

A Study on Decomposition of Environmentally Noxious Gas with Simultaneous Synthesis of Metal Oxide Powder in Transferred DC Thermal Plasma

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Carbon dioxide was directly decomposed by a transferred DC thermal plasma and the effects of plasma induced current on the decomposition efficiency were investigated. The thermal plasma system was operated in a way that the metal oxide particles could be simultaneously produced from an anodic bulk metal (Zn) placed on a carbon crucible, so as to continuously consume atomic and molecular oxygens (O and O₂) generated from the CO₂ decomposition. As the induced current increased from 120 to 160 A by 20 A, the decomposition efficiency increased almost linearly from 53 to 68 %. The amount of ZnO particles produced from the bulk also increased and the particle crystallinity was improved. Although the concentration of carbon monoxide in the effluent was sharply increased at 160 A, further destruction can be done by re-circulating the effluent to plasma chamber.

Keywords: Decomposition, Noxious gas, Metal oxide.

INTRODUCTION

As the use of fossil fuels exponentially increased with the advent of rapid industrial development after the industrial revolution of 18th century, the amount of carbon dioxide artificially generated also correspondingly increased, resulting in adverse climate change by the green house effect [1]. Over the last two decades, there have been extensive researches to reduce CO₂ in the atmosphere, widely known as the main culprit of global warming but considered to be a controllable greenhouse gas. Representative approaches for CO₂ reduction include various fixation strategy [1,2], absorption utilizing absorbents [3-5], membrane technology for separation [6,7], chemical transformation [8,9], etc.

While most other methods require complex processing steps such as additional treatments, thermal plasma technology is relatively simple, clean, fast and thus cost effective. Since thermal plasma can provide exceptionally high energies which are normally impossible by any other conventional method, its application to the destruction of environmentally hazardous gases, especially for species such as CO₂, requiring extremely high energy to break chemical bonds is expected to be very effective.

In this work, we attempt direct decomposition of CO₂ by transferred DC thermal plasma which simultaneously produces metal particles in the same reaction chamber, so as to continuously remove atomic and molecular oxygens (O and O₂), generated from CO₂ decomposition, through oxidation of metal particle. Such approach would lessen chances for carbon or carbon monoxide, produced from the decomposition of CO₂, to recombine with O or O₂, giving rise to the enhancement of CO₂ decomposition efficiency. We used zinc as an anodic bulk metal expected to form metal oxide particles, and investigated the effects of plasma induced current, a major operating parameter in generating thermal plasma, on the efficiency of CO₂ decomposition and the characteristics of produced particles.

EXPERIMENTAL

Thermal plasma system employed in this study is same as the one that applied in previous work [10], and its schematic diagram is shown in Fig. 1. The system consists of five sections: a DC plasma torch generating plasma jet from an arc, a reaction chamber providing an extremely high temperature environment for the destruction of environmentally hazard gases and the formation of nuclei/clusters as well as the growth of particles,

