Journal of Mines, Metals and Fuels, *73(7): 2221-2231; 2025. DOI: 10.18311/jmmf/2025/49185*

Print ISSN : 0022-2755

Journal of Mines, Metals and Fuels

Contents available at: *www.informaticsjournals.co.in/index.php/jmmf*

Optimizing Diesel Engine Combustion Performance and Emissions with Diesel-RK Software Simulation

Samkit Shah[1,2]* and Nimit Patel[3]

[1]Department of Automobile Engineering, Parul University, Vadodara - 391760, Gujarat, India; Samkitshah9999@gmail.com

[2]Department of Automobile Engineering, AD Patel Institute, CVM University, Anand - 388121, Gujarat, India

Abstract

As technology and computer science continue to evolve rapidly, the application of computational tools in engine dynamics has become increasingly streamlined. However, commercial software solutions are often costly, making them inaccessible to independent researchers and scientists in developing regions. In light of this, Diesel Rendering Knowledge (Diesel RK) proves to be a highly beneficial tool for early-career researchers, offering an open-source alternative capable of simulating the thermodynamics and combustion processes of diesel engines. This paper outlines the findings from utilizing Diesel RK to model the combustion and fuel injection processes in a single-cylinder diesel engine operating with a uniform diesel fuel mixture with rate 2.

***Major Findings:** The study demonstrates that Diesel-RK software is an effective and affordable tool for simulating and optimizing diesel engine performance and emissions. Simulations on a single-cylinder engine revealed that engine speed greatly influences efficiency, power output, and emission levels, with optimal performance observed around 2000 RPM. However, higher speeds led to increased emissions, highlighting the trade-off between performance and environmental impact.*

Keywords: *Combustion Chamber, Diesel Engine, Diesel-RK, Power, Pressure, Simulating Combustion, Temperature*

1.0 Preamble

In Compression Ignition (CI) engines, only air is drawn in to the cylinder during the intake stroke. Fuel typically a light fuel oil, though in marine and power generation applications, heated residual fuel is also used is injected directly into the combustion chamber just before ignition occurs.

Engine load is regulated by varying the amount of fuel injected per cycle, while the air flow remains relatively stable at a given engine speed[1].

CI engines are designed in various configurations and are widely used in automobiles, trucks, locomotives, marine vessels, and power generation systems.

One of the most significant challenges for modern four-stroke, high-speed diesel engines is minimizing pollutant emissions while maintaining performance, keeping dimensions compact, and controlling production costs, which are already higher than those of comparable Spark Ignition (SI) engines[1].

A compelling approach to balancing the conflicting demands of engine performance, efficiency, and emissions is the use of a two-stroke cycle combined with compression ignition. This design is widely adopted in large-bore engines, particularly in stationary power plants and naval applications, where maximizing power density and fuel conversion efficiency sometimes exceeding 50% is essential[2].

*Author for correspondence

One of the key advantages of the two-stroke cycle is its ability to operate at twice the frequency of a four-stroke engine. This allows engineers to either reduce the engine's displacement while maintaining the same power output ("downsizing") or lower the engine speed for a given power requirement ("down-speeding")[3]. Additionally, mechanical efficiency is significantly enhanced for two main reasons. First, the gas exchange process is managed through piston-controlled ports, eliminating the energy losses associated with traditional valve trains[4].

Second, since the mechanical power lost per cycle is nearly half that of a comparable four-stroke engine, the overall mechanical losses are lower, even when producing the same indicated power. Unfortunately, the two-stroke technology used in stationary and naval power plants cannot simply be scaled down for smaller bore engines due to several challenges[5]. First, as engine speed increases, combustion characteristics particularly ignition delay change significantly.

Direct Injection (DI) diesel engines, including PCCI configurations and engines running on biofuels.

Spark Ignition (SI) gasoline engines.

SI gas engines, featuring pre-combustion chamber systems, capable of running on different gas types such as methane, propane-butane, biogas, and synthetic gas.

Two-stroke engines, both reversible and non-reversible, as well as reciprocating piston engines like OP motors (Junkers) and OPOC engines.

Dual-fuel engines, equipped with independent fuel injection systems for different fuel types, including RCCI (Reactivity Controlled Compression Ignition) engines.

Diesel-RK features an advanced "Fuel Spray Visualization" module, which enables the simulation results to be presented as animations. This functionality helps model the interaction between fuel sprays and the combustion chamber walls, as well as assess swirl intensity and spray distribution in adjacent areas[6,7]. The visualization tool plays a crucial role in optimizing key design parameters, such as the shape of the piston crown, the number and diameter of nozzle holes, and the direction and angle of fuel injection. It also allows adjustments based on specific swirl intensity levels to enhance combustion efficiency[8]. The simulation results can be exported in multimedia formats compatible with Windows, including AVI or GIF animations. Additionally, the generated visuals can be saved as 2D or 3D images for further analysis[9].

2.0 Scope of Application for Diesel-RK Software

The software can be utilized to address a wide range of challenges in diesel engine analysis and optimization, including[10].

