Comparison of Catalytic Conversion Characteristics of Different Integrated Aftertreatment Systems in Diesel Engine

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Abstract. Pollutants such as NOx, HC, CO, and PM emitted by diesel engines will cause serious air pollution. In order to reduce the exhaust emissions of diesel engines, there are mainly DOC, DPF, SCR, AOC, etc. for the after-treatment technology of the engine. Therefore, the use of integrated aftertreatment systems has become a necessary choice. At present, the layout schemes of integrated aftertreatment systems for diesel engines mainly include DOC + DPF + SCR + AOC, DOC + SCR + DPF + AOC, DOC + CDPF + SCR + AOC, DOC + SCR + DPF + AOC, etc. When processing the system, each sub- aftertreatment system will generate a mutual coupling effect. This coupling interference may promote the system's conversion effect to the pollutants, and it may also weaken the system's conversion effect on the pollutants. The catalytic conversion characteristics of the integrated aftertreatment system are closely related to exhaust parameters and layout schemes. In this paper, simulation methods are used to compare and study the effects of the above four integrated post-treatment systems on the catalytic conversion characteristics of various pollutants under different exhaust parameters.

Keywords: Diesel Engine, Aftertreatment System, Catalytic Conversion, Simulation

1. Introduction
Different arrangements have different effects on the working process of the catalyst [1]. This article is based on DOC + DPF + SCR + AOC as the main research object. First, it compares the catalytic conversion characteristics of DOC + DPF + SCR + AOC and DOC + SCR + DPF + AOC for each pollutant under different exhaust parameters. Impact. In order to investigate the impact of passive DPF regeneration on the integrated post-processing system, a CDPF (Application Catalyst for Passive DPF Regeneration) subsystem was introduced, followed by DOC + DPF + SCR + AOC, DOC + CDPF + SCR + AOC, DOC + SCR + CDPF + AOC three layout schemes are used as the research object. The exhaust parameters of the diesel engine under a defined reference condition, including exhaust temperature, exhaust pressure, and pollutant concentration in the exhaust are used as inputs for the steady-state response characteristics of the integrated aftertreatment system. Parameters, the effects of three integrated aftertreatment systems on the catalytic conversion characteristics of different
pollutants under different exhaust parameters are compared and studied.

2. Simulation Model of Integrated Aftertreatment System

This paper uses GT to build an integrated aftertreatment system simulation model based on the technical parameters of the diesel exhaust aftertreatment system and related chemical reaction parameters obtained by consulting the literature[2][3][4]. The main technical parameters are shown in Table 1 and Figure1 to Figure 4.

Table 1. Integrated aftertreatment system subsystem parts technical parameters

| Subsystem | Carrier material / (mm) | Carrier diameter / (mm) | Carrier length / (mm) | Carrier volume / (L) | Hole density / (cps) | Wall thickness / (mil) |
|-----------|------------------------|------------------------|----------------------|----------------------|----------------------|-----------------------|
| DOC       | Cordierite             | 143.8                  | 101.6                | 1.65                 | 400                  | 4                     |
| DPF       | SiC                    | 143.8                  | 228.6                | 3.71                 | 300                  | 9                     |
| SCR       | Cordierite             | 172                    | 101.6 + 101.6        | 4.72                 | 400                  | 4                     |
| AOC       | Cordierite             | 172                    | 50.8                 | 1.18                 | 400                  | 4                     |

According to the above technical parameters, four types of integrated aftertreatment system...
working process simulation models are established: DOC + DPF + SCR + AOC, DOC + SCR + DPF + AOC, DOC + DCPF + SCR + AOC, DOC + SCR + DCPF + AOC, as shown in Figure 5.

