Research on Emission Characteristics of Non-road Mobile Machinery Based on Power

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Abstract. This paper takes 3 construction machinery as the research object, uses the portable emission measurer (PEMS) to test the emission in the actual operation of construction machinery. And analyzes the relationship between the operating characteristics of construction machinery and the characteristics of NOx emission and CO emission. The research results show that the NOx emission of construction machinery is positively correlated with power, and the NOx emission change rate is positively correlated with the mechanical power change rate. There is no obvious correlation between the CO emissions of construction machinery and power, and the change rate of CO emissions is positively correlated with the rate of mechanical power change.

Keywords: Non-road PEMS, NOx emission, CO emission

1. Overview
Non-road mobile machinery is widely used in national production and construction, and is an important production tool. But at the same time, non-road mobile machinery also emits a large amount of pollutants. According to the data in the China Motor Vehicle Environmental Management Annual Report released by the Ministry of Ecology and Environment in 2020, in 2019, non-road mobile sources emit sulfur dioxide (SO2), hydrocarbons (HC), nitrogen oxides (NOx), and particulate matter (PM). They are 159,000 tons, 435,000 tons, 4.933 million tons, and 240 thousand tons respectively, which are equivalent to the overall emissions of heavy diesel vehicles.

Because the emission control level of non-road mobile machinery is relatively backward, the single emission is higher than that of heavy diesel vehicles. Construction machinery is a kind of non-road mobile machinery with huge possession. Construction machinery mainly works in cities, and emission control technology is backward, causing serious pollution to urban air. According to the data released by the Ministry of Ecology and Environment, in 2017, construction machinery emitted 1.971 million tons of nitrogen oxides with 7.2 million units. The average emission of a single unit is about twice that of heavy-duty diesel vehicles. The emissions are very bad and are a serious threat to the health of citizens.

The current regulations of emission in our country is for diesel engines installed in construction machinery not machinery itself. The test conditions are engine steady-state test cycles that simulate the common operating speed regions of various machinery. In the past two years, European and American countries have added the engine transient test cycle NRTC to their regulations. However, these test methods and test conditions still use the engine as the test object, and do not directly reflect the actual
emissions of construction machinery during actual operation. The standard test cycle in laboratory can only reflect the emissions of construction machinery under specific working conditions, but cannot truly reflect the characteristics of actual emissions. At present, my country's latest regulations have introduced PEMS testing to test the emissions of actual machinery. However, the data of PEMS is only used to evaluate the emission level of machinery, and there is a lack of correlation research on machinery operating characteristics and emission characteristics. Based on the perspective of power and power change rate, this paper studies the emission characteristics of gas emission pollutants (NOx, CO,) and greenhouse gases (CO2) of construction machinery.

2. Test machinery and test conditions
The test equipment uses the Semtech-ECOSTAR portable vehicle emission measurement system (PEMS) produced by the American Sensor Company. The whole equipment includes gas analysis module, particle counting module, sampling control system, Pitot tube flow meter, weather station and GPS system. The gas analysis module can measure carbon monoxide (CO), carbon dioxide (CO2), nitrogen oxides (NOx) and other emission products.

The test sample is selected according to the pollution amount of construction machinery. According to data released by the Ministry of Environmental Protection in 2020: Forklifts, loaders and excavators rank the top three in terms of pollutants in construction machinery. Therefore, we choose forklifts, loaders, and excavators as the research objects. The sample parameters are shown in Table 1

| Number | Type     | Power (kW) | Rotating speed (rpm) | Technical route | Post-processing system |
|--------|----------|------------|----------------------|----------------|------------------------|
| Sample 1 | Forklift | 85         | 2200                 | Common rail    | No                     |
| Sample 2 | Loader   | 150        | 1800                 | Common rail    | No                     |
| Sample 3 | Excavator | 162       | 2000                 | Common rail    | No                     |

The samples selected for the study are all in-use construction machinery, the test location is the actual operating location of the construction machinery, and the test conditions select the actual operating conditions of the machinery.

