

Experimental Investigation on the Performance of a 4-Stroke Diesel Engine Fuelled with Alcohols Using Surface Ignition, Ceramic Heaters, and Glow Plugs

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ABSTRACT

The increasing need to use clean and sustainable fuels has increased the need to conduct a study on the utilisation of alcohol in compression engines. Nevertheless, alcohol fuels have low cetane numbers and a high latent heat of vaporization and thus, have poor auto-ignition properties when used in conventional diesel engines (DEs). This paper provides experimental research on the combustion of a four-stroke DE operating on alcohol with three assisted ignition systems, i.e. surface ignition, ceramic heaters, and glow plugs. A single-cylinder four-stroke DE was gauged under varying loads to evaluate performance alongside combustion characteristics. Outcomes showed that assisted ignition improves alcohol-fuel combustion by increasing thermal efficiency and reducing ignition delay (ID). Ceramic heater assistance performed best at higher loads, glow plugs were more effective for cold-start and low-load conditions, and surface ignition provided only modest benefits. Overall, the study supports the practicality of alcohol-fueled DEs with appropriate ignition support for improved low-emission performance.

Keywords: Experimental investigation, IC engines, Alcohol fuel, Ceramic coating, Hot surfaces, Surface heating, Glow plug

INTRODUCTION

The urgent necessity to attain less reliance on fossil energy and lessen the pollution of the environment has prompted comprehensive studies in requirements of alternative fuels and burning methods to the internal combustion engines (ICEs). Alcohols like methanol, ethanol and higher alcohols can be considered as one of the renewable options because of the presence of oxygen, high-renewability and the ability to cut down on the level of particulate emissions relative to the conventional diesel fuel (Journal of the Energy Institute, 2025). Alcohols naturally include oxygen in their molecule structure which may support the strength of combustion reactions in compression ignition (CI) engines and hide soot formation (Journal of the Energy Institute, 2025). Nevertheless, alcohols have low cetane counts, high latent heat of vaporization, and low energy density which are major disadvantages because they cannot be used in conventional DEs as primary energies (MDPI Energies, 2024). These characteristics lead to long ID and oscillating combustion which can result into amplified brake specific fuel consumption (BSFC) and reduced performance unless appropriate adaptations are made (MDPI Energies, 2024; Journal of the Energy Institute, 2025). Conventional DEs are based on CI, which is a process whereby high temperature and pressure created during the compression stroke are used to trigger automatic self-ignition of injected fuel. When alcohols are used in place of or in part of diesel, they result in delayed auto-ignition, which can cause combustion stability to reduce, raise cycle-to-cycle variability, and unburned hydrocarbons (MDPI Energies, 2024). A thorough examination of alcohol fuels in CI engines states that an augmentation in the alcohol content typically raises the ID and the maximum heat release rate (HRR) and impacts on thermal efficiency and emissions are specific to the alcohol type and content mix (MDPI Energies, 2024). In the case of simple alcohols like methanol and ethanol, it was mentioned that some of the studies showed a higher efficiency in thermal efficiencies in conditions of optimality, but the overall combustion process is still marked with low ignitability relative to diesel (MDPI Energies, 2024). To overcome combustion issues with low-reactivity fuels, researchers have tested ignition aids such as surface ignition, ceramic heaters, and glow plugs, which provide localized high temperatures to promote earlier ignition. Surface ignition uses a hot surface positioned so part of the fuel spray contacts it, enabling faster combustion and improved performance. Ceramic heaters and materials like partially stabilized zirconia (PSZ) are also used to heat combustion chamber areas, enhancing fuel vaporization, ignition, and overall combustion efficiency. Although said assumptions were established through earlier research involving the utilisation of ceramic surface heaters with mixtures of both ethanol and diesel that showed a reduction in NO₈ emissions and a difference in the performance parameters of the engine with alcohols and diesel blends, the research mostly concentrated on moderate blends of alcohols and generic combustion assists as opposed to systematic evaluation across ignition aids (Muthuramathan and Marthandan, 2014). Heated-surface ignition methods can improve alcohol combustion. Glow plugs create localized heat that enhances vaporization, reduces ignition delay, and stabilizes low-cetane combustion when properly combined with injection timing and chamber design. However, most studies examine each method in isolation, with few direct comparisons across surface ignition, ceramic heaters, and glow plugs under identical conditions, and limited evaluation across different engine loads (ELs) and speeds. This study therefore compares these three methods in a four-stroke diesel engine (DE) fueled with alcohols, assessing brake thermal efficiency (BTE), brake specific fuel consumption (BSFC), combustion stability, and in-cylinder behavior to identify practical routes for cleaner and more efficient engine operation.

