Evrimata: Journal of Mechanical Engineering
Vol. 01, No. 03, June, 2024, p.63 – 68 e-ISSN: 3025-1265

The Effect of a Mixture of Gasoline and Ethanol in a Direct Injection System Engine on Power and Specific Fuel Consumption

Fina Rizqiani [1], Bambang Irawan [2]✉

[1-2] *Department of Mechanical Engineering, Malang State Polytechnic, Malang , Indonesia*

finarizqiani55@gmail.com, bambang.irawan@polinema.ac.id

Article Information

Manuscript Received 2024-06-20
Manuscript Revised 2024-07-04
Manuscript Accepted 2024-07-06
Manuscript Online 2024-07-06

ABSTRACT

The reliance on fossil fuels as the primary fuel for vehicles poses a significant challenge in the automotive industry due to the dwindling supplies. Renewable fuels present a viable alternative to address this issue, with ethanol being a notable option as a gasoline additive. Derived from plants, ethanol offers promising prospects for energy sustainability. Its high octane value enhances combustion efficiency, potentially yielding optimal engine power. This research explores the impact of gasoline-ethanol mixtures and engine speed on power and specific fuel consumption in direct injection engines. The study involved testing the power output of an electric generator powered by a single-cylinder direct injection engine and measuring fuel consumption during operation. Findings indicate that E10 delivers the best performance at low and medium speeds, achieving maximum power outputs of 0.119 kW and 0.490 kW, respectively. Conversely, E5 excels at high speeds, producing a power output of 0.644 kW. Regarding fuel efficiency, E15 exhibits the lowest specific fuel consumption (SFC) at low speed (3.83 L/kWh), E10 at medium speed (0.96 L/kWh), and E5 at high speed (0.77 L/kWh). In contrast, E20 demonstrates the lowest efficiency across all engine speeds. These findings can inform the design of direct injection engines utilizing fuel blends of gasoline, ethanol, and diesel. This research provides valuable insights into optimizing engine performance and fuel efficiency with renewable fuel mixtures, offering a sustainable solution for the future of the automotive industry.

Keywords: power, specific fuel consumption, ethanol, gasoline, engine speed.

1. INTRODUCTION

Problems and energy sustainability are increasingly pressing. This requires the automotive industry to look for cleaner and more efficient fuel alternatives. The use of fossil fuels as the main fuel for motor vehicles has a number of disadvantages, including a significant contribution to high fuel consumption and power output as well as limited supply [1]. In this context, ethanol emerges as an attractive alternative fuel due to its renewable nature and potential to increase engine efficiency [2].

The research shows that mixing ethanol with gasoline can affect engine performance, including power output and specific fuel consumption (SFC) [3]. Ethanol has a higher-octane number than gasoline, which allows for increased combustion efficiency and reduced engine knock [4]. Additionally, the better cooling properties of ethanol can help reduce combustion temperatures and improve engine thermal efficiency [5].

Direct injection engines have become standard technology in modern vehicles, offering the advantage of more precise fuel injection control, thereby optimizing combustion [6]. In a direct injection engine, fuel is sprayed directly into the combustion chamber at high pressure, allowing better control of combustion and increased fuel efficiency [7]. However, adapting these engines to different fuel mixtures requires a deep understanding of the interaction between the physical and chemical characteristics of the fuel and the engine's operational parameters [8].

In the research of Irawan et al. found that the use of ethanol as fuel can increase engine power and reduce SFC at certain loads [9]. Various studies in the last decade have explored the effects of gasoline and ethanol blends on engine power and specific fuel consumption. As Mohammed et al. who in his research stated that the use of an ethanol-gasoline mixture can increase thermal efficiency and produce higher power in direct injection engines [10]. The study by Tibaquirá et al. also revealed that the addition of ethanol in gasoline can reduce SFC and increase power output under various operating conditions [11].

Abikusna et al. stated that the use of bioethanol with low distillation as a fuel mixture in gasoline engines can increase engine power. This research shows that even low-quality bioethanol can provide significant results in improving engine performance [12]. In his research, Damanik et al. revealed that the biodiesel blends in diesel engine can increase engine power compared. The results of this research indicate that alternative fuel mixtures can increase overall engine efficiency [13]. Jamrozik et al. also researched the effect of diesel-biodiesel-ethanol blends to performance of direct injection diesel engine. His research found that ethanol mixtures at different levels can significantly influence engine power and SFC [14].

