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Alkali catalyst-based hydrogen generation from waste aluminum foils for fuel cell applications

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Abstract: Hydrogen is used as a source of renewable or non-renewable fuel for various applications including fuel cells. Generation of hydrogen from aluminum is one of the techniques by using alkali solutions as catalysts. The hydrogen produced from metal waste can be used in fuel cells to generate electricity. Among the various alkalis used as catalysts in the release of hydrogen from aluminum, Sodium hydroxide, and Potassium hydroxide were found to be more effective, due to the high ratio of hydrogen production. In this work, various concentrations of NaOH and KOH were used as catalysts and various amount of aluminium foil were used to generate hydrogen. It was found that 2 gm. of aluminum foil with the fixed ratio of water and alkali gives maximum hydrogen production of 1700 ml in 900 s. However, the rate of hydrogen production varies significantly with the mass of aluminium, type of alkali and concentration of alkali. The produced hydrogen was sent to the Polymer Electrolyte Membrane Fuel Cell (PEMFC) directly to produce electricity, and the performance of the fuel cell was also examined.

***Keywords**: Aluminum Waste, Fuel cells, Green Hydrogen, Potassium Hydroxide, Sodium Hydroxide.*

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Introduction

Hydrogen is being used as an alternate energy source in various applications, due to its highest energy content by weight [1-3] and also it belongs to the category of green energy. There has been a lot of research done on producing hydrogen from different sources. For transportation, heating and cooling systems, and energy storage devices, hydrogen can be utilized as a fuel. Hydrogen is also employed in the manufacturing of ammonia and in the oil, food, and other sectors. Additionally, water is a by-product of the fuel cell's interaction of hydrogen and oxygen [4]. Hydrogen and oxygen may be extracted from the water molecule to create hydrogen. Thermal and electrolytic separation are the two main methods used to separate hydrogen and oxygen from water [5]. Also, Hydrogen gas is produced from various methods and used in different applications. [6-11]. Aluminium is one of the most plentiful metals on earth and is also very inexpensive hence it is frequently utilized to create hydrogen from water. [12-18].

Aluminium is a reactive metal that reacts with moisture to make aluminium oxide, which then forms a protective layer on top of the metal. Hydrogen can be producted from Aluminium, determined by the decomposition of aluminum caused by electrochemical oxidation [19-20], the aluminum-water interaction under alkaline circumstances, or the oxidation of mechanically or mechanochemically activated aluminum. The chemistry between aluminium and water will be impacted by this oxide layer. Since, aluminium is an active metal, the surface of alimimium is rapidly oxidised to form a stable coating of aluminium oxide which protects aluminium from the further reaction with oxygen. This coating is solvable in both strongly acidic and basic aqueous solutions.

Therefore, numerous techniques have been developed by researchers to remove this oxide layer so that aluminium metal can successfully combine with water directly to make hydrogen [21]. To remove the oxide layer covering the aluminium metal, promotors like potassium hydroxide (KOH) as well as sodium hydroxide (NaOH) are frequently utilized. The dissociation of the alkali results in the production of sodium (Na^+) and hydroxide (OH^-) ions when sodium hydroxide is introduced to water. The oxide layer on the surface of the aluminium quickly reacted with the ions when scrap aluminium was added to this solution. The oxide layer is removed by the dissociated ions in the aqueous solution, which enables the metal to dissociate the water into hydrogen [22].

$$2\,Al(s) + 6\,H_2O_{(l)} \rightarrow 2\,Al(OH)_{3\,(s)} + 3\,H_{2\,(g)}$$

$$2\,Al(s) + 6\,H_2O_{(l)} + 2\,NaOH_{(aq)} \rightarrow 2\,Na\,Al(OH)_{4\,(s)} + 3\,H_{2\,(g)}$$

The hydrogen created by the aforementioned reaction can be put to use in fuel cells to generate power [23–24]. Different electronic gadgets can be charged using the electricity generated. There are numerous electrochemical cells on the market that store chemical molecules inside of them. the power generated by a redox reaction in these cells when they are in use. However, the fuel cell is a type of electrochemical energy source that generates electricity by continuously bringing in reactants from outside, as and when needed. High efficiency, low emissions, minimal noise while operating, and long operational life are all features of this gadget. We can avoid storing and transporting hydrogen gas along with the cell because we are supplying hydrogen generating within the reaction between aluminium and water and oxygen is received from air.

