Study on NOx emissions from a national V heavy-duty diesel engine

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KEYWORD: SCR; Diesel engine; pollution; Emissions; NOx; Detail components

ABSTRACT: Detail components of nitrogen oxides (NOx) emissions, which is including NO, NO2, and N2O, from a national V heavy-duty diesel engine with selective catalytic reduction (SCR) were studied under different operating conditions by using Fourier transform infrared spectrum (FTIR) technology. Results show that compared to the engine without SCR, descent of NOx emissions from the engine with SCR on different load are different and the higher load, the more drop. NO and NO2 emissions from the engine with SCR have an varying degrees of decline, N2O emissions raise more than 50% as a result of SCR side reaction exists.N2O emissions ascends with the increase of the load, and this is because increasing exhaust temperature leads to higher oxidation reaction rate of NH3 to N2O.

INTRODUCTION

Nitrogen oxide (NOx) is important exhaust emissions of diesel engine, and its detailed components including NO, NO_2, and N_2O[1-3]. High concentrations of NO can cause human neural disorder, NO will generate the nitrite in human body, and it would cause hypoxia by integrating with hemoglobin in the blood. NO will become NO_2 quickly in air, and NO_2 is one of the sources of acid rain and one of the important cause of photochemical smog, it also poisons the body's respiratory system[4]. N_2O is an important greenhouse gas, its greenhouse effect as 300 times much as CO_2 [5-6].

The use of ammonia-based selective catalytic reduction is an important method for reducing heavy diesel engine NOx to meet the national V diesel engine emissions standards[7,8]. It may cause NH_3 leak in the process of using selective catalytic reduction (SCR). NH_3 will cause human ammonia poisoning and inhibit the central nervous system. Our country stipulates the average NH_3 emissions should not more than 25×10^{-6} in the transient ETC emissions test cycle of heavy duty diesel engine [9].

Generally speaking, NO is main ingredients of NOx, NO_2 is secondary components, and N_2O is very small amounts, and so on. Pi-qiang Tan studied the effects of engine load on emissions of NO_2 under different fuel injection advance angle and speed, he found that NO_2 /NOx radio has a significant reduction with the increase of engine load[1]. Tang Tao studied N_2O formation characteristics under different diesel engine aftertreatment systems, he found that SCR which contained Cu zeolite catalyst and Cu/Fe composite catalysts, N_2O production showed a trend of decreases after increase and then increase with the rise of temperature [10]. Klimczak found that redox reaction of NO can produce N_2O in the SCR[11]. Pan Li studied redox reaction of NO in V_2O_5 SCR, he found that N_2O increases with the rise of temperature [12].

From the above literature, we can see that the NOx component have carried out some research in existing public literatures, but it is too few that the system research about the emissions characteristics of NOx detailed components (NO, NO_2, N_2O) and NH_3 in diesel engine equipped with SCR.

Because of this reason, the paper carried out tests on a national V heavy-duty diesel engine, diesel engine exhaust NOx detailed components NO, NO_2, N_2O and NH_3 were studied by using Fourier transform infrared spectrometer (FTIR), and emissions characteristics of NOx detailed components of heavy-duty diesel engine with SCR and without SCR were explores.

Experimental Setup

Engine, SCR and FTIR

In this paper, the research object is a national V heavy-duty diesel engine with electronically controlled and high pressure common rail. The main specifications of the test engine were shown in table 1.

Table 1. Main Specifications of test engine

Items	Parameters
Displacement	8.82L
Cylinder type	6 cylinders line-engine, 4 valves
Type	Inter-cooling turbo
Bore/Stroke	114 mm/144 mm
Ratio	18:1
Rated power	184 kW (2200 r/min)
Max torque	1000N · m (1400 r/min)

In figures of this paper, the engine without SCR referred to as original, and the engine with SCR referred to as SCR. V-W/TiO_2 is main SCR catalyst of this experiment. Main Specifications of the SCR were shown in table 2.

Table 2. Main Specifications of SCR

Items	Parameters
Length of catalytic converter	660.4mm
Diameter of catalytic converter	152.4mm
Stable operation range	180~600 ℃
Urea pump spray range	0~8000ml/h

The emissions of engine without SCR and engine with SCR were measured by AVL FTIR. FTIR is based on Raman Effect through the interferometer interference frequency modulation. To gain spectra, the interference figure is measured and interference figure Fourier transforms is carried out according to the corresponding relationship between interferogram and spectra. And the corresponding groups of atoms or groups of atoms combine information were gained by compared with standard atlas, then the concentration of the quantitative analyst is of the components can be done according to Bill Law[13, 14].

