Generation of brown gas from a dry cell HHO generator using chemical decomposition reaction

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Abstract. Pollution is a factor that makes humans lives worse; because of this pollution, so much of health hazards are uprising. This article mainly contributes to constructing a dry hydroxy cell generator that generates brown gas, which is usually known as hydroxy gas. The primary catalyst used is lye (NaOH) and caustic potash (KOH), which is to be incorporated with stainless steel and followed by supplying a unidirectional current. The reaction is accelerated since the catalyst offers a proxy pathway to expedite the response. The law of electrolysis of faraday governs this process. To lower the consumption of fossil fuel, which is the primary root cause of pollution. This dissertation provides detailed scrutiny on brown gas generators and its best harvest, which is known to be the highest production volume of HHO gas. This journal deals with how the change in the catalyst, power rating and concentration ratio affects the brown gas production and how NaOH differs from KOH in HHO gas production. The average time taken to produce 1 litre of HHO gas using NaOH is about 53 seconds, whereas it is about 80 seconds for KOH.

1. Introduction

Due to the increase in transportation and mobility in our day-to-day life, the use of fossil fuels is rapidly increasing as a coin having both the sides the fossil fuel has two faces as it provides a large concentrated amount of energy to power the internally combusting engines, the main scope of fossil fuels is easily transportable and accessible but the major snag is the amount of excess pollution caused by these fuels make the atmospheric air more hazardous for the living beings. To meet this demand the energy from hydrogen can be used as an alternative source for powering the automobiles, because hydrogen is a fuel which is clean, and it is abundant in this planet. Hydrogen can be produced using certain chemical reactions one of which is said to be the process of breaking down of water molecule by a unidirectional current is coined as electrolysis, so because of this chemical decomposition of water, hydroxy or oxy-hydrogen gas is produced this gas is been termed as Brown gas, this can be treated further to use it as a fuel in automobiles. The major chemical compound used is a catalyst of NaOH which is termed as caustic soda or lye. It is a compound which consists of Na⁺ and OH⁻ ions. The splitting of water is the cleanest methodology adopted for the HHO gas production which is coined as electrolysis is shown in figure 1. The brown gas generator is of two types one is the wet cell and dry cell brown gas generator. The volume of HHO gas produced is been decided by many
parameters like the catalyst used, the number of steel plates, amount of power supplied and the TDS of water.

**Figure 1.** Schematic hydrolysis mechanism of water.

Yoo et al. [1] has discussed that sodium hydroxide is a compound that absorbs carbon dioxide spontaneously from the ambient air and stated that the concentration of the solution plays a major role in capturing. Rao et al. [2] experimented a phenomenon of increasing the mileage of the IC engine by retrofitting it with an HHO wet cell generator. They adopted a methodology of developing a wet cell generator using steel of stainless in nature, they promoted the usage of sodium hydroxide as the base catalyst and a 12V unidirectional supply is fed to the setup and they blended with gasoline and construed that the CO emission is reduced by 26.9% when HHO gas is blended with gasoline and the HC level is reduced by 27.3% and the mileage was also increased in highway, city traffic and off-road by 47.4, 48.6 and 56.3% respectively. De Silva et al. [3] carried out an experimental investigation of fabricating an HHO dry cell generator and tested its performance parameters by varying certain inbuilt parameters of the system and how it ramps up the efficiency of the IC engine. They adopted the development of an HHO generator by using stainless steel with KOH as the catalyst and the electrode are subjected to the unidirectional flow of electrons and they arrived a final decision that when the distance between the plates decreases the production of gas increases and vice-versa, when comparing the result of HHO gas production for 2.5 and 5 mm gap the time taken for 1 litre of HHO gas production was less in the case of 2.5 mm (4 min), and for 5mm it is around 20 min respectively. The hydrogen produced by this system can be employed for powering up IC engines was discussed by EL-Kassaby et al. [4] conducted experimental research of developing an HHO generator setup and performed tests regarding how the brown gas helps in boosting the performance and reducing the emissions. The test rig was developed Using stainless steel as plates with two catalysts namely KOH and NaOH and the outlet was connected to the manifold of the engine and flashback arrestors were employed during the test. They finally construed that the 4g/L of sodium hydroxide provides a higher thermal efficiency when compared to KOH but 6 g/L of KOH produces high efficiency at varying rpm and the emissions like NO\textsubscript{x}, CO and HC were reduced by 15, 18 and 14% respectively. Ma et al. [5] investigated experimentally about how the blending of various ratios of hydrogen with CNG helps in increasing the performance parameters and how this combination contributes to the reduction in emission. They tested with the varying fractions of 0,30 and 55% of hydrogen by volume and blended with CNG and injected into a six-cylinder engine and construed that at different air ratios when hydrogen is injected the emissions are controlled but the major thing which is to be changed is the optimization on spark timings and stated that when air ratio is greater than 1.7 the performance of engine increases due to the increase in hydrogen level and higher thermal efficiency is obviously seen and emission is also reduced due to the enrichment of hydrogen in the air-fuel mixture. Shivaprasad et
al. [6] studied experimentally regarding how the hydrogen + gasoline blending results in improvement of efficiency and as well as in reducing the emission of a high-speed spark-ignition engine. They performed the tests under different ratios of hydrogen levels blended to gasoline and identified the efficiency by measuring various performance assessing parameters. They finally construed a result that the hydrocarbon emissions were lower because of the blending of hydrogen (20%) and the $\eta_{BT}$ is seemed to be increased to the blending ratio of 20% of hydrogen and 80% of gasoline. Chitragar et al. [7] investigated experimentally about different fuels in a four-cylinder IC engine and evaluated its performance and emission parameters. They used a methodology of controlling the fuel injectors with the help of ECU and they injected fuels into the chamber one by one after the complete combustion of the previously sprayed fuel. They construed their results that they encountered an increase and decrease in pressure in the cylinder by 13% and 4.5% when injecting hydrogen and LPG when they are compared with gasoline injection.

