Investigation of 1-Hexanol Diesel Blends on Performance, Combustion and Emission Characteristics of a Diesel Engine

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Abstract. The most potential long-term and renewable substitute of mineral diesel are biofuels. The growth and degradation of energy resources have an enormous influence on the long-term viability of the human community. Alcohols are gaining prominence in the current renewable energy scenario due to their ease of manufacturing and fuel characteristics. In this investigation, hexanol-diesel blend ratios (up to 20% v/v) is taken into account for this investigation in a single cylinder, water cooled, unmodified 4-stroke DI diesel engine. The increase in 1-hexanol volume content correlates to an improvement in combustion thereby promoting brake thermal efficiency. The greater concentration of oxygen in 1-hexanol reduces emission viz. HC and CO and increases value of NOx. Current investigation recommends a feasible option to substitute ULSD for the capabilities of 1-hexanol.

Keyword: 1-Hexanol, CI engine, Combustion, Emissions, Performance

1. Introduction
Currently, energy is a necessary component of the global economy as well as human life. Development and impoverishment of energy sources have a huge impact on ensuring the human community's long-term viability. Furthermore, energy consumption has been steadily growing in comparison to the previous day since science has continued to advance, economic growth has continued to expand, and the demographic of countries has steadily increased [1]. The whole world relies on exhaustible and catastrophic fossil fuels for energy solutions. Renewable sources deliver only
a small portion of the energy. The inhabitant’s growth has resulted in a dramatic increase in energy demand for day-to-day existence. In the last two decades, the usage of vehicles and agriculture has risen at a rapid rate. All of this has a detrimental impact on energy use and emissions [1]–[3].

In comparison to petrol engines, diesel engines are the most efficient energy converters. Biodiesels are a kind of biofuel that may be used as an appropriate alternate for mineral diesel fuel in compression ignition engines. In general, biodiesels have a high cetane number, are deficient of sulphates and other aromatic chemicals, and may be utilized in unmodified CI engines[4]–[6]. However, most biodiesel are unsuitable in raw form, as it has poor atomization characteristics and high flashpoint and viscosity. Biodiesel is not a long-term or better answer for the current situation. The increased viscosity and poor cold flow properties of biodiesel, on the other hand, cause incorrect atomization and charge deposits, which is the most significant disadvantage. As a result, the majority of academics focus their efforts on investigating alcohol's superior fuel characteristics[7], [8].

Alcohol is made from bio-waste, therefore it does not affect the food supply. There are two type of alcohol viz. lower alcohols and higher alcohols[9]. Lower carbon chain alcohols are those with less than or equal to four carbon atoms, whereas larger carbon chain alcohols have more than five carbon atoms. Because they are less hygroscopic than ethanol, higher alcohols are less corrosive to fuel injection and delivery systems[10], [11]. They have high flashpoints, which mean they can be stored and handled safely within the current gasoline distribution infrastructure. Evaporative emissions are reduced due to their lower vapor pressures. Isomers of alcohols with three or more carbon atoms can be differentiated by their chemical structure and hydroxyl group position[12], [13].

Hydroxyl group linked to terminal of a 6-carbon non-natural bio-alcohol is 1-hexanol or n-hexanol. It has added oxygen, enhanced energy content, and comparative cetane number, which helps in reduction of detrimental particulate matter (PM) while combustion. Various researchers are optimistic for the application of these alcohols either in pure or blended form in CI engines under numerous combustion techniques to ensure comparative performance and emissions attributes[14]–[18].

Hexanol use in diesel engines has been the subject of fewer investigations in recent years, although it has lately gotten increasing attention. Although hexanol has a low auto-ignition temperature and latent heat of vaporization but its density, viscosity, cetane number and superior calorific value make it’s a healthier CI engine fuel[19], [20]. Only a few research have looked at the combustion, emissions, and performance of a CI engine that uses n-hexanol/diesel mixes so far. The addition of n-hexanol resulted in a longer ignition delay as well as somewhat higher pressure and HRR peaks[21]. With the addition of n-hexanol, NOx rises, but the smoke was significantly reduced. Concurrently, its lower vapour pressure, larger flash point, less hygroscopic nature, and superior miscibility with diesel result in enhanced mixing stability, storage, and transportation[22]–[24].

