VOL. 19, NO. 18, SEPTEMBER 2024 ISSN 1819-6608
ARPN Journal of Engineering and Applied Sciences

www.arpnjournals.com

EXPERIMENTAL VERIFICATION ON THE EFFECTIVENESS ON HYDROGEN PEROXIDE FUEL BLENDS IN GASOLINE ENGINE OPERATION: EXHAUST EMISSION ANALYSIS

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ABSTRACT

This experiment aims to investigate the effectiveness of hydrogen peroxide on the exhaust emission characteristics of a spark ignition engine. 5%, 10%, and 15% of hydrogen peroxide-gasoline mixtures are the fuel blends used in the current study. Experimental results about emission characteristics of spark ignition fueled with hydrogen peroxide-gasoline blend at an engine speed of 2500RPM with variable loads are presented in detail. The results are then compared to that of gasoline fuel operations. Hydrogen peroxide-gasoline blends indicate lower CO and SO_2 emissions. The most significant penalty will be a slight increase in EGT, HC, and NO_x emissions. It is concluded that a 10% hydrogen peroxide-gasoline fuel blend is the optimum blend for acceptable emission controls.

Keywords: hydrogen peroxide, emission, hydrogen peroxide-gasoline blends.

Manuscript Received 29 July 2024; Revised 14 October 2024; Published 14 December 2024

INTRODUCTION

The current world is facing severe environmental issues which exponentially growing each day. It is our responsibility to minimize the impact of the existing pollution by reducing hazardous exhaust gas emissions. The levels of hazardous emissions such as carbon monoxide (CO), sulfur oxides (SO_x), nitrogen oxides (NO_x), carbon dioxide (CO_2), particulate matter (PM), and hydrocarbon (HC) are unacceptably high. New research focuses on alternative fuels together with the rapid development of new green engines has significantly contributed to cleaner exhaust gas emissions [1].

Decreasing supplies of fossil fuels and steadily rising concentrations of atmospheric carbon dioxide concentrations and levels of atmospheric pollutants are some of the major challenges to modern society. Due to the complex geographical environment and diverse global needs, it is crucial to achieve an optimal clean and efficient combustion mode for the internal combustion engine [2-3]. Hydrogen peroxide (H_2O_2) is one of the promising cleaner and renewable fuels for combustion engines. Hydrogen peroxide is a strong oxidizing agent and oxygenates hence adding oxygen to the reaction during combustion [4]. In spark ignition engine operation, mixing H_2O_2 with gasoline does not boost the octane number of mixture; ideally, H_2O_2 reduces the amount of unburned hydrocarbons and carbon monoxide in the exhaust emissions. Furthermore, the addition of oxygen will cause a leaner combustion and reduce the unburned hydrocarbon [5].

H_2O_2 has been considered a superfine fuel additive in recent years, which effectively optimizes the ignition characteristics of fuels [6]. Saleh et al. explored the effect of H_2O_2 on a diesel engine. They used H_2O_2 with diesel, jojoba oil, and butanol blends. The results showed that the 5% H_2O_2 additive had the optimum fuel consumption and emission characteristics [7]. Yeom studied the evaporative characteristics of emulsified H_2O_2-diesel fuel. The results showed that micro-explosion due to the evaporation of H_2O_2 in the emulsified fuel increases as the mixing ratio increases [8]. Barboza et al. studied the combustion and emissions of emulsified gasoline with 0% to 1.5% H_2O_2 in a spark ignition engine. The results showed that the engine performance was improved by H_2O_2, but the fuel stability was poor [9]. Yoon et al prove that the presence of H_2O_2 in the fuel blend increases the properties such as specific heat and thermal conductivity that influence the combustion quality of the fuel [10].

Nguyen *et al.* studied the effects of Jatropha-H_2O_2 emulsions on the combustion, performance, and emission characteristics of a diesel engine. They used 5%, 10%, and 15% H_2O_2 concentrations mixed along with Jatropha oil and tested them in a compression ignition engine to form emulsion fuels. The results have shown a higher heat release rate and lower CO and NO_x emissions at low and medium loads. Furthermore, the emulsion fuel has shown increased HC emissions but at medium and high power conditions, PM and soot emissions were reduced with the emulsion fuels [11].

