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Development and Experimental Evaluation of a Hydrogen-Fueled Internal Combustion Engine and Emission analysis

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Abstract

Development Hydrogen-Fueled Internal Combustion Engine and Emission analysis .The use of hydrogen hydroxyl (Hydrogen-Hydrogen-Oxygen) gas as a fuel additive in gasoline for SI engines has a favorable impact on enhancing performance and decreasing the repercussions of burning fossil fuels alone. In this study, the effect of injecting HHO gas additive into the gasoline fuel of a gasoline engine was thoroughly investigated in order to increase overall efficiency by percentage 20% . The engine was connected to an electric generator to create electricity at a minimal cost. An experimental setup was developed to assess the performance indicators. The Hydrogen-Hydrogen-Oxygen gas was produced and injected into the intake manifold of the engine while it was running under various load situations. The essential parameters, such as engine RPM and electric generator output voltage/amperes, were measured, and performance indicators were calculated to assess the system's overall efficiency. The results showed that the Hydrogen-Hydrogen-Oxygen additive improved the performance of the gasoline engine more clearly when the gasoline content was lower in the air-fuel mixture.

Introduction

While fossil fuels generate 82% of global energy, they also contribute significantly to greenhouse gas emissions and climate change. Efforts are underway to replace these fuels with cleaner and renewable alternatives. Hydrogen produced using water electrolysis is a promising solution because of its minimal emissions. Currently, this process produces 12-15% of hydrogen. The gas created during water electrolysis is known by a variety of names, including HHO gas, Oxyhydrogen, Hydroxyl, Brown's gas, Hydrogen rich gas, and water electrolysis gas. Rising fossil fuel depletion and pricing have increased the global demand for alternate energy sources. There is a high demand for cost-effective fuel options for internal combustion engines. Increasing awareness is also accelerating the development of more efficient fuel usage technologies. The use of a hydrogen and oxygen combination (HHO), also known as Brown gas or Rhode's gas, is proposed to improve combustion efficiency in engines and minimize emissions.

For more over three decades, the benefits of HHO use have been widely publicized. According to D.J.Cerini, including an onboard hydrogen generator and mixing hydrogen with gasoline in internal combustion engines will improve the lean burn combustion capability A/F ratios, resulting in increased engine efficiency. The hydrogen generating system utilized onboard is commonly known as the hydrogen on demand-supply system.

NASA experiments show that combining HHO with gasoline enhances thermal efficiency in multi-cylinder piston engines, particularly with lean air-fuel ratios. The research also examined flame speed and combustion patterns to establish the best conditions for the fuel mixture.

Engines powered by a gasoline-hydrogen combination consume less energy than gasoline alone. However, the mixture produces more NOx emissions due to greater peak temperatures. Nonetheless, at lower energy consumption levels, NOx emissions from gasoline-hydrogen mixture are lower than those from gasoline-only burning.

Internal combustion engines use hydroxy gas (HHO), which is created through electrolysis with various electrolytes (KOH, NaOH, and NaCl). The trials revealed that HHO increased engine performance by about 20%, reduced emissions by 5% to 15%, and decreased specific fuel consumption (SFC) by 15%. However, at speeds below 1750 rpm, a Hydroxy Electronic Control Unit (HECU) was designed to control the flow rate of HHO to compensate for the slower revolutions and subsequent Air Fuel Ratio changes to prevent the over occupation of a cylinder with HHO.

Applications of HHO Gas in Internal Combustion Engines:

1. Fuel Efficiency Improvement

Mechanism: When mixed with traditional fuels like gasoline or diesel, HHO gas improves the combustion efficiency due to its high flame speed and energy density.

Results: Studies show that adding HHO gas to an engine can reduce the fuel consumption by 10-30%, depending on the engine type and operating conditions.

2. Reduction of Emissions

CO and CO_2 Reduction: HHO enhances the complete combustion of hydrocarbons, reducing carbon monoxide (CO) and carbon dioxide (CO_2) emissions.

NO_x Reduction: The presence of water vapor in the combustion process lowers the peak combustion temperature, which reduces

the formation of nitrogen oxides (NO_x).

3. Improved Engine Performance

HHO gas improves the torque and power output of engines by enhancing the combustion process.

The cleaner combustion reduces engine deposits, which contributes to smoother operation and longer engine life.

The exact test setup, methodology, and results are given on in this paper

Literature Review

Beginnings: Early curiosity.

1. The history of the hydrogen engine begins in the nineteenth century, when Henry Cavendish discovered hydrogen in 1766. Hydrogen's high energy content led to its early identification as a fuel. The idea of using hydrogen in engines emerged in the early nineteenth century, when Sir William Grove proved the potential of fuel cells that convert hydrogen and oxygen into electricity and water.

2. In 1807, de Rivaz created the de Rivaz engine, which was one of the first internal combustion engines fuelled by hydrogen and oxygen. It used an electric spark to start and was intended to power a vehicle, making it an early attempt at automotive propulsion. Although not widely used, it created a crucial foundation for future engine technology.

3. de Rivaz engine

A = Cylinder

B = Spark ignition

C = Piston

D = Balloon containing hydrogen fuel

E = Ratchet

F = Opposed piston with air in and exhaust out valves
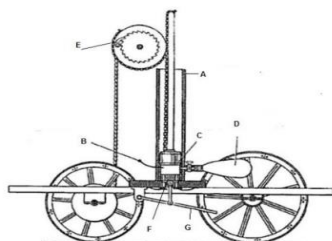
G = Handle for working opposed piston.

Figure 1 Illustration of de Rivaz engine

The Visionaries: 20th Century Pioneers

Engineers like as Rudolph Erin made the first serious attempts to use hydrogen for propulsion in the beginning of the 20th century, but they ran into technical problems, especially with hydrogen storage and safety. During the 1970s oil crisis, academics became interested in hydrogen because of its environmental benefits, including its lack of greenhouse gas emissions. At the time, hydrogen-powered models were being constructed as experiments.