- Predicting torque curves and overall engine performance.
- Forecasting and optimizing fuel consumption for improved efficiency.
- Analyzing and refining combustion and emission processes to enhance environmental performance.
- Detecting and predicting engine knock to prevent damage and ensure smooth operation.
- Optimizing valve timing to maximize engine efficiency and performance.
- Evaluating and fine-tuning the Exhaust Gas Recirculation system for better emission control.
- Enhancing the synergy between turbo charged turbines and emission systems to improve efficiency and reduce pollutants.
- Researching and optimizing fuel spray characteristics, including nozzle configuration, spray shape, injection position, and piston crown design.
- Converting diesel engines to run on gas, enabling flexibility in fuel choices.
- Analyzing and optimizing dual-fuel engine performance, ensuring seamless operation across different fuel types.

3.0 Current Implementation of Diesel-RK in Kirloskar Engines

Conducted an analysis of a Kirloskar TV-1dieselengine, as low-speed, turbocharged, two-stroke engine featuring direct fuel injection. Their research focused on evaluating how varying engine loads influence key operating parameters and efficiencies[11]. The study found that the highest mechanical efficiency of 94.52% was achieved at full engine load (100%). Meanwhile, the peak indicated

efficiency of 52.70% and the highest effective efficiency of 49.34% were recorded at 75% engine load. As the engine load increased, the mean effective pressure rose steadily, starting from 2 bars at the lowest load and reaching 5 bars at the highest[11].

Additionally, the engines effective torque ranged from 2Nm at the lowest load to 4Nm at maximum load-values that align with expectations for this type of diesel engine. The specific effective fuel consumption was observed between 180g/hp and 190g/hp, reinforcing the fact that marine two-stroke diesel engines boast the lowest specific effective fuel consumption among all diesel and internal combustion engines[12].

Compared to other types of internal combustion engines, two-stroke diesel engines exhibit significantly higher effective efficiency, often exceeding 50%.

However, while the previous study primarily examined the impact of engine load, the present research shifts focus to investigating how engine speed affects key performance parameters[13].

4.0 Develop Simulation Model

The Kirloskar TV1 model was chosen for the Diesel-RK simulation due to its well-defined specifications and suitability for analysis. It is a single-cylinder, four-stroke diesel engine, featuring water cooling and delivering a power output of 5.2 kW (7 BHP) at 1500 rpm[14].

The engine has a bore diameter of 87.5 mm and a stroke length of 110 mm, with a compression ratio of 17.5:1 and a total displacement of 661 cc. These characteristics make it an ideal candidate for evaluating combustion performance and optimizing operational efficiency using the Diesel-RK model[15].

5.0 Conducting the Experiment

The current research focuses on an experimental evaluation of diesel fuel performance in a single-cylinder internal combustion engine under five distinct load conditions. The operational efficiency and emission characteristics of the engine test set up are significantly influenced by the type of fuel utilized[16].

Table 1. Input engine data[15]

Parameter	Specification
Manufacturer	Kirloskar Diesel Power Unit TV-1
Engine category	Four-stroke compression ignition engine
Cylinder count	Single-cylinder
Diameter × Stroke length	70 × 100 mm
Adjustable compression ratio	12:1 to 19:1
Maximum output power	3.7 kW @ 1500 RPM
Load measurement system	Electric alternating current generator
Fuel injection orifice size	0.15 mm
Fuel injection pressure range	200-220 bar
Heat dissipation mechanism	Air-based cooling
Combustion chamber structure	Hemi spherical design
Fuel injector quantity	One
Valve mechanism	Two-valve, four-stroke cycle
Primary injector nozzle size	0.19 mm
Primary injection pressure	800-1000 bar
Forced induction system	Yes (supercharged)
Secondary compression stage	Present
Secondary injector nozzle size	0.0684 mm

Before data collection, the engine undergoes an initial warm-up phase and is allowed to stabilize to ensure accurate readings.

Each measurement is recorded three times to obtain are liable and consistent dataset[17]. Key performance indicators such as Brake Thermal Efficiency (ηB.Th.), Brake Specific Fuel Consumption (BSFC), Exhaust

Table 2. Table properties[20]

Property of Diesel-02	Value
Carbon content	0.87 %
Hydrogen content	0.126 %
Oxygen content	0.004 %
Sulfur content	0.025 %
Lower heating value (MJ/kg)	42.5 MJ/kg
Cetane number	48
Fuel density (kg/m^3)	830 kg/m^3
Surface tension (N/m)	0.028 N/m
Dynamic viscosity (Pa.s)	0.003 Pa.s
Molar mass (kg/kmol)	190 kg/kmol

Gas Temperature (EGT), and Volumetric Efficiency (ηVol.) are analyzed. Additionally, emission parameters, including Carbon Monoxide (CO), Carbon Dioxide (CO2), and Nitrogen Oxides (NOx), are systematically assessed to determine the environmental impact of the engine's operation[18].

5.1 Diesel-RK Simulation

5.1.1 Diesel-RK Simulation Process

Step 1: Launch the software and begin by defining the fundamental engine specifications. This includes selecting the engine type (diesel or gasoline) and specifying whether it operates on a two-stroke or four-stroke cycle.

Next, configure the engine's structural details, such as the cylinder arrangement and cooling mechanism[19]. Essential engine parameters must also be established, including piston stroke (S), cylinder bore (D), compression ratio, and engine speed. Additionally, input the surrounding environmental conditions, such as ambient temperature and atmospheric pressure. If applicable, parameters for the turbocharger and inter cooling system should also be specified to ensure accurate simulation result[20].

Step 2: Define the engine specifications, adjustment settings, and operational parameters. To configure these details, navigate through the main menu and access the "Engine Parameters" section. This section encompasses multiple modules, including engine design, where key attributes of the engine are specified. Each parameter must be carefully set to ensure accurate modeling and simulation of engine performance under different conditions[21].

