

EMISSION REDUCTION AND ENGINE PERFORMANCE TRADE-OFF OF METHANOL-ENRICHED DIESEL-BIODIESEL (B10) BLENDS

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ABSTRACT

This work examines how methanol addition influences the performance and exhaust emissions of a diesel engine operating on B10 containing Jatropha biodiesel over 1200–2200 rpm. Methanol was added to the B10 fuel at concentrations of 3–15% by volume. Increasing the methanol fraction caused engine power to decline by approximately 2–9%, whereas brake specific fuel consumption increased by about 3–10%. These changes were mainly associated with the lower energy content and ignition quality of methanol. In contrast, progressively higher methanol contents produced marked reductions in exhaust emissions, with nitrogen oxides (NO_x) decreasing by 2–38%, carbon monoxide (CO) by 15–48%, and particulate matter (PM) by 25–62%. The emission improvement resulted from the combined effects of fuel-bound oxygen, enhanced evaporation, and better fuel–air preparation, which favored oxidation while limiting pollutant formation. Considering both engine performance and emission behavior, methanol concentrations below 10% provided the most suitable compromise under the investigated operating conditions. These findings provide a practical basis for selecting methanol blending levels in diesel–biodiesel fuels and contribute to the development of lower-emission fuel strategies for compression-ignition engines, supporting cleaner and more sustainable engine operation.

Keywords: Diesel-Biodiesel (B10), Methanol, Engine Performance, Exhaust Emissions

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INTRODUCTION

Expansion of the transport sector has intensified fossil-fuel consumption and contributed substantially to environmental deterioration. Pollutants emitted from diesel engines, covering key exhaust pollutants such as PM, NO_x, CO, and hydrocarbons (HC), pose serious risks to human health and ecosystems.¹⁻³ Therefore, tightening emission regulations and identifying effective mitigation strategies have become urgent priorities. Among the available alternatives, biodiesel has received considerable attention as a renewable fuel because of its low toxicity and its potential to reduce CO, HC, and PM emissions, together with lower life-cycle CO₂ emissions.⁴⁻⁶ However, a major drawback of biodiesel is its tendency to increase NO_x emissions, which limits its overall environmental benefit and broader application.⁷⁻⁹ To address this issue, the use of oxygenated additives, particularly methanol, has attracted considerable attention. Owing to its high oxygen content and excellent volatility, methanol can enhance combustion, reduce local flame temperature and consequently lower both NO_x and PM emissions.¹⁰⁻¹² Compared with other alcohols, methanol shows strong potential for improving oxidation efficiency and suppressing soot formation, especially when blended with biodiesel. This combination allows the advantages of each fuel to be utilised while compensating for their individual limitations. Biodiesel, with higher viscosity, improves lubrication properties, whereas methanol promotes fuel evaporation and air-fuel mixing, leading to better combustion quality.¹³⁻¹⁵ Preliminary studies indicate that biodiesel-methanol blends can achieve more effective reductions in NO_x and PM than neat biodiesel, although the impacts on CO and HC depend on blending ratios and operating conditions.¹⁶⁻¹⁸

However, the reported influence of biodiesel–methanol mixtures on engine behavior remains inconsistent because the outcomes depend strongly on operating conditions and blend composition. Quantitative

information describing the simultaneous variation in power, BSFC, and major exhaust pollutants over a wide speed range remains insufficient. In particular, the balance between performance deterioration and emission improvement caused by increasing methanol content in B10 has not been fully established. Accordingly, B10 blends containing 3–15 vol.% methanol were evaluated from 1200 to 2200 rpm. The study aims to determine the effects of methanol concentration on power, BSFC, NO_x, CO, and PM and to identify a blend range that achieves an acceptable compromise between performance and emissions.