Santhosh and Kumar[25], on the other hand, discovered contradictory results when it came to NOx emissions. When compared to mineral diesel operation, 1-hexanol-diesel blends resulted in a significant reduction in NOx emissions at all loads. With larger 1-hexanol mix percentages, the decrease was more apparent. They also saw a small increase in particulate matter emissions, which they endorsed to hexanol's fuel characteristics, such as its lower cetane number. Poures et al.[26] observed lesser soot emissions when uses 1-hexanol-diesel blended fuel in CI engine. When compared to instances fuelled by pure diesel, at high load higher NOx emissions were found, although this may be mitigated by using exhaust gas recirculation (EGR).

However, literature is scarce on the subject. The purpose of this research is to close that gap. In this study, hexanol is taken into account. The test fuels in this study were mixtures of hexanol-diesel blend ratios (up to 20% v/v). And obtained results were compared and discussed under various engine running circumstances.

2. Methodology

The ultra-low Sulphur diesel used in this investigation was obtained from an Indian Oil shop in Srinagar. ThermoFisher Scientific in India provided analytical grade extra pure 1-hexanol. Because of
the alkane-like reaction pathways that begin at a secondary carbon site, 1-hexanol has greater reactivity at lower temperatures. 1-hexanol is blended with ULSD at ratios of 5%, 10%, 15%, and 20% by volume and designated as DHxOH5, DHxOH10, DHxOH15, and DHxOH20 respectively. All of the blends are tested for phase separation over the course of a week and are determined to be stable. The properties of ULSD and hexanol were determined using ASTM-recommended techniques, as shown in Table 1.

| S.No. | Properties                      | Test Methods | ULSD  | 1-Hexanol | DHxOH5 | DHxOH10 | DHxOH15 | DHxOH20 |
|-------|--------------------------------|--------------|-------|-----------|--------|---------|---------|---------|
| 1     | Density (kg/m³)                 | ASTM D4052   | 850   | 823       | 848.6  | 847.5   | 846.1   | 844.2   |
| 2     | Kinematic Viscosity at 40°C (mm²/s) | ASTM D445    | 3.522 | 3.412     | 3.516  | 3.51    | 3.506   | 3.5     |
| 3     | Flash point (°C)                | ASTM D93     | 70    | 60        | 60     | 60      | 60      | 60      |
| 4     | Calorific Value (MJ/kg)         | ASTM D240    | 43.356| 38.211    | 43.35  | 43.1    | 42.8    | 42.5    |

The current experiments were performed on an unmodified single cylinder, 4-stroke, water cooled, direct injection, CI engine. The engine's specs are shown in table 2. For load applications, the engine is equipped with a hydraulic dynamometer as shown in Fig. 1. A constant speed of 1500 rpm is maintained to provide a steady-state condition. For engine measurements, a piezoelectric pressure transducer coupled to a charge amplifier with a precision of 0.25°CA was used to monitor cylinder pressure fluctuation. An inductive proximity sensor was used to identify the beginning and end of each cycle based on the piston top dead center (TDC). Signals from several sensors were recorded and stored on a computer using a data accumulating system and software for processing and analysis. The flow rate of a fixed volume of fuel is measured using a burette and a timer. A pressure transducer was used to detect differential pressure, which was used to determine the airflow rate. In the single-cylinder engine, an air-box was employed to reduce intake air fluctuation. The acquired emissions characteristics are analyzed using an AVL smoke meter and an AVL digas analyzer.

Table 2. Engine Specification

| Power (kW) | 5.2 |
| Speed (rpm) | 1500 |
| Number of cylinders | 1 |
| Combustion chamber | Hemispherical open type |
The heat release rate and the average temperature of the gas in the cylinder are estimated using the “Enginesoft/Labview” software, which employs a 0D model of a single combustion zone with a constant specific heat ratio.

\[
\frac{dQ_n}{d\theta} = \frac{\gamma}{\gamma - 1} P \frac{dV}{d\theta} + \frac{1}{1 - \gamma} V \frac{dP}{d\theta}
\]

Where, \( \frac{dQ_n}{d\theta} \) = net heat release, \( \gamma \) = specific heat ratio, \( \theta \) = Crank angle, 
\( P \) = Incylinder Pressure, and \( V \) = Cylinder Volume.

