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An Experimental Study of the Consumption of Gasoline-Hydrogen Fuel for Long-Tail Marine Engines

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Abstract

Malaysia is a maritime country with a thriving fishing sector that contributes significantly to the supply of raw materials for the food industry and exports. The country's fishermen are categorised into deep-sea fishermen and coastal fishermen. Coastal fishing activities take place within 30 km of the coast and involve the use of boats and small engines, such as long-tail engines powered by petrol or gasoline. The income of fishermen can be significantly impacted by the ratio of fuel consumption to catch. Therefore, reducing the use of gasoline during fishing operations is crucial. Researchers are exploring alternative fuel sources like hydrogen, methanol, and biodiesel to decrease reliance on fossil fuels. This study aims to develop an auxiliary system for marine long-tail engines used by coastal fishermen. A hydrogen generator system based on saline water has been designed. The produced hydrogen fuel will be used in combination with gasoline to reduce fuel costs. As part of the experiment, a test rig for a long-tail gasoline engine was developed and tested using a combination of gasoline and hydrogen fuel. The fuel consumption rate is measured by the ratio of gasoline to hydrogen, such as 25%-75%, 50%-50%, 75%-25%, and 100%-0% (pure gasoline). In this experiment, a long-tail gasoline engine test rig was developed and tested using different gasoline and hydrogen fuel proportions. The fuel ratio was measured to determine the consumption rate, and the engine was tested at speeds of 1500 rpm, 2000 rpm, 2500 rpm, 3000 rpm, and 3500 rpm. The study's results showed that using a combination of gasoline and hydrogen fuel can serve as an alternative to reduce dependence on gasoline for long-tail marine engines.

Keywords: - Hydrogen fuel, long-tail engine, marine engines, coastal fishermen

1. Introduction

Nowadays, the energy-generating process is produced through the use of natural resources such as water, sunlight, air, and minerals from the earth. Part of this generating process is categorised as renewable energy, such as solar energy, power windmills, biomass, bio-fuels, geothermal, hydropower, and agriculture waste. The raw material from the earth's minerals, such as fossil fuels, is used as the main fuel source for the internal combustion engine. Conventional energy sources are those that most of human civilisation has primarily utilised. Because they are non-renewable, a sample of a conventional energy source cannot be replenished once it has been depleted.

Fossil fuels are the largest class of conventional energy sources. Petroleum, coal, natural gas, and their derivatives, including kerosene and propane, are examples of frequently utilised energy sources. The recent revolutionary change has demonstrated the critical importance of energy resources for meeting human needs. This change is central to shifting paradigms and fostering technological innovation. It fulfils the aspirations of intellectually civilised humans by expanding the influence and significance of human resources to meet both present and future needs. Changes to new energy sources and green technology-based alternative fuels are actions that can balance the increasing demand for conventional fuel each year.

According to Annual Fisheries Statistics 2019, Department of Fisheries Malaysia (2019), the fisheries sector successfully recorded production of 1.87 million metric tonnes of food fish, 287.5 million pieces of ornamental fish, and 51.7 million bundles of aquatic plant with a value of RM15.26 billion, an increase of 1.04% in terms of production and 2.65% in terms of value compared to 2018. In 2021, the fisheries subsector produced 1.75 million metric tonnes of edible fish, 242.5 million pieces of ornamental fish, and 24.4 million bunches of aquatic plants worth RM14.88 billion. Edible fish production decreased by 2.1%, from 1.79 million m.t in 2020 to 1.75 million m.t in 2021. The production value of the fisheries industry increased by 7.5%, an increase from RM13.84 billion in 2020 to RM14.88 billion in 2021.

In Malaysia, sea fishermen are categorised into four classes: Zone A, Zone B, Zone C, and Zone C2 and C3. Zone A consists of traditional fishermen and those using anchovy purse seine. Zone B includes fishermen using purse seine, trawl, and kenka, two boats. Zone C consists of traditional fishermen, purse seine, and trawl. The last categories, C2 and C3, include traditional fishermen, purse seine, trawl, and long line. This study focuses on coastal fishermen in Zone A who use gasoline-based internal combustion engines as fuel. The majority of coastal fishermen in this category use gasoline-based long-tail engines. The total number of coastal fishermen registered under category A is 42,748, and there are a total of vessels.

The number of vessels available for category A is directly proportional to the fishing effort. When determining catch effort, factors such as the cumulative number of trips, cumulative number of days, cumulative number of hauls, and cumulative number of hauling hours need to be taken into consideration.

