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Hydrogen Generation in Indian Coal Mine Water: An Experimental Analysis

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ABSTRACT

Mineral consumption is increasing continuously in the world, so most mining industries are using heavy earth moving machinery (HEMM) to meet their production targets. While HEMM is used to extract minerals from the earth crust, the machinery consumes fuel that increases carbon emissions, which have an adverse effect on the environment. In addition, the demand for fossil fuels has increased due to geopolitics, and the depletion levels of fossil fuels have led to consideration of alternative fuel sources. In this article an experimental analysis was performed to produce hydrogen from mine water.In this experiment, electrolysis process are used combine with aluminium foil. The electrolysis is a method where we use electrodes and power to separate ions and produce hydrogen gas. The generation of hydrogen by using aluminium foil and sodium hydroxide involves a chemical reaction between the aluminium and the sodium hydroxide solution.The comparison will be made with different methods of hydrogen generation with the influence of different factors like temperature, pH value, chemical likesodium hydroxide, and aluminium foil. A study concludes that aluminium foil and sodium hydroxide can provide a low-cost, low-energy hydrogen production solution by using aluminium foil and sodium hydroxide. The results of this research can contribute to the development of a sustainable and clean energy system, reducing the dependence on fossil fuels and mitigating the environmental impact of energy production.

KEYWORDS: C*arbon emissions, Fossil fuels, Hydrogen,Mine water*

1. INTRODUCTION

The energy demand is continuously increasing and the majority of nations rely on fossil fuel-based processes, which are inefficient and harmful to the environment. [1].As a result, there is an increasing demand for alternative, sustainable, and clean energy sources like solar, wind, hydraulic and green hydrogen. India complies with Paris agreement to reduce its emissions by net zero by 2070, and increasing the GDP emissions intensity by 33-35% by 2030 compared to 2005 levels [2].It is not feasible without decarbonization of mining sector. The electrical energy is alternative fuel source which needs lithium and cobalt mineral resources for manufacturing of electrical batteries for mobile equipment like dumper, truck. The limitations of batteries emit the carbon limited power and increase the weight of the machinery [3]. Hence the hydrogen is a best alternative to minimize the emission of carbon in mines.

The national hydrogen mission has been launched by union cabinet on 4th January 2021 [4]. In order to produce green hydrogen in the future, businesses like

Reliance Ltd, Adani Group, Larsen & Turbo Ltd, and state-run firms like Indian Oil Corporations Ltd, NTPC Ltd, and GAIL India Ltd have been developing plans. According to a report by the International Energy Agency (IEA), 306 million tonnes of green hydrogen produced from renewable energy will be needed annually to achieve net-zero global emissions by 2050 [5]. Green hydrogen has a significant potential to play a significant role in decarbonizing the mining industry in the coming years as decarbonization targets drive emissions regulations. The green hydrogen is obtained by electrolyzing water to separate the hydrogen from it using renewable energy sources. The green hydrogen currently only makes up 0.1% of the global hydrogen market. Cost reductions in renewable energy production increase the viability of adopting green hydrogen in mining [6]. However, these methods can be expensive and require significant amounts of energy [7]. Mining industry generates huge amount of waste water, which will be stored in sumps, with very less potential usage [8]. So, it can be used as the possible source to generate hydrogen gas.The proposed research work, conducting experimental analysis of the generation of hydrogen using aluminium foil and sodium hydroxide offers a potentially cheaper and more accessible alternative in coal mines.

2. METHODOLOGY

The process of generating hydrogen from mine water involves the following steps shown in Figure 1. This study concentrated on producing hydrogen from mine water that was gathered from Ramagundam Opencast - III Coal Mine Venture is a 6.8 MTPA mine, worked by the Singareni Collieries Organization Limited, a subsidiary of Coal India organization in town Venkatrao palli Jallaram, Ramagiri, Peddapalli, Telangana, India.

