A Combined Experimental and Numerical Modelling study in a Hydrogen/Methane Microwave Plasma for rapid Scale-up of Methane Plasma Pyrolysis

Dirk van den Bekerom[1], Shahriar Mirpour[1], Yves Creyghton[1], Sjoerd Goumans[1], Martijn Ruijzendaal[2], Maria Moreira de Azevedo[2], João Da Cruz Vargas[2], Hariprasad Valiya Parambath[2], Paco Dreverman[3], Sybrand Zijnstra[3], Hans Kroon[4], Hans Linden[1], and Gerard van Rooij[2]

[1]*Netherlands Organisation for Applied Scientific Research, TNO, The Hague, Netherlands*
[2]*Maastricht University, Maastricht, Limburg, Netherlands*
[3]*DEMCON, Best, Netherlands*
[4]*Sitech Services, Geleen, Netherlands*

Abstract: Plasma pyrolysis of methane is being developed to electrify chemical industry by valorizing waste methane. An integrated scale-up approach is pursued where lab-scale (1kW) and intermediate scale (50kW) reactors are operated in parallel. These experiments are supplemented by numerical modelling to determine scaling relationships required for the design of an industrial scale plasma process (10MW).

1. Introduction

The chemical industry must be electrified to reduce carbon emissions to reach the climate goals of 2030 and 2050. The Brightsite Plasmalab is developing plasma pyrolysis technology powered by green electricity to replace existing carbon-emitting processes, with the ultimate goal of scaling up the technology from lab- to industrial scale. As a first application, plasma pyrolysis is being developed for valorization of waste methane to produce ethylene, acetylene, and hydrogen.

2. Methods

In view of the long timescales involved with a sequential scale-up would, a linear strategy would not lead to maturity within the set timelines. In contrast, a parallel scale-up strategy is pursued where different scales of plasma technology are developed simultaneously – each focusing on plasma technology of differing levels of maturity. Experiments at small (1kW) and intermediate (50kW) scales are coupled with 0D and Computational Fluid Dynamics (CFD) modelling to uncover the governing scaling laws required to scale up the technology to industrial scale (10MW unit size). These technological developments are combined with Lifecycle Assessment and Techno-Economical Analyses (TEA & LCA) to identify opportunities for process improvement as well as judging its environmental and economic impacts from an early stage. This contribution focusses on interpretation of the measurements in the 1kW microwave reactors.

3. Results and Discussion

The 1kW microwave plasma reactor is evaluated to assess temperature profiles, conversion, product yields, and energy efficiency in methane/hydrogen mixtures. Pure hydrogen discharges are studied as a reference case in which chemistry can be largely disregarded. 2D Raman scattering is employed to measure spatially resolved temperature profiles in the plasma, depicted in figure 1 (left), as well as downstream gas chromatography for measuring product yields.

The experimental data is interpreted using a 0D-kinetics model. This so called "PQR"-model incorporates Power density profiles, a Quench gas profile, as well as a Radial dependence, modelled by two interacting test volumes – a plasma-heated core and a shell that interacts with the quench gas. In addition, CFD reactor models are employed to gain further insights in heat and mass flow profiles in the reactor. The 0D model is compared to both the experimental data (figure 1, right) as well as the CFD model to gain insights in the axial and radial heat distribution, as well as chemical kinetics. In doing so, the 0D model emerges as a simple but adequate, validated reactor model for the microwave plasma.

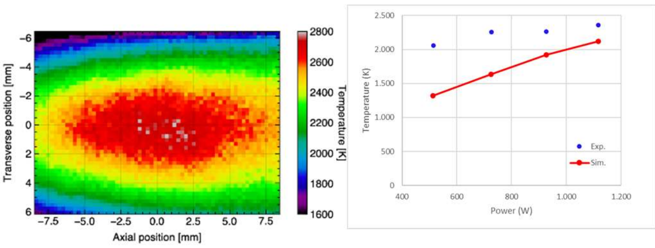

Figure 1 (left): Measured temperature profile in H_2 plasma (right): comparison between temperatures predicted by 0D "PQR"-model and experiment.

4. Conclusion

Plasma methane pyrolysis is developed towards industrial scale. In this scale-up process we use a parallel scaleup approach. The parallel approach consists of experiments at lab (1kW) and benchscale (50kW). Results from the 1kW microwave reactors are compared to 0D modelling to interpret results and develop deeper understanding of heat & mass flow and chemical kinetics.

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