International Journal of Simulation, Optimization & Modelling
ISSN: 3083-967X

Engine Performance Analysis Based on Speed and Throttle Through Simulation

Helmisyah Ahmad Jalaludin[1], Mohd Kamal Kamarulzaman[2], Agung Sudrajad[3], S.M Rosdi[4], Erdiwansyah[5,6]

[1]Faculty of Engineering, Universiti Teknologi MARA, Terengganu
[2]Faculty of Engineering, Universiti Pertahanan Nasional Malaysia, Malaysia
[3]Faculty of Mechanical Engineering, Universitas Sultan Ageng Tirtayasa, Indonesia
[4]Department of Mechanical Engineering, Politeknik Sultan Mizan Zainal Abidin, Malaysia
[5]Department of Natural Resources and Environmental Management, Universitas Serambi Mekkah, 23245, Banda Aceh, Indonesia
[6]Centre for Automotive Engineering, Universiti Malaysia Pahang Al Sultan Abdullah, 26600, Malaysia

Corresponding author: helmisyah@uitm.edu.my

Abstract
Internal combustion engine (ICE) performance is greatly influenced by engine speed and throttle opening, which contribute to brake power, brake thermal efficiency (BTE), and brake-specific fuel consumption (BSFC). This study used simulation and statistical analysis methods, including ANOVA and response surface methodology (RSM), to evaluate the impact of these two parameters on engine performance. The simulation results showed that brake power increased with increasing engine speed and throttle opening, with an average value of 15.09 kW and an R-squared of 0.9886, indicating high model accuracy. Brake thermal efficiency also increased with an average value of 24.03% and an R-squared of 0.9868, indicating increased fuel energy utilization into mechanical energy. Meanwhile, specific fuel consumption decreased with increasing engine speed and throttle opening, with an average of 385.30 g/kWh and an R-squared of 0.9584. This study confirms that optimization of engine speed and throttle opening significantly improves thermal efficiency and reduces specific fuel consumption. These findings have significant implications for designing more efficient and environmentally friendly engines. In addition, the simulation approach allows for a more precise analysis of engine performance without expensive and time-consuming experimental testing.

Article Info
Received: 13 February 2025
Revised: 02 March 2025
Accepted: 03 March 2025
Available online: 25 March 2025

Keywords
Engine speed
Brake power
Thermal efficiency
Simulation
RSM

1. Introduction
The performance of an internal combustion engine (ICE) is influenced by various factors, including engine speed and throttle position. These parameters significantly affect brake power, brake thermal efficiency (BTE), and brake-specific fuel consumption (BSFC). Understanding the relationship between these variables is crucial for optimizing engine performance and fuel efficiency. Previous studies have shown that engine speed and throttle play a vital role in determining an engine's overall efficiency and fuel consumption (Alenezi et al., 2021; Alenezi, Erdiwansyah, Mamat, Norkhizan, & Najafi, 2020; Rosdi, Erdiwansyah, Ghazali, & Mamat, 2025; Szybist et al., 2021). Brake power is a key performance metric that reflects the amount of power delivered by the engine to the main shaft. It is directly affected

by variations in engine speed and throttle. The findings from the simulation indicate that brake power increases with rising engine speed and throttle opening, as illustrated by the quadratic response surface model. This aligns with the fundamental principles of engine dynamics, where higher speeds and greater air-fuel intake improve combustion efficiency (Ferrari, Gurrì, & Vento, 2024; Gani et al., 2025; Onyewudiala & Johnson, 2023; Rosdi, Maghfirah, Erdiwansyah, Syafrizal, & Muhibbuddin, 2025).

