Research on Adaptability of After-treatment Device for Diesel Vehicles In-use Based on Actual Road Conditions

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Abstract. Atmospheric environment is seriously threatened by the particulate matter and nitrogen oxide emissions of diesel vehicles in-use. Feasibility of the emission reduction technology and its application used in the China III diesel vehicles was studied, and an emission control device that meets the target vehicle according to the characteristics of vehicle operating conditions was designed. Furthermore, demonstration of emission treatment of particulate matter and nitrogen oxides in diesel vehicles was implemented. The working conditions and matching applicability between vehicles and after-treatment devices during actual road operation were analyzed, and results of emission reduction were counted. The research indicates that matched with the working conditions, the emission reduction technology for the diesel vehicles in-use can be effectively reduce pollutant emissions under actual road conditions and achieve continuous emission reduction effects.

1. Introduction
Compared with gasoline vehicles, diesel engine has become the leading power assembly for commercial vehicles due to their excellent fuel consumption and power. However, environmental problems caused by diesel vehicle emission have become a major factor restricting its development increasingly [1]. “China Mobile Source Environmental Management Annual Report” [2] published by Ministry of Ecology and Environment of the People’s Republic of China in 2019 showed that NOx exhausted by diesel vehicles is close to 70% of total vehicle emissions, and PM exceeds 90%. Compared with new vehicles, the emission intensity of China III diesel vehicles is greater, and NOx and PM emissions more than 50% of the total emissions of diesel vehicles. Research on the application of emission reduction devices for China III diesel vehicles in-use is of great significance for reducing the emission levels of pollutants of diesel vehicles and improving the atmospheric environment.

At present, the most effective technical method for reducing particulate matter in diesel vehicles is to use the DPF system, and to reduce the emissions of NOx using the SCR system [3, 4, 5, 6]. This paper combined the two systems to study the effect of using DPF + SCR technology to reduce emissions and the adaptability between emission treatment devices and vehicles under actual road operating conditions.

2. Research Scheme and Test Methods
In order to study the suitability of emission control devices on diesel vehicles in-use and evaluate the effect of reducing emissions effectively, this article selected two typical China III heavy-duty diesel trucks to carry out demonstrations of control particulate matter and nitrogen oxides collaboratively, and obtain operating data in real time through remote data transmission to monitor the operating conditions of vehicle and after-treatment device.
2.1. Test Vehicles Selection

In order to ensure the effectiveness of the test, the vehicles selected for the test were two China III heavy-duty diesel trucks of the same batch. Technical parameters of vehicles are shown in Table 1.

| Parameter          | Technical index                           |
|--------------------|-------------------------------------------|
| Model of vehicles  | Logistics vehicle                         |
| Engine form        | Inline, Six-cylinder, Water cooling        |
| Fuel supply form   | Common Rail                               |
| Intake form        | Turbocharger                              |
| Vehicle mileage    | > 400,000 kilometers                      |
| Engine Swept volume| 9.267L                                    |
| Power rating       | 259KW                                     |
| Maximum total mass | 40 ton                                    |

Complete initial emissions testing for vehicles by the opaque smoke meter MEXA600-S produced by Horiba. Before reconstruction of diesel vehicle, the test result of opaque smoke of the diesel vehicles under free acceleration values are 1.3m-1 and 1.7m-1, and engine performance indicators are normal. The test result of opaque smoke of the diesel vehicles meet reconstruction requirements proposed by China Association of Environmental Protection Industry in “Technical guide for in-use diesel vehicle emission control”[8].

2.2. Emissions Treatment Device Selection

Install selected particulate matter and nitrogen oxide collaborative treatment devices integrated by DOC, DPF, and SCR on selected vehicles. Collect exhaust temperature data for two weeks of operation before install the treatment devices on vehicles, and evaluate vehicle operating characteristics. The exhaust temperature of vehicles distribution characteristics are shown in Figure 1.