![Simulation models for the working processes of four integrated aftertreatment systems](image)

**Figure 5.** Simulation models for the working processes of four integrated aftertreatment systems

### 3. Comparison of Catalytic Conversion Characteristics of four Integrated Aftertreatment Systems

In the following comparison, the integrated aftertreatment systems of DOC + DPF + SCR + AOC, DOC + SCR + DPF + AOC, DOC + DCPF + SCR + AOC and DOC + SCR + DCPF + AOC are respectively named as scheme 1, scheme 2, scheme 3 and scheme 4. The method of control variable was used to study the variable parameters, with the exhaust flow rate of 45 g / s, exhaust temperature of 685 K, NOx concentration of $500 \times 10^{-6}$, HC concentration of $150 \times 10^{-6}$, CO concentration of $250 \times 10^{-6}$, particle concentration of $400 \times 10^{-6}$ as the quantitative, and defined as the reference condition. The simulation was carried out by changing different independent variables to study the catalytic conversion of pollutants by different integrated aftertreatment systems under the exhaust parameters Influence.

#### A. Comparison of Two Layout Schemes of Doc + Dpf + Ser + Aoc and Doc + Scr + Dpf + Aoc

The impact of the integrated aftertreatment system with two layout schemes of scheme 1: DOC + DPF + SCR + AOC and scheme 2: DOC + SCR + DPF + AOC on the conversion efficiency of each pollutant under different exhaust parameters is shown in Figure 6.

![Comparison of two layout schemes under different exhaust parameters](image)

**Figure 6.** Comparison of two layout schemes under different exhaust parameters

The simulation results show that, without considering the passive regeneration of DPF, the DPF’s purification of particles takes filtration as the main way and does not involve the catalytic conversion of particles. Therefore, the integrated aftertreatment system with the layout of scheme 1: DOC + DPF + SCR + AOC and scheme 2: DOC + SCR + DPF + AOC has no obvious effect on the conversion efficiency of pollutants under different exhaust parameters.
B. Comparison of Three Different Layout Schemes

According to the above, the comparison of pollutant conversion efficiency between scheme 1: DOC + DPF + SCR + AOC and scheme 2: DOC + SCR + DPF + AOC is not obvious, so the impact on scheme 2: DOC + SCR + DPF + AOC will not be mentioned in the following comparison of multiple schemes. In this section, the research object is scheme 1: DOC + DPF + SCR + AOC, and scheme 3: DOC + CDPF + SCR + AOC and scheme 4: DOC + SCR + CDPF + AOC. The influence of the integrated aftertreatment system of these three schemes on the catalytic conversion efficiency of each pollutant under different exhaust parameters is explored.

When the exhaust temperature is 685 K, NOx concentration is $500 \times 10^{-6}$, HC concentration is $150 \times 10^{-6}$, CO concentration is $250 \times 10^{-6}$ and particle concentration is $400 \times 10^{-6}$, the comparison of the conversion rate of each pollutant with the exhaust mass flow of the three schemes is shown in Figure 7.

(a) NOx conversion rate  (b) CO conversion rate  (c) HC conversion rate  (d) PM conversion rate

**Figure 7.** Comparison of three layout schemes under different exhaust flow rates

The simulation results show that from Figure 7(a), the NOx conversion rate decreases with the increase of exhaust flow, but scheme 3 has the highest NOx conversion rate, which may be related to the preposition of CDPF in scheme 3. When the exhaust passes through DOC and CDPF, the passive regeneration consumes NO$_2$, and the CRT effect is more obvious [5], making the overall NOx conversion rate higher than the other two schemes. There is little difference between scheme 1 and scheme 4 in the catalytic conversion effect of NOx. This is because scheme 4 has less NO$_2$ used for passive regeneration due to more NO$_2$ is reduced when the exhaust gas passes through SCR, which affects the passive regeneration effect of CDPF.