EXPERIMENTAL

Combustion Model

In-cylinder combustion was simulated with the AVL MCC (Mixture-Controlled Combustion) framework.¹⁹ Total heat release is represented by the contributions from premixed and mixing-controlled combustion. Fuel-specific properties, including density, viscosity, and heating value, were assigned to each blend so that changes in composition were reflected in the predicted combustion development. The resulting heat-release rate is calculated using Eqn.-1.

$$\frac{dH_{\text{total}}}{d\alpha} = \frac{dH_{PMC}}{d\alpha} + \frac{dH_{MCC}}{d\alpha} \quad (1)$$

Thermal Transfer Model

Thermal interaction between the cylinder gases and the head, piston, and liner was included in the model. Heat transfer at each boundary was determined from the corresponding surface area, heat-transfer coefficient, and gas-to-wall temperature difference, as given in Eqn.-2.

$$H_{wi} = F_i \cdot \lambda_w \cdot (t_c - t_{wi}) \quad (2)$$

Where:

- + H_{wi} : is the heat transferred from the cylinder gas to the corresponding combustion chamber surface;
- + F_i : is the effective heat-transfer area of the considered surface;
- + λ_w : is the convective heat-transfer coefficient, determined using the Woschni 1978 correlation;
- + t_{wi} : is the temperature of the corresponding wall surface.

Pollutant formation was also incorporated into the simulation framework. The emissions submodels included the Onorati formulation for CO, the Pattas–Hafner approach coupled with the Zeldovich mechanism for NO_x, and the Hiroyasu model for PM prediction. After the combustion, heat-transfer, and emission submodels had been defined, the engine specifications and fuel properties were introduced as model inputs for simulation and subsequent result analysis.¹⁹

Engine Model and Studied Fuels

Engine Description

The simulated engine is a naturally aspirated, four-stroke, direct-injection diesel engine with an inline cylinder arrangement. Its bore and stroke are 110 and 125 mm, respectively, with a 230 mm connecting rod and a compression ratio of 16.7:1. Rated speed is 2200 rpm, where maximum power reaches 56 kW, while peak torque is 280 Nm at 1400 rpm. The minimum BSFC is approximately 206 g/kWh. These specifications formed the basis for constructing the AVL BOOST model.

Diesel Engine Model Development

The numerical model was developed in AVL BOOST based on the actual engine geometry, available technical specifications, and experimental operating data. Individual components in the simulation were arranged to reproduce the configuration and flow path of the real engine. The model parameters were subsequently adjusted using the available experimental data to obtain an appropriate representation of engine performance. The resulting engine configuration used in the simulation is illustrated in Fig.-1.

Studied Fuels

In this study, the fuels used include Diesel-Biodiesel blends (B10) and mixtures with added methanol at proportions ranging from 3% to 15% by volume. The base fuel B10 consists of 90% diesel and 10% Jatropha biodiesel oil, a renewable oxygenated fuel that enhances combustion and reduces emissions. Methanol was chosen because its oxygenated nature and favorable evaporation characteristics

can influence combustion and pollutant formation. However, its relatively low heating value and cetane quality may adversely affect engine output and fuel economy. The blends B10, M3, M6, M9, M12, and M15 were therefore examined to determine how increasing methanol concentration alters engine behavior and exhaust emissions.

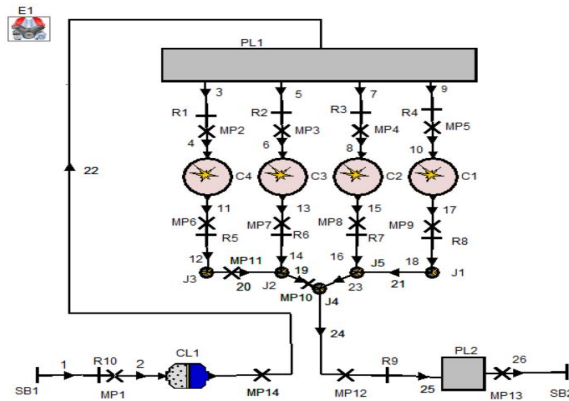


Fig.-1: Diesel-fueled Engine Model

RESULTS AND DISCUSSION

Model Validation

A comparison between the experimental measurements and model predictions of engine power and brake-specific fuel consumption is presented in Fig.-2 and indicates strong agreement across the entire speed range, confirming the reliability of the model. Engine power trends are well captured with deviations below 5%, while BSFC variation is also accurately predicted, with differences ranging from 2.0 to 4.8%. These discrepancies are mainly attributed to model simplifications. Overall, the comparison with published experimental data confirms that the model provides satisfactory accuracy and is suitable for further investigation.¹⁹