Chaiwongsa et al. [8] has experimentally investigated how the HHO system saves fuel when retrofitted to a compact engine. They tested the engine with the fuel blend of hydrogen and gasoline and tested the performance parameters and found the efficiency of the engine is said to be increased and the fuel is combusted easily when this combination is injected. They construed that this blending of gas with gasoline has created potential of saving fuel by 25% respectively. Similarly, the setup performance is also investigated by Rusdianasari et al. [9] experimentally tested the parameters influencing HHO gas production in an HHO generator and they analyzed the parameters to develop the best configuration. They used 316 L steel of stainless in nature and the catalyst used is NaOH they tested it with five different concentration levels and addressed the final results that the production of gas increases with the increase in the concentration level of the lye and construed the fact that the highest amount of gas production was observed with the concentration level of 0.05 M for a current rating of 15A. Alam and Pandey [10] have investigated how the parameters like current, voltage and concentration influence the production of HHO gas. They used caustic potash with de-ionized water for the experimentation and tested for various voltages (3 to 10 V) and current ratings, in addition different concentration was also tested. They finally construed that gas production is increased by 30 to 40% with the increase in these parameters. Concentrated solar absorbers are beneficial to act as hydrogen reactors [11, 12].

In this work the HHO generator is investigated by an experimentation process and how the parameters like current, voltage and concentration of the solution have influence over the production and how much time the solute takes to produce brown gas is also investigated.

2. Materials and methods

2.1. Experimental work

This generator consists of two inlets and two exit openings fitted with a plastic elbow and its threaded side is been sealed using water sealant which is known as polytetrafluoroethylene (PTFE) tape. The assembled setup is shown in figure 2 the elbows are made of Polyvinyl Chloride (PVC) which is of 1/4 inch in its size. The steel which is used in this generator is of stainless in nature and it is known as 316 stainless steel, the steel plates are been insulated by providing neoprene gaskets in-between them. The plates and gaskets are made in order and it is enclosed with PVC enclosures and joined by means of stainless-steel fasteners. The end PVC enclosures not only gives a structure to the generator but also acts as an insulating material and offers protection to the steel plates and gaskets. The neoprene gaskets offer excellent protection from leakage of the fluid which is flowing inside the generator, another important component in this generator is the reservoir tank which is placed at the top of the setup to increase the fluid flow. The reservoir tank used here consists of a reservoir cap which has a rubber gasket seal inside the cap which restricts the leakage of the electrolyte and the HHO gas without mixing with the atmospheric air which is shown in figure 3.
In this process of electrolysis normal water can also be used but due to the dissolved salts and impurities scale formation will occur on the surface of 316 steel and corrosion can also happen which decreases the output of the generator and it affects the volume of oxy-hydrogen production. So, distilled water is used in this process of HHO generation. The detailed specifications of the experimental setup are shown in Table 1.

