SOLAR-DRIVEN ALKALINE ELECTROLYSIS: TECHNICAL AND ECONOMIC ASSESSMENT FOR GREEN HYDROGEN PRODUCTION

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Abstract. This paper analyzes hydrogen production through alkaline water electrolysis powered by photovoltaic systems. The study examines optimal operating conditions including 25-30 wt% KOH concentration, 316L stainless steel electrodes, and system integration parameters. Experimental results show 13-15% overall efficiency with hydrogen production costs of $2-8/kg. The research demonstrates that low current density operation (2.94 mA/cm²) maximizes efficiency while ensuring electrode longevity exceeding 20 years. Findings provide practical guidelines for green hydrogen production in high solar resource regions.

Keywords. alkaline electrolysis, green hydrogen, photovoltaic integration, renewable energy, water splitting, sustainable production

Аннотация. В данной статье анализируется получение водорода с помощью электролиза щелочной воды с использованием фотоэлектрических систем. В исследовании рассматриваются оптимальные условия эксплуатации, включая концентрацию КОН в 25-30 мас.%, электроды из нержавеющей стали 316L и параметры системной интеграции. Результаты экспериментов показывают, что общий КПД составляет 13-15% при затратах на производство водорода в размере 2-8 долларов США за кг. Исследование показывает, что работа при низкой плотности тока (2,94 мА/см2) обеспечивает максимальную эффективность, а срок службы электрода превышает 20 лет. Полученные результаты дают практические рекомендации по производству экологически чистого водорода в регионах с высоким уровнем солнечной энергии.

Ключевые слова. щелочной электролиз, экологически чистый водород, фотоэлектрическая интеграция, возобновляемые источники энергии, расщепление воды, устойчивое производство

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Annotatsiya. Ushbu maqola fotovoltaik tizimlar bilan ishlaydigan gidroksidi suv elektrolizi orqali vodorod ishlab chiqarishni tahlil qiladi. Tadqiqot optimal ish sharoitlarini, shu jumladan 25-30 Vt% KOH kontsentratsiyasini, 316L zanglamaydigan po'lat elektrodlarni va tizim integratsiyasi parametrlarini o'rganadi. Eksperimental natijalar 13-15% umumiy samaradorlikni ko'rsatadi, vodorod ishlab chiqarish xarajatlari 2-8 dollar/kg. Tadqiqot shuni ko'rsatadiki, past oqim zichligi operatsiyasi (2.94 mA/sm2) 20 yildan ortiq elektrod umrini ta'minlashda samaradorlikni oshiradi. Topilmalar yuqori quyosh manbalari mintaqalarida yashil vodorod ishlab chiqarish bo'yicha amaliy ko'rsatmalar beradi.

Kalit so‘zlar. ishqoriy elektroliz, yashil vodorod, fotovoltaik integratsiya, qayta tiklanadigan energiya, suvning bo'linishi, barqaror ishlab chiqarish

1. Introduction

Hydrogen is emerging as a critical energy carrier for achieving carbon neutrality, with the global market projected to reach $2.5 trillion by 2050 [1]. Green hydrogen production via water electrolysis using renewable energy offers a sustainable pathway with zero carbon emissions [2]. Among available technologies, alkaline electrolysis provides the optimal balance of reliability, cost-effectiveness, and longevity for large-scale deployment [3].

This research aims to analyze alkaline electrolysis systems integrated with photovoltaic power sources, focusing on optimizing operational parameters and evaluating techno-economic viability. The study addresses the critical need for practical implementation guidelines in regions with abundant solar resources.

2. Literature Review

Water electrolysis technology has evolved significantly since its discovery in 1800 [4]. Modern alkaline electrolyzers achieve 63-82% efficiency through advances in electrode materials and cell design [5]. The integration with renewable energy sources presents challenges in power matching, with direct coupling resulting in 20-30% efficiency losses [6].

Recent studies demonstrate that 316L stainless steel electrodes exhibit excellent durability in alkaline environments, with corrosion rates below 0.01 mm/year [7]. Advanced power management using maximum power point tracking (MPPT) improves system performance by 12-15% compared to direct coupling [8].