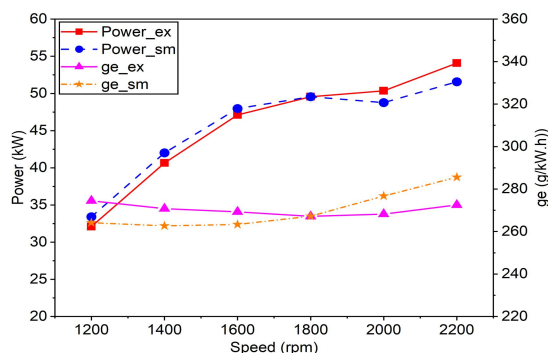


Fig.-2: Variation in Engine Power and Brake-Specific Fuel Consumption Under Diesel Operation

Engine Power and Fuel Consumption Results

Figure-3 shows that adding methanol to B10 fuel leads to a gradual decrease in engine power across the entire speed range. Compared with conventional diesel, B10 reduces power by about 1-2%, while methanol addition from 3-15% results in a more noticeable decrease of approximately 2-9%, especially at medium and high speeds. The observed trend is largely associated with the lower energy content and cetane number of methanol, which reduce combustion energy and delay ignition, along with its high volatility that lowers peak combustion temperature.^{20,21} Despite the power reduction, the oxygenated nature of methanol promotes fuel oxidation and contributes to lower pollutant formation. Therefore, using methanol at appropriate ratios, typically below 10%, is considered a reasonable compromise between performance and environmental benefits.^{21,22}

Figure-4 shows that adding methanol to B10 fuel increases brake specific fuel consumption across the entire speed range. Compared with diesel, B10 causes a slight rise of about 1-2%, while methanol

addition from 3-15% leads to a more significant increase of approximately 3-10%, following a nearly linear trend with blending ratio.

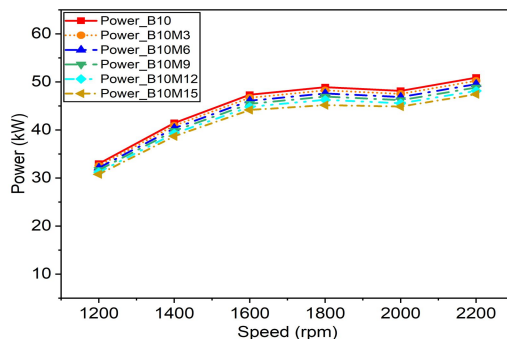


Fig.-3: Variation in Engine Power when Operating with Biodiesel Fuel and Methanol-Added Biodiesel Blends

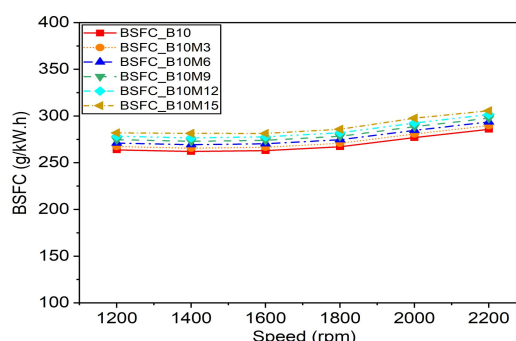


Fig.-4: BSFC Response of B10 to different Methanol Blending Levels

This effect is more pronounced at medium and high speeds, although the minimum BSFC still occurs in the mid-speed range, but at higher values.²⁰⁻²² The rise in BSFC is largely associated with the lower calorific value and cetane number of methanol, which reduce thermal efficiency and delay energy release during combustion. Although its high oxygen content improves combustion, this benefit cannot fully compensate for the reduced fuel energy. Therefore, methanol blending below 10% is recommended to limit BSFC increase while maintaining acceptable engine performance.²⁰⁻²²