3. Analysis of test results
Non-road mobile machinery basically works in a small area, so the emission of non-road mobile machinery is basically independent of the moving speed of the machine during operation. Non-road mobile machinery has various operating methods, and a unified operating method cannot be used to regulate the relationship between operation and emissions. The power required for the operation of non-road mobile machinery comes from diesel engines. Therefore, the impact of changes in operating conditions and workload on the pollutant emissions of non-road mobile machinery can be analyzed through changes in the operating conditions of the diesel engine.

According to the statistics of the Ministry of Ecology and Environment, the main gas emission products of non-road mobile machinery are NOx and CO, so the emission characteristics of these three gas substances are analyzed. The work cycle of non-road mobile machinery is very short, generally no more than 80 seconds. The cycle time and load of different single operations are very similar and present the characteristics of repetitive operations. Therefore, this paper randomly selects 100s of running segments from the test data for emission analysis.
Figure 1. The relationship between NOx emission and power

The NOx emission increase with the increase of power, and the power has a positive correlation with the NOx emissions. The fluctuation range of NOx emission of sample 3 is smaller than that of power fluctuation. The power velocity changes faster when two peaks with larger amplitude appear.

Figure 2. The relationship between CO emission and power

The CO emissions of sample 3 increase with the increase of power, and the CO emissions show a decline after the power stabilizes.
Figure 3. The relationship between the power change rate and the NOx emission change rate

The change rate of NOx emissions of increases with the increase of the power change rate, showing a positive correlation. Corresponding to the three peaks in Figure 3, there are three high points of power change rate, which are also high points of NOx change rate.

Figure 4. The relationship between the power change rate and CO emission change rate

The CO emission change rate increases with the increase of the power change rate, showing a positive correlation.

4. Conclusion
Non-road mobile machinery generally uses diesel engines as power. The non-road mobile machines used in the test are all electronically controlled diesel engines of National III, and there is no after-
treatment system. The emissions of non-road mobile machines are only related to the combustion in the cylinder of the diesel engine. Due to the design and working characteristics of the diesel engine, the air in the cylinder is basically excessive during combustion, so it is easier to generate NOx. Due to the uneven combustion, oxygen-deficient combustion occurs locally in the cylinder, and CO is also generated.

When the diesel engine is running at high load, the fuel quantity per unit volume in the cylinder is high. Under oxyfuel combustion conditions, the fuel can be burned more fully, the temperature in the engine cylinder is higher, and a typical NOx generation environment with high temperature and oxygen enrichment is easily formed, and the NOx concentration in the exhaust gas is easily increased. At the same time, the exhaust volume of the machinery under high load conditions will increase accordingly, resulting in an increase in overall emissions. When the diesel engine is running at low load, the temperature in the cylinder is low and the exhaust flow is low, and NOx emissions are correspondingly reduced. Therefore, NOx emissions and power show a positive correlation.

The CO pollutant generation condition of diesel engines is the high temperature and oxygen-deficient condition. When the power increases, the fuel in the engine cylinder increases faster but the intake air increases slowly, forming a high-temperature hypoxic condition in a short time, which is conducive to the generation of CO. At the same time, when the load increases, the exhaust flow rate increases, which is easy to form a high CO emission; When load is stable, the engine cylinder performs oxygen-enriched combustion, which is not easy to generate CO. Although the exhaust flow rate is high at this time, the CO concentration is very low, and CO emissions are reduced; under low load conditions, the temperature in the engine cylinder is low, and the fuel injection volume is small, forming a condition of low temperature and oxygen enrichment, which is not conducive to the generation of CO. At the same time, the low exhaust flow under low load condition further reduces CO emission.

When the load rise speed up, the temperature rise in the engine cylinder speeds up. Due to the inhomogeneity of combustion, high-temperature oxygen-enriched conditions will appear, which accelerates the rate of NOx generation; when the load drops faster, the fuel injection decreases while the intake air takes away a lot of heat, reducing the rate of NOx generation. Therefore, the load change rate is positively correlated with the change rate of NOx emissions.

When the load rise speed up, the temperature in the cylinder rise speed up. Due to the inhomogeneity of combustion, local conditions of high temperature and oxygen deficiency are easily formed, which accelerates the rate of CO generation. The faster the load drops, while the fuel injection is reduced, the intake air takes away a lot of heat, reducing the rate of CO generation. Therefore, the load change rate of the machinery is positively correlated with the change rate of CO emission.

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