Brake thermal efficiency (BTE) is another critical parameter in engine performance analysis. It represents the efficiency with which an engine converts fuel energy into mechanical energy. The study's ANOVA results show that BTE increases as engine speed and throttle opening rise, highlighting an improvement in energy utilization. This trend is consistent with prior research, which suggests that optimized throttle positioning enhances air-fuel mixing, leading to more complete combustion and improved thermal efficiency (Bahagia, Nizar, Yasin, Rosdi, & Faisal, 2025; Dahham, Wei, & Pan, 2022; Erdiwansyah et al., 2021; Muhibbuddin, Hamidi, & Fitriyana, 2025). Conversely, brake-specific fuel consumption (BSFC) measures the fuel required to generate one unit of brake power over time. The study results reveal a decrease in BSFC as engine speed and throttle opening increase. This suggests that the engine operates more efficiently at higher speeds with an open throttle, as less fuel is needed per unit of power output. Similar trends have been observed in previous studies, reinforcing the importance of optimizing engine operating conditions to minimize fuel consumption (Abdellatief et al., 2021; Masum, Masjuki, Kalam, Palash, & Habibullah, 2015; Yana, Mufti, Hasiany, Viena, & Mahyudin, 2025).

The importance of engine speed and throttle optimization extends beyond performance enhancement; it also has environmental implications. Improved engine efficiency leads to lower fuel consumption and reduced emissions, contributing to sustainable transportation solutions. Advances in simulation techniques allow for precise analysis and optimization of engine parameters, reducing the reliance on costly and time-consuming experimental trials (Aliramezani, Koch, & Shahbakhti, 2022; Fitriyana, Rusiyanto, & Maawa, 2025; Jafari & Nikolaidis, 2019; Li, Zhou, He, Chen, & Xu, 2023). This study aims to analyze the impact of engine speed and throttle position on engine performance using simulation techniques. By leveraging ANOVA and response surface methodology, the research provides insights into optimizing engine operation for maximum efficiency and minimal fuel consumption. The findings contribute to the growing body of knowledge on engine performance optimization, providing valuable guidance for researchers and engineers in the automotive industry.

The novelty of this article lies in its comprehensive use of simulation techniques to analyze engine performance, focusing on the combined effects of engine speed and throttle position. Unlike previous studies that primarily relied on experimental methods, this research leverages advanced statistical tools such as ANOVA and response surface methodology to provide more precise and predictive insights. This approach not only enhances understanding but also facilitates more efficient engine tuning for improved performance and sustainability.

2. Methodology

This study utilizes simulation techniques to analyze the effect of engine speed and throttle position on engine performance. The methodology involves the following key steps:

a. **Simulation Model Development**: A detailed engine model was developed using specialized software to simulate different operating conditions. The model incorporates parameters such as engine speed, throttle position, fuel characteristics, and combustion efficiency.
b. **Experimental Data and Validation**: To ensure accuracy, the simulation model was validated using experimental data obtained from prior studies. The validation process involved comparing simulated results with measured values to confirm model reliability. A multicylinder 4-stroke gasoline engine is selected for testing, with specifications including engine type as shown in table 1, displacement, compression ratio, maximum power, fuel system (carburetor or fuel injection), and cooling system (air or water-cooled). The engine is coupled with an eddy current dynamometer to apply variable loads and measure power output. Commercially available gasoline with a specified octane rating is used as fuel, and SAE-rated engine oil is employed for lubrication.

Table 1. Engine specification

Description	Specification
Number of cylinders	4
Compression ratio	17.3
Total displacement	2 L
Bore	82.7 mm
Stroke	93 mm
Combustion chamber	Swirl chamber
Maximum power	64.9 kW

To ensure accurate data collection, various sensors and instruments are utilized, including a fuel flow meter to measure fuel consumption, an air flow sensor for intake measurement, thermocouples to record exhaust gas and coolant temperature, pressure sensors to monitor in-cylinder pressure, a lambda sensor for air-fuel ratio measurement, a crank angle encoder for precise crankshaft positioning, and an emission analyzer to assess CO, CO_2, NOx, and HC emissions. The engine is tested under different loads and speeds to evaluate performance parameters. The test conditions include varying engine speeds (e.g., 1000 - 6000 RPM in increments of 500 RPM), different load conditions (25%, 50%, 75%, and 100% of full load), and adjustments to fuel injection and ignition timing. The ambient temperature is also monitored and recorded.