Li et al. in his research, he examined various factors that influence combustion, emissions and performance in high-pressure direct injection engines using natural gas fuel. Although the main focus of this research is on natural gas fuel, the power and efficiency improvement mechanisms discovered can be applied to the use of bioethanol [15]. Shylesh et al. analyzing biomass to increase the octane number of renewable fuels, which is important for increasing engine performance with alternative fuel mixtures [16].

Research by Nisak et al. found that ethanol-biodiesel mixtures in diesel engines provide increases in engine power and fuel efficiency. These findings are relevant and can be applied to direct injection engines to understand the impact of using ethanol blends [17]. Further research by Altarazi et al. studied biofuel for alternative fuel and found that biofuel can increase engine power and optimize fuel consumption. This research confirms that biofuel can be an effective alternative in improving engine performance [18].

Kalghatgi in his research analyzed about fuel/engine systems to sustainaible transport. This shows the great potential of using mixed fuels to improve engine performance and fuel efficiency [19]. Ors also reviews bioethanol as an alternative fuel for diesel engines, highlighting various aspects of engine performance and fuel efficiency. This research supports the use of bioethanol as a solution to increase performance and efficiency [20].

Sitorus et al. state that the bioethanol mixture in the otto engine can improve performance and combustion efficiency by reducing specific fuel consumption and engine power [21]. Research by Julianto et al. also shows that a mixture of bioethanol and gasoline can improve the performance of Otto motorbikes, supporting the use of ethanol as an effective fuel mixture [22].

Another study by Ismail et al. found that ethanol can improve combustion efficiency in turbocharged gasoline engines, resulting in a significant increase in power and reduction in SFC [23]. However, challenges remain. Differences in vaporization properties and energy content between gasoline and ethanol can affect combustion characteristics and overall engine performance [24]. Other relevant research was conducted about developing numerical methods to predict heat transfer and the effects of material properties on temperature differences during conduction heat transfer. This method can be applied in the context of fuel temperature optimization to improve engine performance [25].

Further research is needed to determine the optimal ratio of ethanol and gasoline mixture that can provide the best balance between increased engine performance and fuel efficiency. This research topic is particularly relevant in the current scientific context due to increasing pressure from global fuel efficiency regulations and the need for more sustainable energy sources. This study aims to fill the gap in the existing literature by providing comprehensive experimental data on the effects of various ethanol-gasoline blend ratios on direct injection engines. It is hoped that the results of this research will provide useful insights for the development of more efficient and environmentally friendly engine technology, as well as supporting the implementation of ethanol blended fuels on a wider scale.

1.1 Ethanol

Ethanol is an ethyl alcohol compound with the chemical formula C_2H_5OH which is obtained from the fermentation and distillation process of food containing carbohydrates such as; corn, sugar cane, wheat, etc [26]. The physical properties of ethanol are colorless, volatile and flammable. Therefore, ethanol is very suitable for use as fuel [27]. Ethanol is one type of fuel that has the most potential to be developed as an alternative fuel for vehicles, especially in gasoline engines. This is because ethanol has almost the same physical properties and combustion properties as gasoline [28].

1.2 Gasoline

Gasoline is a fossil fuel that is widely used in internal combustion engines. Gasoline is a liquid mixture in the form of hydrocarbon compounds consisting of paraffin, naphthalene and aromatic compounds derived from petroleum. [29]. This liquid is used as fuel for motor vehicles because it has a relatively low boiling point, making it easier to evaporate and burn. The quality of gasoline is determined by the octane index which shows the gasoline's ability to prevent *knocking* in the engine [30].

1.3 Engine Power

Engine power is one of the main indicators of engine performance. Power is produced from the process of burning fuel in the engine cylinder which produces mechanical power [31]. Engine power is the amount of engine performance over a certain period of time [32]. In combustion engines, shaft power is useful for moving loads generated by indicator power. Indicator power is the power obtained from the combustion gas which moves the piston to move all mechanisms [33]. The performance of a combustion engine depends on the power it can produce. The higher the motor rotation frequency, the higher the power it will produce. This is due to the large frequency so that there are more work steps in the same time period [34].

