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# Hydrocarbon and Electrical Requirements in the Plasma During Treatment of $NO_x$ in Light-Duty Diesel Engine Exhaust

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# HYDROCARBON AND ELECTRICAL REQUIREMENTS IN THE PLASMA DURING TREATMENT OF $NO_x$ IN LIGHT-DUTY DIESEL ENGINE EXHAUST

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## Abstract

This paper examines the hydrocarbon ($C_1/NO_x$ ratio) and electrical energy density (ratio of power to exhaust flow rate) requirements in the plasma during plasma-assisted catalytic reduction of $NO_x$. The requirements for treatment of $NO_x$ in heavy-duty and light-duty diesel engines are compared. It is shown that, for light-duty applications, the plasma can significantly enhance the catalytic reduction of $NO_x$ with little fuel penalty incurred in the plasma process.

## Introduction

Plasma-assisted catalytic reduction is based on the selective plasma oxidation of NO to $NO_2$, followed by the selective catalytic reduction of $NO_2$ to $N_2$ [ref. 1]. Addition of hydrocarbon to the exhaust is necessary to efficiently accomplish both the plasma oxidation to $NO_2$ and the catalytic reduction to $N_2$.

The presence of hydrocarbons is critical to the selective partial oxidation of NO to $NO_2$ in a plasma [ref. 1-2]. The concentration of NO in the exhaust determines the amount of hydrocarbon and electrical energy density that has to be provided to the plasma in order to achieve maximum $NO_x$ conversion efficiency. The electrical energy density is the electrical power delivered to the plasma divided by the exhaust gas flow rate. Knowing the electrical energy density requirement allows one to determine the electrical power that the plasma needs for a given exhaust gas flow rate.

This paper examines the hydrocarbon and electrical energy density requirements in the plasma during plasma-assisted catalytic reduction of $NO_x$. The requirements for treatment of $NO_x$ in heavy-duty and light-duty diesel engines are compared.

## Results

Both chemical kinetics calculations and experimental measurements are presented in this section to examine the hydrocarbon and electrical energy density requirements in the plasma. We used propene as the hydrocarbon because the chemical reaction database for propene is more established and facilitates comparison of the modeling to experiments. The plasma reactor used in the experiments is a pulsed corona discharge reactor consisting of a metal wire inside a metal cylinder. The plasma chemistry is not peculiar to this type of plasma processor; all electrical discharge plasma reactors accomplish essentially the same gas-phase plasma chemistry under the same gas conditions [ref. 3-4]. The important control parameter in the plasma reactor is the electrical energy density delivered to the plasma [ref. 3-5].

Figure 1 shows the chemical kinetics calculation of the plasma energy density required to oxidize NO to $NO_2$ in a gas mixture simulating a heavy-duty diesel engine exhaust with an initial NO concentration of 600 ppm. The oxidation efficiency is shown for different values of $C_1/NO_x$, where the hydrocarbon additive is propene. In the absence of hydrocarbons, the oxidation efficiency is very low even at high values of electrical energy density input to the plasma. The maximum oxidation efficiency increases as the $C_1/NO_x$ ratio is increased. A $C_1/NO_x$ ratio of 6 is required to get 80% oxidation efficiency. The maximum oxidation efficiency increases slowly as the $C_1/NO_x$ is increased further. At a $C_1/NO_x$ of 6, the energy density required to achieve maximum oxidation efficiency is around 30 J/L. The energy density required for maximum oxidation approaches 20 J/L at the limit of high $C_1/NO_x$.

Figure 2 shows the chemical kinetics calculation of the plasma energy density required to oxidize NO to $NO_2$ in a gas mixture simulating a light-duty diesel engine exhaust with an initial NO concentration of 100 ppm. Note that for the same $C_1/NO_x$ ratio, the electrical energy density required by the plasma to achieve the same oxidation efficiency is much less compared to that for the case of a heavy-duty diesel engine. When the initial NO concentration is low, the plasma needs to produce a smaller number of radicals; thus, the plasma requires less electrical energy density. At a $C_1/NO_x$ of 6, the energy density required to achieve maximum oxidation efficiency is only around 6 J/L.

Figure 3 shows the comparison between the model predictions and experimental measurements of the oxidation efficiency, as a function of the electrical energy density input to the plasma, for different initial concentrations of NO, with the $C_1/NO_x$ set at 6. The experiment confirms that the electrical energy density requirement is less at lower initial-NO concentration. With an initial NO concentration of about 400 ppm, maximum oxidation efficiency is achieved at an energy density of around 20 J/L. With an initial NO concentration of about 200 ppm, only 10 J/L of energy density is required to achieve maximum oxidation efficiency for the same $C_1/NO_x$ ratio.

Figure 4 shows the comparison between the model predictions and experimental measurements of the oxidation efficiency, as a function of the $C_1/NO_x$ ratio, in a mixture with an initial NO concentration of 215 ppm and electrical energy density input to the plasma of 10 J/L. The experiment confirms the dependence of the oxidation efficiency on the $C_1/NO_x$ ratio.