The testing procedure begins with a warm-up phase, where the engine runs at idle speed for 10–15 minutes to reach steady-state conditions. Baseline testing is conducted under standard conditions without modifications. Performance testing involves measuring brake power (BP), brake thermal efficiency (BTE), and brake specific fuel consumption (BSFC) at different loads and speeds. Additionally, combustion parameters such as pressure vs. crank angle, heat release rate, and ignition delay are recorded. The volumetric efficiency and air-fuel ratio are also evaluated. Exhaust emissions are measured at each operating condition, and all tests are repeated three times to ensure accuracy and minimize errors.

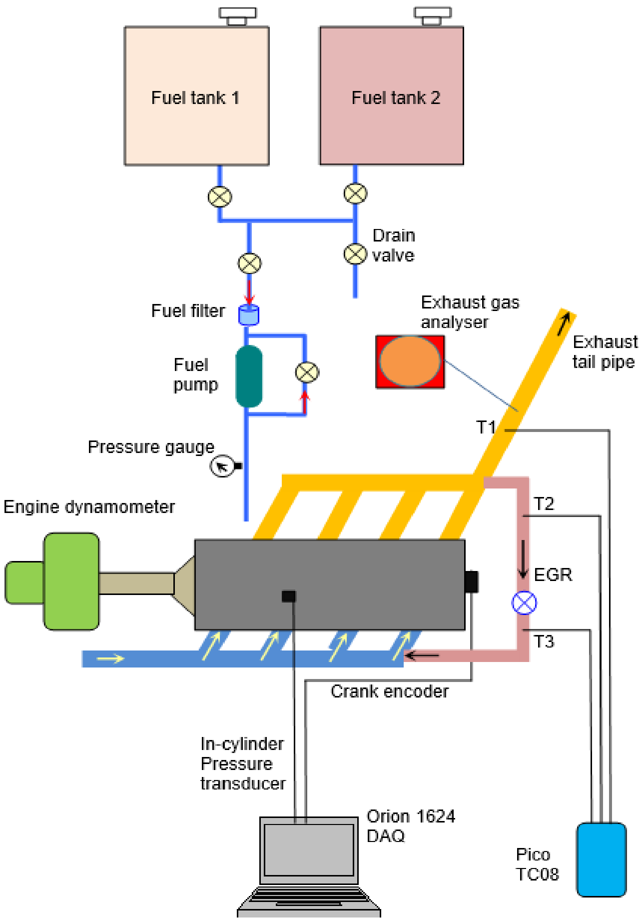

Fig 1. Schematic diagram of the engine

c. **Design of Experiments (DOE)**: The study employs a structured DOE approach to systematically vary engine speed and throttle position. ANOVA was utilized to analyze the significance of these factors on brake power, brake thermal efficiency (BTE), and brake-specific fuel consumption (BSFC).
d. **Response Surface Methodology (RSM)**: RSM was applied to develop predictive models for engine performance parameters. This method allows for visualization of relationships between variables and optimization of engine settings for improved efficiency.
e. **Analysis and Interpretation**: The simulated data were analyzed using statistical tools, including regression analysis and surface response plots. The results were then compared with existing literature to validate findings and assess improvements in engine performance.

This methodological approach provides a robust framework for analyzing and optimizing engine performance, ensuring accuracy and reliability while minimizing the need for extensive experimental testing.

3. Result & Discussion

The initial analysis looked at how brake power was affected by fuel blends, engine speed, and throttle when utilizing various fuels. According to Heywood (1988), brake power is the power that the engine transfers to the main shaft to generate torque and angular speed. The response parameter's ANOVA results for braking power are displayed in **Table 2**. Given that the R-squared is close to 1, the model is significant. **Eq. 1** describes the relationship between engine speed, engine throttle, and braking power. The brake power graph for engine speed and throttle is displayed in **Fig. 2**. Both the (a) scatter graph and the (b) 3D graph display the response surface profile for the quadratic model. The graph indicates that the brake power increases as motor speed and throttle increases.

