

# Study on influence of the NO<sub>x</sub> emissions characteristics entering the steady point in different initial catalyst temperature

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**Abstract.** A bench test was carried out in order to study the influence of the emissions characteristics of NO<sub>x</sub> entering the steady point in different initial catalyst temperatures. The results showed that firstly the NO<sub>x</sub> emissions gradually reduced, then started rising when reduced to about 10 ppm, and finally tended to be stable. The temperature of entering the point was lower, the time when NO<sub>x</sub> reaches the equilibrium state was longer. The ammonia nitrogen ratio was higher, the minimum value NO<sub>x</sub> that could be achieved was lower, the ammonia storage cushioning effect for NO<sub>x</sub> was stronger, and the time in which emissions achieved steady state was also longer.

**Key words.** Diesel engine, nitrogen oxides, elective catalytic reduction, ammonia.

## 1. Introduction

At present, Phase IV Emission Standard has been fully implemented in emissions requirements of China's heavy-duty automotive diesel engine. SCR (Selective Catalytic Reduction) technology which uses urea as a reducing agent has been widely used because of its advantages such as improved fuel consumption by optimized in-cylinder combustion and strong anti-sulfur poisoning, etc., which plays an important role in alleviating air pollution caused by diesel exhaust. SCR upstream temperature has a direct impact on catalyst performance. During the test, presence of hot car stability time inconsistency, piping layout as well as original machine status will result in SCR upstream temperature difference in steady state cycle, thereby affecting NO<sub>x</sub> emission results. In this paper, through A100 operating point of upstream temperature of different catalysts to be switched to steady circulation, effect of initial temperature of different catalysts on NO<sub>x</sub> emissions and ammonia leakage of the steady-state operating point is studied.

The main technical parameters of the diesel engine are listed in Table 1.

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Table 1. Main technical parameters of diesel engine

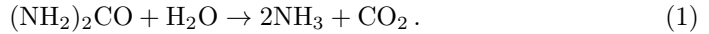
Parameter	Unit	Value
Rated power	kW	110
Rated speed	r/min	2300
Maximum torque	N·m	550
Maximum no-load stabilized speed	r/min	2650
Minimum no-load stabilized speed	r/min	650

## 2. SCR reaction

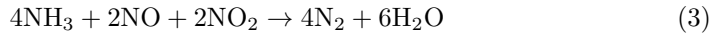
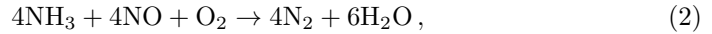
### 2.1. SCR reaction fundamentals

Basic operating principle of SCR system consists of several steps. First, exhaust enters exhaust pipe after flowing out of supercharger turbo. Meanwhile, urea injection unit installed in SCR system upstream sprays quantitative aqueous solution of urea into exhaust pipe in the form of mist. Urea solution drop has hydrolysis and pyrolysis reactions under the role of high temperature exhaust gas, generating required reducing agent  $\text{NH}_3$  which selectively restores  $\text{NO}_x$  to nitrogen  $\text{N}_2$  under catalyst. The main reaction is as follows:

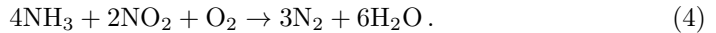
Urea formula is  $(\text{NH}_2)_2\text{CO}$ . This agent is decomposed into  $\text{NH}_3$  and  $\text{CO}_2$  at high temperature, after adding  $\text{H}_2\text{O}$ . This reaction can be completed without catalysis conditions:



Ammonia  $\text{NH}_3$  in SCR catalyst reacts with  $\text{NO}$  and  $\text{NO}_2$  in exhaust gas, generating  $\text{N}_2$  and  $\text{H}_2\text{O}$  [1–3]



and



### 2.2. Ammonia storage capacity

Adjust fixed point hot car to idling after stabilization, then cool catalyst temperature, so that inlet temperature begins to decrease. When inlet temperature reaches  $400^\circ\text{C}$ ,  $350^\circ\text{C}$ ,  $300^\circ\text{C}$ ,  $250^\circ\text{C}$ ,  $200^\circ\text{C}$ , respectively, rapidly switch to A100 operating point, open urea switch and record each parameter variation of  $\text{NO}_x$ ,  $\text{NH}_3$ , SCR second by second. The relevant parameters of A100 operating point under steady state are shown in Table 2.

