Optimization of Ammonia Conversion via Thermal Plasma for Large-scale Hydrogen Production

H.J. Lee, S.P. Kang, S.J. Oh, T.H. Kim*

Department of Chemical Engineering, Wonkwang University, Iksan 54538, Republic of Korea

Abstract: Hydrogen production via ammonia decomposition using thermal plasma was investigated. Through experiments and simulations, plasma power, ammonia concentration, and gas flow rate were optimized, achieving a decomposition rate of 99.99% and a hydrogen production efficiency of 29.84 g/kWh. These results highlight the potential of thermal plasma for sustainable hydrogen production.

1. Introduction

Ammonia(NH_3) is attracting attention as a promising hydrogen carrier due to its high hydrogen content of 17.7 wt% and ability to be easily liquefied under 20 ℃ and 8.6 bar conditions. In particular, it does not emit carbon when burned, and the infrastructure for long-distance transportation is already well established, further increasing its practicality [1].

Thermal plasma provides a high-temperature environment exceeding 10,000 K and rapidly processes large quantities of gas to offer the heat required for large-scale ammonia decomposition. In particular, whereas non-thermal plasma typically processes gas flow rates in the ccm range, thermal plasma enables the processing of gas flow rates in tens of liters per minute, making it a suitable technology to meet the demands of industrial-scale hydrogen production.

This work aims to analyze the ammonia decomposition mechanism using thermal plasma and develop an optimization strategy to increase the economic efficiency of hydrogen production through various experiments and computational analyses.

2. Methods

A DC non-transferred plasma torch was used with nitrogen(N_2) as the plasma forming gas. Plasma gas flow rates were set at 30 L/min and 50 L/min, with input power ranging from 5 to 10 kW. Ammonia was injected at flow rates up to 30 L/min, achieving concentrations at 14-50%(with 30 L/min N_2) and 5-35%(with 50 L/min N_2)

3. Results and Discussion

Figure 1 shows the hydrogen production efficiency according to the input power and ammonia concentration when the plasma gas flow rate is 30 L/min and 50 L/min. At a flow rate of 30 L/min, the maximum hydrogen production efficiency of 15.39 kWh was observed at an input power of 5.80 kW. At a flow rate of 50 L/min, the maximum efficiency of 29.84 g/kWh was achieved at an input power of 10.20 kW. The efficiency tended to decrease as the ammonia concentration increased, which is analyzed to be due to the reduction in the high-temperature region and the decrease in the residence time of the reactants compared to other plasma sources, the thermal plasma system showed significantly superior performance in terms of energy efficiency. For example, the hydrogen

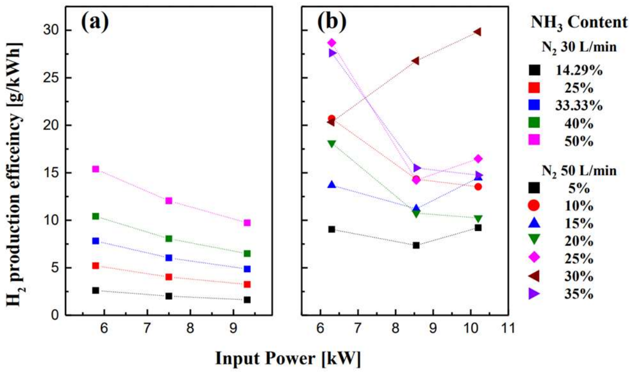

Fig. 1. H_2 production efficiency depending on input power for (a) 30 L/min and (b) 50 L/min nitrogen plasma forming gas.

production efficiency of DBD(Dielectric barrier discharge) plasma was recorded at a maximum of 1.44 g/kWh, microwave plasma at 1.89 g/kWh, and gliding arc plasma at 10.61 g/kWh [2]. In comparison, the thermal plasma system in this study achieved an efficiency that exceeded all of them.

4. Summary and Future plan

Thermal plasma has shown superior energy efficiency compared to other plasma technologies in ammonia decomposition, recording a maximum of 29.84 g/kWh. However, industrial scale application is still lacking, and further research is needed. Future research will be conducted to optimize conditions for ammonia decomposition hydrogen production, analyze mechanisms, and evaluate economic feasibility using DC thermal plasma.

Acknowledgement

This research was supported by the Korea Planning & Evaluation institute of industrial Technology (KEIT) grant funded by the Ministry of Trade, Industry and Energy (RS-2024-00418305).

References

[1] K.H. Lim et al., ACS Sustainable Chem. Eng., **11**, 13, 4903-4933 (2023).

[2] X. Zhang et al., J. Phys. D –Appl. Phys. **57**, 065203 (2024).