1.4 Specific Fuel Consumption

Specific Fuel Consumption *is* a parameter used in evaluating the fuel efficiency of internal combustion engines [35]. SFC is the amount of fuel needed to produce a certain power over a certain period of time, expressed in liters per kilowatt hour (L/kWh) [36]. SFC is determined by equation 1:

$$SFC = \frac{FC}{P} \tag{1}$$

Where, SFC: specific fuel consumption (L/kWh), FC: fuel consumption (L/hour), P: engine power (kW).

In determining fuel consumption, *the* equation 2.

$$FC = \frac{Vin - Vout}{t} \tag{2}$$

Where, Vin: inlet fuel volume (L), Vout: volume of fuel out (L), t : fuel consumed time (hours).

This research focuses on variations in gasoline-ethanol mixtures and their effects on power and specific fuel consumption. This is purposeful to determine the optimal ethanol-gasoline mixture ratio for direct injection system engines, which can increase power without sacrificing fuel efficiency.

2. RESEARCH SIGNIFICANCE

This research has very important significance in various aspects. The use of ethanol as a mixed fuel is an effort to reduce dependence on the use of fossil fuels. The use of ethanol can also increase sustainability and energy security. This research aims to find the optimal mixture that can increase engine power without sacrificing fuel efficiency, considering that ethanol has a lower energy content per volume than gasoline. An in-depth understanding of the effect of gasoline-ethanol blends on specific fuel consumption (SFC) will help reduce fuel consumption and vehicle operating costs. Empirical data regarding power and fuel consumption of various blends will be important evidence in supporting regulation of the use of alternative fuels.

3. RESEARCH METHODS

3.1 Materials

The materials used in this research were gasoline with RON90, 99% ethanol and the addition of diesel to help reduce pressure at the fuel pump.

3.2 Experimental Setup

This research involved a series of systematic experimental procedures to evaluate the effect of gasoline and ethanol mixtures on power and specific fuel consumption (SFC) in engines with direct injection systems. Before the test is carried out, the fuel to be used is prepared. The mixture of gasoline with RON90, ethanol 99% and diesel is varied at E5 (ethanol 5%, gasoline 89% and diesel 6%), E10 (ethanol 10%, gasoline 84% and diesel 6%), E15 (ethanol 15%, gasoline 79 % and diesel 6%) and E20 (ethanol 20%, gasoline 74% and diesel 6%). Each mixture was homogenized by mechanical stirring to ensure even distribution of ethanol. Next, the test machine, namely a single- cylinder direct injection engine connected to a generator, is prepared. The generator is connected to the lamp as a load. The experimental setup of this research is shown as in **Fig. 1**.

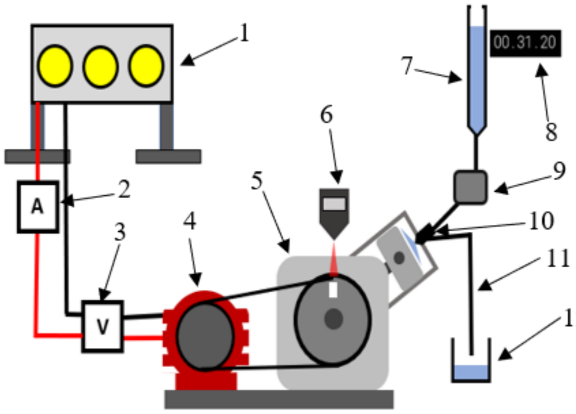

Fig. 1 Experimental Setup

Whereas: 1. Load 2. Ampere Meter 3. Volt Meter 4. Generator 5. Direct Injection Engine 6. Tachometer 7. Burette 8. Stopwatch 9. High Pressure Pump 10. Injector 11. Return Pipe 12. Measuring Cup

Tests are carried out by operating the engine at various load and speed conditions, and data is collected for each test condition and each fuel mixture. Each test was repeated at least three times to ensure repeatability and reliability of the results. The data obtained is analyzed to calculate the specific fuel consumption (SFC) using the relevant formula, and the engine performance is analyzed to evaluate the power and fuel consumption of the specified fuel mixture.

