International Journal of Automotive & Transportation Engineering
ISSN: 3083-9726

One-dimensional Simulation of Industrial Diesel Engine

Muhibbuddin[1], Yusrizal Muchlis[2], Aida Syarif[3], Helmisyah Ahmad Jalaludin[4]

[1]Department of Mechanical and Industrial Engineering, Universitas Syiah Kuala, Indonesia
[2]Department of Mechanical Engineering, Faculty of Engineering, Universitas Abulyatama, Indonesia
[3]Depatment of Renewable Energy Engineering, Politeknik Negeri Sriwijaya, Indonesia
[4]Faculty of Mechanical Engineering, Universiti Teknologi MARA, Terengganu, Malaysia

Corresponding author: muhib@usk.ac.id

Abstract
This paper presents a comprehensive one-dimensional simulation study of a diesel engine using Diesel-RK software to evaluate engine performance and combustion characteristics. The simulation model integrates detailed representations of fuel injection, combustion kinetics, and heat transfer processes, enabling the prediction of key parameters such as engine performance, combustion characteristics and emissions. Results from the simulation were rigorously validated against experimental data across a range of operating conditions, demonstrating excellent predictive capabilities. The findings reveal that the Diesel-RK model accurately captures the complex interplay between design parameters and combustion dynamics, offering a reliable tool for optimizing engine performance and improving emissions control. This study underscores the robustness of one-dimensional simulation techniques in diesel engine analysis and provides valuable insights for future engine development and advanced combustion strategies.

Article Info
Received: 05 January 2025
Revised: 30 January 2025
Accepted: 04 February 2025
Available online: 25 May 2025

Keywords
Diesel engine performance
Brake specific fuel consumption
Ignition delay period
Cylinder pressure
Engine speed optimization

1. Introduction
Diesel engine performance and emissions are critical research areas for improved efficiency and environmental sustainability. This study presents a comprehensive one-dimensional simulation of a diesel engine using the Diesel-RK software, a robust tool renowned for its detailed modelling of combustion phenomena. The simulation framework integrates the complex dynamics of fuel injection, heat transfer, and chemical kinetics, thoroughly examining the combustion process under various operating conditions. Previous studies have shown that one-dimensional simulations can accurately represent the main characteristics of diesel engines in analyzing performance and emissions. This is particularly evident with software such as Diesel-RK, which has been widely applied in combustion process optimization studies [1–4].

The simulation model was developed by incorporating detailed sub-models that capture the essential processes within a diesel engine. In particular, the Diesel-RK software was utilized to simulate the intricate interplay between in-cylinder pressure variations and the progression of the combustion process [5–8]. By carefully calibrating the model parameters with experimental data, the study ensured that the simulated results mirrored real-world engine behaviour, affirming the simulation framework's reliability. Model calibration based on experimental data is essential for improving simulation accuracy, particularly in predicting cylinder pressure variations and combustion dynamics. This enables a more in-depth and realistic engine performance analysis [9–13].

The results obtained from the simulation indicate that the Diesel-RK model delivers excellent predictive capabilities, accurately forecasting key performance indicators such as peak in-cylinder pressure, heat release rates, and exhaust emissions. A rigorous validation compared the simulation outcomes against experimental data, confirming the model's precision across load and speed conditions [14–17]. The study highlights how subtle changes in operating parameters significantly influence combustion characteristics, providing valuable insights into engine optimization and emissions reduction strategies. Simulation using Diesel-RK can predict key performance indicators and the influence of operating parameters on combustion and emission characteristics with high accuracy under various engine operating conditions. These findings are consistent with previous studies [18–21].

In conclusion, this research underscores the effectiveness of one-dimensional simulation techniques in analyzing and predicting diesel engine performance. The successful application of Diesel-RK validates its capability as a reliable simulation tool and opens new avenues for the detailed study of engine dynamics. Future work may extend this approach by incorporating multi-dimensional effects and exploring advanced combustion strategies, further enhancing our understanding and optimising diesel engine performance. Several studies recommend further development by integrating multi-dimensional simulations and advanced combustion strategies, such as low-temperature and alternative fuels. These recommendations aim to reduce emissions further and improve diesel engine efficiency [22–25].