Experiment Procedure

The heavy-duty diesel engine NOx detailed component (NO, NO_2, N_2O) and NH_3 emissions characteristics were studied, test point is present as follows:

Two speeds were choose, respectively for the maximum torque speed 1400 r/min, the rated power speed 2200 r/min, those speed by 10%, 25%, 50%, 25% and 100% load, a total of 10 point.

The mass concentration of the tested urea solution wis 32.5%, which is the standard urea solution used by car. To provide enough ammonia, urea basic injection quantity will be set to 1.2 times as much as the amount of NOx completely reaction in theory, namely the complete decomposition of urea solution produced by the molar ratio of NH_3 and NOx is equal to 1.2:1.

RESULTS AND DiSCUSSION

The average temperature and exhaust flow

NOx production is related to average temperature and exhaust flow of catalytic converter, so it is necessary to studied them.

Figure 1 shows that the average temperature and exhaust flow. It can be seen that average temperature and exhaust flow of catalytic converter were significantly increased with the increase of load at 1400r/min and 2200r/min. And under the same load, average temperature of 1400 r/min significantly higher than that of 2200 r/min, but the exhaust flow rate of 1400 r/min is lower than 2200r/min.

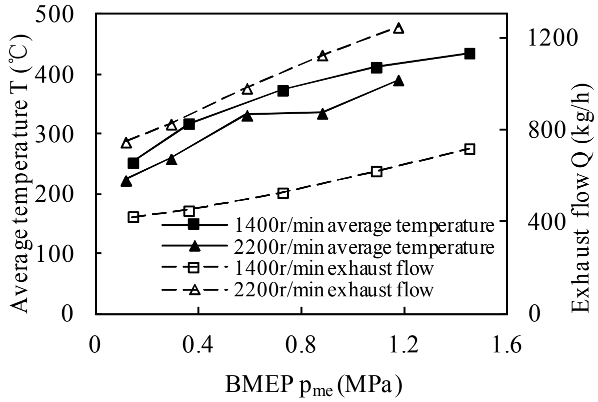

Figure 1. Average temperature and exhaust flow of SCR catalysts

Detail Components of NOx

Figure 2 shows that NOx emissions under different load. In original engine, NOx emissions were raising with the increase of load, and NOx emissions of 1400 r/min is higher than that of 2200 r/min. After adding SCR, compared with the original engine, NOx emissions has varying degrees of decline, but its rule of change is not obvious with the increase of load. After adding SCR, NOx emissions of 1400 r/min has an average decreased by 67.7% and biggest decreased by 92.9%, which appears in the region of the high load. At this load, exhaust temperature is high, SCR catalyst activity is strong, NOx emissions decline significantly. The smallest decline is 30.8% in small load area, where exhaust gas temperature is lower. After adding SCR, NOx emissions of 2200 r/min has an average decreased by 87.6% and biggest decreased by 97.1%, which appears in the region of the middle load. At this load, NOx emissions of the original engine were not very high, but its high exhaust temperature, SCR catalyst activity is strong, NOx emissions decline significantly. The smallest decline of 2200 r/min is 60.4% in the small load where exhaust gas temperature is low.

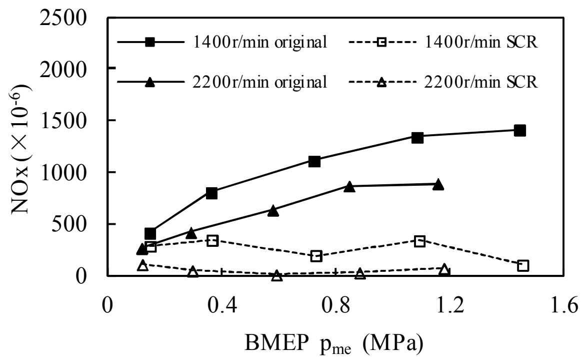

Figure 2. NOx emissions

NO Emissions

Figure 3 shows that NO emissions under different load. In original engine, NO emissions is rising with the increase of load, and NO emissions of 1400 r/min is higher than that of 2200 r/min. This is mainly due to temperature in cylinder of 1400 r/min is higher than that of 2200 r/min. After adding SCR, NO emissions has decrease sharply compared with the original engine, but its rule of change is not obvious with the increase of load. NO emissions of 1400 r/min has an average decreased by 68.2% and biggest decreased by 94.1%. NO emissions of 2200 r/min has an average decreased by 87.4% and biggest decreased by 97.7%.