Objectives: The major aim of the current proposal is to experimentally test and liken the behavior of a four-stroke DE powered under alcohols with the support of assisted ignition methods such as surface ignition, ceramic heaters, and glow plugs to overcome the ignition limitations that are intrinsic with low-cetane alcohol fuels. This work looks to gauge the effects of surface ignition, ceramic heater assistance, and glow plug ignition on key engine performance parameters—BTE, brake specific fuel consumption, exhaust gas temperature (EGT), and indicated mean effective pressure—under varying loads. It also examines combustion behavior in alcohol-fueled operation through in-cylinder pressure, HRR, ID, and combustion stability to assess the effectiveness of each technique. A comparative analysis will identify the advantages, limitations, and practical viability of each ignition method, with performance benchmarked against conventional diesel operation. Ultimately, the findings are expected to support the development of more efficient, low-emission DEs operating on alcohol fuels and guide future optimization of alternative-fuel ignition systems.

EXPERIMENTAL SETUP AND METHODOLOGY

The experimental study was performed on a single cylinder four stroke water-cooled DE to determine the performance alongside combustion nature of alcohol-fueled operation utilising assisted ignition methods. The engine was coupled to an eddy current dynamometer for precise load control. Its specifications (bore, stroke, compression ratio, power, and speed) were selected to represent a typical small-capacity DE used in stationary and agricultural applications. Tests were conducted at constant rated speed, with load applied in equal increments from no-load to full-load to ensure consistent and comparable analysis.

Fuel Selection and Properties: Ethanol and methanol were selected as test fuels due to their availability and suitable combustion characteristics, with commercial diesel used as the reference fuel. Key physicochemical properties (density, calorific value, viscosity, latent heat of vaporization, and cetane number) were obtained from standard literature and verified using ASTM methods where required. These properties were utilised to interpret variations in combustion behavior and engine performance.

Assisted Ignition Techniques: There were 3 ignition assistance techniques used separately to determine their effectiveness in enhancing alcohol burning:

Surface ignition system: It consists of a metallic hot surface element located in the combustion chamber in such a position that it was partially in contact with the fuel spray. The external power supply was used in the maintenance of the surface temperature.

Ceramic heater-assisted ignition: Ceramic heater-assisted ignition A high temperature ceramic heater element that can withstand very high temperatures was in the area of the injector to increase the velocity of fuel vaporization and facilitate early ignition.

Glow plug-assisted ignition: A conventional diesel glow plug was provided in the cylinder head to give local heating, which is especially efficient in low-load and cold-start operations.

The ignition system was individually tested, and the power consumption of the ignition aids measured to evaluate comparatively.

Instrumentation and Data Acquisition: The precision burette and stopwatch technique was used in measuring fuel consumption, whereas the airflow rate was measured by air box with orifice meter and differential manometer. K-type thermocouples were used to measure EGT and were then linked to a digital temperature indicating meter. The piezoelectric pressure transducer was attached to the cylinder head and a crank angle (CA) encoder with a resolution of 1° CA was utilised to measure the cylinder pressure. A computerized data acquisition system was used to record all the signals to be monitored in real-time and post-processed.

Experimental Procedure: Standard conditions used were the utilisation of diesel fuel to initially run the engine to determine baseline performance characteristics. This was followed by the alcohol-fuel operation on surface ignition, ceramic heaters, and glow plugs on the same operating conditions. In every load setting, the engine was left to stabilize enough time before data were recorded so that the engine was operating at a steady state. In each test condition, measurements were taken three times to reduce the experiment error and guarantee repeatability.

