Research on NOx Emission Characteristics of Off-Road Diesel Machinery Based on Remote Monitoring Technology

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Abstract. In order to study and analyze the operating characteristics and NOx emission characteristics of typical non-road diesel machinery under actual operating conditions, this paper takes Excavators, Loaders and Forklifts operating at construction sites as objects, the On-board Emission Test Device (OETD in short) integrating Temperature Sensors, NOx sensors, GPS and GPRS is conducted to carry out experimental tests, and a Monitoring Platform Communicating with OETD by GPRS is used to collect the real-time data of the machinery's geographical location, exhaust temperature and NOx concentration. The study result shows that the Excavator and Loader in the construction site are in long-term operating conditions and the average operating time is long; during the actual operating, the NOx emission concentration of the Loader is high and the range is large, mainly concentrated at 500 ~ 900ppm, while the NOx of Excavators and Forklifts The emission concentration is relatively low, at 400 ~ 450ppm.

1. Introduction
Non-road diesel mobile machinery plays an important role in the development and construction of the national economy. However, due to the low level of non-road diesel machinery emission control technology, long service life, poor maintenance and low fuel quality, etc., the NOx & PM emissions are high [1]. China Motor Vehicle Environmental Management Annual Report (2018) [2] shows that the impact of non-road mobile machinery emissions on air quality cannot be ignored, and NOx & PM emissions are comparable to motor vehicles.

Lu Jun [3], etc. found that NOx emissions from non-road mobile machinery in Shanghai and Hangzhou respectively accounted for 11.1% and 16.1% of all pollution sources in the two cities. Zhang Lijun [4], etc. found that non-road mobile sources have become the third largest NOx and SO2 emission contribution sources in the Pearl River Delta region. Therefore, NOx has become an important pollutant emitted by non-road diesel machinery.

Due to characteristics of non-road diesel machinery operating at construction sites and high mobility [5], the existing vehicle emission periodic inspections, remote sensing telemetry and other measures cannot effectively monitor the characteristics of mechanical operating activities. At the same time, Portable Emission Measurement System (PEMS) cannot be used to test machinery emission (especially NOx) conveniently and largely. Therefore, testing machinery NOx emissions on a large scale requires scientific and technological means to explore new regulatory and testing technologies.

This paper takes Excavators, Loaders and Forklifts operating at construction sites in Tianjin as objects, the On-board Emission Test Device (OETD in short) integrating Temperature Sensors, NOx sensors, GPS and GPRS is conducted to carry out experimental tests, and a Monitoring Platform Communicating with OETD by GPRS is used to collect the real-time data of the machinery's
geographical location, exhaust temperature and NOx concentration, then study and analyze the operating characteristics and NOx emission characteristics of typical non-road diesel machinery under actual operating conditions.

2. Research Method

2.1. Type and Parameters of Machinery
The Excavator, Loader operating at a construction site and the Forklift operated at a certain iron and steel company in Tianjin were selected as the objects to carry out research on activity characteristics and NOx emission characteristics. The machinery parameters are indicated in Table 1.

Table 1. Machinery Parameters

| Type     | Machinery Model | Engine Model | Fuel Type | Standard | After-Treatment |
|----------|-----------------|--------------|-----------|----------|----------------|
| Excavator| KATO HD820III   | 6D34-TLE2A   | Diesel    | China-II | NAN            |
| Loader   | XG951III        | YC6M290-33   | Diesel    | China-II | NAN            |
| Forklift | CPCD30E         | NB495BPG     | Diesel    | China-II | NAN            |

2.2. Test Method
On-board Emission Test Device (OETD in short) integrating Temperature Sensors, NOx sensors, GPS and GPRS with data collection and remote transmission functions is installed on the machineries to collect the real time Geographical Location, Exhaust Temperature and NOx Emission Concentration, and transmit those datas by GPRS to the Monitoring Platform for data analysis. Meanwhile, OETD is provided 12V power by the starter battery, the Temperature Sensor and NOx Sensor are installed at the outlet of the engine exhaust system by punching (in Figure 1) for accurately collecting NOx concentration discharged in air. Data acquisition and transmission frequency is 1Hz.

Considering the influence of the NOx sensor's own characteristic "Dew Point Temperature", the temperature of NOx Sensor was set to 50°C for analyzing the NOx emission characteristics of the machinery in a wide range of exhaust temperature. This paper does not discuss the effects of setting a low "Dew Point Temperature" on the service life of the NOx sensor.

