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Experimental Study on the Plasma Purification for Diesel Engine Exhaust Gas

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Abstract: It is known that the use of ternary catalysis is capable of significantly reducing the emission of pollutants from petrol vehicles. However, the disadvantages such as the temperature and other limitations make it unsuitable for diesel engines. The plasma-assisted catalyst technology has been applied in dealing with the diesel exhaust in the experiment in order to do further research on the effects of plasma in exhaust processing. The paper not only includes the experimental observation on the change of particle concentration after the operation of purification device, but also builds the kinetic model of chemical reactions to simulate the reactions of nitrogen oxides in plasma through using the software of Matlab, then compares the calculation results with experimental samples and finally gets some useful conclusions in practice.

1 Introduction

In recent years, energy and environmental problems have become much more serious, but the demand for fossil fuels continues increasing. According to the investigation and study[1], the exhaust gas from the burning of car engine fuel (including carbon monoxide, hydrocarbon, nitrogen oxides, sulfur dioxide and carbon black particles, etc.) accounts for 60% to 90% of air pollution which does great harm to the living environment. At the same time, the exhaust gas includes a lot of these harmful gases and greenhouse gases, which pose a great threat to the human respiratory system and other physical functions [2, 3].

As for current treatment of motor vehicle exhaust, the three - element catalysis [4, 5] has been seen as the internationally recognized mainstream technology that can effectively reduce the emission of gasoline vehicles. But the ternary catalytic has many limitations like the higher requirements of exhaust gas temperature which means the temperature drop in the exhaust pipe will result in the decrease of catalytic conversion efficiency, some harmful gas components of the diesel engine exhaust which can make the catalyst deactivation, and the practicability of most catalytic converter which does not apply to diesel engines. For diesel engine, the running process and combustion mode are greatly different from gasoline engine, and the emissions of *CO* and *HC* produced by diesel engine combustion is relatively low, while the concentration of particulate matter (generally refers to carbon black) and *SOx* is higher. Therefore, the main task of dealing with diesel engine exhaust is to remove harmful gas components including *SOx* ,particulate matter and *NOx*. So far, there are mainly EGR [6], SCR[7] and other technologies for the treatment of diesel engine exhaust, but their efficiency is still not high.

In this paper, non-thermal plasma coupled with catalytic diesel particulate filter technology has been used to generate a large number of active ionic groups from dielectric barrier discharge, and a series of chemical reactions occurring with the impact of the gas molecules. Experimental data measured through the specific instruments are presented by the statistics achieved through the comparison and analysis between particle concentration of exhaust gas purification as well as the comparison between purification segment according to the simulation of chemical reaction model and actual exhaust gas ingredients.

2 Exhaust gas reprocessing test station

Post-treatment experiment platform of diesel engine exhaust mainly consists of diesel engine system, thermal power plant system, exhaust gas purification system and the corresponding measurement system. As for the measurement system, it mainly includes power measurement named multimeter, real-time measurement of exhaust particulate matter named Dustmate and measurements of exhaust gas compositions named KANE AUTOplus, as shown in Fig.1.