This study aims to conduct a one-dimensional simulation on a 4M50 industrial diesel engine using Diesel-RK software to evaluate engine performance and combustion characteristics. Specifically, this study focuses on the analysis of the relationship between engine rotation speed and essential parameters, such as maximum cylinder pressure, ignition delay, specific fuel consumption (BSFC), torque, and brake power, through a model calibration process with experimental data to ensure the accuracy of simulation predictions under various operating conditions. This study's novelty lies in applying one-dimensional simulation using Diesel-RK in detail on a 4M50 industrial diesel engine, which has not been widely studied in previous literature. This study provides new contributions in the form of a comprehensive analysis of the sensitivity of operational parameters to combustion dynamics and engine performance at high speeds, as well as model validation that shows a high level of accuracy against accurate experimental data, thus strengthening the use of Diesel-RK as a design optimization tool and emission control for industrial diesel engines.

2. Methodology

The simulation study used the Diesel-RK one-dimensional engine simulation software, specifically configured to model an industrial diesel engine model 4M50. This engine was selected due to its relevance in industrial applications and the availability of detailed specifications and an engine layout image (provided below). The first step involved gathering all pertinent engine parameters, including geometrical dimensions, thermodynamic properties, and operational characteristics. As detailed in Table 1 and illustrated in Figure 1, these specifications were used to define the engine's configuration within the simulation environment accurately.

Once the engine geometry and operating conditions were established, the Diesel-RK software was employed to develop a comprehensive model of the 4M50 engine. The model incorporated critical processes such as fuel injection, atomization, vaporization, combustion, and heat transfer. By discretizing the engine cycle into fine time steps, the simulation captured transient phenomena, including the evolution of in-cylinder pressure and temperature profiles throughout the combustion process. Detailed sub-models representing the chemical kinetics and thermodynamic behaviour were integrated to ensure that the physical and chemical interactions were well represented.

Calibration of the simulation model was a pivotal aspect of the methodology. Initial simulation outputs were compared with available experimental data and manufacturer's performance curves. This iterative calibration process involved adjusting key parameters such as fuel injection timing, spray characteristics, and heat loss coefficients to align the simulation results with empirical observations. The calibration not only validated the accuracy of the Diesel-RK model but also provided insights into the sensitivity of engine performance to various operating conditions, ensuring that the simulation could reliably predict the behaviour of the 4M50 engine across a range of scenarios.

Finally, a series of simulation runs were performed under varying speeds to assess the engine's performance and combustion characteristics comprehensively. The analysis focused on critical performance metrics, including peak in-cylinder pressure, combustion duration, and exhaust emissions. A sensitivity analysis was also conducted to examine the effects of variations in fuel injection parameters and ambient conditions. The results from these simulations demonstrated excellent predictive capabilities, thereby affirming the robustness of the Diesel-RK model as a tool for both engine performance evaluation and the development of optimized combustion strategies for the 4M50 diesel engine.

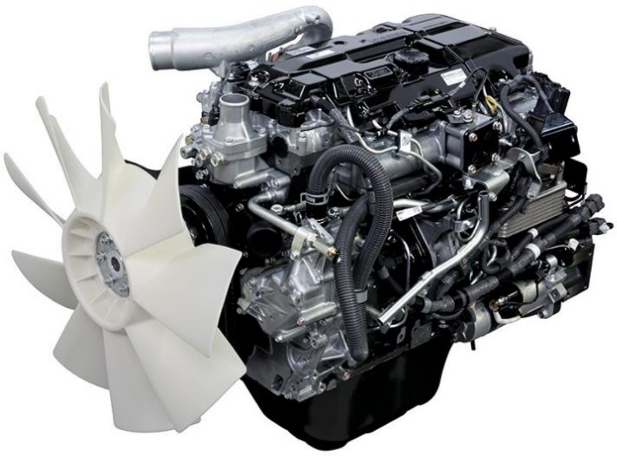

Figure 1: Industrial inline-four diesel engine (Model 4M50)

Table 1 presents the technical specifications of the 4M50 inline four-cylinder diesel engine, which has an engine capacity of 4.9 liters. This engine has a cylinder diameter (bore) of 114 mm and a piston stroke (stroke) of 120 mm, which indicates a large stroke to cylinder diameter ratio to improve thermal efficiency. The compression ratio of this engine is 17.5, which is a common characteristic of diesel engines to ensure optimal fuel combustion. In addition, this engine has the same intake and exhaust valve diameter, which is 38 mm, which contributes to the efficiency of air flow in the combustion chamber. With a fuel injection pressure of up to 500 bar, this engine is designed to produce better combustion and improve fuel efficiency as well as reduce exhaust emissions.

