The effect of turbulence on NH_3 conversion: A computational Gliding Arc Plasmatron study

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Abstract: There is a need to improve plasma reactor design for increased gas conversion, with increased turbulent flow as a possible solution. However, this has been subject to turbulent discussion, as turbulence increases both thermal conductivity and species diffusion. In this work, we show the effect of turbulence on plasma cracking of NH_3 in a Gliding Arc Plasmatron (GAP). To understand this we solve thermal chemistry and physics in a 2D-axisymmetric model.

1. Introduction

Past research has shown that the way forward with plasma-enhanced NH_3 cracking is using warm plasmas, where NH_3 decomposition occurs via heavy particle kinetics instead of electron impact reactions, as 5.72 eV electrons needed exceed any acceptable energy cost. [1]

We recently developed a multi-dimensional model, showing the need for coupling all physics and chemistry, and the importance of including diffusion in plasma models. [2]

In this work we present a new self-consistent 2D-axisymmetric model of a GAP to crack NH_3 under warm plasma conditions at high flow rates.

2. Methods

The modelled GAP is simulated for a range of plasma powers (220 – 850 W) and flow rates (10 – 20 NLM), while the inlet flow consists of pure NH_3, based on the work of Fedirchyk et al. [3]

First, a 3D fluid flow model is used to calculate the axisymmetric inlet flow pattern, needed for a correct description of the swirling flow in the GAP. In a 2D-axisymmetric model, we solve the Navier-Stokes, heat transfer, Ohmic current continuity and chemical transport equations, all coupled, using COMSOL Multiphysics 6.2.

Specifically, we studied the effects of turbulence by comparing with and without turbulent diffusivity and turbulent thermal conductivity, keeping the overall model the same.

3. Results and Discussion

Figure 1 validates the model with the experimental results of Fedirchyk [3], showing excellent agreement, both in trend and absolute value, without the use of any fitting.

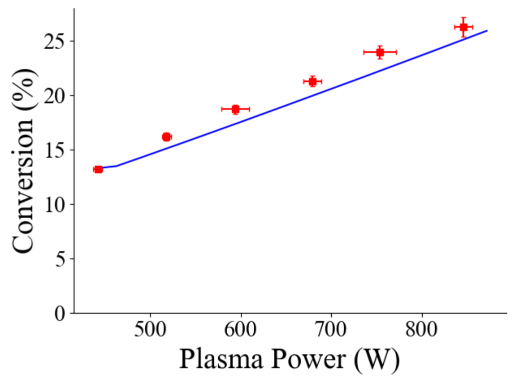

Fig. 1. Conversion (%) vs. plasma power (W) showing experimental (red) and calculated conversion (blue) for a 20 NLM case.

Note that the turbulence of the flow is classified using the relative turbulent intensity [4], which states a flow as highly turbulent when above 0.2. The GAP has values of 0.26 near the plasma edge, making it clearly turbulent, while the plasma center has values close to 0.1. Indeed, the high temperature in the plasma center increases the dynamic viscosity of the gas, leading to less turbulence.

First, due to low turbulence, the total thermal conductivity is not affected by turbulence in the plasma center, but near the walls of the reactor, 90 % of the thermal conductivity is turbulent. This creates additional heat flow to the wall, which the wall radiates away. Artificially removing the turbulent thermal conductivity reduces the radiation from the wall by 40 %, which corresponds to 80 W at a plasma power of 800 W, hence 10 % of total plasma power.

Second, we also investigated the relative importance of turbulent diffusion by comparing it to the standard diffusion coefficient for H radicals. While the standard diffusion coefficient determines all diffusion in the plasma center, the turbulent diffusion contributes for 62 % of all diffusion of H near the plasma edge, which results in a slightly higher (0.5 %) NH_3 conversion.

However, combining both effects, the energy loss at the walls due to turbulent thermal conductivity outweighs the additional conversion by turbulent diffusion, resulting in a net loss of 2 % of conversion for the same plasma power.

4. Conclusion

We have modelled the effects of turbulence on warm plasma-based NH_3 cracking, to understand the beneficial and negative effects. For a GAP, the additional energy loss to the walls outweighs the additional conversion, resulting in a loss of 2 % conversion at typical plasma powers.

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References

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