4. RESULTS AND DISCUSSION

After testing various gasoline-ethanol mixtures, the power produced by the generator was measured. The data obtained are shown in **Table. 1**.

Table. 1 Power Test Results Data (kW)

Fuel	Engine Speed (rpm)		
	1300	1600	1900
E5	0.078	0.346	0.628
	0.137	0.306	0.663
	0.092	0.325	0.640
E10	0.092	0.518	0.611
	0.114	0.460	0.677
	0.150	0.491	0.612
E15	0.069	0.361	0.653
	0.085	0.425	0.666
	0.105	0.319	0.554
E20	0.082	0.329	0.615
	0.118	0.423	0.532
	0.069	0.372	0.577

The results of this research show that the power produced by fuel can be influenced by the type of fuel and engine speed. Fuel with a higher ethanol content tends to provide higher power at certain engine speeds. This may be due to the different combustion characteristics of fuels with higher ethanol content. In addition, engine speed also affects the power produced, with some combinations of fuel and engine speed showing higher power than others.

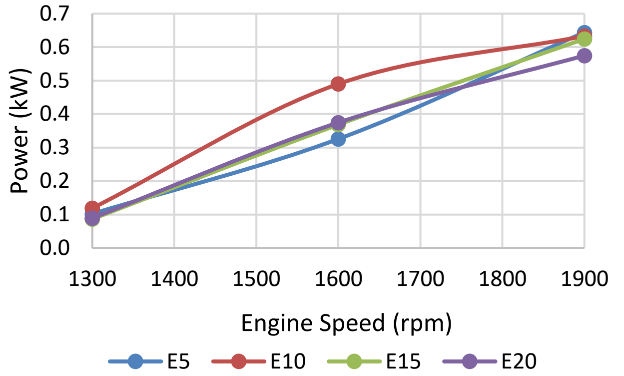

Fig. 2 Correlation of Engine Speed and Power

Fig. 2 shows that E10 fuel produces the highest power at 1300 rpm and 1600 rpm. This shows that this mixture produces more optimal performance under these conditions compared to other mixtures. However, at 1900 rpm, the power produced by the E10 is slightly lower than the E5. E5 fuel produces the highest power at 1900 rpm, but its performance is lower at lower engine speeds (1300 rpm and 1600 rpm).

E15 and E20 fuels generally produce lower power compared to E5 and E10 at all engine speeds. The reduction in power is clearly visible on the E15 and E20 at 1300 rpm and 1600 rpm. This suggests that higher ethanol content may affect combustion efficiency, especially at low engine speeds.

These results indicate that the selection of a mixture of gasoline and ethanol must consider the engine operating conditions, especially the most commonly used engine speeds. The E10 blend offers better performance at low and medium revs, while E5 is superior at high revs. The SFC data obtained is shown in **Table.2**.

Table. 2 SFC Test Results Data (L/kWh)

Fuel	Engine Speed (rpm)		
	1300	1600	1900
E5	5,055	1,179	0.777
	2,543	1,248	0.710
	4,143	1,205	0.828
E10	5,118	0,931	1,182
	3,774	0,974	1,287
	2,780	0,978	1,329
E15	4,970	1,278	0,751
	3,755	1,055	0,762
	2,751	1,556	0,844
E20	4,736	1,521	1,221
	3,231	1,276	1,588
	5,996	1,468	1,317

Table. 2 shows that fuel with a higher ethanol content tends to have a lower SFC at certain engine speeds. This may be due to the different combustion characteristics of fuels with higher ethanol content. Additionally, engine speed also affects SFC, with some combinations of fuel and engine speed showing lower SFC than others .

