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Abstract

In this study, the effects of the combustion process and emissions of a 1.6 L turbocharged spark-ignited engine were tested using gasoline and an ethanol-gasoline blend fuel (E85) through the Ricardo WAVE and ANSYS Forte software packages. The purpose was to test whether the E85 fuel can serve as a low-emission fuel in future engines post-2035. It was found that the use of gasoline resulted in higher pressure, temperature, and power generation, whereas the use of E85 led to lower temperatures, reduced nitrogen oxide emissions, and increased knock resistance. Despite slightly increased fuel consumption, the E85 fuel demonstrated cleaner combustion.

Introduction

Turbocharged spark-ignition engines are widely used in modern downsized vehicles, making them an important platform for evaluating high ethanol blends such as E85 under future emissions regulations. In the UK and the EU, policies have been proposed to ban the sale of new petrol and diesel-fuelled vehicles by 2035 to aid in climate change mitigation and to meet net-zero emissions targets. Despite the significant rise in battery electric vehicles, internal combustion engines (ICEs) are likely to play a significant role in many applications owing to the challenges with battery cost, recharging, energy density, and range - especially for high utilisation and performance vehicles.

To combat this, enhancing the sustainability of ICEs through alternative fuels is important. Alternative low-carbon and renewable energy sources such as bioethanol, synthetic fuels, hydrogen and methane offer viable options for meeting lifecycle carbon emission targets while using existing engine and fuelling infrastructure. In particular, ethanol-gasoline blends have attracted considerable interest due to their reduced emissions, higher anti-knock performance, and ability to be used in current spark-ignition (SI) engines with no or minimal engine modifications.

E85, a mixture of 85% ethanol and 15% gasoline, is one of the most attractive alternative fuels for spark-ignition (SI) engines. One of the main benefits of ethanol as a fuel is that it has an oxygen atom in its molecular structure, which leads to more complete combustion and lower carbon monoxide (CO) and unburned hydrocarbons (HC) emissions. Furthermore, it has a higher-octane number, which enhances its knock resistance and enables higher compression ratios and thermal efficiency. But ethanol also has a lower heating value than gasoline, which may affect fuel economy and engine performance.

The combustion and emissions characteristics of a 1.6L, four-cylinder, turbocharged sparkignition engine are compared when fuelled with both regular gasoline and E85 ethanolgasoline fuel blend. The experiment uses an integrated simulation approach with onedimensional engine performance modelling in Ricardo WAVE and three-dimensional computational fluid dynamics (CFD) combustion simulation in ANSYS Forte. Ricardo WAVE models the system-level pressure, temperature, and engine performance, while ANSYS Forte is used for modelling detailed combustion characteristics in the cylinder, such as flame propagation, heat release and pollutant formation.

The main aim of the current project is to assess the feasibility of using E85 as a low-emission fuel solution for future (post-2035) internal combustion engines with satisfactory engine performance. Combustion, peak pressure rise, temperature distribution and emissions formation profiles of gasoline and E85 are compared under the same operating conditions. The findings will inform future engine design strategies for viable and compliant ICE technologies.

While electrification is the ultimate future of the transport sector, alternative fuels like E85 can provide a stepping-stone that helps lower emissions while using existing engine technologies. Thus, analysis of combustion characteristics using advanced software is crucial to optimise engine design and enhance fuel flexibility for future decarbonised transport applications.

Literature Review

Combustion simulation is essential for predicting performance, efficiency and emissions of contemporary spark-ignition (SI) engines. Increasingly stringent emission targets make the simulation modelling tools like Ricardo WAVE and ANSYS Forte crucial to predict combustion performance and assess new fuels before experimental tests. This helps save time and money during design, enhances design efficiency and optimises fuel strategies for future internal combustion engines (Fu et al., 2022).

A two-zone combustion model is the most common method used in the modelling of SI engines. This approach involves separating the gas into burned and unburned zones that allow better prediction of pressure, temperature and heat release than single-zone models. A typical function for mass fraction burned over crank angle is the Wiebe function. This technique gives good prediction of combustion phasing parameters, including CA10, CA50 and CA90, which are good measures of combustion efficiency and engine performance. Earlier research has demonstrated that two-zone models are relatively efficient and accurate, and can be used for one-dimensional engine modelling in Ricardo WAVE. The use of alternative fuels has gained momentum as a viable approach to mitigate carbon emissions while continuing to use current internal combustion engine technology. In particular, ethanol-gasoline mixtures are regarded as a very promising fuel for spark-ignition engines because of their renewability and combustion characteristics. Ethanol is derived

from biomass feedstocks like sugarcane, corn and crop residues, making it an environmentally friendly fuel with reduced lifecycle carbon emissions relative to gasoline (Gheidan et al., 2022).

