DEVELOPMENT OF 2-WHEELER ENGINE TO OPERATE WITH HYDROGEN

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Abstract – The petroleum product requirements are increasing day by day and natural availability of the fuel is in fixed quantity. Large portion of such fuel is being consumed for transport applications. Various researches are going on alternate sources of fuels particularly for use in I C Engines. Moreover, the energy available in these petroleum products are from carbohydrates which considerably effects our environment. Authors have conceptualized to use hydrogen as the fuel in the existing I.C. Engines. It is available in abundant quantity from water and also no effect on the environment to run automobiles. Moreover hydrogen is having high calorific value, easy to ignite and may not need significant modifications in I C Engines. Paper is justifying theoretical and also practical use of hydrogen as fuel. The engine selected is working on two wheeler where limited space is available for production of hydrogen. The Electrolysis process was selected for producing hydrogen since space requirement is less and system is possible to operate on the bike. In our experiment we are not storing hydrogen due to its explosive property and efforts will be needed for safety. This paper reviews various concepts proposed by different authors, design the system including the rate of hydrogen production, carry out experimentation to run the vehicle and also investigate the saving in pollution.

Key Words: **Hydrogen, Two-wheeler engine, Alternative fuel, I.C. Engine, Onboard production, pollution**

I. INTRODUCTION

The internal combustion engines are using fossil fuel to produce mechanical work by combustion. Its rate of consumption is increasing day by day and therefore available natural stock has to vanish someday. Therefore, we conceived the idea of considering hydrogen as alternative fuel which is available in abundant quantity and this natural resource will never be exhausted. Moreover. hydrogen is an environmentally friendly having good amount of energy and many research papers have considered it to be the ideal energy carrier [2]. The calorific value of hydrogen is much more than the diesel, petrol and natural gas which means that the automobile shall run for longer distances and more efficiently for same amount of fuel.

However, use of hydrogen create the problems of premature ignition and also back fire condition can occur. The pre-ignition is caused due to energy needed by hydrogen is less, wider flammability range and shorter quenching distance. Backfire conditions develops due to premature ignition occurs near the fuel intake valve and the resultant flame travels back into the induction system.

Several methods were studied or production of hydrogen as fuel. However, electrolytic hydrogen production was selected since it has been widely studied and several procedural advantages exists [3,4]. Hydrogen is also used in various other applications which include for military, industrial and commercial purposes. However, the share of electrolytic hydrogen is only 4% [6,7] in the global production. It is mainly due to the cost of production is high

The use of hydrogen (H2) as a fuel is environment friendly due to fewer emissions presents in the exhausts. The combustion of hydrogen with air however can also produce oxides of nitrogen (NOx):

$$H_2 + O_2 + N_2 = H_2O + N_2 + NO_x$$

The oxides of nitrogen are generated due to the high temperatures in the combustion chamber. At high temperature nitrogen in the air combines with the oxygen in the air.

In addition to oxides of nitrogen, traces of carbon monoxide and carbon dioxide can be present in the exhaust gas, due to seeped oil burning in the combustion chamber. The small amount of hydrogen peroxide (H_2O_2) may be found in the exhaust of the hydrogen-operated engine [9]. In the hydrogen-fueled engine, the principal exhaust products are water vapor and NOX [12]. However, with formation of special strategy the emission can be controlled to few parts per millions.

Electrolysis of pure water requires excess energy in order to break the water molecules into oxygen and hydrogen the form of over potential to overcome various activation barriers. A minimum voltage of 1.23V is required to be applied to a water molecule at laboratory conditions to break the bonds between hydrogen and oxygen atoms [10]. The electrolysis of pure water occurs very slowly since its electrical conductivity is about one millionth that of seawater. The efficiency of electrolysis is increased through the addition of salt/acid in electrolyte

The higher self-ignition temperature of hydrogen (858 K) needs an external source to initiate the combustion as in gasoline engines. Hydrogen is preferred to be used in gasoline engine since self- ignition temperature is high. In diesel engine it can be used with combination of other fuels and alone use is not recommended. In S.I engine hydrogen can be used as a sole fuel while in CI engines, we have to use a mixture of diesel and hydrogen both as fuel together.

The efficiency of the internal combustion engine is very low due to loss of energy in the exhaust, cooling of the engine [11]. The efficiency of hydrogen used engine can be increased by increasing the compression ratio. In these engines' hydrogen has higher ignition temperature and therefore higher compression ratio can be used without pre - ignition takes place.