Table 2. ANOVA result response for brake power

Parameter	value
Std. Dev.	1.14
Mean	15.09
C.V. %	7.58
PRESS	176.51
R-Squared	0.9886
Adj R-Squared	0.9843
Pred R-Squared	0.9744
Adeq Precision	48.359

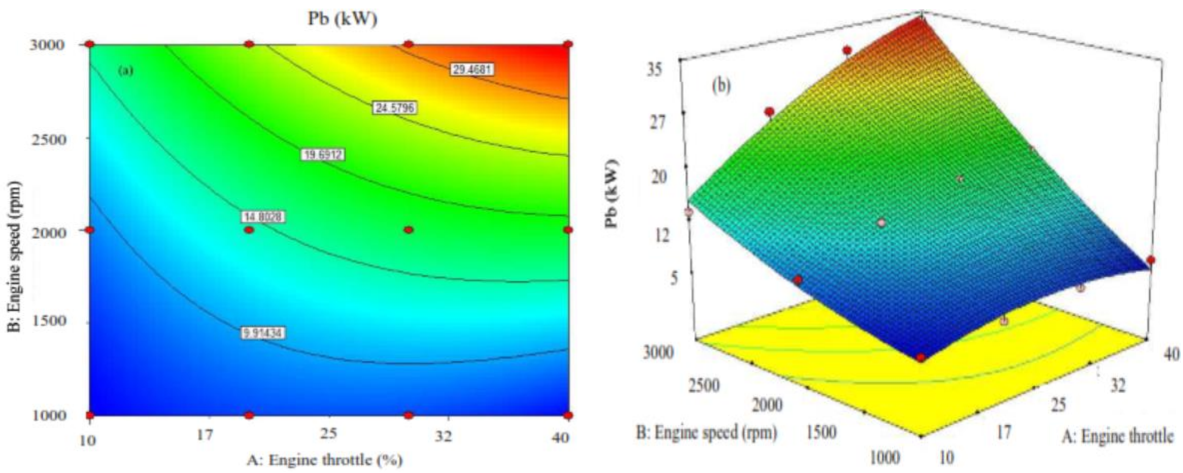

Fig. 2. Graph brake power for engine speed and engine throttle (a) scatter (b) 3D

Pb =15.44+4.72 * A+9.45 * B+0.58 * C[1]+0.043 * C[2]-0.24 * C[3]-0.51 * C[4]+0.25 * C[5]+0.10 * C[6]+4.57 * AB+0.11 * AC[1]-0.042 * AC[2]-0.090 * AC[3]-0.19 * AC[4]+0.10 (1)

* AC[5]+0.069 * AC[6]+0.38 * BC[1]+0.030 * BC[2]-0.21 * BC[3]-0.34 * BC[4]+0.14 * BC[5]+0.091 * BC[6]-2.27 * A2+1.38 * B2

Brake thermal efficiency is the ability of fuel's thermal power to generate and transfer power to the crankshaft (Duan et al., 2025; Güler & Özkan, 2022; Wang, Shuai, Li, & Yu, 2021). The ANOVA response for brake thermal efficiency is displayed in **Table 3**. With an R-squared of 0.9868, which is near to 1, it demonstrates that the model is significant. **Eq. 2** illustrates the connection between engine throttle, engine speed, and brake thermal efficiency. The brake thermal efficiency graph is displayed in **Fig. 3**. Engine speed and throttle increase in tandem with brake thermal efficiency.