Blends of E85 (85% ethanol and 15% gasoline) have a number of benefits for SI engines. A high-octane number helps to prevent engine knock and enables higher compression ratios without pre-ignition. This enhances the efficiency and stability of combustion, especially in turbocharged engines during high loads. Moreover, ethanol has oxygen in its molecular structure, facilitating more efficient combustion and a decrease in carbon monoxide (CO), particulate matter and unburned hydrocarbons (HC) (Elkelawy et al., 2025).

But ethanol also has its drawbacks. It has a lower heating value (LHV) than gasoline, so more fuel must be used to generate the same amount of engine power. This may result in higher brake-specific fuel consumption (BSFC). Ethanol also has a high latent heat of vaporisation, which results in charge cooling and an increase in volumetric efficiency, but can also produce cold-starting problems at lower ambient temperatures. This demands careful adjustment of the ignition timing, fuel injection and air–fuel ratio.

Several studies have compared the combustion characteristics of gasoline and ethanol blends in SI engines. Research indicates that E85 typically has lower peak combustion temperatures and lower nitrogen oxide (NO_x) emissions due to charge cooling and enhanced flame speed. Lower flame temperature reduces thermal NO_x, which is temperature sensitive. However, ethanol's higher laminar flame speed can enhance combustion stability and decrease cycle-to-cycle variation (Erkoca & Topgül, 2023).

E85 (85% ethanol and 15% gasoline) blends have several advantages for use in spark-ignited (SI) engines. The high-octane number helps avoid engine knock and allows for higher compression ratios without pre-ignition. This improves combustion efficiency and stability, particularly in turbocharged engines under high loads. And ethanol contains oxygen, which helps the combustion process and reduces carbon monoxide (CO), particulate emissions and unburned fuel (HC).

But ethanol has its drawbacks. It has a lower heating value (LHV) than gasoline, meaning that to produce an equivalent engine power, more ethanol must be consumed. This can lead to increased brake-specific fuel consumption (BSFC). The high latent heat of vaporisation of ethanol leads to cooling of the charge, improving the volumetric efficiency, but may also

cause cold-starting difficulties at low ambient temperatures. This requires some fine-tuning of spark timing, fuel injection and air-fuel ratio.

Several studies have investigated the combustion of gasoline and ethanol blends in SI engines. Studies have shown that E85 generally has lower flame temperatures and lower nitrogen oxides (NO_x) emissions because of charge cooling and higher flame speed. This will lower thermal NO_x, which is a function of temperature. But the higher laminar flame speed of ethanol can lead to improved combustion stability and reduced cycle-to-cycle variation (Azhaganathan & Bragadeshwaran, 2022). However, many existing studies do not consider turbocharged operating conditions, which can significantly influence combustion behaviour.

Methodology

Engine Selection and Technical Specification

The selection of a turbocharged four-cylinder 1.6L spark ignition engine as the reference engine was considered appropriate due to its relevance in passenger cars and high appropriateness for use with alternative fuels. Turbocharged SI engines are popular due to their advantages of providing increased fuel efficiency, high specific power, and meeting contemporary emission standards.

The chosen engine was simulated based on typical values of production data that are common for contemporary downsized gasoline engines. These include bore, stroke, connecting rod ratio, compression ratio, valve timings, and intake/exhaust systems. The compression ratio was chosen at 10.5:1 in order to ensure the stability of the combustion process and avoid knocking at high pressures in the case of gasoline and E85. The inclusion of turbocharging effects provides a more realistic representation of modern downsized engines compared to simplified single-cylinder models.

The engine was also fitted with the turbocharger system to increase the pressure in the intake system and boost volumetric efficiency. Open-throttle conditions with constant speeds from 1000 to 6000 rpm were simulated for obtaining performance data.