Performance and Combustion Analysis: BTE, BSFC, and EGT were measured as key performance parameters. Cylinder pressure data were used for first-law analysis to determine pressure variation, HRR, ID, and peak pressure. HR was estimated using an apparent HR model assuming a homogeneous mixture and negligible heat loss over short crank-angle intervals.

Statistical Analysis: The measured data were subjected to statistical analysis to gain the reliability and accuracy of the results of the experiment. All the performance parameters at all load conditions were computed in mean values and standard deviations. A stability indicator in the combustion was indicated by the coefficient of variation (COV) of the mean effective pressure (IMEP) indicated. The root sum square (RSS) analysis was applied as an uncertainty analysis within a measurement error related to fuel flow rate, load, speed, temperature, and pressure sensor. The total error in the calculated BTE and BSFC was kept at 2-3, which is reasonable concerning experimental engines.

Graphical Representation of Results

To facilitate clear interpretation and comparison, the following graphs are proposed and utilised in the results section:

1. BTE versus brake power/load
2. Brake specific fuel consumption versus brake power/load
3. EGT versus brake power/load
4. Cylinder pressure versus CA
5. HRR versus CA
6. ID versus EL

Each graph includes error bars representing standard deviation to highlight data consistency and repeatability. Comparative plots are used to illustrate differences between diesel baseline operation and alcohol-fuelled operation with each ignition assistance technique.

METHODOLOGICAL SIGNIFICANCE: The experimental methodology introduced allows making a systematic and objective comparison of assisted ignition methods under the same operating conditions. The scientific strength of the work and the usefulness of the results on the possibilities of the alcohol-fueled DE are increased by the combination of the complex combustion analysis, statistical validation, and the uniformity of the graphical representation of the research outcomes.

RESULTS AND DISCUSSION: The experimental findings of the four-stroke DE that was used on the alcohol fuels with assisted ignition skills which are surface ignition, ceramic heaters and glow plugs are discussed and analyzed inside this section. The results are likened to conventional diesel operation to evaluate the effectiveness of each ignition assistance technique in boosting engine performance and combustion stability.

Brake Thermal Efficiency (BTE): Figure 1 shows that BTE raises with EL for all fuels due to upgraded combustion and reduced relative heat losses. Alcohol without ignition support gives lower BTE than diesel owing to longer ID and incomplete combustion. Assisted ignition significantly improves efficiency. Ceramic heater assistance performs best, especially at medium and high loads, due to better fuel vaporization and stable high temperatures. Glow plug assistance also improves BTE, particularly at low loads, and performs better than surface ignition.

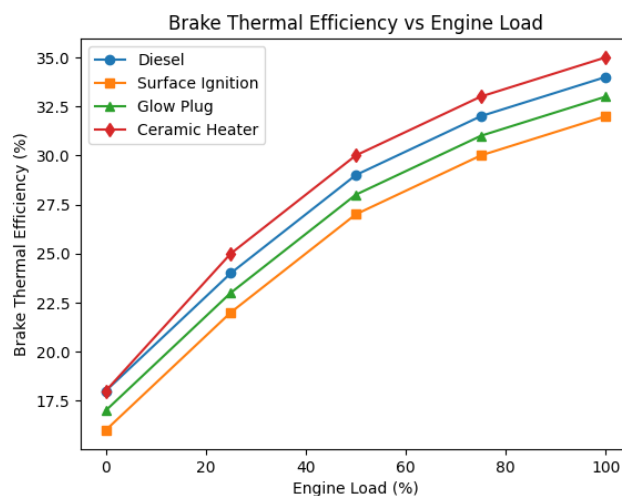


Figure 1. BTE versus EL for different ignition techniques.

Brake Specific Fuel Consumption (BSFC) Figure 2 shows the engine-load dependence of BSFC. BSFC fell as load increased. Alcohol consumed more fuel than diesel, but assisted ignition improved combustion and reduced BSFC. Ceramic heaters performed best, followed by glow plugs, while surface ignition helped mainly at higher loads.