From the literature, sodium borohydride was reported to be widely used raw material for hydrogen production [7, 25, and 26]. But, only limited literature is available on waste materials like aluminum foils and cans for the fuel cell applications [23, 27]. Thus, the current focus is on producing hydrogen for fuel cells using waste materials that contain aluminum. Also in the present work, various concentrations of NaOH and KOH were taken as potential catalysts for the removal of oxide layer. The produced hydrogen is passed into the hydrogen-oxygen fuel cell to produce electricity. The amount of hydrogen produced and electricity produced in each condition was studied.

Methods and Materials

Materials

Panreac provided the sodium hydroxide and potassium hydroxide pellets, which were used exactly as they were delivered. For the preparation of all the aqueous solutions, deionized water was employed. Aluminium foil (15 µm thickness) was used in this study. High analytical grade was used for the rest of the reagents. The aluminium foil were cut into small pieces and stored in a dry container kept at room temperature away from direct sunlight without moisture content.

Methods

In a semi-batch reactor, research is carried out. A 500 ml airtight cylindrical flask with a feed input and a gas exhaust nozzle serves as the reactor. The hydrogen gas generated inside the reactor is delivered to the burette and gathered there by pushing water downstream utilising an aspiratory bottle linked to the gas burette. An illustration of the experimental setup is shown in Figure 1. In order to carry out the reaction, a mixture with a known alkali proportion were introduced to the digester, and a known weight of aluminium foil was kept in the forefront of it to serve as the major source of aluminium. The studies have utilised various aluminium foil weights and alkali concentrations. The amount of gas produced has been measured using a gas analyzer. The experiment is conducted at a temperature of 30°C. To carry out the reaction, several preparations are loaded with various alkali strengths and weights of aluminium foil.

According to the experimental design below, the hydrogen production was done under different conditions for mass of aluminium foil, concentration of sodium hydroxide and potassium hydroxide. In this experiment mass of aluminium foil was varied from 0.5 g to 2 g, concentration of sodium hydroxide and potassium hydroxide was varied from 1 M to 4 M. Batch experiments of this type were carried out in a glass reactor. According to one-variable-at-a-time (OVAT) approach one factor was varied keeping other factors constant at center level. A spontaneous reaction began when the aluminium foil was poured into the reactor and water and alkali were added. Water displacement was used to determine how much hydrogen was created from the reaction because hydrogen is not very soluble in water. The reaction's hydrogen was directed toward a glass container containing water, forcing the water out of the container. A digital thermometer was used to measure the reaction's temperature. Collected waste aluminium foils was cut in to small pieces and cleaned with KOH and NaOH before being used as a raw material in the aluminium water technique of producing hydrogen gas. Additionally, a predetermined amount of water and alkali are added to the aluminium. Production of hydrogen gas was then done in reactors with an aluminium mass. (1, 1.5 and 2g) in water to alkali volume ratio of 1.5:1 mL. Produced hydrogen was passed to the polymer electrolyte membrane fuel cell. Polymer Electrolyte Membrane Fuel Cell (PEMFC) with a maximum capacity of 1 W, 200 mW per cell, 0.4-0.96 V per cell was used in this experiment. PEMFC is connected with USB cable and PC with installed software. Current and voltage are recorded for different conditions of hydrogen production as mentioned above.