A marine long-tail engine typically refers to a type of propulsion system used in small watercraft, especially in regions like Southeast Asia, as studied by Tuan et al. (2021). It consists of a long, straight driveshaft with a propeller mounted at the end. The engine is usually situated at the stern of the boat, while the long shaft extends from the engine to the propeller. This design allows for effective propulsion in shallow waters, particularly useful in areas with extensive marshes, mangroves, or narrow waterways where conventional propellers might get stuck or damaged. The driveshafts on these engines are exceptionally long and movable; they can extend several feet beyond the boat's transom, as mentioned by Kaewkhiaw (2024). The boat can be propelled even in shallow waters because of the long-tail engine's exposed shaft that runs from the engine to the propeller. It is flexible for different water depths because the shaft's length can be changed. The longer, straight shaft of the long-tail engine makes it possible to place the propeller lower in the water, which is perfect for negotiating shallow seas as studied by Kaewkhiaw (2016). This lowers the possibility of running into underwater obstructions and opens access to places that traditional outboards cannot reach. Excellent steering control made possible by the long-tail engine enables precise handling in confined spaces, helping to navigate past obstructions or through small spaces.

Long-tail engines are typically designed with a focus on durability and simplicity. Their straightforward construction means fewer parts can fail, which can be advantageous in rough or demanding environments. The simpler design makes these engines easier to maintain and repair, often using basic tools and techniques. This is particularly useful in remote areas with limited access to specialised repair services. When compared to other marine engine types, long-tail engines are typically less expensive to maintain and operate. This makes them popular for small-scale commercial and recreational boat operators and coastal fishermen. They tend to have lower fuel consumption than larger outboard marine engines, which can reduce operating costs. The engine's basic design means fewer components require regular maintenance or adjustment. This can lead to lower overall maintenance costs and less frequent servicing. Many long-tail engines allow easy access to the drive shaft and other components, simplifying routine checks and repairs. Users of long-tail engines, especially coastal fishermen, should consider all these aspects and factors as they can significantly impact the daily income of fishermen who rely solely on their coastal catches.

Hakim & Sari (2023) reviewed hydrogen extraction from saltwater, which has gained attention due to the abundance of saltwater and the potential for renewable energy. Several methods for producing hydrogen gas from saltwater include electrolysis of seawater, desalination followed by electrolysis, and biological methods. Electrolysis uses electricity to separate water into hydrogen and oxygen. However, when electrolysis is used on seawater, the process is more complicated due to salts and other impurities. Mohammed-Ibrahim & Moussab (2020) mentioned challenges such as the presence of salts like sodium chloride (NaCl) in seawater, which can lead to issues such as corrosion and the generation of chlorine gas (Cl_2) as a secondary product. Advanced electrodes and membranes are needed to address these challenges and maintain effectiveness.

The process involves desalination followed by electrolysis. First, seawater is desalinated to remove salts and impurities, and then the purified water undergoes electrolysis. Desalination can be achieved through processes like reverse osmosis or distillation, followed by electrolysis of the freshwater obtained. However, desalination is energy-intensive and costly, so overall energy and cost efficiency need to be considered, especially for economical hydrogen production. The next method involves biological processes, where certain algae and bacteria produce hydrogen through biophotolysis or dark fermentation, as reviewed by Bapu et al. (2011). These microorganisms use sunlight or organic matter to produce hydrogen. Research is ongoing to enhance the efficiency and scalability of these biological methods. However, scaling up these biological processes to meet large-scale hydrogen production demands remains a challenge.

According to Hissler (2022), hydrogen can be used in internal combustion engines, similar to gasoline or diesel engines. The advantage of using hydrogen is that it produces only water vapour and heat as exhaust, rather than CO_2 and other pollutants. Marine gasoline engines can be modified to run on hydrogen by adjusting the engine's fuel delivery and ignition systems to accommodate the different properties of hydrogen compared to gasoline. Hydrogen can be stored as a compressed gas, a liquid, or in chemical compounds. Each storage method has different requirements in terms of storage pressure, temperature, and safety. Compressed hydrogen is stored at high pressures of up to 700 bar and requires strong, lightweight containers. Liquid hydrogen is stored at extremely low temperatures of -253°C and requires cryogenic tanks. Hydrogen carriers are stored in chemical compounds, such as metal hydrides, which release hydrogen when needed.