3. Result and Discussion:

In this section, the effect of 1-hexanol blends on cylinder pressure, net heat release rate, performance, and emissions characteristics are discussed.

3.1. Combustion Characteristics: The vital indicators to evaluate engine combustion are in-cylinder pressure and net heat release rate. Figure 2 shows the influence of 1-hexanol on these parameters. Combustion is influenced by variables such as cetane number, calorific value, and viscosity. Lower calorific value and cetane ratings tend to lengthen the ignition delay, allowing fuel to accumulate during the delay period, resulting in higher burning rates[16]. As a result, it is clear that gradually increasing 1-hexanol causes a steady rise in ignition delay, peak pressure, and peak heat release rate. The longer ID causes the combustion process to shift to the expansion stroke, resulting in a larger combustion chamber volume. As a result, the rate of heat loss to the surrounding is higher, resulting in reduced cylinder pressure. The addition of 1-Hexanol to diesel fuel, on the other hand, increases the rich oxygen concentration, which aids in the combustion process. Despite the fact that 1-hexanol has a low heating value, the hexanol blends have higher heat release rate than ULSD. In comparison to ULSD, the DHxOH20 has a higher volatility and lower density. Because 1-Hexanol contains water, it vaporizes at a slower pace and requires more heat to do so. This endothermic process causes cold patches in the cylinder and slows the flame propagation. As a result, just a tiny amount of charge will be burned in the premixed combustion zone, and the entire combustion process will change to diffusion combustion. At the identical test circumstances, the addition of hexanol resulted in greater atomization and faster mixing of fuel vapors with air than the diesel, resulting in a higher heat release rate by 7.5% for DHxOH10 and 12.12% for DHxOH20 over the first combustion process.
3.2. **Performance Characteristic:** Performance metrics are used to clarify an engine's energy conversion efficiency, which is then described using graphs of brake thermal efficiency and brake specific fuel consumption. BTE is a function of the amount of heat input from the fuel, as seen in fig. 3. At low loads, BTE is reduced with the addition of 1-hexanol. At low load, the greatest decrease is seen for DHxOH10, which is 14.28 percent. When compared to ULSD, 1-hexanol has a lower calorific value and cetane number, resulting in reduced BTE. Aside from that, when the engine load was raised, the gap between the BTE for 1-hexanol mixed fuel and ULSD fuel was widened. The growing ratios in fuel consumption at the highest engine load may be deduced. DHxOH20 exhibits better brake thermal efficiency of 33.02% compared to 27.62%, 27.83%, 28.5%, and 28.66% of DHxOH15, DHxOH10, DHxOH5 and ULSD respectively. When can be observed, as engine loads increased, the BSFC numbers fell. The addition of 1-hexanol to plain diesel fuel has also resulted in an increase in BSFC values. Because of the calorific value of 1-hexanol, the above-mentioned situations might occur. The quantity of fuel injected to create a desired amount of power has been adjusted correspondingly. The viscosity, density, latent heat of evaporation, and calorific value, all have an impact on engine performance and combustion characteristics.

3.3. **Emission Analysis:** In this section various gas emissions viz. carbon monoxide (CO), unburnt hydrocarbon (HC), oxides of nitrogen (NOx), and Smoke opacity has been discussed analyzed.

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**Fig. 2. Variation of Peak pressure and Heat release rate with crank angle**

**Fig. 3. Variation of BTE and BSFC at all engine loads**
3.4. **Carbon Monoxide Emission:** Fig 4. depicts the variations of CO with load for 1-hexanol blends and ULSD. According to the graph, all tested fuel samples has decreased CO emission manners as the engine load increased. This is explicated by several characteristics, such as higher BTE at full loads and an advance flame-out duration, because peak pressure resulted in lower CO emissions, as previously noted. Furthermore, due to the better quantity of oxygen, 1-hexanol emits less CO than diesel fuel at part load. Full load had a high stoichiometric air-fuel ratio there-by increasing the CO emission as compared to conventional diesel fuel. The CO emission was found to be 25%, 31.8%, 34.7%, and 40% higher than that of ULSD at full load.