5.1.2 General Parameters

This section provides a comprehensive description of the fundamental engine characteristics and components. Key specifications such as bore size, stroke length, compression ratio, and nominal operating speed are defined here. Additionally, details related to the cooling system, friction loss calculations, and heat exchanger parameters are specified[22,23].

5.1.3 Fuel Injection System and Combustion Chamber

In this section, essential parameters for mixture formation and combustion calculation in diesel and forced combustion engines must be entered. This includes defining fuel injection system attributes, combustion chamber characteristics, and other crucial settings that influence engine performance[23].

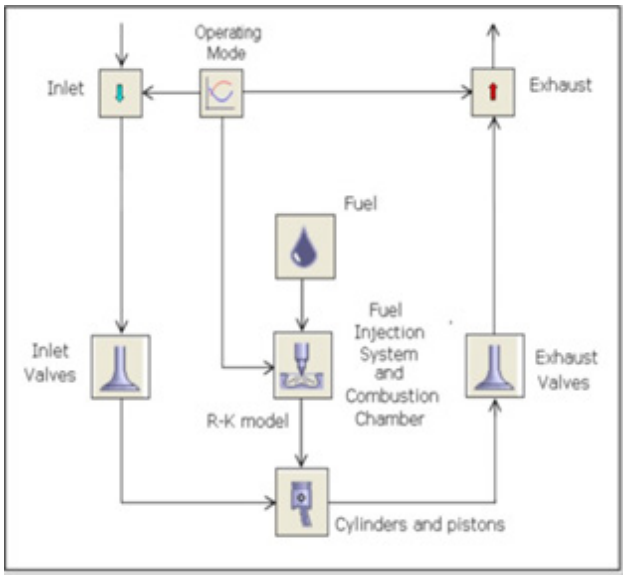


Figure 1. Input operating mode.

5.1.4 Gas Exchange System

Configure intake and exhaust parameters, including valve timing, port design, and pipe structure for optimal airflow.

5.1.5 Fuel Properties

Select fuel type and input its properties to define combustion characteristics.

5.1.6 Operating Mode

Set engine speed, fuel injection per cycle, injection timing, pressure, and ambient temperature for accurate performance simulation. A supercharger delivers a consistent boost across the RPM range but does not smooth out the power curve of a diesel engine[23]. However, it has higher parasitic losses and is less efficient than a turbocharger, which is also more compact and lightweight. Turbocharger sutilize exhaust gases to spin a turbine and compressor fan, while superchargers are engine-driven *via* a belt and gear system[24,25]. Once all parameters were defined, a Kirloskar diesel engine model was developed using Diesel-RK software, as illustrated in Figure 2.

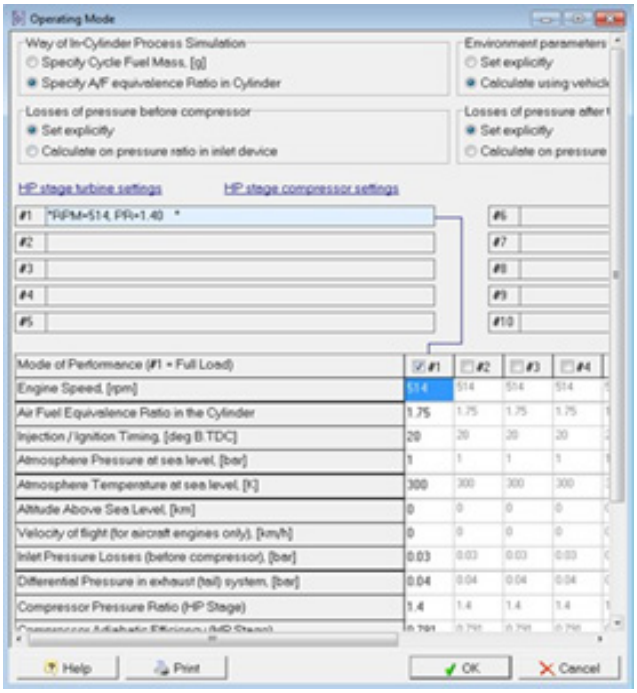


Figure 2. Save the project and observe the outcomes[25].

6.0 Findings and Analysis

By simulating the prepared engine model, various theoretical and analytical parameters of the Kirloskar diesel engine were obtained using Diesel-RK. The recorded data includes engine performance metrics across different RPMs, compression ratios, and loading conditions[26].

These results enabled comparative analysis by examining variations in RPM, compression ratio, and engine load. Following the simulation in Diesel-RK, key performance indicators such as piston engine power (kW), brake torque, piston engine efficiency, indicated

