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Modeling and Performance Analysis of Hydrogen Powered Hybrid Bike

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ABSTRACT

Alkaline water electrolysis represents a fundamental method for hydrogen generation, offering simplicity and cost-effectiveness. Operating at a standard voltage of 1.23 V, electrolyzers efficiently split water molecules into hydrogen and oxygen. Central to this process are the electrodes within the electrolytic cell, where the cathode serves as the site for hydrogen production via reduction reactions. To enable the integration of hydrogen into conventional spark-ignition (SI) engines, a blend of liquefied petroleum gas (LPG) and hydrogen at a 4:1 ratio is utilized, strategically adjusting combustion characteristics. This blended fuel undergoes meticulous preparation through a vaporizer unit to ensure precise mixing ratios before introduction into the engine's combustion chamber via a bypass line on the input manifold. Here, controlled air mixing at a stoichiometric ratio of 17:1 ensures optimal combustion. The combustion of this LPG-hydrogen mixture is marked by the distinct blue flame characteristic of hydrogen combustion, signifying complete combustion. Leveraging vaporized fuel delivery enhances fuel-air mixing within the combustion chamber, promoting thorough combustion and reducing emissions of nitrogen oxides and hydrocarbons in the exhaust gas, thereby contributing to cleaner combustion processes in conventional SI engines. Furthermore, hydrogen gas demonstrates rapid combustion tendencies, presenting a potential hazard with its flammability range spanning from 4% to 75% concentration in the atmosphere. These inherent characteristics highlight the necessity for rigorous safety protocols and engineering innovations to effectively manage the challenges inherent in utilizing hydrogen as a vehicle fuel source.

Keywords: hydrogen, emission, electrolysis, combustion, LPG.

INTRODUCTION

Fossil fuels like coal and petroleum are the remains of prehistoric living organisms buried underneath the earth's surface millions of years ago and they are in the inadequate stream. Ultimately the assets of these fuels will get empty. So as a precautionary measure, it is important to find new ways to power our technology [1]. Alkaline water electrolysis (AWE) is vital for large-scale green hydrogen production and energy storage. Modeling aids in understanding and optimizing AWE processes, yet comprehensive reviews of modeling efforts are lacking. This review offers a detailed examination of existing models across various domains, including thermodynamic, electrochemical, thermal, and gas purity models. It establishes a concise modeling framework and compares different modeling approaches [2]. The review highlights the impact of parameters and conditions on AWE performance while identifying research strengths and areas for improvement. Urgent needs include experimental validation for electrochemical models, development of gas purity control strategies, and further enhancement of thermal modeling accuracy [3]. Explored performance of advanced zero-gap alkaline electrolyzers under varied conditions, including diaphragm thickness, temperature, and pressure. Developed semiempirical current-voltage model based on experimental data from a 20 Nm^3/h electrolyzer, revealing significant impact of these factors on efficiency and operation at higher current densities compared to traditional alkaline electrolyzers [4].

Automobile made of light weight structures [5] powered by hydrogen fuel can have a cutting edge in the modern applications. The desirable characteristics of a perfect fuel can be possibly gratified by hydrogen as a fuel. Abundance and clean burning, hydrogen which has very high energy content. With the limited fossil fuels sustainability and the environmental impact of harmful emissions, it is convinced that the H2 combustion engine will be an essential position [6]. Automobile made of light weight structures powered by hydrogen fuel can have a cutting edge in the modern applications.

Gasoline is one of the fossil fuels, is also called crude oil. It contains mainly of a mixture of hydrocarbons, with traces of various nitrogen and sulphur contents. The petroleum configuration will comprise many trace of elements, they are: carbon (93 –97%), hydrogen (10–14%), nitrogen (0.1–2%), oxygen (1–1.5%) and sulphur (0.5–6%) and few traces of metals in the very small percentage of the petroleum composition. The burning of petrol causes emission which causes pollution to the environment [7]. The harmful emissions are oxides of nitrogen, oxides of sulphur, soot, particulates, unburned hydrocarbons etc.