Emission Results

Figure-5 shows that adding methanol to B10 fuel significantly reduces NO_x emissions across the entire engine speed range. Compared with diesel, B10 only slightly decreases NO_x by about 1-3%, while methanol addition from 3-15% leads to a more pronounced reduction of approximately 2-38%, especially at high speeds where thermal NO_x formation is dominant. The decline in NO_x is linked to the combined effect of methanol's lower energy content and strong evaporative cooling, which moderate in-cylinder temperature and consequently weaken thermal- NO_x formation.^{22,23}

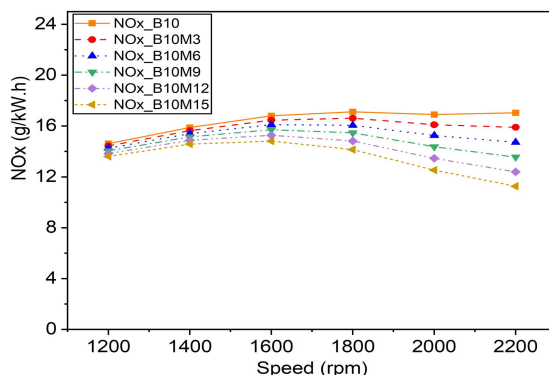


Fig.-5: NO_x Emission Behavior of the Engine Operating on Biodiesel-Methanol Blended Fuels

Its strong evaporation also cools the intake mixture, while the low cetane number prolongs ignition delay, further reducing temperature peaks. Although methanol contains oxygen that can enhance combustion, the cooling effect dominates, resulting in an overall decrease in NO_x . Overall, methanol addition is an effective approach to reduce NO_x emissions, though it should be optimized, typically below 10%, to balance performance and fuel efficiency.²¹

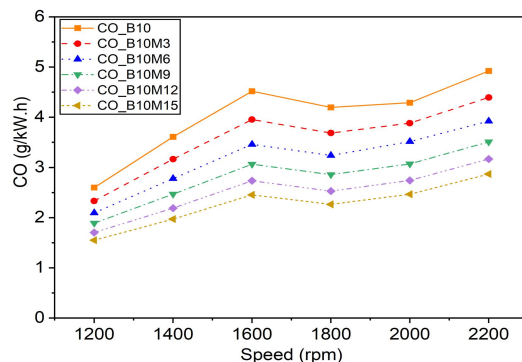


Fig.-6: Effect of Methanol Addition to Biodiesel on Engine CO Emissions

Figure-6 shows that adding methanol to B10 fuel significantly reduces CO emissions across the entire engine speed range. Compared with diesel, B10 lowers CO by about 8-12%, while methanol addition from 3-15% results in a greater reduction of approximately 15-48%, with the strongest effect observed at high speeds.^{21,22} This decline can be primarily explained by the additional oxygen supplied by methanol during combustion, which enhances the oxidation of CO to CO_2 and improves combustion efficiency.²³ Its high volatility also promotes better fuel-air mixing, reducing locally rich zones that typically generate CO.²⁴ Although methanol lowers combustion temperature, the improved oxidation effect dominates, leading to a substantial decrease in CO emissions.²¹ Overall, methanol addition is an effective approach for reducing CO emissions, though blending ratios should be optimized, typically below 10%, to maintain a balance between emission reduction and engine performance.^{22,24}