Converting existing marine gasoline engines to use hydrogen requires modifications to the fuel system, ignition system, and possibly the engine's internal components to accommodate hydrogen's high combustion temperatures and different burn characteristics. Hydrogen combustion or fuel cells generate zero emissions at the point of use, significantly reducing marine engines' environmental impact. Moreover, hydrogen can be produced using renewable energy sources, contributing to a cleaner energy cycle. However, according to K. Jain & K. Jain (2021), hydrogen internal combustion engines may not be as efficient as fuel cells, which are generally more effective at converting fuel to energy (Razali et al., 2016).

The cost of producing, storing, and using hydrogen as a marine fuel is currently higher than traditional marine fuels. However, costs are expected to decrease as technology advances and economies of scale come into play. The transition to hydrogen fuel presents challenges in engine design and meeting marine regulations. Government policies and incentives can speed up the adoption of hydrogen as a marine fuel by supporting research, developing infrastructure, and providing subsidies.

2. Methodology

This study was conducted based on methodological planning based on two main points. That is the development of a test rig equipped with an engine platform, dynamometer, and petrol oil tank and the development of a hydrogen gas generator through the salt water electrolysis process. The main engine used in this experiment has been modified to adjust the dual fuel supply of gasoline and hydrogen. The engine used in this study is the SUBARU EX17 model. The air-cooled, 4-stroke gasoline fuel type is the most commercial engine available. The fuel system utilises a transistorised magneto ignition system, which consists of two windings that help produce voltage to give the spark plug its spark. The engine has an 8.5 compression ratio and a maximum power of 5.7 HP at 4000 rpm, with a maximum torque of 11.3 Nm at 2500 rpm. The fuel tank has been modified from the engine body to facilitate the process and experiments. According to the engine service manual, Table 1 shows the engine specifications, and Fig. 1 shows the cross-sectional view along the engine shaft used in this experiment. The used engine has been slightly modified on the fuel supplied into the combustion chamber.

Table 1. Engine specifications

Model	**EX17**
Type	Air-cooled, 4-cycle, slant single-cylinder OHC, horizontal PTO shaft
Bore x Stroke mm (in.)	67x48 (2.64x1.89)
Piston displacement ml (cu.in)	169 (10.31)
Continuous output kW(HP)/rpm	2.6(3.5)/3000 2.9(4.0)/3600
Maximum output kW(HP)/rpm	4.2[5.7]/4000
Maximum torque N.m[kgf . m](Ibf.ft)/rpm	11.3[1.15](8.34)/2500
Direction of rotation	Counterclockwise as viewed from PTO shaft side
Fuel	Automobile(unleaded)gasoline
Fuel Tank capacity Liter(US gal.)	3.2(0.85)
Lubricant	Engine oil SAE 10W-30, 20W, 30W
Lubrication	Mechanical splashing type
Lubricating oil capacity Liter(US gal.)	0.6(0.156)
Carburetor	Float type
Ignition system	Transistorised
Spark plug	NGK BR6HS
Governor	Centrifugal flyweight type
Dry weight kg(Ib)	15(33.08)
Dimension Length x width x height Mm(in.)	304x354x335 (11.97x13.94x13.19)