Meanwhile, HORIBA OBS-2000 was used to verify the accuracy of NOx sensor data of OETD by comparison.

![Figure 1. Installation and Arrangement of Temperature and NOx Sensors](image)

During the test, all three machines were operated in accordance with the daily operating method, and the data collection time was from March to September 2019.
3. Test Results and Analysis

3.1. NOx Emission Data Accuracy Verification
Taking the Loader as an example, OBS-2000 and OETD are used to test NOx concentration emission at the same time when the exhaust temperature reaches the "Dew Point Temperature" in actual operating. The data of the two different devices are shown in Figure 2.

![Figure 2. Comparison of NOx concentration by OBS-2000 and OETD](image)

It can be seen from Figure 2 that during the machinery operating, the NOx concentration between the OETD and OBS-2000 has a high consistency, the range of concentration data and the change trend are basically the same, and the correlation coefficient is 0.9068, which indicates that OETD can collect NOx emission concentration data steadily and reliably by remote monitoring methods. It is possible to study and analyze the characteristics of NOx concentration emission of non-road diesel machinery in actual operating by this method.

3.2. NOx Emission Characteristics of Different Machinery

3.2.1. Characteristics of excavator nox emissions
The Excavator is usually in a continuous and non-moving state during operating. Considering the influence of noise from large amount of data of exhaust temperature and NOx under the operating condition, the study uses the 32 times moving average method to analyze the characteristics and trends of NOx emissions and exhaust temperature, in Figure 4.

![Figure 3. Characteristics of instantaneous NOx concentration and exhaust temperature distribution from Excavator](image)

It can be seen from Figure 4 that the NOx concentration of the Excavator varies significantly with temperature, and the increase in exhaust temperature causes the NOx emission level to rise. At the
same time, the exhaust temperature fluctuations are consistent with the operating characteristics of the Excavator. During the operating of the Excavator, the cycle of "Digging-Rotating-Unloading-Rotating-Digging" is frequently repeated. This will cause changes in exhaust temperature and NOx concentration.

The distribution of NOx concentration emissions from Excavators is shown in Figure 5. During the normal operating of the Excavator, the NOx concentration is low, the maximum emission concentration is less than 800ppm, the peak concentration ratio of emissions appears at about 500ppm, and the average NOx concentration is 450ppm.

![Figure 4. Distribution characteristics of NOx concentration from Excavator](image)

**Figure 4.** Distribution characteristics of NOx concentration from Excavator

### 3.2.2. Characteristics of loader nox emissions

The Loader’s power and displacement are usually relatively large. The changes in exhaust temperature and NOx emissions during actual operating are shown in Figure 6.

![Figure 5. Characteristics of instantaneous NOx concentration and exhaust temperature distribution from Loader](image)

**Figure 5.** Characteristics of instantaneous NOx concentration and exhaust temperature distribution from Loader

In addition to the normal loading and unloading operating, the Loader is also frequently moving. The Loader exhaust temperature is at a high level under high load conditions. As the exhaust temperature rises, the exhaust NOx also increases. Loader NOx emissions fluctuate between 500 ppm and 1200 ppm.
During the Loader operating, the NOx emissions levels are concentrated in the range of 500ppm to 800ppm, which is a single peak distribution. The main reason is that the machine is often in idle and low load conditions. The exhaust temperature is relatively high below 250 °C.

4. Conclusion
(1) NOx concentration correlation coefficient between OETD and OBS-2000 is 0.9068, which proves that OETD can be used to test and analyze NOx concentration emissions of non-road diesel machinery in actual operatingss.
(2) Through remote monitoring technology research and prediction, the average annual hours of use of Excavators, Loaders and Forklifts is approximately higher than the recommended average annual hours of use of construction machinery in the Technical Guide for Non-road Mobile Pollution Source Emission Inventory Preparation (Trial) 770 hours / year), which may lead to an underestimation of non-road diesel machinery emissions.
(3) NOx emissions are mainly related to the operating status of the machinery (loaded and no-load), and NOx emissions will increase during the loading process of the machinery. In the actual operating, the NOx emission concentration of the Loader is high and the range is large, mainly concentrated at 500 ~ 900ppm, while the NOx emission concentration of the Excavator and Forklift is relatively low, at 400 ~ 450ppm.

5. References
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