The Turning Point: Advances in Storage and Safety

1. Late 20th and early 21st century:

During this time, significant advances were made in hydrogen storage technology. Researchers investigated several methods for storing hydrogen efficiently, such as compressed gas, liquid hydrogen, and solid-state materials. Metal hydrides and nanocarbon tubes were among the most promising materials, providing compact and safe storage solutions.

2. Scientific Advances After World War II:

World War II had a substantial impact on scientific progress, accelerating advancements in a variety of sectors due to wartime necessities and discoveries. The decades following the war saw continuing development and improvement of technologies resulting from the fight.

3. Messerschmitt Me 163 Komet:

Messerschmitt built the Me 163 Komet, a groundbreaking rocket-powered interceptor aircraft. It is the first rocket-powered combat aircraft ever built and the first manned aircraft to reach 1,000 km/h (620 mph) in level flight.

4. Development of the Me 163:

The Me 163 was developed by German aeronautical engineer Alexander Lippisch and the Deutsche Forschungsanstalt für Segelflug (DFS) beginning in 1937. This basic effort led to the design of the Me-163 rocket plane.
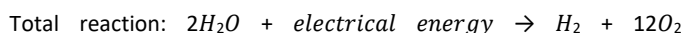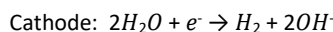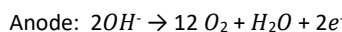
Methodology

This section was divided into two parts.

1. HHO electrolyzer model description and assumptions. The mathematical model, which includes thermodynamic, electrical, chemical, and thermal models, predicts the properties of the HHO electrolyzer, including gas flow rate, design, and experimental dry alkaline electrolyzer components.

2. The following part covers engine parameters and combustion process. The practical and theoretical results were compared to demonstrate model validation.

Model description

The water molecules are split into hydrogen and oxygen by passing direct current between the anode and cathode of the two electrodes. The two electrodes are separated by an aqueous electrolyte with high ionic conductivity. An alkaline electrolyzer (NaOH) uses aqueous sodium hydroxide as its electrolyte. Clean water has a lower conductivity, hence this chemical compound will increase the conductivity of the electrolyte. The electrodes should be structurally sound, exhibit good catalytic performance, be corrosion resistant, and have good electric conductivity. Furthermore, there should be no electrolyte-electrode reactions. The cathode (- terminal) generates hydrogen, while the anode (+ terminal) generates oxygen. The equations below reflect the reaction at the cathode, anode, and the total reaction for splitting water:

Anode: $2OH^- \rightarrow 12\ O_2 + H_2O + 2e^-$

Cathode: $2H_2O + e^- \rightarrow H_2 + 2OH^-$

Total reaction: $2H_2O + electrical\ energy \rightarrow H_2 + 12O_2$

Water electrolysis converts electrical and thermal energy into chemical energy. The hydrogen will subsequently be used to store the chemical energy. The mathematical model is separated into four stages: thermodynamic, electrical, chemical, and thermal, as the electrolytic cell and electrical energy are converted into chemistry. During this process, some thermodynamic variables experience energy imbalance.

Thermodynamic model.

Thermodynamics provides a framework for understanding reaction equilibrium and thermal effects in electrochemical reactors. Furthermore, it provides the foundation for a consideration of the factors that drive transport phenomena in electrolytes before moving on to describe the properties of electrolyte solutions. For the water splitting reaction, the following assumptions might be made:

(a) hydrogen and oxygen are ideal gases,

(b) water is an incompressible fluid

(c) the gas and liquid phases are separated

The following gives the relationship between the enthalpy, Gibbs free energy, and entropy:

$$\Delta G = \Delta H - T\Delta S$$

Gibbs Free Energy predicts whether a reaction or process will occur spontaneously or not by calculating enthalpy, temperature, and entropy. Remember that a spontaneous reaction is a chemical or physical process that starts naturally and continues without external intervention once started. In spontaneous reactions, reactants convert into products without the need for extra energy input from the surroundings.

A non-spontaneous reaction is a chemical or physical process that does not occur naturally under certain conditions and requires external energy to continue. Non-spontaneous reactions require the input of energy from an external source to turn reactants into products. This energy input often raises the system's Gibbs free energy, allowing the reaction to proceed. Non-spontaneous processes include electrolysis of water, which produces hydrogen and oxygen gas.

If a process's Gibbs Free Energy is negative, it is considered spontaneous. If Gibbs Free Energy is positive, the process isn't spontaneous.

Figure2 Exergonic Reaction and Endergonic Reaction

It is important to note that spontaneous doesn't mean fast; in fact, many spontaneous reactions are extremely delayed. For instance, the spontaneous transformation of diamond to graphite is extraordinarily slow. So we don't have to worry about diamond jewelry turning into graphite.

Electrochemical cells turn chemical energy into electrical energy, and vice versa. The overall quantity of energy produced by an electrochemical cell, and hence the amount of energy available for electrical work, is determined by both the cell potential and the number of electrons transported from the reductant to the oxidant during a reaction. The resulting electric current is measured in coulombs (C), a SI unit that represents the number of electrons traveling through a given place in one second.

A coulomb is a unit of measurement that connects energy (in joules) to electrical potential (in volts). Electric current is measured in amperes (A); 1 A is defined as the flow of 1 C/s past a given point (1 C = 1 A.s):

$$\frac{1\,J}{1\,V} = 1\,C = 1\,A.S$$

In chemical reactions, however, we must connect the coulomb to the charge on one mole of electrons. The charge on one mol of electrons, known as the faraday (F), is calculated by multiplying the charge on the electron by Avogadro's number:
$F = 96{,}485\ C/mole$.
The total charge transferred from reductant to oxidant is zF, where z represents the number of electrons.

