
Pravin Nitnaware (ptnitnaware@dypcoeakurdi.ac.in)  
D Y Patil College of Engineering Akurdi Pune-411044

Jiwak Suryawanshi  
Visvesvaraya National Institute of Technology

Research Article

Keywords:

Posted Date: February 20th, 2023

DOI: https://doi.org/10.21203/rs.3.rs-2591507/v1

License: This work is licensed under a Creative Commons Attribution 4.0 International License. Read Full License
Abstract

Alternative fuels are the need of the current situation as conventional fuels are depleting very quickly and causing increase in amounts of pollution. Hydrogen as a clean fuel with Higher Calorific Value plays important role in increasing combustion characteristics. When compared with the performance of ethanol as a fuel, ethanol-hydrogen blends have demonstrated a 5% increase in power production, 15% reduction in hydrocarbon emissions, and 12% reduction in carbon dioxide emissions. All tests are conducted at speed of 2500, 3000, 3500, 4000, and 4500 rpm with the Wide-Open-Throttle (WOT) condition. CO & HC emissions are reduced using ethanol, whereas hydrogen addition enhanced the decreased power output, higher brake-specific fuel consumption and in cylinder pressure.

1. Introduction

Research is being done on sources of alternative fuels and renewable energy sources to prevent and minimize total dependence on fossil fuels. Some of these resources include hydrogen and ethanol. Since ethanol has a greater octane rating than gasoline, it can withstand higher compression pressures without experiencing any knocking. However, due to its lower heating value, ethanol has a lower energy density per gallon than gasoline. Compared to petroleum products, ethanol burns in the air more thoroughly and cleanly, and it also creates less carbon dioxide and hydrocarbons. Because ethanol has a higher-octane rating than gasoline, it can operate spark ignition engines with higher compression ratios and a considerably higher rate of exhaust gas recirculation without experiencing any sort of knocking. When using ethanol as fuel, engine oil doesn’t become contaminated for a longer period of time, and the engine is put under less stress, which lowers the cost of engine maintenance overall. Ethanol is also less expensive than alternative bio fuels.

Because ethanol has a lower energy density than gasoline, it requires 1.5 times as much ethanol to drive the same distance. Due to its high enthalpy of vaporization, ethanol lowers the combustion temperature and slows laminar flame speed. Since pure ethanol is very difficult to evaporate, starting a car in cold weather is challenging because fuel injection becomes challenging.

Because of its capacity to absorb water, ethanol is extremely corrosive. Because prolonged sitting of ethanol with absorbed water in gasoline and tank lines might result in serious corrosion.

In SI engines, hydrogen and ethanol can be used to overcome the drawbacks of using ethanol alone. Due to its increased heating value, hydrogen can increase the energy density of a mixture as a whole. Additionally, the addition of hydrogen can boost power output while decreasing specific fuel consumption and toxic emissions. This is possible because of hydrogen’s high-octane number.

This study investigates the impact of combining ethanol and hydrogen on the SI engine’s performance at MBT spark timing.

