Opportunities for using hydrogen to transition to green energy

Maya Abdullayeva[1*], and *Gulchin* Mammadli[1]

[1]Azerbaijan State Oil and Industry University, Azerbaijan

Abstract. The article explores the pivotal juncture of procuring and integrating hydrogen as a transformative milestone in sustainable energy. The environmental impact is scrutinized through distinctions between "gray," "blue," and "green" hydrogen, with green hydrogen, derived from renewable sources, standing out for its potential to combat climate change. The method section details an investigation into the electrocatalytic activities of Ni-Mo thin films as cathodes in water electrolysis. The study underscores the effectiveness of these films, particularly the non-thermally treated ones, as cathodes in a neutral environment. The chemical reactions during electrolysis are outlined, and the catalytic activity is compared with other electrodes, revealing promising results for Ni-Mo thin films. A method for preparing solutions and an electrochemical coupling device used for deposition are also given.. The conclusion emphasizes the advanced idea of using hydrogen as a main energy source, calling for measures, legislative initiatives, and support for innovative projects to propel the development of hydrogen-based energy solutions.

1 Introduction

In the ever-evolving tapestry of sustainable energy, the pivotal juncture of procuring and integrating hydrogen as a viable energy source emerges as a transformative milestone in our relentless pursuit of a cleaner and more secure future. As we embark on a comprehensive exploration of the multifaceted realm of hydrogen energy, it becomes increasingly apparent that the acquisition process extends beyond the realm of technological advancements. This intricate journey involves a delicate dance between economic considerations, environmental imperatives, and strategic dimensions, demanding an in-depth examination of the challenges and opportunities that arise when adopting hydrogen as our primary energy carrier [1]. The transition to a hydrogen-based economy triggers a profound reassessment of economic models and investment strategies. While hydrogen boasts its credentials as a clean and efficient energy carrier, the substantial upfront costs associated with infrastructure development and technology implementation cannot be disregarded. Governments, industries, and investors grapple with the strategic allocation of resources, aiming to catalyze the growth of a burgeoning hydrogen economy [2].The economic viability of hydrogen energy pivots on addressing the cost-effectiveness of production,

* Corresponding author: mayaabdullayeva@hotmail.com

distribution, and storage. Crucial factors such as innovations in manufacturing processes, advancements in electrolysis technology, and the realization of economies of scale play pivotal roles in determining the affordability of hydrogen. A nuanced understanding of the economic landscape becomes imperative for stakeholders as they embark on this transformative journey, striving to strike a harmonious balance between sustainability goals and fiscal responsibility [3].In the pursuit of mitigating the environmental impact of traditional energy sources, the purchase of hydrogen emerges as a beacon of sustainability. The nuanced distinctions between "gray," "blue," and "green" hydrogen assume paramount importance, offering insights into the environmental footprint of the production process. Notably, green hydrogen, derived from renewable sources like solar or wind energy through water electrolysis, stands out as the vanguard in environmentally conscious energy procurement. Its potential to generate zero greenhouse gas emissions aligns seamlessly with global efforts to combat climate change, compelling nations and corporations to navigate the intricate landscape where environmental responsibility converges with energy procurement considerations [4]. Beyond economic and environmental dimensions, the purchase of hydrogen becomes a strategic investment in global energy security. Diversifying energy sources, reducing dependence on finite fossil fuels, and establishing resilient energy infrastructures emerge as critical components of strategic planning. Nations, attuned to the geopolitical significance of energy independence, increasingly incorporate hydrogen into their energy portfolios, envisioning a more secure and resilient energy supply chain. The strategic purchase of hydrogen aligns with broader geopolitical goals, fostering stability and reducing vulnerabilities associated with traditional energy dependencies [5]. In conclusion, the acquisition of hydrogen energy transcends conventional paradigms of energy procurement. It represents a strategic, economic, and environmental choice, shaping the trajectory of a global transition toward sustainable energy practices. As nations and industries grapple with the complexities of this transformative journey, the commitment to purchase hydrogen heralds a new era of energy exploration—one where environmental consciousness and economic pragmatism converge to redefine the way we power our planet. Join us in the upcoming sections of this blog series, where we delve even deeper into the nuanced landscape of hydrogen procurement, exploring emerging technologies, international collaborations, and the ever-evolving dynamics of a hydrogen-driven world. Together, let's navigate the path to a future where the purchase of hydrogen energy is not just a choice but a collective commitment to a sustainable and resilient energy future [6].