The maximum work output of an electrochemical cell (ωmax) is equal to the product of the cell potential ($\in ocell$) and the total charge transferred during the process (zF):.
$$\omega_{max} = zF \in^{ocell}$$

The change in free energy (ΔG) represents the highest amount of work possible during a chemical process (ΔG = ωmax). The link between an electrochemical cell's potential and ΔG is as follows: $\Delta G = zF \in^{ocell}$

Reversible voltage $Urev$ is the electrical work done in an electrochemical process operating at pressure of 1 bar and temperature of 25°C, as indicated by: : $U_{rev} = \frac{\Delta G}{zF}$

The electromotive force or equilibrium cell voltage is the minimum voltage required for electrolysis to occur ($Urev$). The actual minimum voltage in the electrolysis cell is the voltage of the thermoneutral cell (Utn). This is due to the drop in the optimal voltage required to separate water molecules as the electrolyte temperature increases. The cell voltage is below $Urev$, hence hydrogen cannot be generated. Water splits due to heat absorption from the surroundings. When the cell voltage exceeds, it generates exothermic waste heat, which increases cell losses.

The total energy in water electrolysis is approximated as the enthalpy change, which can be used to determine Utn. For reversible processes, the heat demand equals the thermal irreversibility TS, which is included in the value of H. U_{tn} is then stated as: $U_{tn} = \frac{\Delta H}{zF}$
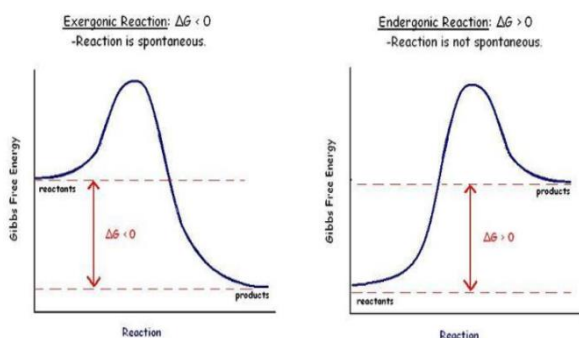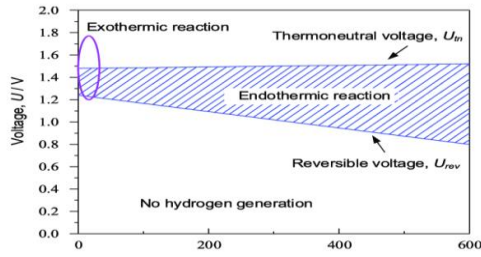
Figure 3 Temperature, T/^{0}C

The values of $Urev$ and Utn are 1.229 and 1.482 V, respectively, and fluctuate based on pressure and temperature. Temperature affects $Urev$ more than Utn. As temperature increases, $Urev$ decreases somewhat, whereas Utn remains constant. In an electrochemical model, perfect water electrolysis requires a cell voltage equal to $Urev$. This cell's potential is significantly higher than $Urev$ due to an irreversible process in overvoltage potential that reduces the cell's efficiency.

Electrical model.

The electrical model is designed to compute the electrolyzer's voltage (V) and current (I). The electrolyte's ohmic loss, oxygen and hydrogen overvoltage, and the electrical impedance of the electrodes and circuits are the primary reasons of overvoltage potential. Empirical current-voltage (I-U) relationships can be utilized to model the electrode kinetics of an electrolyzer cell. The electrolysis cell potential is calculated by adding the $Urev$ and any additional overvoltage potential from the sources. These figures show the overall potential of the electrolysis cell:

$$U_{cell} = U_{rev} + U_{act} + U_{ohm}$$

where $Uact$ is the activation overvoltage and $Uohm$ is the overvoltage caused by ohmic losses. $Uact$ occurs when the anode and cathode undergo concurrent half-reactions due to their electrochemical kinetics. $Uact$ can be represented as a function of r, s, and t, as shown in Table 1 :

$$U_{act} = s * \log(\frac{t}{A} * I + 1)$$

$$U_{act} = s * \log(\frac{t_1 + \frac{t_2}{T} + \frac{t_3}{T^3}}{A} * I + 1)$$

where s, $t1$, $t2$, and $t3$ represent the electrodes' coefficient overvoltage, I for their current density, T for the cell's temperature, and A for their electrode area. Ohmic excess voltage $Uohm$ represents internal ohmic losses in a cell. These losses are proportional to the electrical current that passes through the cell and are connected with electrical energy loss in the form of heat generation. The electrolyte causes the majority of ionic losses. The $Uohm$ is represented as:

$$U_{ohm} = \frac{r}{A} * I$$

$$U_{ohm} = \frac{r_1 + r_2 T}{A} * I$$

here r_1 and r_2 are the ohmic resistances of electrolyte parameter, respectively.
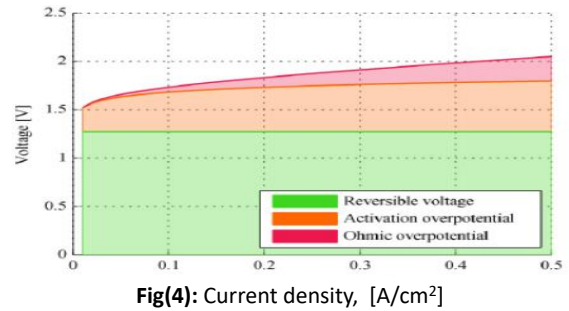
Fig(4): Current density, [A/cm^2]

Table 1 " electrodes' coefficient overvoltage "

Coefficient	Value	Unit
r	8.05 x 10^{-5}	$\Omega.m^2$
r	-2.5 x 10^{-7}	$\Omega.m^2.^0C^{-1}$
s	0.185	V
t$_1$	1.002	A^{-1}.m^2
t$_2$	8.424	A^{-1}.m^2 ^{0}C^2
t$_3$	247.3	A^{-1}.m^2 ^{0}C^2

Chemical model.