2. Literature Review
The compression ratio rises with increased substitution of hydrogen to ethanol. The combustion duration shortens due to an increase in end-of-compression temperature and pressure [1]. The ideal operating condition is at CR 11:1 with a 60–80% hydrogen replacement of the ethanol in the fuel. Under stoichiometric conditions, the stated engine power slightly increases with rising ethanol percentage, but the ISEC values fall [2]. The TDC was closer with increasing ethanol levels, maximum in-cylinder pressure, maximum normalized HRR data, and pressure data. Additionally, the emissions of CO and particular THC significantly improved when the ethanol ratio increased. The greatest reduction in specific CO emissions was 7.33%, and the greatest reduction in THC emissions was 6.62%. According to research, raising the ethanol ratio caused NOx emissions to rise by 14.29%. The high flame speed and oxygen concentration of ethanol fuel are the cause of this rise. Ethanol and methanol's evaporative cooling action always increases PN emissions after the dopant addition eliminates the diluting impact [3]. The effects of dilution-based suppression and evaporative cooling-based augmentation on PN emissions are not homogeneous. The evaporative cooling effect on PN formation depends on the operating condition and injection timing since the fuel vaporization details depend on the fuel film geometry and the heat and mass transfer processes. Ethanol engines use less specific fuel as a result of improved hydrogen addition [4]. The hydrogen-infused gasoline's advantage is that it uses less hydrogen than conventional fuel, which greatly eliminates issues with hydrogen storage in automobiles. Due to its high heat of vaporization, ethanol fuel lowers the peak temperature inside the cylinder, which in turn lowers NOx emissions. As the percentage of hydrogen addition rose, nitrogen oxide emissions also increased. Although NOx emissions increased as CR increased, ethanol fuel at 12 CR with hydrogen addition (0-3.5 mass%) was still less polluting than gasoline fuel at 7 CR. Engine power is higher with ethanol that contained any amount of hydrogen than it was with pure gasoline. The E15 fuel ratio increased combustion duration while reducing premixing combustion duration, resulting in low emissions, high indicated power, and efficiency with little fuel consumption (at 12 to 18° CA a TDC) [5]. These outcomes are the result of bio ethanol's low carbon content, which prevents soot formation and necessitates less air for the combustion of fuel mixtures with low luminosity and radiation. Except for E5, when the engine ran on E10 or E15 fuel at 2700 rpm, the emissions were comparatively low, and the performance was slightly improved. Due to the accelerated combustion that produced a greater in-cylinder pressure and temperature than that of E0 and E15, the rate of NOX generation increased more rapidly with E5 and E10 than it did with E0 and E15. The varied ethanol and gasoline ratios show that utilizing ethanol reduces the levels of HC and CO emissions as compared to using gasoline [6]. Compared to gasoline, ethanol-gasoline blends consume more fuel due to a decrease in caloric value. As the percentage of the additive is increased, the thermal efficiency of the brakes increases. In the future, ethanol may be utilized as an additive for gasoline as the E60 and E40 produced the best results for all evaluated parameters at all engine loads. Brake thermal efficiency rises as the volume percentage of ethanol fuel in the mixture does as well. E60 increases load with good thermal efficiency. Specific fuel consumption rises as the proportion of ethanol in fuel does. This is because ethanol has a lower heating value than gasoline; E60 performs better than E0 and E20. Theoretical analysis and simulation to evaluate the relative change in SI engine performance when using hydrogen and alcohol in addition to gasoline [7]. It is observed that for lean mixtures, the hydrogen addition reduced CO and NOx emission levels compared to the addition of
ethanol. The heat released was nearly at the top dead centre when compared to ethanol, despite the fact that the hydrogen addition greatly improved the heat release rate (HRR). Hydrogen improved engine emissions whereas ethanol enhanced power, engine thermal efficiency, and engine availability. According to the research, 15% hydrogen and the same amount of ethanol in the blends were determined to be adequate for enhancing engine efficiency and emissions.

On the basis of the already known research literature, it is concluded that additional research is required to confirm the effects of the ethanol-hydrogen blend on the performance of SI engines at MBT Spark timing.

3. Experimentation

3.1 Experimental Setup

An engine test bed that has a hydrogen delivery system that injects hydrogen into the intake manifold as well as direct-injection fuel systems for gasoline & ethanol is used for the test experiment. Hydrogen distribution is given the necessary attention by using a flame arrestor to stop hydrogen from flashing back into flame. The combustion-related parameters are maintained using separate ECUs for gasoline and hydrogen. Engine performance at different speeds is measured using an eddy current dynamometer. MBT spark timings are measured and tracked via crank angle marking.

3.2 Crank Angle

A mark is made on the crank angle teeth gear to determine the engine crank angle. Timing light was used to measure the crank angle positions. The timing light receives a signal from the high-tension spark plug cable when the engine is running and converts it into light. During engine running, this is utilized to measure the MBT spark timing at various loads and speeds.

3.3 Flame Trap

During engine operation, a flame trap is employed to prevent the spread of a backfire into the gaseous fuel cylinder. The gaseous injector and compressed gaseous fuel cylinder share a supply connection with the flame trap. The flame trap also serves as a buffer volume to step-down the gas pressure from the gas cylinders, which is 150 bars, to the flame trap, which are only 2 bars absolute. Additionally, the buffer space inside the flame trap dampens pressure oscillations during engine running caused by changes in gaseous fuel consumption. A pressure gauge that displays the gas pressure inside the flame trap is installed on the flame trap. Additionally, the flame trap has a pressure release valve installed as a safety measure to prevent any instances of excessive pressure inside the flame trap. In Fig. 3.3, a flame trap with a hydrogen rotameter is displayed.

3.4 Experimental Procedure

The air, fuel, speed, and exhaust pressure measuring devices were calibrated prior to running the real engine testing. Initial performance tests were conducted with the engine running solely on gasoline in
order to ensure uniformity of the experiment findings and to create a basis for comparing the results. Wide open throttle (WOT) is used in all experiments, which are run at speeds of 2500, 3000, 3500, 4000, and 4500 revs per minute. Experimental data on fuel and air consumption, different temperature, voltage, current generated, and exhaust gas emissions are collected for each loading point after the engine has warmed up and reached a stable operating condition (i.e., when the engine lubricating oil temperature became constant). The host computer records the cylinder crank angle event for later analysis. Trends were then examined using plots of power production, brake thermal efficiency, brake-specific fuel consumption, and exhaust pollutants. After a certain amount of time, the fuel filter is changed.