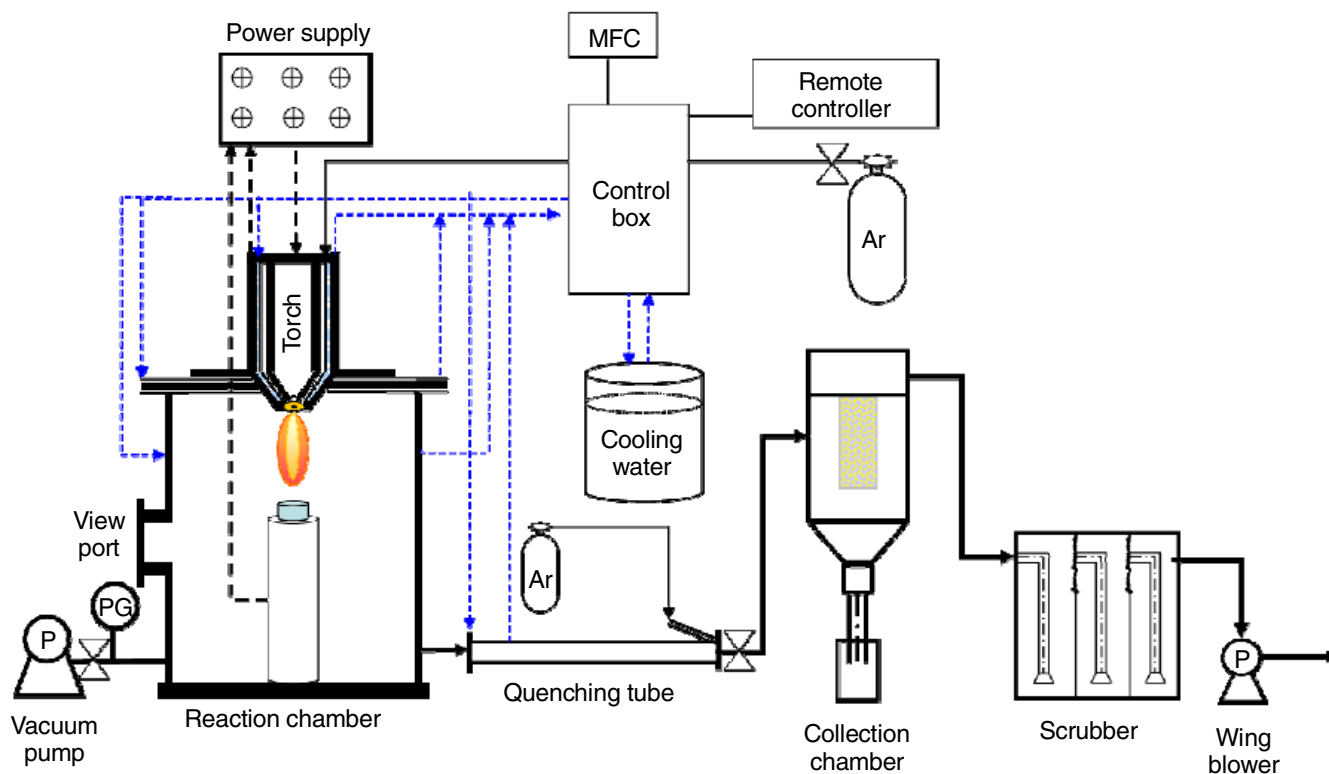


Fig. 1. Schematic diagram of the transferred DC thermal plasma system [Ref. 10]

a quenching tube in which the produced particles are quickly cooled down to prevent further growth, a collection chamber where the particles are deposited on a filter and a scrubber eliminating pollutants from the effluent. In order to study the complex CO_2 decomposition process, the top flange of reaction chamber was modified, as shown in Fig. 2, so as to directly introduce CO_2 in to the plasma flame formed between cathode and anode.

The plasma torch was operated in a transferred mode so that the arc extended from the electrode of plasma torch to an anodic bulk metal placed in a carbon crucible. The crucible was placed 10 cm below the plasma nozzle, the flow rates of plasma gas (pure argon) and CO_2 gas was fixed at 20 L/min and

2 L/min, respectively, while the induced current to generate thermal plasma was varied from 120 to 160 A. Compositions of effluent from the reaction chamber were measured by the conventional gas chromatograph technique, the characteristics of produced particles were analyzed by FE-SEM (FEI, Quanta 200), EDS (Horiba) and XRD (Rigaku, MAX-2500V).

RESULTS AND DISCUSSION

The SEM images and corresponding XRD patterns of the particles produced from anodic bulk zinc in the plasma reaction chamber, where direct decomposition of CO_2 takes place by the transferred DC plasma, are shown for various plasma input currents in Fig. 3. From SEM images, although the produced