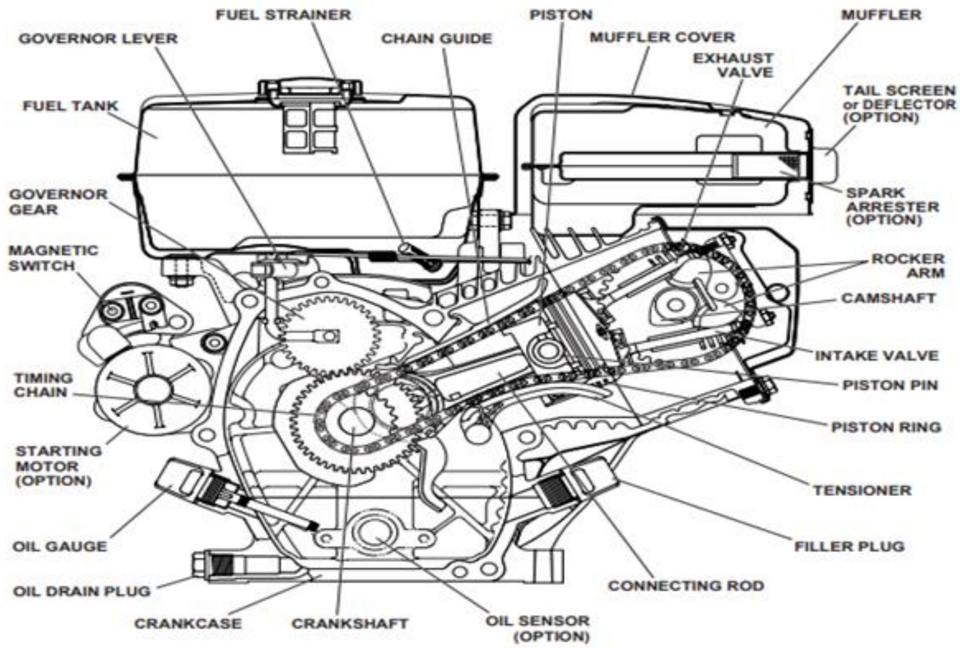

Fig. 1. Cross-sectional view along the shaft

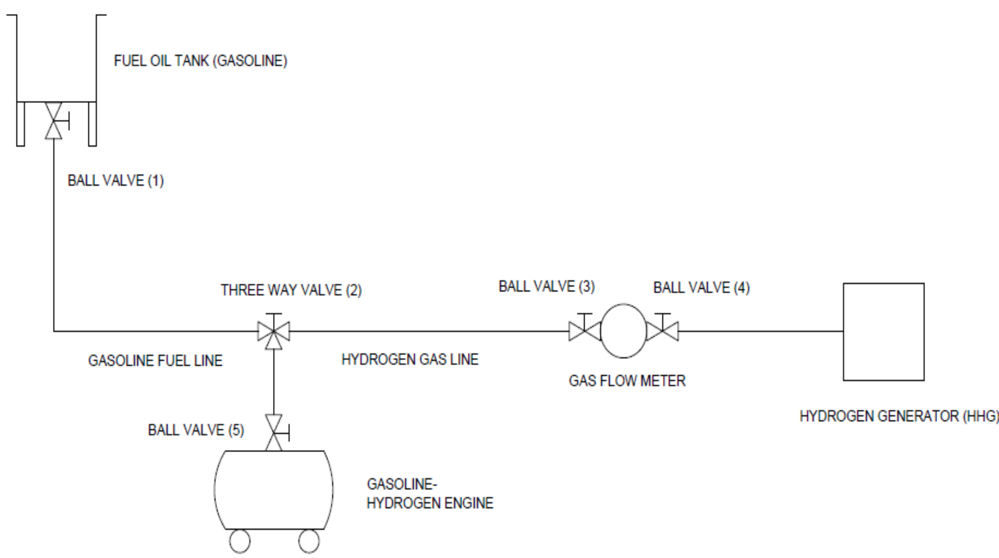

Fig. 2. Gasoline-Hydrogen piping system

This experiment was developed as shown in Fig. 2, which shows the piping system for the engine test rig. This system has four main components: the engine, fuel oil tank (gasoline), hydrogen generator, and three-way valve. The fuel tank (gasoline) provided in this study has a capacity of 10 litres, and the material used is stainless steel. This tank has a fuel outlet valve to control the gasoline flow through the three-way valve. The hydrogen generator was developed using the concept of electrolysis, which uses saline water as an electrolyte. This generator is equipped with an outlet valve and gas flow meter. The function of the outlet valve is to control the flow rate of hydrogen gas generated by the three-way valve. This system is also equipped with a three-way valve to adjust the amount of fuel volume, whether gasoline or hydrogen. The flow rate is measured by the volume fuel ratio of gasoline-hydrogen such as 25%-75%; 50%-50%; 75%-25%; and gasoline completely with a gasoline-hydrogen combination ratio of 100%-0%.

The experiment started with the engine started using gasoline. First of all, the outlet valve (1) of the tank and engine inlet valve (5) is opened. The engine is started and operates at an idle speed of around 1000 rpm. After completing the warming-up process, the engine was started with the help of the fuel oil for a few seconds. The source was changed over to hydrogen gas by closing the fuel tank outlet valve (1) and changing the three-way valve (2) direction to the hydrogen gas line. Then, the hydrogen generator outlet valve (4) is opened slowly to allow the gas to go into the gas flowmeter first. After getting a minimum reading of 0.5 bar, the gas flow meter outlet valve (3) is opened. With that, the sequence of changing over from gasoline fuel to hydrogen gas is done.