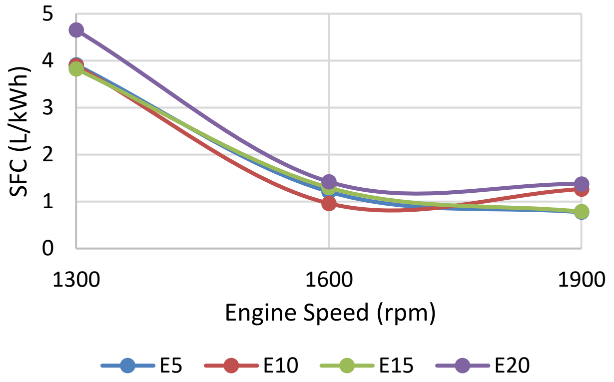

Fig. 3 Correlation of Engine Speed and SFC

Fig. 3 shows that at 1300 rpm, E15 fuel shows the lowest SFC, namely 3.83 L/kWh. Meanwhile, E20 has the highest SFC of 4.65 L/kWh. At 1600 rpm, E10 fuel is the most efficient with the lowest SFC of 0.96 L/kWh, and E20 again shows the lowest efficiency with an SFC of 1.42 L/kWh. E5 fuel shows the highest fuel efficiency at 1900 rpm with the lowest SFC of 0.77 L/kWh, while E20 still has the lowest efficiency with the highest SFC of 1.38 L/kWh.

1 5 fuel has the lowest SFC, but at medium and high revs the required fuel consumption increases. E10 fuel has the lowest SFC at medium revs, but fuel consumption at low and high revs is slightly higher than E5 and E15. The use of E5 fuel produces the lowest SFC at high revs so that E5 fuel is more suitable for operational conditions with high engine revs. Meanwhile, E20 fuel tends to have the highest SFC at all engine speeds. This shows that ethanol content higher than 10% tends to have higher fuel consumption.

The lower temperature of ethanol compared to gasoline causes the compression temperature in the combustion chamber to decrease, so that fuel requirements in the combustion process increase slightly. These results indicate that to reduce fuel consumption, the mixture of gasoline and ethanol must be adjusted to the engine's operational conditions. In addition, the energy in ethanol is lower than gasoline resulting in a decrease in energy in gasoline-ethanol mixtures with a high percentage of ethanol. This decrease in energy has an impact on the power produced and the need for more fuel to produce maximum power.

The constraints of this study encompass several elements. Initially, the investigation employs a single-cylinder diesel engine that has undergone compression pressure modification to operate as a gasoline engine with a direct injection system. Subsequently, the testing concentrates on the specific power and fuel consumption of a single-cylinder direct injection engine. Additionally, the fuel variation includes mixtures of gasoline and ethanol with compositions of E5 (89% Gasoline, 5% Ethanol, and 6% Diesel), E10 (84% Gasoline, 10% Ethanol, and 6% Diesel), E15 (79% Gasoline, 15% Ethanol, and 6% Diesel), and E20 (74% Gasoline, 20% Ethanol, and 6% Diesel). Moreover, the experiments were conducted at engine speeds of 1300 rpm, 1600 rpm, and 1900 rpm. Lastly, the ethanol content in the mixture is 99%, and the gasoline used has a Research Octane Number (RON) of 90.

5. CONCLUSION

The results of this research indicate that the use of E10 fuel offers the best balance between engine power and fuel consumption at medium engine speeds. Meanwhile, E5 fuel is recommended for operational conditions with high engine speeds, and E15 fuel can be used for low speeds. E20 fuel produces low power and the highest SFC at various engine speeds. This shows that adding too much ethanol to the fuel mixture reduces engine performance. Based on these results, E10 fuel is recommended for vehicle applications that operate at various engine speed conditions.

6. ACKNOWLEDGMENTS

The author would like to thank Mr. Bambang Irawan as the supervisor who has helped and provided support to the author in completing this research. Also to fellow thesis tutors who helped the author during the research.

7. AUTHOR CONTRIBUTIONS

Conception and design: Fina Rizqiani, Bambang Irawan
Methodology: Fina Rizqiani
Data acquisition: Fina Rizqiani
Analysis and interpretation of data: Fina Rizqiani
Writing publication: Fina Rizqiani, Bambang Irawan
Approval of final publication: Fina Rizqiani
Resources, technical and material supports: Fina Rizqiani, Bambang Irawan
Supervision: Bambang Irawan

8. REFERENCES

[1] H. Stančin, H. Mikulčić, X. Wang, and N. Duić, "A Review on Alternative Fuels in Future Energy System," *Renewable and Sustainable Energy Reviews*, vol. 128, p. 109927, Aug. 2020, doi: 10.1016/j.rser.2020.109927.