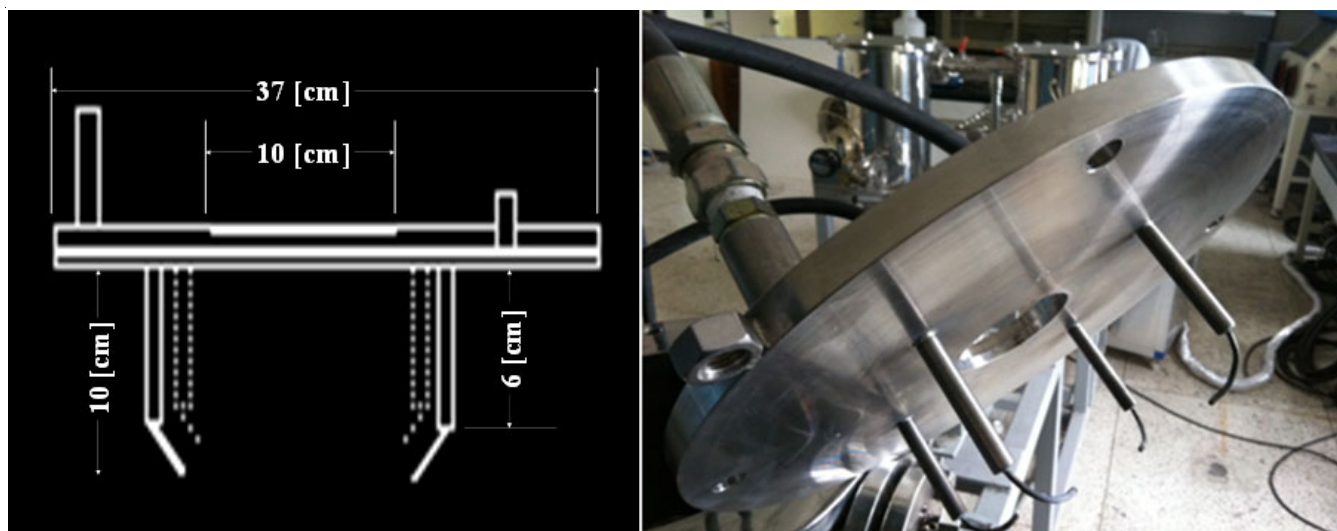


Fig. 2. Modified top-flange of the reaction chamber for direct CO_2 decomposition experiment

