NH_3 cracking with warm plasma: advantages and limitations

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Abstract: In this contribution, we analyse the products of NH_3 cracking in several different atmospheric pressure warm plasma reactors in a variety of conditions. We calculate the energy cost of plasma-based NH_3 cracking and compare the reactors with each other to better understand the mechanisms behind the cracking process and how different factors influence them. Results show that NH_3 cracking in warm plasma is dominated by thermal chemistry.

1. Introduction

Rising interest in NH_3 as a fuel source and an H_2 carrier has sparked demand for an efficient NH_3 cracking process. Plasma-based NH_3 cracking can have several advantages over thermo-chemical cracking: it can speed up the NH_3 cracking process due to much higher temperatures than conventional catalysis, reduce the reactor's costs and size by not using catalysts, and be entirely powered by renewable electricity. Until recently, most research in this direction was focused on cold plasma, such as DBD, often in combination with catalysts. NH_3 cracking using warm plasma systems was much less common but featured better energy costs than cold plasma reactors. We investigated the feasibility and limitations of NH_3 cracking in warm plasma reactors by comparing insights gained from experiments with several reactors under various conditions.

2. Methods

The investigated plasma reactors used the following sources of atmospheric pressure warm plasma: rotating gliding arc (RGA), atmospheric pressure glow discharge (APGD), gliding arc plasmatron (GAP), pin-to-pin (P2P) low-current arc discharge, and microwave (MW) plasma torch. The reactors operated at different powers and flow rates, but the specific energy input (SEI) is a useful common metric for comparing them. The inlet composition was either pure NH_3 or a mixture of 4-10% NH_3 with H_2 and N_2. The NH_3 and H_2 concentrations in the reactor products were measured using NDIR and TCD gas detectors. The obtained concentrations were used to calculate NH_3 conversion. The power deposited into the plasma was measured for all plasma sources and used to estimate the energy cost of NH_3 cracking.

3. Results and Discussion

Figure 1 shows the NH_3 conversion as a function of the energy cost of NH_3 cracking achieved by the investigated reactors operating with pure NH_3 feed. It presents the best-performing operating conditions, corresponding with each reactor's highest feed flow rate and shortest residence time of NH_3 inside a reactor. All reactors feature improved conversion with the increase of SEI. The RGA reactor, operating at the highest SEI range, shows significant instability during NH_3 cracking, complicating its analysis. The APGD, P2P, and GAP reactors operate in similar SEI ranges and can be split by their displayed behaviour of conversion and energy cost of NH_3 cracking into two groups: P2P and GAP vs APGD. The difference between them can be attributed to the plasma volume in the APGD being much closer to the reactor volume than in the P2P and GAP reactors, which could cause higher heat loss to the reactor walls and increased energy cost at the same SEI.

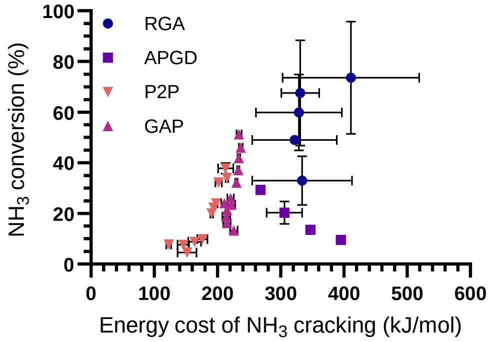

Fig. 1. NH_3 conversion as a function of energy cost of NH_3 cracking with pure NH_3 at best-performing feed flow rates for each reactor: RGA – 1 l/min, APGD – 3 l/min, GAP and P2P – 20 l/min

4. Conclusion

Our results indicate thermal cracking as the dominant NH_3 cracking mechanism in warm plasma reactors. The non-thermal cracking mechanism in plasma is less efficient than the thermal one, as indicated by the warm plasma reactors consistently outperforming cold plasma and achieving lower energy costs of NH_3 cracking. The obtained energy costs still exceed those of the thermo-catalytic cracking by a factor of 3, indicating inefficiencies in the reactor design. The most significant factors contributing to the performance of plasma cracking include plasma size and flow dynamics inside the reactors, impacting the thermal efficiency, plasma temperature, and plasma current and voltage in the case of arc-based plasma sources, which impacts the possible contribution of non-thermal chemistry to NH_3 cracking.

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References

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