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Integrated Process for Carbon Valorization Using Plasma-Sorbent Systems

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Plasma technology has emerged as a promising approach for CO_2 conversion and plays an increasingly important role in carbon valorization to combat climate change. Over the past few decades, research into plasma-based CO_2 conversion has gained significant attention, leading to notable advancements in technology development. Various topics have been explored, including chemical reaction mechanisms in plasma, reactor design, and plasma-catalysis. However, most current studies focus solely on using plasma to drive chemical reactions, often overlooking the source of CO_2 and the broader process development. Our recent research demonstrates that plasma technology also holds potential beyond chemical conversion, particularly in process functionalities such as separation. This paves the way for the concept of an integrated plasma reactor, offering a simpler and more cost-effective solution for CO_2 capture and conversion [1].

This concept is built upon the development of the plasma-sorbent system, which enables the simultaneous capture and conversion of CO_2 within a single reactor. In this system, a sorbent material first adsorbs CO_2 from ambient air or flue gas. The interaction between the plasma and sorbent then facilitates both the desorption of CO_2 and its immediate conversion into CO or other valuable chemicals.

To establish the plasma-sorbent system, the properties of the sorbent are a critical factor to consider, as they significantly influence the performance such as energy efficiency and CO_2 conversion. In our study, four different types of sorbent materials were investigated in a packed-bed dielectric barrier discharge (DBD) reactor: zeolite 5A, $KHCO_3$, hydrotalcite MG-30, and Lewatit VP-OC 1055. The results, which will be presented in this talk, focus on the stability of the sorbents under plasma conditions and the mechanisms of plasma-induced CO_2 desorption. Plasma heating was found to play an important role in CO_2 desorption in several cases. For instance, with zeolite 5A, the CO_2 desorption behavior in a plasma reactor closely resembles that observed with conventional electric heating, and in-line with the prediction from a model that only consider thermal desorption effect, as shown in Fig. 1 [2]. However, the in-situ conversion of CO_2 within the plasma can accelerate desorption due to changes in partial pressure. Based on the experimental results from testing different types of sorbents, sorbent design tailored for plasma environment can be made. The key design considerations will be presented along with an example.

Furthermore, the plasma-sorbent system often exhibits transient behavior, characterized by variations in CO_2 concentration, plasma power, and reactor temperature. These dynamic profiles result from the complex interactions between the plasma and the sorbent material. To illustrate this, we will examine the case of $KHCO_3$ packed in a DBD reactor as a representation, highlighting the observed changes in voltage, discharge power, dielectric properties, and sorbent morphology.

Moreover, the plasma-sorbent system operates in a cyclic manner, which differs fundamentally from conventional flow reactors. As such, the operational scheme must be carefully designed, with particular attention to optimizing plasma exposure time and power input to achieve both high CO_2 conversion and optimal energy efficiency.

Finally, the design of multi-reactor systems will be discussed as a strategy for continuous production and effective recycling of unreacted CO_2. Two basic connection topologies: series and parallel configurations, will be presented, as illustrated in Fig. 2 [3].

References

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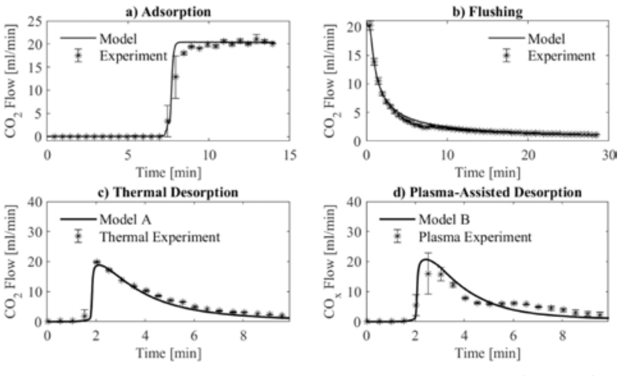

Figure 1. The experimental and modelled CO_x flows for DBD reactor packed with Zeolite 5A. Adapted from [2].

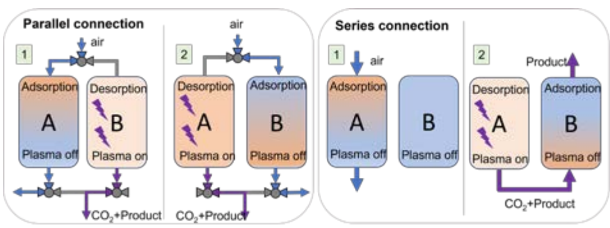

Figure 2. Series connection and parallel connection of plasma reactors. Adapted from [3].