Chapter 1
Plasma Reactors:
A Sustainable Solution for Carbon Dioxide Conversion

Erfan Nouri
https://orcid.org/0000-0002-6558-7848
University of Guilan, Iran

Alireza Kardan
University of Guilan, Iran

Vahid Mottaghitalab
https://orcid.org/0000-0001-7211-3141
University of Guilan, Iran

ABSTRACT

The chapter explores the potential of plasma reactors as a sustainable solution for carbon dioxide (CO_2) conversion. The diverse types of plasmas used in CO_2 conversion are discussed. Mechanisms of plasma-based CO_2 conversion are examined, with a specific focus on direct CO_2 dissociation assisted by plasma, plasma-catalytic processes, and electrochemical CO_2 reduction using plasma. In addition, the chapter delves into the various types of plasma reactors employed for CO_2 conversion and provides a comprehensive comparison of their designs. The analysis of different reactor designs aims to assist in selecting the most suitable plasma reactor for specific CO_2 conversion applications. Furthermore, the chapter delves into the future perspectives of plasma reactors for CO_2 conversion. The chapter concludes by summarizing the essential findings and highlighting the importance of plasma reactors as a sustainable solution for CO_2 conversion, emphasizing their potential impact on mitigating greenhouse gas emissions and contributing to a more environmentally friendly future.

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1. INTRODUCTION

Global climate change is a pressing issue in our modern world. Human activities, primarily the emission of greenhouse gases, particularly CO_2, are the leading cause of this problem. In order to mitigate the impacts of climate change, it is essential to adopt a comprehensive approach that focuses on reducing carbon emissions and decreasing the existing excessive amount of CO_2 in the atmosphere. Undoubtedly, there is growing interest in exploring the potential of carbon capture and utilization (CCU) as a means of converting CO_2 into valuable fuels and chemicals (Norhasyima & Mahlia, 2018). The cradle-to-cradle principle emphasizes the reduction of reliance on fossil fuels by utilizing waste gas as a renewable feedstock, thereby facilitating technological advancement (Vertongen et al., 2022). Various alternative technologies are under development for industry electrification, such as plasma technology (Snoeckx & Bogaerts, 2017).

The composition of plasma is a collection of differently-formed entities, including but not limited to electrons, ions, excited species, radicals, and molecules. When an electric field is utilized to produce a plasma, such as in the case of gas breakdown, the application of electric power prioritizes the heating of electrons in the plasma over other particles. As a result, the gas molecules are stimulated through electron impact reactions. The division of energy towards favorable chemical processes, such as the splitting of CO_2 (Fridman, 2008), varies according to the discharge condition and parameters involved. Due to its easily adjustable on/off feature, a plasma reactor holds considerable promise in converting intermittent renewable energy into chemical storage. Additionally, it offers significant advantages such as independence from rare resources and the ability to scale up according to the energy market's demands (Fridman, 2008).

Various forms of plasma reactors have been studied in the context of CO_2 conversion (Fridman, 2008). The structure of dielectric barrier discharges (DBDs) is straightforward, allowing them to function effectively in normal atmospheric conditions. These discharges have the potential to achieve significant conversion rates, reaching up to 30%. However, their energy efficiency is relatively restricted, typically between 5% and 10% (Aerts et al., 2015; Uytdenhouwen et al., 2018). Microwave (MW) plasmas achieve significantly greater energy efficiencies, primarily around 50%, occasionally reaching as high as 80-90%. However, these efficiencies are generally only observed when operating at lower pressures (Bongers et al., 2017). The drawbacks associated with gliding arc reactors can be effectively addressed. These reactors are capable of operating at atmospheric pressure, resulting in favorable energy efficiencies of approximately 30%. Nonetheless, the conversion rate of these reactors is confined to 8-9% due to the limitation in the fraction of gas that flows through the reactor (Ramakers et al., 2017; Trenchev et al., 2017). The utilization of atmospheric pressure glow discharges (APGD) is becoming increasingly popular for both fundamental research, such as the investigation of the transition from glow to arc (Boyle & Haworth, 1956; Bruggeman & Brandenburg, 2013), and practical applications like gas conversion (Wang et al., 1999; Wanten et al., 2022) and surface modification (Cernak et al., 1995; Shaw et al., 2016).

In summary, the book chapter explores the potential of plasma technology in addressing the challenge of CO_2 conversion. The chapter begins by discussing the types of plasmas used in CO_2 conversion, highlighting their properties and methods of generation. The mechanisms of plasma-based CO_2 conversion are then examined, with a focus on understanding the chemical reactions and physical processes involved. Subsequently, attention turns to plasma reactors for CO_2 conversion, where different reactor types and their operational parameters are explored. Furthermore, a comparison and analysis of these reactor designs is conducted, considering their respective advantages and disadvantages. Lastly, future

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