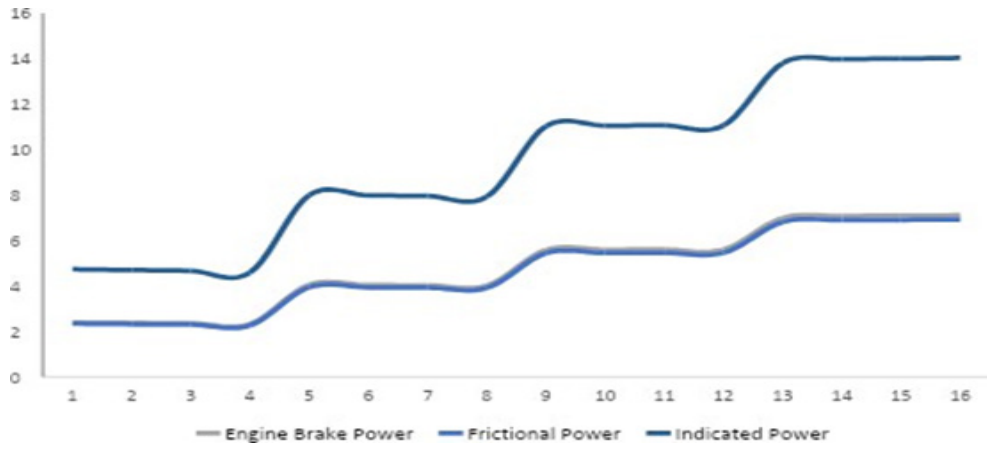


Figure 3. RPM *vs* CR *vs* BP *vs* FP *vs* IP.

Table 3. Reading Table 1 of DIESEL-RK

Test Run	Engine Speed	Comp Ratio	Engine Brake Power	BMEP	Torque	Brake Fuel Consume	Frictional Power	Indicated Power	Indicated Mean Pr	Mechanical Eff.	Vol. Eff	Bosch No.	Particul. Matter	CO_2	NoX-Wet	Nox-Dry
Unit	rpm	/	KW	bar	Nm	kg/kWh	KW	KW	bar	%	%	_	g/kwh	g/kwh	ppm	ppm
1	1000	15	2.3916	7.4745	22.92	0.3017	2.3423	4.7339	10.563	0.8538	0.8512	1.4646	0.43924	972.02	951.9	13.95
2	1000	16	2.3812	7.4224	22.74	0.3034	2.3197	4.7009	10.551	0.8549	0.8495	1.4703	0.44208	977.77	1017.2	14.96
3	1000	17	2.3621	7.3649	22.57	0.3061	2.3023	4.6644	10.537	0.8499	0.8471	1.4617	0.44178	986.41	1122.5	16.618
4	1000	18	2.3243	7.2476	22.197	0.31016	2.2658	4.5901	10.449	0.8451	0.84801	1.6047	0.39508	999.9	1030.9	15.424
5	1500	15	4.0492	8.4173	25.78	0.27548	3.9472	7.9964	11.688	0.85781	0.87368	0.91557	0.22964	887.64	850.1	11.377
6	1500	16	4.0417	8.4017	25.732	0.27551	3.9399	7.9816	11.723	0.85444	0.8725	0.91257	0.22837	887.65	908.18	12.127
7	1500	17	4.0307	8.3789	25.662	0.275994	3.9293	7.9600	11.734	0.85101	0.87116	1.1015	0.29022	889.15	976.92	13.039
8	1500	18	4.014	8.3441	25.556	0.27652	3.9129	7.9269	11.743	0.84744	0.86985	1.1038	0.29134	891.01	1084.1	14.471
9	2000	15	5.5852	8.7077	26.669	0.26852	5.4446	11.0298	12.181	0.84972	0.88143	0.83222	0.20305	865.25	710.55	9.2756
10	2000	16	5.5968	8.7258	26.725	0.26912	5.4559	11.0527	12.258	0.84678	0.87993	0.80955	0.19532	862.29	790.98	10.266
11	2000	17	5.604	8.7371	26.759	0.267	5.4630	11.0670	12.314	0.84399	0.87913	0.79312	0.18981	860.33	860.47	11.118
12	2000	18	5.6016	8.7332	26.76	0.26677	5.4605	11.0621	12.361	0.84093	0.87796	0.78638	0.18746	859.6	913.11	11.766
13	2500	15	6.9914	8.7201	26.707	0.27017	6.8154	13.8068	12.404	0.8382	0.88783	0.9122	0.22934	870.55	581.92	7.6379
14	2500	16	7.0762	8.8259	27.031	0.26671	6.8981	13.9743	12.58	0.83651	0.88701	0.65664	0.151919	859.39	685.52	8.8709
15	2500	17	7.088	8.8406	27.076	0.26588	6.9096	13.9976	12.656	0.83365	0.88569	0.63599	0.14549	856.72	744.76	9.59
16	2500	18	7.1079	8.8654	27.152	0.26479	6.9290	14.0369	12.726	0.83112	0.88467	0.62164	0.14081	853.2	833.01	10.661

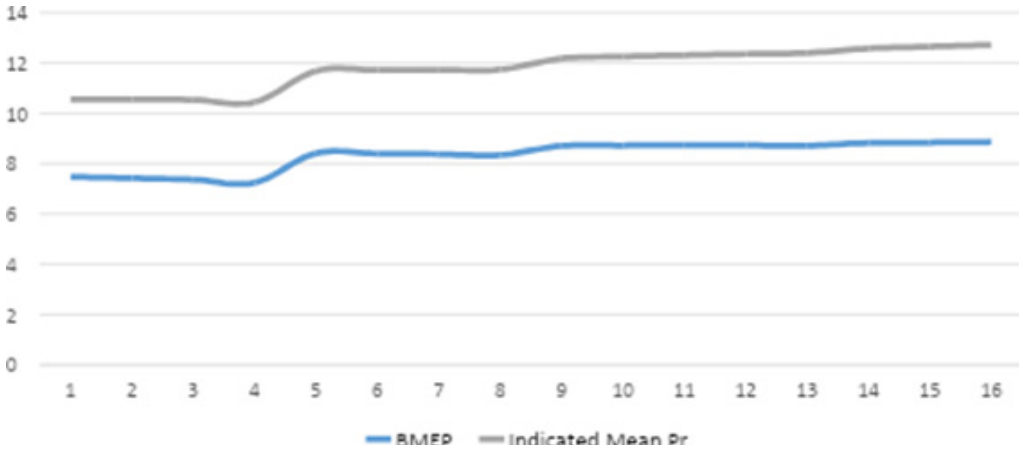


Figure 4. RPM *vs* CR *vs* BMEP.

