P 16: Atmospheric Pressure Plasmas and their Applications III

Time: Wednesday 14:00–16:00 Location: WW 1: HS

Invited Talk P 16.1 Wed 14:00 WW 1: HS

CO_2 dissociation by microwave plasmas: experimental studies on interfaces in view of industrial applications — •Rodrigo Antunes[1], Christian K. Kiefer[1], Ante Hecimovic[1], Katharina Wiegers[3], Arne Meindl[1], Andreas Schulz[3], and Ursel Fantz[1,2] — [1]Max Planck Institute for Plasma Physics, 85748 Garching b. München, Germany — [2]University of Augsburg, 86159 Augsburg, Germany — [3]University of Stuttgart, Stuttgart 70569, Germany

Microwave plasma (MW) torches are known to be an efficient technology for the conversion of CO_2 to CO up to atmospheric pressure. However, in order to evaluate its industrial applicability, the interfaces of the process in which the plasma torch will be integrated should be considered. For example, the CO_2 upstream might contain impurities such as that from carbon capture facilities, while the plasma-produced downstream mixture must have very low amounts of O_2 if to be used as feed gas in a Fischer-Tropsch reactor for fuel synthesis.

This talk provides an overview of the state-of-the-art for the dissociation of CO_2 by means of MW plasma torches. The influence of various relevant parameters on the conversion and energy efficiency is discussed. From the insights gained by the wall-plug efficiency, optimisation routes can be outlined. Using multiple membranes accommodated in the plasma effluent, the removal of O_2 from the outlet stream is demonstrated. Long-term performance stability and compatibility with intermittent power sources showcases that the plasma technology is a relevant addition to the portfolio of gas conversion techniques.

P 16.2 Wed 14:30 WW 1: HS

Development of a hybrid reactor for plasma-enhanced electrocatalysis for NH3 production — •Martin Leander Marxen[1], Luka Hansen[1], Gustav Sievers[2], Volker Brüser[2], and Holger Kersten[1] — [1]Plasmatechnology Group, IEAP, Kiel University, Kiel, Germany — [2]Plasma Process Technology, INP Greifswald, Greifswald, Germany

Plasma-catalytic approaches are promising for the conversion of mixtures of nitrogen (N_2) and hydrogen (H_2) into ammonia (NH_3) [1,2]. Activation of the reaction sluggish N_2 molecules is achieved by collisions with the highly energetic electrons present in the discharge.

In proton-exchange-membrane-electrolysis (PEM-electrolysis), water (H_2O) is split up into oxygen (1/2 O_2), protons (2 H^+) and electrons (2 e^-) at the anode. The protons permeate the membrane and are reduced at the cathode [3].

A hybrid reactor was developed, in which a surface dielectric barrier discharge (SDBD) is located right underneath the cathode of a PEM-cell. By operating the SDBD with N_2, excited, ionized and dissociated N_2 species will be present at the cathode of the PEM-cell, where they can react with the produced H / H^+ and, thus, be reduced to NH_3. The development and characterization of the reactor will be presented.

[1] K. H. R. Rouwenhorst, Green chem 22 (2020), 19

[2] A. Bogaerts et al., J Phys D: Appl Phys 53 (2020), 44

[3] S. S. Kumar und V. Himabindu, Mater Sci for Energy Technol 2 (2019), 3

P 16.3 Wed 14:45 WW 1: HS

CFD and Heat Transfer Modeling of a Microwave Atmospheric Plasma Torch for CO_2 Conversion — •Stefan Merli, Katharina Wiegers, Marc Bresser, Andreas Schulz, Matthias Walker, and Günter Tovar — IGVP, University of Stuttgart, Stuttgart, Germany

Microwave plasma torches at atmospheric pressure offer an interesting way to split CO_2 and convert it to O_2 and CO, the latter of which is an important base material for chemical synthesis. The investigated microwave plasma torch creates a CO_2 plasma inside a quartz tube via two resonators. To protect the quartz tube from the hot plasma of around 6000 K, tangential gas inlets generate a rotational cold gas flow around the tube surface. The hot gas from the plasma and the cold gas are then mixed in a nozzle to increase the amount of converted gas. The nozzle and the subsequent expansion zone also cause the gas to cool quickly, which quenches back reactions from CO and O_2 to CO_2. Since the gas flow conditions and the temperature distribution are of great importance for a high conversion efficiency, CFD and heat transfer simulations were carried out in Comsol Multiphysics. The aim is to improve the conversion efficiency by optimizing geometry of the torch and the nozzle with regard to hot/cold gas mixing and effective quenching. A comparison of simulations and experiment reveals different flow regimes of the effluent for different gas flows which are attributed to increasing turbulences in the expasion zone. Since the turbulences increase cooling and the contact with the wall, they are beneficial for quenching and therefore for a high conversion efficiency.