As can be seen from Fig. 1, as the temperature rises, ammonia storage capacity of the catalyst continues to decrease. When the temperature reaches  $450^\circ\text{C}$ , there is almost no ammonia storage capacity.

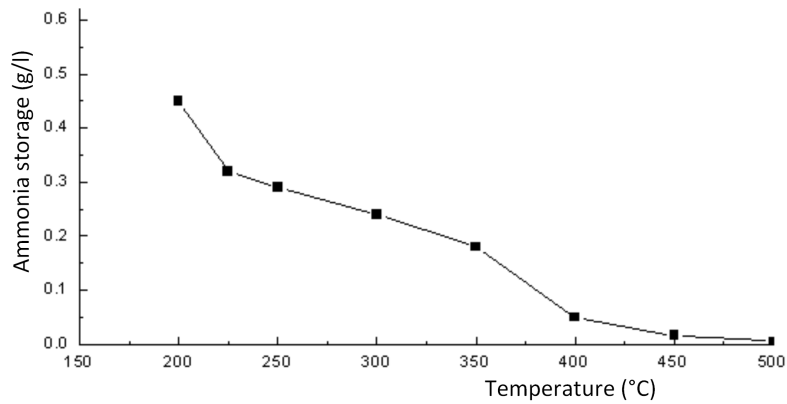


Fig. 1. Ammonia storage amount of catalyst obtained in sample test

### 3. Bench test system

A 4l diesel engine was chosen for bench test. The main parameters of diesel engine are shown in Table 1, and test bench system layout is shown in Fig. 2.

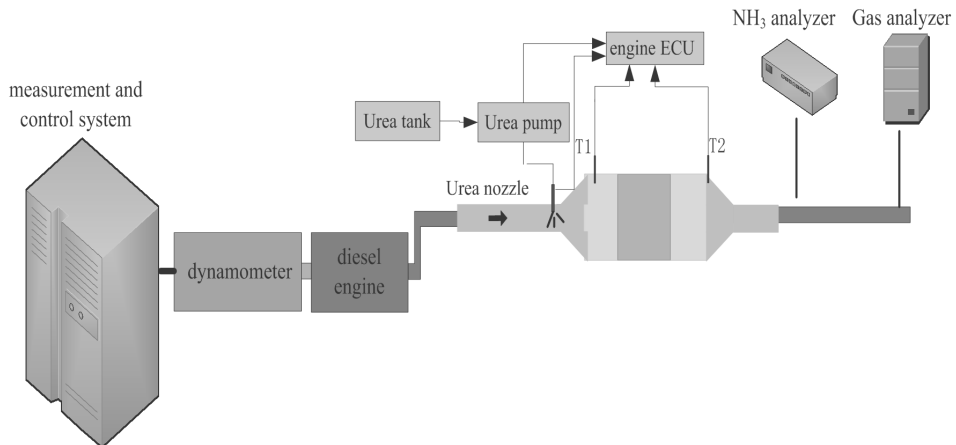


Fig. 2. Bench test system

Table 2. Parameters of A100 operating point under steady state

Parameters	Unit	Value
Rotate speed	r/min	1417
Torque	N·m	536
Power	kW	79.7
Airspeed	h <sup>-1</sup>	27000
Set ammonia nitrogen ratio	-	0.83

#### 4. Test results and analysis

When initial temperature was lowered to 250 °C, NO<sub>x</sub>, NH<sub>3</sub> and SCR inlet temperature variations with time are shown in Fig. 3. NO<sub>x</sub> and NH<sub>3</sub> emission results at different initial temperatures are shown in Figs. 4 and 5.