Sanjeevannavar *et al*. have reported a significant reduction of NO_x and HC emissions and, an increase in heat release rate (HRR) and in-cylinder pressure for 10% H_2O_2 concentrations. H_2O_2 is a potential additive due to its higher hydrogen (H_2) and oxygen molecule content, which enhances the combustion process in the engine [12]. The use of H_2O_2 as an additive in diesel engines has shown improvement in emissions without sacrificing engine performance. Unfortunately, there was limited investigation on the application of H_2O_2-gasoline blends in spark ignition engines. In this paper, various percentages of H_2O_2-gasoline blends were explored to study their effects on the emission characteristics of spark ignition engines.

METHODOLOGY

In this study, gasoline fuel has been used as the baseline study, and three types of H_2O_2-gasoline blends were prepared by mixing H_2O_2 with volume concentrations of 5%, 10%, and 15%, respectively to gasoline fuel. H_2O_2 has been thoroughly mixed with gasoline and polysaccharide emulsifier to reduce surface tension between both gasoline and H_2O_2 as well as stabilize the blend for a longer period. A magnetic stirrer has been used to blend the mixture to reach a constant blending speed. A single-cylinder, 4-stroke spark ignition (SI) engine equipped with carburetion and air cooling systems has been used in this study. The engine specification and properties of fuels used in the study are shown in Table-1 and Table-2, respectively. The loads for this experiment are 1000 W, 1500 W, 2000 W, 2500 W, and 3000W. In this present study, the investigation is limited to an optimal engine speed of 2500 RPM. The results have been recorded using the data acquisition (DAQ) system by DEWESOFT SIRIUS software. In this study, the measurement of exhaust emissions was conducted using BACHARACH and MRU-air Portable Combustion Gas Analyzers. Both gas analyzers satisfy the reference method standard of US EPA CTM 034 with a maximum detection limit variation of 2ppm for each emission. The gas sampling probe of both gas analyzers is inserted into the exhaust hose fitting for a minimum of 60 seconds to obtain a stabilized reading.

Table-1. Specification of the engine.

Engine model	SHV6000EXE
Engine type	4 stroke, air cooled, overhead valve
Fuel type	Gasoline
Number of cylinders	1
Displacement volume, cm^3	420
Bore, mm	90
Stroke, mm	66
Compression ratio	9.4 : 1
Max power output, hp	15

Table-2. Properties of fuels used in the study.

Type of fuel	Density (kg/m^3)	Lower Calorific Value (kJ/kg)
Gasoline Alone	752	41050
Gasoline + 5% H_2O_2	770	40680
Gasoline + 10% H_2O_2	789	40210
Gasoline + 15% H_2O_2	807	39890

RESULTS AND DISCUSSIONS

The variation of carbon monoxide emission with engine speed at 2500 RPM for various ratios of fuel blends is shown in Figure-1. This study shows that the H_2O_2-gasoline blend fuel has a lower concentration of CO emission as compared to gasoline alone (GA). A higher concentration of CO in GA is generated when the engine runs rich while a rich mixture is required during engine starting and accelerating with load. 10% H_2O_2-gasoline blend shows the lowest concentration of CO emission followed by 15% and 5% H_2O_2-gasoline blends, respectively. CO emission is formed when there is an inadequate amount of oxygen to convert all carbon to CO_2 while some fuel molecules remain unburned and some carbon ends up as a CO component.

The peroxide content in the fuel acts as an excellent oxidant carrier with an increase in the OH radicals in the H_2O_2-gasoline blends. H_2O_2 spawned more OH radicals by $H_2O_2 \rightarrow 2OH$ and triggered intense combustion and increased combustion temperature [13]. CO emissions were influenced by the synergistic effects of H_2O_2 and the promotion of H_2O_2 to the active radicals in the reaction system greatly reduced the CO produced during the combustion process [14]. In addition, micro explosions of H_2O_2 during combustion provide better atomization leading to a better mixing of the in-cylinder charge. It can be concluded that H_2O_2 in the blends contributes to better mixing, local lean regions and complete combustion are the factors that affect lower CO emission.