2 Materials and methods

This study explores the electrocatalytic activities of nickel-molybdenum (Ni-Mo) thin films as cathodes in water electrolysis. The hydrogen evolution reaction, a multistep process influenced by various factors, was investigated with a focus on different mechanisms under varying conditions such as environment, electrode material, and temperature. The Folmer-Geirovsky mechanism, particularly observed on mercury electrodes, involves the discharge of hydroxyl ions leading to the reduction of hydrogen. In neutral and alkaline media, the hydrogen release reaction follows a sequence of stages, including the Folmer phase, Tafel phase, and electron transport of hydrogen or water. Platinum and other platinum group metals are known for their versatility as catalysts, exhibiting stability over a wide potential range in various solutions. Nickel electrodes, especially in alkaline solutions, are commonly used as cathode materials [7]. Ni-Mo thin films with different molybdenum mass fractions were studied for their catalytic activity. The mass fraction of molybdenum decreased after thermal treatment due to partial oxidation of nickel and molybdenum in the thin layer. Figure 1 presents the catalytic activities of water electrolysis for various electrodes (cathodes) in a 0.5 M Na_2SO_4 electrolyte. Comparative characterization included platinum, nickel, and steel-3 electrodes. Notably, the Ni-Mo thin films with 73.5% nickel, 13.3% molybdenum, and 13.2% oxygen, without thermal treatment, exhibited the highest catalytic activity, surpassing that of the platinum electrode by approximately 1.5 times.

Chemical Reactions: The following reactions were observed during the electrolysis process:

$$H^+ + e^- + * \rightarrow H^* \text{ (sour)} \quad (1)$$

$$H_2O + e^- + * \rightarrow H^* + OH^- \text{ (neutral and alkaline)} \quad (2)$$

$$H^* + H^+ \rightarrow H_2 + 2\,* \text{ (acidic, neutral and alkaline)} \quad (3)$$

$$H^* + e^- + H^+ \rightarrow H_2 + * \text{ (sour)} \quad (4)$$

$$H_2O + e^- + H^* \rightarrow H_2 + OH^- + * \text{ (neutral and alkaline)} \quad (5)$$

Note: * represents active centers in the reactions [8].

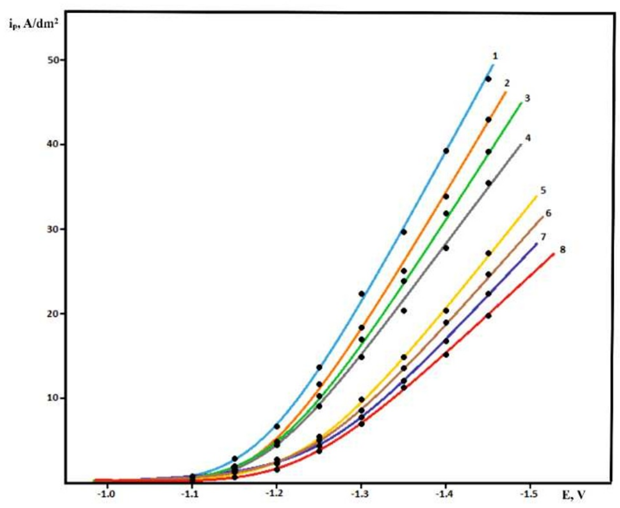

Fig. 1. Cathodic polarization curves at different electrodes in 0.5 M Na_2SO_4 electrolyte: 1 – $Ni_{73.5}Mo_{13.3}O_{13.2}$ (Ni substrate without thermal treatment); 2 – $Ni_{83.4}Mo_{2.1}O_{14.5}$ (on Pt substrate); 3 – $Ni_{68.2}Mo_{11.5}O_{20.3}$ (after thermal treatment on Ni substrate); 4 – Ni; 5 – Pt; 6 – $Ni_{70.12}Mo_{14.59}O_{15.29}$ (Steel–3 substrate), 7 – Steel–3, 8 – $Ni_{13.79}Mo_{64.85}O_{21.36}$ (Ni substrate).

The numbers written in the indexes of the elements included in the composition of the alloy are the percentage mass share of the elements included in the composition of those alloys. It can be seen from the curves that electrochemically synthesized Ni - Mo thin films work effectively as cathodes in neutral environment. The catalytic activity of nickel-molybdenum thin films was investigated depending on their composition. The obtained data are presented in table 1, and the smallest Tafel bias was observed for the non-thermally treated layers containing 73.5% nickel and is 105 mV (figure 1-curve 1). After thermal treatment, the amount of nickel in the layers decreased to 68.2% and the inclination angle of the Tafel curve increased (Figure 1-curve 3). After thermal treatment, the decrease in the catalytic activity of thin films is associated with a change in the structure of the films. It is known that the catalytic activity of amorphous alloys is always higher than the activity of crystalline alloys, which is explained by the large surface area of amorphous alloys [9].

