

Analysis of the Mechanism and the Current Situation of the Plasma Purification Technology for Diesel Exhaust

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Abstract: In this study, the mechanism and the current situation of the plasma purification technology for diesel exhaust is introduced. Research indicates that cleaning the diesel exhaust with the plasma produced by corona discharge or dielectric barrier discharge has too high energy consumption to direct use without catalyst. To solve this problem, the study gives some new ways about cleaning diesel exhaust with arc discharge.

Keywords: Arc discharge, diesel, exhaust, plasma

INTRODUCTION

According to the rules adopted at European conference, the Euro V standard came into effect. This standard is suitable for diesel cars, gasoline cars and light commercial trucks, but the Euro VI is only suitable for diesel cars. The Euro VI and Euro V standards make higher demands on the amount of the PM and NO_x for diesel and gasoline vehicles. According to the standard, the amount of NO_x emission from diesel car must be less than 180 mg/km, which has been reduced by 27% compared with the amount of Euro IV and the amount of PM has also reduced by 80% compared with Euro IV. So all the diesel vehicles must solve the problem of the emission of PM and NO_x. The vehicle fleet of China is about 225 millions in 2011, which includes 65 million diesel vehicles. Once the new standard put into effect, a large number of diesel vehicles will cannot meet the demands and be not allowed to run. Therefore, the need for a new technology for control the diesel exhaust which accords with the situation of our country is imminent.

The main technological measures on decrease the exhaust of diesel engine often includes inside machine processing and outside machine processing. A large number of structure improvements on diesel engine has been done recently years, but which couldn't meet the more and more strict standards for exhaust emission, so the outside machine processing (post processing technology) attracts more and more attention (Shenhua *et al.*, 2001; Yiming *et al.*, 2002; Johnson, 2002; Rajanikanth and Ravi, 2002; Rajanikanth *et al.*, 2002, 2003; Meixiang and He, 2002).

In the post processing technology, the plasma could not only have a good purifying effect for PM, but also clean NO_x, HC and CO in synchronism (Kai *et al.*, 2011; Thomas *et al.*, 2000), which overcome the "inborn

weakness" of high amounts of PM and NO_x for diesel vehicles. It is a new subject for some experts to study the plasma diesel exhaust purification technology.

THE MECHANISM OF THE PLASMA PURIFICATION TECHNOLOGY

The purification mechanism of the diesel exhaust treated with low temperature plasma as follow: The purpose of cleaning diesel exhaust is achieved by using a series of chemical and physical reactions caused by a large number of high energy electrons, excited particles, atoms and free radicals which be included in the low temperature plasma produced in normal pressure.

In the process of the cleaning exhaust with low temperature plasma, there are kinds of reactions including oxidation reactions and reduction reactions, which depend on the average energy of electrons, the electron density, the gas temperature, the molecular concentration of pollutant gas and the other gas composition (Qingdao and Xueli, 2004).

The exhaust composition of diesel engine is of great difference form that of gasoline. The PM emissions from diesel is generally 30~50 times than gasoline's, or even higher, the NO_x emissions from diesel is as same as gasoline's, but the HC and CO emissions from diesel is less than gasoline's. The low temperature plasma technology is main suitable for PM and NO_x.

The mechanism of low temperature plasma for removing PM: The mechanism of the low temperature plasma could remove PM as follow Guibing (2004): with the action of OH and O, the soot oxidation degradation into CO and H₂; with the adsorption and reduction of the NO_x, the soot also could oxidate degradate into NO and N₂. To form a hypothesis, PM consists of C and H, could be expressed as C_xH_y

- Glow discharge
- Arc discharge
- Corona discharge
- Dielectric barrier discharge
- RF discharge
- Microwave discharge

Glow discharge could generate under low pressure, but it is very low pressure. Corona discharge could generate under atmospheric pressure by using asymmetric electrodes (needle-plate electrodes and needle-needle electrodes), but it is difficult to obtain large volume plasma. Dielectric barrier discharge is a combination of the advantages of the two previous ones, it could generate large volume plasma under atmospheric pressure. RF discharge and microwave discharge are belongs to non-electrode discharge, could avoid electrode contamination and obtain pure plasma, but it needs low pressure. One of the demands of purification for diesel exhaust is atmospheric pressure and there are only three modes which include arc discharge, corona discharge and dielectric barrier discharge could generate plasma under normal pressure. Most of the related studies focus on corona discharge and dielectric barrier discharge, but little on arc discharge in the current situation.

The study on corona discharge and dielectric barrier discharge: Tsinghua University designed a lightweight corona discharge device and made a experiment of removing NO by using cold plasma (Wenhua and Xudong, 2004). Meixiang *et al.* (2005) and Okada (1983) made a basic research on removing NO_x by using dielectric barrier reactor under imitative condition of diesel exhaust. The result indicates that the low temperature plasma could be used to remove NO_x, but the efficiency of that NO could be converted into N₂ become lower and the energy consumption increases when the feed gas contains O₂. Many domestic and foreign experts (Miyamoto and Ogawa, 1988; Salvat, 2000; Coroller, 2002; Shangxiu, 1989) studied the influence of various components as O₂, H₂O, HC and NO_x on the purification of NO_x and the results show that the exist of O₂, H₂O, HC could be useful for the oxidation of NO into NO₂, but not for degeneration of NO into N₂.