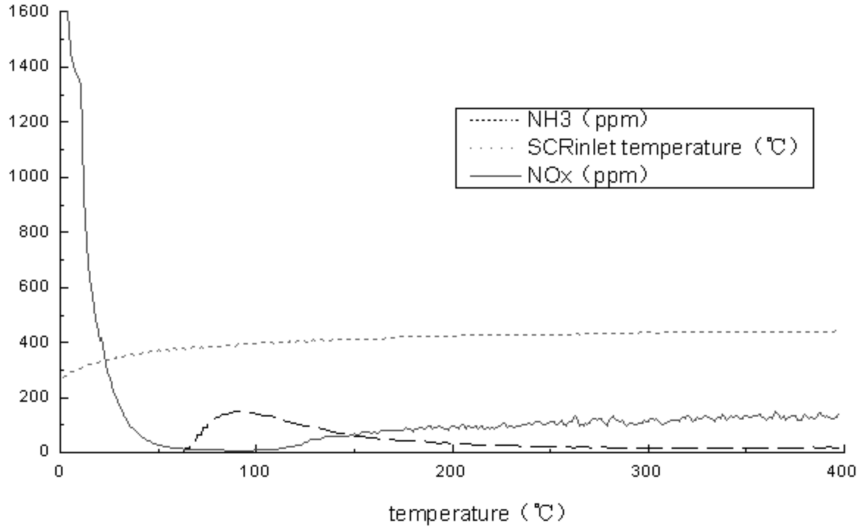


Fig. 3. NO<sub>x</sub>, NH<sub>3</sub> and SCR upstream temperature variations vs. time

As can be seen in Fig. 3, after start of urea injection, NO<sub>x</sub> first decreases, then begins to rise after reaching a low point, to be gradually stabilized after a period of time; ammonia leakage first gradually increases, and begins to decrease after a peak to be stabilized after a period of time. This is because in initial injection, temperature of catalyst inside SCR is low, catalyst activity is weak while ammonia storage capacity is strong, catalyst saturated ammonia storage capacity is large, then a large amount of NH<sub>3</sub> is adsorbed on active catalyst sites [4]. As the temperature increases, catalyst activity gradually improves, with NO<sub>x</sub> conversion efficiency constantly improved and NO<sub>x</sub> emissions decreased. Since the temperature rises rapidly, when NH<sub>3</sub> is massively released at low temperature, it reacts with NO<sub>x</sub>, so NO<sub>x</sub> emissions decreases rapidly. When released NH<sub>3</sub> cannot be completely consumed, ammonia leakage is caused. As the temperature continues to rise, catalyst activity continues to improve, ammonia storage capacity gradually weakens, with increasingly less storage of NH<sub>3</sub>. NO<sub>x</sub> rises slowly, and when the time reaches about 400s, NO<sub>x</sub> emission is stabilized.

Define that NO<sub>x</sub> concentration corresponding to maximum theoretical conversion efficiency is  $A$ , then

$$A = A_0 - A_1 . \quad (5)$$

Here,  $A_0$  represents the original machine NO<sub>x</sub> emission concentration at oper-

ating point,  $A_1$  represents theoretically consumed NO<sub>x</sub> volume concentration at ammonia injection complete reaction at the operating point (NH<sub>3</sub> and NO<sub>x</sub> are calculated in 1: 1 ratio). According to calculation of actual urea injection quantity and mass of exhaust gas, NO<sub>x</sub> concentration corresponding to point A is 107 ppm. As can be seen in Fig. 3, at about 230 s, NO<sub>x</sub> concentration reaches 107 ppm, indicating that ammonia stored at low temperature before the time is involved in the reaction, but the time can be approximately considered as the moment when ammonia storage is almost exhausted.