Faraday's law states that the rate of oxyhydrogen production in a cell is determined by the electrical work output or the number of electrons exchanged between the electrodes. The Faraday efficiency is the ratio of real hydrogen produced in the electrolyzer to the theoretical maximum amount. The current losses in the gas pipes are due to Faraday efficiency. Temperature has a significant impact on Faraday efficiency, as rising current reduces resistance and increases current losses. An empirical expression of Faraday efficiency at a given temperature is expressed as:

$$\eta_f = \frac{(\frac{I}{A})^2}{f_1 + (\frac{I}{A})^2} * f_2$$

Table 2 shows the temperature-dependent coefficients ($f1$ and $f2$). The pace at which electrons move between electrodes dictates how much hydrogen is produced by the electrical current. In addition, the number of cells connected in series affects the amount of hydrogen produced. The rate of hydrogen generation is calculated using this formula:

$$Q_{H2} = \eta_f * \frac{n\,I}{zF}$$

Table 2 " temperature-dependent coefficients "

Coefficient	Value, mA^2 cm^{-4}	Temperature, °C
$f1$	150	40
$f1$	200	60
$f1$	250	80
$f1$	250	80
$f2$	0.99	40
$f2$	0.985	60
$f2$	0.98	80
$f2$	0.96	80

Thermal model.

Using basic or advanced thermal models, the electrolyte temperature and heat loss of the electrolyzer can be estimated.

$$\Delta E = Q - P\Delta V$$

The work (PV) is ignored because the mathematical model focuses on the phase shift of the solution (electrolyte dissolved in water), but the outcomes of an electrochemical reaction occur at atmospheric pressure. The irreversible voltage is less than the reversible voltage. The heat of the electrolyte should consider both the concentration (CA) and the speed constant (k) when employing KOH, NaOH, and NaHCO3 during water electrolysis.

$$Q_{electrolyte} = kC^2$$

The speed constant changes with the temperature as described. $k = k_o e^{(-E/TR)}$

The experiment and Results:

Test duration or number of experiments varies depending on measurement conditions

Test Conditions: Engine Load: Tested under various load conditions (light, medium, and full load).

Engine Speed: Varied across a range of RPMs (e.g., idle, medium, and high speeds).

Ambient Conditions: Controlled temperature and humidity to ensure consistent results

The requirements:

1-Dry Alkaline Electrolyzer with these specifications:

Table 3 " specifications of Dry Alkaline Electrolyzer "

Electrolysis cell specifications	Value
End-plate material	Acrylic
Electrodes material	Stainless steel 304
Gasket material	Rubber
Electrodes dimensions	180 x 180 mm
End-plate dimensions	210 x 210 mm
Gasket inner dia.	15 cm
Electrolysis cell capacity	2.1 L
Voltage	12 V
Amperage	15.9 A

These are the characteristics of the gas leaving and heading to the combustion chamber in the electric generator:

Table 4 " characteristics of the gas "

HHO gas specifications	Value
Chemical Formula	$H_2 + O_2$ (2 parts hydrogen, 1 part oxygen)
Common Names	Brown's gas, oxyhydrogen, hydrogenoxygen gas
Production Method	Electrolysis of water
Molecular Weight	Approximately 18 g/mol (for H_2O, the product)
Density	Approximately 0.08375 kg/m³ (hydrogen), 1.429 kg/m³ (oxygen)
Boiling Point	Hydrogen: -252.87°C, Oxygen: -182.96°C
Flammability	Highly flammable
Autoignition Temp	Approximately 570°C
Flame Temperature	Around 2800°C in air, 3200°C in oxygen
Energy Content	~120-142 MJ/kg (hydrogen)

2-Electric generator with these specifications:

Table 5 " specifications of Electric generator "

Engine Parameters	Specifications
Type	4 Strokes/Air Cooling/Single Cylinder/OHV/Horizontal Shaft
Combustion System	Direct injection
No. Of Cylinder	Single Cylinder
Bore x Stroke	68 x 54 mm
Connection Rod length	82 mm
Engine Displacement	169 cc
Starting Mode	Recoil
Fuel Tank Capacity	15 L
Oil Capacity	0.6 L
Compression Ratio	8.5:1
Combustion Chamber	Re-entrant piston bowl
Fuel Intake System	Intake Vacuum
Cooling	Air Cooled
Ignition Timing Advance	10° BTDC
Rating and Idling Speed	3000 rpm & 750 rpm
Max. Net Torque	12.4 Nm (1.26 Kgfm) / 2500 rpm

Net Power	2.8 Kw (3.7 HP) / 3000 rpm
Ignition System	Transistorized
Fuel Cons. At Cont. Rated Power	1.7 L/h – 3600 rpm
Specific Fuel Consumption	354 g/Kw.h
Fuel Injection	Carburetor
Fuel Pressure	80.6 Kpa
Valves (Intake, Exhaust)	1,1
Intake Valve Open (IVO)	13° BTDC
Intake Valve Closed (IVC)	22°ABDC
Exhaust Valve Open (EVO)	22° BBDC
Exhaust Valve Closed (EVC)	13° ATDC
Overlap	0°
Engine Speed	3000 rpm
Volume BDC	194.3 cm³
Volume TDC	25.3 cm³
Dry Weight	16.1 Kg

The combination of a dry cell electrolyzer, a four-stroke internal combustion engine, and an electric generator offers an innovative technique to increasing fuel efficiency and lowering pollutants. The electrolyzer produces HHO gas, which can be injected into the engine's air intake system. When the engine operates, the HHO gas mixes with the regular fuel, resulting in a more thorough combustion. This improved combustion process may result in increased engine efficiency and lower hazardous emissions.

After learning about our electric generator's features, we will do a two-stage combustion model analysis. The first stage involves routine use of the generator on gasoline. The second stage involves adding hydroxy gas to the gasoline, comparing the results, and analyzing them in the following chapter to determine the percentage of savings and change in mechanical power. The generator's voltage, the effect of adding hydroxy gas on the strains on the cylinder wall, and an examination of the change in the ensuing exhaust gasses.