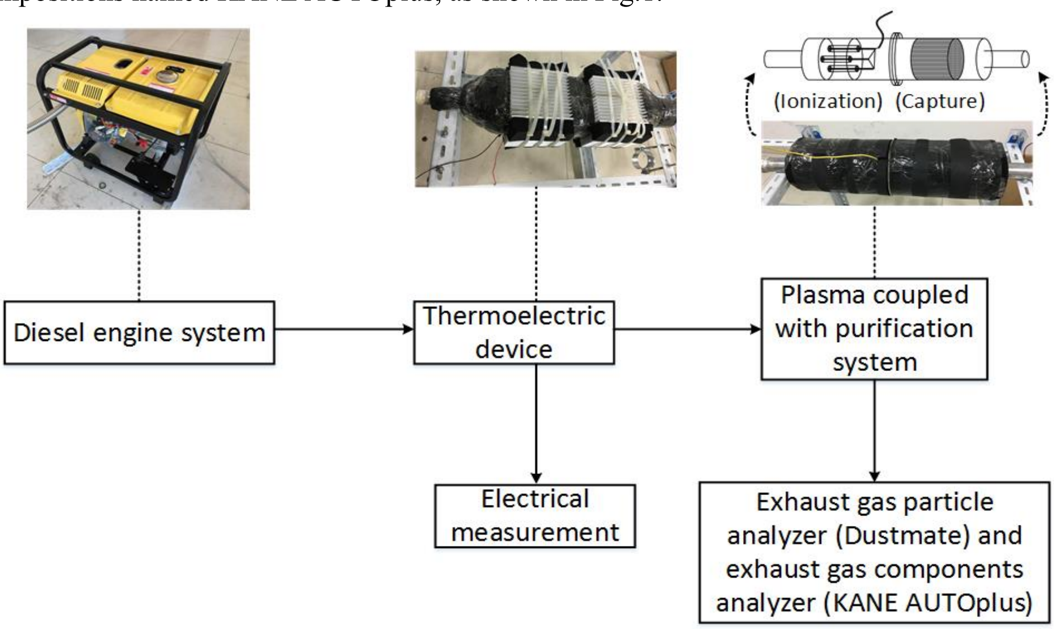

Fig.1 Experimental platform for exhaust post-treatment of diesel engine

After experimental devices came into operation, the diesel engine system produces high-temperature exhaust gas which flows through the pipeline into the thermoelectric device and conducts heat exchange with the inner wall of the device(that is, heat energy is converted into electricity, which generates electricity for the plasma purification system), then the exhaust flows into the purification plant. Due to the effect of ionization, the reactive plasma produced by the pulsed high voltage output power is chemically reactive with hydrocarbons, nitrogen oxides and black carbon in the exhaust gas, and the subsequent capture devices can not only capture particulate matter, but deal with other harmful gas components in the catalytic convert agent as well. Experimental measurement can be performed by the on-line particle analyzer named Dustmate and the on-line exhaust gas components analyzer.

In the experimental system, the change of purification parameter is transmitted to the purifier by a cable. The purifier is mainly composed of a shell, plasma discharge part and particle trap part. As for plasma discharge, its major part includes discharge electrodes (material for W80), catalyst carrier (cordierite ceramics), catalyst and the conductive paint coating composition. The materials including CuO and $La_{0.6}K_{0.4}Mn_{0.5}Fe_{0.5}O_3$ have been used as the main components of the catalyst , and the carrier coating is Al_2O_3 doped with ZrO_2 and CeO_2.

High-voltage pulse power generator has been adopted as high-voltage power supply with the parameter shown as follow: input voltage AC220V with frequency 50Hz, input pulse amplitude voltage 0~+25 kV, pulse current 0~5mA, ten grades of output frequency from 500Hz to 1000Hz with adjustable pulse width and output voltage +24 V.

3. Experimental results and analysis of exhaust gas treatment

3.1 Changes in the concentration of nitrogen oxides before and after the exhaust purification

Purification device makes use of plasma technology to assist catalysis by means of ionization producing large number of reactive ion group which will promote the conversion of harmful gas such as nitrogen oxides, hydrocarbon and carbon monoxide. Chemical equation has mainly been divided into two:

Ionization: $NO+C+HC+O_2 \xrightarrow{NTP} NO_2+CO+CO_2+H_2O$ (1)

Capture catalysis: $C+NO_2 \xrightarrow{NTP+\text{catalyze}} N_2+CO_2$ (2)

A large number of reactive ion groups firstly transform nitrogen oxides (mostly NO) into NO_2, then the particle concentration has been reduced under the combined effect of plasma and catalyst, and the harmful gas NO_2 has been turned into harmless nitrogen.

During the experiments, the changes of different components have been compared by the analysis of the exhaust components before and after the reaction. After the devices run in a stable condition(after 20 minutes), the experimental results are being continuously measured for 15 groups before and after the beginning with the time interval between each group 1 minute. According to the initial concentration of the experimental measurements, the change of NO concentration over time has been simulated (original gas components $NO+N2+O2$) , and the results of experiment and simulation are shown in Fig. 2.