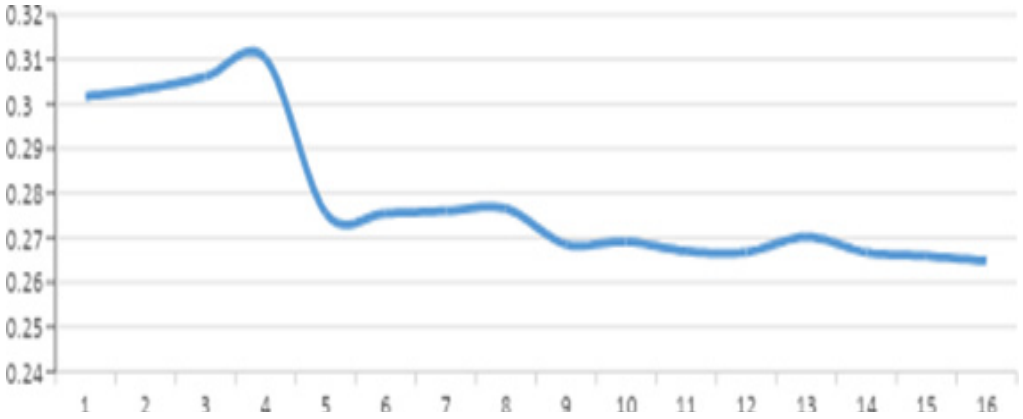


Figure 5. RPM *vs* CR *vs* BFPS.

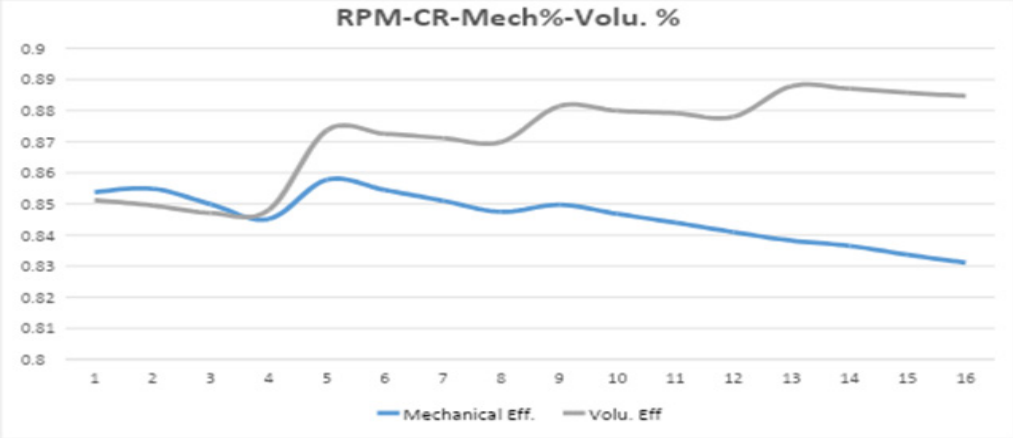


Figure 6. RPM *vs* CR *vs* Mech% *vs* Volu%.

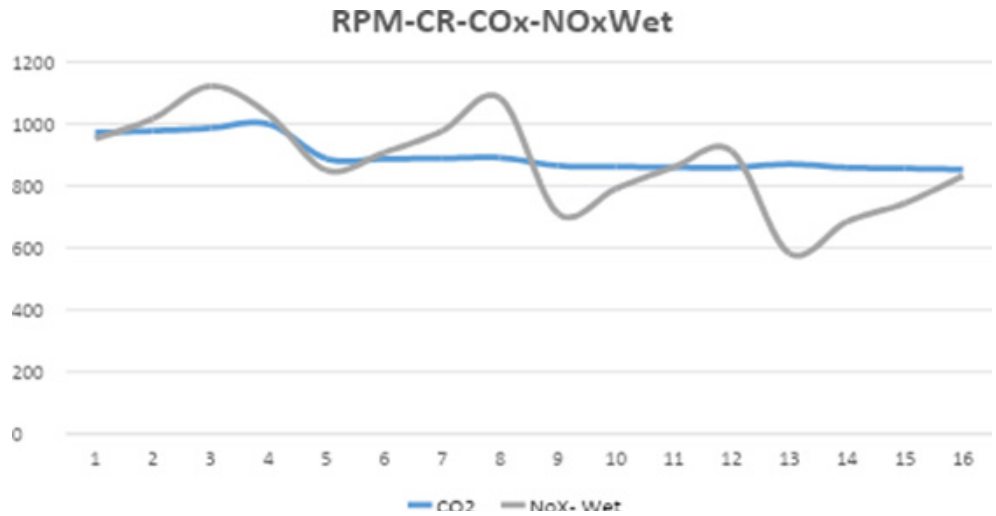


Figure 7. RPM *vs* CR *vs* COx *vs* NOx.