**Table 1. Specifications of the HHO generator.**

| Items                        | Details                          |
|------------------------------|----------------------------------|
| 316 stainless steel electrode plates | 2 mm (13 plates)                |
| PVC Enclosures               | 13mm (2 plates)                  |
| Fasteners                    | 14 pairs                         |
| DC Power Supply              | 5V 5A                            |
|                              | 5V 20A                           |
|                              | 12V 30A                          |
|                              | 12V 40A                          |
| Reservoir Tank               | 5 litre                          |
| Quality of Water             | Deionized water (4 litre)        |
| NaOH & KOH                   | 25, 50, 75, 100, 125, and 150 g   |
| Neoprene Rubber              | 3 mm                             |
| Phase separator              | 2 litre                          |

2.2. Experimental procedure

When the terminals are been fed by a unidirectional current the plates gets energized and the electrolysis process picks up but during the absence of a catalyst the reaction tends to be slower so the main thing was to select a catalyst, two catalyst has been selected, one is NaOH and another one is KOH, distilled water is used as an electrolyte but due to the absence of ions it cannot conduct unidirectional current but when the catalyst is mixed it conducts, another reason for the addition of a catalyst is to alter the speed of the reaction but it should not alter its form, the main merit of catalyst is it will not take a seat in the reaction process. The plates are made of 316 stainless steel and it is stacked together with an introduction of gaskets in-between them. When the supply is given after mixing it with catalyst the reaction starts and HHO gas is formed. The main issue lies in diluting the sodium and potassium hydroxide flakes in de-ionized water. When performing the experiment, the flakes are been first dissolved in the de-ionized water and constant stirring is been done such that the flakes are been completely dissolved if, not these flakes will block the flow path inside the HHO generator. Supply when provided to the plates, the current flows and the reaction starts such that the molecules are broken down during the reaction, the gasket offers an excellent resistance to the leakage of solution.

The gas comes out of the outlet valve of the generator. This is fed again to the reservoir which already contains the solution of distilled water and catalyst which is diluted and filled into it. The process is
similar to a thermo-siphon such that the HHO gas which is collected in the reservoir will pressurize the diluted solution so that the circulation of diluted fluid flows without any interruption. The reservoir heats up so material with good resistance to heat is been selected in order to avoid melting of the reservoir since it is an exothermic reaction. On passing unidirectional current the reaction yields hydroxy gas. So, the product of this exothermic reaction is a mixture of oxygen and hydrogen. Then this HHO gas is been collected by opening the valve of the reservoir tank so that the gas enters a phase separator which also acts as a flashback arrester when the line is connected for application purposes. Distilled water plays a major role in boosting up the production volume of HHO gas. The test is been conducted for various quantity of NaOH with 4 litres of distilled water and the same quantity was followed for KOH. After performing the test based on the chemical platform of distilled water with NaOH and distilled water with KOH the test results are calculated. The corrosion rate of NaOH on 316 steel is around 19mmpy but the temperature required for corrosion is above 65°C in case of 316 steel with NaOH but the temperature initially after the introduction of the diluted solution inside the reservoir was around 20°C after the process was started and the temperature was measured which was less than 65°C while testing so, there is a less possibility of corrosion. The input supply was also varied by a rectifier unit which gave different ratings of current and voltage. NaOH when diluted with distilled water yields more amount of HHO gas, when compared with KOH and the production time for producing 1 litre of HHO gas, is faster when using NaOH with distilled water rather than KOH with distilled water. The time taken for producing 1litre of HHO gas was calculated by an inverted tube experiment also known as water displacement test and the readings are observed for a time gap of about 5 minutes. The schematic representation of HHO gas production is shown in figure 4.

Figure 4. Schematic representation of HHO gas production.

Reaction occurrence when lye is mixed with water

NaOH + H₂O → Na⁺ + OH⁻ ions  (1)

Reaction occurrence when caustic potash is mixed with water

KOH + H₂O → K⁺ + OH⁻ ions  (2)

The production of hydrogen can also be depicted using chemical equations
The reduction reaction occurring at cathode

2H₂O + 2e⁻ → H₂ + 2OH⁻  (3)

The oxidation reaction occurring at anode

4OH⁻ → O₂ + 2H₂O + 4e⁻  (4)

Overall Net reaction

2H₂O → 2H₂↑ + O₂↑  (5)
3. Calculations and parametrical concepts

Average time taken for 1000ml rise is calculated by,

\[ \text{Average} = \frac{\sum_{i=1}^{n} X_i}{n} \]  \hspace{1cm} (6)

Where, \( n \) = total number of terms

The concentration ratio can be calculated by following relations,

Amount of substance \( n \) (mol) is calculated by,

\[ n = \frac{m}{M} \]  \hspace{1cm} (7)

where, \( m \) = mass of the substance in its purest form (g)

\( M \) = molar mass of the substance in its purest form (g/mol)

To find out the concentration ratio,

\[ C = \frac{n}{V} \]  \hspace{1cm} (8)

Where, \( n \) = Amount of substance (mol)

\( V \) = volume of the solvent (L)

The input unidirectional power is supplied to the generator so as to emerge the process of electrolysis.