2.1 Saltwater Electrolysis

The production and use of hydrogen gas save the use of gasoline fuel used by coastal fishing marine engines. Among the hydrogen gas generation processes used is through the electrolysis process. Electrolysis is a process where an electric current is passed through a substance, typically an electrolyte solution compound, causing a chemical reaction to occur. This reaction results in the decomposition of the substance into its constituent elements or ions. The following are some important elements that need to be understood in the process of producing hydrogen gas using salts such as electrolytes, electrodes, electric currents, and chemical reactions. An electrolyte is a substance that conducts electricity in the form of ions. Common electrolytes include aqueous solutions of salts, acids, or bases. Electrodes are conductive surfaces that come into contact with the electrolyte. There are typically two electrodes; the anode is a positive electrode and the cathode is a negative electrode. Meanwhile, electric current is a flow of electric charge through the electrolyte, facilitated by an external power source such as a battery or power supply. The last element is a chemical reaction which is produced in the electrode. These reactions depend on the specific electrolyte and can involve the reduction of cations; positively charged ions at the cathode and the oxidation of anions; negatively charged ions at the anode.

According to Abdel-Aal et al. (2010), electrolysis of salt water can indeed produce hydrogen gas, among other products. When an electric current is passed through a solution of salt water, it undergoes electrolysis. At the cathode; the negative electrode, hydrogen gas is produced according to the reaction,

$$2H_2O(l) + 2e^- \rightarrow H_2(g) + 2OH^-(aq) \quad (1)$$

At the anode; positive electrode, chlorine gas is produced according to the reaction,

$$2Cl^-(aq) \rightarrow Cl_2(g) + 2e^- \quad (2)$$

Additionally, sodium hydroxide, NaOH, is formed in the solution as a by-product of the reaction at the cathode.

$$2H_2O(l) + 2e^- \rightarrow H_2(g) + 2OH^-(aq) \quad (3)$$

So, the overall reaction is,

$$2H_2O(l) + 2NaCl(aq) \rightarrow H_2(g) + Cl_2(g) + 2NaOH(aq) \quad (4)$$

However, it’s important to note that the efficiency of hydrogen production via this method might be influenced by factors such as the concentration of salt in the water, the type of electrodes used, and the current applied.

3. Result and Discussion

After the experiment was carried out in this study, the variable that is fuel consumption was determined according to the volume fuel ratio of gasoline-hydrogen such as 25%-75%; 50%-50%; 75%-25%; and 100%-0%. Fuel consumption is measured by measuring the time it takes to consume 3 ml of gasoline at speeds of 1500 rpm, 2000 rpm, 2500 rpm, 3000 rpm, and 3500 rpm. The results obtained through this experiment are a combination ratio that will be compared with the basic fuel for this engine, which is full gasoline or a combination of gasoline-hydrogen 100%-0%. At each engine speed, fuel consumption time was recorded three times, and the average time was determined. Table 2 below shows the overall results of fuel consumption records according to their respective ratios.

Table 2. Fuel consumption (seconds) at four different Gasoline–Hydrogen ratios

Engine Speed (rpm)	Fuel Consumption (s)			
	Gasoline-Hydrogen Ratio 25%-75%	**Gasoline-Hydrogen Ratio 50%-50%**	**Gasoline-Hydrogen Ratio 75%-25%**	**Gasoline-Hydrogen Ratio 100%-0%**
1500	54.9	53.2	42.4	53.6
2000	34.7	35.6	36.4	39.1
2500	24.6	25.2	25.3	25.1
3000	19.1	21.3	18.8	20.3
3500	19.2	17.4	15.2	18.1

The results obtained in Table 2 show that each fuel consumption for each gasoline-hydrogen ratio will be compared with the main reference ratio, which is the full use of gasoline with a ratio of 100% -0 %. This comparison is done to study the trend of fuel consumption as a result of the combination of ratios that have been determined. Table 3 below records the comparison of fuel consumption at a gasoline-hydrogen ratio of 25%-75% compared to the main reference ratio of gasoline-hydrogen of 100%-0%. Fig. 3 shows a comparison graph of fuel consumption trends for both ratios.

This result represents a hypothetical measurement related to fuel consumption or efficiency at a blend where 25% of the fuel energy comes from gasoline and 75% from hydrogen. This would represent the time-related efficiency or consumption of pure gasoline, with 100% of the fuel energy derived from gasoline. The time-related efficiency or consumption is 53.6 seconds. The fuel consumption at the 25%-75% gasoline-hydrogen ratio is 1.3 seconds higher, which means more fuel is consumed compared to the 100%-0% gasoline-hydrogen ratio at 1500 rpm. At a maximum speed of 3500 rpm, a difference of 1.1 seconds of excess time was recorded using a Gasoline-Hydrogen Ratio of 25%-75%. However, the reading of the gasoline-hydrogen ratio 100%-0% shows the advantage of longer fuel consumption at speeds of 2000 rpm, 2500 rpm, and 3000 rpm with 4.4 seconds, 0.5 seconds, and 1.2 seconds, respectively.