4. Results And Discussion

All tests were run with the throttle wide open, at 1.0 bar of manifold absolute pressure, with MBT Spark timing. MBT spark timing for gasoline and ethanol-hydrogen mixtures varies with regard to speed. Following experiments with gasoline, tests with ethanol were run at varied speeds. The power loss was greater than 40% as a result of ethanol's reduced heating value. Hydrogen is diluted with ethanol to make up for the power loss. Hydrogen is supplied via manifold injection, whereas ethanol is supplied using sequential injection. When ethanol and hydrogen are combined, power is seen to be 30% higher than when ethanol is used alone. For several equivalency ratios, performance and emission characteristics were plotted against speed.

4.1 Effect on Equivalence Ratio

The stoichiometric ratio in a multi-cylinder sequential injection SI engine was used for all trials. Figure 4.1 shows that the equivalency ratio grows as speed increases. The maximum speed is 3000 rpm. Due to incomplete combustion, the equivalency ratio is greater than 1 at both lower and higher speeds. The equivalency ratio is greater than gasoline up to 3500 rpm due to ethanol's lower heating value. The equivalency ratio decreases with speed increase and 5% hydrogen blend. Although the equivalency ratio of hydrogen and ethanol (H2E) drops as a result of the higher heating value of hydrogen (120 MJ/kg), hydrogen still outperforms ethanol at 4500 rpm.

4.2 Effect on Brake Power

As engine speed rises, brake power rises as well. As seen in Fig. 4.2, dedicated gasoline engines have demonstrated greater stopping power whereas ethanol and hydrogen-ethanol mixtures have decreased. Ethanol must be used in combination with gasoline in order to increase its power. When compared to pure gasoline as a fuel, a 15% ethanol blend with gasoline reduces brake power by only 5%. Ethanol addition to gasoline aids in reducing the effects of greenhouse gases (GHG). As seen in Fig. 8, employing 5% H2E blend only slightly improves brake power at 4500 rpm, and there is little difference at lower rpm.

4.3 Effect on Brake Thermal Efficiency

It allows for the transformation of heat into work. Because it is a gasoline-only engine, the brake thermal efficiency (BTE) for gasoline is between 30 and 35 percent Fig. 4.3. Higher friction and heat losses are
observed to cause the BTE of gasoline and all blends to fall by 8% at higher speeds. Due to the lower heating value of ethanol and hydrogen as a gaseous fuel, the thermal efficiency of the brakes decreased by about 23% when ethanol and hydrogen were blended with gasoline. The full combustion and higher heating value of hydrogen increase thermal efficiency with engine speed.

4.4 Effect on Volumetric Efficiency

Figure 10's volumetric efficiency graph illustrates the charge intake at various speeds. Due to a decrease in charge density at higher temperatures, volumetric efficiency falls as speed increases Fig. 4.4. Comparing sequential injection systems to naturally aspirated engines reveal increased power output. The volumetric efficiency is greatest at wide open throttle, and it declines as speed rises. Due to hydrogen being a gaseous fuel, ethanol hydrogen blends' volumetric efficiency is reduced by 18%.

4.5 Effect Carbon Monoxide emissions

Incomplete fuel combustion results in carbon monoxide emissions. By taking oxygen from the blood, it harms the human body and makes people feel lightheaded. When there is less oxygen available, something happens. The uniform mixing of the fuel and air results in lower CO emissions from gaseous fuel. According to Fig. 4.5, CO emissions from gasoline combustion are less than 200 gm/kW h at 2500 rpm and get smaller as speed increases. At 4500 rpm, it is almost 100 gm/kW h due to the fuel burning completely at a higher temperature. Due to complete combustion at all speeds, ethanol and H2E have demonstrated a significant reduction in CO emissions. Hydrogen contributes to a reduction in CO emissions because of its increased heating value and optimum ethanol mixture. Additionally, the natural OH group in ethanol reduces CO. CO emissions were nearly nonexistent at 4500 rpm.