Electrical generator combustion model:

1. Gasoline combustion model

2. Gasoline + HHO gas combustion model

Gasoline combustion model:

1. Air-to-Fuel Ratio:

The air-to-fuel ratio (AFR) is an important factor in the combustion process of internal combustion engines. It represents the ratio of the mass of air and the mass of fuel in the combustion mixture.

Stoichiometric AFR

• **Stoichiometric Ratio**: The optimal or stoichiometric AFR for gasoline is 14.7 to 1. This implies that 14.7 kg of air is required to completely burn 1 kg of gasoline.

• **Balanced Reaction**: At this ratio, all the fuel

theoretically combines with all the oxygen in the air, resulting in full combustion with minimal emissions.

Rich and Lean Mixtures

• **Rich Mixture**:

An AFR below the stoichiometric ratio (e.g., 12:1) indicates excess fuel or insufficient air, resulting in a rich mixture. This can lead to incomplete combustion, increased emissions of unburned hydrocarbons (HC), and higher carbon monoxide (CO) emissions.

• **Lean Mixture**: An AFR greater than the stoichiometric ratio (e.g., 16:1) implies excess air or insufficient fuel, resulting in a lean mixture. This can lead to increased nitrogen oxide (NOx) emissions and engine knocking or misfire. The stoichiometric combustion reaction in the absence of HHO gas :
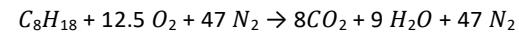
$$C_8H_{18} + 12.5\ O_2 + 47\ N_2 \rightarrow 8CO_2 + 9\ H_2O + 47\ N_2$$

The air-fuel ratio is determined by calculating the ratio of the mass of the air to the mass of the fuel, as well as the ratio of the volume of the air to the volume of the fuel,

$$\frac{A}{F_{by\ mass}} = \frac{m_{air}}{m_{fuel}} = \frac{12.5(2*16 + 3.76*14*2)}{1*(12*8 + 1*18)} = 15:1$$

$$\frac{A}{F_{by\ volume}} = \frac{Vmole_{air}}{Vmole_{fuel}} = \frac{12.5(1 + 3.76)}{1} = 59.5:1$$

2. Engine power output:

• Fuel power output (Qf)

To calculate the power resulting from the ignition of fuel within the combustion chamber, we must first know the characteristics of this fuel, such as its enthalpy value and ignition temperature.

Table 6 Properties of gasoline

Property	Value
Chemical Formula	C_4-C_{12} H_8-H_{24}
Density	0.71-0.77 g/cm³
Boiling Point	27 – 225 ºC
Octan Number	87-100
Heating Value	42.4 – 44.4 MJ/Kg
Flash Point	-40ºC
Ignition Temperature	246-280ºC

Fuel power (Qf) represents the energy input from the fuel. This can be determined using the fuel consumption rate and the caloric value of gasoline.

Fuel consumption rate (m_{fuel}): The amount of fuel utilized per unit time. This may be estimated or measured.

Calorific value of gasoline ($CV_{gasoline}$) : When fuel is combusted, it releases energy per unit mass. For gasoline, this is usually around 44 MJ/kg..

$$Q_f = m_{fuel} * CV_{gasoline}$$

$$Q_{fact} = Q_f * \eta c$$

Indicated power (Pi):

The power of the pressure of gases acting on the piston..

$$Pi = Q_{fact} * \eta i, th$$

Work indicated = $imep * V_d$

$$V_d = \frac{\pi\, D^2 l}{4}$$

$$Mep(KPa) = \frac{6.28 * nr * T}{V_d(dm^3)}$$

$$Pi = imep * \frac{\pi l D^2 * N}{4 * 60 * ni}$$

Mean piston speed S_P:

S_P = 2LN/60

• Brake power (P_b):

The braking power (BP) of an internal combustion (IC) engine is the actual power available at the engine's crankshaft and is a useful indicator of engine performance. It can be calculated using the following mathematical equations:

BP= 2 π N T

Using Dynamometer Readings

If you have a dynamometer, you may determine brake power directly from the results:

BP = 2 π N T = 2πN (F·R)

Gasoline + HHO gas combustion model:

1. Air-to-fuel ratio:

The stoichiometric combustion reaction with HHO gas is:
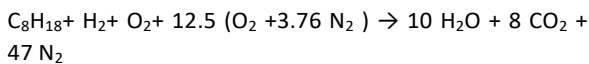
C_8H_{18}+ H_2+ O_2+ 12.5 (O_2 +3.76 N_2) → 10 H_2O + 8 CO_2 + 47 N_2

The air-fuel ratio is determined by calculating the ratio of the mass of the air to the mass of the fuel, as well as the ratio of the volume of the air to the volume of the fuel,

$$\frac{A}{F_{by\ mass}} = \frac{m_{air}}{m_{fuel}} = \frac{12.5(32 + 3.76 * 28) * 32}{(12 * 8 + 18 + 2)}$$
$$= 15.1:1$$

$$\frac{A}{F_{by\ volume}} = \frac{Vmole_{air}}{Vmole_{fuel}} = \frac{12.5(1 + 3.76) + 1}{1}$$
$$= 60.5:1$$

2. Engine power output:

• Fuel power output (Qf)

$Q_f = m_{Gasoline} * CV_{gasoline} + m_{HHO} * CV_{HHO}$

Exhaust gas analysis:

The goal of exhaust gas analysis is to identify the composition and concentration of various gases. Analysis is required, especially for determining the air-fuel ratio, excess air, combustion products, and unburned components. This is an important aspect in protecting the environment and eliminating pollution.