Table 1: Specifications of an inline-four diesel engine

Specification	Description
Engine	4M50 in-line four diesel engine
Engine capacity [L]	4.9
Bore [mm]	114
Stroke [mm]	120
Compression ratio	17.5
Intake valve diameter [mm]	38
Exhaust valve diameter [mm]	38
Injection pressure [bar]	500

3. Results and Discussions

Figure 2 shows the relationship between engine speed and Brake Mean Effective Pressure (BMEP). BMEP increases as the engine speed increases from 1000 rpm to a peak of around 6.85 bar at 2000 rpm. This increase indicates optimal combustion efficiency in the range of rotation, where the air and fuel supply are in ideal conditions to produce maximum adequate pressure in the cylinder. After passing

2000 rpm, BMEP decreases even though the engine speed increases. This decrease is caused by a shorter time for the combustion process due to the high engine speed, so the combustion gas expansion process is less than optimal, which causes a decrease in the average adequate pressure in the cylinder. This phenomenon is common in diesel engines, where volumetric efficiency and optimal injection timing are reduced at high speeds.

Figure 3 shows a graph of the relationship between engine speed and Brake Power (BP). Unlike BMEP, Brake Power consistently increases as engine speed increases from 1000 rpm to 2400 rpm. This increase indicates that the higher the engine speed, the greater the mechanical energy the engine produces to do real work, which is transferred through the output shaft. This increase in Brake Power is due to the rise in engine work cycles per unit time at higher speeds, so the energy produced in a particular time increases even though the effective pressure efficiency begins to decrease at high speeds. This confirms that the power output of a diesel engine can still increase to a certain extent even though BMEP decreases, as long as the fuel supply is adequate and the injection system can meet the combustion needs at high speeds. However, it is essential to note that Brake Power can begin to decrease at speeds higher than 2400 rpm due to limitations in airflow and volumetric efficiency.

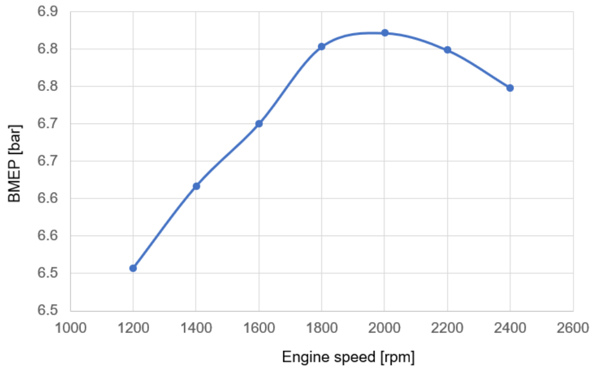

Figure 2: Brake means compelling pressure

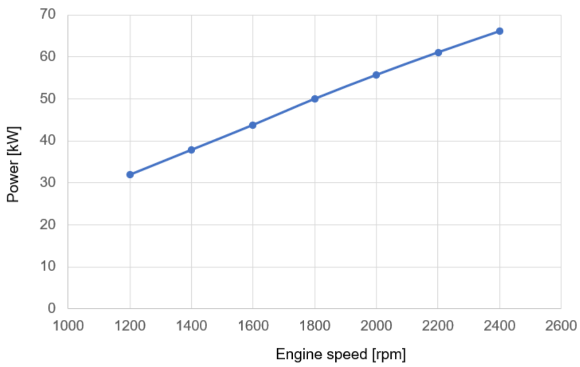

Figure 3: Brake Power

Figure 4 shows the relationship between torque and engine speed. Torque increases with increasing engine speed from 1000 rpm to a peak of around 266 Nm at 2000 rpm. This increase in torque occurs because, in this rotation range, the air and fuel filling process is in optimal condition, resulting in more efficient combustion and maximum thrust on the piston. After 2000 rpm, torque decreases even though the engine speed increases. This decrease is caused by reduced volumetric efficiency at high speeds, where the cylinder filling time becomes shorter so that the amount of air and fuel entering is reduced, causing a decrease in the thrust generated in the combustion chamber. This phenomenon illustrates the general characteristics of diesel engines, where maximum torque is usually achieved at medium speeds and will decrease at high speeds due to limitations in the filling and combustion processes.