Liquefied petroleum gas (LPG) comprehends propane and butane as their main constituent, which is gases at atmospheric temperature and pressure. Liquefied Petroleum Gas is a clean and portable fuel [8]. The use of LP gas as a motorized fuel (Auto Gas) is becoming gradually popular. The LPG engines also emit major harmful emissions from which are similar to those from other internal combustion engines are carbon dioxide (CO_2), hydrocarbons (HC), carbon monoxide (CO), and nitrogen oxides (NOx) [9]. To ensure accurate measurement of pollutants, several precautions are typically employed. Firstly, it's essential to calibrate the pollutant measurement equipment regularly to maintain accuracy. Additionally, proper sampling techniques must be followed, including selecting appropriate sampling locations and ensuring a sufficient sampling duration to capture representative pollutant levels. Quality control measures, such as using certified reference materials and conducting duplicate measurements, help validate the accuracy of the results. Environmental conditions, such as temperature and humidity, should be monitored and recorded during sampling to account for any potential influences on pollutant levels. Finally, data validation procedures, such as outlier detection and data comparison with regulatory standards, are essential to verify the reliability of the pollutant measurements. Overall, adherence to these precautions ensures reliable and accurate assessment of pollutant levels in the environment.

The passage provided offers insights into the integration of hydrogen and LPG as a blended fuel for conventional spark-ignition (SI) engines, highlighting its potential benefits in terms of combustion efficiency and emission reduction. However, it lacks a thorough examination of the practical challenges and limitations that may arise from implementing this blended fuel in real-world scenarios. Additionally, there is a need for empirical data or experimental results to validate the claimed improvements in combustion efficiency and emission reduction. Further research could focus on conducting comprehensive testing and analysis to assess the performance and feasibility of the blended fuel under various operating conditions.

Hydrogen is the most promising fuel which will serve as an energy source in future due to its combustion properties like wide range of flammability, high auto-ignition temperature, low ignition energy, high diffusivity, very low density. Hydrogen can also be used as fuel for vehicle or direct combustion for heat or an indirect way. Hydrogen can also serve as fuel for internal combustion engines, but unlike the fuel cells, hydrogen fuel will produce tailpipe emissions which is more efficient. A hybrid vehicle is one that can run on two or more different fuels. A hydrogen-powered hybrid bike innovatively combines traditional petrol fuel with cleaner alternatives such as LPG and hydrogen, offering versatility and reduced emissions. This hybrid system allows riders to choose between petrol, LPG, or a blend of LPG and hydrogen (LPG + H_2) based on their preferences and fuel availability. The key emission-reduction strategy lies in blending LPG and hydrogen in a 4:1 ratio, optimizing combustion efficiency and minimizing environmental impact. By incorporating hydrogen's clean-burning properties and leveraging the accessibility and affordability of LPG, the hybrid bike achieves a lower carbon footprint compared to conventional petrol-powered vehicles, making it a sustainable and practical transportation solution for eco-conscious riders.

Hydrogen production

Alkaline water electrolysis

Alkaline water electrolysis is traditional technology, less affluent, simplest and suitable method for hydrogen production. Alkaline electrolysis is a mature process, suitable electrolysers are manufactured industrially. If a generation of electricity is done by pollution-free processes, alkaline electrolysis is the most suitable way to produce hydrogen. Alkaline water electrolyser decomposes water at the cathode to hydrogen and HO-. So that it migrates through the electrolyte thereby discharging at the anode and liberates the O_2. The electrolyte solution is an aqueous comprising either NaOH or NaCl with a typical concentration of 0.025 M and operating temperatures are between 343 K and 363 K and operating pressure up to 3 MPa [10].