Table 3. Comparison of fuel consumption (seconds) at Gasoline-Hydrogen ratio 25%-75% and Gasoline-Hydrogen ratio 100%-0%

Engine Speed (rpm)	**Fuel Consumption (s)**	
	Gasoline-Hydrogen Ratio 25%-75%	**Gasoline-Hydrogen Ratio 100%-0%**
1500	54.9	53.6
2000	34.7	39.1
2500	24.6	25.1
3000	19.1	20.3
3500	19.2	18.1

The average fuel consumption for both combinations or the ratio to the speed that has been tested is 30.5 seconds for Gasoline-Hydrogen Ratio 25%-75% and 31.2 seconds for Gasoline-Hydrogen Ratio 100%-0%, respectively. There is a difference of 0.7 seconds or around 2% more fuel consumption time in the same quantity recorded by Gasoline-Hydrogen Ratio 100%-0%. This means that a Gasoline-Hydrogen Ratio of 100%-0% still has an advantage over a Gasoline-Hydrogen Ratio of 25%-75%. Referring to Fig. 3, the trend shows almost the same fuel consumption rate for both ratios. This 2% difference shows that a Gasoline-Hydrogen Ratio of 25%-75% can be used as an alternative factor in reducing dependence on gasoline fuel.

The next combination ratio is the Gasoline-Hydrogen Ratio of 50%-50% compared to the Gasoline-Hydrogen Ratio of 100%-0%. Table 4 compares fuel consumption between the Gasoline-Hydrogen Ratio of 50%-50% and the Gasoline-Hydrogen Ratio of 100%-0%. The average fuel consumption rate is 34.3 seconds and 34.9 seconds, respectively. This average is also equivalent to a 0.02% difference, which is the advantage of fuel consumption time for the gasoline-hydrogen ratio of 100% -0 %. This margin is too small. Referred to Fig. 4, the linear trend is almost the same for both ratios.

Table 4. Fuel consumption (seconds) at Gasoline-Hydrogen ratio 50%-50% and Gasoline-Hydrogen ratio 100%-0%

Engine Speed (rpm)	**Fuel Consumption (s)**	
	Gasoline-Hydrogen Ratio 50%-50%	**Gasoline-Hydrogen Ratio 100%-0%**
1500	53.2	53.6
2000	35.6	39.1
2500	25.2	25.1
3000	21.3	20.3
3500	17.4	18.1
1500	53.2	53.6

Referring to Table 5, comparing the use of gasoline-hydrogen fuel 75%-25% with gasoline 100% overall shows that the use of gasoline fuel 100% is more economical. Fuel consumption savings of 100% gasoline is approximately 21%. The high percentage of time savings in this ratio is when the speed is 1500 rpm, which is 21%. When the speed reaches 2000 rpm, the fuel consumption savings are only 7%, which is equal to the engine speed at 3000 rpm. When the engine speed is at the maximum speed of 3500 rpm, the fuel consumption savings is 16%. However, the engine does not have an economical reading when the speed is 2500 rpm. The average consumption for both ratios is 24.6 seconds and 31.2 seconds, respectively.

Table 5. Fuel consumption (seconds) at Gasoline-Hydrogen ratio 75%-25% and Gasoline-Hydrogen ratio 100%-0%

Engine Speed (rpm)	**Fuel Consumption (s)**	
	Gasoline-Hydrogen Ratio 75%-25%	**Gasoline-Hydrogen Ratio 100%-0%**
1500	42.4	53.6
2000	36.4	39.1
2500	25.3	25.1
3000	18.8	20.3
3500	15.2	18.1

Fig. 5 illustrates that there is an unequal trend between the two fuel ratios. Fuel consumption for Gasoline-Hydrogen Ratio 75%-25% is less economical than Gasoline-Hydrogen Ratio 100%-0%. Fuel consumption savings of 100% gasoline is approximately 21%.

