Emission Characteristics of Hybrid Electric Bus During Peak Period Based On Remote Monitoring

Chen Jin-chao¹, Zhang Xiao-wen², Li Su¹*, Qi Song-bo², You Xiao-qing¹

¹College of Energy and Environmental Engineering, Hebei University of Technology, Tianjin 300401, China
²China Automotive Technology and Research Center Co. Ltd, Tianjin 300300, China

* Corresponding author: jinchao_chen2021@163.com

Abstract. Based on the OBD remote monitoring system, the real-time data of Tianjin 607 bus is collected, and two representative groups of data are selected for analysis. The results show that the vehicles start and stop frequently during peak period, the frequency of electric motor use increases from 27.72% in off-peak period to 53.72% in peak period, the average driving speed is faster than usual, and the drivers tend to drive more intensely for catching up time. Under the same working conditions, the frequency of electric motor use is positively correlated with the emission reduction benefits brought by the use of hybrid electric vehicles. Under different road conditions, especially in the peak operation, the exhaust temperature is low, which has a greater impact on the actual emission reduction benefits of the electric motor. The key to fundamentally alleviate the emission problem of bus in peak period is to improve the vehicle operation conditions and the conversion rate of SCR system.

1. Introduction

With the continuous growth of the number of motor vehicles, vehicle exhaust emissions have attracted more and more attention. As one of the exhaust pollutants, nitrogen oxides are mainly divided into nitric oxide and nitrogen dioxide, which have different degrees of toxicity to human body [1-2]. According to statistics, the number of diesel vehicles in China accounts for only 4.6% of the total number of vehicles, but the proportion of NOx emission is as high as 78% [3]. Therefore, reducing NOx emission from diesel vehicles is an effective means to control pollutants. Compared with other types of heavy diesel vehicles, buses are closer to people [4-5], and their pollutants have a more direct impact on people. During the peak period, the road traffic volume increases, the number of people getting on and off the bus stops is more, the start and stop are frequent, and the vehicle load becomes larger. Therefore, the study of vehicle emission characteristics during peak period is helpful to provide strategies to reduce pollutant emissions.

At present, the portable emission measurement system (PEMS) is a mature and widely used exhaust emission monitoring technology, which has large equipment, high cost and needs to be installed on the vehicle for follow-up test. Therefore, due to the limitations of its equipment, it is impossible to realize real-time monitoring and measurement of each vehicle with PEMS. In addition, PEMS test has certain requirements, sometimes can not perfectly reflect the actual working process of a bus. OBD (on board diagnostics) system, can read ECU data through CAN bus, so as to obtain relevant parameters of vehicle transient conditions. The vehicle terminal can read the OBD data and upload it to the server through the wireless network and GPRS system. The remote monitoring platform can read and analyze the data packets uploaded by the terminal to the server and carry out calculation and processing. A complete
monitoring system can monitor the vehicle operation status online in real time. Liu [6] research shows that the actual road NOx emissions collected by the remote emission management platform are basically consistent with the results of PEMS equipment, so this study uses the remote monitoring system to analyze the bus.

2. Methods and materials

2.1 Remote monitoring system based on OBD
The on-board terminal is from China Automotive Research and Development Center (Tianjin) Co., Ltd., which meets the requirements of GB/17691-2018 standard. The vehicle terminal uses TCP/IP network control protocol as the underlying communication protocol, and uploads data packets to the server through 4G and GPRS system. The acquisition frequency is 1Hz, and the upload frequency to the server is 0.1Hz, and the packet loss rate is less than 1%. Through the derivation of historical data and driving trajectory, the time and space are fitted to form a complete experimental data. The operation and emission characteristics analysis of the actual road vehicles by remote monitoring system requires the collection of the whole distance parameter information.

2.2 Vehicle and data selection
Two buses with the same route of bus 607 are selected, and the whole section passes through 43 stations; the two cars have the same model, just the departure time is different. The time difference between the two cars is 30 minutes, that is, car A starts at 7:00 and car B starts at 7:30. The test time is the same day working hours, with a total of three round trips. The characteristic operation time is mainly selected for comparison. As the first working period of vehicle a is just in the peak period, the peak period of 108 minutes for vehicle a and the flat peak period of 92 minutes for car A are selected respectively. The two test vehicles have the same path, from the North Square bus station of Tianjin station to Yang-cun bus station, as shown in Figure 1. Nearly 80% of the whole section is the trunk road of Beijing-Tianjin highway, but due to the particularity of bus work, it needs to stop at each passing station, so it needs to keep in and out of the auxiliary section.

| number | Parameter type            | Vehicle parameters         |
|--------|---------------------------|----------------------------|
| 1      | Vehicle model             | ZK6105CHEVPG4              |
| 2      | Engine model              | YC6J220-50                 |
| 3      | Rated capacity            | 81/10-36                   |
| 4      | Maximum engine power      | 162kW                      |
| 5      | displacement              | 6494mL                     |
| 6      | Maximum torque            | 800N·m                     |
| 7      | Rated speed               | 2500rpm                    |

The vehicle is Yutong heavy industry diesel hybrid electric vehicle, and the emission stage is China V standard. See Table 1 for detailed vehicle information.