Figure 5 shows the comparison between the model predictions and experimental measurements of the electrical energy density required by the plasma, as a function of initial NO concentration, to achieve maximum oxidation of NO to $NO_2$, when $C_1/NO_x$ is 6. The experiments validate the chemical kinetics calculations over the range of initial NO concentrations relevant to both light-duty and heavy-duty diesel engines.

**Conclusions**

The use of a plasma provides a way of enhancing the efficiency for catalytic reduction of $NO_x$. The plasma requires electrical power. The plasma also requires the presence of hydrocarbons to efficiently accomplish the selective partial oxidation of NO to $NO_2$. In this paper we have examined the hydrocarbon and electrical power requirements in the plasma. The requirements for treatment of $NO_x$ in heavy-duty and light-duty diesel engines are compared. We have shown that the plasma in a light-duty application requires much less electrical power because of the lower initial-NO level and lower exhaust flow rate. The total fuel penalty for plasma-assisted catalytic reduction of $NO_x$ in a light-duty application is determined mostly by the amount of hydrocarbon additive required by the catalyst. Thus, for light-duty applications, the plasma can significantly enhance the catalytic reduction of $NO_x$ with little fuel penalty incurred in the plasma process.

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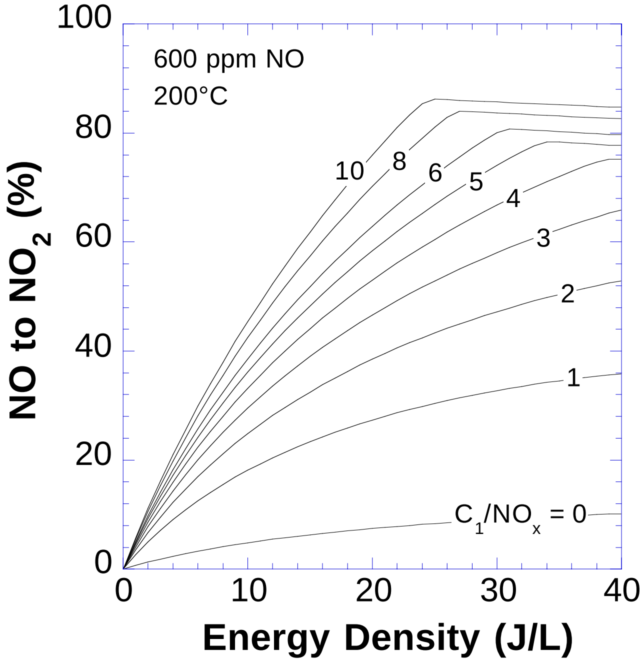


Figure 1. Chemical kinetics modeling of the plasma oxidation of NO to $NO_2$ in a gas mixture simulating a heavy-duty diesel engine exhaust, using propene additive. Initial NO concentration = 600 ppm, in 10% $O_2$, 10% $CO_2$, 5% $H_2O$, balance $N_2$. Gas temperature = 200°C.

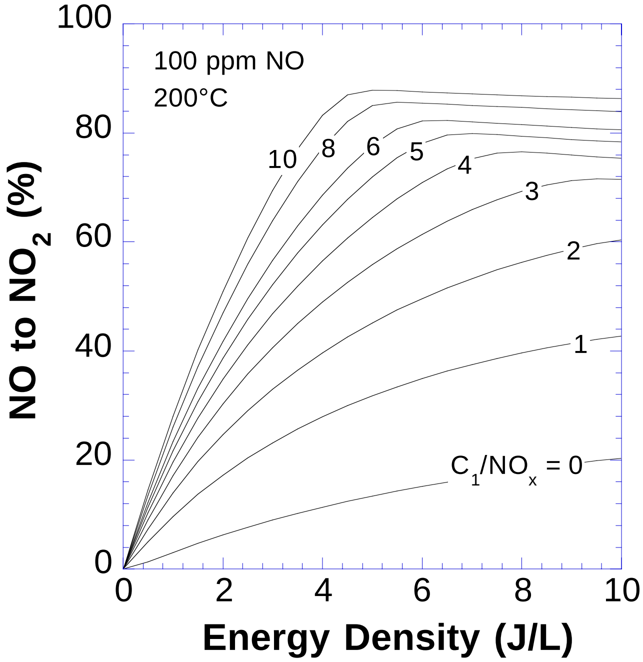


Figure 2. Chemical kinetics modeling of the plasma oxidation of NO to $NO_2$ in a gas mixture simulating a light-duty diesel engine exhaust, using propene additive. Initial NO concentration = 100 ppm, in 10% $O_2$, 10% $CO_2$, 5% $H_2O$, balance $N_2$. Gas temperature = 200°C.