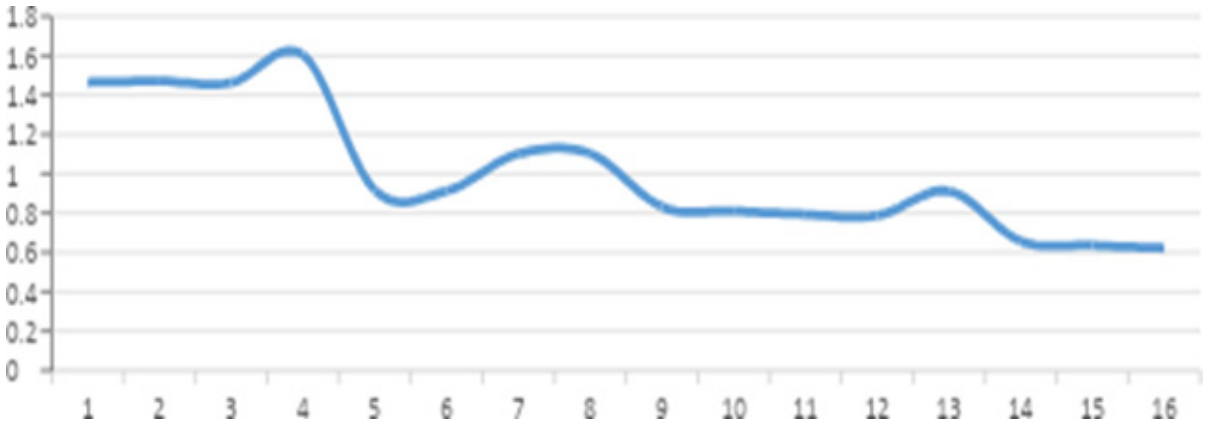


Figure 8. RPM *vs* CR *vs* Bosch no.

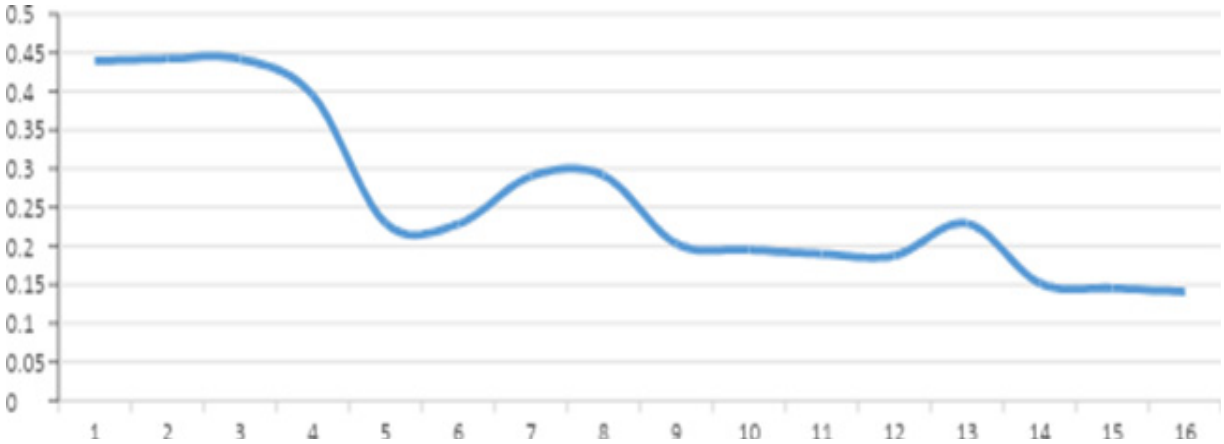


Figure 9. RPM vs CR *vs* Particulate.

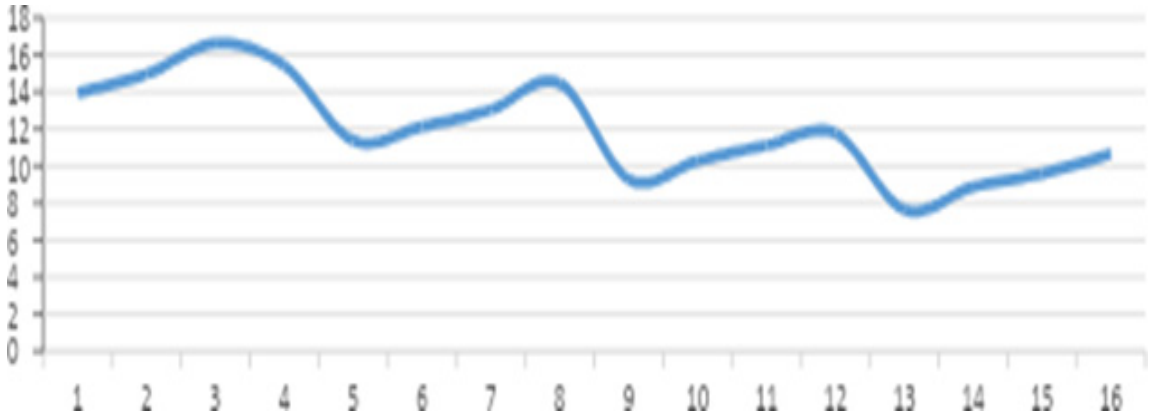


Figure 10. RPM *vs* CR *vs* NOx dry.

efficiency, mechanical efficiency, maximum cylinder pressure, Bosch smoke number, and emission levels (CO_2g/kWh, NOg/kWh, SO_2) were evaluated[27].