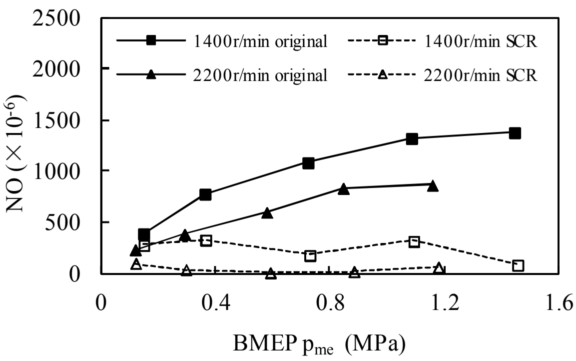

Figure 3. NO emissions

NO_2 Emissions

Figure 4 shows that NO_2 emissions under different load. In original engine, NO_2 emissions of 1400 r/min ascends firstly and then decline with the improvement of mean effective pressure, and then increase around 1 MPa. NO_2 emissions of 2200 r/min ascends firstly and then decline with the increase of the mean effective pressure.

After adding SCR, NO_2 emissions has fallen sharply compared with the original engine. NO_2 emissions of 1400 r/min is on the rise roughly with the increase of the mean effective pressure, NO_2 emissions of 2200 r/min change smaller with the increase of the mean effective pressure, emissions are mostly around 3×10^{-6}.

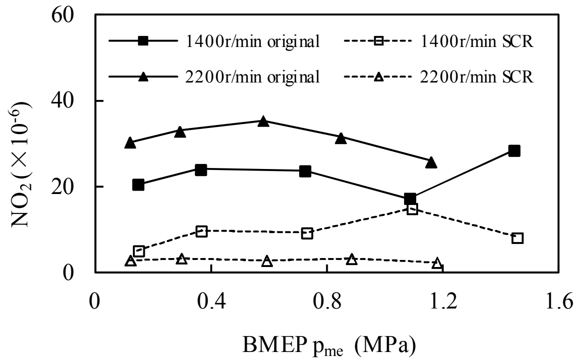

Figure 4. NO_2 emissions

It is important to note that NO_2 emissions of 2200 r/min more than 1400 r/min in the original engine, but after adding SCR, NO_2 emissions of 2200 r/min less than 1400 r/min. After adding SCR, $NO_{2\ \mathrm{emissions}}$ of 1400 r/min has an average decreased by 56.6% and biggest decreased by 75.6% compared to the original engine. NO_2 emissions of 2200 r/min has an average decreased by 90.9% and biggest decreased by 92.3%. The main reason is that NH_3-based SCR have different reaction under different conditions[15-17]: standard SCR reaction and rapid SCR reaction.

Standard SCR reaction is mainly catalytic reduction reaction between NH_3 and NOx, it has higher rate of reaction at 300 ℃ ~ 400 ℃, reaction rate will lower when the temperature is lower, the reaction is as follows:

$$4NH_3 + 4NO + O_2 \rightarrow 4N_2 + 6H_2O \qquad (1)$$

The rate of reaction (1) is slow relatively, when the radio of NO/NO_2 rising, NO_2/NO radio to 1 at someplace, there is a more ideal reaction process, namely rapid SCR reaction, it can be working under the low temperature. The reaction is as follows:

$$4NH_3 + 2NO + 2NO_2 \rightarrow 4N_2 + 6H_2O \qquad (2)$$

Figure 5 shows that NO_2/NO ratio of original engine under different load. NO_2/NO ratio of 1400 r/min has fallen with the increase of load, it means that rapid SCR reaction reduces, standard SCR reaction increases, the reduction of NO_2 decreases, and NO_2 emissions of original engine don't change much, so the range of NO_2 emissions decline isn't big after adding SCR.

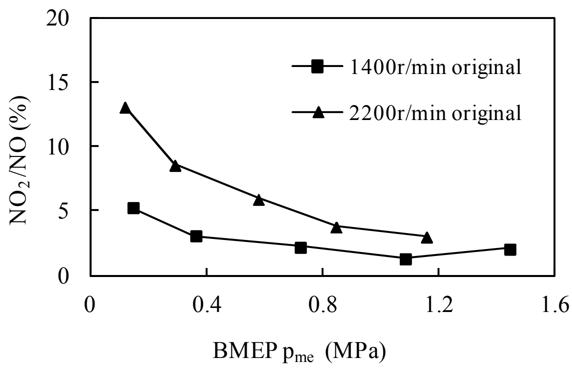

Figure 5. NO_2/NO ratio without SCR at different load

N_2O Emissions

Figure 6 shows that N_2O emissions under different load. With the improvement of mean effective pressure, the original engine N_2O emissions don't change much. N_2O emissions of 1400 r/min is mainly about 2.0×10^{-6}, while it is mainly about 2.5×10^{-6} of 2200 r/min. After adding SCR, N_2O emissions has raised sharply compared with the original engine. With the increase of mean effective pressure, N_2O emissions of 1400 r/min and 2200 r/min were on the rise. Considering that the greenhouse effect of N_2O is about 300 times of carbon dioxide, N_2O emissions should bring to the forefront after adding SCR.

