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Editorial

Special Issue on Plasma Processes for Renewable Energy Technologies

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1. Introduction

The use of renewable energy is an effective solution to mitigate global warming. Environmental plasma processing is also an effective means to mitigate global environmental hazards arising from the emission of nitrogen oxides, (NO_x), sulfur oxides (SO_x), particulate matter (PM), volatile organic compounds (VOC), and carbon dioxide (CO_2) into the atmosphere. By combining both technologies, we can develop an extremely effective environmental improvement technology. Nuclear energy used for power generation is another effective source for the generation of discharge plasmas. Accordingly, a special issue of the journal *Energies* on plasma processes for renewable energy technologies was planned. In this issue, we focused on environment plasma technologies that can effectively utilize renewable electric energy sources, such as photovoltaic power generation, biofuel power generation, and wind turbine power generation. However, any latest research results on plasma environmental improvement processes were welcome for submission. We were looking for studies on the following technical subjects, among others, in which plasma can either use renewable energy sources or be used for renewable energy technologies:

- Plasma decomposition technology of harmful gases, such as the plasma denitrification method;
- Plasma removal technology of harmful particles from combustion machines, such as electrostatic precipitation;
- Plasma decomposition technology of harmful substances in liquid, such as gas–liquid interfacial plasma;
- Plasma-enhanced flow induction and heat transfer enhancement technologies, such as ionic wind device and plasma actuator;
- Plasma-enhanced combustion and fuel reforming;
- Other environmental plasma technologies.

The keywords are as follows: nonthermal plasma, plasma denitrification, electrostatic precipitator, gas–liquid interfacial plasma, ionic wind, plasma actuator, plasma-enhanced combustion, and fuel reforming.

2. A Short Review of the Contributions to This Issue

The contributions to the special issue are reviewed briefly as follows.

Liu et al. [1] contributed a paper entitled "Experimental and Numerical Investigations of Plasma Ignition Characteristics in Gas Turbine Combustors". This study reported a reliable ignition, which is critical for improving the operating performance of modern gas turbine combustors. Recently, plasma-assisted ignition has attracted interest to realize combustion improvement in internal combustion engines. Based on an optical experiment, the plasma jet flow feature during discharge was analyzed. Then, a detailed numerical study was conducted to investigate the effects of different plasma parameters on the ignition enhancement of a combustor used in gas turbines. The results showed that plasma has a good ability to expand the ignition limit and decrease the minimum ignition energy. For the studied plasma ignitor, the initial discharge kernel was not a sphere, but a jet flow cone with a length of approximately 30 mm. Furthermore, the numerical comparisons indicated that the additions of plasma active species and the increases in the initial energy, plasma jet flow length, and discharge frequency can benefit the acceleration of kernel growth and flame propagation via thermal, kinetic, and transport pathways. The result is very effective for the improvement of combustion in internal combustion engines and high-performance combustion.

Ahn et al. [2] contributed a paper entitled "Control Strategy for Power Conversion Systems in Plasma Generators with High Power Quality and Efficiency Considering Entire Load Conditions". In this paper, a control method for the power conversion system (PCS) of plasma generators connected with a plasma chamber was presented. The PCS generated the plasma by applying a high-magnitude and high-frequency voltage to the injected gases in the chamber. With regard to the PCS, the injected gases in the chamber were equivalent to the resistive impedance, and the equivalent impedance had a wide variable range, according to the gas pressure, the amount of injected gases, and the ignition state of gases in the chamber. In other words, the PCS for plasma generators should operate over a wide load range. Therefore, a control method for the PCS in plasma generators was proposed to ensure stable and efficient operation over a wide load range. In addition, the validity of the proposed control method was verified via simulation and experimental results based on an actual plasma chamber.