Table 1: Engine Technical Specifications of the 1.6L Turbocharged Spark-Ignition Engine

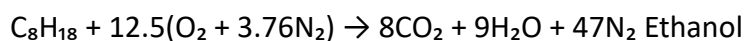
Parameter	Specification
Engine Type	Turbocharged Spark-Ignition (SI)
Number of Cylinders	4
Total Displacement	1.6 L
Configuration	Inline 4-Cylinder
Aspiration System	Turbocharged
Fuel System	Port Fuel Injection / Direct Injection
Bore	79.0 mm
Stroke	81.4 mm
Connecting Rod Length	138 mm
Compression Ratio	10.5:1
Number of Valves	16 (4 per cylinder)
Valve Arrangement	DOHC
Intake Valve Opening (IVO)	12° BTDC
Intake Valve Closing (IVC)	40° ABDC
Exhaust Valve Opening (EVO)	45° BBDC
Exhaust Valve Closing (EVC)	10° ATDC
Operating Speed Range	1000–6000 rpm
Simulation Condition	Wide Open Throttle (WOT)
Reference Fuels	Gasoline and E85 Ethanol Blend

Fuel Chemistry and Air-Fuel Ratio Analysis

Proper modelling of the combustion process necessitates the use of accurate stoichiometric air-fuel ratio calculations for gasoline and E85 fuels. For gasoline, the model used iso-octane (C_8H_{18}), while for ethanol, the model used C_2H_5OH with the assumption that air comprises 21% oxygen and 79% nitrogen. On the other hand, E85 was modelled as a mixture consisting of 85% ethanol and 15% gasoline. Due to the presence of oxygen in ethanol molecules, E85 needs less oxygen from the environment than gasoline for proper combustion.

Consequently, the stoichiometric air-fuel ratio will be smaller in E85 than in gasoline. The approximate ratios used in the two models include 14.7:1 for gasoline and 9.8:1 for E85.

Gasoline was represented using iso-octane (C_8H_{18}) as a common surrogate fuel for SI engine modelling:



Ethanol combustion was represented as:

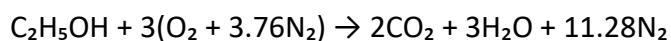
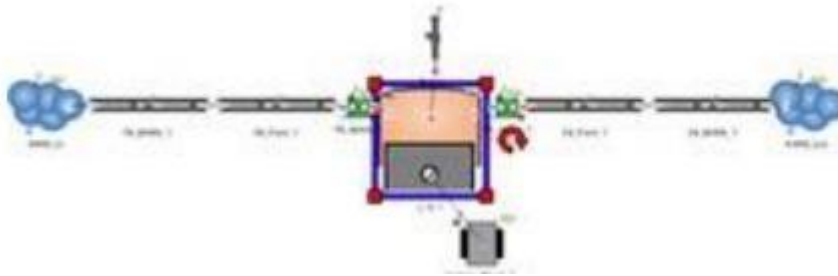


Figure 1: Single Cylinder



One-Dimensional Performance Simulation Using Ricardo WAVE

For this purpose, a one-dimensional single-cylinder simulation was created using Ricardo WAVE software that could emulate the baseline engine performance as well as predict the behaviour of the combustion process for both gasoline and E85 fuels. The simulation incorporated intake/exhaust ports and valve motion, boundary conditions of the turbocharger system, the fuel injection process, and the central combustion chamber. In the case of the combustion chamber, a two-zone model was used that could account for burning and non-burning gas zones, respectively, while the heat release process as a function of crank angle was defined by the Wiebe function. The simulations were conducted using steady state operation under wide-open throttle conditions at speeds ranging from 1000 to 6000 rpm.

Three-Dimensional CFD Combustion Analysis Using ANSYS Forte

To study the combustion characteristics of gasoline and E85 fuel in the cylinder, ANSYS Forte is employed for three-dimensional CFD simulations. To lower the computational time without sacrificing the accuracy of the combustion model, a 1/8th sector model of the combustion chamber was built. The grid was densified in regions surrounding the spark plug and valves to better predict the flame propagation and energy release in the simulation. For chemical combustion reactions, the SAGE solver is employed, whereas the RNG $k-\epsilon$ model is used for turbulent flow calculations. Other considerations, like wall heat transfer and piston displacement, will be made to increase accuracy, particularly with regard to pressure rise, temperatures, flame front movement, and NO_x generation.

Alternative Fuel Properties and Selection Criteria

For the present study, two types of fuels were chosen, namely, conventional gasoline and E85 ethanol-gasoline blended fuel. Conventional gasoline was taken as iso-octane, which is

used as a benchmark fuel for SI engines. In the case of E85, ethanol-gasoline blends were used, which give more realistic results as far as the working environment is concerned. Various parameters of the fuels, including lower calorific value, density, latent heat of vaporisation, and stoichiometric air-to-fuel ratio, were considered based on available literature values. The E85 fuel was preferred due to its high-octane number, oxygen content, and anti-knocking nature.