Table 3. ANOVA response for brake thermal efficiency

Parameter	Value
Std. Dev.	0.73
Mean	24.03
C.V. %	3.03
PRESS	63.44
R-Squared	0.9868
Adj R-Squared	0.9817
Pred R-Squared	0.9736
Adeq Precision	58.081

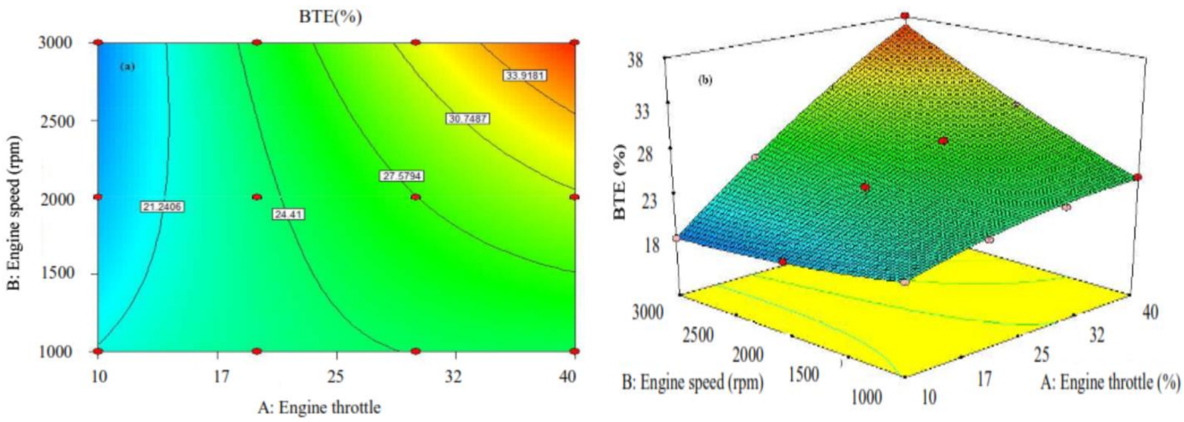

Fig. 3. Graph BTE as a function engine speed and engine throttle (a) scatter (b) 3D

BTE =24.22+5.66 * A+2.28 * B+1.56 * C[1]+0.41 * C[2]-0.56 * C[3]-1.75 * C[4]+1.01 * C[5]+0.27 * C[6]+3.89 * AB-0.043 * AC[1]-0.22 * AC[2]-4.286E-003 * AC[3]+0.24 * AC[4]-0.19 * AC[5]-0.044 * AC[6]-0.032 * BC[1]+9.523E-003 * BC[2]+0.022 * BC[3]-0.032 * BC[4]-0.049 * BC[5]-0.040 * BC[6]-0.94 * A^2+0.49 * B^2 (2)

The quantity of gasoline used for every unit of brake power in an hour is known as brake specific fuel consumption (Selvakumar, Maawa, & Rusiyanto, 2025; Thangavelu, Ahmed, & Ani, 2014, 2016; Thangavelu, Rajkumar, Pandi, Ahmed, & Ani, 2019). The ANOVA response for brake-specific fuel consumption is displayed in **Table 3**. Model terms are considered significant when the Prob > F value is less than 0.0500. Additionally, it demonstrates that R-squared is around 1 at 0.9584. **Eq. 3** illustrates the relationship between engine throttle, engine speed, and brake specific fuel consumption. The relationship between engine throttle, engine speed, and brake specific fuel consumption is depicted in **Fig. 3(a)** scatter graph and **(b)** 3D graph. According to this study, the brake specific fuel consumption drops as engine speed and throttle increase.