Table 1. Electrodeposition of the components from the solution containing.

No	Taken substrates	Electrode	∂ E/∂lgi (mV)
1.	Pt	Platinum	160
2.	Ni	Nickel	230
		$Ni_{73.5}Mo_{13.3}O_{13.2}$, not subject to heat treatment	170
		After heat treatment $Ni_{68.2}Mo_{11.5}O_{20.3}$	210
3.	Steel brand Steel-3	Steel – 3	280

From the data given in Table 1. it can be concluded that platinum is the best anode in the oxygen release reaction (160 mV), followed by $Ni_{73.5}Mo_{13.3}O_{13.2}$ alloy (170 mV) with a small difference. The preparation of solutions used chemicals of sufficiently high purity salt of nickel(II) sulfate ($NiSO_4$ $7H_2O$) from Indian Central Drug House (p) Ltd., originally taken as a starting component for the production of nickel-molybdenum alloy as a source of nickel ions and molybdate sodium (Na_2MoO_4) from the Indian company Qualikems Fine Chem Pvt Ltd · $2H_2O$) as a source of molybdate ions, the required amount was weighed out on an analytical balance, then both salts were dissolved in 25% (7 M) ammonia solution (NH_4OH) from Qualikems Fine Chem Pvt Ltd., India.The pH of the electrolyte was equal to 11.2. Using the background electrolyte containing 0.1 M H_3BO_3 + 7 M NH_4OH, the process of electrodeposition of the components from the solution containing nickel and molybdate ions was studied both separately and together. The process was carried out in the galvanostatic and potentiostatic mode using electrolytes with the following compositions [10-11].

$$0.107\ M\ NiSO_4 + 0.13\ M\ NiCl_2 + 0.1\ M\ H_3BO_3 + 7\ M\ NH_4OH \tag{6}$$

$$0.124\ M\ Na_2MoO_4 + 0.1\ M\ H_3BO_3 + 7\ M\ NH_4OH \tag{7}$$

$$0.107\ M\ NiSO_4 + 0.124\ M\ Na_2MoO_4 + 0.13\ M\ NiCl_2 + 0.1\ M\ H_3BO_3 + 7\ M\ NH_4OH \tag{8}$$

The IVIUMSTAT Electrochemical Interface device was used as a potentiostat for the research work. The IVIUMSTAT Electrochemical Interface potentiostat was connected through a computer and the computer was equipped with the IviumSoft program. IVIUMSTAT potentiostat has many applications. Thus, through this device, linear, cyclic polarization, potential - time, current strength - time, electrochemical analysis, capacitance measurements, etc. it is possible to conduct research [12]. The potentiostatic deposition of nickel-molybdenum layers was conducted in a 45 ml glass cell with three electrodes and a water jacket. The working electrode, acting as the cathode, included options of Pt wire, Ni plate, or Steel-3 plate. A Pt plate served as the auxiliary electrode, and a silver/silver chloride (Ag/AgCl/KCl) reference electrode, equipped with a Luggin capillary, was used to measure electrode potential [13]. For surface process study, the Luggin's capillary was positioned at an angle of 20 - 25° to the working electrode surface. The catalytic activity of nickel-molybdenum films was examined in a glass electrolyser with a 0.5 M neutral sodium sulfate (Na2SO4) solution and a Teflon electrolyser with a 3.0 M NaOH electrolyte. Polarization curves were drawn using the IVIUMSTAT Electrochemical Interface potentiostat (Figure 2) [14].

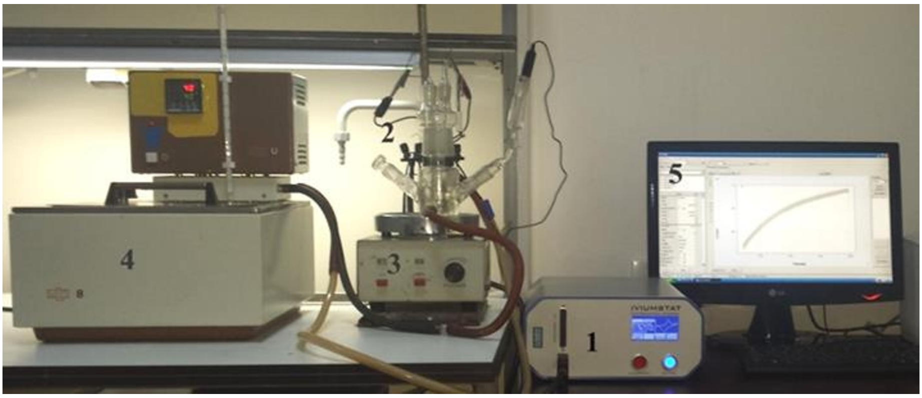

Fig. 2. Devices and equipment used to perform electrochemical measurements. 1 - "IVIUMSTAT Electrochemical Interface" potentiostat, 2 - three-electrode electrochemical cell, 3 - magnetic stirrer, 4 - thermostat, 5 - computer..