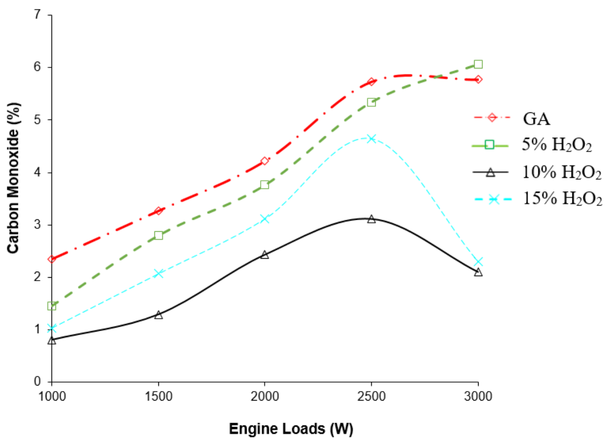

Figure-1. Variation of carbon monoxide emissions.

The variation of the hydrocarbon emission at 2500 RPM for various loads and ratios of fuel blends is shown in Figure-2. In this study, 5%, 10%, and 15% H_2O_2-gasoline blends have higher HC emissions compared to GA while the 5% H_2O_2-gasoline blend has the highest concentration of HC emission among all the fuel blends. At this point, GA has shown the lowest HC emission as compared to other fuel blend operations.

VOL. 19, NO. 18, SEPTEMBER 2024 ISSN 1819-6608
ARPN Journal of Engineering and Applied Sciences

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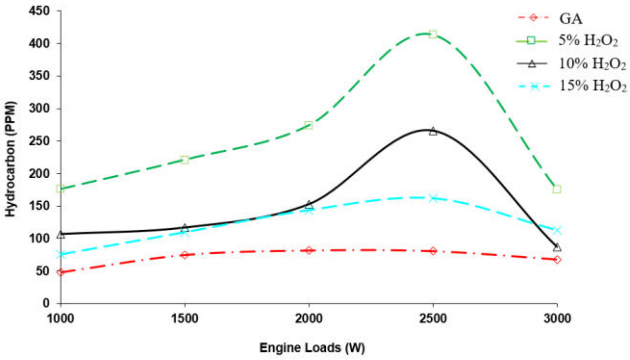

Figure-2. Variation of hydrocarbon emissions.

It is noted that H_2O_2-gasoline blends have lower combustion flame speed as compared to GA fuel which contributes towards a minimal mass fraction of the fuel burnt in the case of H_2O_2-gasoline blends. Hence, a higher amount of unburnt hydrocarbon is left after the combustion. In addition, incomplete combustion occurs in the combustion chamber when an engine operates over a definite lean limit causing frequent misfires and unburned fuel leads to increased HC emission. This is also supported by Chen et al. reported if an SI engine operates with actual air-fuel ratios over a certain lean limit, partial combustion could occur, leading to numerous misfires and then resulting in increased HC emission. Excess oxygen leads to a lower charge of initial HC level during low-load operation and it also contributes to the addition of post-flame oxidation [15]. Therefore, it can be concluded that H_2O_2-gasoline blends increase the concentration of HC emission. Figure-3 shows the nitric oxide (NO_x) emission at 2500 RPM for various ratios of fuel blends. It shows that NO_x concentration increases as load increases for all types of fuel operations starting from 1000 W to 1500 W and further increase in load decreases NO_x emissions. It can be seen that the H_2O_2-gasoline blend causes higher NO_x emissions as compared to GA. It is believed that the increase of micro-explosion of H_2O_2 and combustion of hydrogen molecules causes high combustion temperature which contributes towards higher NO_x production. It shows the effect of hydrogen on combustion temperature leads to an increase in NO_x emissions. Hydrogen increases energy release, which has a positive contribution to enhancing charge temperature to form thermal NO_x in both the flame front and the post flame of the charge [16].