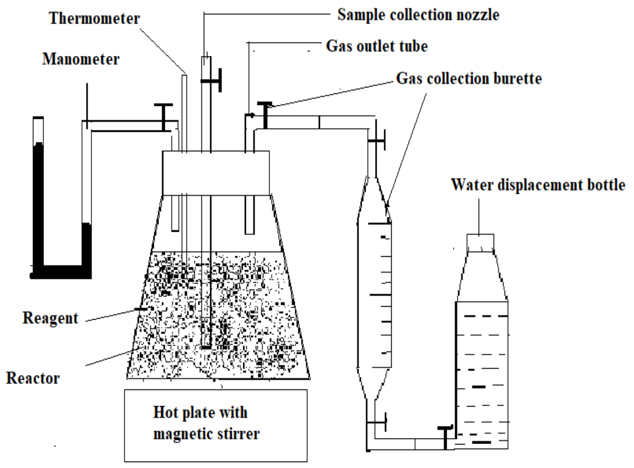

Fig. 1 Schematic diagram of experimental set up

Results and Discussion

Hydrogen gas was produced at different concentration of sodium hydroxide and potassium hydroxide for different amounts of time, and with different amounts of aluminium foil. Volume of hydrogen produced with respect to time is measured using water displacement setup. Current and voltage were recorded from the polymer electrolyte membrane fuel cell.

Influence of KOH concentration on the hydrogen generation

For 1M, 2M, 3M, and 4M KOH concentration as well as for 1g, 1.5g, and 2g of aluminum foil, Fig. 2 depicts the influence of KOH concentration on the volume of hydrogen production with regard to time. 2g of aluminium with 2M and 3M KOH produces more amount of hydrogen than 1g and 1.5g of aluminium. There is no hydrogen production for 0.5g. Moreover, beyond 2 gm of aluminium initially the reaction was very fast, but as the time passes the reaction become slower due to the formation of oxide layer on it. As a result, the total production rate is not significant. 2M KOH with 2g of aluminium foil shows highest volume of hydrogen production in comparison with other molarities of KOH and mass of aluminium foil. 2M KOH with 1g of aluminium foil shows lowest volume of hydrogen production in comparison with other molarities of KOH and mass of aluminium foil. However, the production of hydrogen is higher in the case of 2M KOH in comparison with other molarities of KOH. Hence the concentration of KOH and mass of aluminium significantly changes the production of hydrogen.

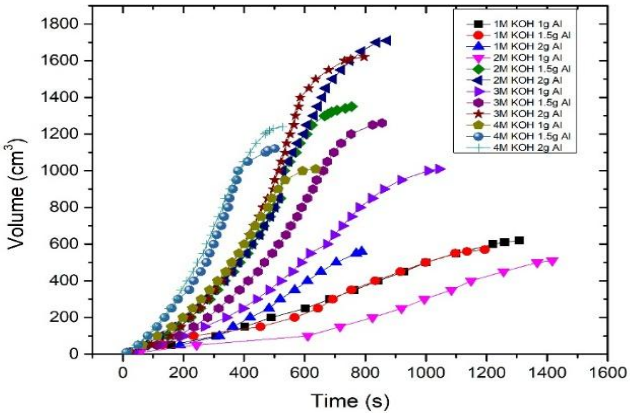

Fig. 2 Variation of production of hydrogen in cc against time in s at different KOH concentration

Influence of NaOH concentration on the hydrogen generation

For 1M, 2M, 3M, and 4M NaOH concentration as well as for 1g, 1.5g, in addition 2g of foil of aluminum, Fig. 2 depicts the influence of KOH concentration on the volume of hydrogen production with regard to time. 2g of aluminium with 2M and 4M KOH produces more amount of hydrogen than 1g and 1.5g of aluminium. There is no hydrogen production for 0.5g.

2M NaOH with 2g of aluminium foil shows highest volume of hydrogen production in comparison with other molarities of NaOH and mass of aluminium foil. 4M NaOH with 1g of aluminium foil shows lowest volume of hydrogen production in comparison with other molarities of KOH and mass of aluminium foil. Concentration of NaOH and the mass of aluminium significantly affects the volume of hydrogen production and the rate of production of hydrogen, which corroborates with the previous studies [28-35].

