Research on Technical Characteristics of CDPF + SCR for China-III Heavy-Duty Diesel Vehicles Emission Retrofit Based on Remote Monitoring Method

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Abstract. In order to study the technology of reducing heavy-duty diesel vehicles PM and Nox emission, a China-III sprinkler driving on Tianjin expressway was selected to equip with CDPF+SCR for demonstration of PM and NOx emission retrofit. By using the remote monitoring method, the vehicle speed, engine speed, exhaust temperature and pressure drop of upstream and downstream CDPF, NOx concentration upstream and downstream SCR, geographical location and other data were collected and analyzed in real time, and analyze the characteristics of CDPF passive regeneration, SCR conversion efficiency and DPF matching with SCR. The results show that the idling speed and the middle and low speed operating conditions of the sprinkler are evenly distributed, exhaust temperature at 175~275 ℃ accounts for 74%, and CDPF started passive regenerative emission retrofit at 220℃, NOx concentration after installing SCR was mainly concentrated below 800ppm, the average NOx concentration was 620ppm, and the reduction rate of NOx concentration was 51.6%.

1. Introduction

Due to the advantages of low fuel consumption, high torque output and wide power coverage, diesel engines are widely used in the fields of transportation and engineering machinery [1]. However, as the main source of PM and NOx emissions, emission sharing rate of diesel vehicles exceeds 70% and 90% respectively, and has become the top priority of vehicle pollution prevention and control [2]. In order to reduce PM emissions from in-use diesel vehicles, United States, Korea and Europe have successfully carried out DOC, DPF emission retrofit for diesel vehicles [3]. Meanwhile, DPF has been successfully installed in Beijing, Tianjin, Shanghai, Nanjing and other provinces and cities since 2008. However, as another important pollutant, NOx has not been effectively controlled. According to “Action Plan for Prevention and Control of Diesel Truck Pollution” issued by Ministry of Ecology and Environment of China, the DPF+SCR retrofit technology can effectively reduce PM and NOx emission from in-use diesel vehicles [4-5].

Cheng Xiaozhang et.al [6] conducted SCR/DOC+DPF+SCR performance tests on heavy-duty diesel engine platforms. Wang Jialei [7] carried out numerical simulation and demonstration research on emission reduction effect of DPF+SCR retrofit of diesel vehicles in Shanxi Province. He Y[8], Schaefer M[9] conducted systematic studies on the effects of DPF+SCR technology on PM and NOx emission reduction. However, few researches are carried out on the technical characteristics and matching relationship of DPF+SCR in diesel vehicle emission retrofit at home and abroad.

In order to study the characteristics of DPF+SCR technology in emission retrofit of diesel vehicles, in this paper, a China-III sprinkler was selected in Tianjin for emission retrofit by adding CDPF+SCR, by means of remote monitoring, data such as vehicle speed, engine speed, exhaust...
temperature and pressure drop before and after CDPF installation, NOx concentration before and after SCR installation and geographical location were collected and analyzed, the characteristics of CDPF passive regeneration, SCR conversion efficiency and DPF matching with SCR were analyzed under actual road condition.

2. Research Approach

2.1. Parameters of Diesel Vehicle and DPF+SCR Device
A China-III diesel sprinkler was selected as the test vehicle to carry out emission retrofit demonstration by installing DPF+SCR in Tianjin. The parameters of test vehicle and DPF+SCR are shown in Table 1 and Table 2 respectively.

| Items                  | Parameters                  |
|------------------------|-----------------------------|
| Vehicle model          | KFM1281YHLC                 |
| Engine type            | ISDE160.30                  |
| Power/Displacement     | 4.5L/118kW                  |

Table 2 Parameters of DPF+SCR

| Device     | Parameters                  |
|------------|-----------------------------|
| DOC        | Size, Volume: Φ7.5*3, 4.34L |
|            | Substrate material and CPSI: Cordierite, 300 |
|            | Precious metal content and Proportion (Pt: Pb: Rh): 25g/ft^3, 5:1:0 |
| CDPF       | Size, Volume: Φ7.5*6, 8.68L |
|            | Substrate material and CPSI: Cordierite, 300 |
| V- SCR     | Size, Volume: Φ7.5*6.8.68L |
|            | Substrate material and CPSI: Cordierite,300 |

2.2. DPF+SCR Devices Installation and Related Control Strategies
Considering that the original vehicle muffler of the test vehicle is arranged under the chassis, this paper adopts U-shaped structure DPF + SCR in order to keep vehicle's passability and ensure effect of emission retrofit. The main work of emission retrofit is to remove the original vehicle silencer, replaced with DPF+SCR device and related components (urea tank, urea injection controller, data transmission device, etc.) on its location. The comparison of exhaust system structure before and after emission retrofit is shown in Figure 1.

![Original vehicle muffler](image1)
![DPF+SCR retrofit](image2)

**Figure 1** Comparison of DPF+SCR retrofit

In the retrofit, DPF+SCR does not communicate with the engine ECU of the test vehicle, and operates mainly according to the corresponding control strategies of speed. CDPF starts to regenerate
at 220°C and achieves the best regeneration effect at 300-400°C. SCR starts to spray urea when the exhaust temperature reaches 220°C.