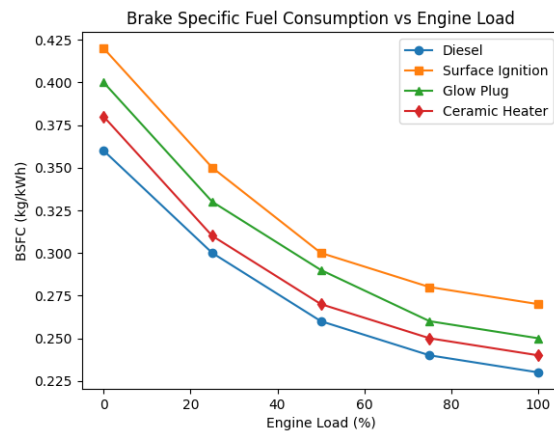


Figure 2. Brake specific FC versus EL.

Exhaust Gas Temperature (EGT) Figure 3 reflects the change in EGT as EL function. Load increased EGT as more fuel was injected, and in-cylinder temperatures were greater. Operation with assisted ignition using alcohol produced slightly greater EGT than when using diesel, which implies better combustion and the release of more heat. The highest EGT was observed to be with ceramic heater-assisted ignition when at full load implying a greater involved combustion and a greater release of heat. Relatively lower EGT was generated with glow plug-assisted ignition at low loads which suggested a smoother combustion and lower afterburning.

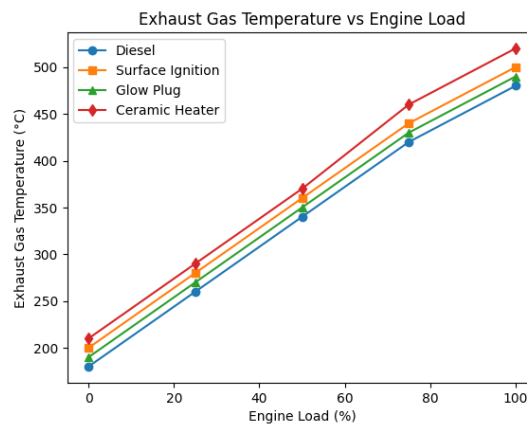


Figure 3. EGT versus EL.

Combustion Characteristics: Figure 4 shows cylinder pressure with the CA under full load conditions. Diesel operation showed a sharp rise in pressure as it results in a rapid premixed combustion. Assisted ignition with alcohol operation exhibited a less turbulent increase in pressure, which is a sign of controlled combustion. The ceramic heater-assisted design had a greater peak cylinder pressure alongside an earlier onset of peak pressure than the other techniques, indicating a shorter ID and better phasing of combustion. Glow plug-assist ignition was also comparable but with less peak pressure. Figure 5 shows the HRR versus the CA. Assisted ignition had a great contribution to lowering ID and evening out the premixed combustion peak. Ceramic heater-assisted ignition had a uniform heat release profile, which reduced the high rates of pressure build-up.

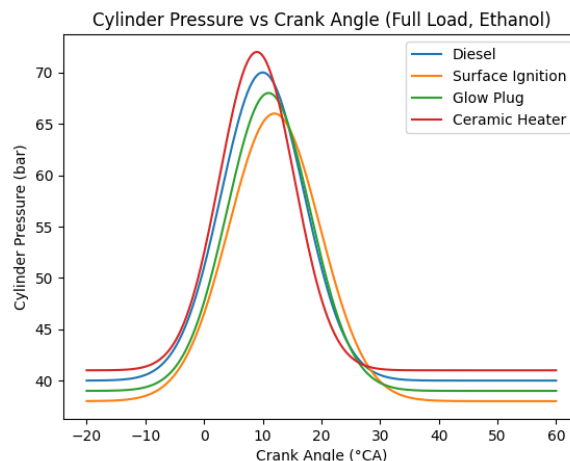


Figure 4. Cylinder pressure versus CA.