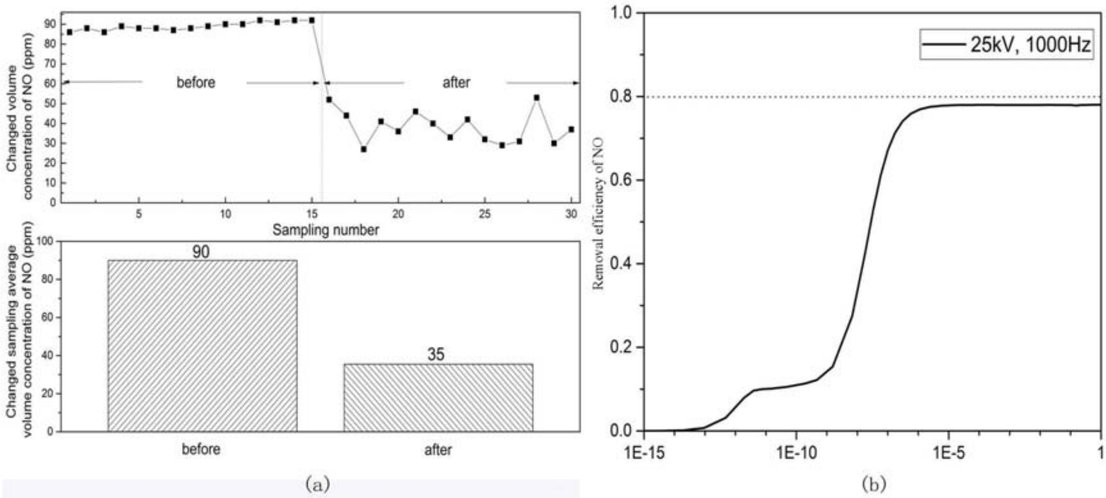

Fig. 2 The results of experiment and simulation for NO volume concentration in exhaust gas (a) experimental results; (b) simulated results

According to the results of the experiments, Fig.2(a) presents the change of NO volume concentration before and after the operation of the purification device. Combining Eq.(1) and (2), NO is consumed by the chemical reaction with the concentration reduced. According to Fig.2 (b), it can be seen that NO is rapidly reduced with purification device working in a very short period of time. When the initial concentration of NO in the experimental exhaust is about 90ppm, the simulated results show that the volume concentration of NO decreases obviously during chemical reaction and the final NO removal efficiency is around 80%. The experimental results also indicate that the average concentration of NO after chemical reaction was about 33ppm and the removal efficiency was approximately 63%. The theoretical calculation was slightly higher than the experimental value.

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3.2 The Analysis of particle concentration before and after the exhaust purification

The concentration of PM1.0, PM2.5, PM10 and TSP (total suspended particulates) was measured through the specific instrument (Dustmate). When measuring, the system firstly starts running to a stable condition, then every 14 groups of samples before and after the operation are tested respectively. The results are shown in Fig.3.

According to the experimental results, it can be seen from Fig.3 that the concentration of particulate matter is reduced obviously. Fig.3 (a) shows the change of PM1.0 concentration in exhaust gas when the device is running in an stable condition. The overall results are basically stable, and the removal efficiency is more than 60%. Fig.3(b) indicates that the original PM2.5 concentration is about 250g/m^3 before the reaction, and the concentration after the start of purification is basically maintained at about 200g/m^3. Fig.3(c) shows the change of PM10 concentration, and the average initial concentration is maintained at over 6000g/m^3. Compared with the concentration after opening, removal efficiency of PM10 is about 55%. In Fig.3 (d), the TSP which represents the total suspended particulates is greater than 6000g/m^3 when the experimental samples has not been purified, and the concentration reduction after starting the purification device is obvious with the removal efficiency more than 50%. Fig.4 shows the average concentration of samples in each working condition which directly presents the variation of particle concentration in different size interval.