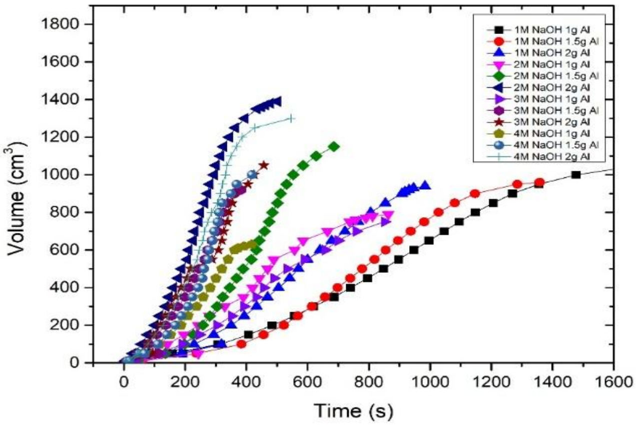

Fig. 3 Variation of production of hydrogen in cc against time in s at different NaOH concentration

Fuel cell performance

Enactment of the polymer electrolyte membrane fuel cell was studied by passing produced hydrogen from aluminium foil and oxygen from air in to the fuel cell. Figures 4-7 shows the current, voltage and power results obtained from the fuel cell. Figure 4 express the fuel cell current against voltage graph for 2g aluminium foil and 3M KOH and Figure 5 shows the power vs voltage graph for 2g aluminium and 3M KOH. This 2g aluminium foil and 3M KOH shows highest energetic efficiency in comparison with other concentration of KOH.

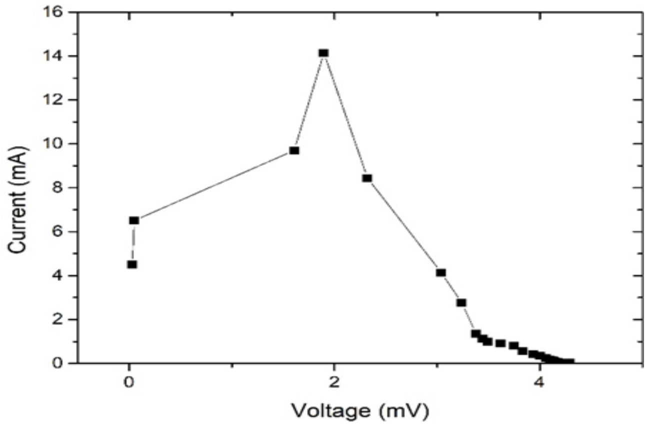

Fig. 4 Current vs voltage for 2g aluminium and 3M KOH

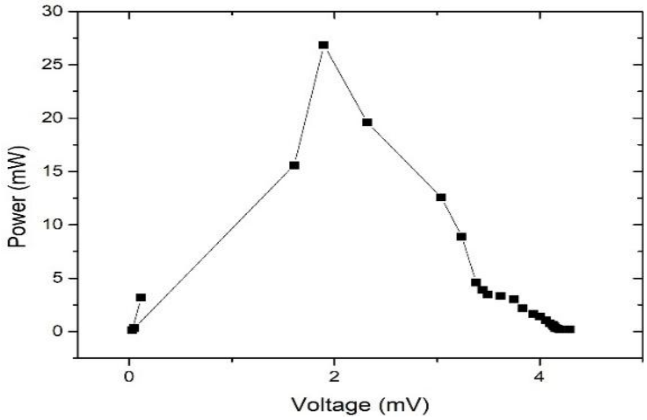

Fig 5: Power vs voltage for 2g aluminium and 3M KOH

Similarly Figure 6 shows the current vs voltage graph for 2g aluminium foil and 1M NaOH and Figure 7 shows the power vs voltage graph for 2g aluminium and 1M NaOH. 2g aluminium foil and 1M NaOH shows highest energetic efficiency in comparison with other concentration of NaOH.