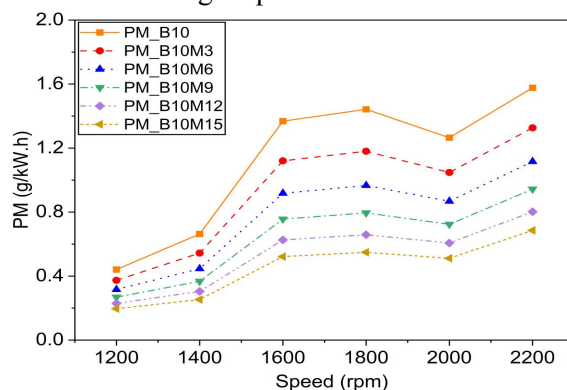


Fig.-7: Effect of Methanol Addition to Biodiesel on Engine PM Emissions

Figure-7 shows that adding methanol to B10 fuel significantly reduces particulate matter emissions across the entire engine speed range. Compared with diesel, B10 lowers PM by about 15-20%, while methanol addition from 3-15% results in a larger reduction of approximately 25-62%, with the most notable effect at high speeds.^{21,22} This trend indicates a nearly linear relationship between methanol ratio and PM reduction.²³ The decrease in PM is mainly due to the oxygen content of methanol, which enhances oxidation of soot precursors and limits particle formation.²⁴

In addition, methanol lacks long carbon chains, reducing the formation of polycyclic aromatic hydrocarbons, and its high volatility improves fuel-air mixing, minimising locally rich regions.^{21,23} Overall, methanol addition is highly effective in reducing PM emissions, though blending ratios should be optimized, typically below 10%, to balance emission benefits with engine performance.^{22,24}

CONCLUSION

Within the investigated range of 1200–2200 rpm, blending 3–15 vol.% methanol with B10 shifted the engine toward lower emissions at the expense of performance. As the methanol fraction increased, engine power decreased by approximately 2-9%, while brake specific fuel consumption rose by about 3-10%. In contrast, substantial reductions were obtained in NO_x, CO, and PM emissions, with decreases of 2-38%, 15-48%, and 25-62%, respectively. The results demonstrate that methanol can enhance the emission characteristics of B10, although excessive blending levels adversely affect engine performance and fuel economy. Considering both aspects, methanol contents below 10% are recommended as a suitable blending range under the investigated conditions. Further optimisation of injection timing and boosting may help compensate for the loss in performance while preserving the emission benefits.

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CONFLICT OF INTERESTS

The authors declare that there is no conflict of interest.

AUTHOR CONTRIBUTIONS

The present work is related to *SDG-7: Affordable and Clean Energy*. All the authors contributed significantly to this manuscript, participated in reviewing/editing and approved the final draft for publication. The research profile of the authors can be verified from their ORCID ids, given below:

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REFERENCES

1. C. P. Onuoha, I. N. Etim and E. E. Oguzie, *Vietnam Journal of Chemistry*, **62**, 421–436(2024), <https://doi.org/10.1002/vjch.202300368>
2. N. V. Tuan, N. P. Truong and N. T. Nghia, *RASAYAN Journal of Chemistry*, **17(4)**, 1436–1443(2024), <http://doi.org/10.31788/RJC.2024.1748845>
3. S. Babamohammadi, A. R. Birss, H. Pouran, J. Pandhal and T. N. Borhani, *Carbon Capture Science & Technology*, **14**, 100379(2025), <https://doi.org/10.1016/j.ccst.2025.100379>
4. J. V. L. Ruatpuia, G. Halder, M. Vanlalchhandama, F. Lalsangpuii, R. Boddula, N. Al-Qahtani, S. Niju, T. Mathimani and S. L. Rokhum, *Fuel*, **370**, 131829(2024), <https://doi.org/10.1016/j.fuel.2024.131829>
5. N. V. Tuan, N. P. Truong and L. D. Hieu, *Discover Applied Sciences*, **7(4)**, 258(2025), <https://doi.org/10.1007/s42452-025-06733-8>
6. A. Suhara, Karyadi, S. G. Herawan, A. Tirta, M. Idris, M. F. Roslan, N. R. Putra, A. L. Hananto and I. Veza, *Clean Technologies*, **6(3)**, 886–906(2024), <https://doi.org/10.3390/cleantechnol6030045>
7. H. Xu and S. Yu, *Journal of Mechanical Science and Technology*, **39(10)**, 6363–6369(2025), <https://doi.org/10.1007/s12206-025-0960-4>
8. H. Valera, S. S. Chauhan, S. Biswas, J. Čedík, M. Pexa and A. K. Agarwal, *Fuel*, **407**, 137025(2026), <https://doi.org/10.1016/j.fuel.2025.137025>
9. D. Tan, Y. Meng, J. Tian, C. Zhang, Z. Zhang, G. Yang, J. Hu and Z. Zhao, *Energy*, **269**, 126785(2023), <https://doi.org/10.1016/j.energy.2023.126785>
10. D. Yang, S. Wei, Y. Ma, J. E and J. Zhao, *Fuel*, **368**, 131647(2024), <https://doi.org/10.1016/j.fuel.2024.131647>