[2] L. Xu, S. Xu, X. Lu, M. Jia, and X. S. Bai, "Large Eddy Simulation of Spray and Combustion Characteristics of Biodiesel and Biodiesel/Butanol Blend Fuels in Internal Combustion Engines," *Applications in Energy and Combustion Science*, vol. 16, Dec. 2023, doi: 10.1016/j.jaecs.2023.100197.

[3] A. F. Kheiralla, E. Tola, and J. M. Bakhit, "Performance of Ethanol-Gasoline Blends of Up to E35 as Alternative Automotive Fuels," *Adv Biores*, vol. 8, no. 5, pp. 130–140, 2017, doi: 10.15515/abr.0976-4585.8.5.130140.

[4] L. Behnke *et al.*, "Maximizing Net Fuel Economy Improvement from Fusel Alcohol Blends in Gasoline Using Multivariate Optimization," *Fuel Communications*, vol. 11, p. 100059, Jun. 2022, doi: 10.1016/j.jfueco.2022.100059.

[5] C. Wang, S. Zeraati-Rezaei, L. Xiang, and H. Xu, "Ethanol Blends in Spark Ignition Engines: RON, Octane-Added Value, Cooling Effect, Compression Ratio, and Potential Engine Efficiency Gain," *Appl Energy*, vol. 191, pp. 603–619, 2017, doi: 10.1016/j.apenergy.2017.01.081.

[6] M. V. Kumar, A. V. Babu, and P. R. Kumar, "The Impacts on Combustion, Performance and Emissions of Biodiesel by Using Additives in Direct Injection Diesel Engine," *Alexandria Engineering Journal*, vol. 57, no. 1, pp. 509–516, Mar. 2018, doi: 10.1016/j.aej.2016.12.016.

[7] M. Mofijur *et al.*, "Impact of Nanoparticle-Based Fuel Additives on Biodiesel Combustion: An Analysis of Fuel Properties, Engine Performance, Emissions, and Combustion Characteristics," *Energy Conversion and Management: X*, vol. 21, Jan. 2024, doi: 10.1016/j.ecmx.2023.100515.

[8] S. J. M. Algayyim, K. Saleh, A. P. Wandel, I. M. R. Fattah, T. Yusaf, and H. A. Alrazen, "Influence of Natural Gas and Hydrogen Properties on Internal Combustion Engine Performance, Combustion, and Emissions: A Review," *Fuel*, vol. 362, Apr. 2024, doi: 10.1016/j.fuel.2023.130844.

[9] B. Irawan, Y. A. Winoko, E. Puspitasari, and T. Dwiyono, "Analysis of Fuel Pressure on the Performance of Motorcycle Engine with Ethanol Fuel," in *IOP Conference Series: Materials Science and Engineering*, IOP Publishing, Feb. 2021, pp. 1–7. doi: 10.1088/1757-899x/1073/1/012081.

[10] M. K. Mohammed, H. H. Balla, Z. M. H. Al-Dulaimi, Z. S. Kareem, and M. S. Al-Zuhairy, "Effect of Ethanol-Gasoline Blends on SI Engine Performance and Emissions," *Case Studies in Thermal Engineering*, vol. 25, pp. 1–9, 2021, Accessed: Jun. 03, 2024. [Online]. Available: http://www.elsevier.com/locate/csite

[11] J. E. Tibaquirá, J. I. Huertas, S. Ospina, L. F. Quirama, and J. E. Niño, "The Effect of Using Ethanol-Gasoline Blends on the Mechanical, Energy and Environmental Performance of In-Use Vehicles," *Energies (Basel)*, vol. 11, no. 1, pp. 1–17, 2018, doi: 10.3390/en11010221.

[12] S. Abikusna, B. Sugiarto, D. Suntoro, and Azami, "Low Grade Bioethanol for Fuel Mixing on Gasoline Engine Using Distillation Process," in *AIP Conference Proceedings*, American Institute of Physics Inc., Mar. 2017, pp. 1–10. doi: 10.1063/1.4979235.

[13] N. Damanik, H. C. Ong, C. W. Tong, T. M. I. Mahlia, and A. S. Silitonga, "A Review on the Engine Performance and Exhaust Emission Characteristics of Diesel Engines Fueled with Biodiesel Blends," *Environmental Science and Pollution Research*, vol. 25, no. 16, pp. 15307–15325, Jun. 2018, doi: 10.1007/s11356-018-2098-8.