It can be seen from Figure 7(b) that the change of CO conversion rate in scheme 1 is not obvious with the exhaust flow, the decrease of CO conversion rate in scheme 4 is small with the increase of exhaust flow, and the decrease of CO conversion rate in scheme 3 is the largest with the increase of exhaust flow. Due to the passive regeneration strategy adopted in scheme 3 and scheme 4, CDPF will oxidize the particles by using the exhaust gas of NO$_2$ in the exhaust gas, and new co will be generated in the oxidation process, resulting in the overall CO conversion rate of scheme 3 and scheme 4 is smaller than that of scheme 1. Although the passive regeneration strategy is adopted for scheme 3 and scheme 4, different catalytic conversion effects on CO are produced due to different arrangement positions of CDPF.

It can be seen from Figure 7(c) that under the three arrangements, the HC conversion efficiency decreases with the increase of exhaust flow; and the three arrangements have little difference in the HC catalytic conversion effect, because in the three arrangements, HC in the exhaust is oxidized in DOC first, and then does not generate HC when the exhaust passes through the subsequent subsystem.

From Figure 7(d), it can be seen that the particle purification rate in scheme 1 increases slightly with the increase of exhaust flow. In scheme 3 and scheme 4, because DPF adopts regeneration strategy, the conversion effect of DPF to particles can reach a very high level and the difference is not obvious under the dual effects of physical filtration and oxidation of particles.

Under the conditions of exhaust flow of 45 g / s, NOx concentration of $500 \times 10^{-6}$, HC concentration of $150 \times 10^{-6}$, CO concentration of $250 \times 10^{-6}$ and particle concentration of $400 \times 10^{-6}$, the comparison of the conversion rate of each pollutant with the change of gas temperature is shown in Figure 8.
Figure 8. Comparison of three layout schemes under different gas temperature

It can be seen from Figure 8(a) that under the three arrangements, the NOx conversion rate increases first and then decreases with the increase of exhaust temperature. The exhaust temperature is in the range of 600k - 750k, and the conversion efficiency of scheme 3 to NOx is slightly higher than that of the other two schemes. According to the relevant literature [6], in this exhaust temperature range, the catalyst activity in the subsystem CDPF catalytic converter is higher, so the oxidation effect of NOx on particles is better in the process of passive regeneration, so the NOx conversion rate is relatively high.

It can be seen from Figure 8(b) that the change trend of CO conversion rate with exhaust temperature is different under the three layout schemes, and the change of CO conversion rate with exhaust temperature in scheme 1 is not obvious. The CO conversion rate of scheme 3 and scheme 4 decreases first and then increases with the increase of exhaust temperature, and the CO conversion rate reaches the lowest value when the exhaust temperature is near 600k. According to the CO concentration at the inlet and outlet of CDPF subsystem in scheme 3 shown in Figure 9 under different exhaust temperatures, CDPF generates more CO in the passive regeneration process when the exhaust temperature is near 600k, which will lead to The CO conversion rate of the whole system becomes smaller.

Figure 9. CO concentration at inlet and outlet of CDPF under different exhaust temperatures in scheme 3

It can be seen from Figure 8(c) that under the three arrangements, the HC conversion efficiency increases with the increase of gas temperature, and the three arrangements have little difference in the HC catalytic conversion effect, similar to figure 7 (c).

It can be seen from Figure 8(d) that the change of particle purification efficiency is not obvious with the increase of gas temperature in all three schemes. However, in scheme 3 and scheme 4, because DPF adopts regeneration strategy, the purification effect of DPF is better than that of scheme 1, and the difference between the two schemes is not obvious.

Under the conditions of exhaust flow of 45 g / s, exhaust temperature of 685 K, HC concentration of $150 \times 10^6$, CO concentration of $250 \times 10^6$ and particle concentration of $400 \times 10^6$, the comparison of pollutant conversion rate with NOx concentration in the three layout schemes is shown in Figure 10.
From Figure 10(a), it can be seen that the NOx conversion rate of scheme 1 and scheme 4 increases with the increase of NOx concentration in the exhaust gas, and the difference between the two schemes is not obvious. In scheme 3, the NOx conversion rate can reach a very high level at different NOx concentrations, and the change is unclear with the increase of NOx concentration, which is higher than scheme 1 and scheme 4, because scheme 3 is more favorable for CRT effect.