4.6 Effect on Hydrocarbon emissions

Incomplete fuel combustion results in hydrocarbon emissions, which lower the engine's thermal efficiency. Figure 4.6 demonstrates how the increasing temperature caused the gasoline's HC emission to substantially decrease at 4000 rpm. The combustion of gasoline and ethanol has been improved by the addition of hydrogen. Because of incomplete combustion and lower temperature, HC emissions in gasoline are higher at lower speeds and decrease when speed is increased. Due to the higher heating value of hydrogen and the hydroxyl group in ethanol, the HC emissions for an ethanol and ethanol hydrogen blend are less than 0.1 gm/kW h at all speeds.

4.7 Effect on emissions of Oxides of Nitrogen

The main constituents of greenhouse gases are oxides of nitrogen, which engines produce at combustion temperatures above 1200°C. According to Fig. 4.7, there is a sharp rise in NOx production over 4000 rpm, which is mostly caused by hydrogen with a higher heating value. Due to the complete combustion of the fuel in the engine, which is a special SI engine for gasoline fuel, gasoline has exhibited NOx levels below 1 gm/kW h. Less time is available for combustion at faster speeds, and less heat is transferred to the environment, resulting in a slower rise in exhaust gas temperature.

4.8 Effect on Brake Specific Energy Consumption (BSEC)
This indicator demonstrates how well heat is transformed into work. In comparison to the BSFC, it provides a better comparability. Due to incomplete combustion and decreased efficiency, BSEC rises. Due to gasoline's larger calorific value than ethanol and ethanol hydrogen mixes, Fig. 4.8 illustrates that brake-specific energy consumption is higher when using gasoline. Due to hydrogen's lower density than ethanol, adding hydrogen to ethanol did not result in an increase in BSEC when compared to pure ethanol. Due to the faster flame, BSEC drops with the addition of hydrogen.

4.9 Effect on Brake Specific Fuel Consumption

With an increase in engine speed, BSFC rises. Due to its reduced heating value, ethanol has increased BSFC at all speeds. Because hydrogen has a lower density than ethanol, ethanol-hydrogen mixes have increased in BSFC. The BSFC is lower in gasoline because of complete combustion, and it rises with increased speed because of incomplete combustion. According to Fig. 4.9, the BSFC for gasoline is below 0.3 gm/kW h and below 0.4 gm/kW h for ethanol blends at all speeds.

4.10 Cylinder Pressure

Cylinder pressure is the gas pressure inside an engine cylinder that is at its highest point after the top dead center (TDC). Figure 4.10 demonstrates the continual upward trend in cylinder pressure during gasoline combustion as engine speeds have increased. When compared to the findings of pure ethanol and pure ethanol-hydrogen blended fuel, the cylinder peak pressure value is also very high. This is mostly because gasoline has a higher heating value and a higher calorific value. While pure ethanol has showed an increase in cylinder pressure at high engine speeds, the combustion performance of ethanol-hydrogen blended fuels displays surprisingly consistent values of cylinder pressure.

5. Conclusion

5% H2E (Hydrogen-Ethanol) fuel is a preferable alternative than Ethanol and Gasoline under MBT Spark timing. At 4500 rpm, the Equivalence Ratio of 5%H2E is lower than Gasoline but better than Ethanol. 5% H2E has demonstrated a significant reduction in CO emission. CO emissions were nearly nonexistent at 4500 rpm. The HC emissions for a 5%H2E blend at all speeds are less than 0.1gm/kW h, which is much less than those of gasoline. Due to increased flame speed brought on by the addition of hydrogen, BSEC has dropped. While using 5%H2E instead of gasoline, BSFC is increased, although it is still lower than pure ethanol. Cylinder Pressure is approximately 11% less when using 5%H2E compared to pure ethanol and is substantially lower when using gasoline. NOx Emission by 5%H2E is dramatically raised from 2500 to 4500 and peaked at almost 9gm/kWhr which are significantly greater than Gasoline. The BTE of 5%H2E is approximately 46% less than that of gasoline and, with a small variation, less than that of ethanol. BSFC for ethanol and ethanol-hydrogen mixes seems to be very high compared to gasoline. The volumetric efficiency of ethanol-hydrogen blends is lowered by 18% between 2500 and 4500 rpm since hydrogen is a gaseous fuel.