Devices and devices used in the process :

Microinterferometer (MII-4) - measuring microscope with optical interference (Figure 3) was determined using a MII - 4 micro interferometer. The principle of operation of the device is based on the phenomenon of light interference [15-16].

Fig. 3. Microinterferometer (MII-4) - measuring microscope with optical interference.

Microhardness measuring microscope (PMT - 3) (Figure 4.) Microhardness of alloys is one of the important properties characterizing their physical properties. PMT-3 device is used to measure microhardness. The microhardness measuring device is a microscope designed to measure the microhardness of glass, abrasive, ceramic, mineral and other materials [17].

Fig. 4. Microhardness measuring microscope (PMT - 3).

3 Results and Discussion

Unraveling the Tapestry of Hydrogen Energy Procurement.

Your article provides a comprehensive exploration of the multifaceted landscape surrounding the procurement and integration of hydrogen as a pivotal energy source. Here, we delve into a discussion that further dissects the various dimensions covered in your article:

- Economic Considerations and Investment Strategies: the upfront costs associated with hydrogen infrastructure development and technology implementation are indeed substantial. As we transition to a hydrogen-based economy, stakeholders must strategically allocate resources to catalyze growth. Discussing potential financing models, public-private partnerships, and governmental incentives could shed light on addressing economic challenges.
- Environmental Impacts and Hydrogen Types: your emphasis on the environmental footprint of hydrogen production, distinguishing between "gray," "blue," and "green" hydrogen, is crucial. Expanding on this, a discussion could explore how advancements in technology and increased adoption of green hydrogen can contribute to achieving sustainability goals. Additionally, touching on challenges and breakthroughs in reducing the carbon footprint during hydrogen production could provide a more nuanced view.
- Strategic Importance for Global Energy Security: the strategic aspect of hydrogen procurement in the context of global energy security is a compelling dimension. Elaborating on specific geopolitical considerations, international collaborations, and potential geopolitical shifts resulting from the widespread adoption of hydrogen as an energy carrier could add depth to this discussion.
- Electrolysis and Catalyst Development: the method section introduces the electrolysis of water as the main method for obtaining hydrogen, and the study on Ni-Mo thin films as cathodes is fascinating. A more in-depth discussion on the significance of this research, potential scalability, and the role of catalyst development in optimizing the efficiency of electrolysis could enhance the technical understanding for readers.
- Economic Viability and Affordability: the economic viability of hydrogen energy is closely tied to factors like manufacturing processes and economies of scale. Exploring

how ongoing innovations, government policies, and market dynamics impact the cost-effectiveness of hydrogen production and distribution could provide valuable insights.
- Methodology and Experimental Insights: the detailed description of the experimental setup and methodology is crucial. Discussing the implications of the study's findings, potential areas for further research, and how these insights contribute to the broader field of hydrogen energy research would be beneficial.
- Future Prospects and Challenges: concluding the discussion with a forward-looking perspective on the future of hydrogen energy, including emerging technologies, regulatory developments, and potential challenges that may arise, can provide readers with a sense of what to anticipate in the evolving landscape.

In result, this article lays a solid foundation for understanding the intricate facets of hydrogen energy procurement. A more elaborate discussion on the above points could enrich the reader's comprehension and foster a more engaging exploration of the transformative journey towards sustainable energy practices.

4 Conclusion

In conclusion, the journey towards hydrogen energy represents a pivotal shift in our pursuit of a sustainable and secure future. As highlighted in this exploration, the procurement and integration of hydrogen as a primary energy source require a delicate balance of economic, environmental, and strategic considerations. The economic viability hinges on addressing production, distribution, and storage costs through technological innovations and achieving economies of scale. Environmental consciousness plays a critical role, with distinctions between "gray," "blue," and "green" hydrogen guiding sustainable practices. Moreover, the strategic purchase of hydrogen contributes to global energy security by diversifying sources and reducing reliance on finite fossil fuels. The article calls for continued exploration of emerging technologies, international collaborations, and evolving dynamics in the hydrogen-driven world, fostering a future where hydrogen procurement is not just a choice but a shared commitment to a sustainable and resilient energy future.

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