Working

Once electric current is provided to electrolytic solution through the electrodes, ionisation takes place in the electrolyser unit. Due to the ionisation action, a water molecule separates as hydrogen and oxygen ions. Hydrogen to the low atomic weight unit. Due to the ionisation action, a water molecule separates as hydrogen and oxygen ions. Hydrogen to the low atomic weight gets drifted to the top of the electrolyser unit and the oxygen settles down at the bottom just above the water level. Hydrogen gas formed is positively charged as they get attracted to the cathode and the oxygen ion which is negatively charged, is attracted towards the anode [11]. Therefore, hydrogen is progressed at the cathode and oxygen gas evolves at the anode. Since water molecule contains two molecules of hydrogen and one molecule of oxygen, the production of hydrogen will be more.

Factors affecting the hydrogen production

There are various factors which affect the production of hydrogen in the electrolyser unit. But some of which plays a most important role in the production of hydrogen [12]. The significant factor which influences the hydrogen construction is the applied voltage, as per the voltage applied the production rate increases. Here using 12 V, 5 A supply as usual in the two-wheelers [13]. The electrolysis setup for producing hydrogen is shown in Figure 1.

The concentration of the electrolytic solution also plays an important role, the concentration of the solution has to be around 0.025 M for the peak production of hydrogen in the unit. As a result, 1.461 g of NaCl is involved in one litre of H_2O. Consider 1 kg of NaCl has been taken,

$$Molality = \frac{No.\ of\ moles\ of\ solute}{Mass\ of\ solvent} \quad (1)$$

$$0.025M = \frac{y}{1\text{kg}} \quad (2)$$

$$No.\ of\ moles\ of\ NaCl = 0.025\ \text{Kg M} \quad (3)$$

$$No.\ of\ moles = \frac{Weight\ of\ NaCl}{Molar\ mass\ of\ NaCl} \quad (4)$$

$$Weight\ of\ NaCl = 0.025 \times 58.44 = 1.461\ \text{g/L} \quad (5)$$

The other most important factor which affects the rate of production of hydrogen is the surface area of the electrodes (Anode and cathode). In order to escalate the outward extent of the electrodes number of plates has been arranged alternately of cathode and anode which are connected in series, such a way that contact between the plates and the electrolytic solution is increased which increase the production rate of hydrogen [14, 15].

The material used for the electrodes also affects the hydrogen production. Various materials can be used like copper, graphite, aluminium etc. Graphite shows the better production due to its porosity effect but due to the slurry formation and easy decomposition of graphite, it is chosen aluminium as the electrode material which is low cost, easily available, low density. The various electrodes utilised for hydrogen generation are shown in Figure 2.

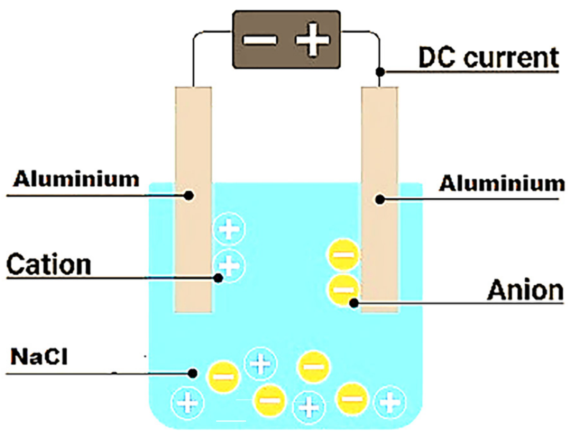


Figure 1. Electrolysis setup

(a) Cu-Cu (b) Al-Al (c) Al sheet array (d) Cu-Zn (e) Graphite

Figure 2. Tested electrodes

Hydrogen as fuel

A vehicle which can run on of two or more fuel is defined as a hybrid vehicle. Hydrogen powered hybrid bike is a hybrid bike which uses petrol, LPG + H_2 as fuels in order to reduce the emission from the vehicle. The blend of the LPG and hydrogen is done in the ratio of 4:1 which will reduce the emission in a promising way [16]. Hydrogen produced in the electrolyzer setup cannot be used directly in the conventional SI engine without any modifications as the energy content (calorific value) is very high, it may result in the explosion. Hence it has to be unified through added fuel.