7.0 Overall Findings

The impact of engine speed on key performance parameters plays a crucial role in the commercial production of diesel engines. This study explores the application of Diesel-RK in analyzing the performance characteristics of a single-cylinder, two-stroke, turbocharged Kirloskar diesel engine with direct fuel injection. Numerical simulations were conducted at four distinct engine speeds-1000, 1500, 2000, and 2500 rpm-to assess their influence on various performance metrics.

The highest specific fuel consumption and engine efficiency, recorded at 0.31053kg/kWh and 0.26486, respectively, were observed at engine speeds of 1000 rpm and 2500 rpm. The greatest power output occurred at 2500 rpm, attributed to the maximum engine torque at this speed. Cylinder pressure showed a significant rise with increasing engine speed, reaching 2.0451 bar at Inlet Valve Closing (IVC), 3.7801 bar at Exhaust Valve Opening (EVO), and 60.141 bar at Top Dead Center (TDC). This trend suggests that as the piston moves from Bottom Dead Center (BDC) to TDC during compression, pressure builds up to the level required for combustion before decreasing when the exhaust valve opens. Additionally, optimal cylinder temperature values at 2500 rpm were recorded at 1822 K (IVC), 1790 K (EVO), and 1687 K (TDC), demonstrating a notable increase with engine speed.

Engine speed had a notable effect on heat exchange parameters, with values increasing as speed rose. In terms of environmental impact, both the Bosch number and Hartridge smoke level were significantly affected, indicating a rise in smoke emissions and soot concentration as engine speed increased. Additionally, combustion parameters were highly influenced, as higher engine speeds accelerated the heating rate of the combustion chamber during cranking. Turbo charging and gas exchange parameters exhibited a steady increase from 1000 rpm to 2000 rpm but showed a decline at 2500 rpm.

As engine speed rises, the heat transfer coefficient in the intake manifolds decreases, while that in the intake port increases. Similarly, engine speed affects exhaust system parameters, with the exhaust manifold's heat transfer coefficient remaining constant due to thermal equilibrium, where as the exhaust port's heat transfer coefficient increases. This also leads to a rise in Lustrous numbers[28].

These findings highlight the critical role of engine speed in evaluating performance parameters, with optimal values observed at 2000rpm. The findings suggest that numerical simulation serves as a highly effective tool for optimizing and enhancing the performance of internal combustion engines. Rather than repeatedly developing new prototype systems for testing and evaluation, simulations provide a more efficient and cost-effective alternative for performance analysis and refinement[29].

8.0 Data Availability Statement

The raw data for this study were obtained using the Diesel-RK engine simulation software. Any additional data derived from the analysis, which support the study's findings, can be made available upon request by contacting the corresponding author, Samkit Shah.