Figure 1. Exhaust temperature distribution of vehicle under actual road

The exhaust temperature is relatively high under normal vehicles operating conditions. The DPF adopting the passive regeneration technology route can realize continuous regeneration under normal vehicle running conditions. Refer to Figure 2 for a schematic diagram of the vehicle's matching emission control device system structure.
The emission control device used in the test is composed of three main parts: DOC, DPF, and SCR. The system integrates DCU controller, differential pressure sensor P, DPF upstream and downstream temperature sensors T1 and T2, SCR upstream and downstream NOx concentration sensors, urea supply system, data acquisition and remote transmission device. The DCU collects exhaust temperature and exhaust NOx concentration, and then achieves accurate metering of urea to control the urea feed pump and urea nozzle. The emission control device does not communicate with the ECU of vehicles, so the closed-loop management of the NOx conversion rate is achieved through the exhaust temperature and the concentration of nitrogen oxide in the upstream and downstream of the SCR.

The technical parameters of the emission control device used in the test are shown in Table 2.

| Parameter                                      | Technical index                        |
|------------------------------------------------|----------------------------------------|
| Device structure                               | DOC+DPF+SCR                            |
| Carrier volume, material and number of holes of DOC | 11.1L,Cordierite,300                   |
| Carrier volume, material and number of holes of DPF | 22.2L,Cordierite,200                   |
| Regeneration method of DPF                     | Continuous passive regeneration        |
| Carrier volume, material and number of holes of SCR | 22.2L,Cordierite,300                   |
| The main components of the catalyst            | Pt,Pd,Rh                               |

2.3. Remote Monitoring of Operating Conditions
Acquiring data through the remote monitoring system has the advantages of large amount of data, low cost and more intuitive reflection of the actual road operation characteristics of vehicles and after-treatment. To meet the requirements of monitoring for continuous operation status of demonstration vehicles, this article uses the "Remote Online Monitoring Platform for Heavy-duty Diesel Vehicle Emissions" for remote monitoring of data. The interface of the remote monitoring platform is shown in Figure 3.
Figure 3. The interface of the remote monitoring platform

Through remote monitoring, the GPS position of vehicles, exhaust temperature, exhaust pressure difference, NOx concentration emission, urea level and other data can be obtained in real time, providing a means for data acquisition and result analysis of emission control operations.

3. Results and Analysis
By installing emission control devices on vehicles to conduct emission control demonstration operations, different from vehicle emission levels under fixed operating conditions, this paper take the advantage of the remote monitoring platform and emission testing equipment to obtain vehicle and after-treatment device operating condition , to analyse operation and emissions of vehicles after treatment under the actual road.

3.1. Analysis of Operating Conditions
The two China III heavy-duty diesel trucks selected for the test belong to the same fleet. By comparing the vehicle operating parameters, the characteristics of its operating conditions are very close. Random interception of the actual running speed of the vehicle for 8 consecutive hours within a day is shown in Figure 4.

Figure 4. Vehicle running speed curve

The speed characteristics of the vehicle running during a continuous month are shown in Figure 5.
Figure 5. Vehicle running speed characteristic distribution

The test vehicles selected to run more on medium and high speed sections. Logistics vehicles are mainly in high-speed operation. The running time of vehicle speeds greater than 50km/h accounts for nearly 50% of the total operating time. The average speed of the entire operating cycle is 37km/h, while the average speed of high-speed operation (speed is greater than 50 km/h) is 52km/h. At higher operating speeds, the exhaust temperature of the vehicle continues to remain at a high level, which is conducive to the after-treatment device in a good working state and improves the efficiency of exhaust pollutant conversion, while achieving a good exhaust treatment effect.

3.2. Matching Adaptation Analysis
This paper analyzed the operating parameters of emissions-treated China III heavy-duty diesel vehicles under actual road operation. Intercept a typical short trip of a vehicle, and its running speed curve is shown in Figure 6.