LPG + H_2 blend

Liquefied petroleum gas is chosen to blend with hydrogen because of its two main properties. First is that both hydrogen and LPG are at vapour state, unlike the petrol which is a liquid which on spraying gets converted to semi-liquid state, hence the mixing of fuel will much better comparatively [17, 18]. And the next one is, on comparing with both petrol and diesel the emission from LPG is much lesser. On mixing with hydrogen in the ratio of 4:1 the emission is further reduced abruptly. Figure 3 depicts the experimental setup's layout.

Working

Hydrogen is produced from the Electrolysis process with the help of the electrolyzer unit where the electric current is supplied to ionize the water molecule to hydrogen and oxygen. Due to the difference in the atomic weights of the produced ions (H_2 and O_2) the hydrogen will get drifted up to the top of the container and oxygen molecules will settle just above the water level. The water molecules contain one molecule of an oxygen atom and two molecules of a hydrogen atom, so the production of hydrogen will be comparatively more to that the oxygen, even though there will be some amount of oxygen mixed with the hydrogen gas. LPG is stored in the cylinder under a pressurized condition and it is sent to the vaporizer where it is vaporized. Then LPG and hydrogen gas mixed inside the vaporizer in the ratio of 4:1 by adjusting the diameter of the orifice in the inlet of vaporizer unit. And the mixture is sent just before carburettor where this mixture is mixed with air around the ratio of 17:1 (stoichiometric ratio) then it is sent to the combustion chamber.

Chemical equations

In water with a negligible quantity of salt, by means of negatively charged cathode, a reduction

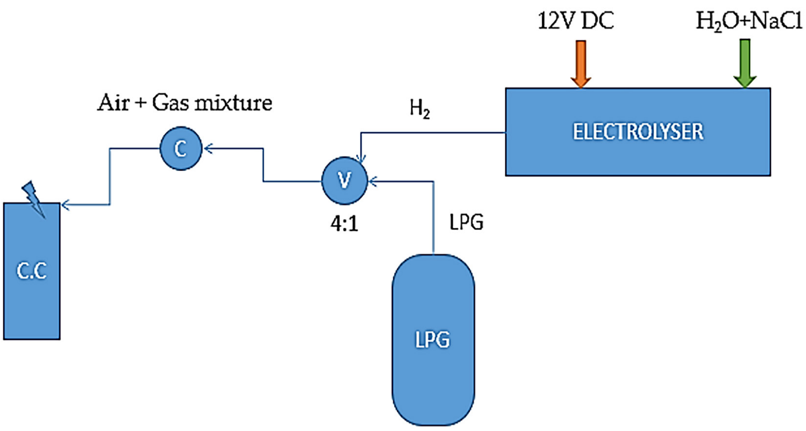


Figure 3. Layout of the experimental setup

reaction takes place. It is with the electrons (electric current) from the negative electrode to hydrogen forms hydrogen gas (the half reaction balanced with acid).

- Cathode – hydrogen reduced

$$4H_2O + 4e^- \rightarrow 2H_2 + 4OH^- \quad (6)$$

At the positively exciting anode, an oxidation response arises, which is producing oxygen and altering electrons to the anode (positively charged electrode) to complete the circuit:

- Anode – hydrogen oxidized

$$2H_2O \rightarrow O_2 + 4H^+ + 4e^- \quad (7)$$

- Overall reactions:

$$2H_2O \rightarrow O_2 + 2H_2 \quad (8)$$

$$4OH^- + 4H^+ \rightarrow 4H_2O \quad (9)$$

Hydrogen gas will form at the cathode since it is being attracted to the negative charge and the oxygen gas will form at the anode since it is negatively charged ion. LPG is a mixture of various gases but the main constituents are propane and butane. Both the gases reacts similarly with the oxygen during combustion to produce heat [19]. When propane reacts with oxygen it produces carbon di oxide and water with the release of large amount of heat.

$$C_3H_8 + 5O_2 \rightarrow 3CO_2 + 4H_2O \quad (10)$$

When butane (C4H10) reacts with oxygen, carbon dioxide and water are produced.

$$2C_4H_{10} + 13O_2 \rightarrow 8CO_2 + 10H_2O + heat \quad (11)$$

Formation of blue flame shoes the complete combustion in the combustion chamber. As a result, the significance of HC in the exhaust is reduced. Hence, the emission control of the vehicle is done more effectively [19, 20].