P 16.4 Wed 15:00 WW 1: HS

Ammonia synthesis in an atmospheric catalytic RF plasma — •Steijn Vervloedt and Achim von Keudell — Experimental Physics II, Ruhr University Bochum, Bochum, Germany

The synthesis of ammonia is a vital part of the production of nitrogen-based artificial fertilisers. Also, in the future, it might prove a worthy candidate for energy storage, by acting as a hydrogen carrier. In this contribution, the recent results of ammonia synthesis in an atmospheric RF-plasma are presented, as well as the impact of introducing various catalysts. The plasma physics and chemistry are simplified by using helium as a buffer gas. The nitrogen and hydrogen are admixed up to $\sim$1%, to minimise their impact on the plasma dynamics. The products of the plasma are measured with ex-situ infrared Fourier transform (FTIR) absorption spectroscopy. The plasma dynamics are probed by observing trends in the emission of the second positive and first negative systems of nitrogen. Furthermore, a kinetic model is able to explain the experimentally observed trends. The results indicate that the synthesis is very sensitive to the plasma properties, e.g. the electron energy distribution and differences of less than 0.1 eV are sufficient to explain the results. This likely originates from the sensitivity of the NH_3 production - which happens mostly at the surface - to the atomic nitrogen flux towards the surface where the rate-limiting step is the electron-induced dissociation of nitrogen molecules.

P 16.5 Wed 15:15 WW 1: HS

Enhancing CO_2 Conversion and Oxygen Separation Performance by Optimizing the Gas Flow of an Atmospheric Plasma Torch — •Katharina Wiegers, Stefan Merli, Marc Bresser, Andreas Schulz, Matthias Walker, and Günter Tovar — IGVP, University of Stuttgart, Stuttgart, Germany

The chemical industry needs to switch from processes that use fossil raw materials to renewable sources. Carbon dioxide (CO_2) is the base product for closing the carbon cycle. One possibility to convert CO_2 is through a plasma process at atmospheric pressure that splits CO_2 into carbon monoxide (CO) and oxygen (O_2). Since out of the two products, only CO is needed for industrial purposes, a gas separation step is required. By using oxygen-conducting ceramic hollow fiber membranes, oxygen can be removed from the product gas in situ. A promising candidate for the membrane material is $La_{0.6}Ca_{0.4}C_{0.5}Fe_{0.5}O_3$, which results in fibers with a high thermal stability of up to 1200°C inside CO_2 plasma. Moreover, the amount of produced CO can be further increased by improving the quenching of unwanted back reactions. This can be achieved by optimizing the gas management by introducing a restriction in the flow regime. Therefore, a nozzle has been designed with the aim to improve the quenching effect and, at the same time, increase the volume of the plasma interacting with the membranes and thus the amount of O_2 removed. The O_2 permeation in the fiber could thus be increased from 2.2 to 4.6 mL $\cdot$ min^{-1}.

P 16.6 Wed 15:30 WW 1: HS

Experimental observations on microsecond and nanosecond pulses applied to a surface dielectric barrier discharge — •Gerrit Hübner, Nils Schoeneweihs, Dominik Filla, Sebastian Wilczek, Thomas Mussenbrock, and Ihor Korolov — Ruhr-Universität Bochum

The conversion of volatile organic compounds (VOCs) has long been an area of interest in the plasma community. Surface dielectric barrier discharges (SDBD) have been used for such conversions, however the details behind the formation and behaviour of plasma streamers, typically observed in such discharges, are yet to be fully understood. This work focuses on investigation of a SDBD driven by microsecond and nanosecond pulses operated in mixtures of Helium and Nitrogen (or Oxygen). We use phase resolved optical emission spectroscopy (PROES) to study the spatio-temporal surface streamer dynamics on a nanosecond timescale. The quenching rates by He and N2 of the

Helium-I 706 nm emission line are also determined from the measured effective lifetime. We have calculated and compared the streamer propagation speed for different discharge conditions. The experimental findings are compared with fluid (nonPDPSIM) simulations and a very good qualitative agreement is found providing a deep understanding of the streamer behaviour on the ns time scale. **This work is supported by the DFG via SFB1316 (A5)

P 16.7 Wed 15:45 WW 1: HS

Influence of EHD Force on Gas Dynamics in Atmospheric Pressure Plasma Discharges: A Computational Analysis — •Sebastian Wilczek, Máté Vass, Alexander Böddecker, Ihor Korolov, and Thomas Mussenbrock — Chair of Applied Electrodynamics and Plasma Technology, Faculty of Electrical Engineering and Information Technology, Ruhr University Bochum

Recent advancements in plasma technology have led to the development of various atmospheric pressure plasma discharges for gas conversion. Most of these discharges, such as dielectric barrier discharges, ignite streamers that significantly impact the gas dynamics. The electrohydrodynamic (EHD) force plays a crucial role in this context, exerting a significant momentum transfer on the process gas and altering the overall gas dynamics. This work presents an analysis of results obtained from 2D plasma simulations, which are subsequently integrated into pure fluid simulations via OpenFOAM. The study highlights the formation of vortices in the gas dynamics, demonstrating significant consistency with experimental measurements, including particle image velocimetry (PIV) and Schlieren techniques. The findings offer valuable insights into the complex interactions between EHD forces and gas dynamics in plasma-based gas conversion processes, contributing to the broader understanding and optimization of these applications.

**This work is supported by the DFG via SFB1316