Construction of Driving Cycle and Establishment of Emission Inventory of Urban Buses in Tangshan City

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Abstract. The project team selected eight typical buses (CNG, LNG, gasoline-electric hybrid, gas-electricity hybrid) at different emission stages in the built-up area of Tangshan City to test the emission of gaseous pollutants and particulate matter under actual road conditions, systematically evaluated, analyzed and compared the test results, and established the VSPbin emission rate database and emission factor list of typical urban buses in built-up areas based on the actual travelling characteristics of Tangshan. In this study, four cycles of acceleration, constant speed, deceleration and idle speed were selected to analyze the travelling cycle of buses in Tangshan. The results showed that the proportion of acceleration was higher, while deceleration also had a higher proportion; The area of bus travelling was mainly in the urban area, and the travelling cycles were relatively complicated, so there were frequent acceleration and deceleration during the travelling process. For the buses, with the raising of emission standards and the use of hybrid technology, the emissions of CO\textsubscript{2} and NO\textsubscript{x} from the buses at National IV were decreased by 13% and 53.5% respectively compared with those from the buses of the same tonnage at National III; The emissions of CO\textsubscript{2} and NO\textsubscript{x} from the nature gas-electric hybrid buses at National V were reduced by 20% and 18.8% respectively compared with those from the nature gas-fueled buses of the same tonnage at National V.

1. Introduction
The creation of motor vehicle emission inventory and analysis of emission characteristics are the basis for controlling urban vehicle emissions [1]. In order to stabilize the environmental quality of the cities during the Blue Sky Protection Campaign, it is very important to discuss the policies of vehicle exhaust pollution control, so as to establish the basis for the policies of effective vehicle emission control. In this study, field surveys, data and statistical yearbook inquiries were used to investigate the main models of urban buses in Tangshan. Selecting typical vehicles in view of the urban buses, combining the actual road characteristics of Tangshan to select a representative road, and using the portable emission measurement system (PEMS) to investigate the actual travelling characteristics and emissions, were conducive to understanding the regional or local pollution characteristics caused by buses and scientifically formulating targeted measures for bus pollution control and improvement [2].

2. Test Method and Equipment

2.1. Test Equipment
Vehicle-mounted emission testing used a portable emission measurement system (PEMS) to be placed...
directly in a vehicle travelling on the actual road, collecting motor vehicle travelling parameters and pollutant emission concentrations on second by second [3], to provide reliable data for the analysis of vehicle exhaust emission characteristics.

This project uses SEMTECH-DS vehicle-mounted emission tester to test the gaseous pollutants (CO, NOx, THC, CO2, etc.) exhausted by vehicles on the actual road [4]. The vehicle’s running speed and position are recorded by GPS. At the same time, an electrical low-pressure impactor (ELPI +) was used to record the concentration of particulate matter in real time. The schematic diagram of PEMS device connection is shown in figure 1.

![Figure 1. The schematic diagram of PEMS device connection.](image)

2.2. Test Vehicle Models

In this study, the types of motor vehicles in Tangshan were researched, and through field investigation, the buses were selected mainly according to emission standards, fuel types and hybrid power. A total of 8 vehicles were selected for the test. The detailed parameters of test vehicles are shown in table 1.

| No. | Fuel type   | Total mass (t) | emissions standards | Vehicle type |
|-----|-------------|----------------|---------------------|--------------|
| 1   | CNG         | 16000          | National III        | Large bus    |
| 2   | CNG         | 16000          | National III        | Large bus    |
| 3   | CNG         | 12200          | National V          | Large bus    |
| 4   | LNG         | 18000          | National V          | Large bus    |
| 5***| DieselE*    | 16500          | National IV         | Large bus    |
| 6   | DieselE*    | 16000          | National IV         | Large bus    |
| 7   | CNGE**      | 17800          | National V          | Large bus    |
| 8   | CNGE**      | 18000          | National V          | Large bus    |

Note: * Diesel-electric hybrid vehicle; ** natural gas-electric hybrid vehicle; *** No. 5 Diesel-electric hybrid bus refitted and added with SCR system catalyst for urea aftertreatment.