Figure 5 shows a graph of the relationship between Brake Specific Fuel Consumption (BSFC) and engine speed. BSFC describes the engine's specific fuel consumption in kg/kWh units, where the lower the BSFC value, the more efficient the engine is in producing power. This graph shows that BSFC decreases from around 0.233 kg/kWh at 1200 rpm to the lowest value of around 0.227 kg/kWh at 1800 rpm. This lowest value indicates the most efficient engine operating point because there is an optimal balance between fuel supply, combustion pressure, and gas expansion process at that speed. After passing 1800 rpm, BSFC increases again to around 0.231 kg/kWh at 2400 rpm. The increase in BSFC at high speeds is caused by the growing need for fuel to maintain combustion stability, but with decreasing thermal efficiency due to the less-than-optimal air-filling process and shorter combustion time. This confirms that diesel engines have an efficient operating range at medium speeds, an essential reference in optimizing performance and fuel consumption.

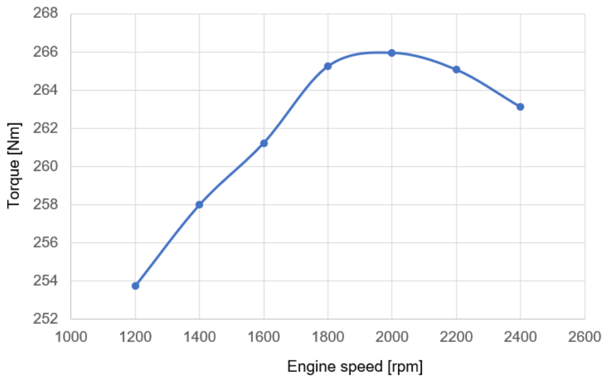

Figure 4: Torque

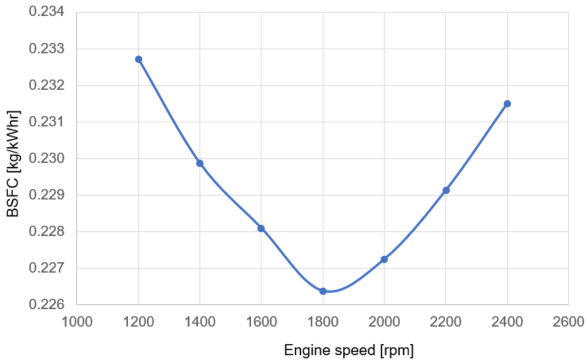

Figure 5: Brake Specific Fuel Consumption

Figure 6 shows the relationship between engine speed and ignition delay period in crankshaft degrees (°CA). The higher the engine speed, the ignition delay period tends to increase, starting from around 5°CA at 1000 rpm to more than 10°CA at 2400 rpm. This increase in ignition delay occurs because, at higher engine speeds, the absolute time (in seconds) for the air and fuel mixture process becomes shorter due to the high frequency of the engine cycle. In addition, the time available for the increase in temperature and pressure in the cylinder before ignition is also reduced, causing the mixture to require more crankshaft degrees to reach autoignition conditions. This condition can affect engine performance because an ignition delay that is too long can cause a sudden increase in peak pressure (premixed combustion), which has the potential to produce engine vibration and increase NOx emissions.
Figure 7 shows the relationship between engine speed and maximum cylinder pressure. The graph shows an increasing trend of maximum pressure as engine speed increases, starting from around 98 bar at 1000 rpm to more than 106 bar at 2400 rpm. This increase indicates that the amount of fuel injected per cycle increases at high speeds. The combustion process occurs more intensively, producing greater heat energy and growing pressure in the chamber. However, there is a slight plateau or stabilization of pressure between 1800 rpm and 2000 rpm, which is likely due to the interaction between the increasing ignition delay and the increasingly limited combustion time at these speeds. This increase in maximum pressure is essential to produce greater engine power. Still, it also needs to be controlled not to exceed the design limits of engine components to prevent mechanical damage and maintain engine life.