RESULTS AND DISCUSSION

The work is done on the available conventional SI engine (TVS Centra bike). The set up was made on the bike for reducing the emission by using alternative fuel. The bike is capable of running with the help of both petrol and blend fuel of hydrogen with LPG.

Design and analysis

The following design is used to show temperature distribution inside the combustion chamber. Specifications of combustion chamber is given below. Figure 4 shows the design of the engine cylinder with the fin arrangement. In which, thermal analysis is conducted with the above specifications. From the analysis, the following results are obtained. Though overheating and the development of high pressure in the cylinder, it is safe to operate on normal conditions without any chance of explosion. Figure 5 shows the thermal analysis which is done in ANSYS software for the engine cylinder with the specified parameters. The engine cylinder seems to be stable under a normal condition with the temperature of 673 K (approx) and 17 bar (approx) as the internal load acting on the inner wall of the cylinder.

Due to the high temperature and pressure (high calorific value) inside the cylinder, high value of torque is obtained on the crank [21–23]. The Figure 6 shows the temperature at various points from the inner wall to fins of the engine cylinder. The numerical data recorded alongside corresponding element sizes of 0.35 mm indicates a noteworthy trend: as the number of elements increases, implying higher mesh density, the individual element sizes decrease. Consequently, this reduction in element size correlates with an increase in peak temperature. However, once the element size diminishes below 1.5 mm, a stabilization of temperature is observed, with

Material	: Grey cast iron
Bore	: 51mm
Stroke	: 48.8mm
Fin thickness	: 2mm
Pitch	: 8.5mm
Thermal conductivity	: 46 w/mk
Film coefficient	: 5.7 w/m2k
Pressure	: 17 bar
Temperature	: 673K

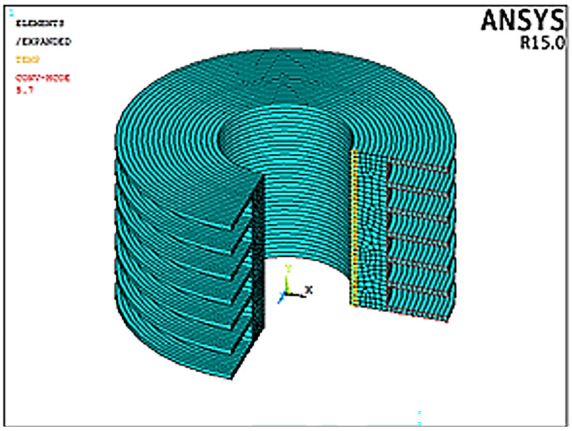
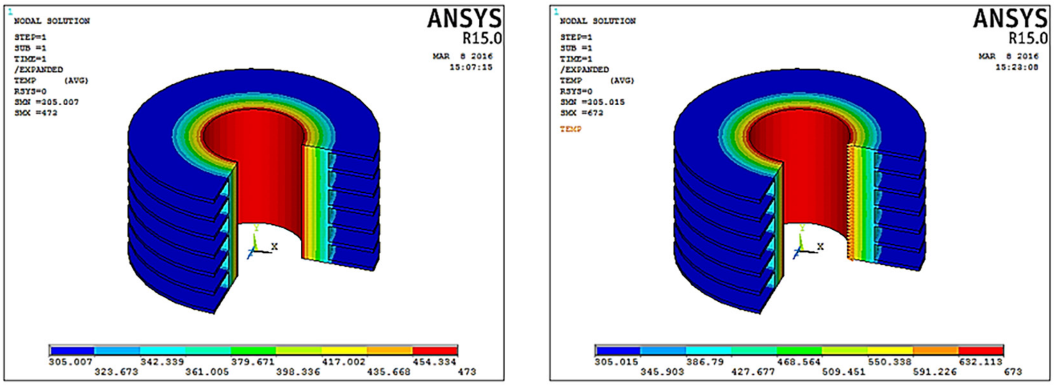