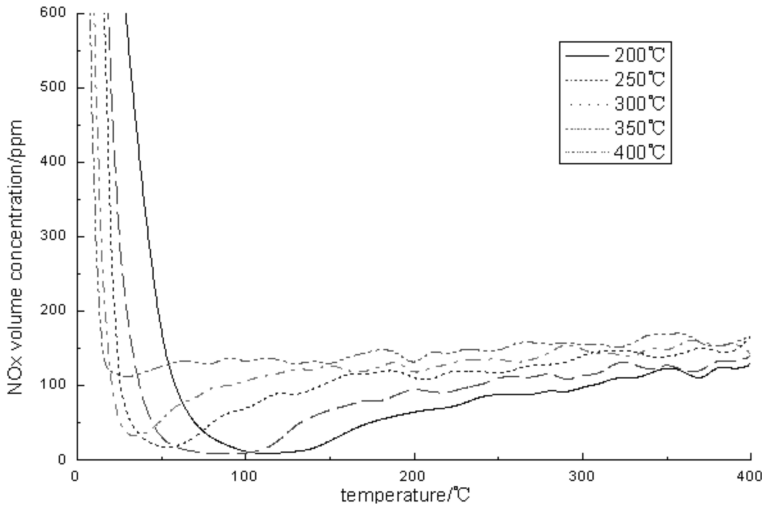


Fig. 4. NO<sub>x</sub> volume concentration variation under different initial temperatures vs. time

As can be seen from Fig. 4 and Fig. 5, the lower is initial temperature at operating point, the lower is minimum NO<sub>x</sub> value, the longer time is required to reach the lowest point and the higher is ammonia leakage peak. This is because the lower is temperature at the operating point, the stronger is catalyst ammonia storage capacity, the longer is the storage time and the greater is ammonia storage amount. As the temperature rises, more NH<sub>3</sub> can be released, so minimum value of NO<sub>x</sub> emissions is lower, corresponding leakage of ammonia will be higher, and the time needed for increasing NO<sub>x</sub> to reach equilibrium will be longer.

As can be seen from Fig. 4, when the temperature is 200 °C, the time for NO<sub>x</sub> emissions to reach the lowest point is longest, about 130 s. Also, the time for ammonia storage exhaust is longest, about 310 s; at 400 °C, after circulation, the time required for NO<sub>x</sub> to touch the bottom is the shortest, about 30 s, indicating that there is basically no ammonia storage at 400 °C.

Each operating point emission result recorded by ESC cycle is the average of measured values after the point runs 30 s (what is shown is about 90–120 s region). As can be seen from Fig. 4, under the condition that urea injection amount is equal, different cycle temperatures will lead to quite different collected NO<sub>x</sub> emission results. To ensure consistency of emission results, temperature into circulation should

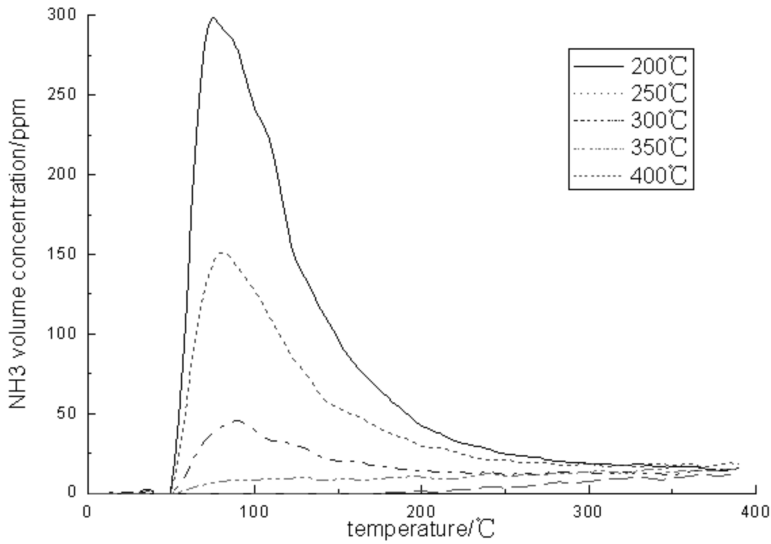


Fig. 5.  $\text{NH}_3$  volume concentration variation under different initial temperatures vs. time

be consistent as far as possible.