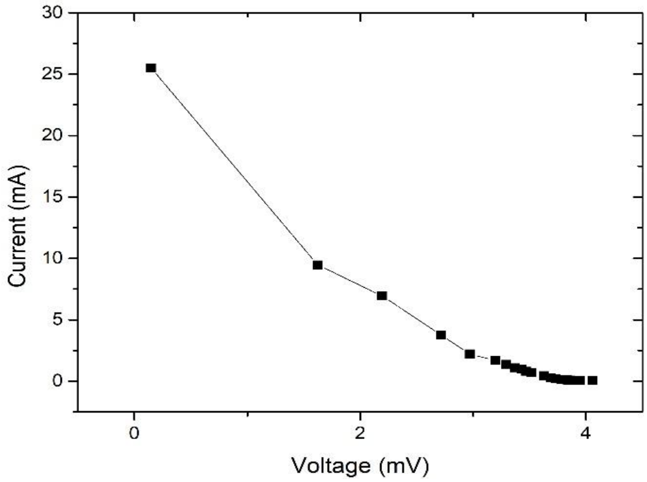

Fig 6: Current vs voltage for 2g aluminium and 1M NaOH

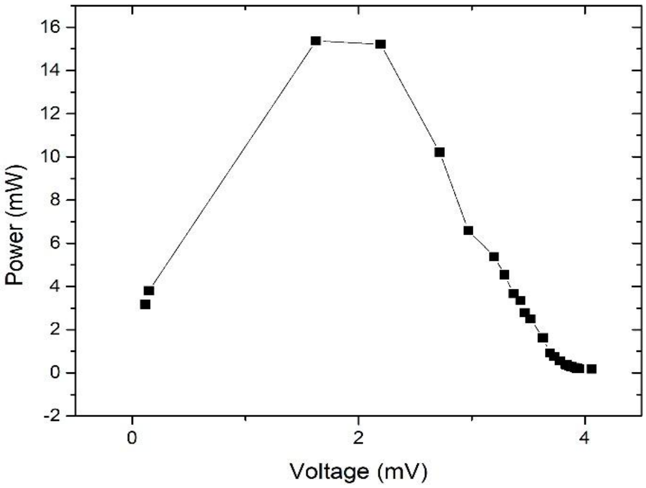

Fig 7: Power vs voltage for 2g aluminium and 1M NaOH

Conclusion

Based on the findings, hydrogen can be made in a straightforward and inexpensive manner by combining aluminium, which originates from discarded aluminium foil, with water and sodium hydroxide or potassium hydroxide. In order to provide power, to produce high-purity hydrogen for application in fuel cells. The kind of alkali, the concentration of alkali, and the mass of aluminum all influence how much hydrogen is produced. In comparison with 1g as well as 1.5g of aluminum, 2g of aluminum produces hydrogen at a higher rate. However, there is no hydrogen generation for 0.5g of aluminum. Energetic efficiency is higher for 2g aluminium and 3M KOH in comparison with other concentration of KOH. Production of hydrogen and energetic efficiency of potassium hydroxide is higher in comparison with sodium hydroxide.