Author conceived the idea of using hydrogen as a fuel in small engine where it can be produced on board system and used parallely. This paper provides reasons of using hydrogen as fuel, development of portable hydrogen production system, modification in fuel supply system, reduction in pollution and estimation of power produced.

II. Hydrogen as a Fuel

Hydrogen is the most abundant element present on earth [13]. The ever-increasing demands for fossil fuels could lead to exhaustion of all petroleum products from earth. Increase in global warming due to the emission of carbonaceous matter to the atmosphere. Need to develop efficient engines in order to improve transportation. Hydrogen has a high calorific value compared to hydrocarbons. Also, it is not a pollutant and so it does not contaminate the groundwater.

Several research papers have concluded that hydrogen is usable in IC & EC engine but minor modifications in engine [14]. Major reason of accepting hydrogen as fuel is due to its unique properties in applications for I C Engines. Hydrogen has high calorific value and low density which makes it use for long distances running of automobiles without refueling the system.

Hydrogen has a wide flammability range in comparison with all other fuels. Therefore, hydrogen can be used in an internal combustion engine over a wide range of fuel-air mix-tures. It provides an important advantage where the engine can run on lean mixtures. It provides better fuel economy and the combustion reaction is more complete when a vehicle is run on a lean mixture. Further -more the final combustion temperature is reduced considerably which reduces the amount of pollutants such as nitrogen oxides in the exhaust of the engine [15].

Hydrogen has very low ignition energy to initiate the combustion process. Gasoline requires 0.24mJ energy to burn while hydrogen requires only 0.02mJ energy. Therefore, almost one tenth of the energy is required to initiate and sustain the ignition of engines running on hydrogen fuels. However, the major draw- back is that hot gases and hot spots on the cylinder can serve as sources of ignition, creating problems of premature ignition and flashback.

Hydrogen has a small quenching distance than gasoline. It helps hydrogen flames to travel closer to the cylinder wall than other fuels before they extinguish. Thus, it is more difficult to quench a hydrogen flame than a gasoline flame. However, the smaller quenching distance also increase the tendency for backfire since the flame from a hydrogen-air mixture more readily passes a nearly closed intake valve, than a hydrocarbon-air flame.

Hydrogen has high auto ignition temperature which can be used advantageously to improve the efficiency of the engine. It provides engine to run at high compression ratio without pre-ignition of fuel takes place. Thus, the maximum final temperature which limits the compression ratio is high for hydrogen engines. However, higher ignition temperature makes it difficult to use directly in diesel engines

Hydrogen has high flame speed as considered in thermodynamic cycle at stoichiometric ratios. The flame travel of hydrogen is nearly an order of magnitude higher than that of gasoline. This means that hydrogen engines can more closely approach the thermodynamically ideal engine cycle and therefore provides better thermal efficiency. However, At leaner mixtures the flame velocity decreases significantly.

Hydrogen has very high diffusivity in comparison to other fuels considered for applications in I C engines. High diffusion rate helps in forming a homogeneous mixture with air which provides uniform and quick combustion. More - over, if hydrogen leak develops, it disperses quickly and avoids the unsafe working conditions.

Hydrogen is used extensively in the space pro-gram since it has the best energy-to-weight ratio of any fuel. Liquid hydrogen is the fuel of choice for rocket engines, and has been utilized in the upper stages of launch vehicles on various space missions including Geosynchronous Launch vehicle in India.

III. Fuel Delivery system

A proper design of fuel delivery system can reduce or eliminate the pre-ignition of hydrogen. Fuel delivery system is broken in-to three main types: Carbureted injection system hydrogen and air mixture is injected into the air intake manifold. In the case of port injection, it is injected at the inlet port. Direct cylinder injection forms the air fuel mixture inside the combustion cylinder after the air intake valve has closed.

3.1. Fuel Carburetion Method [CMI]

The simplest method of inducing hydrogen into the engine by mixing in carburetor. This system does not require the hydrogen supply pressure and also easy to adopt in the usual petrol engine. However, premixing of fuel and air may cause pre-ignition and also back fire is more susceptible.