![Fig. 4. Variation of carbon monoxide with bmep.](image)

3.5. **Unburnt Hydrocarbon Emissions:** Fig 5. depicts variation of unburnt hydrocarbon emissions as a function of load. The graph shows that HC emission rises for all of the tested fuel samples with an increase in the engine load. To begin with, the lower cetane number of hexanol degrades the blends self-ignition properties, which raises HC emissions. Furthermore, HC emissions also reduce with high oxygen content of the hexanol blends reduces. All of these elements work in opposition to one another, causing HC emissions to rise or fall as a result of their cumulative influence. In summary, DHxOH20 has highest HC emissions among 1-hexanol diesel blends.

![Fig. 5. Variation of unburnt hydrocarbon with bmep.](image)

3.6. **Oxides of Nitrogen:** Thermal NOx, rapid NOx, and fuel NOx are the three commonly recognized processes for NOx formation. The Zeldovich mechanism produces thermal NOx, which is produced by the high-temperature reaction of nitrogen with oxygen. Fig. 6 depicts NOx emissions for ULSD and all hexanol-diesel mixes as a function of engine load. The term NOx refers to a mixture of nitric oxide.
(NO) and nitrogen dioxide (NO₂). With DHxOH blends, the dominance of lower cetane number and high latent heat of vaporization may be shown at low loads. At full load, more NOx emissions are obtained than with ULSD. Fuel buildup occurs as a result of the ignition delay produced by DHxOH. When there is a lot of oxygen available, the combustion temperature rises, which leads to a lot of NOx.

Fig. 6. Variation of NOx with bmep.

3.7. **Smoke Opacity**: Alcohols are oxygenated molecules containing hydroxyl radicals that may be found in even locally fuel-rich zones and aid in the oxidation of unsaturated hydrocarbon species rather than participating in soot generation processes. Higher fractions of alcohol in blends result in reduced smoke opacity because combustion is aided by the presence of fuel-bound oxygen. For all test fuels, Fig. 7 depicts the changes in smoke opacity as a function of engine load. Because of its higher oxygen concentration than the other fuel samples, the DHxOH20 blend emits the least smoke.

Fig. 7. Variation of smoke opacity with bmep.

4. **Conclusion**

The influence of 1-Hexanol on the combustion, performance, and emission characteristics of a CI engine is illustrated in this study. The following are the study’s main findings:

- Because 1-Hexanol has a lower Cetane number, a lower latent heat of vaporization, and a lower calorific value, it has a longer ignition delay and a longer combustion duration, which deteriorates combustion and has a negative impact on performance.
The increase in brake thermal efficiency corresponds to the increase in 1-hexanol volume content. The greatest increase is shown in DHxOH20, which is 13.21% greater at full load than ULSD.

With an increase in 1-Hexanol content in the mix, BSFC drops. When compared to ULSD, DHxOH20 has the lowest fuel usage, which is 13.4% lower at complete load.

For 1-hexanol blends at full load, earlier flame-out duration resulted in less combustion time, resulting in an increase in CO emissions. Additionally, the higher oxygen concentration of the hexanol blends lowers HC emissions by promoting oxidation of unburned hydrocarbons.

The combustion temperature rises when there is a lot of oxygen available, increasing the risk of NOx. Because combustion is facilitated by the presence of fuel-bound oxygen, higher alcohol percentages in blends result in less smoke opacity.

In the light of the increasing costs of the reliance on fossil fuels, it has also been shown that, on the basis of preliminary investigations, 1-hexanol is the possible option to reduce the utilization of carbon fuels in CI engines. Overall, the performance of fuel combined combustibles compared to that of ULSD is sufficient.