Now the research institute home and abroad usually use many different methods (for example, DPF and SCR (Qingyun, 2001; Cooper and Thoss, 1992; Hammerle *et al.*, 1995; Page *et al.*, 1999; Chandler *et al.*, 2000; Meixiang *et al.*, 2005)) to reduce PM and NO_x simultaneously to meet more and more strict standard. Besides PM, NO_x and CO, there is a lot of O₂. That using the oxidation-reduction reaction between NO_x and PM from diesel engine itself to generate CO₂ and N₂ is a post-processing technology with good application

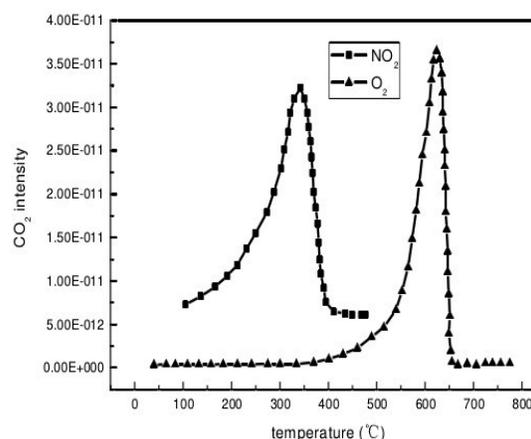


Fig. 2: The performance comparison curve of NO₂ and O₂ oxidated PM respectively

future. Yashida (Yamazoe and Teraoka, 1990) made a study on the possibility of the oxidation and reduction reaction between soot-O₂-N₂ for the first time and the result indicates that the oxidation reaction between NO and C could occur under low temperature (300°C). The findings of the studies of Johnson Matthey company (Neeft *et al.*, 1996) and Su Qingyun are shown in Fig. 2.

Figure 2 shows that the oxidation of NO₂ for soot is stronger than that of O₂ (Neeft *et al.*, 1997). The findings of Cooper's experiments show that NO could be oxidated into NO₂ with the catalytic Pt and the NO₂ could further oxidate soot (Nejar *et al.*, 2007). Penetrante coming from Lawrence Livermore National Laboratory of America devoted himself to research on post-processing technology with plasma (Penetrante *et al.*, 1999). The team lead by him made theoretical and experimental analysis on the feasibility of this method and pointed out that the energy consumption is too high when plasma is used to clean HC and PM directly and plasma reactor should be used with catalytic device. So, no matter corona discharge or dielectric barrier discharge, it is difficult to put into real use that only using plasma remove PM and NO_x simultaneously and the catalytic materials must be assisted to reduce the energy consumption.

CONCLUSION

Facing with more and more strict standard, the plasma PM/NO_x post-processing integrated control technology would be the development trend of diesel exhaust post-processing strategies. Recent years, the studies mainly on corona discharge and dielectric barrier discharge are more and more widely and the application is also progressing rapidly. Because of the disadvantage of high energy consumption it must be used with catalytic, which increase the cost and secondary pollution in the process. To solve this problem, this study put forward the new idea about the application of arc discharge in the purification of the diesel exhaust.

RECOMMENDATIONS

The disadvantage of corona discharge is that the electron has enough energy only in a small range near electrode and the electron far away from electrode can obtain little energy so the free radicals and some active materials only produced near the electrode. A lot of energy could be wasted on inefficient ionic mobility and molecular vibration easily so that the energy efficiency per unit volume reduced. Compared with corona discharge, despite dielectric barrier discharge could produced large space uniform discharge, but a considerable part of electrical energy converted into heat energy, so the energy is still not high.

There are two ideas to solve the problem of high consumption in the process of the purification of the diesel exhaust. The first one is using catalytic to increase the purification efficiency. The second one is enhancing the electron excitation ability to increase the active materials at the beginning of the generation of plasma, which could promote the interaction between components in the diesel exhaust to increase the efficiency.

I think that the second ideas could be achieved with arc discharge. Since it was invented by Patel, the carbon dioxide laser has been consider as gas laser with high energy conversion efficiency and strongest output. The working substance of gas laser mainly consists of two gas of CO₂ and NO_x. CO₂ is the main gas which generates plasma radiation and NO_x is the auxiliary gas. Document (Wenzheng *et al.*, 2009) introduced the effect of temperature and pressure for the laser running and pointed out when the temperature goes up and NO_x exists, in the discharge space, the glow discharge would be unstable contraction and transition to arc discharge gradually. According to the principle of gas laser, we could use CO₂ and NO_x in the diesel exhaust. Through discharge excitation, the transition of CO₂ molecular from low energy level to high energy level forms population inversion. In this process, because of negative nature of the oxides of nitrogen, they trapped a large number of electrons to form negative ionics, so the discharge is unstable and forms arc discharge. Because arc discharge use the components of itself to form plasma environment, so form the arc discharge (Weihong, 2007), not only its efficiency would be increase, but also its energy consumption would be lower than other discharge mode.

In the early 1990s, Czenichovski (1994) put forward gliding arc discharge non-equilibrium plasma technology. Some people besides Du Changming studied on the methods of removing PAH and carbon black particles (Changming *et al.*, 2006) in the soot simultaneously using gilding arc discharge. These studies show that the method of removing PM and NO_x simultaneously using arc discharge plasma is feasible in

theory. Now our team is actively working on related theoretical and experimental research.

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