3.2. Inlet Manifold and Inlet Port Injection

In this method, fuel is induced into the engine at the inlet port after the beginning of the intake stroke. The air is injected separately at the beginning of the intake stroke. Such an arrangement dilute the hot residual gases and also cools the hot spot, if any. It makes less amount of air or hydrogen at any time in manifold and reduces the pre-ignition of the fuel. In port injection, the inlet supply pressure is higher than the carburetor injection system, but it is less than Direct injection system.

In the constant volume injection (CVI) system, a mechanical cam operated device is used to time the injection of the hydrogen in-to each cylinder. Where - as the electronic fuel injection (EFI) system meters the hydrogen before injection in-to each cylinder. The CVI system uses instant injection timing and variable fuel rail pressure, where - as the EFI system uses variable injection timing and constant fuel rail pressure

3.3 Direct Injection System [DI]

It is more sophisticated method to induce hydrogen directly into the combustion chamber during the compression stroke. The system permits the fuel delivery after the closing of the intake valve and thus, completely prevents the occurrence of backfire. It also prevents pre-ignition in the intake manifold but pre-ignition in combustion chamber is not avoided. The air fuel mixture in non-homogeneous due to less mixing time and more NOx emission are reported. Direct injection systems also require higher fuel pressure to inject into cylinder during compression stroke. The power output of a direct injected hydrogen engine increases 20% more than the power output of a gasoline engine.

IV. FUEL SUPPLY SYSTEM USED

Fuel Carburation Method (CMI) was used for supply of hydrogen into engine, since the pressure of hydrogen gas generated by the electrolysis process was low. Moreover, it was easy to convert a standard gasoline engine to run on hydrogen gas without significance modifications. Due to these reasons Port Injection Method or Direct Injection Methods were not used.

In this system fuel is injected into the carburetor where vacuum is created as per Bernoulli's principle. Equalization of pressure head causes vacuum inside the carburetor and fuel was injected into the ports of the engine.

The volume occupied by the fuel is about 1.7% of the mixture. As per literature such system causes decrease in about 15% of output power. Another problem associated with such method is backfiring which may cause serious injury to the engine component. Therefore, a water shield was created between fuel injection and production of hydrogen.

V. HHO Generator

The hydrogen was generated and used in engine. Since, it was used on a bike the HHO generator has to be portable and produce hydrogen gas continuously. The electrolysis process was selected since it is easy form, small in size and battery power is available on the vehicle itself. However, the cost of production of hydrogen is high.

The generator was fabricated from plastic material which was made airtight so that no hydrogen leaks out to atmosphere. To increase the rate of hydrogen production 8 electrode plates were placed inside the chamber. The distance between electrode plates needs to be uniformly maintained for constant power consumption and hydrogen production. The equal distance was maintained by using specially fabricated spacers and locked appropriately in their locations.

Plates are alternately connected to positive and negative of the batteries as required for the electrolysis process. Four batteries were connected in parallel to provide required voltage of. 48 V. The figure shows the schematic diagram of battery, plates connection and generation of hydrogen in HHO generator. The generated gas is supplied to the carburetor with a water shield to separate engine with the hydrogen generated mechanisms.

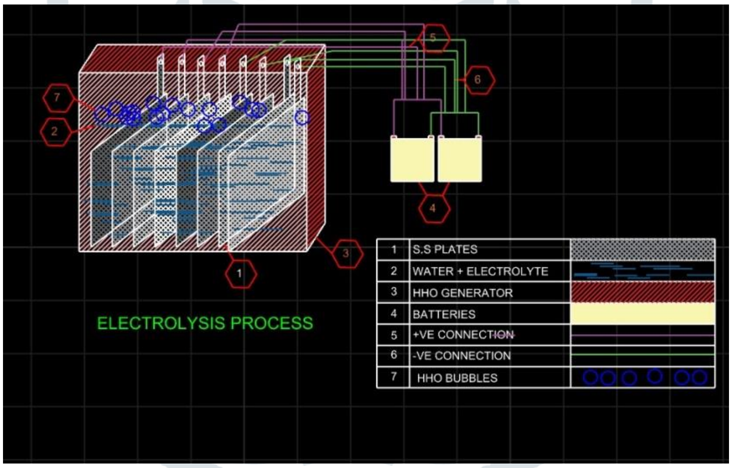

Figure 1 - Schematic diagram

VI. Emission Characteristics

The hydrogen fuel contains only H_2 molecules which burns efficiently and carbon molecules are not existing which causes pollution. Therefore, the combustion of Hydrogen in the presence of oxygen produces water vapors and nitrogen oxide as given in the following chemical equation.

$$H_2 + O_2 + N_2 \rightarrow H_2O + N_2 + NOx$$

The oxides of nitrogen are generated due to the high combustion temperatures inside the combustion chamber of the engine. Nitrogen in the air combines with the excess oxygen at high temperature which causes the formation of various oxides of nitrogen (NO_x). The amount of NOx formed depends on the air-fuel ratio, compression ratio, engine speed, ignition timing and also specific provisions are made to dilute the thermal environments.

