembangan Teknik Lingkungan*, vol. 20, pp. 755–764, 09 2023.

[12] G. Alemayehu, D. Firew, R. B. Nallamothu, A. Wako, and R. Gopal, “Operating parameters optimization for lower emissions in diesel engine with pcci-di mode using taguchi and grey relational analysis,” *Heliyon*, vol. 8, no. 6, p. e09679, 2022.

[13] D. Du, Z. Hao, X. Guo, W. Jiang, and S. Yang, “Study on combustion characteristics under methanol gasoline emission optimization based on orthogonal matrix analysis,” *Environmental Progress & Sustainable Energy*, vol. 44, no. 1, p. 14536, 2025.

[14] G. Pohit and D. Misra, “Optimization of performance and emission characteristics of diesel engine with biodiesel using grey-taguchi method,” *Journal of Engineering*, vol. 2013, 01 2013.

[15] V. M. Kannan and K. S. Amirthagadeshwaran, “Advances in automobile engineering optimization of diesel engine parameters using genetic algorithm,” *Advances in Automobile Engineering*, vol. 11, no. 1000180, pp. 1–5, 2022.