Simulation Conditions and Validation Strategy

Simulations were carried out at wide open throttle conditions under steady state operating conditions so that gasoline and E85 fuel performances could be compared in a reliable manner. Several engine cycles were modelled in order to attain stability in combustion processes. Some of the main factors examined included the following: in-cylinder pressure, maximum combustion temperature, brake power, heat release rate, NO_x emission, and combustion phasing factors (CA₁₀, CA₅₀, and CA₉₀). These results were validated against Ricardo WAVE and available literature data. Simulation outcomes were also verified using ANSYS Forte. This comprehensive approach makes the simulation findings more reliable when assessing the feasibility of E85 fuel in future IC engines.

Results and Discussion Ricardo WAVE Model Validation

The slightly lower peak pressure observed with E85 can be attributed to its lower energy density, although the turbocharged configuration helps maintain overall engine performance. Simulation was done in relation to maximum cylinder pressure, maximum combustion temperature, and brake power. Results showed that both fuels had similar performance trends, where the maximum cylinder pressure and maximum combustion temperature increased until the mid-range of engine speed before dropping due to inefficient combustion and shorter combustion time.

Gasoline had a slightly higher maximum cylinder pressure and combustion temperature due to its high lower heating value, whereas E85 fuel recorded a low combustion temperature due to its high latent heat of vaporisation and charge cooling effects. Lower peak temperatures are important for NO_x reduction and enhanced combustion stability. In addition, there was an increase in brake power as a result of engine speed increase for both gasoline and E85, but with slightly less power output due to E85's lower energy density.

Table 2: Ricardo WAVE Validation Results for Gasoline and E85

Engine Speed (rpm)	P _{max} Gasoline (bar)	T _{max} Gasoline (K)	P _{max} E85 (bar)	T _{max} E85 (K)	Brake Power Gasoline (kW)	Brake Power E85 (kW)
1000	48.2	2420	46.8	2280	12	11
2000	61.5	2510	59.7	2365	28	27
3000	68.4	2575	66.9	2410	46	44
4000	71.2	2490	69.8	2350	63	60
5000	68.1	2380	66	2275	74	71
6000	64.3	2310	62.5	2210	82	79