It can be seen from Figure 10(b) that the CO conversion rate of scheme 1 and scheme 4 does not change significantly with the increase of NOx concentration in the exhaust gas, and there is no significant difference between the two schemes. However, the CO conversion rate in scheme 3 increases with the NOx concentration in the exhaust gas and the effect is not as good as scheme 1 and scheme 4, and shows a decreasing trend.

It can be seen from Figure 10(c) that under the three arrangements, the HC conversion efficiency does not change significantly with the increase of NOx in the exhaust gas, and the three arrangements have little difference in the HC catalytic conversion effect.

It can be seen from Figure 10(d) that the particle purification efficiency of the three schemes does not change significantly with the increase of NOx concentration in the exhaust gas.

Under the conditions of exhaust flow of 45 g / s, exhaust temperature of 685 K, NOx concentration of $500 \times 10^{-6}$, HC concentration of $150 \times 10^{-6}$ and particle concentration of $400 \times 10^{-6}$, the comparison of pollutant conversion rate with CO concentration in the three layout schemes is shown in Figure 11.

From Figure 11(a), it can be seen that the NOx conversion rate of scheme 1 and scheme 4 has little change with the increase of CO concentration in the exhaust gas, and the difference between the two schemes is not obvious. The change of scheme 3 with the increase of CO concentration in exhaust gas is unidentified and higher than scheme 1 and scheme 4.

From Figure 11(b), it can be seen that the CO conversion rate of scheme 1 and scheme 4 does not change significantly with the increase of CO concentration in the exhaust gas, and there is no significant difference between the two schemes. However, with the increase of NOx concentration in the exhaust gas, the CO conversion in scheme 3 is not as effective as scheme 1 and scheme 4, and shows an increasing trend.

From Figure 11(c), it can be seen that under the three arrangements, the HC conversion efficiency does not change significantly with the increase of CO concentration in the exhaust gas, and the three arrangements have little difference in the HC catalytic conversion effect.

It can be seen from Fig. 11 (d) that the change of particle purification efficiency is not obvious with the increase of CO concentration in exhaust gas.

Under the conditions of exhaust flow of 45 g / s, exhaust temperature of 685 K, NOx concentration of $500 \times 10^{-6}$, CO concentration of $250 \times 10^{-6}$ and particle concentration of $400 \times 10^{-6}$, the comparison
of pollutant conversion rate with HC concentration in the three schemes is shown in Figure 12.

![Figure 12. Comparison of three layout schemes under different HC concentration](image)

(a) NOx conversion rate  (b) CO conversion rate  (c) HC conversion rate  (d) PM conversion rate

From Figure 12(a), it can be seen that the NOx conversion rate of scheme 1 and scheme 4 slightly increases with the increase of HC concentration in the exhaust gas, and the difference between the two schemes is not obvious.

From Figure 12(b), it can be seen that the CO conversion rate of scheme 1 and scheme 4 does not change significantly with the increase of HC concentration in exhaust gas, and the difference between the two schemes is not significant. However, with the increase of HC concentration in exhaust gas, CO conversion in scheme 3 is not as effective as scheme 1 and scheme 4, and shows an increasing trend.

From Figure 12(c), it can be seen that under the three arrangements, the HC conversion efficiency does not change significantly with the increase of CO concentration in the exhaust gas, and the three arrangements have little difference in the HC catalytic conversion effect.

It can be seen from Figure 12(d) that the particle purification efficiency of the three schemes does not change significantly with the increase of HC concentration in the exhaust gas. However, in scheme 3 and scheme 4, the purification effect of scheme 1 is better than that of scheme 1, and the difference between the two schemes is not obvious.

Under the conditions of exhaust flow of 45 g/s, exhaust temperature of 685 K, NOx concentration of $500 \times 10^5$, CO concentration of $250 \times 10^5$, and HC concentration of $150 \times 10^5$, the comparison of pollutant conversion rate with particle concentration in the three layout schemes is shown in Figure 13.