Exhaust system of generator

Exhaust gas flow operations in a spark ignition engine in which the valve's opening and closing angles are fixed when the exhaust exits the silencer. The primary function of an engine exhaust muffler is to minimize noise while maintaining other exhaust parameters at an ideal level. The function of engine exhaust mufflers is to reduce engine noise emissions.
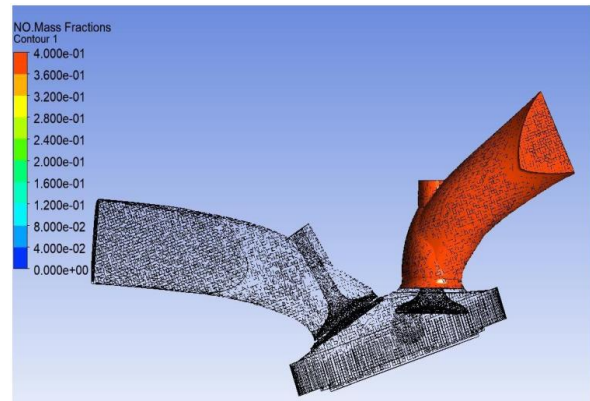
Exhaust system components:

• Exhaust pipe

• Exhaust Muffler

NOx emission coming out of the engine

WHY SHOULD WE CONTROL NOX?

Gives the configuration and dimensions of the combustion chamber used in the simulations as well as the fuel and air rates that travel through the system.

Fig(5): NO Mass Fraction

4. Results and Discussions

1. Alkaline water electrolysis:

Impact of operating temperature on enthalpy, entropy, and Gibbs free energy

Temperature and Enthalpy: As temperature rises, the enthalpy of an alkaline electrolyzer drops until it reaches a minimum at 80 degrees Celsius.

This trend was investigated using Python programming. Entropy and Temperature: As the temperature rises, entropy drops until it reaches its lowest value at 300°C. Gibbs free energy falls as temperature rises, hitting a low of 1.54 J at 300°C. Higher temperatures enhance reaction kinetics, which reduces energy loss due to electrode polarization. This process is endothermic.

Effect of operating temperature on cell power and voltage

At a constant temperature of 27°C, cell power (current density × cell voltage) rises with current density and peaks at 140A. Cell voltage increases with current density, whereas reversible voltage remains constant at 1.227 V. The entire cell voltage reaches 2.4V at increasing current density. Temperature Effects on Cell Voltage: Higher temperatures reduce the cell voltage needed for the same current density. The cell voltage reaches its peak at 40°C and drops to its lowest at 80°C. Elevated temperatures accelerate reaction kinetics, reduce reversible voltage, and decrease ohmic resistance, resulting in lower cell voltage and less voltage loss.
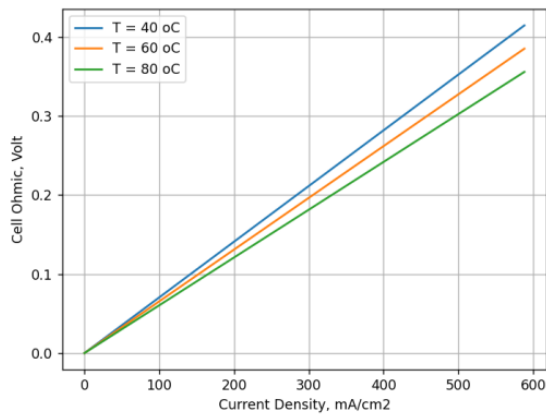
Influence of operating temperature on ohmic voltage

Figure 5 depicts the ohmic voltage with varying current densities at different temperatures. Ohmic Voltage Drop: The ohmic effect, which is controlled by current density, causes the electrode cell to drop in voltage. Gas bubbles formed by the ohmic effect diminish the conductivity of the electrode, increasing the ohmic resistance during electrolysis.

Temperature Effect on Voltage: As the temperature rises, the overvoltage potential diminishes. At higher temperatures, less energy is required to initiate reactions at the electrodes, and gas bubbles collapse, resulting in lower activation and ohmic voltages. For example, the highest activation and ohmic voltages are at 40°C and drop as the temperature rises to 80°C.

Ohmic vs activation overvoltage: Ohmic overvoltage is induced by ion transport from the electrolyte to the electrodes, whereas activation overvoltage is caused by reactions at the anode and cathode. Higher temperatures accelerate reactions and reduce electrolyte resistance, resulting in lower ohmic and activation overvoltages.

At zero current, the reversible voltage is around 1.6 V. Factors that influence ohmic overvoltage include the electrical conductivity of the electrodes and electrolyte, the distance between electrodes, and the presence of gas bubbles on the electrode surfaces.

Fig(6): ohmic voltage with different current densities at different temperatures

Influence of current density on activation voltage

Figure 6 compares the activation voltage to the current density at various operating temperatures (40°C, 60°C, and 80°C).

Voltage Behavior At Low Temperatures: The maximum voltage is obtained at the lowest temperature of 40°C with a current density of 250 mA/cm². This is due to activation overvoltage caused by the electrochemical kinetics of the anode and cathode processes.

Linear Relationship: Voltage rises linearly with current density up to 0.42 V. The effect of temperature on activation overvoltage is that as the operating temperature rises, the activation overvoltage decreases. This is because higher temperatures accelerate the processes and reduce electrolyte resistance, lowering both activation and ohmic overvoltages.

Overall Cell Voltage: As temperature rises, the cell voltage drops due to a decrease in both overvoltages. The cell voltage is the sum of the activation overvoltage, ohmic overvoltage, and reversible voltage (URev).

Activation Activation overvoltage remains constant once current density reaches 250 mA/cm² as temperature increases. The activation voltage has a steep curve from 0 to 50 mA/cm² and gradually diminishes after that. This decline occurs as the ohmic effect's impact on activation polarization weakens.