After adding SCR, N_2O emissions is increased sharply compared to the original engine, this is mainly due to the reaction of SCR in addition to the normal reaction (1) and (2), there are side effects occur under high temperature, those reactions will produce N_2O [18, 19]:

$2NH_3+2O_2 \rightarrow N_2O + 3H_2O$ (3)

$4NH_3+4NO+3O_2 \rightarrow 4N_2O + 6H_2O$ (4)

At the same time, because of using urea as a reducing agent of SCR reactions, there is side effects might generate NH_4NO_3, if it is attached in the surface of the SCR, part of NH_4NO_3 occur decomposition to generate the N_2O at low temperature[19, 20] :

$NH_4NO_3 \rightarrow N_2O + 2H_2O$ (5)

It is important to note that N_2O emissions of 1400 r/min is less than that of 2200 r/min in original engine, but after adding SCR, N_2O emissions of 1400 r/min is more than that of 2200 r/min. After adding SCR, , N_2O emissions of 2200 r/min has an average increase by 61.9% and biggest increase by 83.1% compared with original engine, N_2O emissions of 1400 r/min has an average increase by 2.23 times and biggest increase by 3.29 times.

It is result of comprehensive action among the reaction (3), (4) and (5). After adding SCR, N2O emissions of 2200 r/min ascends firstly and then decline with the improvement of mean effective pressure, this is due to the exhaust temperature of 2200 r/min is lower than 1400 r/min, the N_2O under low load is mainly generated by the decomposition of NH_4NO_3, which mainly comes from the reaction (5). NH_4NO_3 decomposition will increase with temperature increasing properly, and when the exhaust temperature increased to a certain temperature, the generation of NH_4NO_3 decrease, N_2O emissions becomes down. And when the exhaust temperature continues to raise, reaction (3) and (4) increase, so the N_2O emissions continue to rise again. N_2O emissions of 1400 r/min rise with the increase of the load, this is mainly due to the average effective pressure increase, the exhaust temperature increased, NH_4NO_3 generation decreases, reaction (5) decreases, but it is increased that NH_3 is oxidized into N_2O by NO_2 or O_2, the reaction (3) and (4) increase significantly, so the N_2O emissions rise gradually, and because exhaust gas temperature of 1400 r/min is higher than 2200 r/min, N2O emissions is generated more than 2200 r/min by reaction (3) and (4).

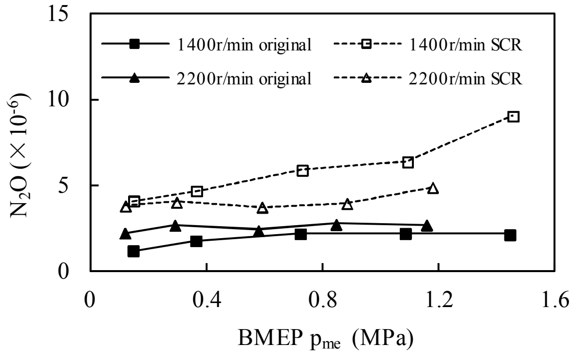

Figure 6. N_2O emissions

Conclusions

Detail components of NOx emissions including NO, NO_2, and N_2O from a national V heavy-duty diesel engine with SCR were studied by using FTIR technology. Main conclusions are as follows:

(1) In original engine, with the increase of the load, NO emissions continues to raise, NO_2 emissions ascends firstly and then decline, N_2O emissions is rare.

(2) Compared with the original engine, NOx emissions of diesel engine with SCR have varying degrees of decline, the drop of high load is more ideal.

(3) After adding SCR, NO and NO_2 emissions were lower significantly, NO_2 emissions decreases significantly under the rated speed. It is due to the slightly higher NO_2/NO radio cause of SCR reaction more quickly.

(4) The N_2O emissions from the engine with SCR is more than 50% the emissions from the engine without SCR, particularly higher under the maximum torque speed at full load, and this is because the SCR side reaction exists. N_2O emissions is rising with the increase of the load, the main reason is high temperature lead N_2O generation rate increases by NH_3 oxidation reaction.

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