4. Conclusion

The conclusion that can be concluded from this study is that the three ratio combinations, namely the Gasoline-Hydrogen Ratio of 25%-75%, Gasoline-Hydrogen Ratio of 50%-50%, and Gasoline-Hydrogen Ratio of 75%-25%, have shown their ability when compared to the full use of gasoline. A comparison of fuel consumption Gasoline-Hydrogen Ratio of 25%-75% with a Gasoline-Hydrogen Ratio of 100%-0% shows a saving of 2.5% of fuel if using gasoline completely. While the comparison of fuel consumption Gasoline-Hydrogen Ratio of 50%-50% with a Gasoline-Hydrogen Ratio of 100%-0% shows a saving of 0.02% fuel if using a Gasoline-Hydrogen Ratio of 50%-50%. The third fuel consumption comparison is a Gasoline-Hydrogen Ratio of 75%-25% with a Gasoline-Hydrogen Ratio of 100%-0%, showing a 21% fuel saving if using a Gasoline-Hydrogen Ratio of 100%-0%. This study has successfully opened up space for further development and research on the potential of hydrogen as an alternative fuel to fossil fuel sources, especially in helping coastal fishermen save fuel costs.

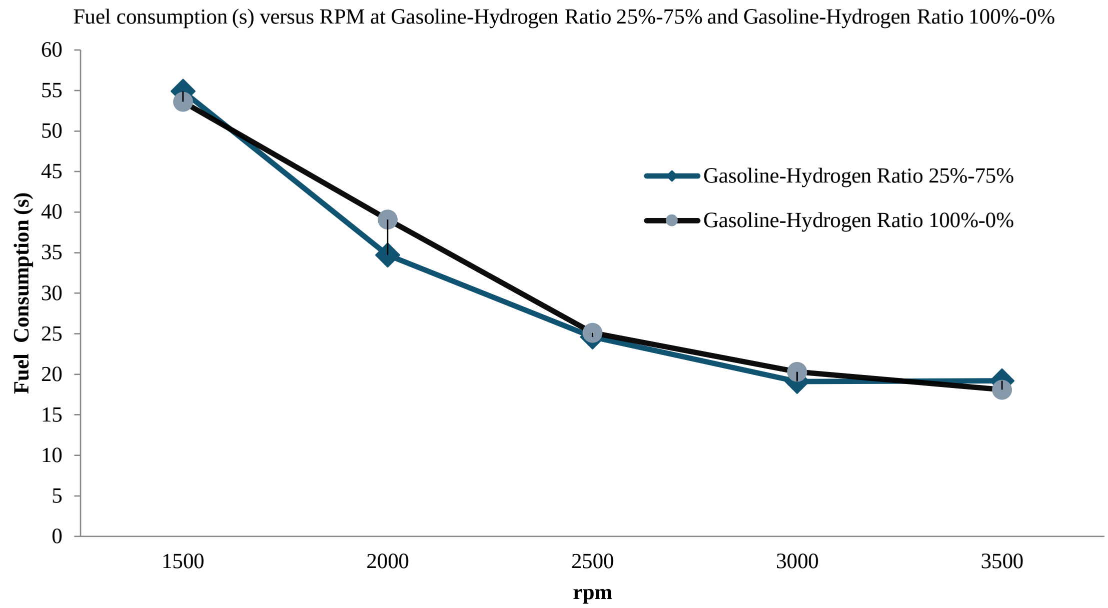

Fig. 3. Comparison graph fuel consumption (s) versus rpm at Gasoline-Hydrogen ratio 25%-75% and Gasoline-Hydrogen ratio 100%-0%