Figure 4. Isometric view of the FE model with fins



(a) Gasoline (b) Hydrogen-LPG

Figure 5. Temperature distribution on the engine cylinder wall

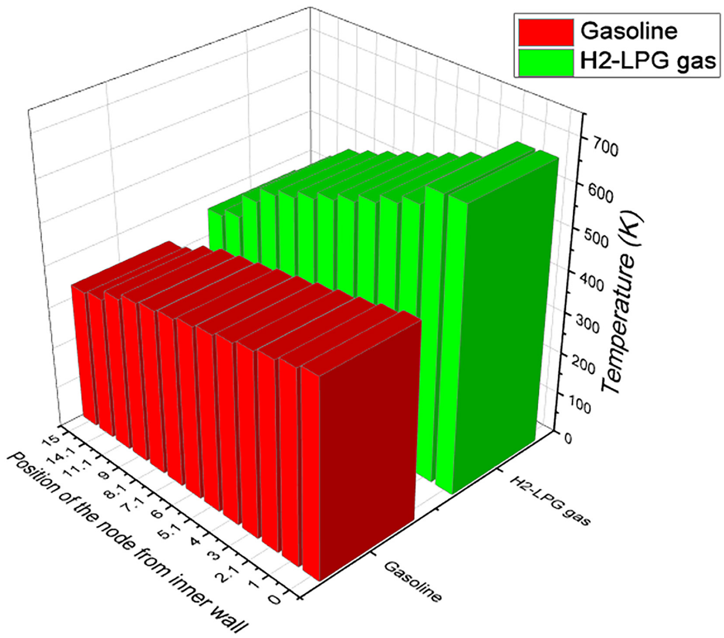


Figure 6. Nodal temperatures from inner wall

minimal fluctuations noted thereafter. Specifically, at this threshold, the temperature registers a mere 0.028% increase, suggesting that further decreases in mesh size would yield negligible impact on temperature. This observation underscores the diminishing returns in temperature variation as mesh size continues to decrease [24, 25]. Temperature distribution across the cylinder thickness has been analyzed using the ANSYS software and the graph has been plotted between temperature and thickness of the cylinder.

Emission test

It is directed emission test for the alternative fuel (LPG + H_2), LPG and petrol. The results obtained has been compared so that the fuel with better emission outcomes can be identified [26]. Figure 7 compares the results of the emission tests conducted on LPG and petrol. The emission test results have been presented for the purpose of comparison. The fuels, hydrogen with LPG blend, LPG, and petrol was tested in the same engine cylinder with help of the gas analyzer unit [27, 28]. For the alternative fuel use in the engine, the testing values of NOx, CO, CO_2, and HC content values in the exhaust gas of the engine is tabulated. Figure 8 contrasts the findings of the emission experiments done on petrol and H_2 + LPG. From the tabulation, it is clear that the NOx, and HC values are reduced more effectively when using LPG and H_2 blend fuel compared to that of the