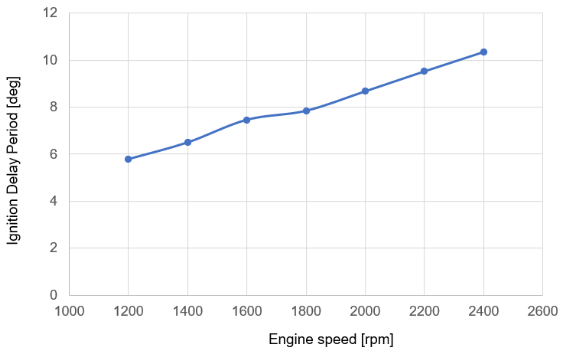

Figure 6: Ignition delay period

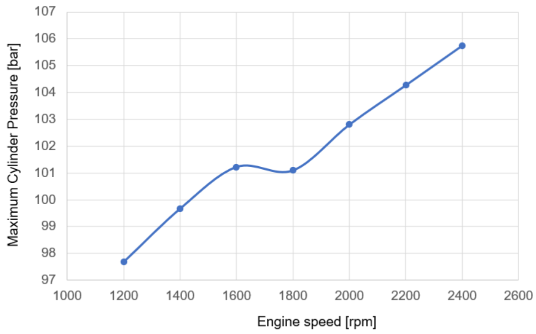

Figure 7: Maximum cylinder pressure

4. Conclusion

This study successfully demonstrated the application of Diesel-RK for one-dimensional simulation of the industrial diesel engine model 4M50. By incorporating detailed engine specifications and calibrating the simulation model with experimental data, the research confirmed that the Diesel-RK framework accurately predicts key engine performance metrics such as in-cylinder pressure, heat release rates, and exhaust emissions. The high level of agreement between simulated outcomes and real-world data underscores the robustness of the modelling approach and its potential utility in engine design and optimization.

References

[1] A. Shekh, K. Patel, N. Patel, B. Pathak, Multi-Parameter Analysis of Low-Capacity CI Engine Powered with Biodiesel from Various Feedstock using Diesel RK Software, J. Heat Mass Transf. Res. 10 (2023) 301–314.

[2] K.A. Olaiya, I.O. Alabi, A.P. Okediji, Performance characteristics of a single-cylinder two-stroke diesel engine using diesel-RK software, (2020).

[3] M.F. Ghazali, S.M. Rosdi, Erdiwansyah, R. Mamat, Effect of the ethanol-fusel oil mixture on combustion stability, efficiency, and engine performance, Results Eng. 25 (2025) 104273. https://doi.org/https://doi.org/10.1016/j.rineng.2025.104273.

[4] S.M.M. Rosdi, Erdiwansyah, M.F. Ghazali, R. Mamat, Evaluation of engine performance and emissions using blends of gasoline, ethanol, and fusel oil, Case Stud. Chem. Environ. Eng. 11 (2025) 101065. https://doi.org/https://doi.org/10.1016/j.cscee.2024.101065.

[5] I. Sinha, A. Datta, B.K. Mandal, Numerical Investigation on Energetic, Combustion, and Emissions Parameters of a Diesel Engine Fueled With Diesel/Butanol and Diesel/Pentanol, J. Therm. Sci. Eng. Appl. 16 (2024).

[6] D. Li, M. Ikram, J. Xiaoxia, A brief overview of the physical layer test system: Development of an IoTbased energy storage and electrical energy distribution system, Int. J. Eng. Technol. 1 (2025) 131–140.

[7] M.I. Muzakki, R.K.H. Putro, Greenhouse Gas Emission Inventory at Benowo Landfill Using IPCC Method, Int. J. Sci. Adv. Technol. 1 (2025) 18–28.

[8] M. Nizar, M. Muhibbuddin, W. Maawa, Community Empowerment through the Utilization of Agricultural Waste as Environmentally Friendly Biocoke Fuel, Int. J. Community Serv. 1 (2025) 10–18.

[9] S. Hautala, M. Mikulski, E. Söderäng, X. Storm, S. Niemi, Toward a digital twin of a mid-speed marine engine: From detailed 1D engine model to real-time implementation on a target platform, Int. J. Engine Res. 24 (2023) 4553–4571.