Using $v$-VSP microoperation mode method, because the maximum speed of the bus is 69 km/h in this test, the Bin grid division method is redefined. The calculation formula of VSP is shown in Equation 1.

$$VSP = v(1.1a + 0.132) + 0.0000302v^3$$

In the formula, $VSP$ is the engine specific power (kW/t). $v$ is the vehicle speed (m/s); $a$ is the instantaneous acceleration of the vehicle (m/s$^2$).
Referring to the VSP-Bin working condition division rules of Motor Vehicle Emission Simulator [7], according to the vehicle running state (deceleration, idle speed, acceleration and constant speed) and instantaneous VSP, the VSP is divided into bin. The increment of VSP is 2kW/t, starting from -8kW/t to above 12kW/t, and the running status of VSP is braking ($a<-0.89m/s^2$), idle (0~1.6km/h), low speed (1.6~25km/h), medium speed (25~50km/h) and high speed ($v>50km/h$). There are 38 Bin grids in total, as shown in Table 2.

### Table 2. $v$-VSP partition interval

| VSP/($kW/t$) | $a/ (m/s^2)$ | $v/ (km/h)$ | 1.6≤$v$≤25 | 25≤$v$≤50 | $v$≥50 |
|--------------|--------------|--------------|-------------|------------|--------|
| -8≤VSP≤-6   | $a<-0.89$    | $v<1.6$      | Bin0        | Bin1       | Bin26  |
| -6≤VSP≤-4   | Bin3         | Bin15        | Bin2        | Bin27      |        |
| -4≤VSP≤-2   | Bin4         | Bin16        | Bin28       | Bin29      |        |
| -2≤VSP≤0    | Bin5         | Bin17        | Bin30       | Bin31      |        |
| 0≤VSP≤2     | Bin6         | Bin18        | Bin32       | Bin33      |        |
| 2≤VSP≤4     | Bin7         | Bin19        | Bin34       | Bin35      |        |
| 4≤VSP≤6     | Bin8         | Bin20        | Bin36       | Bin37      |        |
| 6≤VSP≤8     | Bin9         | Bin21        | Bin38       | Bin39      |        |
| 8≤VSP≤10    | Bin10        | Bin22        | Bin40       | Bin41      |        |
| 10≤VSP≤12   | Bin11        | Bin23        | Bin42       | Bin43      |        |
| VSP>12      | Bin12        | Bin24        | Bin44       | Bin45      |        |

3. Results and discussion

#### 3.1 Vehicle operation analysis

The average speed of car A is 23.73km/h, and the average driving speed is 32.21km/h. The average speed of car B is 25.10km/h, and the average driving speed is 30.21km/h. The frequency of motor use of car A...
is 42.03%, and that of car B is 36.62%. It shows that the half-hour parking situation is eased and the vehicle runs more smoothly.

The average speed is 24.75km/h, the average speed is 31.41km/h, and the maximum speed is 64.72km/h; the average speed is 26.61 km/h, the average driving speed is 30.32km/h, and the maximum speed is 64.32km/h. Because it takes more time to stop in the rush hour, drivers are easy to drive fiercely, and the speed is higher than usual on the road with low traffic flow. The two time periods are divided into different working conditions, which are mainly divided into acceleration, uniform speed, deceleration and parking. As shown in Figure 2, the smooth and uniform driving time in the peak period is about 10% higher than that in the peak period. The traffic flow is large during the peak period, and the number of stations increases. Therefore, the road starts and stops frequently, the waiting time at stations increases, and the parking time increases significantly.

![Fig. 2 Proportion of peak and off-peak working conditions and peak period](image)

Only 27.72% of the off-peak hours use the motor, while the average use frequency of the motor in the peak hours is 53.72%, which indicates that the buses start and stop frequently in the peak hours, the speed is low, and the engine is not working. The electric hybrid motor car will give priority to start the motor under the low speed and low power operation condition, and further divide the operation condition during the peak period, as shown in Figure 3. Most of the time, it is in the idle operation condition, so the starting frequency of the motor is greatly increased.