References

[1] N. Kumar and H. S. Pali, “Effects of n-Butanol Blending with Jatropha Methyl Esters on Compression Ignition Engine,” *Arab. J. Sci. Eng.*, vol. 41, no. 11, pp. 4327–4336, 2016, doi: 10.1007/s13369-016-2127-1.

[2] P. Kumar and N. Kumar, “Study of ignition delay period of n-Butanol blends with JOME and diesel under static loading conditions,” *Energy Sources, Part A Recover. Util. Environ. Eff.*, vol. 40, no. 14, pp. 1729–1736, 2018, doi: 10.1080/15567036.2018.1486904.

[3] N. Kumar, S. Bansal, V. Vibhanshu, and A. Singh, “Utilization of blends of Jatropha Oil and N-butanol in a naturally aspirated compression ignition engine,” *SAE Tech. Pap.*, vol. 11, 2013, doi: 10.4271/2013-01-2684.

[4] A. Deep, N. Kumar, M. Kumar, A. Singh, D. Gupta, and J. S. Patel, “Performance and emission studies of diesel engine fuelled with orange peel oil and n-butanol alcohol blends,” *SAE Tech. Pap.*, 2015, doi: 10.4271/2015-26-0049.

[5] S. M. Palash, H. H. Masjuki, M. A. Kalam, A. E. Atabani, I. M. Rizwanul Fattah, and A. Sanjid, “Biodiesel production, characterization, diesel engine performance, and emission characteristics of methyl esters from Aphanamixis polystachya oil of Bangladesh,” *Energy Convers. Manag.*, vol. 91, pp. 149–157, 2015, doi: 10.1016/j.enconman.2014.12.009.

[6] V. T. Lamani, A. K. Yadav, and K. N. Gottekere, “Performance, emission, and combustion characteristics of twin-cylinder common rail diesel engine fuelled with butanol-diesel blends,” *Environ. Sci. Pollut. Res.*, vol. 24, no. 29, pp. 23351–23362, 2017, doi: 10.1007/s11356-017-9956-7.

[7] A. K. Singh, A. Sharma, and N. Kumar, “Performance and Emission Analysis of a CI Engine in Dual Mode with CNG and Karanja Oil Methyl Ester,” in *SAE Technical Papers*, Sep. 2014, no. March 2016, doi: 10.4271/2014-01-2327.

[8] A. E. Atabani and S. AL Kulthoom, “Spectral, thermoanalytical characterizations, properties, engine and emission performance of complementary biodiesel-diesel-pentanol/octanol blends,” *Fuel*, vol. 282, Dec. 2020, doi: 10.1016/j.fuel.2020.118849.

[9] M. A. Ghadikolaei et al., “Impact of lower and higher alcohols on the physicochemical properties of particulate matter from diesel engines: A review,” *Renew. Sustain. Energy Rev.*, 8
vol. 143, no. March, p. 110970, 2021, doi: 10.1016/j.rser.2021.110970.

[10] B. Rajesh Kumar, S. Saravanan, D. Rana, and A. Nagendran, “A comparative analysis on combustion and emissions of some next generation higher-alcohol/diesel blends in a direct-injection diesel engine,” *Energy Convers. Manag.*, vol. 119, pp. 246–256, 2016, doi: 10.1016/j.enconman.2016.04.053.

[11] B. Gainey and B. Lawler, “The role of alcohol biofuels in advanced combustion: An analysis,” *Fuel*, vol. 283, no. August 2020, p. 118915, 2021, doi: 10.1016/j.fuel.2020.118915.

[12] A. Imran, M. Varman, H. H. Masjuki, and M. A. Kalam, “Review on alcohol fumigation on diesel engine: A viable alternative dual fuel technology for satisfactory engine performance and reduction of environment concerning emission,” *Renew. Sustain. Energy Rev.*, vol. 26, pp. 739–751, 2013, doi: 10.1016/j.rser.2013.05.070.

[13] P. Pramod Kumar and S. Murugesan, “Analysis of performance and emission parameters of IC engine fuelled with neem biodiesel and n-octanol additives,” *Int. J. Innov. Technol. Explor. Eng.*, vol. 8, no. 8, pp. 2237–2241, 2019.

