

Investigation of Deposits in Urea-SCR System Based on Vehicle Road Test

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ABSTRACT

In vehicles with urea-SCR system, normal operation of the urea-SCR system and engine will be influenced if there are deposits appearing on exhaust pipe wall. In this paper, a commercial vehicle is employed to study the influence factors of deposits through the vehicle road test. The results show that, urea injection rate, temperature and flow field have impacts on the formation of deposits. When decreasing the urea injection rate of calibration status by 20%, the deposit yield would reduce by 32%. If the ambient temperature decreased from 36 °C to 26 °C, the deposit yield would increase by 95%. After optimizing the exhaust pipe downstream of the urea injector by removing the step surface, only a few flow marks of urea droplets are observed on the pipe wall, and no lumps of deposits existing. In this case, we have improved exhaust flow field by removing step surface and placing the nozzle in the center of exhaust pipe and conducted a durability test of traveling for 5500km, but which couldn't completely avoid the formation of deposits on the exhaust pipe wall. Then, the deposits-related problems have been solved after forwarding the injector close to the exit of turbo and wrapping the exhaust pipe with heat preservation material because the exhaust temperature increased by over 50 °C and the wall temperature increased by over 100°C. Finally, a calculation model of critical injection rate for avoiding deposit formation is proposed.

CITATION: Zhu, N., Lv, L., and Ye, C., "Investigation of Deposits in Urea-SCR System Based on Vehicle Road Test," *SAE Int. J. Engines* 10(2):2017, doi:10.4271/2017-01-9275.

INTRODUCTION

With rapid development of global economy, environment protection problems have attracted extensive attention. Vehicle exhaust makes air pollution more and more serious, especially in areas with advanced industries, busy traffic and large population. Under the background of increasingly stringent emission regulations concerning heavy diesel engines, the control technology is an active area of research to reduce the NOX emission of diesel engine. At present, SCR (Selective Catalytic Reduction) technology which adopts urea water solution as reducing agent remains generally considered as one of the most effective way to reduce NOX emission of diesel engine [1, 2, 3]. However, urea deposit formation on exhaust pipe walls is an issue for commercial vehicles.

Deposits in general show in three places of SCR system: interior part of urea injector, exhaust pipe wall and catalyst entrance. Deposits on the exhaust pipe wall may decrease utilization rate of urea. Concentration weakening of NH_3 , which reacts with SCR, could lead to reducing the conversion efficiency of SCR system. Serious deposits may cause partial and even complete blocking of the exhaust pipe, increase exhaust backpressure and thus influence the performance of engine. Hence, in order to guarantee the normal operation of the SCR system and engine, deposits-related problems on the exhaust pipe wall are very urgent.

Urea water solution streaming into the exhaust pipe is gradually heated by high-temperature exhaust. When reaching a certain temperature, the liquid begins to evaporate. Evaporated gas mainly consists of water vapor, because the boiling point of water is lower than that of urea. In the case that water evaporates too fast, the urea solid will separate out and form into crystal. The crystal could be easily dissolved in water and decomposed by heating. There is little influence on the SCR system and engine.

Deposits are side products of urea via a series of chemical reactions. Deposits can be hardly dissolved in water and decomposed by heating. Once formed up, deposits are so hard to be cleaned that bringing significant influence on the SCR system and engine.

In order to explore generation reasons and influence factors of deposits, scholars carried out numerous relevant researches [10, 11, 12, 13, 14, 15]. Paul Way [4] analyzed the component of deposits. The outcome indicates deposits are composed of undecomposed urea (occupy 5~15%), biuret (occupy 5~15%) and CYA (occupy 70~95%). Research of Guanyu Zheng [5] indicates pipe wall temperature exerts certain influence on the formation of deposits. Lifeng Xu [6] researched the influence of exhaust temperature and catalyst types (iron zeolite and copper zeolite) on deposits production, the results of which show that the lower the exhaust temperature is, the more easily the deposits form. Iron zeolite forms deposits more easily than copper zeolite. Vadim O.Strots [7] conducted a study on

the proportion of deposits in urea consumption under different exhaust temperatures and ambient temperatures, the results of which show that the lower the exhaust temperature is, the bigger the proportion of deposits will account for. When exhaust temperature is 220 °C and ambient temperature is -3°C, 25% of urea will form into deposits, depending on the exhaust system design.

At present, the studies on deposits are mostly conducted on lab bench. It is necessary to carry out relevant tests and researches on the whole vehicle, because the lab is unable to simulate the certain conditions during the real vehicle travelling. This paper studies the influence factors of deposits on exhaust pipe wall through the vehicle road test, and provides support for vehicle to solve the problems of deposits.