[14] A. Jamrozik, W. Tutak, M. Pyrc, and M. Sobiepanski, "Effect of Diesel-Biodiesel-Ethanol Blend on Combustion, Performance, and Emissions Characteristics on a Direct Injection Diesel Engine," *Thermal Science*, vol. 21, pp. 591–604, 2017, doi: 10.2298/TSCI160913275J.

[15] M. Li, H. Wu, T. Zhang, B. Shen, Q. Zhang, and Z. Li, "A Comprehensive Review of Pilot Ignited High Pressure Direct Injection Natural Gas Engines: Factors Affecting Combustion, Emissions and Performance," *Renewable and Sustainable Energy Reviews*, vol. 119, 2019, Accessed: Jun. 04, 2024. [Online]. Available: https://www.sciencedirect.com/science/article/pii/S1364032119308597

[16] S. Shylesh, A. A. Gokhale, C. R. Ho, and A. T. Bell, "Novel Strategies for the Production of Fuels, Lubricants, and Chemicals from Biomass," *Acc Chem Res*, vol. 50, no. 10, pp. 2589–2597, Oct. 2017, doi: 10.1021/acs.accounts.7b00354.

[17] R. Z. K. Nisak, N. Ilminnafik, and S. Junus, "Performance and Emissions of Mixed Ethanol-Biodiesel Calophyllum Inophyllum Fueled Diesel Engine," *International Journal of Emerging Trends in Engineering Research*, vol. 9, no. 8, pp. 1124–1128, Aug. 2021, doi: 10.30534/ijeter/2021/16982021.

[18] Y. S. M. Altarazi *et al.*, “Effects of Biofuel on Engines Performance and Emission Characteristics: A Review,” *Energy*, vol. 238, Jan. 2022, doi: 10.1016/j.energy.2021.121910.

[19] G. Kalghatgi, “Development of Fuel/Engine Systems—The Way Forward to Sustainable Transport,” *Engineering*, vol. 5, no. 3. Elsevier Ltd, pp. 510–518, Jun. 01, 2019. doi: 10.1016/j.eng.2019.01.009.

[20] İ. Örs, “Experimental Investigation of the Cetane Improver and Bioethanol Addition for the Use of Waste Cooking Oil Biodiesel as an Alternative Fuel in Diesel Engines,” *Journal of the Brazilian Society of Mechanical Sciences and Engineering*, vol. 42, no. 4, Apr. 2020, doi: 10.1007/s40430-020-2270-1.

[21] T. B. Sitorus, J. A. R. Siagian, and B. Christopel, “Study on the Performance of the Otto Engine by Using Mixtures of Gasoline-Bioethanol of Nira,” in *IOP Conference Series: Materials Science and Engineering*, Institute of Physics Publishing, Jan. 2020. doi: 10.1088/1757-899X/725/1/012015.

[22] E. Julianto, D. Stiawan, F. Fuazen, and E. Sarwono, “Effect of Ignition System in Motorcycle to Performance and Exhaust Gas Emissions with Fuel RON 88, RON 90, AND RON 92,” *SINTEK JURNAL: Jurnal Ilmiah Teknik Mesin*, vol. 14, no. 2, p. 74, Dec. 2020, doi: 10.24853/sintek.14.2.74-79.

[23] F. B. Ismail, A. Al-Bazi, and I. G. Aboubakr, “Numerical Investigations on the Performance and Emissions of a Turbocharged Engine Using an Ethanol-Gasoline Blend,” *Case Studies in Thermal Engineering*, vol. 39, pp. 1–12, Nov. 2022, doi: 10.1016/j.csite.2022.102366.

[24] A. Jamrozik, W. Tutak, M. Gruca, and M. Pyrc, “Performance, Emission and Combustion Characteristics of CI Dual Fuel Engine Powered by Diesel/Ethanol and Diesel/Gasoline Fuels,” *Journal of Mechanical Science and Technology*, vol. 32, no. 6, pp. 2947–2957, Jun. 2018, doi: 10.1007/s12206-018-0551-8.