3.1. Specific energy

The energy which is in need to govern the process of chemical decomposition, so as to produce one kilogram of HHO gas expressed in as J/Kg.

3.2. Temperature of the HHO generator

During the process of electrolytic decomposition whatever the input energy supplied will not be utilized fully there are losses, this loss of input energy is retransformed into heat this generated heat and also the heat produced during chemical reactions is combined and results in the rise of the temperature of the generator and its auxiliary components and so, that the heat energy is also transferred to the process fluid and results in some loss of quantity of the working fluid may arise which can be compensated during top-up period.

3.3. Efficiency of the HHO generator

\[ \eta = \frac{\text{Output (HHO gas)}}{\text{Input (unidirectional power)}} \]  \hspace{1cm} (9)

Here, the generator is fed by a unidirectional power source which represents the input so based on the corresponding input the corresponding mechanism of decomposition is been established and the fruitful outcome is the useful energy which is been acquired by the process in the form of brown gas. The amount of output energy is measured based on the amount of gas produced and the input directly corresponds to the amount of power supplied and the input is measured by measurement devices.

4. Result and discussion

From the experimental data, the time taken to produce 1 litre of HHO gas is been made into a graphical representation with respect to the time duration in figure 5 and figure 6 for both NaOH and KOH for a mass of solute of 150 g, from which a conclusion can be arrived that NaOH is more
effective than KOH in the process of producing HHO gas because the time for producing 1 litre of HHO gas is less than KOH and the reaction tends to be faster in the case of NaOH as solute though the same quantity appears for KOH, the average time for 1000 ml rise of HHO for NaOH and KOH is said to be 53 and 80 seconds respectively.

![Figure 5](image5.png)

**Figure 5.** Time taken for 1 litre production of HHO gas by using NaOH.

![Figure 6](image6.png)

**Figure 6.** Time taken for 1 litre production of HHO gas by using KOH.

Similarly, the current rating also has an influence over the production of HHO gas, when there is more amount of electron flow the reaction tends to be faster because of the rapid movement of molecules in the solution present in the generator so, more amount of gas is generated; the setup is tested for varying current and voltage ratings and the increase in the rating of current has made an appreciable output in increasing the production such that, they are directly proportional to each other and sometimes the distance between the steel plates also influences this phenomenon because the decrease in the gap between the plates promotes the larger flow of electrons so that the production tends to increase and vice-versa. The volumetric flow rate of HHO with respect to the current rating is shown in figure 7. From which it is obvious that the flow rate increases when the flow of electron increases and the volumetric flow rate of HHO is increased by 49.6 % for NaOH when comparing with KOH.
The concentration of the solution also comes into play, in increasing the production of the gas, the more the amount of concentration of the solution, the reaction rate will be rapid enough to meet the production. The concentration of the solution is calculated by means of the ratio between the moles present in the solute to the solvent volume, by observing the graphical representation which is shown in figure 8 it is clearly evident that when the NaOH concentration increases the production rate tends to increase rapidly and figure 9 also resembles the same for KOH in which the gas production is also said to be directly proportional to the concentration ratio and the comparison between NaOH and
KOH with respect to gas production is shown in figure 10. The concentration ratio for NaOH and KOH is 0.94 and 0.67 M respectively.

![Figure 10. Comparison of gas production over different concentration of NaOH and KOH.](image)

5. Conclusion

The main reason why NaOH reacts more than KOH is due to their electro-negativity in nature because Na\(^+\) ions have less electronegativity than K\(^+\) ions, so the sodium ions are more eager to release a hydroxy group. So, this promotes the production of HHO gas yield.

- Reaction rate is directly proportional to the concentration of the solution and as well as the current rating.
- The percentage increase of volumetric flow rate is around 49.6% for NaOH when it is compared to KOH.
- Usage of de-ionized water not only boosts the gas generation but also eliminates the scale formation on the plates.
- This generator can be used for onboard fuel generation for IC engines and can also be utilized for various applications.