- 11.K. D. Cung, J. Wallace, V. Kalaskar, E. M. Smith III, T. Briggs and D. C. Bitsis Jr., *Fuel*, **357**, 129664(2024), <https://doi.org/10.1016/j.fuel.2023.129664>
- 12.M. Q. Kadhim and P. P. Oshchepkov, *Frontiers in Energy Research*, **12**, 1449652(2024), <https://doi.org/10.3389/fenrg.2024.1449652>
- 13.J. Wei, C. He, C. Fan, S. Pan, M. Wei and C. Wang, *Energy Conversion and Management*, 238, 114121(2021), <https://doi.org/10.1016/j.enconman.2021.114121>
- 14.Y. Wang, G. Xiao, B. Li, H. Tian, X. Leng, Y. Wang, D. Dong and W. Long, *Fuel*, **317**, 123414(2022), <https://doi.org/10.1016/j.fuel.2022.123414>
- 15.M. A. Murugan and N. Ganesan, *Sustainable Energy Technologies and Assessments*, **80**, 104403(2025), <https://doi.org/10.1016/j.seta.2025.104403>
- 16.Y. H. Pu, Q. Dejaegere, M. Svensson and S. Verhelst, *Energies*, **17**(7), 1719(2024), <https://doi.org/10.3390/en17071719>
- 17.Z. Wang, Z. Jie and X. Liu, *Journal of Marine Science and Engineering*, **12**(12), 2210(2024), <https://doi.org/10.3390/jmse12122210>
- 18.J. Dierickx, J. Verbiest, T. Janvier, J. Peeters, L. Sileghem and S. Verhelst, *Fuel Communications*, **7**, 100010(2021), <https://doi.org/10.1016/j.jfueco.2021.100010>
- 19.N. D. Tien and N. V. Tuan, *Cleaner Energy Systems*, **13**, 100248(2026), <https://doi.org/10.1016/j.cles.2026.100248>
- 20.S. Pandey, *Heat Transfer*, **51**(4), 3334–3352(2022), <https://doi.org/10.1002/htj.22453>
- 21.D. Z. Zhou, W. M. Yang, H. An, J. Li and C. Shu, *Energy Conversion and Management*, **89**, 798-807(2015), <https://doi.org/10.1016/j.enconman.2014.10.054>
- 22.Q. H. Hassan and H. Al-Abboodi, *Combustion Engines*, **201**(2), 150-157(2025), <https://doi.org/10.19206/CE-204494>
- 23.N. A. Visan, D. C. Niculescu, R. Ionescu, E. Dahlin, M. Eriksson and R. Chiriac, *Journal of Marine Science and Engineering*, **12**(6), 952(2024), <https://doi.org/10.3390/jmse12060952>
- 24.H. Dave, H. Choksi, C. K. Chan, M. A. Mumtaz and N. Naik, *Global Challenges*, **10**(3), e00546(2026), <https://doi.org/10.1002/gch2.202500546>

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