Table 3. ANOVA response for brake specific fuel consumption

Parameter	Value
Std. Dev.	22.52
Mean	385.30
C.V. %	5.84

Parameter	Value
PRESS	63977.65
R-Squared	0.9584
Adj R-Squared	0.9425
Pred R-Squared	0.9126
Adeq Precision	30.351

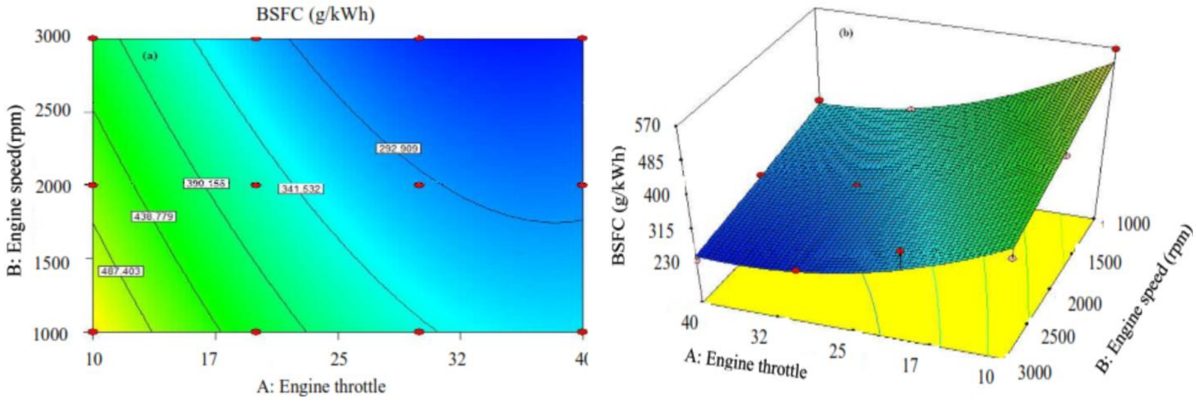

Fig. 4. Graph of BSFC as a function of engine throttle and engine speed (a) scatter (b) 3D

$$BSFC = 353.62-100.21 * A-51.38 * B-30.69 * C[1]-4.55 * C[2]+9.90 * C[3]+29.72 * C[4]-16.55 * C[5]-3.63 * C[6]+12.39 * AB+6.66 * AC[1]+4.74 * AC[2]-1.14 * AC[3]-9.01 * AC[4]+3.16 * AC[5]-0.19 * AC[6]+0.81 * BC[1]-1.99 * BC[2]-1.75 * BC[3]-0.21 * BC[4]-0.49 * BC[5]+0.76 * BC[6]+54.35 * A^2+2.23 * B^2 \quad (3)$$

4. Conclusion

The simulation results in this study indicate that engine speed and throttle opening have a significant effect on the performance of the internal combustion engine (ICE). Some of the main findings obtained are:

a. Based on the ANOVA analysis, brake power increases with increasing engine speed and throttle opening. The statistical model used has an R-Squared value of 0.9886, indicating high accuracy in predicting brake power. The average brake power obtained is 15.09 kW, with a standard deviation of 1.14.
b. Thermal efficiency increases with increasing engine speed and throttle opening, as shown by the ANOVA results with an R-Squared of 0.9868. The average BTE value obtained is 24.03%, with a standard deviation of 0.73. This indicates an increase in the efficiency of converting fuel energy into mechanical energy.
c. Results show that specific fuel consumption decreases as engine speed and throttle opening increase. ANOVA gives an R-Squared value of 0.9584, with an average BSFC of 385.30 g/kWh and a standard deviation of 22.52. This trend confirms that at high speeds and open throttles, the engine operates more efficiently in terms of fuel consumption per unit of output power.

Overall, this study confirms that optimizing engine speed and throttle opening can improve thermal efficiency and reduce specific fuel consumption, which ultimately results in improving overall engine efficiency. In addition, the use of simulation methods and statistical analysis used in this study allows engine performance optimization without the need for expensive and time-consuming physical testing.