2.3. Test Route

Due to the uniqueness of urban buses, the speed is required to be within 50 km/h. This test selected a ring test route in the built-up area, and the test route included 42 bus stops. During the test, the buses normally stopped at bus stops along the road, as shown in figure 2.
3. Study on Characteristic Parameters of Motor Vehicle Travelling

3.1. Selection of Travelling Parameters

Generally, some statistical parameters are utilized to describe the overall motion characteristics of motor vehicle travelling behavior usually, such as travel time, travelling distance, average speed, maximum acceleration, etc. In this study, three characteristic values of average speed (V), acceleration (a), and relative positive acceleration (RPA) were used as the statistical characteristic parameters to describe the travelling of a motor vehicle.

\[ V = \frac{D}{T} \quad (1) \]

where, \( D \) — total travelling distance, m; \( T \) — total travelling time, s

\[ a_i = \frac{v_{i+\Delta t} - v_{i-\Delta t}}{2\Delta t} \quad (2) \]

where, \( a_i \) — the acceleration of the motor vehicle at ith second, \( m/s^2 \); \( \Delta t \) — the time interval between the ith seconds and the \( i+\Delta t \), here \( \Delta t = 1 \), s;

\[ RPA = \frac{\int_0^T (v_i a_i^+) \, dt}{T} \quad (3) \]

where, \( a_i^+ \) — the positive acceleration of the motor vehicle at ith second, \( m/s^2 \).

For the relative positive acceleration (RPA), it mainly needs to consider the impact of vehicle engine acceleration on fuel consumption and emissions during an operating cycle [4]. The travelling cycles experienced by vehicles on actual roads are complex and changeable, roughly divided into the following four cycles: acceleration, deceleration, constant speed, and idle speed. Because there is no uniform standard in the world to delimit the above four driving cycles, different researchers have different criteria for delimiting travelling cycles during data processing, and as long as the delimitation criteria are within a reasonable range and has a basis, they are allowed.

The delimitation criteria for acceleration, deceleration, constant speed and idle speed in this study are as follows:

- Acceleration: the acceleration \( a \geq 0.14 \, m/s^2 \) during the vehicle travelling;
- Deceleration: the acceleration \( a \leq -0.14 \, m/s^2 \) during the vehicle travelling;
- Constant speed: the absolute value \( a \) of the acceleration during the vehicle travelling is less than 0.14 \( m/s^2 \), and the vehicle travelling speed is \( v \geq 1 \, km/h \);
- Idle speed: the absolute value \( a \) of the acceleration during the vehicle travelling is less than 0.14 \( m/s^2 \), and the vehicle travelling speed is \( v < 1 \, km/h \).
In the meantime, this study calculated the proportion of four driving cycles in an operating cycle through the above delimitation criteria, so as to determine the characteristics of different travelling cycles and further determine the fuel consumption and emission under each driving cycle. For example, the proportion of idle speed during travelling mainly involves the idle-speed driving under the cycles of moderate congestion and severe congestion, and the fuel consumption at idle speed accounts for a larger proportion [5].

In this study, the four driving cycles of acceleration, constant speed, deceleration and idle speed were selected to analyze the travelling cycles of buses in Tangshan, and the results are shown in table 2. Thereinto, the proportion of acceleration was relatively higher, and meanwhile, there was a higher proportion of deceleration; the area of bus travelling was mainly in the urban area, and the travelling cycles were relatively complicated, so there were frequent acceleration and deceleration during the travelling process.

| Vehicle type | Road length /km | urban district | Proportion of driving mode /% | Proportion of driving mode /% |
|--------------|-----------------|----------------|-------------------------------|-------------------------------|
| Bus          | 24.0            | 100            | idling | accelerate | Slow down | Uniform speed |
|              |                 |                | 27.1   | 30.8       | 22.4      | 19.7           |

### 3.2. Travelling Characteristic Analysis

In order to calculate the distribution of travelling speed and acceleration, this study used scatter plots to describe them, as shown in figure 3.

Because of the speed limit during the bus travelling, the maximum speed was about 60 km/h, but acceleration was widely distributed, concentrated on [-4.5, 4.5] m/s$^2$, mainly due to the following two factors:

1. The bus routes were mostly in urban areas, and the vehicle cycles were more complicated;
2. It was related to the more radical driving style of bus drivers.

As a parameter that considers the impact of accelerated operation of the vehicle engine on fuel consumption and emissions during an operating cycle, the relative positive acceleration (RPA) can reflect the acceleration intensity of the vehicle during driving. Figure 4 shows the distribution of speed and relative positive acceleration during travelling. It can be seen from figure 4 that the relative positive acceleration of the bus is widely distributed, especially in the low-speed phase, where the travelling behavior is more intense, and there are more frequent acceleration and deceleration behavior.

