S16-2

Emission Aftertreatment for Combustion Systems Using Nonthermal Plasma Combined with Chemical Processes

大気圧プラズマ複合プロセスによる燃焼機器排ガス処理

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The authors have been carrying out the applications of nonthermal plasmas to emission control for combustion systems such as marine diesel engines or bio-fuel boiler, and now some are on commercial stages. In this lecture, pilot-scale apparatus and experimental results concerning these systems are discussed. We achieved highest removal efficiency of NO_x reduction greater than 100 g (NO_2)/kWh when the nonthermal plasma is combined with other chemical processes (adsorption or wet chemical scrubbing). The efficiency is approximately ten-times higher than that in the case with plasma application only.

1. Introduction

One of important and successful environmental applications of atmospheric-pressure corona discharge or plasma is electrostatic precipitator (ESP), which have been widely used for coal- or oil-fired boilers in electric power plants and particulate matter control emitted from glass melting furnace system, etc. In the ESPs, steady high voltage is usually applied to a pair of electrodes (at least, one of these has sharp edge). Unsteady pulsed high voltage is often applied for the collection of high-resistivity particulate matter (PM) to avoid reverse corona phenomena which reduce the collection efficiency of the ESPs. It was found that unsteady high voltage can treat hazardous gaseous components (NO_x, SO_x, hydrocarbon, and CO) in the exhaust gas, and researches were shifted from PM removal to hazardous gases aftertreatment with unsteady corona discharge induced plasmas.

In our laboratory, we have tried to develop nonthermal-plasma environmental applications technology since 1998. Main research topics are as follows: diesel engine emission control, boilers emission control, NO_x removal for glass melting furnace, VOC control from factories, odor and dioxin controls from garbage incinerators, CO_2 and PFC emission and moisture controls in various environments, and indoor electric air cleaner. **Our all papers are listed in [1]**. In the lecture, recent results on diesel engine and boiler emission controls are presented among these topics.

2. Marine Diesel Engine Emission Control [2-5]

Figure 1 shows the experimental setup for the aftertreatment system in the marine diesel engine (6DK-20e, output power = 1071 kW, Daihatsu Diesel MFG Co., Ltd, fuel: A-heavy oil or marine diesel oil). In this system, the combination of adsorption and the NTP is used for reduction of NO_x. The exhaust gas emitted from then engine is first separated and approximately 13% of the bypassed gas the flow rate of which is controlled by the flow regulation valve passes through a set of ceramics diesel particulate filters (DPFs). More than 95% of the PM in the exhaust gas is captured in the DPFs. The accumulated PM in the DPF is treated by nonthermal plasma-induced ozone (O_3) injection technology [3, 5]. After this process of the PM removal, NO_x in the exhaust gas is treated by NTP combined with repeated adsorption and desorption processes. In the adsorption process, for an effective NO_x adsorption to adsorbents, the exhaust gas is cooled from 270°C down to

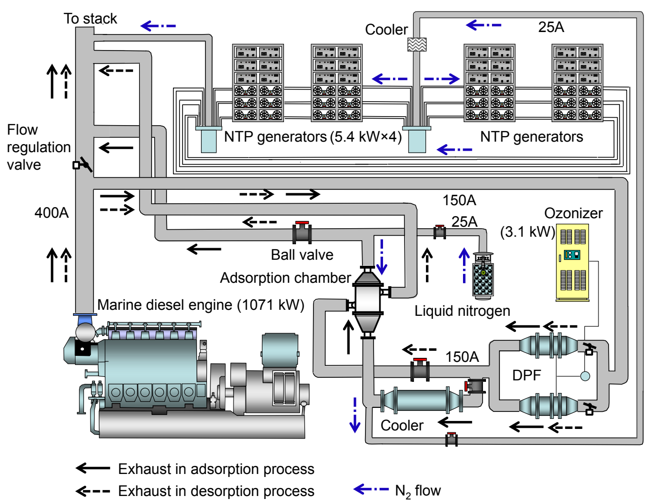

Fig. 1. Schematic diagram of experimental setup for the aftertreatment system in the marine diesel engine

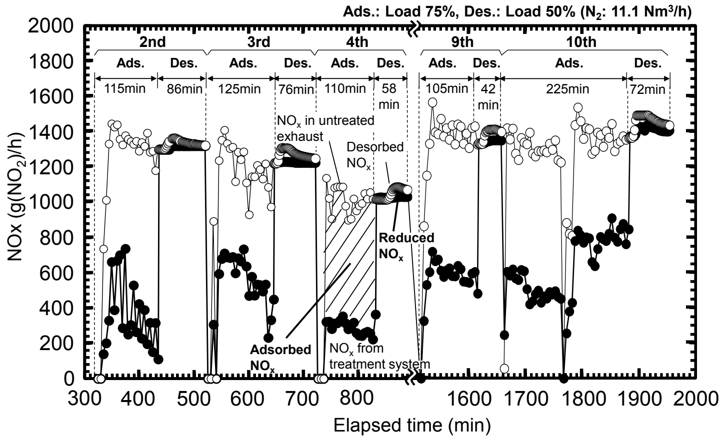

Fig. 2. Time-dependent NO_x emission from the aftertreatment system for the marine diesel engine

Fig. 3. Plasma hybrid clean ® boiler system

approximately 45°C with the water-cooling type cooler. An adsorption chamber that contains adsorbents adsorbs NO_x of 92% in maximum. Finally, the exhaust gas is flowed out from a stack. In the desorption process, after the valves are controlled, N_2 gas of lower flow rate of 11.1 ~ 22.2 Nm^3/h supplied from liquid N_2 cylinder passes through the chamber. The direction of the N_2 gas is opposite to that of the exhaust gas in the adsorption. Simultaneously, the chamber is heated up by the waste heat of the exhaust gas. As a result, high-concentration (typically 1% = 10000 ppm) NO_x flows out from the chamber, and introduced to the NTP reactors of total 21.6 kW in maximum.

Figure 2 shows a time-dependent NO_x emission before and after the gas passes through the aftertreatment system for operation cycles 2 ~ 4, 9, and 10. Exhaust gas is continuously treated during these repeated cycles. In this graph, the mass flow rate of NO_x is taken in the vertical axis evaluated based on the molecular mass of NO_2 with the unit of $g(NO_2)/h$. Furthermore, the untreated NO_x is indicated by white circles with lines, and treated NO_x is indicated by black circles with lines. NTP is applied only in the desorption processes, and the input power to the NTP generator is 21.6 kW in the cycles 2 ~ 4 and 12.0 kW in the cycles 9 and 10. It is known this graph that large amount of NOx is treated. At 10th cycle, the highest system energy efficiency among these cycles of η_{system} = 161 $g(NO_2)/kWh$ is achieved. Application of the highest recorded energy efficiency to the requirement of the IMO (International Maritime Organization) emission standards from Tier II to III corresponds to only 4.3% (= 6.9 / 161 × 100) of the engine output power.

More detailed description on the pilot-scale experiment was explained in our recent paper [2].

3. Bio-fuel Boiler Emission Control [6-9]

The results for the pilot-scale application of the NTP to bio-fuel boiler (**Fig. 3**, steam generation rate = 2.5 ton/h) are presented in the lecture.

Acknowledgments

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