![Fig. 3 Proportion of time in each bin during peak period](image)

3.2 Vehicle emission analysis

According to the real-time vehicle data, including vehicle speed $v$ (km/h), air intake $m_{\text{in}}$ (kg/h), engine fuel flow $L_f$ (L/h), SCR downstream sensor concentration $c$ (ppm), etc. According to Equations (2), (3) and (4), the driving range and NOx emission of diesel engine during operation can be calculated, and the emission factors of diesel engine during operation and total stroke can be obtained respectively.
In the formula, $n_{out}$ is the total mass flow rate of exhaust gas, kmol/h; $M_{air}$ is the molecular mass of air, 29g/mol; $M_C$, $M_H$ is the molecular weight of carbon and hydrogen, respectively; $\rho_f$ is the fuel density, 0.84kg/L; $k$ is the fuel H:C ratio, 1.95; $M_{NO_x}$ is the average molecular weight of NOx, in g/mol, the volume ratio of NO in NOx is about 90%, and NO2 is 10%, taking 31.6g/mol; $m_{NO_x}$ is the mass flow rate of NOx, g/s; $S$ is the mileage, m.

Compared with vehicle a and vehicle B, the emission reduction rate of vehicle a is 37.80% and that of vehicle B is 58.10%, which indicates that reducing peak operation time can effectively reduce pollutant emissions.

The proportion of motor working time and NOx emission of diesel engine in each Bin grid are calculated, and the diesel engine and overall emission factors in all bin grids are obtained respectively. The motor is used to reduce the NOx produced by the engine, so as to reduce the emission. The emission factors of traditional diesel engine in each working condition are compared with the recommended values in the “Guide” (Technical guide for compiling air pollutant emission inventory of road vehicles), as shown in Figure 4. During the low-speed operation, the emission is more likely to be higher than the recommended value, while during the medium and high-speed operation, the emission is better and basically lower than the recommended value. This shows that the emission problem is more serious when the diesel engine is started in the low-speed zone. If the vehicle is in the low-speed zone for a long time and the diesel engine is used frequently, the emission will exceed the standard, which will aggravate the environmental pollution.

NOx emission reduction can be achieved by replacing internal combustion engine with motor. The emission reduction of each Bin is shown in Figure 5. The proportion of electric motor and engine working time is too low under high-speed running condition (Bin26~37), which is not representative and will not be described in detail. The curve of electric motor working time proportion and emission reduction efficiency basically fit, showing a high correlation. It shows that the higher the motor frequency is, the less the total NOx emission is.
The total emission factor of diesel engine is 4.267 g/km in peak period, but it is 3.442 g/km in off-peak period, which indicates that the vehicles start and stop frequently in peak period, the engine working condition is bad, the sudden increase of throttle opening leads to the sudden increase of fuel injection, the sudden increase of combustion temperature and pressure in combustion chamber, and the production of NOx increases immediately. At the same time, when the vehicle runs at low speed, the motor is used and the engine is not working, the combustion cycle temperature of the internal combustion engine will be reduced, the thermal efficiency will be reduced, the fuel consumption and emission will be increased, and the emission temperature will also be affected. When the temperature of SCR catalyst reaches 210°C, the SCR system will inject urea. When the temperature rises to 230°C, the SCR system will reach the best working state, and the NOx conversion rate will be greatly improved \cite{8}. Under the condition of low vehicle speed for a long time, the exhaust temperature is too low, so that the conversion efficiency of SCR system is low or even does not work.

The emission factor calculation is carried out for the motor and the traditional diesel engine. The total emission factor of the vehicle in the peak period is 2.367 g/km, and the off-peak period is 2.011 g/km. Even though the frequency of motor in peak period is nearly twice that in off-peak period, the emission reduction effect is basically equal to that in off-peak period, which indicates that when the vehicle runs smoothly, the engine combustion condition is good and the SCR system works well, can the NOx emission be reduced fundamentally.

**4. Conclusion**

1) Through the remote monitoring system, the data of the whole vehicle operation can be obtained, and different time and space data can correctly reflect the actual operation status of the bus, which further shows the feasibility of remote communication data analysis of vehicle operation. The peak period has more parking and acceleration and deceleration conditions than off-peak period, accounting for 61% of the total. In peak period, bus drivers are often affected by time factors, which is faster than usual, and the possibility of intense driving is increased.

2) For the hybrid electric bus which needs to be started and stopped frequently, the motor frequency is generally between 35% and 55%. Under the same road conditions, the motor running time is positively correlated with the emission reduction rate, and the use of hybrid electric vehicle can effectively reduce NOx emissions; nevertheless, different working conditions have different effects, especially in low speed and high power conditions, the engine will start to meet the requirements of higher torque ratio, the SCR system has extremely low efficiency in the case of low exhaust temperature, and the NOx emission will increase significantly.

3) Even though the motor frequency is 53.72% in the peak period, the emission reduction effect is not ideal, which is similar to the off-peak emission reduction rate of motor which only accounts for 27.72%, which is 44.52% and 41.59% respectively. The key to fundamentally alleviate the emission...
The problem of hybrid electric bus is to improve the bus operating conditions, optimize the engine combustion and improve the SCR system conversion rate.

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