Figure 6. Speed curve of vehicle short trip

The short trip segment has a maximum speed of 73km/h and an average speed of 31.5km/h. For such vehicles, the segment is sufficiently representative. The upstream and downstream exhaust gas temperatures of the DPF under this segment were calculated, and the matching between the after-treatment device and the vehicle's operating status was studied.

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During this short trip, the average exhaust temperature of the DPF upstream of the vehicle was 276°C, the average downstream exhaust temperature was 262°C, and the average temperature loss was 5%. The small temperature loss keeps the downstream exhaust gas temperature of the DPF at a high level, and provides a suitable reaction temperature for SCR to convert the NOx. This is due to the thermal insulation measures upstream of the after-treatment. The conditions where the downstream exhaust temperature of DPF is higher than the upstream account for 35% of the total operating conditions, and most of them occur within 200 ~ 350s from high to low upstream of DPF. In this process, DPF continuously regenerates under the action of high temperature. The oxidation reaction of particulate matter causes the downstream exhaust gas temperature of the DPF to be higher than the upstream. Figure 8 shows the exhaust pressure change in DPF during vehicle running.

During normal operation of the vehicle, the exhaust temperature is at a high level, which can meet the regeneration temperature requirements of the passive regeneration after-treatment device. The exhaust pressure is mainly stable below 8Kpa. With the increase of vehicle speed, the increase of the engine speed causes the vehicle exhaust pressure to increase, but continuously maintains high exhaust temperature condition for a period of time, and the vehicle exhaust pressure gradually returns to
normal and stable within a reasonable range. Passive regenerative DPF can keep good running state during the actual road operation of this type of vehicle.

3.3. Analysis of Emission Reduction Effects
Evaluate emission reduction effects for vehicles treated with emissions. In order to ensure that the emission reduction effect continues to keep a good state, free accelerated exhaust smoke detection is performed every 60 days, a total of three consecutive times, and the results are counted. The test results of vehicle emission are shown in Figure 9.

![Test results of vehicle emissions](image)

**Figure 9. Test results of vehicle emissions**

After the emission retrofitted, the vehicle particulate matter emissions were significantly reduced, and the smoke value was reduced by more than 90%, meeting the requirements of emission retrofitting.

This paper analyzed NOx emission reduction effect by comparing NOx emission concentration in SCR upstream and downstream of the vehicle. In a typical short trip segment of a vehicle under actual road operation, the statistical conversion efficiency of vehicle NOx emission is shown in Figure 10.

![Conversion efficiency of NOx](image)

**Figure 10. Conversion efficiency of NOx**

According to the conversion efficiency of nitrogen oxides of the vehicle under the actual operation, the downstream exhaust gas temperature of the DPF in this short trip segment remains at a high level, which accounts for 90% above 250°C, it can be judged that the after-treatment device is in good operation state. SCR system works well, with an average conversion efficiency of 56.7%, which can effectively reduce NOx emissions.
4. Conclusions

(1) By adopting the method of installing an emission control device, and matching an appropriate after-treatment device for exhaust retrofitting according to the vehicle working conditions, it can effectively reduce the particulate matter and nitrogen oxide emission levels of China III heavy-duty diesel vehicles under actual road operation, and obtain a good continuous emission reduction effect. Exhaust smoke reduction rate of over 90% and average NOx conversion efficiency of over 56%.

(2) Using remote data transmission to study the effect of vehicle emission control can effectively obtain the vehicle's actual running status on the real road, and is a powerful means to ensure the operating steady of the emission retrofitting device.

(3) For the in-use diesel vehicles exhaust retrofitting, the vehicle operating conditions play a decisive role in reducing emissions, and the matching between vehicle and the retrofitting technology route plays a decisive role in vehicle exhaust retrofitting.

The use of sections to divide the text of the paper is optional and left as a decision for the author. Where the author wishes to divide the paper into sections the formatting shown in table 2 should be used.

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