![Figure 13. Comparison of three layout schemes under different Soot concentration](image)

(a) NOx conversion rate  (b) CO conversion rate  (c) HC conversion rate  (d) PM conversion rate

From Figure 13(a), it can be seen that the NOx conversion rate does not change much with the concentration of particles in the exhaust gas under the three arrangements. The difference between scheme 1 and scheme 4 is not obvious. Scheme 3 is better than scheme 1 and scheme 4 in NOx conversion rate under different exhaust particle concentration.

From Figure 13(b), it can be seen that the CO conversion rate does not change much with the concentration of particles in the exhaust gas under the three arrangements. There is no obvious difference between scheme 1 and scheme 4. The conversion efficiency of scheme 3 to CO under different exhaust particle concentration is not as good as scheme 1 and scheme 4.

From Figure 13(c), it can be seen that under the three arrangements, the HC conversion efficiency does not change significantly with the increase of particle concentration in the exhaust gas, and the three arrangements have little difference in the HC catalytic conversion effect.

It can be seen from Figure 13(d) that the change of particle purification efficiency is not obvious with the increase of particle concentration.
4. Conclusions
In this paper, taking DOC+DPF+SCR+AOC as the research object, by changing different diesel engine exhaust parameters, the integrated aftertreatment system was used to convert NOx, HC, CO and PM under different exhaust parameters, different catalytic converter structural parameters and chemical reaction parameters, conclusions are drawn from the research:

(1) Without considering the passive regeneration of DPF, since DPF purification of particles is mainly by filtration and does not involve the catalytic conversion of particles, the integrated post-treatment system with the layout of scheme 1: DOC + DPF + SCR + AOC and scheme 2: DOC + SCR + DPF + AOC has no obvious effect on the conversion efficiency of pollutants under different exhaust parameters.

(2) Scheme 3: the catalytic conversion of DOC + CDPF + SCR + AOC to NOx has the best effect in three schemes, which may be related to the preposition of CDPF in scheme 3. When the exhaust gas passes through doc and then CDPF, the passive regeneration consumes NO2, and the CRT effect is more obvious, making the overall NOx conversion rate higher than the other two schemes.

(3) Because there are more NO2 reduced when the exhaust gas passes SCR in scheme 4, there are less NO2 used for passive regeneration in CDPF, so the passive regeneration effect of CDPF is affected, so the catalytic conversion effect of scheme 1 and scheme 4 on NOx is not different.

(4) Due to the passive regeneration strategy adopted in scheme 3 and scheme 4, new co will be generated in the oxidation process of exhaust gas after CDPF, resulting in the overall CO conversion rate of scheme 3 and scheme 4 is smaller than that of scheme 1.

(5) Although the passive regeneration strategy is adopted for scheme 3 and scheme 4, different catalytic conversion effects on CO are produced due to different arrangement positions of CDPF. In scheme 3, when the exhaust gas passes through CDPF, the particles will react fully with the NO2 produced by the upstream doc oxidation and a small amount of NO2 emitted by the original engine, and then a large amount of CO will be produced. In scheme 3, the CO conversion efficiency is the lowest among the three schemes. In scheme 4, SCR is arranged at the upstream of CDPF, which makes a large amount of NO2 in exhaust gas be reduced to N2 when passing SCR, so the amount of NO2 used for passive regeneration of CDPF will be small, and the amount of CO generated will be small, so the CO conversion efficiency in scheme 4 is higher than that in scheme 3.

(6) Among the three arrangements, HC in the gas is oxidized in doc first, and no HC is produced when the exhaust gas passes through the subsequent subsystem, so the three arrangements have little difference in the effect of HC catalytic conversion.

(7) In scheme 3 and scheme 4, because DPF adopts regeneration strategy, under the dual effects of physical filtration and oxidation of particles, the conversion effect of DPF to particles can reach a very high level and the difference is not obvious, and the purification effect is better than scheme 1.

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