The exhaust gas analysis was carried out by Indus Scientific gas analyzer. The gas analysis of exhaust gases revealed that in addition to oxides of nitrogen some traces of carbon monoxide and carbon dioxide were also present. The presence of small amount of carbon dioxide and carbon mono oxides were due to burning of lubricating oil which seeped through the piston rings and cylinder wall. However, a well design operating strategy shall almost eliminate the presence of such emission in the exhaust of hydrogen engine.

Following was the comparison of exhaust gas analysis of petrol engine and hydrogen engine.

Table 1 – Emission test report

Exhaust gas	Bike running condition		
	On petrol	Petrol + Hydrogen	On Hydrogen
Co	7.174	5.674	5.166
HC ppm	975	842	652
CO_2	7.36	6.08	1.94
O_2	0.70	0.61	0.01

Following are the conclusions of the test carried out on the exhaust gases which have used petrol, petrol plus hydrogen and only hydrogen as a fuel.

- The amount of CO has decreased drastically in the exhaust gas due to the use of oxygen directly. During the electrolysis process oxygen was generated and that was used for combustion. Small amount of Co presence was due to burning of lubricating oil which seeped through the piston ring.
- Traces of HC presence was also is in part per million.
- Considerable reduction is seen in carbon dioxide gas also. Small amount is found due to carbon deposition in engine due to the use of gasoline oil.
- Oxygen was present due to excess amount was injected for complete combustion of hydrogen.

VII. Major Estimation

7.1 Air Fuel ratio

Salient feature of requirement of air fuel ratio, power estimation from battery and plate requirements for production of hydrogen are presented. These were estimated based on the following assumptions made [19].

1. The volumetric efficiency of the engine was assumed to be a constant 85% (obtained from previous engine testing on gasoline).
2. The design compression ratio was 9.5:1.
3. The calculations were performed for the case of stoichiometric operating conditions.
4. The maximum injection opening duration was specified as a 45-degree crank angle. Such a large angle for injection was specified to provide a conservative initial valve design. To maintain similar engine operation with a smaller angle of injection a higher mass flow rate of hydrogen during the injection would be necessary. It was reasoned that the higher the mass flow rate through the valve, the more difficult it would be to consistently meter a precise amount of hydrogen per injection.
5. The relevant hydrogen fuel and air properties were used
6. Standard atmospheric properties of air were assumed
7. Stoichiometric air-fuel ratio and energy content

The stoichiometric composition [20] of fuel and air is that which provides the chemically precise amount of oxidant to completely burn all the fuel. The actual mass ratio of air to fuel, ma/mf, can be expressed as the air excess ratio - the relative amount of mass of air over that required for stoichiometric combustion. Because air is used as the oxidizer instead of oxygen, the nitrogen in the air was also present.

Moles of N_2 in air = 3.762 moles N_2

Number of moles of air = 4.762 moles of air

The weight of O_2 = 32 g

Weight of N_2 = 105.33 g

The weight of air = weight of O_2 + weight of N_2

= 137.33 g

The weight of H2 = 4 g

Stoichiometric air/fuel (A/F) ratio for hydrogen and air is: A/F based on the mass = mass of air/mass of fuel = 34.33:1

A/F based on volume = volume (moles) of air/volume (moles) of fuel = 2.4:1

% H_2 = Volume (mole) of H_2 / Total volume

= Volume H_2 / (Volume of air + volume of H_2)

= 2 / (4.762 + 2) = 29.6%

As these calculations show, the stoichiometric or chemically correct A/F ratio for the complete combustion of hydrogen in air is about 34:1 by mass. This means that for complete combustion, 34 grams of air are required for every gram of hydrogen. This is much higher than the 14.7:1 A/F ratio required for gasoline engine.

