20aF-4

Towards Commercial Plasma Applications for Environmental Protection Technology
プラズマによる大気環境技術実用化に向けて

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Pilot-scale experiments have been conducted over the years for various environmental protection applications using various types of plasma. The electrohydrodynamically-assisted electrostatic precipitator for collection of low resistive diesel particulates and plasma ESP for being able to collect and incinerate particulates at the same time, nitrogen plasma for NOx reduction, excited species injection, flue gas recirculation for NOx and PM reduction and regeneration, wet-type NOx removal, integrated diesel emission control, and gas-phase dioxin control were explored towards commercial applications.

1. INTRODUCTION

Over the years, bench-scale experiments have been investigated to demonstrate the effectiveness of nonthermal plasma. However, there has been very limited information regarding the pilot-scale experiments. When the real flue gas was treated as a pilot-scale experiments, various unexpected technical difficulties were encountered such as flue gas constituents, load gas temperature and moisture variations, which influence system and cost performance. We overcome some of these problems for most of the applications and successful pilot-scale experiments were conducted towards commercial applications.

2. PILOT-SCAL EXPERIMENTS

2.1 Particulate (PM) Removal by EHD ESP

The collection of low resistive diesel particulates (PMs) has been known to be extremely difficult because of low resistive, which contains 99% of carbon, resulting in particle reentrainment or resuspension in the electrostatic precipitator (ESP). The use of diesel particulate filter (DPF) was excellent and has been widely used, but not cost effective. Based on fundamentals of reentrainment theory, the new electrohydrodynamically-assisted ESP (EHD ESP) was investigated using the 3.5L diesel engine generator.

Since the adhesion force was dominated for small PMs such as less than 500 nm, no reentrainment occurred even for the conventional ESP. However, because electrostatic repulsion force by induction charge was dominated over the adhesion force for large PMs (>1,000nm), severe reentrainment occurs. The EHD ESP utilizes the ionic wind to transport the charged large particles (>1,000nm) into the zero or lower electrostatic field zone such as pocket attached to the collection plate of the ESP. The captured PMs in the pocket was exposed to zero electric field, so that no electrostatic repulsion force was induced, resulting in reduction of PM reentrainment [1,2].

The flue gas velocity can be selected higher because particle migration velocity becomes higher for large particles, resulting in the reduction of the ESP sizing. The number collection efficiency was greater than 95% for particle size ranging of 500-5,000nm and 80~85% for 300~500nm during 20 min operation even the flue gas velocity of 7.3 m/s for the EHD ESP, while the collection efficiency for the conventional ESP showed negative after during 20 min operation [1,2].

2.2 PM Removal by Plasma ESP

As an extension of the EHD ESP, the plasma ESP was developed. The low-resistive diesel PMs were effectively captured in the low electrostatic field zone and at the same time, collected PMs were incinerated by ozone and oxidation product of NO_2 in the flue gas by the surface discharge plasma which no particle handling device or storage space is required for the system [3].

2.3. NOx Reduction by Nitrogen Plasma

The selective catalytic reduction (SCR) system for NOx removal has been used widely but showed some practical limitations such as low gas temperature operation due to the usage of catalysts, sulfur poisoning, and ammonia leakage. Extremely cost effective NOx reduction technology was developed using adsorption and desorption (concentration), followed by N_2 plasma without using catalysts or ammonia required for SCR. Advantages are the significant reduction of gas volume and applicable for low gas temperature [4].

2.4. NOx Reduction by Recirculation (EGR)

Another interesting technology was flue gas recirculation. The adsorbed NOx in the adsorbent was regenerated using ambient air to obtain high concentration of NOx and was recirculated into the part of the intake air (EGR). The results showed that NOx generation was not influenced by NOx concentration used as a part of intake of the diesel engine [5].

2.5 NOx Reduction by Plasma Wet-System

The wet pilot-scale NOx removal system by plasma combined wet system has been investigated over the years for boiler application using city gas and heavy oil. The NO from the boiler flue gas was first oxidized by the ozonizer to form NO_2 by the plasma and was reacted with strong reduction chemical such as Na_2SO_3 to form nontoxic Na_2SO_4. More than 90% of NOx reduction was achieved [6]. Furthermore, bio oils such as waste vegetable oil, rice bran oil, fish oil were mixed with heavy oil as a multi-fuel boiler and successful NOx reduction efficiency was demonstrated [7].

2.6 Integrated Diesel Engine Emission Control

Figure 1 shows the integrated diesel engine emission control, which consists of EHD ESP or plasma ESP for PM reduction, NOx adsorption and desorption by N_2, followed by nitrogen plasma, reactive species injection for PM incineration in EHD ESP, and adsorption tower, and high concentrated NOx recirculation (EGR) system [8].

During the plasma absent time, reactive species are injected before the ESP in order to incinerate PMs deposited on the EHD ESP collection plates and plasma ESP electrodes by O_3 and NO_2. Also, the reactive species can be injected into the adsorption tower where uncollected PM deposited on the adsorbent can be incinerated with the same manner. This is useful techniques for improving the overall diesel emission control. The integrated plasma combined hybrid system, leading to extremely cost effective system towards zero emission control.

2.7 Gas Phase Dioxin Removal

A pilot-scale dioxin removal was conducted from the incinerator plant with the flue gas volume of approximately 5,000 Nm^3/hr after removing solid-phase dioxin by the bag filters. The plasma reactor consisted of 18 tube reactors in the wire-cylinder configuration, energized by a 50kW pulse generator. The decomposition efficiency was 70% for coplanar PCBs, 80% for PCDFs, and more than 95% for PCDDs with 3~6 Wh/m^3. All cases were less than 1 ng-TEQ/m^3 to meet the requirement. Note that decomposition efficiency decreased with decrease of chlorination degree in both PCDDs and PCDFs [9].

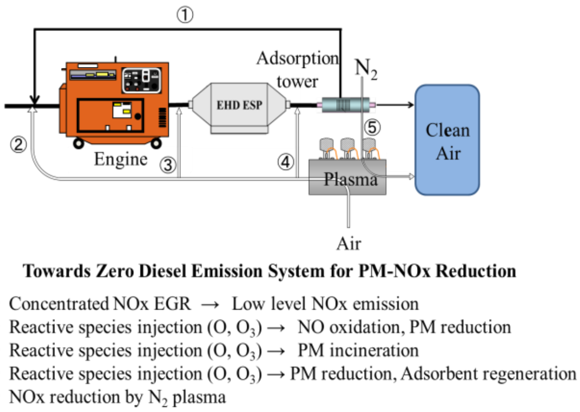

Fig. 1. Integrated diesel engine emission control using plasma combed system

Acknowledgments

These studies were supported by a Grant-in-aid for Scientific Research of Japan and Promotion of Science, Japan Society of Technology Agency.

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