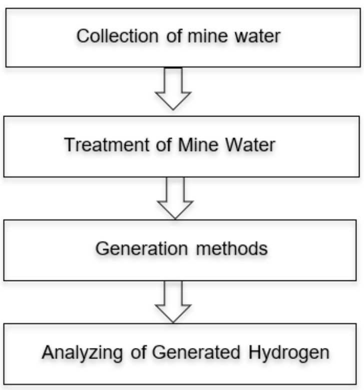

Fig. 1 Flowchart of proposed methodology for generation of hydrogen.

Calculation of hydrogen in grams:

- Calculating moles of water
- The equation [1] can be used to calculate moles of water:

$$\text{Number of moles} = \frac{\text{Given Mass}}{\text{MolarMass}} \qquad ...(1)$$

- Molar mass for the water is 18 grams/moles.
- Mass of hydrogen calculated by using above formula
- Molar mass of hydrogen gas is 2g/mol.
- Thus, by using above formula we can calculate amount of hydrogen in grams.

3. Water quality analysis

It is crucial to guarantee that the water quality meets the regulatory standards set forth in order to encourage the effective exploitation of mine water.Water quality is an important factor that affects the efficiency of hydrogen generation through electrolysis. Here are AWWA (American water Works Association) standard values for water quality parameters that are typically recommended for optimal electrolysis performance [9].

Conductivity - The recommended conductivity level for water used in electrolysis is less than 20 micro Siemens per centimeter (μS/cm). Higher conductivity levels can increase energy consumption and reduce efficiency.

pH value - The recommended pH level for water used in electrolysis is between 6.5 and 8.5. If the pH is too low, it can affect the efficiency of the electrolysis process and reduce hydrogen production.

Total Dissolved Solids (TDS) - The recommended TDS level for water used in electrolysis is less than 500 parts per million (ppm). Higher TDS levels can lead to electrode fouling, corrosion, and impurities that can reduce the efficiency of the electrolysis process.

Alkalinity - The recommended alkalinity level for water used in electrolysis is less than 200 ppm. High alkalinity levels can cause scaling and fouling of the electrode surfaces, reducing efficiency.

Hardness - The recommended hardness level for water used in electrolysis is less than 100 ppm. High hardness levels can cause scaling and fouling of the electrode surfaces, reducing efficiency.

3.1. Water quality analysis in coal mine water

The collected samples are tested by the accurate laboratory which is located in Vijayawada, Andhra Pradesh, India. The samples are tested with the test method IS 3025. The Bureau of Indian Standards developed the IS 3025 standard as a guide for the sampling and testing of water and wastewater in India. It provides instructions for various tests and analyses to guarantee consistent and dependable results and covers a variety of biological, chemical, and physical parameters.All reported metrics (conductivity, pH, TDS, alkalinity, and hardness), according to the data given, are in compliance with the established requirements.The following data was collected from RG3 area OC 2. The range of reported concentrations is shown In Table 1.

Table 1: Coal mine water quality

Parameter	Range of concentration reported	Permissible limit per AWWA
pH	5.9	6.5 to 8.5
Total Dissolved Solids	784	500
Conductivity	28	< 20 (μS/cm)
Alkalinity	300	200 ppm
Hardness	135	100 ppm

As per Table 1, the composition and quality of collected mine water is compared to standards required for generation of hydrogen. It is observed the quality of collected water is not within the standards.

3.2 Treated coal mine water quality analysis

The first step is to treat mine water to remove impurities and dissolved solids that can affect the efficiency of the electrolysis process. The mine water was collected from RG3 area OC 2. Treatment of coal mine water by filter beds involves the use of a specialized system that removes impurities from the water through physical and chemical processes. Filter beds are typically made up of layers of different materials that work together to remove impurities from the water. The first layer of a filter bed is typically composed of a coarse material such as gravel or crushed stone. This layer helps to remove larger particles and debris from the water through the process of physical filtration. As the water passes through this layer, the larger particles become trapped in the spaces between the rocks and are removed from the water. The second layer of a filter bed is typically composed of a finer material, such as sand or fine gravel. This layer helps to remove smaller particles and impurities from the water through the process of physical and chemical filtration. The finer particles in this layer trap smaller impurities in the water, while the chemical properties of the material help to neutralize and remove dissolved minerals and other contaminants [10]. The treated water is then stored in a tank for further steps.