Stoichiometric air fuel ratio: A/F 34.3 kg/kg

7.2 Fuel requirement to run engine

1. The volume of air produced per engine cycle:

   Vpc (air) = Swept Volume × volumetric efficiency (Va / Vd)

   $= ((\pi/4) \times (\text{BORE})^2 \times (\text{STROKE LENGTH})$ [21] $\times$ volumetric efficiency

   $= ((0.7854) \times (47)^2 \times (54.5)) \times 0.85$

   $= 8.075 \times 10^{-5}\ m^3$

2. Volume flow rate of air:

   Vfr (air) = Vpc (air) × engine speed / 2

   = 8.075 × 10-5 × 3500 / 2

= 0.14131 m3/min

3. Mass flow rate of air into the engine:
   mfr (air) = [P(air) × Vfr(air)] / [R(air) × T(air)]
   = ((1.01325 × 105) × 0.141) / (287.1 × 293.15)
   = 0.16975 kg/min
4. The mass flow rate of fuel into the engine:
   (mfr) fuel = (mfr) air / (A/F) stoichiometric
   = 0.16975 / 34.3
   = 0.0049490 kg / min
   = 0.296 kg / min
   Thus 0.269 kg of hydrogen is required per min
5. Amount of fuel required per hour in Liters:
   Considering Ideal RPM=1500
   Displacement volume, V=100cc=0.1L
   Time, t=60 minutes
   Total Displacement Volume/hr=RPM*V*t/2=1500*0.1*60/2=4500 L/hr
   Considering A/F ratio = 150:1 Practically required in engine,
   Therefore, hydrogen gas required =4500/151=29.8013L/hr
6. Current Required:
   V=29.8013 L/hr of H2 gas t=3600 s
   let current = I in ampere
   Considering that gas is at Room Temperature and Pressure, thus 1 mole of any gas = 24 L
   Moles of H2 =29.8013/24 = 1.2417 mole of H_2
   Moles of electrons required to produce 1.2417 moles of H_2 = 2* 1.2417=2.4834 mole of e-
   Since 2 e- are required to produce 1 H2 molecule.
   Therefore, Charge of 2.4834 moles of e-, Q =2.4834*96500=239648.1 C
   Since Charge of 1 mole of e- = 96500 C
   We know that Q=It,
   Therefore, I=Q/t=239648.1/3600=66.5689 A
   Thus, the current required to generate 29.8013 L of H2 gas is 66.5689 A.
   we have used 80 amps. (40*2 batteries) after considering various losses.

Now, we are using 12 V and 80 amp. Since we are using 4 cells, each cell having one positive and one negative plate. Thus, providing a potential difference of 12 volts and 20 amperes between two electrodes. The graph below shows that when current increases, the hydrogen generation will also increase. [23]

7. Dimension for HHO generator electrode:

- To prevent overheating during electrolysis, the current supplied should be less than 0.084 A / cm2
- Let us assume 0.083 A / cm2 current on the electrode plate.
- Let X*Y = surface area of plate
- X*Y = I/0.083
- X*Y = 80 / 0.083
  = 983.85 cm2

As per the configuration and space availability, we have used 4 pairs of plates as electrode.
The required area of each plate = 983.85/4 = 240.96 cm^2
Container dimension selected was
X = 14 cm & Y = 18 cm
Here, 14*18=252 > 240.96 cm2
Hence, we will use plates of dimension 14 cm * 18 cm.

Conclusion

Major out- come of the analysis and experiments carried on use of hydrogen in the modified petrol engine are summarized below:
- Hydrogen gas is possible to use in I. C. Engine as a fuel
- Hydrogen can also be used in internal combustion engines as blended fuel with petrol
- Hydrogen should be used in spark ignition engines with modifications in the existing systems.
- Pre-ignition can be avoided by adopting proper design of injection system
- Backfiring in hydrogen engines can be avoided by proper shielding of hydrogen generation system - Thermal efficiency of the hydrogen operated engine is higher than gasoline and diesel operated engines.
- Power output of hydrogen engine is better.
- Use of hydrogen is attractive for reducing global warming and pollutions
- In hydrogen engine high lean mixture can be used and that will also reduce NOx emissions.
- The current requirement for the production of hydrogen is high which increases production cost of hydrogen high.
- Due to high rate of current consumption battery discharges quickly.
- Hydrogen requires low energy for initiation of flammability which needs special precautions.