Figure 3. The speed-acceleration distribution of buses.  
Figure 4. The speed-relative positive acceleration distribution of the bus.
4. Study on the Emission Factors of Motor Vehicles on the Actual Road

In this study, the pollutants emitted at unit distance traveled by a motor vehicle were used to represent the emission characteristics of the motor vehicle. The pollutant emission (g) during a certain distance or under a certain cycle was obtained by calculation, and then the travelling mileage (km) during the certain distance or under the certain cycle was divided, to obtain the average emission factor (g/km) of this travelling cycle. As a method adopted by various national standards, this one can visually represent the characteristics of the relationship between pollutants and motor vehicle travelling cycles.

4.1. Calculation of the Basic Emission Factor

Figure 5 shows the detected emission factors of gaseous emissions from the vehicles. Among the buses, the maximum allowable total masses of No.1 and No.2 at National III and those of No.5 and No.6 at National IV were relatively close (about 16 t), while compared with the buses at National III, the CO₂ emissions of those at National IV were significantly reduced by about 13 %. Among the buses at National V, the total mass of No. 4 and No. 8 were the same (18 t), and their fuels are natural gas, but the CO₂ emissions of the gas-electric hybrid No. 8 was quite lower, about 80% of No. 4. As can be seen, strict emission standards and the application of hybrid technology can effectively reduce CO₂ emission. At the same time, with the increase of vehicle tonnage, CO₂ emission was increased significantly. For example, the emission from No. 7 (17.8 t) was 73.1% higher than that from No. 3 (12.2 t).

Among the buses, with the stricter emission standards and the use of hybrid electric vehicles, the NOx emission of the buses at National IV was significantly lower than those of the same tonnage at National III, with a reduction of about 53.5%. Among the gas-fueled buses at National V, the emission of No. 8 with hybrid power was significantly lower by 18.8% than that of No. 4 of the same tonnage with hybrid power.

Meanwhile, the high-tonnage No. 7 had a higher NOx emission by 34.7% than No. 3 which also uses natural gas as fuel but is low-tonnage. After the refitting of the post-processing system, the emission of NOx from the diesel-fueled No.5 vehicle refitted with SCR was not lower than that from the diesel-fueled No. 6.

Figure 6 shows the detected emission factors of particulate matter from the vehicles. Among the buses, the emission of particulate matter did not decrease with the stricter emission standards, such as the emission of particulate matter from the vehicle at national III significantly lower than that from the vehicle at national IV; The emission of particulate matter also did not increase with the increasing tonnage, but reduce with the use of hybrid power.

4.2. Speed-based Emission Factors

In this study, the travelling cycles of motor vehicles were further subdivided according to speed. From 5 km/h to 115 km/h, every 10 km/h was divided into an interval, with a total of 11 speed intervals, and pollutant emission factors of each interval were calculated.

The changes of emission factors of gases and particulate matter from the vehicles with the speed range were shown in figures 7 and 8.

For gaseous pollutants, except for the hybrid vehicles, the emission factors of other models showed a decreasing trend with the increasing speed; The diesel hybrid models presented a trend of first decline, then rise and finally decline, while natural-gas hybrid models showed a trend of rise first and then decline. This may be related to the fact that hybrid buses mostly use electricity at low speeds and only use gasoline at high speeds.

Regarding the quality and quantity of particulate matter, the emission trend of diesel hybrid vehicles was consistent with the change trend of gaseous pollution, but that of gas-electric hybrid vehicles was increased with the rising speed, while that of non-hybrid vehicles declined with the rising speed.
Figure 5. The detected emission factors of gaseous emissions from the vehicles.

Figure 6. The detected emission factors of particulate matter from the vehicles.
Figure 7. The changes in emission factors of gaseous pollutants from the buses at different speed intervals.

Figure 8. The changes in emission factors of the mass and quantity of particulate matter from the buses at different speed intervals.

5. Conclusions

The project team selected three kinds of fuels (diesel oil, CNG and gas-electricity hybrid) and the buses at National III to V stages to conduct emission tests on the actual road. The study found that with the stricter emission standards, the pollutant emissions of bicycles were decreased, among which NOx emission are reduced by more than 90. Compared to gasoline fuel, the emissions of CO\textsubscript{2} and NO\textsubscript{x} from CNG-fueled taxis showed decreasing trends. With the stricter emission standards and the use of hybrid technology, the emissions of CO\textsubscript{2} and NO\textsubscript{x} from the buses at National IV could be reduced by 13% and 53.5% compared to those from the buses of the same tonnage at National III; The emissions of CO\textsubscript{2} and NO\textsubscript{x} from the nature gas-electric hybrid buses at National V were reduced by 20% and 18.8% respectively compared with those from the nature gas-fueled buses of the same tonnage at National V.

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