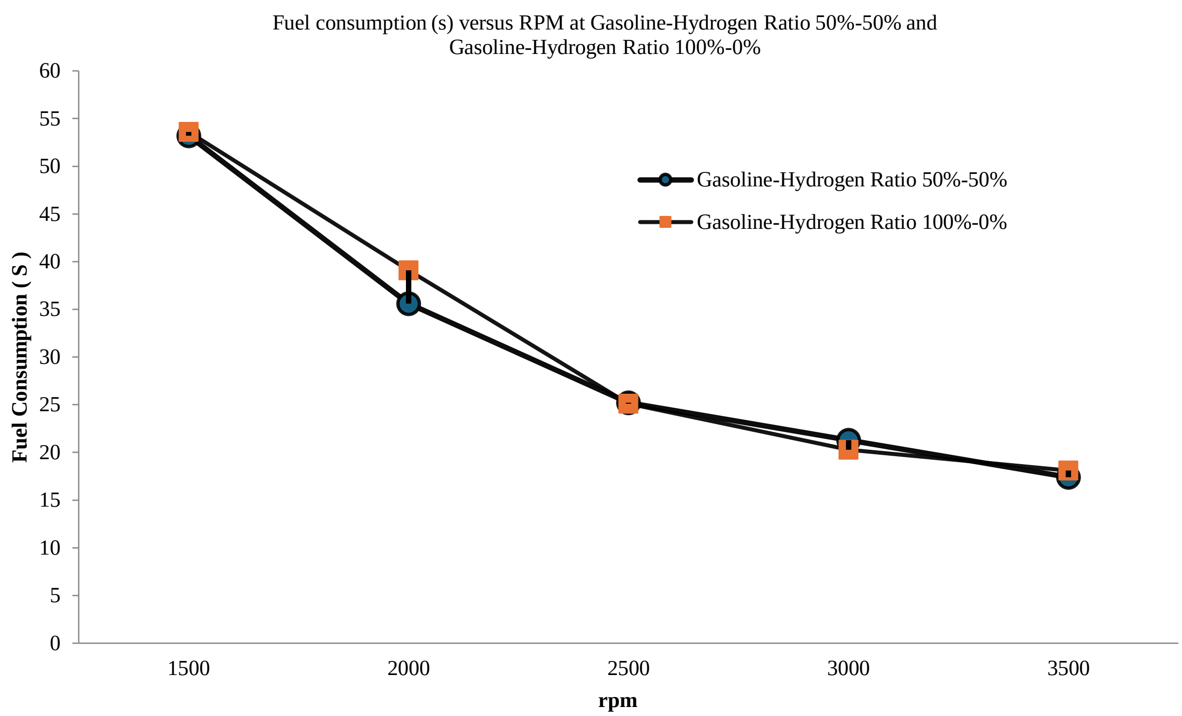

Fig. 4. Comparison graph fuel consumption (s) versus rpm at Gasoline-Hydrogen ratio 50%-50% and Gasoline-Hydrogen ratio 100%-0%

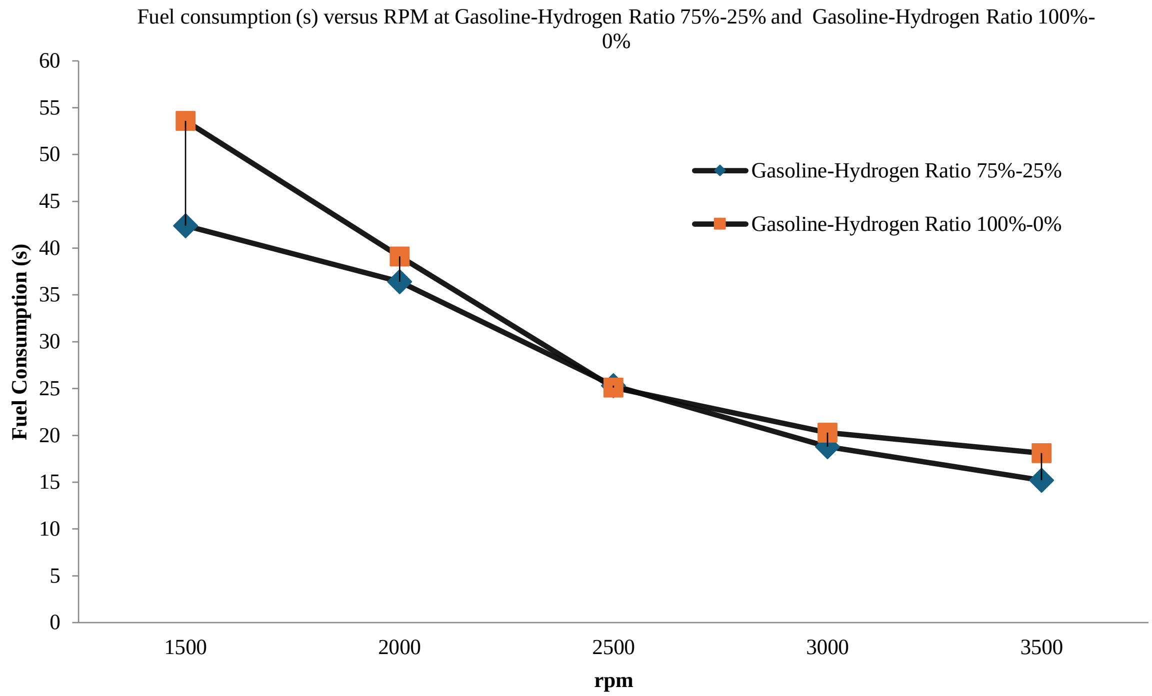

Fig. 5. Graph fuel consumption (s) versus rpm at Gasoline-Hydrogen ratio 75%-25% and Gasoline-Hydrogen ratio 100%-0%

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