Tamošiūnas et al. [3] contributed a paper entitled "Gasification of Waste Cooking Oil to Syngas by Thermal Arc Plasma". The objective of this experimental study was to conduct experiments gasifying waste cooking oil (WCO) to syngas. WCO can be used as an alternative potential feedstock for syngas production. The WCO was characterized to examine its properties and composition in the conversion process. The WCO gasification system was quantified in terms of the produced gas concentration, H_2/CO ratio, lower heating value (LHV), carbon conversion efficiency (CCE), energy conversion efficiency (ECE), specific energy requirements (SER), and the tar content in the syngas. The best gasification process efficiency was obtained at the gasifying-agent-to-feedstock (S/WCO) ratio of 2.33. At this ratio, the highest concentrations of hydrogen and carbon monoxide, the H_2/CO ratio, the LHV, the CCE, the ECE, the SER, and the tar content were 47.9%, 22.42%, 2.14, 12.7 MJ/Nm^3, 41.3%, 85.42%, 196.2 kJ/mol (or 1.8 kWh/kg), and 0.18 g/Nm^3, respectively. The authors concluded that the thermal arc–plasma method used in this study can be effectively used for the gasification of WCO to high-quality syngas with a low content of tars.

Yamasaki et al. [4] contributed a paper entitled "Plasma–Chemical Hybrid NO_x Removal in Flue Gas from Semiconductor Manufacturing Industries Using a Blade-Dielectric Barrier-Type Plasma Reactor". A combustion abatement system is used to treat perfluorinated compounds (PFCs), which are used in the semiconductor manufacturing system. NO_x is emitted in the flue gas from semiconductor manufacturing plants as a byproduct of the combustion for the abatement of PFCs. To treat NO_x emission, a combined process consisting of a dry plasma process using nonthermal plasma and a wet chemical process using a wet scrubber was performed. For the dry plasma process, a dielectric barrier discharge plasma was applied using a blade-barrier electrode. Two oxidation methods, direct and indirect, were compared in terms of NO oxidation efficiency. For the wet chemical process, sodium sulfide (Na_2S) was used as a reducing agent for NO_2. Experiments were conducted by varying the gas flow rate and input power to the plasma reactor, using NO diluted in air to a level of 300 ppm to simulate exhaust gas from semiconductor manufacturing. The results demonstrated that the proposed combined process is promising for treating NO_x emissions from the semiconductor manufacturing industry.

Kawada et al. [5] contributed a paper entitled "Development of an Electrostatic Precipitator with Porous Carbon Electrodes to Collect Carbon Particles". Exhaust gases from internal combustion engines contain fine carbon particles. If a biofuel is used as the engine fuel for low-carbon emission, the exhaust gas still contains numerous carbon particles. For example, the ceramic filters currently used in automobiles with diesel engines trap these carbon particles, which are then burned during the filter regeneration process, thus releasing additional CO_2. Electrostatic precipitators are generally suitable to achieve low particle concentrations and large treatment quantities. However, low-resistivity particles, such as carbon particles, cause re-entrainment phenomena in electrostatic precipitators. In this study, the author developed an electrostatic precipitator to collect fine carbon particles. Woodceramics were used for the grounded electrode in the precipitator to collect the carbon particles on the carbon electrode. Woodceramics electrodes had higher resistivity and roughness compared with those of stainless-steel electrodes. We evaluated the influence of woodceramics electrodes on the electric field formed by electrostatic precipitators and calculated the corresponding charge distribution. Furthermore, the particle-collection efficiency of the developed system was evaluated using an experimental apparatus.

Yoshida [6] contributed a paper entitled "Fundamental Evaluation of Thermal Switch Based on Ionic Wind". The author described that a significant amount of thermal energy (mainly under 200 °C) is wasted across the world. To utilize the waste heat, efficient heat management and thermal switching are required. In this paper, the basic characteristics of a thermal switch that controls the flow of heat by switching on/off the ionic wind were discussed. The study was conducted through experiments and numerical simulations. A heater made of aluminum block maintained at 100 °C was used as a heat source, and the rate of heat flow to a copper plate placed over it was measured. Ionic wind was induced by corona discharge with a needle placed on the heater. The ratio of heat transfer coefficients was obtained in the range of 3–4, with an energy efficiency of approximately 10. The heat flux at this condition was approximately 400 W/m^2. The numerical simulations indicated that the heat transfer was enhanced by ionic winds, and the results were observed to be consistent with the experimental ones. The numerical prediction of heat transfer using the ionic wind is a novel result, and future research and development can be expected.