[14] S. Y. No, “Utilization of Pentanol as Biofuels in Compression Ignition Engines,” *Front. Mech. Eng.*, vol. 6, no. April, pp. 1–19, 2020, doi: 10.3389/fmech.2020.00015.

[15] M. Tuner, “Combustion of Alternative Vehicle Fuels in Internal Combustion Engines,” no. A report on engine performance from combustion of alternative fuels based on literature review, pp. 1–39, 2015.

[16] H. Suhaimi et al., “Analysis of combustion characteristics, engine performances and emissions of long-chain alcohol-diesel fuel blends,” *Fuel*, vol. 220, no. November 2017, pp. 682–691, 2018, doi: 10.1016/j.fuel.2018.02.019.

[17] B. Gainey and B. Lawler, “The role of alcohol biofuels in advanced combustion: An analysis,” *Fuel*, vol. 283, p. 118915, Jan. 2021, doi: 10.1016/j.fuel.2020.118915.

[18] D. Damodharan, A. P. Sathiyagnanam, D. Rana, S. Saravanan, B. Rajesh Kumar, and B. Sethuramasamyraja, “Effective utilization of waste plastic oil in a direct injection diesel engine using high carbon alcohols as oxygenated additives for cleaner emissions,” *Energy Convers. Manag.*, vol. 166, no. January, pp. 81–97, 2018, doi: 10.1016/j.enconman.2018.04.006.

[19] J. Yan, S. Gao, W. Zhao, and T. H. Lee, “Study of combustion and emission characteristics of a diesel engine fueled with diesel, butanol-diesel and hexanol-diesel mixtures under low intake pressure conditions,” *Energy Convers. Manag.*, vol. 243, p. 114273, 2021, doi: 10.1016/j.enconman.2021.114273.

[20] Y. H. Teoh, K. H. Yu, H. G. How, and H. T. Nguyen, “Experimental investigation of performance, emission and combustion characteristics of a common-rail diesel engine fuelled with bioethanol as a fuel additive in coconut oil biodiesel blends,” *Energies*, vol. 12, no. 10, pp. 1–17, 2019, doi: 10.3390/en12101954.

[21] S. Duraisamy, L. Kasirajan, S. Kasinathan, R. Kadasari, and C. T. Rajagopal, “Performance test and emission characteristics of diesel fuel blended with n-hexanol,” *Therm. Sci.*, vol. 24, pp. 1–8, 2020, doi: 10.2298/TSC190414435D.

[22] S. Sharbuddin Ali and M. R. Swaminathan, “Effective utilization of waste cooking oil in a diesel engine equipped with CRDi system using C8 oxygenates as additives for cleaner emission,” *Fuel*, vol. 275, no. April, p. 118003, 2020, doi: 10.1016/j.fuel.2020.118003.

[23] D. Babu and R. Anand, “Effect of biodiesel-diesel-n-pentanol and biodiesel-diesel-n-hexanol blends on diesel engine emission and combustion characteristics,” *Energy*, vol. 133, pp. 761–776, 2017, doi: 10.1016/j.energy.2017.05.103.

[24] M. Nour, Z. Sun, A. I. El-Seesy, and X. Li, “Experimental evaluation of the performance and emissions of a direct-injection compression-ignition engine fueled with n-hexanol–diesel blends,” *Fuel*, vol. 302, no. May, p. 121144, 2021, doi: 10.1016/j.fuel.2021.121144.

[25] K. Santhosh and G. N. Kumar, “Effect of injection time on combustion, performance and emission characteristics of direct injection CI engine fuelled with equi-volume of 1-hexanol/diesel blends,” *Energy*, vol. 214, p. 118984, 2021, doi: 10.1016/j.energy.2020.118984.
[26] M. V. De Poures, A. P. Sathiyagnanam, D. Rana, B. Rajesh Kumar, and S. Saravanan, “1-Hexanol as a sustainable biofuel in DI diesel engines and its effect on combustion and emissions under the influence of injection timing and exhaust gas recirculation (EGR),” Appl. Therm. Eng., vol. 113, pp. 1505–1513, 2017, doi: 10.1016/j.applthermaleng.2016.11.164.