References

Abdellatief, T. M. M., Ershov, M. A., Kapustin, V. M., Ali Abdelkareem, M., Kamil, M., & Olabi, A. G. (2021). Recent trends for introducing promising fuel components to enhance the anti-knock quality of gasoline: A systematic review. *Fuel*, 291, 120112. Retrieved from https://doi.org/https://doi.org/10.1016/j.fuel.2020.120112

Alenezi, R. A., Erdiwansyah, Mamat, R., Norkhizan, A. M., & Najafi, G. (2020). The effect of fusel-biodiesel blends on the emissions and performance of a single cylinder diesel engine. *Fuel*, 279, 118438. Retrieved from https://doi.org/https://doi.org/10.1016/j.fuel.2020.118438

Alenezi, R. A., Norkhizan, A. M., Mamat, R., Erdiwansyah, Najafi, G., & Mazlan, M. (2021). Investigating the contribution of carbon nanotubes and diesel-biodiesel blends to emission and combustion characteristics of diesel engine. *Fuel*, 285, 119046. Retrieved from https://doi.org/https://doi.org/10.1016/j.fuel.2020.119046

Aliramezani, M., Koch, C. R., & Shahbakhti, M. (2022). Modeling, diagnostics, optimization, and control of internal combustion engines via modern machine learning techniques: A review and future directions. *Progress in Energy and Combustion Science*, 88, 100967. Retrieved from https://doi.org/https://doi.org/10.1016/j.pecs.2021.100967

Bahagia, B., Nizar, M., Yasin, M. H. M., Rosdi, S. M., & Faisal, M. (2025). Advancements in Communication and Information Technologies for Smart Energy Systems and Renewable Energy Transition: A Review. *International Journal of Engineering and Technology (IJET)*, 1(1), 1–29.

Dahham, R. Y., Wei, H., & Pan, J. (2022). Improving thermal efficiency of internal combustion engines: recent progress and remaining challenges. *Energies*, 15(17), 6222.

Duan, H., Hu, W., Wang, J., Yin, X., Hu, E., & Zeng, K. (2025). Effects of diesel pilot-injection strategy on a methanol/diesel dual-direct injection engine. *Applied Thermal Engineering*, 261, 125106. Retrieved from https://doi.org/https://doi.org/10.1016/j.applthermaleng.2024.125106

Erdiwansyah, Mahidin, Husin, H., Nasaruddin, Zaki, M., & Muhibbuddin. (2021). A critical review of the integration of renewable energy sources with various technologies. *Protection and Control of Modern Power Systems*, 6(1), 3. Retrieved from https://doi.org/10.1186/s41601-021-00181-3

Ferrari, A., Gurrì, S., & Vento, O. (2024). Injected Fuel Mass and Flow Rate Control in Internal Combustion Engines: A Systematic Literature Review. *Energies*, 17(24), 6455.

Fitriyana, D. F., Rusiyanto, R., & Maawa, W. (2025). Renewable Energy Application Research Using VOSviewer software: Bibliometric Analysis. *International Journal of Science & Advanced Technology (IJSAT)*, 1(1), 92–107.

Gani, A., Saisa, S., Muhtadin, M., Bahagia, B., Erdiwansyah, E., & Lisafitri, Y. (2025). Optimisation of home grid-connected photovoltaic systems: performance analysis and energy implications. *International Journal of Engineering and Technology (IJET)*, 1(1), 63–74.

Güler, M., & Özkan, M. (2022). Energy balance analysis of a DI diesel engine with multiple pilot injections strategy and optimization of brake thermal efficiency. *Applied Thermal Engineering*, 204, 117972. Retrieved from https://doi.org/https://doi.org/10.1016/j.applthermaleng.2021.117972

Jafari, S., & Nikolaidis, T. (2019). Meta-heuristic global optimization algorithms for aircraft engines modelling and controller design; A review, research challenges, and exploring the future. *Progress in Aerospace Sciences*, 104, 40–53. Retrieved from https://doi.org/https://doi.org/10.1016/j.paerosci.2018.11.003

Li, J., Zhou, Q., He, X., Chen, W., & Xu, H. (2023). Data-driven enabling technologies in soft sensors of modern internal combustion engines: Perspectives. *Energy*, 272, 127067. Retrieved from https://doi.org/https://doi.org/10.1016/j.energy.2023.127067