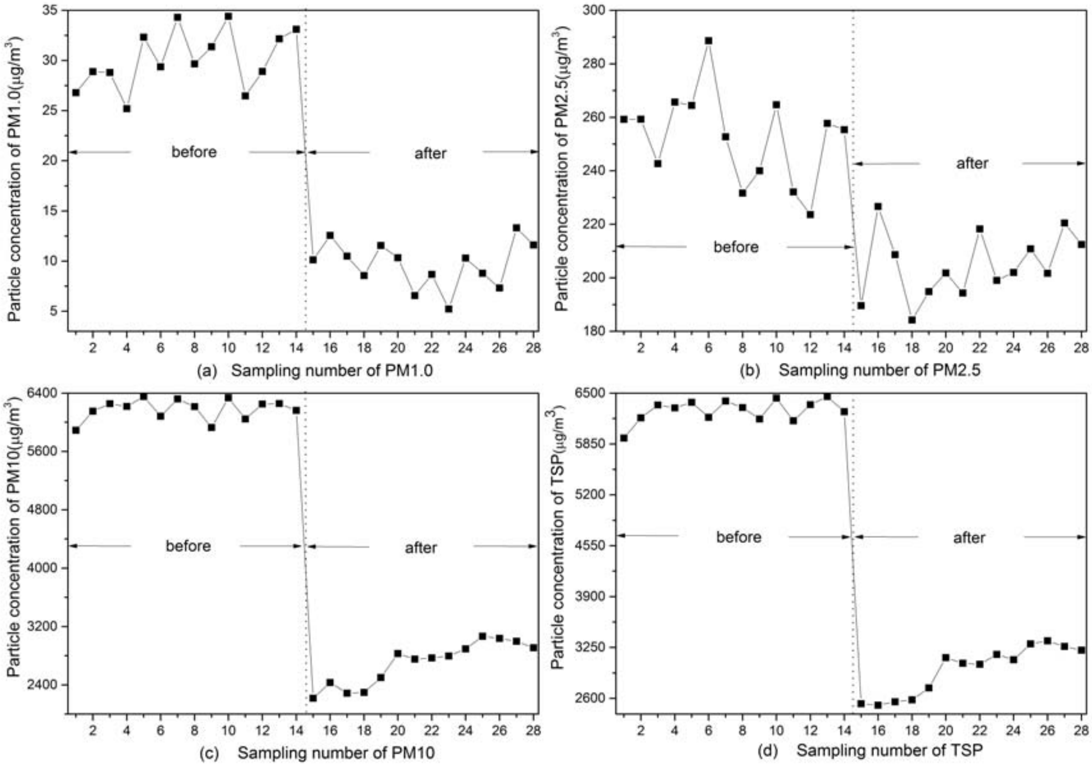

Fig. 3 results of particle sample concentration

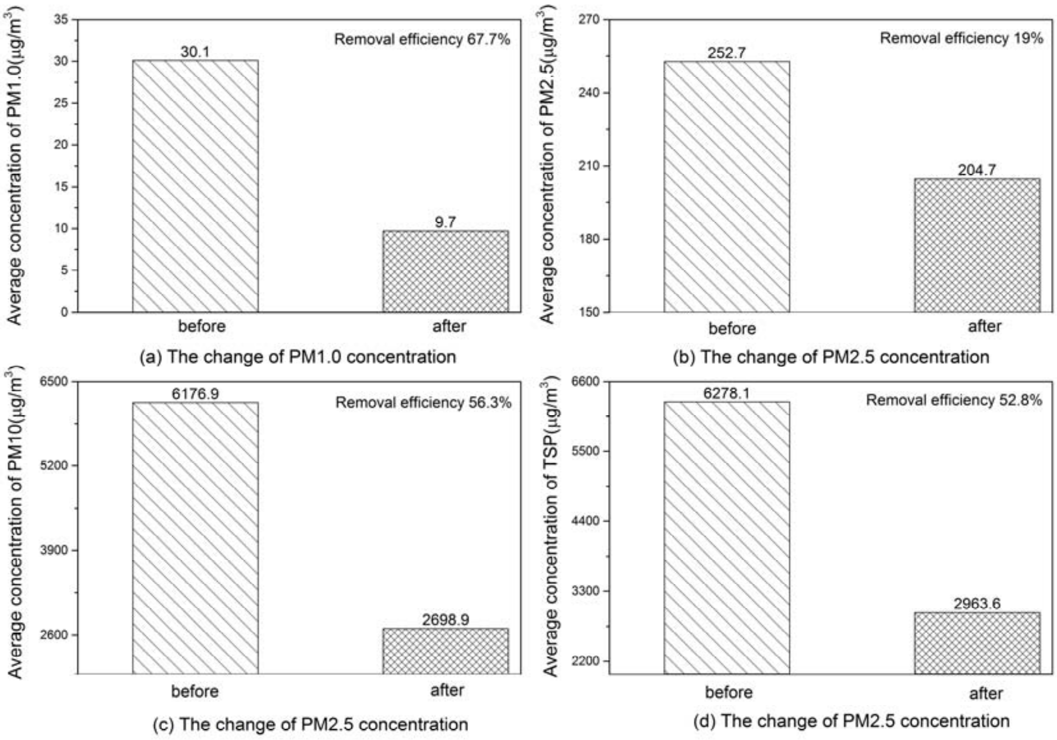

Fig. 4 Comparison of the average concentration of particles before and after Purification

4 Conclusion

Non-thermal plasma technology is applied to vehicle exhaust gas purification. According to the numerical simulation, it can be found that the concentration of *NO* in the simulated gas (*NO+N2+O2*) decreases rapidly over time. At the same time, almost all the *NO* in the simulation was reacted, and the simulated results has a certain deviation with the experimental results, but the trend can still be roughly predicted.

When plasma-assisted catalytic technology has been applied to deal with particulate matter in the experiment, the change of particle concentration in different size interval has a certain difference and declined obviously, so plasma-assisted catalysis can not only deal with harmful gas components but also have some effect on the particulate matter.

The impact between high-energy electron and gas molecules in plasma is the key to the chemical reaction, which generates a large number of active ionic groups to promote the reaction.

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