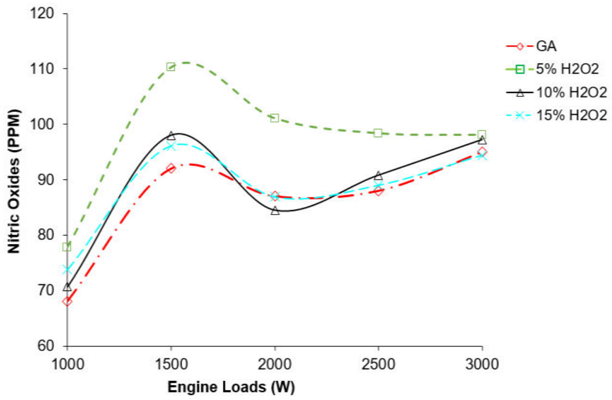

Figure-3. Variation of nitric oxide emissions.

The formation of NO_x emission is highly dependent on combustion temperature, oxygen content, and air combustion duration. The formation of NO_x is directly proportional to the peak combustion reaction temperature, with higher temperatures producing higher NO_x emissions. The higher the combustion reaction temperature, the more dissociation takes place and more NO_x will be formed. In this phenomenon, high flame temperature and excess oxygen concentration combine nitrogen molecules to form various types of nitric oxides. Furthermore, the load of the engine influences the amount of NO_x emission. The engine load may increase or decrease NO_x emission as a higher engine load increases the burned gas mass fraction and thus offsets the peak temperature, depending on the exact engine condition [17].

Figure-4 shows the variation of carbon dioxide (CO_2) emission at 2500 RPM with various loads and ratios of fuel blends. The graph indicated that the 5% H_2O_2-gasoline blend shows the highest CO_2 emission as compared to other ratios of fuel blends. Meanwhile, the lowest CO_2 emission is in GA operation. The lowest CO_2 emission can be associated with the highest CO emission as discussed in the previous section. In this study, 15% H_2O_2 shows lower concentration of CO_2 emission among all fuel blends. This is because higher oxygen contents in the blended fuels improve the combustion process causing an increase in CO_2 emission. The combustion of CO in the presence of additional oxygen components increases CO_2 emission. Another possible explanation of this phenomenon is the dissociation of CO_2 (>1000°C) and water (H_2O) (>1300°C) produces more O_2 at the high-temperature combustion zone and introduces more complete combustion of the charge at the beginning of the power stroke. During the expansion process, while the piston moves down to BDC, the pressure and temperature of the charge drop gradually and cause a re-association of H_2O and CO_2 which leads to an increase in CO_2 emission [18].

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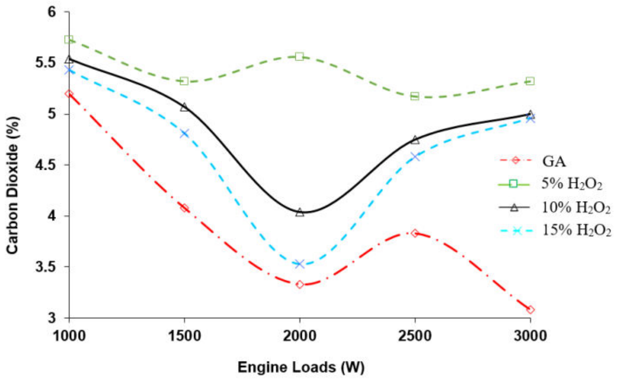

Figure-4. Variation of carbon dioxide emissions.

Figure-5 shows the exhaust gas temperature (EGT) variations at 2500 rpm for various ratios of fuel blends. It shows that a 5% H_2O_2 fuel blend produces the highest EGT throughout all loads and all ratios of H_2O_2-gasoline blends increased the EGT. Higher EGT for 10% H_2O_2 compared to 15% is due to the optimal concentration of H_2O_2 providing an additional oxygen molecule that enhances the combustion process resulting in high combustion temperature in the cylinder charge. Spark ignition (SI) engines are configured to maximize the flame propagation from the spark plug into the unburned mixture until all mixtures are ignited. As the flame front advances, the pressure and temperature of combustion will rise which is caused by the released product of combustion. The propagation will also compress and heat the unburned mixture. This study shows that H_2O_2-gasoline blends raise EGT due to wide-range flammability and complete combustion. H_2O_2 molecules dissociate which forms hydrogen and oxygen molecules. The formed oxygen helps in hydrogen molecule combustion and hence increases the charge temperature [19].