Zukeran et al. [7] contributed a paper entitled "Collection Characteristic of Nanoparticles Emitted from a Diesel Engine with Residual Fuel Oil and Light Fuel Oil in an Electrostatic Precipitator". The purpose of the study was to investigate the collection characteristics of nanoparticles emitted from a diesel engine in an electrostatic precipitator (ESP). The experimental system consisted of a diesel engine (400 mL) and an ESP; residual fuel oil and light fuel oil were used in the engine. Although the peak value of distribution decreased as the applied voltage increased owing to the electrostatic precipitation effect, the particle concentration, at a size of approximately 20 nm, increased compared with that at 0 kV in the exhaust gas from the diesel engine with residual fuel oil. However, the efficiency was increased by optimizing the applied voltage, and the total collection efficiency in the exhaust gas, using the residual fuel oil, was 91%. In contrast, the particle concentration, for particle diameters smaller than 20 nm, did not increase in the exhaust gas from the engine with light fuel oil. Zukeran et al. are an expert group on ESPs and we believe their study will be a great success in the future.

Kuwahara et al. [8] contributed a result of high reduction efficiencies of adsorbed NO_x in pilot-scale after-treatment using nonthermal plasma in marine diesel-engine exhaust gas. The marine diesel-engine exhaust gas is one of the recent targets to be treated from the viewpoint of global environmental protection [9]. In this paper, an efficient NO_x reduction aftertreatment technology for a marine diesel engine that combines nonthermal plasma (NTP) and NO_x adsorption/desorption was reported. The aftertreatment technology can also treat particulate matter using a diesel particulate filter and regenerate it via NTP-induced ozone. The investigated marine diesel engine generates 1 MW of output power at 100% engine load. NO_x reduction was performed by repeating the adsorption/desorption processes with NO_x adsorbents and NO_x reduction using NTP. Experiments were performed for a larger number of cycles compared with those in our previous study; the amount of adsorbent used was 80 kg. The relationship between the mass of desorbed NO_x and the energy efficiency of NO_x reduction via NTP was established. This aftertreatment achieved a high reduction efficiency of 71% via NTP and a high energy efficiency of 115 $g(NO_2)/kWh$ for a discharge power of 12.0 kW. This is a significant value for marine NO_x treatment in the exhaust gas.

3. Conclusions

Plasma is an effective way to make, use, or treat gas. Plasma is also effective to build a better life. Furthermore, to clean the atmospheric environment, which has been polluted by fossil fuel exhaust gases, and to regain blue skies around the world, exhaust gas aftertreatments for thermal power plants and vehicles are indispensable. However, it is not necessary to replace the existing exhaust gas aftertreatment system, such as the selective catalytic reduction method, for thermal power plants and vehicles with environmental plasma technologies. From a global perspective, the majority of combustion systems do not have an exhaust gas aftertreatment system, mainly in developing countries. Plasma treatment should be an effective low-cost method for mitigating this problem. In particular, the wet NO_x treatment method via ozone injection has been attracting attention because the cost of plasma devices has recently decreased. This system should attract further attention in the future.

In addition to the exhaust gas cleaning from combustion equipment, the equipment and concepts of cleaning machines for PM, NO_x, and CO_2 that have already diffused into the atmospheric air are promising. The concepts of atmospheric air cleaners, such as "cleaning equipment for the atmosphere", which uses renewable energy sources or power generated by nuclear power plants, and "cars that can clean the air", which can use surplus power from electric vehicles, have already been proposed. The air cleaner concept is already used in various industries such as an air cleaner in a closed space of a subway station platform contaminated with PM generated by the friction of the train wheels. In addition, there are significant advances in plasma environmental cleaning technology, and there is a possibility of application to marine diesel engines [9]. We look forward to the future development of various environmental plasma technologies reported in this special issue.

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