Acknowledgments

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References

1. T. N. Vezirolu, F. Barbir, “Hydrogen: the wonder fuel”, *Int. J. Hydrog. Energy*, 17-6 391−404. (1992).
2. M. Balat, “Potential Importance of Hydrogen as a Future Solution to Environmental and Transportation Problems”, *Int. J. Hydrog. Energy* 33, 4013–4029, 2008.
3. I.P. Jain, “Hydrogen the Fuel for twenty-first Century“, *Int. J. Hydrog. Energy*, 34, 7368– 7378, (2009).
4. Aldo Vieira Da Rosa, Juan Carlos Ordonez, *Fundamentals of Renewable Energy Processes*, 4th Edition, Academic Press, Elsevier, (2021).
5. P. Nikolaidis, A. Poullikkas, “A comparative overview of hydrogen production processes“. *Renewable Sustainable Energy* Rev. 67, 597−61, (2017).
6. G. Taylor, R. Jason, T. Gabl, L. Pourpoint, “Portable Power Generation for remote areas using hydrogen generated via maleic acid-promoted hydrolysis of ammonia borane“. *Molecules* 24, 4045, (2019).
7. H.N. Abdelhamid, “A review on hydrogen generation from the hydrolysis of sodium borohydride”. *Int. J. Hydrog. Energy* 46,726–765, (2021).
8. F. Dawood, M. Anda, G.M. Shafiullah, “Hydrogen production for energy: an overview”. *Int J Hydrogen Energy* 45, 3847-3869, (2020).
9. X. Xie, N. Cui, B. Wang, Y. Zhang, X. Zhao, L. Lin, B. Wang, W. Du, “Recent advances in hydrogen generation process via hydrolysis of Mg-based materials: A short review”. *J. Alloys Compd*. 816, 152634, (2020).
10. X. Xie, N. Cui, B. Wang, Y. Zhang, X. Zhao, L. Lin, B. Wang, W. Du, “Recent advances in hydrogen generation process via hydrolysis of Mg-based materials: A short review”. *J. Alloys Compd*. 816, 152634, (2020).
11. Liuzhang Ouyang, Jun Jiang, Kang Chen, Min Zhu Zongwen Liu, “Hydrogen Production via Hydrolysis and Alcoholysis of Light Metal-Based Materials: A Review” *Nano-Micro Lett*. 13, 134, (2021).
12. K A Trowell, S. Goroshin, D.L. Frost, J.M. Bergthorson. “Aluminum and its role as a recyclable, sustainable, carrier of renewable energy”. *Appl. Energy* 275, 115112, (2020).
13. D Rohendi, A Rachmat, N Syarif, M Said, I Ihsansah, “The Production of Hydrogen from Aluminum Waste by Aluminum-Water Methods at Various Conditions,” *IOP Conf. Ser.: Earth Environ. Sci.* 396, 012009, (2019).
14. K.K. Singh, A. Meshram, D. Gautam, A. Jain, “Hydrogen production using waste aluminium dross: from industrial waste to next-generation fuel”, Agronomy *Research* 17(S1), 1199–1206, (2019).
15. X. Salueña-Berna, M. Marín-Genescà, L. Massagués Vidal, J.M. Dagà-Monmany, “Waste Aluminium Application as Energy Valorisation for Hydrogen Fuel Cells for Mobile Low Power Machines Applications”. *Materials* 14, 7323, (2021).
16. X.S. Berna, M. Marín-Genescà, J. Dagà-Monmany, “Analysis of Valorisation Process of Aluminium Breakage Scraps to Obtain Green Hydrogen”. *Metals* 11, 598, (2021).
17. A. Bolt, I. Dincer, M. Agelin-Chaab, “A Review of Unique Aluminium–Water Based Hydrogen Production Options”. *Energy Fuels* 35, 1024–1040, (2021).
18. S.R. Askhadullin, V.K. Milinchuk, “Generation of hydrogen by hydroheterogeneous compositions based on aluminum and alkali metals”, *Nuclear Energy and Technology* 7(2), 133–138, (2021).
19. S.P. Tekade, D. Z. Shende, K. L. Wasewar. 2018. “Hydrogen Generation in Water Splitting Reaction Using Aluminium: Effect of NaOH Concentration and Reaction Modelling Using SCM”. *Int. J. Chem. React. Eng* 16: 7, (2018).
20. Z Deng, Y Tang, L Zhu, Y Sakka, J. Ye, Effect of Different Modification Agents on Hydrogen-Generation by the Reaction of Al with Water, *Int. J. Hydrog. Energy*, 35, 9561–68, (2010).
21. B.C. Bunker, G. C Nelson, K. R Zavadil, J. C Barbour, F. D Wall, J. P Sullivan, C. F Windisch, M. H Engelhardt, D. R. Baer. Hydration of Passive Oxide Films on Aluminium”. *J. Phys. Chem. B*, 106, 4705–13, (2002).
22. Shyam P. Tekade, Diwakar Z. Shende, Kailas L. Wasewar, “Potassium Hydroxide Activated Hydrogen Generation Using Aluminium in Water Splitting Reaction”, *Int. J. Chem. React. Eng*. 1-8, (2018).