Table 2: Table showing water quality after treatment

Parameter	Range of concentration reported	Permissible limit per AWWA
pH	7	6.5 to 8.5
Total Dissolved Solids	490	500
Conductivity	18	< 20 (μS/cm)
Alkalinity	178	200 ppm
Hardness	84	100 ppm

As per Table 2, the composition and quality of collected mine water is compared to standards required for generation of hydrogen. It is observed the quality of collected water is within the standards.

Its observed that from the collected sample (refer Table 1 and Table 2) the without purified water reported that pH value of 5.9, conductivity value of 28 μS/cm, a total dissolved solids value 784 ppm, an alkalinity value of 300 ppm, and hardness value of 135 ppm. The purified water reports pH value of 7, conductivity value 18 µS/cm, total dissolved solids value of 490 ppm, an alkalinity value of 178 ppm, and hardness value 84 ppm. Hence we take purified water of research work due to more suitable for generation of hydrogen as per the permissible limit of AWWA.

4. Generation of hydrogen

Electrolysis is a method where we use electrodes and power to separate ions and produce hydrogen gas.The generation of hydrogen by using aluminium foil and sodium hydroxide involves a chemical reaction between the aluminium foil and the sodium hydroxide solution.

4.1 Generation of hydrogen through electrolysis process

The 250 ML of water was placed into one container, which is tightly sealed with caps made of outlet pipes for collecting generated oxygen and hydrogen from the anode and cathode. The generated gases are then collected into a balloon, where the amount of hydrogen is measured. The Electrolysis process has been tested for two times with DC supply 27 V and 54 V with variations of pH of 8, 10, 14.

$$H_2O(s) + Energy \longrightarrow H_2(g) + O_2(g) \qquad \ldots(2)$$

In Eq. (2) water is charged with an electrical current during electrolysis, which separates water into its oxygen and hydrogen components [11]. The atomic components of oxygen and hydrogen are separated from their chemical bond (charge splits). The cathode, which is negatively (-) charged, and the anode, which is positively (+) charged, is the two poles where the resultant ions originate. At the cathode, hydrogen ions gather and react with it to form hydrogen gas, which is then collected. At the anode, oxygen immediately begins a parallel reaction.

4.2 Generation by adding aluminium foil

A potential source of hydrogen and energy is the reaction between metals and water shown in Table 3. It observed that the green propellant system that uses water as the oxidizer and solid powdered aluminum as the fuel may be fascinating.

Table 3: Potential reactions between water and metal for the production of hydrogen

Reaction	Heat release per unit mass of metal, kJ/g	Hydrogen release per unit mass of metal, cm^3/g
$Li + H_2O = LiOH + 1/2H_2$	28.77	1600
$Na + H_2O = NaOH + 1/2H_2$	6.08	487
$K + H_2O = KOH + 1/2H_2$	3.58	286
$Mg + 2H_2O = Mg(OH)_2 + H_2$	14.71	933
$Ca + 2H_2O = Ca(OH)_2 + H_2$	10.35	559
$Al + 3H_2O = Al(OH)_3 + 3/2H_2$	16.95	1244

The condensed result of this reaction, sodium hydroxide, is environmentally safe in addition to having reasonably high energy content and a significant volumetric and gravimetric hydrogen release. The oxidizer (water) is simple to get and store. Al powder is not reactive in air at ambient circumstances and is relatively affordable. The potential of the Al/H2O system for many applications linked to hydrogen and heat generation is indicated by the high heat of reaction and big amount of hydrogen that evolved such as: fuel cells, automotive and marine propulsion, and more [12].