9.0 References

1. Shaik AA, Reddy SR, Raju VD, Govindarajan M. Combined influence of compression ratio and EGR on diverse characteristics of a research diesel engine fueled with waste mango seed biodiesel blend. Energy Sources A Recovery Util. 2024; 46(1):15608-15631. https://doi.org/10.1080/15567036.2020.1811809
2. Ahmed ZA, Sharma DK. A modelling and analysis of exhaust gas recirculation systems to lower the NOx emission from internal combustion engines: A review on advanced and novel concepts. Int J Renew Energy Technol. 2018; 9(1/2):118. https://doi.org/ 10.1504/IJRET.2018.10011073
3. Chaudhari AJ, Kulkarni V, Sahoo N. State-of-the-art technology in variable compression ratio mechanism for spark ignition engine. Sadhana-Acad P Eng S. 2018; 43(12):1-16. https://doi.org/10.1007/s12046-018-0987-7
4. Fischer M, Kreutziger P, Sun Y, Kotrba A. Clean EGR for gasoline engines- Innovative approach to efficiency improvement and emissions reduction simultaneously. SAE Technical Papers. 2017. https://doi.org/10.4271/2017-01-0683
5. Galindo J, Dolz V, Serrano JM, Bernal MA, Odillard L. Impacts of the Exhaust Gas Recirculation (EGR) combined with the regeneration mode in a compression ignition diesel engine operating at cold conditions. Int J Engine Res. 2021; 22(12):3548-3557. https://doi.org/10.1177/14680874211013986
6. Gondhane S, Goyal K, Shinde A. Exhaust gas recirculation and variable compression ratio effect for rape seed oil methyl ester powered by diesel engine. ICIIIME. 2017; 5(6):1324-1329.
7. Khan IR, Takalkar MK. Study of Variable Compression Ratio Engine (VCR) and different innovations to achieve VCR. IJRASET. 2017; 5(XI):1473-1478. https://doi.org/10.22214/ijraset.2017.11213
8. Lou D, Ren Y, Zhang Y, Sun X. Study on the effects of EGR and spark timing on the combustion, performance, and emissions of a stoichiometric natural gas engine. ACS Omega. 2020; 5(41):26763-26775. https://doi.org/10.1021/acsomega.0c03859
9. Marchitto L, Tornatore C, Valentino G, Teodosio L. Impact of cooled EGR on performance and emissions of a turbocharged spark-ignition engine under low-full load conditions. SAE Technical Papers. 2019. https://doi.org/10.4271/2019-24-0021
10. Mishra RK, Soota T, Singh R. Effect of variable compression ratio on performance of a diesel engine fueled with Karanja biodiesel and its blends. IOP Conf Ser Mater Sci Eng. 2017; 225:012064. https://doi.org/10.1088/1757-899x/225/1/012064
11. Mo YK, Shim JK, Lim DJ. Kinematic structure analysis of variable compression ratio engine mechanisms. Trans KSAE. 2018; 26(2):159-166. https://doi.org/10.7467/KSAE.2018.26.2.159
12. Mohiuddin K, Kwon H, Choi M, Park S. Effect of engine compression ratio, injection timing, and exhaust gas recirculation on gaseous and particle number emissions in a light-duty diesel engine. Fuel. 2021; 294:120547. https://doi.org/10.1016/j.fuel.2021.120547
13. Piqueras P, Morena JD. Sanchis EJ, Pitarch R. Impact of exhaust gas recirculation on gaseous emissions of turbocharged spark-ignition engines. Appl Sci. 2020; 10(21):1-17. https://doi.org/10.3390/app10217634
14. Pohjalainen T, Larmi M. Novel crank mechanism increasing engine efficiency and reducing CO_2 emissions. SAE Technical Papers. 2015. https://doi.org/10.4271/2015-01-1259
15. Rao PG, Prasad LSV. Combined influence of compression ratio and exhaust gas recirculation on the diverse characteristics of the diesel engine fueled with novel palmyra biodiesel blend. Energy Convers Manag X. 2022; 14:100185. https://doi.org/10.1016/j.ecmx.2022.100185
16. Sawarkar, Mohini, Rao SVU, Raj A, Narayana KS, Rao TVH, Naik RT. Effect of variable compression ratio on performance and emissions characteristics of IC engine. IJETT. 2016; 37(6):317-326. https://doi.org/10.14445/22315381/IJETT-V37P256
17. Shah S, Patel N. Performance of internal combustion engine with combine effect of recirculated exhaust gas and variable compression ratio. JMMF. 2025; 73(3):681-694. https://doi.org/10.18311/jmmf/2025/48018
18. Shelat SJ, Patel SM. An experimental investigation of CI engine using environmentally friendly waste plastic fuels and its blends with diesel and nano additives. JMMF, 2025; 73(2):385-400. https://doi.org/10.18311/jmmf/2025/47502

19. Shelat SJ, Patel SM. Performance characteristics of a Compression Ignition (CI) engine using an environmentally friendly waste plastic fuel. JMMF. 2024; 72(9):923-936. https://doi.org/10.18311/jmmf/2024/45074
20. Santhosh M, Padmanaban KP. Experimental investigation on engine performances, combustion characteristics and emission of exhaust gases of VCR engine fuelled with cotton seed oil methyl ester blended with diesel. Int J Green Energy. 2016; 13(14):1534-1545. https://doi.org/10.1080/15435075.2014.977438
21. Sarkan B, Stopka O, Gnap J, Caban J. Investigation of exhaust emissions of vehicles with the spark ignition engine within emission control. Procedia Eng. 2017; 187:775-782. https://doi.org/10.1016/j.proeng.2017.04.437
22. Shen K, Li F, Zhang Z, Sun Y, Yin C. Effects of LP and HP cooled EGR on performance and emissions in turbocharged GDI engine. Appl Therm Eng. 2017; 125:746-755. https://doi.org/10.1016/j.applthermaleng.2017.07.064
23. Su J, Xu M, Li T, Gao Y, Wang J. Combined effects of cooled EGR and a higher geometric compression ratio on thermal efficiency improvement of a downsized boosted spark-ignition direct-injection engine. Energy Convers Manag. 2014; 78:65-73. https://doi.org/10.1016/j.enconman.2013.10.041
24. Szybist JP, Wagnon SW, Splitter D, Pitz WJ, Mehl M. The reduced effectiveness of EGR to mitigate knock at high loads in boosted SI engines. SAE Int J Engines. 2017; 10(5):2305-2318. https://doi.org/10.4271/2017-24-0061
25. Takaki D, Tsuchida H, Kobara T, Akagi M, Tsuyuki T, Nagamine M. Study of an EGR system for downsizing turbocharged gasoline engines to improve fuel economy. SAE Technical Papers. 2014; 1:1199. https://doi.org/10.4271/2014-01-1199
26. Thomas R, Sreesankaran M, Jaidi J, Paul DM, Manjunath P. Experimental evaluation of the effect of compression ratio on performance and emission of SI engine fuelled with gasoline and n-butanol blend at different loads. Perspect Sci. 2016; 8:743-746. https://doi.org/10.1016/j.pisc.2016.06.076
27. Verma S, Das LM, Kaushik SC, Bhatti SS. The effects of compression ratio and EGR on the performance and emission characteristics of diesel-biogas dual fuel engines. Appl Therm Eng. 201; 150:1090-1103. Elsevier Ltd. https://doi.org/10.1016/j.applthermaleng.2019.01.080
28. Zu XH, Yang CL, Wang HC, Wang YY. Experimental study on diesel engine exhaust gas recirculation performance and optimum exhaust gas recirculation rate determination method. R Soc Open Sci. 2019; 6(6). PubMed:31312475. https://doi.org/10.1098/rsos.181907