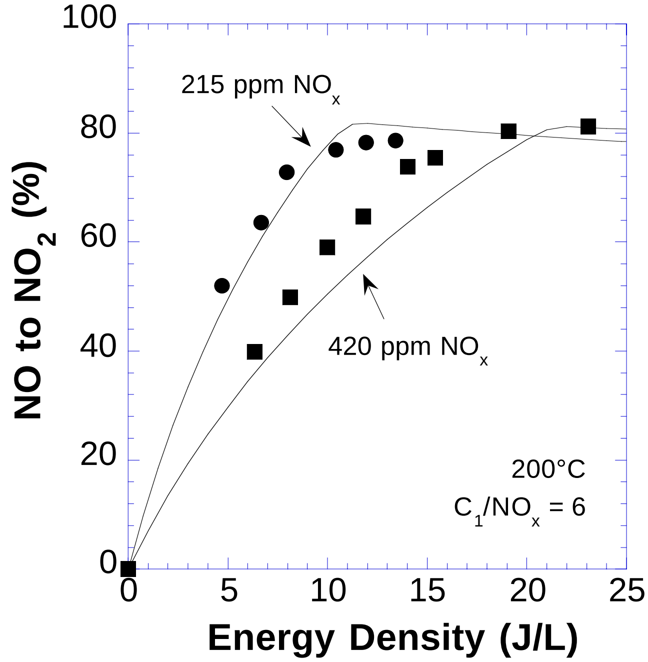


Figure 3. Experimental measurements (points) and modeling predictions (lines) of the plasma oxidation of NO to $NO_2$ in a gas mixture containing various initial concentrations of NO in 10% $O_2$, 10% $CO_2$, 5% $H_2O$, balance $N_2$. Propene additive. Gas temperature = 200°C.

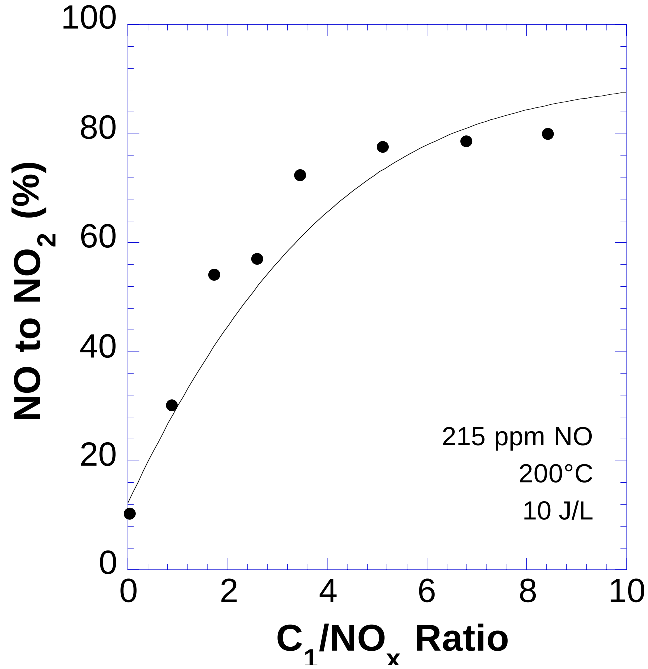


Figure 4. Experimental measurements (points) and modeling prediction (line) of the plasma oxidation of NO to $NO_2$ as a function of the $C_1/NO_x$ ratio in a gas mixture containing 215 ppm of NO in 10% $O_2$, 10% $CO_2$, 5% $H_2O$, balance $N_2$. Propene additive. Gas temperature = 200°C. Electrical energy density input to the plasma = 10 J/L.

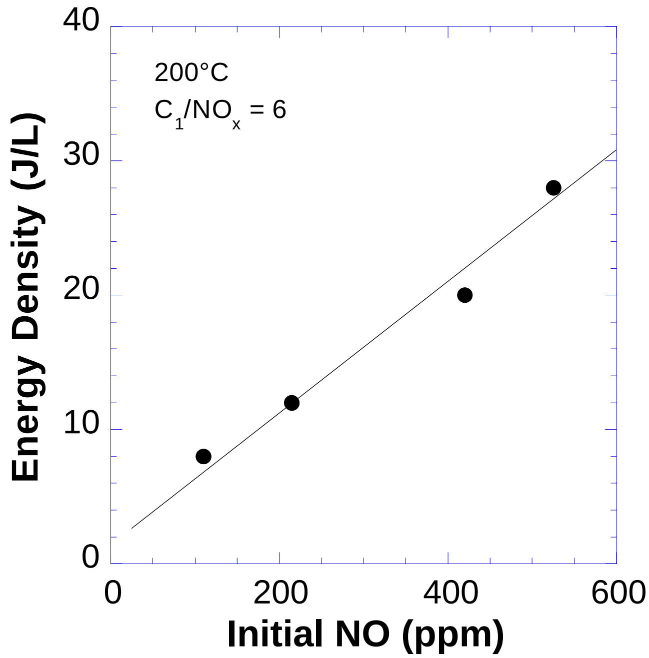


Figure 5. Experimental measurements (points) and modeling prediction (line) of the electrical energy density required by the plasma, as a function of initial NO concentration, to achieve maximum oxidation of NO to $NO_2$ with $C_1/NO_x = 6$. Simulated diesel exhaust with 10% $O_2$, 10% $CO_2$, 5% $H_2O$, balance $N_2$. Propene additive. Gas temperature = 200°C.