The levelized cost of hydrogen (LCOH) from renewable electrolysis has decreased from $16/kg in 2010 to current levels of $2-8/kg, driven by declining renewable energy costs and improved electrolyzer efficiency [9]. Regions with high solar resources can achieve the lower end of this cost range [10].

3. Research Methodology

Experimental Setup

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The experimental system consisted of:

-Electrolyzer: Six 316L stainless steel plates (170×130×1 mm each), total active area 2,652 cm^2

-Power supply: 150 Wp polycrystalline silicon PV panel with MPPT controller

-Operating conditions: 13 V, 7.8 A (101.4 W input power)

-Current density: 2.94 mA/cm^2

- Electrolyte: 30 wt% KOH solution

Measurement Procedures

Performance tests included: Response to dynamic solar variation, static nature at various temperatures (25-80°C) and a long-term stability test that involves 1,000 hours of nonstop operation, the rate at which hydrogen is produced using the volumetric displacement technique.

Data Analysis

System efficiency was calculated as:

$$\eta_{system} = \eta_{PV} \times \eta_{converter} \times \eta_{elec}$$

Where $\eta_{PV} \approx 20\%$, $\eta_{converter} \approx 97\%$, $\eta_{elec} \approx 70\%$

4. Analysis and Results

Electrolyte Optimization

Conductivity measurements confirmed optimal performance at 30 wt% KOH: - At 25°C: $\sigma = 0.54$ S/cm - At 80°C: $\sigma = 0.68$ S/cm - Temperature coefficient: 0.02 K^{-1}.

System Performance

Table 1.

Experimental Results

Parameter	Value	Unit
Operating voltage	13.0	V
Current	7.8	A
Power consumption	101.4	W
H_2 production rate	3.24	L/h
Mass flow rate	0.29	g/h
Specific energy	39	kWh/kg
Electrolyzer efficiency	71.2	%
Overall system efficiency	13.2	%

The low current density operation minimized overpotentials:

- Activation overpotential: 0.25 V

- Ohmic overpotential: 0.18 V

- Concentration overpotential: <0.05 V

Temperature Effects

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Increasing temperature from 25°C to 80°C resulted in: 22% reduction in cell voltage, 28% increase in H_2 production and 15% improvement in efficiency. Optimal operating temperature: 60-70°C balancing performance and durability.

Long-term Stability

After 1,000 hours operation: Cell voltage increased <2%, Electrode corrosion rate was 0.009 mm/year and projected lifetime is predicted to >20 years.

Economic Analysis

Table 2.

Hydrogen Production Costs

System Scale	LCOH ($/kg)	Capacity Factor
Small (<10 kW)	5.2-7.8	20%
Medium (10-100 kW)	3.5-5.0	25%
Large (>100 kW)	2.2-3.8	30%

Capital costs breakdown:

- Electrolyzer: $800/kW
- PV system: $400/kW
- Balance of plant: $300/kW
- Total: $1,500/kW

5. Conclusions and Recommendations

5.1 Conclusions

This study demonstrates that alkaline electrolysis integrated with photovoltaic systems provides a viable pathway for green hydrogen production. Optimal operation at 30 wt% KOH, 60-70°C, and low current density (2.94 mA/cm²) maximizes efficiency while ensuring longevity. Overall solar-to-hydrogen efficiency of 13-15% is achievable with proper system integration using MPPT control. Production costs of $2-8/kg H_2 are competitive with conventional methods when carbon pricing is considered. 316L stainless steel electrodes demonstrate exceptional durability with > 20-year projected lifetime.5.2 Recommendations

1. Implement modular designs for scalability and optimize current density based on local electricity costs.
2. Focus on advanced electrode coatings and improved gas separation techniques.
3. Prioritize regions with >25% solar capacity factor and co-locate with industrial hydrogen consumers.
4. Establish regulatory frameworks and carbon pricing mechanisms to incentivize green hydrogen adoption.
5. Conduct field testing under real-world conditions and develop predictive maintenance strategies.

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The transition to green hydrogen represents both a challenge and opportunity. This research confirms technical viability with rapidly improving economics, requiring coordinated efforts in technology, policy, and market development.

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