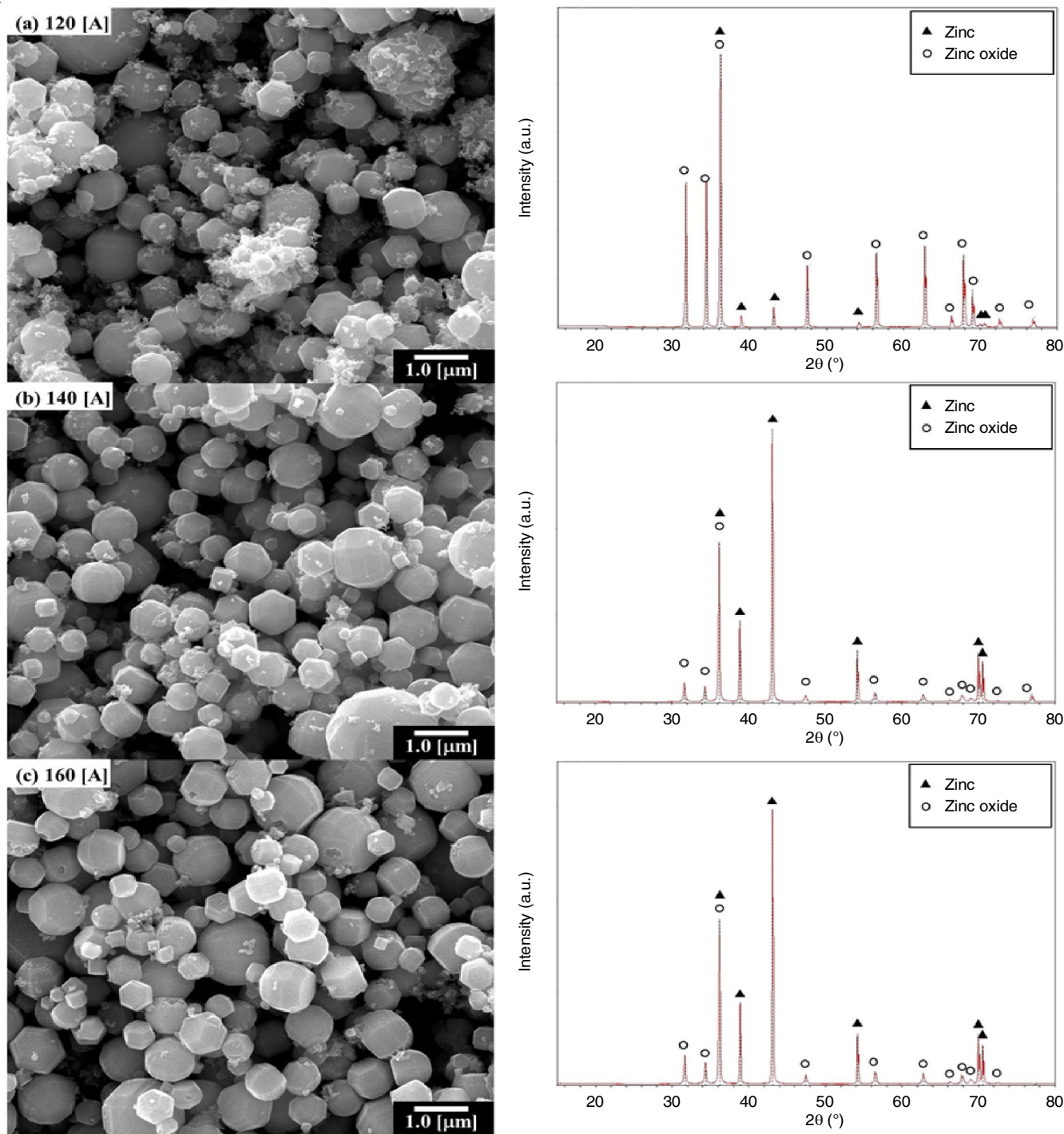


Fig. 3. SEM images and XRD patterns of the metal oxide particles produced during direct decomposition of CO_2 by thermal plasma

particles are found to be almost spherical, particle size slightly decreased as the induced current increased. The higher induced current can generate higher temperature plasma jet and provide an environment that higher temperature gradient exists, thus suppressing further growth of particles, as they flow away from the plasma flame to the chamber wall, by quicker quenching [6]. The produced particles were identified to be either Zn or ZnO by XRD analysis and the amount of ZnO increased with the induced current. In the plasma flame extended from the plasma torch, CO_2 decomposes and generate both atomic and molecular oxygens (O and O_2), at the same time, abundant

nuclei generated from the anodic bulk Zn also form clusters which grow to larger particles by the condensation and coalescence process. Since all these complicated processes occur intensively in the plasma flame zone, metal particles immediately oxidize as they form. Hence, the production rate of ZnO particles would increase with the induced current which has a profound impact both on the evaporation rate of the bulk metal and on the generation rate of atomic and molecular oxygens. Furthermore, XRD patterns reveal that crystalline structures of (100) and (002) present between 30° and 35° dramatically reduced at the higher induced current.