3. Test Results and Analysis

3.1 Operation Characteristic Analysis of Test Vehicle

In order to facilitate the data analysis of vehicle speed and exhaust temperature, the author divided the interval between the two parameters, as shown in Table 3.

| Number | Speed(km/h) | Exhaust Temperature(℃) |
|--------|-------------|-------------------------|
| A0     | 0<V≤5       | 0<T≤25                  |
| A1     | 5<V≤10      | 25<T≤50                 |
| ...    | ...         | ...                     |
| A12    | 55<V≤60     | 275<T≤300               |

![Table 3 Interval division of vehicle speed and exhaust temperature](image)

The distribution of test vehicle speed and exhaust temperature during the entire operation period is shown in Figure 2. The distribution ratio of the test vehicle in idle, low and medium speed operating conditions is relatively average. Among them, A0 idle condition accounts for 32.7% of the whole operating condition, A1~A10 low speed condition (0,40] km/h accounts for 32.7%, A11~A12 medium speed condition (40,60] km/h accounts for 34.6%. As the distribution of the test vehicle operating conditions is relatively balanced, the distribution of exhaust temperature is also relatively average. A0~A8 Medium and low temperature working conditions (0,200] °C and A9~A12 high temperature working conditions (200,300] °C respectively accounted for 50% of the whole working conditions, among which A8~A11 medium high temperature working conditions (175,275] °C accounted for 74%. The peak point is at A9 (200,225] °C, accounting for 31.6%.

3.2 Characteristic Analysis of DPF Passive Regeneration

In order to study the characteristics of passive regeneration of CDPF in the post-processing device, the author selects a running segment of the test vehicle to study and analyze the relationship between the vehicle speed and the DPF inlet / outlet temperature and pressure drop, as shown in Figure 3.
It can be seen from Figure 3 (a) that the changes in the rise and fall of the DPF inlet/outlet temperature are consistent with the changes in the operating speed of the test vehicle. At the beginning of vehicle operation, the temperature of the DPF inlet/outlet is rapidly increased from 100/150 ℃ to 225/270 ℃, and then the temperature is maintained at 250~300 ℃ when the speed is maintained in the range of 40~50km/h. When the vehicle speed decreases, the DPF inlet/outlet temperature gradually decreases to 200 ℃. In addition, the outlet temperature of the DPF is lower than the inlet temperature by 30 to 50 ℃ for a long time, which is mainly due to the heat loss of exhaust pollutants when filtering in the DPF.

In this paper, the CDPF lightening temperature is 220 ℃, and the DPF pressure drop shown in Figure 3 (b) is always in the range of 3 ~ 7kPa in the entire operating condition segment. It can be seen that more than 80% of the test vehicle operating conditions in the above-mentioned operating condition segment are in a passive regeneration state.

### 3.3 Characteristic Analysis of SCR

SCR is usually tightly coupled downstream of the DPF in the post-processing device system. The matching between the two is critical to the SCR performance: First, when the DPF outlet temperature is low, the SCR does not reach the light-off temperature, which makes the SCR system unable injected urea or NOx conversion efficiency is low. Second, when the DPF outlet temperature is too high, although the SCR system has high NOx conversion efficiency, it can easily cause thermal shock damage to the SCR carrier and the V2O5 of the vanadium SCR to thermally volatilize, causing heavy metal pollution.

The control strategy of SCR urea injection is controlled by exhaust temperature, NOx concentration at the inlet and outlet of SCR, vehicle speed and other factors. One of the control strategies of urea injection is to keep the urea injection rate constant when the exhaust temperature of the SCR outlet is lower than a certain temperature, and to increase the urea injection rate when the exhaust temperature is higher than the certain temperature.
injection in SCR system adopted in this paper is that the exhaust temperature should reach above 220°C.

In order to study the influence of the matching of the whole post-processing system on SCR performance, the author studied and analyzed the correlation between vehicle speed, SCR inlet temperature and NOx conversion efficiency under the same operating condition fragment above. The whole operation process was divided into three stages, as shown in Figure 4.

![Figure 4](image-url)

**Figure 4** Actual road speed, SCR inlet temperature and NOx conversion efficiency

Stage 1: after the vehicle starts, the exhaust temperature increases rapidly with the vehicle speed. However, in the first 10min of this stage, before the exhaust temperature reaches 220°C, the NOx conversion efficiency is 0. When the exhaust temperature reaches 220°C and remains within the range of 180~300°C, the SCR control strategy starts urea injection, at which point the NOx conversion efficiency reaches 60~80%.

Stage 2: when the vehicle is in the idle stage, although the exhaust temperature is still above 220°C, according to the SCR control strategy, no urea is injected in the idle condition, so the NOx conversion efficiency is 0. However, when the vehicle stops and idles, the NOx conversion efficiency does not immediately decrease to 0, mainly because the SCR supported catalyst has the function of ammonia storage. Although no urea is injected, NOx emission can be reduced by releasing stored ammonia gas at this temperature.

Stage 3: when the vehicle is running at a low speed (less than 20km/h), the exhaust temperature gradually drops to below 250°C, and the ammonia storage function of SCR also keeps the NOx conversion efficiency at a relatively high level. After the stored ammonia gas is released, the NOx conversion efficiency is 0 because SCR does not spray urea.

4. Conclusion

(1) In the operation condition of the diesel sprinkler on the urban expressway, the exhaust temperature in the range of 200~300°C accounts for 50% of the whole operating condition, which can ensure the CDPF to achieve passive regeneration in the actual road operation.

(2) The post-processing device (CDPF+SCR) was applied in the emission retrofit, and the reduction rate of NOx reached 51.6%. After emission retrofit, the concentration of NOx was mainly lower than 800ppm, accounting for 84% of the whole operating condition.

(3) In the matching process of CDPF+SCR, the CDPF outlet temperature in the passive regeneration process is always lower than 300°C, which will not cause volatilization of V2O5 in
vanadium SCR. Therefore, vanadium SCR technology can be used when choosing CDPF passive regeneration technology.

5. References

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