In this process, we have been tested with 250 ml of water for three times with variations of pH of 8, 10, 14, with Al foil and addition of sodium hydroxide. The Weight of aluminium foil is determined by the addition ratio reference to NaOH.The ratio of NaOH and Al = 2:1 [13]. The reactions undergo as below [14]

$$2Al + 2NaOH + 2H_2O \rightarrow 2NaAlO_2 + 3H_2$$

5. Result

The result of the experimentstudy investigated the potential of hydrogen generation from mine water using electrolysis and other methods by using aluminium foil as a catalyst. The experiment was conducted on 250 ml of water, with a time duration of 10 minutes, and varying pH levels of 8, 10, and 14. The temperature of the solution was also varied between 23°C, 50°C, and 80°C.The relationship between the NaOH and pH value of water shown in Figure 2.

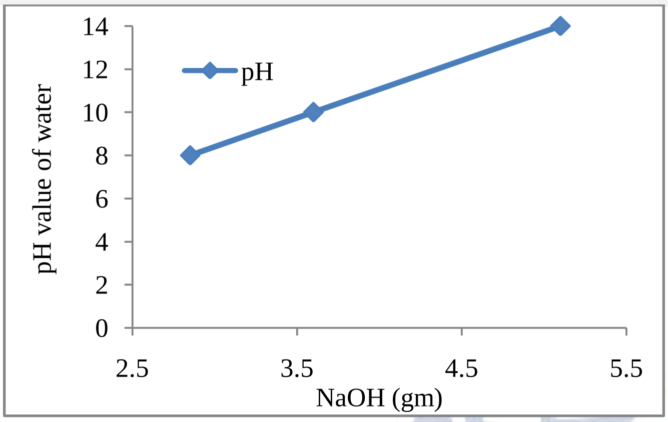

Fig 2. Relationship between the NaOH and pH value of water

The resultof the experiment shown the production of hydrogen gas increased with increasing pH levels and temperature. The highest hydrogen production rate was observed at pH 14 and a temperature of 80°C. This is because at higher pH levels, the water molecules tend to dissociate more easily, releasing more hydrogen ions. Similarly, an increase in temperature causes more water molecules to ionize, leading to a higher hydrogen production rate. The results indicated that the use of aluminium foil as a catalyst for hydrogen generation from mine water was highly effective. The aluminium foil acted as a reducing agent, promoting the formation of hydrogen gas by accepting electrons from the water molecules.

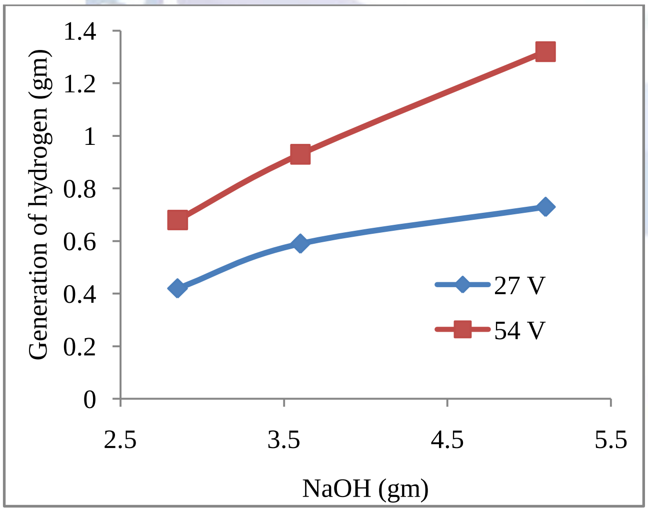

Fig 3: graph shows hydrogen generation with electrolysis process

This reaction was facilitated by the formation of a thin oxide layer on the surface of the aluminium foil, which acted as a catalyst for the reaction. The hydrogen production with Electrolysis process (27V and 54V) with pH 8,10, and 14 with time duration 10 minutes as shown in Figure 3. Itsrepresent the hydrogen generation from electrolysis process with 27V current with 10 mins of time duration for various pH values 8,10, and 14 with quantity of 250 ml water. Later we increased the power to 54V and measured the same for different pH 8,10,14. The readings are measured and plotted in the graph. It clearly shows that with increase in power and high pH value the quantity of hydrogen generation is increased, i.e., 1.32gms. The hydrogen production with chemical process (NaOH and Al) in time duration 10 minutes shown in Figure 4.