Masum, B. M., Masjuki, H. H., Kalam, M. A., Palash, S. M., & Habibullah, M. (2015). Effect of alcohol–gasoline blends optimization on fuel properties, performance and emissions of a SI engine. *Journal of Cleaner Production*, 86, 230–237. Retrieved from https://doi.org/10.1016/j.jclepro.2014.08.032

Muhibbuddin, M., Hamidi, M. A., & Fitriyana, D. F. (2025). Bibliometric Analysis of Renewable Energy Technologies Using VOSviewer: Mapping Innovations and Applications. *International Journal of Science & Advanced Technology (IJSAT)*, 1(1), 81–91.

Onyewudiala, J. I., & Johnson, N. (2023). Exploring The Energetic Efficiency of Internal Combustion Engines: A Comparative Study of Ignited Spark Exergy and Energy Analysis for Hydrogen Fuel, Methane, and Gasoline. *ASRIC JOURNAL ON ENGINEERING SCIENCES*, 88.

Rosdi, S. M., Erdiwansyah, Ghazali, M. F., & Mamat, R. (2025). Evaluation of engine performance and emissions using blends of gasoline, ethanol, and fusel oil. *Case Studies in Chemical and Environmental Engineering*, 11, 101065. Retrieved from https://doi.org/https://doi.org/10.1016/j.cscee.2024.101065

Rosdi, S. M., Maghfirah, G., Erdiwansyah, E., Syafrizal, S., & Muhibbuddin, M. (2025). Bibliometric

Study of Renewable Energy Technology Development: Application of VOSviewer in Identifying Global Trends. *International Journal of Science & Advanced Technology (IJSAT)*, 1(1), 71–80.

Selvakumar, P., Maawa, W., & Rusiyanto, R. (2025). Hybrid Grid System as a Solution for Renewable Energy Integration: A Case Study. *International Journal of Science & Advanced Technology (IJSAT)*, 1(1), 62–70.

Szybist, J. P., Busch, S., McCormick, R. L., Pihl, J. A., Splitter, D. A., Ratcliff, M. A., … Miles, P. (2021). What fuel properties enable higher thermal efficiency in spark-ignited engines? *Progress in Energy and Combustion Science*, 82, 100876. Retrieved from https://doi.org/https://doi.org/10.1016/j.pecs.2020.100876

Thangavelu, S. K., Ahmed, A. S., & Ani, F. N. (2014). Bioethanol production from sago pith waste using microwave hydrothermal hydrolysis accelerated by carbon dioxide. *Applied Energy*, 128, 277–283. Retrieved from https://doi.org/https://doi.org/10.1016/j.apenergy.2014.04.076

Thangavelu, S. K., Ahmed, A. S., & Ani, F. N. (2016). Impact of metals on corrosive behavior of biodiesel–diesel–ethanol (BDE) alternative fuel. *Renewable Energy*, 94, 1–9. Retrieved from https://doi.org/https://doi.org/10.1016/j.renene.2016.03.015

Thangavelu, S. K., Rajkumar, T., Pandi, D. K., Ahmed, A. S., & Ani, F. N. (2019). Microwave assisted acid hydrolysis for bioethanol fuel production from sago pith waste. *Waste Management*, 86, 80–86. Retrieved from https://doi.org/https://doi.org/10.1016/j.wasman.2019.01.035

Wang, Z., Shuai, S., Li, Z., & Yu, W. (2021). A review of energy loss reduction technologies for internal combustion engines to improve brake thermal efficiency. *Energies*, 14(20), 6656.

Yana, S., Mufti, A. A., Hasiany, S., Viena, V., & Mahyudin, M. (2025). Overview of biomass-based waste to renewable energy technology, socioeconomic, and environmental impact. *International Journal of Engineering and Technology (IJET)*, 1(1), 30–62.