Journal of CO_2 Utilization 19 (2017) 68–78

Contents lists available at ScienceDirect

Journal of CO_2 Utilization

journal homepage: www.elsevier.com/locate/jcou

Conversion of CO_2 in a cylindrical dielectric barrier discharge reactor: Effects of plasma processing parameters and reactor design

Danhua Mei, Xin Tu*

Department of Electrical Engineering and Electronics, University of Liverpool, Brownlow Hill, Liverpool, L69 3GJ, UK

ARTICLE INFO

Article history:
Received 26 December 2016
Received in revised form 25 January 2017
Available online 28 March 2017

Keywords:
Non-thermal plasma
Dielectric barrier discharge
CO_2 conversion
Energy efficiency
Reactor design

ABSTRACT

Direct conversion of CO_2 into CO and O_2 was carried out in a cylindrical dielectric barrier discharge (DBD) reactor at atmospheric pressure and low temperatures. The influence of plasma processing parameters (e.g. discharge frequency, CO_2 flow rate, discharge power, discharge length, discharge gap, and dielectric material's thickness) on the plasma CO_2 conversion and energy efficiency of the process was investigated. The major products of this reaction were CO and O_2, which suggests the stoichiometric conversion of CO_2 into CO and O_2 was achieved. The results indicate that discharge frequency has a negligible influence on the conversion of CO_2 at a constant discharge power. Increasing discharge power or decreasing feed flow rate enhanced CO_2 conversion but lowered the energy efficiency when all other parameters were kept constant. In addition, decreasing the discharge gap and the dielectric material's thickness, or enlarging the discharge length, increased both conversion of CO_2 and process efficiency. Two regression models for the plasma process were developed to elucidate the relative significance of these plasma processing parameters on the plasma conversion of CO_2. It was found that the flow rate of CO_2 and discharge power play the most important role in CO_2 conversion, while the energy efficiency is most significantly influenced by the discharge power. Modification of the plasma design was explored by using different inner and outer electrodes in the DBD system. The combination of the Al foil outer electrode with the stainless steel (SS) screw-type inner electrode showed an enhanced CO_2 conversion and energy efficiency compared to other electrode forms, leading to the maximum CO_2 conversion of 27.2% and maximum energy efficiency of 10.4% in this work. The use of the SS screw-type inner electrode could lead to an enhanced local electric field near the sharp edge of the electrode, while the use of Al foil as an outer electrode could enlarge the effectiveness of discharge area compared to the mesh electrode. Both effects contributed to the enhanced efficiency of the plasma CO_2 conversion.

1. Introduction

The increasing energy demand of modern society has significantly increased the consumption of carbon-containing fossil fuels on an unprecedented scale, which unfortunately releases a large amount of carbon dioxide into the atmosphere. CO_2 is considered as the main contributor to the greenhouse gas effect and global warming. The concentration of CO_2 in the atmosphere increased to ~400 ppm in 2013, which is 42% more than that of preindustrial level [1]. The growing CO_2 concentration has caused catastrophic effect to the ecosystem, including the increase of surface temperature and sea-level, the change of hydrological and vegetation patterns, and increasing the occurrence of disastrous weather. From this perspective, it is of primary importance to reduce the emission of CO_2, especially from anthropogenic sources. To limit the long term global temperature increase to less than 2.0 °C above pre-industrial levels, worldwide CO_2 emissions in 2050 must be 40–70% lower than those in 2010 [2]. The UK government has committed to reduce CO_2 emission by at least 80% by 2050 from the 1990 level [3].

Carbon capture and storage (CCS) was proposed to reduce CO_2 emission from human activities. It involves capturing carbon from industrial processes then injecting and storing it in different forms (e.g. geological, ocean and mineral storages) [4]. Although CCS is considered technically feasible, it is not a permanent solution to the carbon emission due to the high cost, the low public acceptance and the risk of leakage during or after injection [5]. Therefore, it is vital to develop other sustainable alternatives which have little or no environmental impacts and zero CO_2 emissions. Carbon capture and utilization (CCU) is a promising approach to sustainably reduce

* Corresponding author.
E-mail address: xin.tu@liverpool.ac.uk (X. Tu).