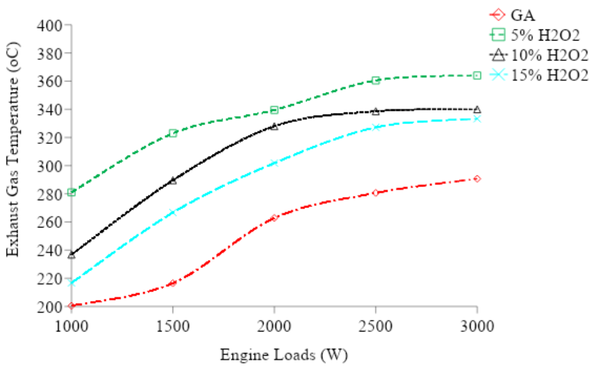

Figure-5. Variations of exhaust gas temperature.

Figure-6 presents the variation of sulfur dioxides (SO_2) emissions at 2500 RPM with various loads and ratios of fuel blends. It indicates GA operation produces the highest SO_2 concentrations for all loads range and 10% H_2O_2-gasoline blends operation produces the lowest SO_2 concentrations throughout all loads range. H_2O_2-gasoline blend operation shows a decrease in SO_2 emissions in the range between 1 to 7 ppm as compared to GA operation. In the H_2O_2-gasoline blend operation, the 5% H_2O_2 blend produces the highest SO_2 concentrations. In this research**,** sulfur components are solely contributed from gasoline pilot fuel since it contains a maximum of 0.5 % by weight meaning that levels of sulfate emissions depend on the amount of gasoline injected into the cylinder.

One possible explanation of this phenomenon is richer mixture during GA operation contributes to higher SO_2 emissions as compared to an operation without H_2O_2. The reduced exhaust concentrations of SO_2 are due to the substantial oxidizing property of H_2O_2 in the blended fuel generating micro-explosion of hydrogen molecules which helps the combustion and reduces the amount of gasoline fuel injected. The presence of hydrogen in the stoichiometric mixture ratio increases the quality of combustion and reduces the factor of energy losses via technical influences such as friction in cylinder walls, the situation of a mixture of rich and poor, and as well as combustion misfire [20]. Figure 6 also explains that SO_2 emissions can be controlled by lean mixture during H_2O_2-gasoline blends operation and lowering the mixing-controlled combustion temperature during GA operation. Ashok & Saravanan observed similar findings in their studies with H_2O_2 blended fuels [21].

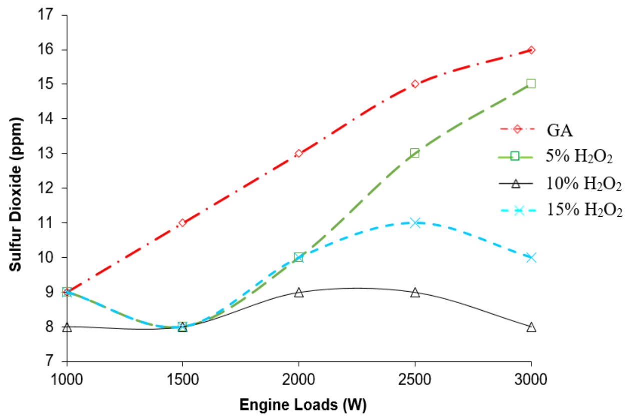

Figure-6. Variation of sulfur dioxide variations.