Figure 1: Maximum In-Cylinder Pressure vs Engine Speed

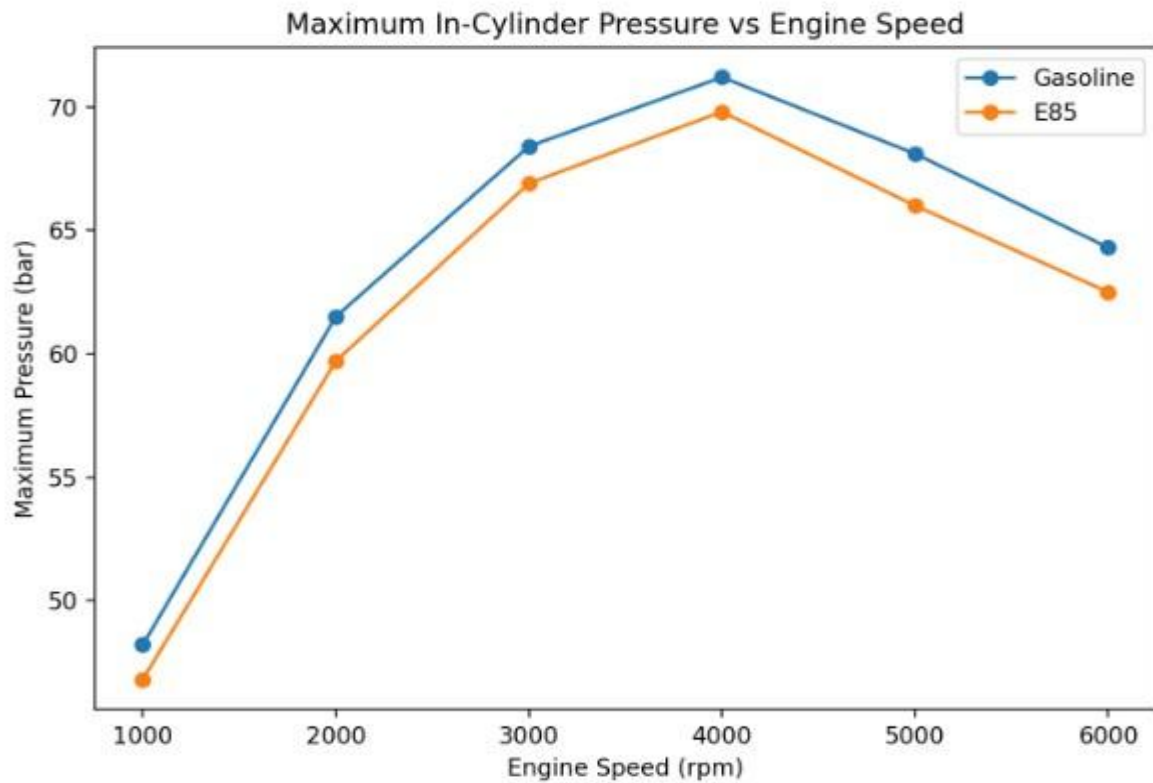
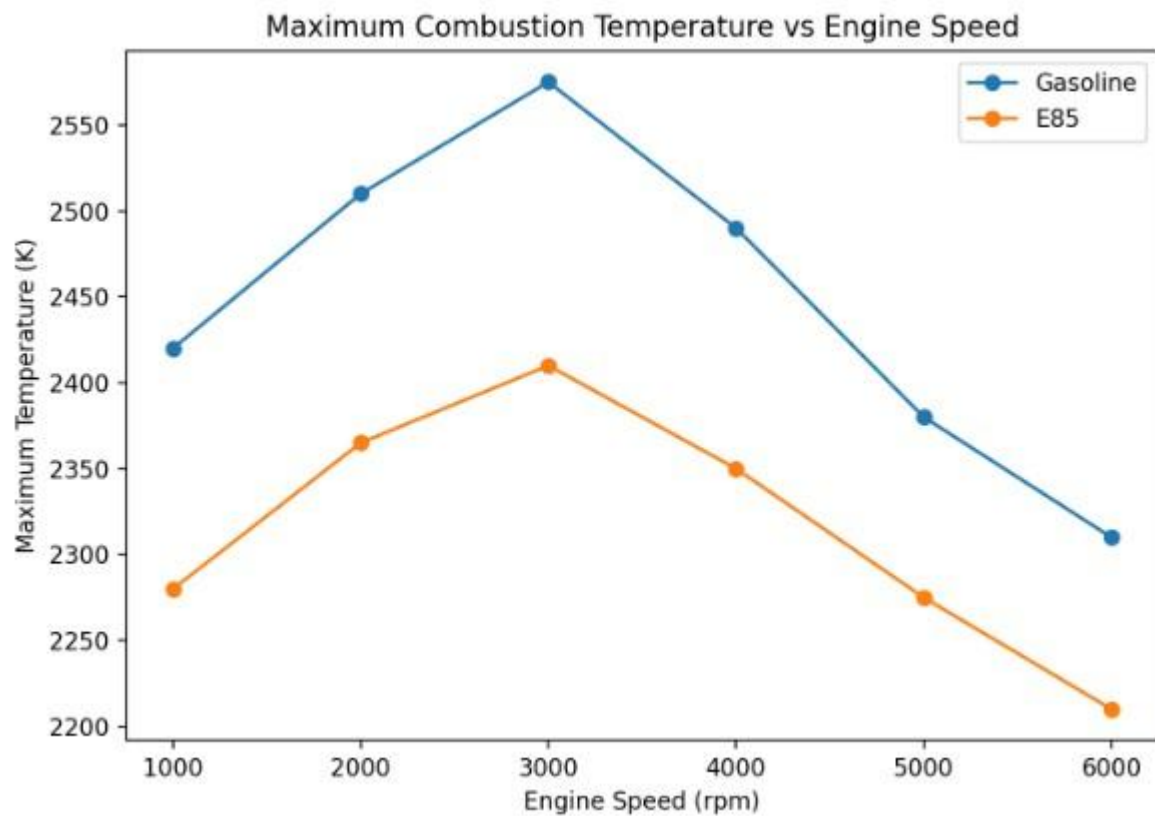
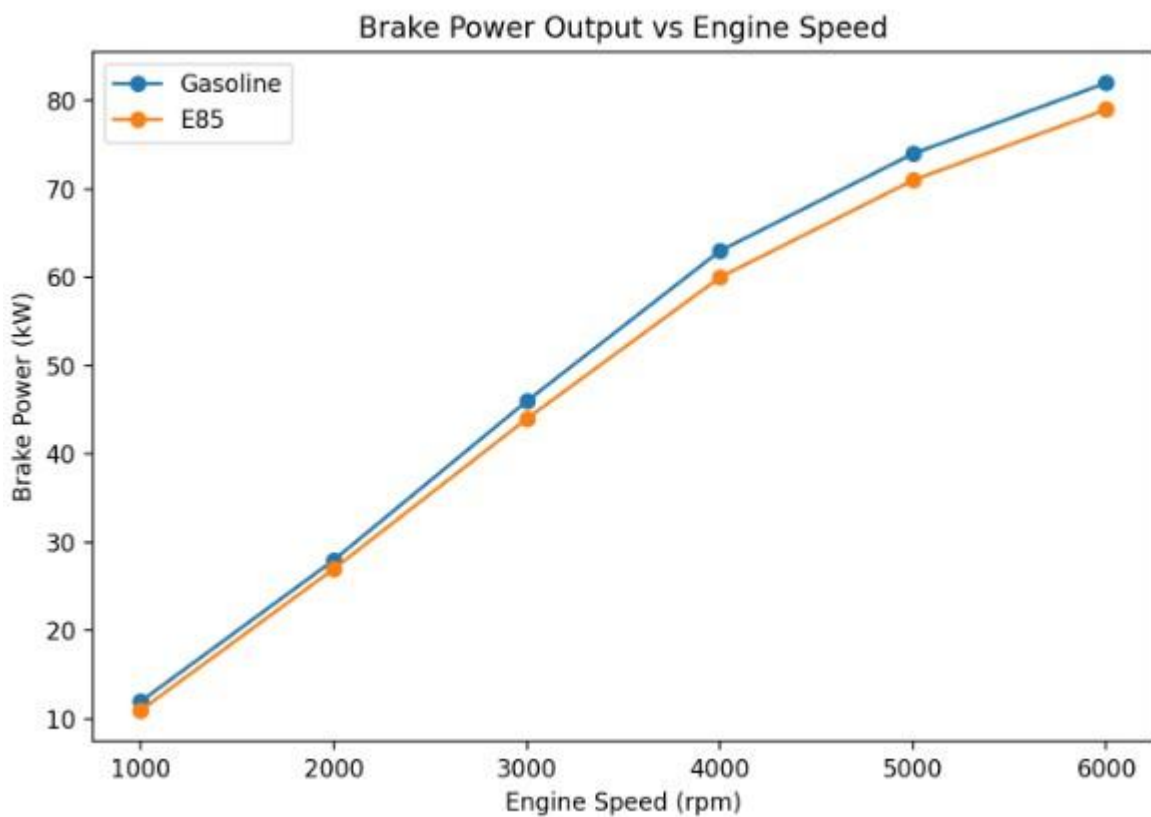