23. X. Huang, T Gao, X Pan, D Wei, L Chunju, L Qin, and Y. Huang. "A Review: Feasibility of Hydrogen Generation from the Reaction between Aluminium and Water for Fuel Cell Applications". *J. Power Sources* 229, 133–110, (2013).

24. L. Soler, J Macanas, M Munoz, J. Casado. "Aluminium and Aluminium Alloys as Sources of Hydrogen for Fuel Cell Applications". *J. Power Sources* 169,144–49, (2007).

25. Manna, J., Roy, B., Pareek, D., & Sharma, P. "Hydrogen generation from NaBH4 hydrolysis using Co-B/$AlPO_4$ and Co-B/bentonite catalysts". *Catalysis, Structure & Reactivity*, 3(4), 157-164, (2017).

26. Dai, H. B., Ma, G. L., Kang, X. D., & Wang, P. "Hydrogen generation from coupling reactions of sodium borohydride and aluminum powder with aqueous solution of cobalt chloride". *Catalysis Today*, *170*(1), 50-55, (2011).

27. Gabriella Amberchan, Isai Lopez, Beatriz Ehlke, Jeremy Barnett, Neo Y. Bao, A'Lester Allen, Bakthan Singaram, Scott R. J. Oliver. "Aluminum Nanoparticles from a Ga–Al Composite for Water **Splitting** and Hydrogen Generation**"**. *ACS Applied Nano Materials*, 5(2), 2636-2643, (2022).

28. Amelia, I., Rohendi, D., Rachmat, A., Syarif, N., Yulianti, D. H., Sya'baniah, N. F., & Rahmah, M. "Hydrogen production from aluminum waste with sodium activator using aluminum-water method". In *AIP Conference Proceedings* Vol. 2638, No. 1, (2022). AIP Publishing.

29. Chen, Y. K., Teng, H. T., Lee, T. Y., & Wang, H. W. "Rapid hydrogen generation from aluminum–water system by adjusting water ratio to various aluminum/aluminum hydroxide". *International Journal of Energy and Environmental Engineering*, 5, 1-6, (2014).

30. Singh, Robin, Ramesh Kumar Guduru, and Rakesh Kumar Vij. "A study on production of hydrogen using Al scrap feedstock." *Environmental Science and Pollution Research*, 1-10, (2024).

31. Urbonavicius, Marius, et al. "Hydrogen from industrial aluminium scraps: Hydrolysis under various conditions, modelling of pH behaviour and analysis of reaction by-product." *International Journal of Hydrogen Energy* 50, 431-446, (2024).

32. Gai, W. Z., Wang, L. Y., Lu, M. Y., & Deng, Z. Y. "Effect of low concentration hydroxides on Al hydrolysis for hydrogen production". *Energy*, 268, 126731, (2023).

33. Maulana, F. R., Fadhilah, N., Wahyuono, R. A., & Risanti, D. D. "Hydrogen Production from Waste Aluminum Foil AA1235 Using the Aluminum-Water Reaction Method with Thickness Variations". *Advanced Materials Research*, 1175, 9-15, (2023).

34. Deebika, P., & Saravanakumar, M. P. "Utilization of RO rejects and waste aluminum scraps for hydrogen generation". *International Journal of Hydrogen Energy*, 48(91), 35516-35531, (2023).

35. Mezulis, A., Richter, C., Lesnicenoks, P., Knoks, A., Varnagiris, S., Urbonavicius, M., ... & Kleperis, J. "Studies on Water–Aluminum Scrap Reaction Kinetics in Two Steps and the Efficiency of Green Hydrogen Production". *Energies*, 16(14), 5554, (2023).