Activation Losses: Alkaline electrolysis encounters activation losses because energy is required to activate reactions at the electrodes.
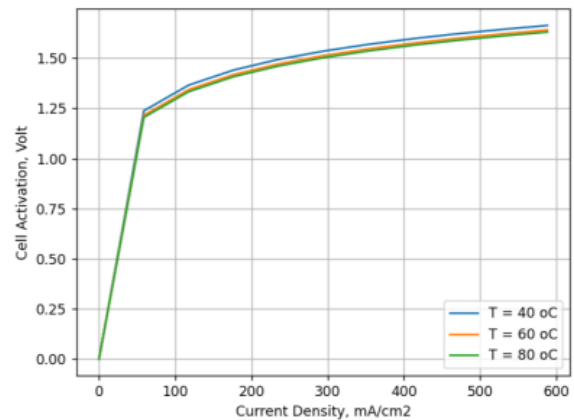
Fig(7): activation voltage with the current density at different operating temperatures

Influence of operating temperature on hydroxy flow rate

HHO Yield and Current Density:

The amount of hydrogen and oxygen mixture (HHO) produced is related to the current density. HHO flow rates grow linearly with current density, and they are unaffected by operating temperature.

Temperature Impact on Energy Efficiency: As temperatures rise, energy efficiency improves. The best efficiency is achieved at 80°C, while the lowest is at 20°C. At 20°C, initial heating uses more energy, lowering efficiency.

Ideal operating temperature: The electrolyzer is thought to be most efficient at 80°C. At this temperature, alkaline electrolysis produces large amounts of HHO while using relatively little power.

Effect of Current Density: Higher current density accelerates the dissociation reaction, resulting in a faster flow rate of HHO.

Energy Efficiency Considerations: As temperatures rise, energy efficiency improves due to lower energy losses. Faraday's law indicates that the rate of oxyhydrogen synthesis is proportional to the flow of electrons between the electrodes, implying that larger current densities increase production rates.

In conclusion, while temperature has no direct effect on HHO yield, it has a substantial impact on energy efficiency, with 80°C being the best temperature for efficient production.
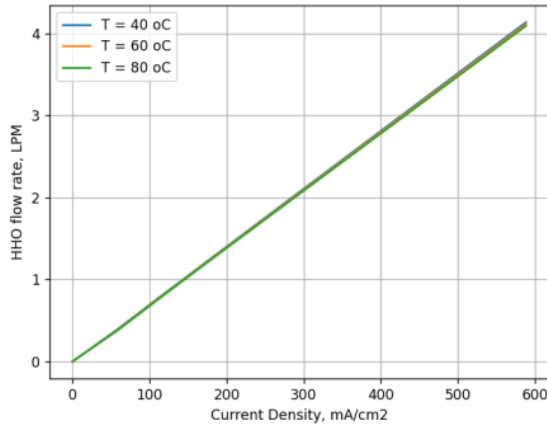
Fig(8): Current Density /HHO Flow rate

Influence of cell power on heat generation

Figure 7 shows that raising the cell power causes more heat to be created. A linear relationship was found between cell power and heat generation. At an 8-watt cell power, the stable increase in produced heat reaches its peak of 1.8 watt. Increased cell power leads to an increase in cell voltage, which raises the operating temperature and produces heat.
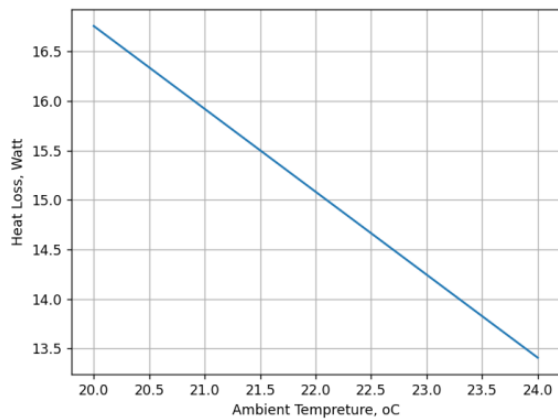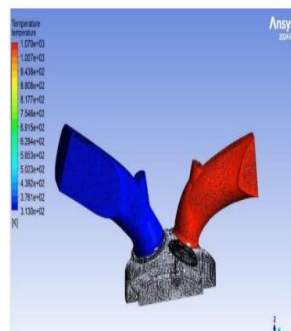