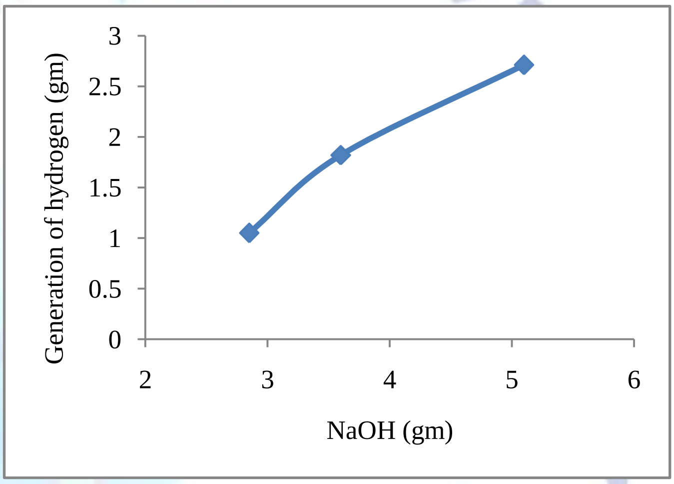

Fig 4: graph shows hydrogen generation with chemical process

In Figure 4, represent the hydrogen generation from chemical process with addition of Aluminium foil and NaOH in the ratio of 1:2, with 10 mins of time duration for various pH values 8,10,14 with quantity of 250 ml water. The pH value varies with amount of NaOH addition [1]. Later we measured the hydrogen generation for different pH 8,10,14. The readings are measured and plotted in the graph (fig (2)). It clearly shows that with increase in pH value the quantity of hydrogen generation is increased, i.e2.71 gms. The temperature effect (at 23°C, 50°C, 80°C) on hydrogen generation in electrolysis and chemical process at pH 14 with time duration of 10 minutes as shown in Figure 5. We observed that hydrogen generation from both electrolysis and chemical process. The highest values from both methods are considered. By varying the temperature of water to 23°C, 50°C, 80°C, observed the hydrogen generation from both the methods with pH 14, with time duration 10 mins and quantity of water 250 ml. It clearly shows that with increase in temperature the quantity of hydrogen generation is increased, i.e., 4.18gms.

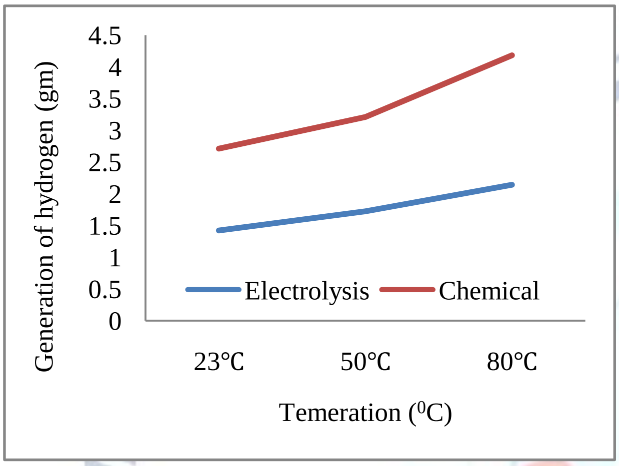

Fig5: graph shows effect of temperature on hydrogen generation.

5. Conclusion

Based on result of experiment we observed that the potential of hydrogen generation from mine water using aluminium foil as a catalyst. The results showed that the use of aluminium foil as a catalyst for hydrogen generation from mine water was highly effective, with the highest hydrogen production rate observed at pH 14 and a temperature of 80°C, that is 4.18gms of hydrogen for 250 ml of water for the time duration 10 minutes. If successfully scaled up, this method could significantly contribute to reducing the environmental impact of mining activities while providing a sustainable and cost-effective source of energy.

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