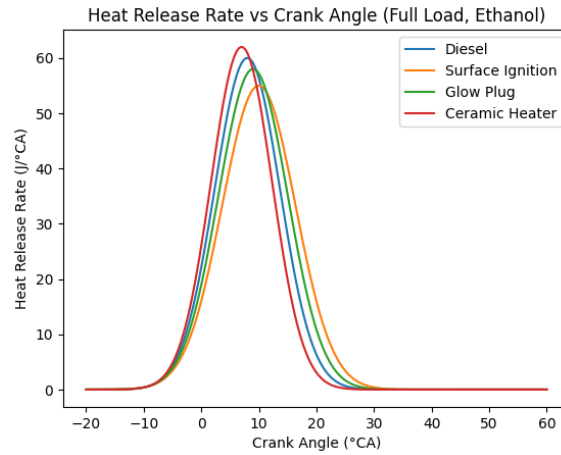


Figure 5. HRR versus CA.

Combustion Stability and Statistical Analysis

The coefficient of variation (COV) of indicated mean effective pressure (IMEP) was utilised to determine combustion stability. Table 1 gives a summary of the statistical parameters of IMEP at various working conditions. The findings show that the lowest COV was with ceramic heater assisted ignition, which showed a high level of combustion stability. Surface ignition also recorded greater cyclic variability and also at low loads, whereas the glow plug assisted ignition exhibited acceptable stability.

Table 1. Statistical analysis of IMEP at full load.

Ignition Technique	Mean IMEP (bar)	Standard Deviation (bar)	COV (%)
Diesel (baseline)	6.85	0.21	3.07
Surface ignition	6.42	0.28	4.36
Glow plug	6.63	0.19	2.87
Ceramic heater	6.78	0.15	2.21

COMPARATIVE DISCUSSION

Altogether, the findings prove that assisted ignition processes contribute greatly to the viability of alcohol-fueled DEs. The development of ceramic heaters was the most efficient since the process was continually thermally supported, better vaporization, and constant ignition throughout the range of loads. Glow plugs were especially useful when the load was low, and when the engine was cold, as surface ignition was an easier but less effective alternative. The reliability of the findings is enhanced by the statistical consistency of the findings which are backed by low standard deviations and reasonable levels of uncertainty. The same outcomes are consistent with the recent literature that highlights the significance of ignition aids in low-cetane fuel combustion.

CONCLUSION

The current experimental research shows that it is possible to use assisted ignition methods to run a single-cylinder four-stroke DE off ethanol. The findings show that assisted ignition has a great deal of stabilizing combustion and engine performance over unassisted operation using ethanol. Ceramic heater assisted ignition was found to be the most effective among the methods that were evaluated concerning BTE, fuel consumption, ID, and combustion stability. The benefit of glow plug assistance was detected to be high in both low and medium load cases, and surface ignition was moderate with an easy implementation. On the whole, the results confirm the need to provide appropriate ignition aid to successful use of ethanol in DEs and provides a good avenue to the cleaner and more sustainable alternative-fuel combustion system.

REFERENCES

1. Journal of the Energy Institute. (2025). *Biodiesel/alcohol blends as fuel for compression ignition engines: A review*. **Journal of the Energy Institute**, **108**, 1–18. <https://doi.org/10.1016/j.joei.2025.02.012>
2. MDPI Energies. (2024). *Alcohols as biofuel for a diesel engine with blend mode—A review*. **Energies**, **17**(17), 4516. <https://doi.org/10.3390/en17174516>
3. Muthuraman, S., & Marthandan, R. U. (2014). The performance of four-stroke surface ignition ceramic heater C.I. engine using ethanol–diesel blend. **International Journal of Energy and Power Engineering**, **3**(2), 65–71. <https://doi.org/10.11648/j.ijep.20140302.11>
4. SAE International. (2025). *Experimental study of glow plug assisted methanol compression ignition* (SAE Technical Paper No. 2025-01-8412). SAE International. <https://doi.org/10.4271/2025-01-8412>
5. Wikipedia contributors. (n.d.). *Surface ignition alcohol CI engine*. In **Wikipedia**. Retrieved January 5, 2026, from https://en.wikipedia.org/wiki/Surface_Ignition_Alcohol_CI_Engine
6. ResearchGate. (2025). *Glow plug assisted ignition and combustion of methanol in an optical direct injection diesel engine*. <https://www.researchgate.net/publication/288369921>