MATERIAL AND METHODS

Experimental Setup

A commercial vehicle is employed to conduct the research. We installed after-treatment parts, including exhaust pipes, catalytic converter, urea injector, Grundfos pump (compressed air-assistant type, compressed air pressure was 0.4~0.6 MPa), controller and sensors etc. onto the test vehicle. Technical parameters of the engine and the test vehicle are shown in [Table 1](#).

Table 1. Technical Parameters

Parameter Name		Parameter Value
Vehicle	The Maximum Allowable Total Mass	31000 kg
	Unladen Mass	10200 kg
Engine	Displacement	11.12 L
	Quantity of cylinders	6
	Air Admission Mode	Supercharged Inter-cooling
	Fuel System	High Pressure Common Rail
	Rated Rotate Speed	1900 r/min
	Rated Power	257 kW

The arrangement and assembly of the after-treatment system which is used for testing are shown in [Figure 1. \(a\)](#). As shown in [Figure 1. \(b\)](#), urea injector is located in the entrance of the catalytic converter, the nozzle deviating 10 mm far from the exhaust pipe center, and with a sudden changed cross-section (hereinafter referred to as step surface) downstream of the injector. Technical parameters of the injector are shown in [Table 2](#).

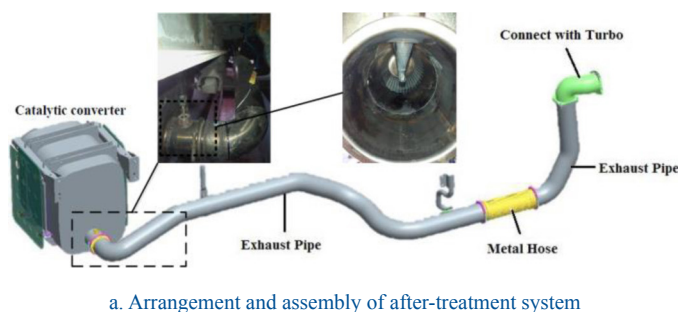


Figure 1.

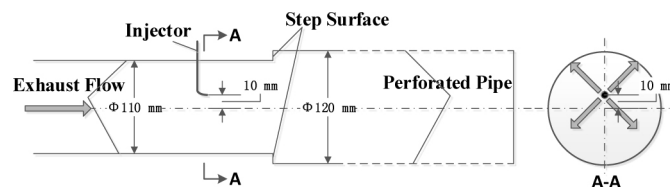


Figure 1. (cont.) Arrangement and assembly of after-treatment system

Table 2. Injector specifications

Parameter Name	Parameter Value
Working Temperature	-40~700 °C
Body Materials	316 Stainless Steel
Droplet Sauter Mean Diameter	<40 μm
Nozzle Diameter	4×0.5 mm

Experimental Contents

Firstly, we conducted research according to requirements for vehicle load capacity (gross weight 30.5 t), driving speed (90-100km/h) and road conditions (expressway). The deposits on exhaust pipe wall showed once again. In addition, we researched the formation process of deposits.

Secondly, the influences of injection rate, exhaust flow field and ambient temperature on the formation of deposits were researched through the vehicle road test. The driving routes of road tests are shown in [Figure 2](#). The traveling distance for each vehicle test is 500 km, including suburban road, plain expressway and mountain road. As shown in [Figure 1. \(b\)](#), we realized that there are some defects in the structure of exhaust pipe, such as the step surface and the nozzle position. In addition, the injection rate, the injection path and the ambient temperature have influence on the formation of deposits. The test plans are shown in [Figure 3](#). Test 1 is a benchmark test. The arrangement and assembly of the after-treatment system are shown in [Figure 1](#), and the injection rate in Test 1 is satisfied with emission regulations by rating test. On the basis of the benchmark test, the injection rate is reduced by 20% in test 2, the nozzle is in the place of pipe center in test 3, axial direction injector is used in test 4, the step surface is removed in test 5, and the average ambient temperature is about 26 °C in test 6.

Finally, optimizing exhaust flow field by removing step surface and placing the nozzle in the center of exhaust pipe, we have conducted a road durability test of 5500km and verified the deposits inside of the catalytic converter.