References

1. Hydrogen-Fueled Internal Combustion Engine: A Review of Technical Feasibility S.K. SHARMA *, P. GOYAL and R. K. TYAGI International Journal of Performability Engineering, Vol. 11, No. 5, September 2015, pp. 491-501.
2. HYDROGEN FUELLING OF AN INTERNAL COMBUSTION ENGINE A thesis submitted for the Degree of Doctor of Philosophy by Neil Glasson Department of Mechanical Engineering University of Canterbury Christchurch NEW ZEALAND 1992
3. J. W. Richards, Journal of the Franklin Institute, 152 (1901) 201.
4. J. W. Richards, Journal of the Franklin Institute, 141 (1896) 192.
5. J. W. Richards, Journal of the Franklin Institute, 160 (1905) 377.
6. Seth Dunn, World watch paper 157, August 2001, 3 (2002) 16.
7. R. F. de Souza, J. C. Padilha, R. S. Gonçalves, M. O. de Souza and J. Renault-Berthelot, J. Power Sources, 164 (2007) 792.
8. USE OF HYDROGEN GAS AS SUPPLEMENTARY FUEL IN 4 –STROKE SI ENGINE Mr.Deorukhkar Sairaj R.1, Prof.Bhosale M.R.2, Mr.Salunkhe M.R.3,
9. Ladommatos N., Abdelhalim S.M., Zhao H. and Hu Z, Effects of EGR on heat release in diesel combustion, SAE Transactions 980184: pp. 1-15, 1998.
10. Electrical Efficiency of Electrolytic Hydrogen Production Kaveh Mazloomi1, *, Nasri b. Sulaiman1, Hossein Moayedi2
11. Development of High-Efficiency Engine by combining I. C. Engine and E C Engine Prof. V. K. Manglik
12. JamesW.Heffel, "NOXemissionandperformancedataforahydrogenfuelled internal combustion engine at 1500 rpm using exhaust gas recirculation," Internal Journal of Hydrogen Energy, Vol. 28, pp. 901-908, 2003. doi:10.1016/S0360-3199(02)00157-X
13.HYDROGEN USE IN INTERNAL COMBUSTION ENGINE: A REVIEW International Journal of Advanced Culture Technology Vol.3 No.2 87-99 (2015) http://dx.doi.org/10.17703/IJACT.2015.3.2.87
14. Hydrogen Operated Internal Combustion Engines - A New Generation Fuel International Journal of Emerging Technology and Advanced Engineering Website: www.ijetae.com (ISSN 2250-2459, Volume 2, Issue 4, April 2012).
15. Hydrogen Usage in I.C. Engines Chaganti Sri Krishna Sharma International Journal of Scientific & Engineering Research, Volume 7, Issue 8, August-2016 440 ISSN 2229-551
16. HYDROGEN PRODUCTION AND STORAGE. INTERNATIONAL ENERGY AGENCY
17.https://www.google.com/search?q=electrolysis+statrt+at+what+volt&oq=electrolysis+statrt+at+what+volt&aqs=chrome..69i57.17862j0j7&sourceid=chrome&ie=UTF-8
18. Factors affecting electrolysis Prepared by Janadi Gonzalez-Lord.
19. HYDROGEN FUELLING OF AN INTERNAL COMBUSTION ENGINE A thesis submitted for the Philosophy by Neil Glasson Department of Mechanical Engineering University of Canterbury Christchurch NEW ZEALAND 1992 page 45-48.
20. Hydrogen Usage in I.C. Engines Chaganti Sri Krishna Sharma International Journal of Scientific & Engineering Research, Volume 7, Issue 8, August-2016 440 ISSN 2229-551(topic-4).
21. Bajaj discover DTS-i user guide 4 – 5 gear. Link www.
22. PAPER • OPEN ACCESS Generation of oxy-hydrogen gas and its effect on the performance of spark ignition engine To cite this article: N N Patil et al 2017 IOP Conf. Ser.: Mater. Sci. Eng. 263 062036
23. https://www.researchgate.net/profile/Viswanathan_Saji/publication/262418591/figure/fig1/AS:455359568584704@1485577589776/A-schematic-of-basic-water- electrolysis-cell.png
24. ELECTROLYSIS PAPER
25. https://www.hho-1.com/maximum-hydrogen-production-electrolysis-output/
26. https://youtu.be/cqjn3mup1So