References


Tables
Table 1
Comparison of Properties of Gasoline, Ethanol and Hydrogen

<table>
<thead>
<tr>
<th>Property</th>
<th>Units</th>
<th>Gasoline</th>
<th>Bioethanol</th>
<th>Hydrogen</th>
</tr>
</thead>
<tbody>
<tr>
<td>Chemical formula</td>
<td></td>
<td>C$<em>8$H$</em>{18}$</td>
<td>C$_2$H$_5$OH</td>
<td>H$_2$</td>
</tr>
<tr>
<td>Composition (C, H, O)</td>
<td>Mass %</td>
<td>86, 14, 0</td>
<td>52, 13, 35</td>
<td>0,100,0</td>
</tr>
<tr>
<td>Molecular weight</td>
<td>g/mol</td>
<td>100–105</td>
<td>46.07</td>
<td>2.02</td>
</tr>
<tr>
<td>Density at 20°C</td>
<td>Kg/m3</td>
<td>751</td>
<td>789</td>
<td>0.0838</td>
</tr>
<tr>
<td>Specific Gravity at 20°C</td>
<td>g/cm3</td>
<td>3.66</td>
<td>0.787</td>
<td>0.0696</td>
</tr>
<tr>
<td>Boiling Point</td>
<td>°C</td>
<td>27–225 °C</td>
<td>78.5 °C</td>
<td>-253 °C</td>
</tr>
<tr>
<td>Flash point</td>
<td>°C</td>
<td>-43 °C</td>
<td>13°C</td>
<td>&lt; -253 °C</td>
</tr>
<tr>
<td>Lower Heating Value</td>
<td>MJ/kg</td>
<td>43.44</td>
<td>26.95</td>
<td>119.96</td>
</tr>
<tr>
<td>Higher Heating Value</td>
<td>MJ/kg</td>
<td>46.52</td>
<td>29.84</td>
<td>141.88</td>
</tr>
<tr>
<td>Viscosity at 20°C</td>
<td>g/cm-sec</td>
<td>0.0037–0.0044</td>
<td>0.0119</td>
<td>8.81 E-5</td>
</tr>
<tr>
<td>Stoichiometric air-fuel ratio</td>
<td>W/W</td>
<td>14.2–15.1</td>
<td>8.97</td>
<td>34.3</td>
</tr>
<tr>
<td>Research octane number</td>
<td></td>
<td>91–100</td>
<td>108.61–110</td>
<td>130</td>
</tr>
<tr>
<td>Auto ignition temperature</td>
<td>°C</td>
<td>230–480</td>
<td>423</td>
<td>585</td>
</tr>
<tr>
<td>Flammability Range in Air</td>
<td>Vol %</td>
<td>1.4–7.6</td>
<td>4.3–19.0</td>
<td>4.0–75.0</td>
</tr>
<tr>
<td>Laminar flame speed (100 kPa, 325 K)</td>
<td>cm/s</td>
<td>0.33</td>
<td>0.39</td>
<td>0.374</td>
</tr>
</tbody>
</table>

Figures
<table>
<thead>
<tr>
<th>ECU 1</th>
<th>Gaseous Processor</th>
<th>9. Hydrogen flame trap</th>
</tr>
</thead>
<tbody>
<tr>
<td>ECU 2</td>
<td>Gasoline Processor</td>
<td></td>
</tr>
<tr>
<td>1.</td>
<td>Exhaust Gas Analyzer</td>
<td></td>
</tr>
<tr>
<td>2.</td>
<td>Eddy Current Dynamometer</td>
<td></td>
</tr>
<tr>
<td>3.</td>
<td>Crank Angle &amp; rpm Sensor sensor</td>
<td></td>
</tr>
<tr>
<td>4.</td>
<td>Hydrogen Mixer</td>
<td></td>
</tr>
<tr>
<td>5.</td>
<td>Gasoline Fuel Pump</td>
<td></td>
</tr>
<tr>
<td>6.</td>
<td>Injectors</td>
<td></td>
</tr>
<tr>
<td>7.</td>
<td>Injector Rail</td>
<td></td>
</tr>
<tr>
<td>8.</td>
<td>Crank Angle Timing Gear</td>
<td></td>
</tr>
</tbody>
</table>

**Figure 1**

*Fig.3.1: Schematic Diagram of Experimental Setup*
Figure 2

Fig. 3.2: Experimental setup
Figure 3

Fig. 3.3: Flame Trap with Fuel Supply
Fig. 4.1: Equivalence Ratio w.r.t speed
Figure 5

Fig. 4.2: Brake Power w.r.t speed
Figure 6

Fig. 4.3: Brake Thermal Efficiency w.r.t speed
Figure 7

Fig. 4.4: Volumetric Efficiency w.r.t speed
Figure 8

Fig. 4.5 : Carbon Monoxide w.r.t Speed
Figure 9

Fig. 4.6: Hydrocarbon w.r.t Speed
Figure 10

Fig. 4.7 : Oxides of Nitrogen w.r.t Speed
Figure 11

Fig. 4.8 : Brake Specific Energy Consumption
Figure 12

Fig. 4.9: Brake Specific Fuel Consumption
Figure 13

Fig. 4.10: Cylinder Pressure w.r.t Speed