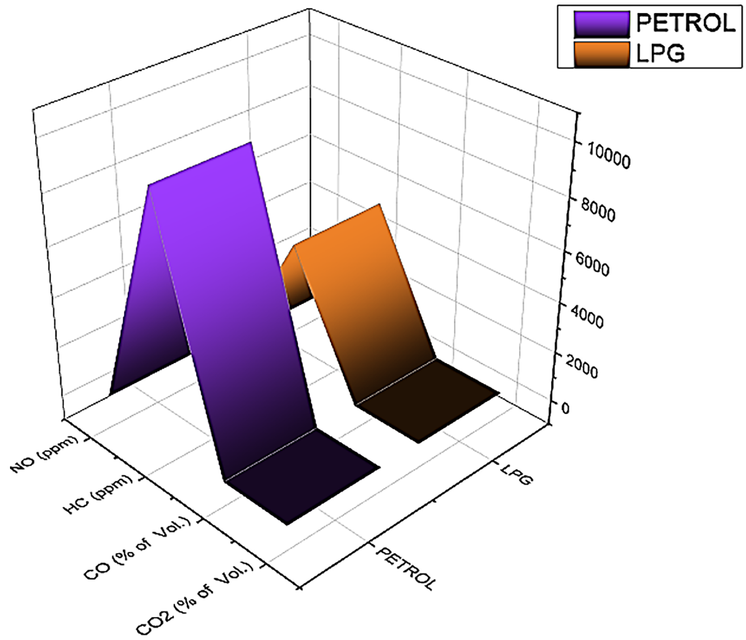


Figure 7. Emission test results between petrol and LPG

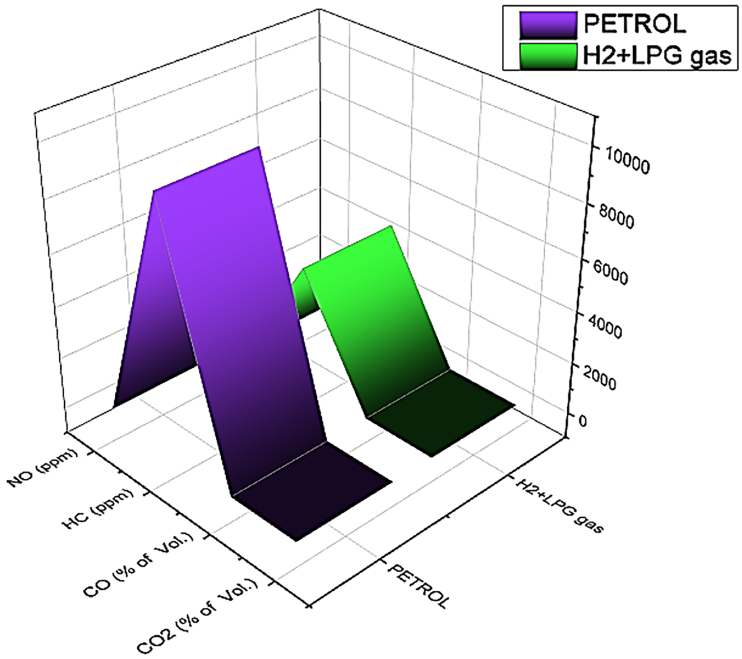


Figure 8. Emission test results between Petrol and H_2 + LPG

petrol as fuel [23]. Thus, the emission and fuel cost are reduced in a considerable amount. Hydrogen is the most promising fuel which may serve as an energy source in future.

CONCLUSIONS

Because storing hydrogen is expensive, time-consuming, and dangerous, hydrogen with LPG mix fuel can be used as a substitute fuel in this activity. Thus, rather than storing hydrogen, it is decided to produce and use it while the car is in motion. Figure 9 shows a manufactured model. This technique balances safety considerations with efficient emission management. In conclusion, hydrogen may be produced simply and affordably using alkaline water electrolysis. This hydrogen can then be combined with LPG to be used in traditional SI engines. Cleaner

Figure 9. Fabricated model of bike which uses LPG + H_2 as fuel

emissions and increased combustion efficiency are the results of better combustion characteristics brought about by the addition of hydrogen to the fuel mix. To ensure hydrogen's safe use as a vehicle fuel source, strict safety regulations and creative engineering solutions are crucial, given the gas's quick combustion and flammability. In order to advance the practical application of hydrogen as a sustainable energy carrier in transportation systems, more research and development in this field is imperative.

Because hydrogen has a high compression ratio, the engine's thermal efficiency is likewise raised. The engine runs more smoothly because of full combustion, which reduces knocking, and low operating costs. But there are a number of benefits. There are several restrictions, such as the vehicle's weight increasing because of the additional storage tanks. A flame made of hydrogen is almost undetectable. In the atmosphere, hydrogen gas burns rapidly and has a concentration of 4–75%. Therefore, in order to lower the vehicle's weight and drag loss, several modifications must be done.

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