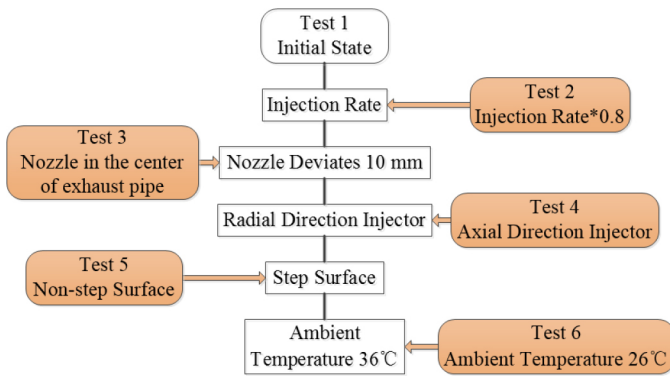


Figure 3. Test plan

RESULTS AND DISCUSSIONS

Formation Process of Deposits

The formation process of deposits can be divided into three parts [8, 9]: urea water solution forms the wall film when running into a blank wall in the exhaust pipes; and then, the wall film will form soft crystal when the concentration of urea is higher than the certain critical value; at last, the soft crystal will form into deposits when it undergoes a series of complicated physical and chemical reactions in different temperatures.

Figure 4 shows the shape of deposits on exhaust pipe wall after the vehicle traveling for 500km and 1000km respectively. It can be seen that the deposits on exhaust pipe wall indicate a process of continuous expansion and growth. As shown in Figure 5, with the increase of travelling distance, the deposits production also witnesses an increase and the formation rate of deposits increase rapidly. When deposits are formed on the exhaust pipe wall, atomization space of urea liquid drops tend to be so small that evaporation and pyrolyzation process cannot be finished normally, which lead to the fact that the urea drops would accumulate on the formed deposits and finally the deposits grow to the position nearby the nozzle. Figure 4(c) shows the partial enlarged drawing of deposits in upper right of exhaust pipes. The urea drops spray to the upper right of exhaust pipes almost directly adhere to the existing deposits and form into new deposits so that the drops who participate in the reaction of catalytic reduction cannot flow with exhaust into the catalyst, which should influence the performance of SCR system.



a. 500km

b. 1000km

c. Deposits

Figure 4. Formation process of deposits on the exhaust pipe wall

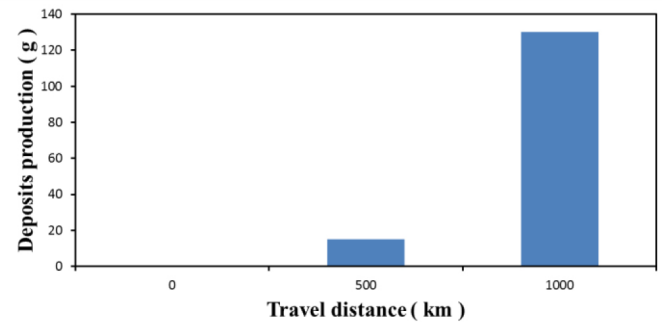
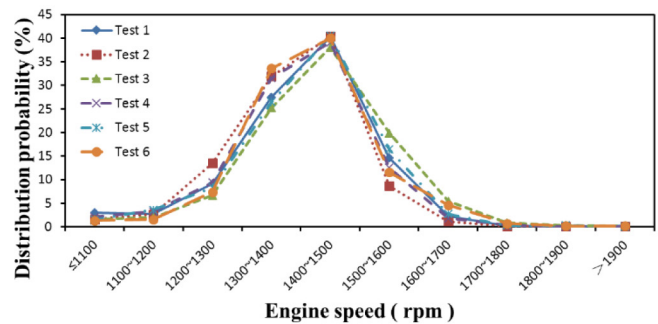


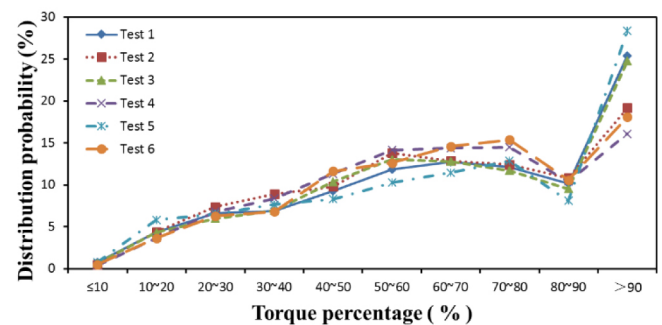
Figure 5. Deposits production versus mileage

Influence Factors of Deposits

Figure 6 shows the statistical results for engine operation conditions of test 1- test 6. The operation condition distribution of each test is basically the same. The main interval of engine speed ranges from 1300 r/min to 1500 r/min, and torque percentage ranges from 90% to 100%.



a. Engine speed distribution



b. Torque percentage distribution

Figure 6. Test conditions

In order to compare the deposits production in various urea consumption conditions, deposit yield is defined as the deposits production to the mass of urea (dry urea in the urea water solution):

$$x = \frac{m_{\text{deposit}}}{m_{\text{urea}} \times 32.5\%} \times 100\%$$

(1)

Where, x is the deposit yield, m_{deposit} is the deposits production and m_{urea} is the urea water solution consumption.