Further studies, include how this system can be successfully blended with other conventional fuels and how it helps to increase the performance and reduce the emissions with safety as a major concern by developing a flashback arrestor which is to be retrofitted with this system thereby avoiding flame front returning back to the generator. Thus, these observed results fetch a way for further studies in this domain.

Nomenclature

- \(t\) Time taken for a litre rise of brown gas
- \(Na^+\) Positively-charged Sodium ion
- \(K^+\) Positively charged potassium ion
- \(OH^-\) Hydroxide ion
- \(\eta_{bt}\) Brake thermal efficiency

Abbreviations

- CNG Compressed Natural Gas
- CO Carbon monoxide
- ECU Electronic Control Unit
- HC Hydrocarbon
- HHO Oxyhydrogen gas
- IC Internal Combustion Engine
KOH Potassium Hydroxide
LPG Liquefied Petroleum Gas
M Molarity
NaOH Sodium Hydroxide
NO\textsubscript{X} Nitrogen Oxides
TDS Total Dissolved Solids

Conflict of interest
The authors do not have any sort of conflict of interests.

References

[1] Yoo, M., Han, S., & Wee, J. (2013). Carbon dioxide capture capacity of sodium hydroxide aqueous solution. *Journal of Environmental Management*, **114**, 512-519.

[2] Rao, V. H., Saravana Kumar, R., Ishan Nitin, M., Sampath Kumar, S., & Rajendra Kumar, S. (2018). Hydroxy production as a mileage booster for two-Wheeler. *IOP Conference Series: Materials Science and Engineering*, **402**, 012177. doi:10.1088/1757-899X/402/1/012177

[3] De Silva, Subhashini & Senevirathne, L & Warnasooriya, Td. (2015). HHO Generator – An Approach to Increase Fuel Efficiency in Spark Ignition Engines. *European Journal of Advances in Engineering and Technology*. 2015. 1-7.

[4] EL-Kassaby, M. M., Eldrainy, Y. A., Khidr, M. E., & Khidr, K. I. (2016). Effect of hydroxy (HHO) gas addition on gasoline engine performance and emissions. *Alexandria Engineering Journal*, **55**(1), 243-251.

[5] Ma, F., Wang, M., Jiang, L., Deng, J., Chen, R., Naeve, N., & Zhao, S. (2010). Performance and emission characteristics of a turbocharged spark-ignition hydrogen-enriched compressed natural gas engine under wide open throttle operating conditions. *International Journal of Hydrogen Energy*, **35**(22), 12502-12509.

[6] Shivaprasad, K., Raviteja, S., Chitragar, P., & Kumar, G. (2014). Experimental investigation of the effect of hydrogen addition on combustion performance and emissions characteristics of a spark ignition high speed gasoline engine. *Procedia Technology*, **14**, 141-148.

[7] Chitragar, P., Shivaprasad, K., Nayak, V., Bedar, P., & Kumar, G. (2016). An experimental study on combustion and emission analysis of four cylinder 4-Stroke gasoline engine using pure hydrogen and LPG at idle condition. *Energy Procedia*, **90**, 525-534.

[8] Chaiwongsa, P., Pornsuwancharoen, N., & Yupapin, P. P. (2009). Effective hydrogen generator testing for on-site small engine. *PhysicsProcedia*, **2**(1), 93-100.

[9] Rusdianasari, Bow, Y., & Dewi, T. (2019). HHO gas generation in hydrogen generator using electrolysis. *IOP Conference Series: Earth and Environmental Science*, **258**, 012007.

[10] Alam, N., & Pandey, K. M. (2017). Experimental study of hydroxy gas (HHO) production with variation in current, voltage and electrolyte concentration. *IOP Conference Series: Materials Science and Engineering*, **225**, 012197.

[11] Senthil, R. (2020). Effect of charging of phase change material in vertical and horizontal rectangular enclosures in a concentrated solar receiver. *Case Studies in Thermal Engineering*, **21**, 100653. doi:10.1016/j.csite.2020.100653.

[12] Senthil, R., Chezian, A., & Arsath, Z. H. A. (2021). Heat transfer augmentation of concentrated solar absorber using modified surface contour. *International Journal of Engineering and Technology Innovation*, **11**(1), 24-33. doi:10.46604/IJETI.2021.5676.