Fig(9): cell power/ heat generation

Exhaust Gas Emissions: Exhaust gas emissions will be compared to determine the environmental impact of introducing HHO gas. Ideally, the addition of HHO gas should reduce the emissions of pollutants such as CO, NOx, and unburnt hydrocarbons.
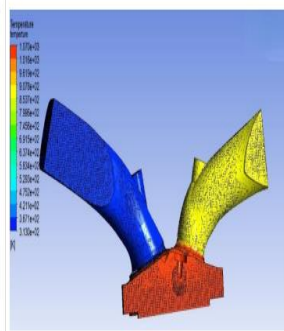
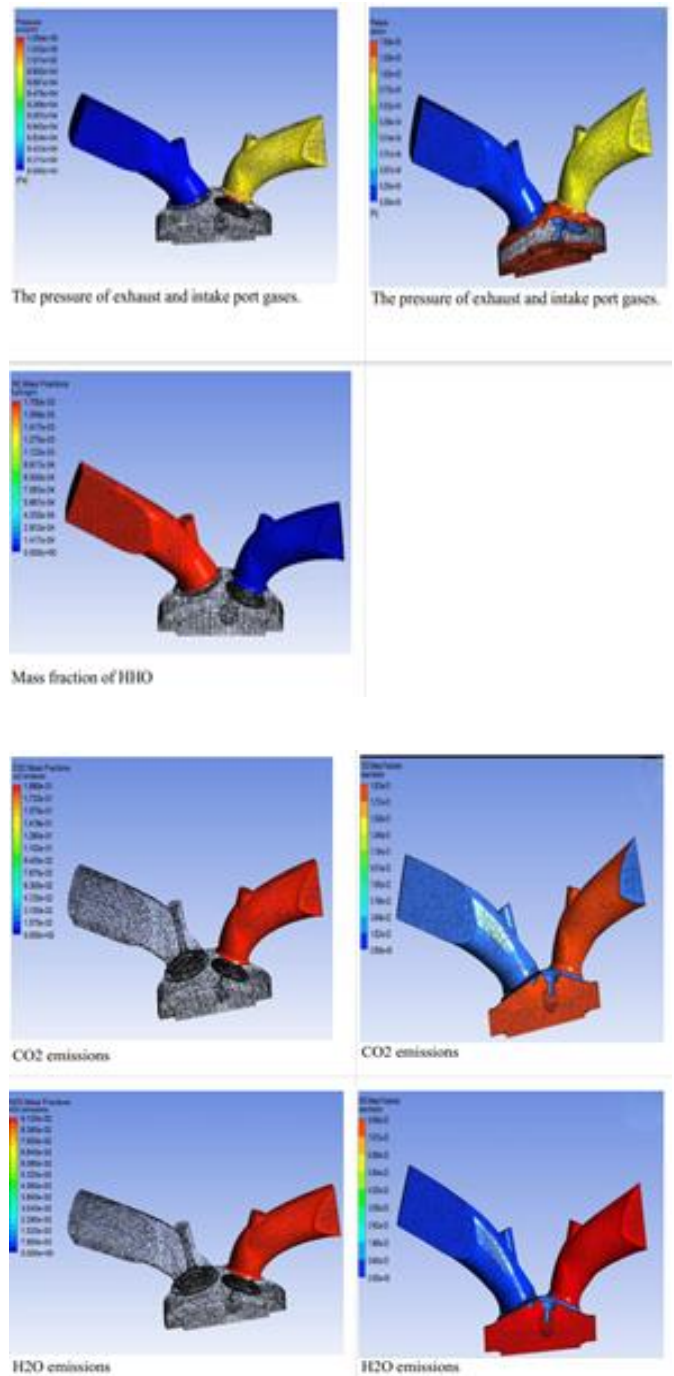**Ansys simulation**

Using gasoline and HHO gas.　　Using gasoline only

The temperature of exhaust and intake mixtures.　　the temperature of exhaust and intake mixtures.

The pressure of exhaust and intake port gases.　　The pressure of exhaust and intake port gases.

Mass fraction of HHO

CO2 emissions　　CO2 emissions

H2O emissions　　H2O emissions

According to the results shown in the figures, when using gasoline and HHO in our project, the temperature of the intake gases did not differ from using gasoline only, but for the exhaust gases, the temperature became higher in using gasoline, which is due to the heat energy released from the HHO after it burned that comes from the cell. For the pressure, the pressure of the intake gases was also the same as using HHO and gasoline and using gasoline only.

For the mass fractions of exhaust gases and that we really focused in our project which is reducing the emission analysis from the results when using the benzene only the CO_2 gas emissions are more high than using the gasoline and HHO and as known for all CO_2 gas is from the bigger causes that increase global warming, and for the emissions of H_2O it is higher in case of using HHO and gasoline than the case of using the gasoline only and that is harmful for the exhaust port engines using iron or cast iron but it can be cured by making the exhaust ports from stainless steel.

Conclusions and Recommendations

1-Fuel economy: The inclusion of HHO gas increases fuel economy by allowing for a more thorough combustion process. This leads to improved fuel economy and maximum energy extraction from the fuel.

2-Engine Performance: HHO gas improves engine performance, improving both indicated and brake power. The engine's power and responsiveness improve as the combustion process becomes more efficient.

3-Emission Reduction: Using HHO gas greatly lowers harmful exhaust emissions such as carbon monoxide (CO), hydrocarbons (HC), and nitrogen oxides. This is due to an enhanced combustion mechanism that reduces unburned hydrocarbons and contaminants.

4-Operating Temperature: Using HHO gas, the engine runs at lower temperatures, minimizing thermal stress on components and perhaps increasing engine life. Lower temperatures increase engine efficiency and performance.

5-Fuel Consumption: Using HHO gas as a booster reduces fuel consumption, allowing the engine to produce the same power while using less fuel. This results in cost savings for the operator.

6-Production and distribution Optimization: Efficient production and distribution of HHO gas is critical. Fine-tuning the electrolysis parameters, such as voltage and current, is required to maximize HHO generation while reducing energy usage.

7-Engine parameter adjustments, such as ignition timing and air-fuel ratio, are required to properly benefit from HHO gas. This may necessitate complex engine control systems that dynamically modify settings based on HHO gas concentration.

8-Material Considerations: To deal with improved combustion efficiency and anticipated temperature changes, engine components may need to be manufactured of materials with stronger thermal and mechanical resistance.

9-Comprehensive safety precautions are required due to the highly combustible nature of HHO gas. This involves reliable gas production and distribution systems, as well as suitable storage, handling, monitoring, and safety standards to prevent leaks and risks.

10-Long-Term Testing: Run long-term tests to determine the engine's longevity and reliability with HHO gas. This helps identify potential problems over time and offers information on engine longevity and maintenance requirements.

11-Cost-benefit Analysis: Conduct a rigorous cost-benefit analysis to determine the economic viability of using HHO gas. Consider the expenses of HHO generation, engine upgrades, and the possible savings on fuel usage and pollution reduction.

Type of engine: Both hydrogen internal combustion engines and hydrogen fuel cells

Capacity : 0.15 Litres/minute per 1L of engine size is ideal.

Generation rate : 737.6 cm^3 min^{-1}

Operating load conditions: Only 7 to 10 amps of current are needed to create enough HHO for a standard 3L engine

Power output improvement percentage is 20.06%

Emission reduction percentages up to 13% for CO_2, up to 72% for Total Hydrocarbons, up to 69% for Methane, up to 48% for NO_x in relation to bare Gasoline fuel.

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