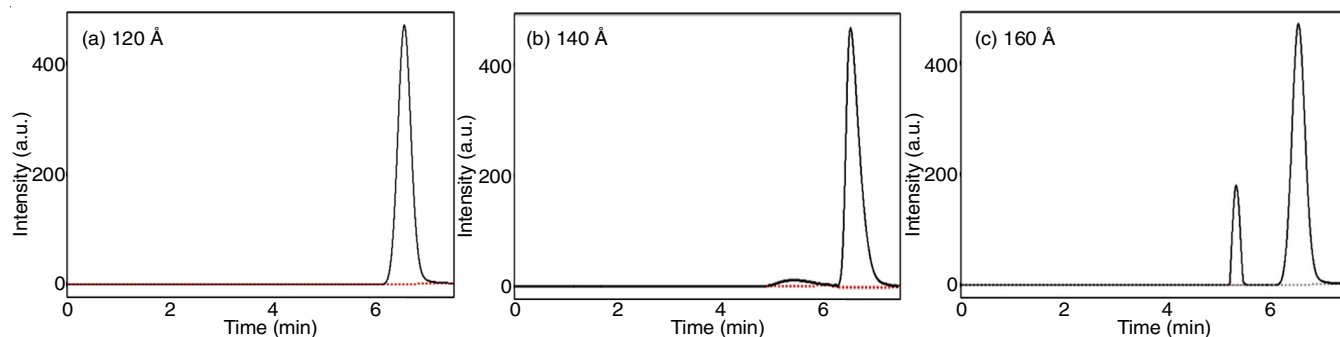


Fig. 4. Effects of the plasma input current on the surface area (measured by BET)

To quantify the efficiency of CO₂ decomposition, composition of effluent from the reaction chamber was analyzed by GC shown in Fig. 4. With the induced current of 120 A, only CO₂ peak was shown around 6.5 min, implying that the generation rate of oxygens from the decomposition of CO₂ might be much lower than that of metal particles from bulk. Thus, it is believed that all oxygens might be consumed to oxidize metal particles, in turn preventing carbon from forming CO. The CO peak starts to appear, however, around 5.5 min with 140 A and dramatically enlarged with 160 A. From these observations, it can be concluded that the induced current would greatly enhance the decomposition rate of CO₂. Fig. 5 presents the effect of the induced current on the CO₂ decomposition efficiency quantified from GC analyses. As the induced current increased from 120 to 160 A by 20 A, the decomposition efficiency increased almost linearly from 53 to 68 %.

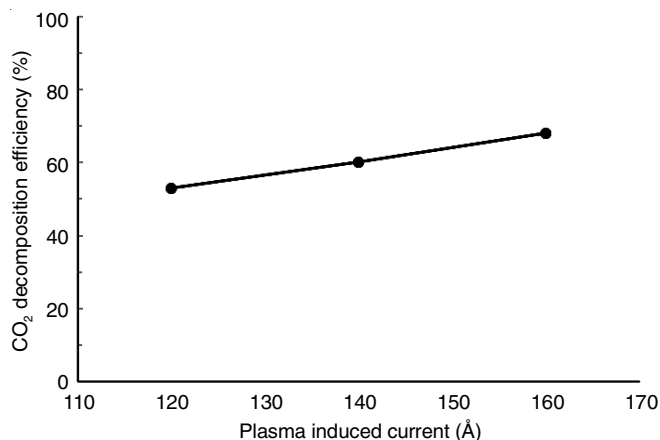


Fig. 5. Effects of the plasma input current on the CO₂ decomposition efficiency

Conclusion

Carbon dioxide was directly decomposed by a transferred thermal plasma, in which arc was generated between a cathode inside the plasma torch and an anodic bulk metal placed on a support, to atomic and molecular oxygens (O and O₂) which are in turn consumed through the oxidation of metal particles formed by the evaporation of anodic bulk metal. Consequently, there are fewer chances for carbon or carbon monoxide produced from the decomposition of CO₂ to recombine with the oxygens, enhancing the decomposition efficiency. Utilizing zinc as an anode, the effects of the induced current to generate thermal plasma

on the efficiency of CO₂ decomposition and the characteristics of produced metal oxide powder were investigated. The CO₂ decomposition efficiency increased almost linearly from 53 to 68 % for CO₂ flow rate of 2 L/min as the induced current increased from 120 to 160 A by 20 A. Although the produced powder was comprised of Zn and ZnO, the amount of ZnO increased with the induced current, also indicating the enhanced decomposition efficiency. In all cases, oxygen peak was not observed from the GC analysis of the effluent from the plasma chamber. The amount of CO in the decomposed gas, however, increased as the induced current increased, implying that the decomposed gas need further treatment. The possibility of further decomposition of CO need to be examined and may be done by recirculating the effluent to plasma chamber.

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CONFLICT OF INTEREST

The authors declare that there is no conflict of interests regarding the publication of this article.

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