Figure-7 depicts the variation of oxygen (O_2) emissions at 2500 RPM with various loads and ratios of fuel blends. It shows that for H_2O_2-gasoline blends operation, O_2 concentration increases as load increases until 2000W, further increase in load decreases O_2 emissions and finally increases at maximum load of 3000W. It can be seen that H_2O_2-gasoline blend operations produce higher O_2 emissions as compared to GA operations throughout all ranges of loads. It can also be observed that O_2 emissions for 15% H_2O_2-gasoline blends operation will always be the highest as compared to all fuel blends. Lower O_2 concentrations for GA operation are due to a lower rate of CO oxidation which causes higher CO concentrations in the cylinder charge as discussed in the earlier section. Lower CO_2 concentration in GA operation is also another possible reason for lower O_2 emissions. The same reason is also

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applicable for H_2O_2-gasoline blend operations though it is higher than that of GA operation. It can be concluded that higher O_2 concentrations in H_2O_2-gasoline blend operations throughout all load ranges are due to the auto-dissociation of hydrogen and oxygen components in H_2O_2 during mixing-controlled and late combustion phases [22].

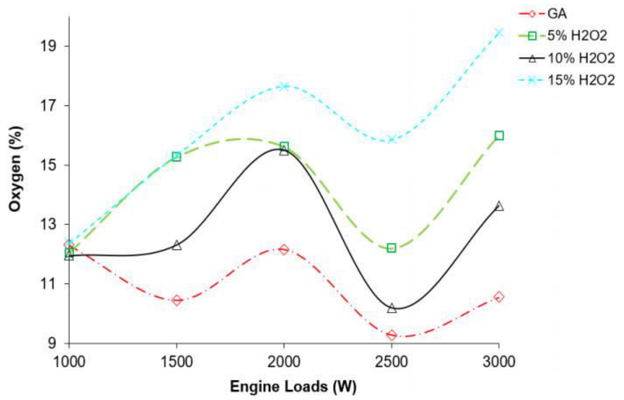

Figure-7. Variation of oxygen variations.

CONCLUSIONS

An experimental investigation has been conducted to research the effects of H_2O_2 on exhaust emission characteristics of a single-cylinder spark ignition engine fueled with H_2O_2–gasoline blends at constant engine speed and variable loads. From the above analysis and discussion, the conclusions were provided as follows:

- Higher concentration of CO in GA operation. 10% H_2O_2-gasoline blend shows the lowest concentration of CO emission followed by 15% and 5% H_2O_2-gasoline blends.
- 5%, 10%, and 15% H_2O_2-gasoline blends have shown slightly higher HC emission as compared to GA operation.
- H_2O_2-gasoline blend causes higher NO_x emission compared to GA. It is because the increase of micro-explosion of H_2O_2 and combustion of hydrogen molecules causes high combustion temperature which contributes towards higher NO_x emission.
- 5% H_2O_2-gasoline blend shows the highest CO_2 emission compared to other fuel blends. Meanwhile, the 15% H_2O_2-gasoline blend shows the lowest concentration of CO_2 emission among all fuel blends.
- 5% H_2O_2-gasoline blend produces the highest EGT at all loads range. Higher EGT for 10% H_2O_2 as compared to 15% is due to the concentration of H_2O_2 providing an additional oxygen molecule which enhances the combustion process resulting in high combustion temperature in the cylinder charge.
- GA operation produces the highest SO_2 concentrations for all loads range and 10% H_2O_2-gasoline blends operation produces the lowest SO_2 concentrations throughout all loads range.
- H_2O_2-gasoline blend operations showed higher O_2 emissions as compared to that of GA operation for all ranges of loads. It can also be observed that O_2 emissions in 15% H_2O_2-gasoline blends operation will always be the highest throughout all loads.

The above results suggest that H_2O_2-gasoline blends show some improvement in exhaust emission analysis as compared to GA. It has shown lower CO and SO_2 emissions throughout all load ranges. A slight increase in EGT, HC, and NO_x emissions is seen at the constant engine speed of 2500 RPM. It is concluded that a 10% hydrogen peroxide-gasoline fuel blend is the optimum blend for acceptable emission controls. Hence, H_2O_2-gasoline fuel blends appeared to be an effective alternative fuel to improve exhaust emissions characteristics of spark ignition engines.

ACKNOWLEDGEMENTS

The authors would like to thank the University Teknikal Malaysia Melaka for funding this research.

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