[25] M. D. Manshadi, N. Alafchi, A. Tat, M. Mousavi, and A. Mosavi, “Comparative Analysis of Machine Learning and Numerical Modeling for Combined Heat Transfer in Polymethylmethacrylate,” *Polymers (Basel)*, vol. 14, no. 10, May 2022, doi: 10.3390/polym14101996.

[26] B. Dogan and D. Erol, “The Future of Fossil and Alternative Fuels Used in Automotive Industry,” in *3rd International Symposium on Multidisciplinary Studies and Innovative Technologies*, Institute of Electrical and Electronics Engineers Inc., Oct. 2019. doi: 10.1109/ISMSIT.2019.8932925.

[27] Z. Stępień, G. Żak, J. Markowski, and M. Wojtasik, “Investigation into the Impact of the Composition of Ethanol Fuel Deposit Control Additives on Their Effectiveness,” *Energies (Basel)*, vol. 14, no. 3, Feb. 2021, doi: 10.3390/en14030604.

[28] Y. M. D. E. Saputra and M. H. Tullah, “Experimental Study of the Effect of Increased Compression Ratio on the Torque and Power of the Honda CB 150R Engine Using E85 Fuel,” *MOTIVECTION : Journal of Mechanical, Electrical and Industrial Engineering*, vol. 3, no. 1, pp. 11–18, Jan. 2021, doi: 10.46574/motivection.v3i1.82.

[29] K. Aydin and R. Kenanoğlu, “Effects of Hydrogenation of Fossil Fuels with Hydrogen and Hydroxy Gas on Performance and Emissions of Internal Combustion Engines,” *Int J Hydrogen Energy*, vol. 43, no. 30, pp. 14047–14058, Jul. 2018, doi: 10.1016/j.ijhydene.2018.04.026.

[30] M. AlAbbad, J. Badra, K. Djebbi, and A. Farooq, “Ignition Delay Measurements of a Low-Octane Gasoline Blend, Designed for Gasoline Compression Ignition (GCI) Engines,” *Proceedings of the Combustion Institute*, vol. 37, no. 1, pp. 171–178, 2019, doi: 10.1016/j.proci.2018.05.097.

[31] V. De Bellis *et al.*, “Development and Validation of a Phenomenological Model for Hydrogen Fueled PFI Internal Combustion Engines Considering Thermo-Diffusive Effects on Flame Speed Propagation,” *Energy Convers Manag*, vol. 308, May 2024, doi: 10.1016/j.enconman.2024.118395.

[32] T. T. Birhanu and D. S. Zeleke, “Evaluating the Effect of Diethyl Ether and Moringa Oleifera Antioxidant Additives on the Performance and Emission Characteristics of Jatropha Biodiesel-Diesel Blended Fuel on CI Engine – An Experimental Investigation,” *Heliyon*, vol. 10, no. 10, May 2024, doi: 10.1016/j.heliyon.2024.e31436.

[33] U. Ngwaka *et al.*, “Evaluation of Performance Characteristics of a Novel Hydrogen-Fuelled Free-Piston Engine Generator,” *Int J Hydrogen Energy*, vol. 46, no. 66, pp. 33314–33324, Sep. 2021, doi: 10.1016/j.ijhydene.2020.02.072.

[34] A. Prestasi, B. Pamuji Lestari, N. Ana Mufarida, and A. Irawan, “Machine Work Achievement Analysis Using Mixed Pertamax and Methanol (CH3OH) in 4 Stroke Engine,” *J-Proteksion*, vol. 3, no. 1, pp. 9–16, 2018.

[35] S. Szwaja, M. Gruca, and M. Pyrc, “Investigation on Ethanol-Glycerol Blend Combustion in the Internal Combustion Sparkignited Engine. Engine Performance and Exhaust Emissions,” *Fuel Processing Technology*, vol. 226, Feb. 2022, doi: 10.1016/j.fuproc.2021.107085.

[36] M. A. Asokan *et al.*, “Effect of Antioxidants on CI Engine Characteristics of Safflower Biodiesel with Varying Fuel Injection Pressures,” *Case Studies in Thermal Engineering*, vol. 60, Aug. 2024, doi: 10.1016/j.csite.2024.104658.