Figures 6 and 7 show over-time variation of  $\text{NO}_x$  and  $\text{NH}_3$  volume concentration corresponding to urea injection in accordance with different ammonia nitrogen ratios under the same conditions after switched to A100 operating point. As shown in the Figure, with increase of ammonia nitrogen ratio, minimum value that  $\text{NO}_x$  can achieve is lower, and  $\text{NO}_x$  duration seen from the chart in lower emission region is also longer. This is because the larger ammonia nitrogen ratio, the more ammonia stored in low-temperature period after spray, the greater ammonia emissions with increasing temperature, and the stronger  $\text{NO}_x$  buffering effect. But when ammonia nitrogen ratio reaches 1,  $\text{NO}_x$  emission reaches the lowest value almost without further rise. This is because urea injection at this time is large, and all the  $\text{NO}_x$  can be completely consumed in theory.

## 5. Conclusion

1. The lower temperature after starting driving cycle, the lower minimum value of  $\text{NO}_x$  that can be achieved, the longer time needed to reach the lowest point, the longer time for exhaust of ammonia storage, and the higher ammonia leakage peak. Therefore, to ensure consistency of the test results, stabilization of hot car time and other measures should be taken to ensure consistency of each time entering test cycle temperature.
2. The higher ammonia nitrogen ratio, the lower minimum value of  $\text{NO}_x$  that can be achieved, the stronger buffering effect of ammonia storage on  $\text{NO}_x$ , and the

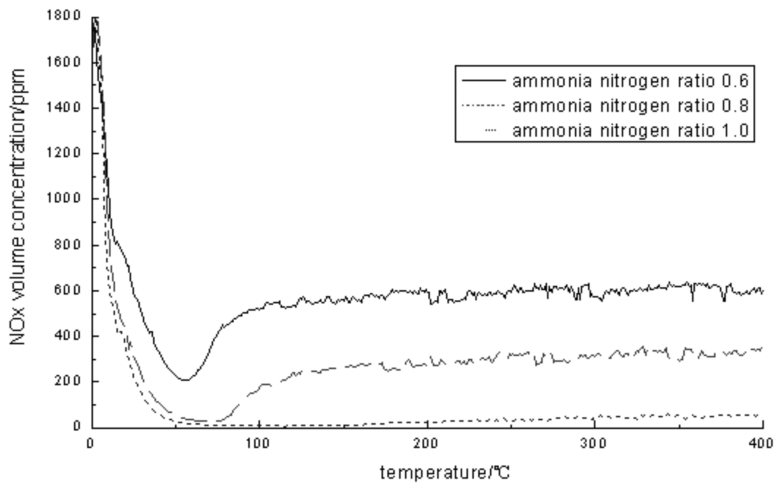


Fig. 6. NO<sub>x</sub> volume concentration variation vs. time under different ammonia nitrogen ratios

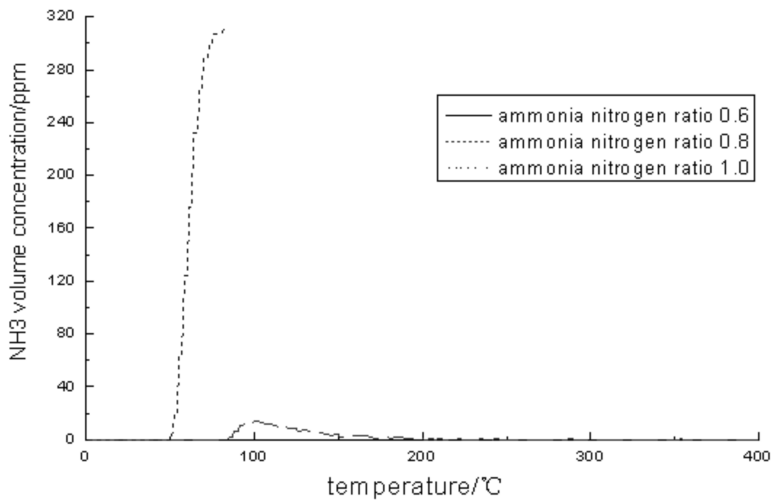


Fig. 7. NH<sub>3</sub> volume concentration variation vs. time under different ammonia nitrogen ratios

longer time for emission results to be stabilized. Therefore, when ammonia nitrogen ratio is relatively high, operating point entry should be maintained at a higher temperature to reduce NH<sub>3</sub> overflow.

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