[10] G. Maghfirah, A.F. Yusop, Z. Zulkifli, Using VOSviewer for Renewable Energy Literature Analysis: Mapping Technology and Policy-Related Research, Int. J. Eng. Technol. 1 (2025) 83–89.

[11] A. Rao, W. Li, M.S. Abbasi, M.I. Shahid, M. Farhan, S. Zulfiqar, T. Chen, F. Ma, X. Li, Machine learning-enhanced combustion modeling for predicting laminar burning velocity of ammonia-hydrogen mixtures using improved reaction mechanisms, Energy. (2025) 135259. https://doi.org/https://doi.org/10.1016/j.energy.2025.135259.

[12] P. Selvakumar, A. Gani, J. Xiaoxia, M.R. Salleh, Porosity and Pore Volume Analysis of EFB Fiber: Physical Characterization and Effect of Thermal Treatment, Int. J. Eng. Technol. 1 (2025) 100–108.

[13] C.H.E.W.A.N.M. NOOR, F. Arif, D. Rusirawan, Optimising Engine Performance and Emission Characteristics Through Advanced Simulation Techniques, Int. J. Simulation, Optim. Model. 1 (2025) 10–20.

[14] F. Mihalič, M. Truntič, A. Hren, Hardware-in-the-loop simulations: A historical overview of engineering challenges, Electronics. 11 (2022) 2462.

[15] M. Muhibbuddin, M.A. Hamidi, D.F. Fitriyana, Bibliometric Analysis of Renewable Energy Technologies Using VOSviewer: Mapping Innovations and Applications, Int. J. Sci. Adv. Technol. 1 (2025) 81–91.

[16] N. Khalisha, I. Caisarina, S.Z. Fakhrana, Mobility Patterns of Rural Communities in Traveling Traveling from The Origin Area to the Destination, Int. J. Sci. Adv. Technol. 1 (2025) 108–119.

[17] I. Iqbal, S.M. Rosdi, M. Muhtadin, E. Erdiwansyah, M. Faisal, Optimisation of combustion parameters in turbocharged engines using computational fluid dynamics modelling, Int. J. Simulation, Optim. Model. 1 (2025) 63–69.

[18] U. Rajak, P. Nashine, T.S. Singh, T.N. Verma, Numerical investigation of performance,

combustion and emission characteristics of various biofuels, Energy Convers. Manag. 156 (2018) 235–252. https://doi.org/https://doi.org/10.1016/j.enconman.2017.11.017.

[19] B. Dağ, S. Aydın, R. Şener, Investigating the influence of heterocyclic Schiff bases as a biofuel additive on combustion, performance and emissions, Case Stud. Therm. Eng. 67 (2025) 105836. https://doi.org/https://doi.org/10.1016/j.csite.2025.105836.

[20] M. Bastani, S. Tabejamaat, M. Mani, H. Ashini, Numerical and experimental investigation of microturbine combustion chamber performance and emissions through biogas consumption with varied component ratios, Fuel. 380 (2025) 133234. https://doi.org/https://doi.org/10.1016/j.fuel.2024.133234.

[21] M. Muhtadin, S.M. Rosdi, M. Faisal, E. Erdiwansyah, M. Mahyudin, Analysis of NOx, HC, and CO Emission Prediction in Internal Combustion Engines by Statistical Regression and ANOVA Methods, Int. J. Simulation, Optim. Model. 1 (2025) 94–102.

[22] Y. Shi, R.D. Reitz, Multi-dimensional Modelling of Diesel Combustion: A Review, Model. Diesel Combust. (2022) 279–319.

[23] Z. Liu, Y. Zhang, J. Fu, J. Liu, Multidimensional computational fluid dynamics combustion process modeling of a 6V150 diesel engine, J. Therm. Sci. Eng. Appl. 14 (2022) 101009.

[24] K. Kohse-Höinghaus, Clean combustion: Chemistry and diagnostics for a systems approach in transportation and energy conversion, Prog. Energy Combust. Sci. 65 (2018) 1–5. https://doi.org/https://doi.org/10.1016/j.pecs.2017.10.001.

[25] H.A. Jalaludin, M.K. Kamarulzaman, A. Sudrajad, S.M. Rosdi, E. Erdiwansyah, Engine Performance Analysis Based on Speed and Throttle Through Simulation, Int. J. Simulation, Optim. Model. 1 (2025) 86–93.