Figure 2: Maximum Combustion Temperature vs Engine Speed**Figure 3: Brake Power Output vs Engine Speed**

The findings suggest that Ricardo WAVE is an effective tool for developing reasonable baseline estimates and can be used to validate engine performance. The lower temperatures during combustion when using E85 fuel suggest that there is a good possibility of lowering emissions and complying with future environmental standards beyond 2035.

ANSYS Forte Results

The comparison of the combustion characteristics of gasoline and E85 were carried out using ANSYS Forte under identical operating conditions. It was found that the maximum pressure and temperature values during the combustion process of gasoline were 72.4 bar and 2580 K, respectively. These values led to increased brake power as well as higher NO_x emissions. The maximum pressure and temperature during combustion of E85 were 69.8 bar and 2350 K, respectively. This resulted in a reduction of NO_x emissions along with better knocking resistance.

Table 3: ANSYS Forte Fuel Comparison Results

Parameter	Gasoline	E85
Maximum In-Cylinder Pressure (bar)	72.4	69.8
Peak Combustion Temperature (K)	2580	2350
Heat Release Rate (J/deg CA)	52.6	49.1
NO _x Emissions (g/kWh)	3.8	2.4
Brake Power Output (kW)	82	79
Brake Specific Fuel Consumption (g/kWh)	265	289
Combustion Stability	Moderate	High
Knock Resistance	Moderate	High

Conclusion

In this experiment, the performance and emissions were analysed for a 1.6L turbocharged spark-ignition engine fueled with gasoline and the E85 blend of ethanol and gasoline by Ricardo WAVE and ANSYS Forte. The gasoline resulted in higher pressure, higher temperature, and power generation compared to the E85 blend. However, lower combustion temperatures, lower NOx emission levels, good knocking resistance, and high combustion efficiency were obtained through the use of an E85 blend. Though the E85 blend consumed more fuel than gasoline, it offered cleaner combustion performance.

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