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Gaseous emissions from compressed natural gas buses in urban road and highway tests in China

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ABSTRACT

The natural gas vehicle market is rapidly developing throughout the world, and the majority of such vehicles operate on compressed natural gas (CNG). However, most studies on the emission characteristics of CNG vehicles rely on laboratory chassis dynamometer measurements, which do not accurately represent actual road driving conditions. To further investigate the emission characteristics of CNG vehicles, two CNG city buses and two CNG coaches were tested on public urban roads and highway sections. Our results show that when speeds of 0–10 km/hr were increased to 10–20 km/hr, the CO_2, CO, nitrogen oxide (NO_x), and total hydrocarbon (THC) emission factors decreased by (71.6 ± 4.3)%, (65.6 ± 9.5)%, (64.9 ± 9.2)% and (67.8 ± 0.3)%, respectively. In this study, The Beijing city buses with stricter emission standards (Euro IV) did not have lower emission factors than the Chongqing coaches with Euro II emission standards. Both the higher emission factors at 0–10 km/hr speeds and the higher percentage of driving in the low-speed regime during the entire road cycle may have contributed to the higher CO_2 and CO emission factors of these city buses. Additionally, compared with the emission factors produced in the urban road tests, the CO emission factors of the CNG buses in highway tests decreased the most (by 83.2%), followed by the THC emission factors, which decreased by 67.1%.

Introduction

Natural gas vehicles are highly regarded worldwide. In the year 2000, there were approximately 1.29 million natural gas vehicles operating globally, and by the end of 2012, that number exceeded 16.7 million. The market for natural gas vehicles in China has also flourished. The average growth rate per year was 45.9% for the period 2002–2012. By 2012, China had the sixth highest number of natural gas vehicles in the world, with a total exceeding 1.58 million vehicles (IANGV-International Association for Natural Gas Vehicles, 2013). Approximately 98% of natural gas vehicles purchased in China operate on compressed natural gas (CNG). In recent years, CNG vehicles have mainly been used in public transport to replace diesel-powered buses and gasoline-powered taxis (Goyal and Sidhartha, 2003; Pastorello et al., 2011; Suthawaree et al., 2012; Yang et al., 1997).

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In Beijing, there are approximately 3000 CNG buses running in the bus group, making Beijing the city with the most CNG buses in the world (Ling, 2012).

As the number of natural gas vehicles increases worldwide, it is essential to thoroughly understand the emission characteristics of these vehicles. Many studies using dynamometers or road tests have been conducted to characterize CNG vehicle exhaust emissions (Clark et al., 1999; Jayaratne et al., 2009, 2010; Hallquist et al., 2013; Lanni et al., 2003; Ullman et al., 2003; Wang et al., 2011; Zhang et al., 2014b). The experimental results revealed that particulate matter mass emissions from the CNG buses were much lower than those from diesel buses (Jayaratne et al., 2009; Lanni et al., 2003; Ullman et al., 2003; Wang et al., 2011), whereas the opposite was observed with regard to total hydrocarbon (THC) emissions. Studies have also indicated that the THC emission factors from CNG buses with an oxidation catalyst are 5–6 times higher than those of diesel buses (Euro IV) with selective catalyst reduction (SCR) (Wang et al., 2011). More than 95% of the THC emissions from CNG vehicles consist of methane, which is an important greenhouse gas that is not reactive in the atmosphere and does not harm human health (Nanaki et al., 2014; Ullman et al., 2003). Furthermore, compared with diesel buses, the nitrogen oxide (NO_x) emissions of CNG buses were lower (Nanaki et al., 2014; Wang et al., 2011; Zhang et al., 2014a).

Most studies on CNG vehicle emissions have relied on laboratory chassis dynamometer measurements (Jayaratne et al., 2009, 2010; Lanni et al., 2003; Ullman et al., 2003), which do not completely represent actual road driving conditions. Only a few studies have characterized CNG vehicle emissions in real road tests (Wang et al., 2011; Zhang et al., 2014b).

In this study, we conducted urban road and highway tests of CNG city buses and coaches to further study the characteristics of CNG vehicles. The influence of speed on CO_2, CO, NO_x and THC emission factors was analyzed for all test vehicles. We also investigated the emission levels and fuel consumption (FC) of CNG coaches in urban road versus highway tests. Because most previous studies have shown that particulate matter mass emissions from CNG vehicles are relatively low (Jayaratne et al., 2009; Lanni et al., 2003; Ullman et al., 2003; Wang et al., 2011), only gaseous emissions were considered in this study. Our results will help improve the exhaust emission factors of CNG vehicles in real road conditions and facilitate the compilation of an urban/regional emission inventory for these vehicles, thereby improving the accuracy of CNG vehicle emission calculations.

1. Methods

1.1. Bus specifications

The four CNG vehicles tested in this study were selected from in-service transport city buses in Beijing and coaches from Chongqing. The specifications of these buses are summarized in Table 1. City buses BJ1# and BJ2# belonged to the same transport fleet in Beijing and they were subjected to the same service patterns, which complied with the China IV emission regulations (equivalent to Euro IV). Coaches CQ1# and CQ2# belonged to the same transport fleet in Chongqing and they were subjected to the same service patterns, which complied with the China II emission regulations (equivalent to Euro II).

1.2. Measurement system

During the road tests, the tail gas from the buses was channeled into a flowmeter through a tube connected to the exhaust pipe. An air pump attached at the end of the measurement system then pumped the gas into a gas analyzer to determine the CO_2, CO, NO_x and THC concentrations. The gas analyzer was an onboard vehicle emissions analyzer (SEMTECH-DS, American Sensors Company, MI, USA), which consisted of a string of modular, stand-alone measurement subsystems. These included a flame ionization detector (FID) for THC measurement, a non-dispersive ultraviolet (NDUV) analyzer for NO and NO_2 measurement, and a non-dispersive infrared (NDIR) analyzer for CO and CO_2 measurements.

All the instruments were loaded in the test buses. Additionally, the vehicle speed, altitude, longitude and latitude of the running bus were recorded every second using a global positioning system (GPS) mounted on the SEMTECH-DS analyzer.

1.3. Driving cycles

The two city buses tested in Beijing were driven and their emission data collected on the same urban roads, including flat arterial roads and residential roads, which were also part of the daily driving routes of the bus group. The coaches in Chongqing were tested along the same routes, which consisted of urban roads and highways with abundant upward and downward slopes; these routes were also included in the daily driving routes of the coaches' transport fleet. Fig. 1 shows the real road speed and altitude during the driving cycles of the test buses in

Table 1 – Specifications of the four CNG buses used in the road tests.

No.	ID	City	Brand	Engine power (kw)	Mileage (10^3 km)	Engine displacement (L)	After-treatment
1	BJ1#	Beijing	QingNian	147	102	5.88	3-way catalyst
2	BJ2#			147	125	5.88	
3	CQ1#	Chongqing	HengTong	172	607	6.2	–
4	CQ2#			172	607	6.2	

CNG: compressed natural gas.