http://dx.doi.org/10.1016/j.jcou.2017.02.015
2212-9820/

carbon emissions. Rather than being treated as a waste, the captured and separated CO_2 from industrial processes can be used as a feedstock to produce value-added chemicals and fuels (e.g. CO, CH_4, methanol, and DME) [6,7]. In recent years, different technologies have been proposed for the conversion of CO_2 into valuable chemicals and fuels, including thermochemical

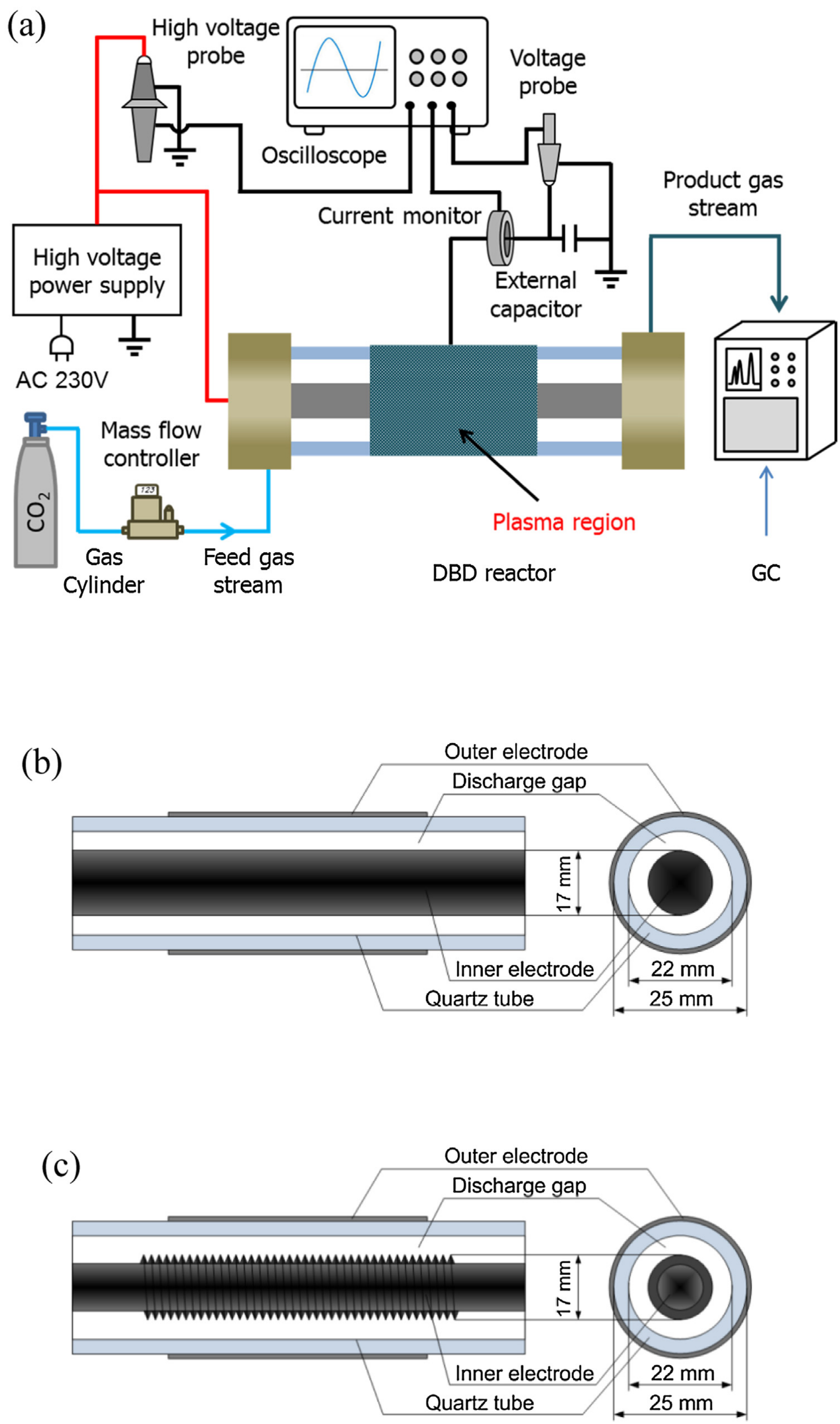

Fig. 1. Schematic diagram of the experimental system: (a) Experimental setup; (b) DBD reactor with a SS rod inner electrode; (c) DBD reactor with a SS screw-type inner electrode.