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Multi-Phase Plasma with Gas-Liquid-Solid for Environmental Application

気-液-固マルチフェーズプラズマによる環境応用プロセス

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Thermal plasmas have attracted extensive attention due to their unique advantages, and it is expected to be utilized for a number of industrial applications. The advantages of thermal plasmas with multi-phase conditions are beneficial for innovative processing based on the high enthalpy to enhance reaction kinetics, high chemical reactivity, and oxidation or reduction atmospheres in accordance with required chemical reactions.

1. Introduction

Thermal plasmas have attracted extensive attention due to their unique advantages, and it is expected to be utilized for a number of innovative industrial applications such as decomposition of harmful materials, recovery of useful materials from wastes, and synthesis of high-quality and high-performance nanoparticles. The advantages of thermal plasmas with multi-phase conditions including high enthalpy to enhance reaction kinetics, high chemical reactivity, and oxidation or reduction atmospheres in accordance with required chemical reactions are beneficial for innovative processing.

Recently, successful application based on gas-solid reaction was developed for in-flight glass melting. The granulated raw material with small diameter is injected into thermal plasmas and the powders contact fully with the plasma. The high heat-transfer and temperatures of the plasma melt the raw materials quickly. In addition, the decomposed gases of carbonates are removed during the in-flight treatment to reduce the refining time considerably.

The example of gas-liquid reaction is the water plasma generation for waste treatment. A DC arc water plasma torch which is operated at atmospheric pressure by using evaporated cooling water as plasma forming gas directly. Since a large amount of H, O, and OH radicals are generated in water plasma, decomposition reactions and syngas production are accelerated in the treatment of water-soluble organic compounds.

In spite of these experimental efforts for industrial applications, thermal plasma generation with multi-phase conditions and its characteristics remain to be explored. Among various thermal plasma reactors, arc plasma as an energy source with high energy-efficiency has been applied in many applications.

2. Multi-Phase AC Arc for In-Flight Melting

Most glass is produced by the typical Siemens-type melter fired in air with heavy oil or natural gas as the fuel. This type of melter has been used for more than 140 years because of its good large-scale performance and continuous melting system. A long time is required for the dissolution of SiO_2 in the melting process and to allow the bubbles in the glass to escape in the fining process. The key is to decrease the melting and fining times to reduce the energy consumed in glass production. The high temperature of thermal plasmas makes it easy to melt raw glass powders quickly. Reducing the formation of bubbles in molten glass is an effective method of shortening the fining time.

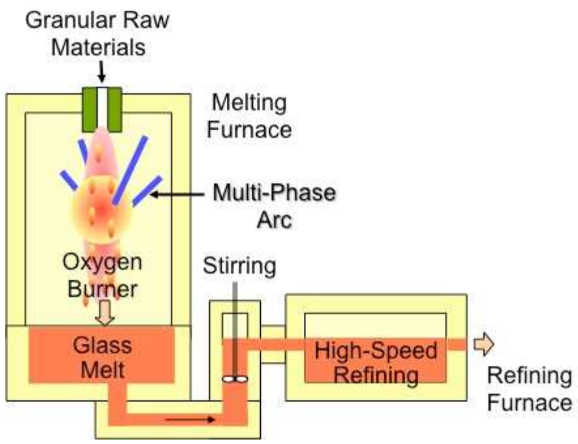

Fig. 1. Gas-solid reaction for in-flight glass melting

An innovative in-flight glass melting technology shown in Fig. 1 was developed from the above point of view [1]. Granulated raw material with a small diameter is dispersed in the melter, where the particles are in full contact with the plasma and burner flame. In addition, CO_2 formed by the carbonates decomposition is removed while the raw material is still in-flight to reduce the fining time considerably. The total vitrification time is evaluated to be only 2 - 3 h for the same rate of productivity as that obtained using the fuel-fired melter.

The multi-phase AC arc shown is suitable heat source for the in-flight reaction between gas and solid because it possesses many advantages such as high energy efficiency, large plasma volume, and long residence time of the treated materials [2]. The arc discharge takes 20 ms for a periodic cycle while the frequency of power source used for 12-phase AC arc is 50 Hz. Most power sources for generating arc plasma are accomplished by DC power supply, however it takes more cost in the apparatus for converting AC to DC. The single-phase or three-phase AC power supplies have a characteristic of intermittent discharge which limits the application of arc plasma systems generated by AC power supply. Therefore, a multi-phase AC power supply was developed to obtain a more effective arc plasma reactor.

The granulated raw materials of two types of glass, soda-lime glass and alkali-free glass, were heated by the multi-phase AC arc to investigate the feasibility of in-flight melting technology for glass production [3]. The vitrification degree, decomposition degree, morphology, average diameter, and composition of powders were characterized. Also, the in-flight melting behavior of particles was studied and the results for different heating sources were compared to provide guidelines for the glass industry.

Innovative in-flight melting technology was successfully developed for multi-phase plasma processing based on gas-solid reaction. The high vitrification degree achieved within milliseconds reveals that the new in-flight melting technology can reduce energy consumption and shorten the production cycle.

3. Water Plasma for Waste Treatment

A water plasma torch was developed for waste treatment processes based on gas-liquid reaction [4]. The hafnium embedded into a copper rod used as cathode material can overcome the erosion problems and achieve a long operating time in oxidation atmosphere. The torch can generate stable 100%-water plasmas using DC discharge without additional steam generator or gas supply system. Using the water plasma produced by the plasma torch, we succeed in decomposing liquid waste of phenol, acetone, and alcohol solutions.

The roles of CH, CH_3, and OH radicals in water plasmas were investigated in the decomposition process for gas-liquid reaction as shown in Fig. 2 [5]. The decomposition mechanisms as well as the intermediate behaviors were considered from the comparative study on acetone and glycerine decomposition. CH radical generated from both of acetone and glycerine decomposition was oxidized to form CO. Incomplete oxidation of CH_3 leads to C_2H_2 formation as well as soot formation. The negligible amount of soot generation from glycerine decomposition even at high concentration indicated that oxidation of CH and CH_3 was enhanced by OH radical.

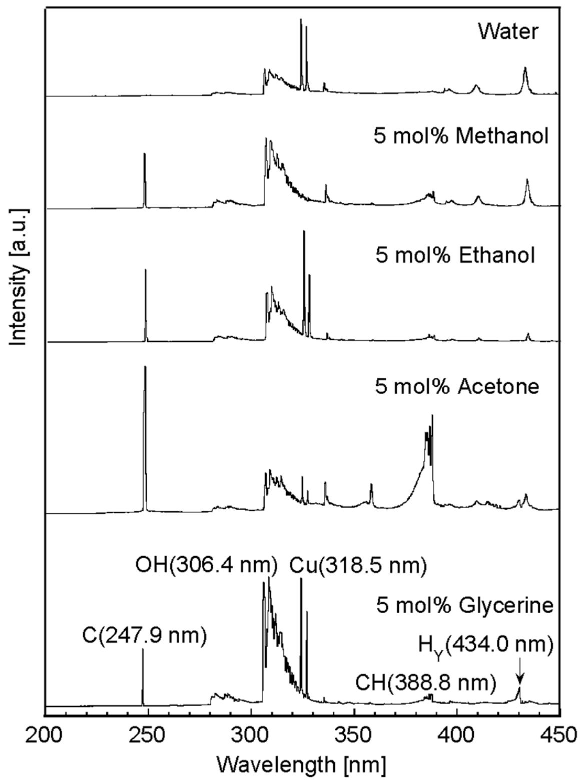

Fig.2. Optical emission spectra for organic solution decomposition by multi-phase water plasma.

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