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On-road emission characteristics of CNG-fueled bi-fuel taxis

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HIGHLIGHTS

- CNG vehicles were rapidly developed in China.
- Real-world emissions from CNG bi-fuel taxis were examined using PEMS.
- Impact of driving cycle on emissions for CNG taxis was analyzed.
- Emissions for CNG taxis were compared with gasoline vehicles and standards.
- Increases in HC and NO_x were observed for CNG taxis compared with gasoline vehicles.

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ABSTRACT

To alleviate air pollution and lessen the petroleum demand from the motor vehicle sector in China, natural gas vehicles (NGVs) have been rapidly developed over the last several years. However, the understanding of the real-world emissions of NGVs is very limited. In this study, the emissions from 20 compressed-natural-gas-fueled bi-fuel taxis were measured using a portable emission measurement system (PEMS) under actual driving conditions in Yichang, China. The emission characteristics of the tested vehicles were analyzed, revealing that the average CO_2, CO, HC and NO_x emissions from the tested compressed-natural-gas (CNG) taxis under urban driving conditions were 1.6, 4.0, 2.0 and 0.98 times those under highway road conditions, respectively. The CO, HC and NO_x emissions from Euro 3 CNG vehicles were approximately 40%, 55% and 44% lower than those from Euro 2 vehicles, respectively. Compared with the values for light-duty gasoline vehicles reported in the literature, the CO_2 and CO emissions from the tested CNG taxis were clearly lower; however, significant increases in the HC and NO_x emissions were observed. Finally, we normalized the emissions under the actual driving cycles of the entire test route to the New European Driving Cycle (NEDC)-based emissions using a VSP modes method developed by North Carolina State University. The simulated NEDC-based CO emissions from the tested CNG taxis were better than the corresponding emissions standards, whereas the simulated NEDC-based HC and NO_x emissions greatly exceeded the standards. Thus, more attention should be paid to the emissions from CNG vehicles. As for the CNG-fueled bi-fuel taxis currently in use, the department of environmental protection should strengthen their inspection and supervision to reduce the emissions from these vehicles. The results of this study will be helpful in understanding and controlling emissions from CNG-fueled bi-fuel vehicles in China.

1. Introduction

Energy security, climate change, air pollution and alternative fuels are being widely researched. Natural gas, which is regarded as a promising alternative to oil because of its comparatively large reserves, high combustion efficiency and low emissions, is widely studied and used throughout the world (Jahirul et al., 2010; Aslam et al., 2006; Hao et al., 2000).

In China, with the rapid growth of both the economy and the motor vehicle fleet, emissions from vehicles have become the most significant source of air pollution in urban cities (He et al., 2002, 2005; Huo et al., 2007). To alleviate air pollution and reduce the petroleum demand from the motor vehicle sector in China, more cities have begun to promote the use of natural gas vehicles (NGVs). As a result, the number of NGVs has increased rapidly in the last

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several years. By the end of 2011, there were approximately 1 million NGVs in China, which accounted for 6.6% of the total NGV population in the world (INAGV, 2013). Due to this rapidly increasing alternative motor vehicle population, an understanding of its emission advantages and disadvantages in the real world is required.

In previous studies, many researchers have focused on comparing emissions from vehicles fueled with natural gas with those fueled with other fuels using the chassis dynamometer method. Jahirul et al. (2010) compared the engine performance and the emissions from a retrofitted car engine that was fueled with compressed natural gas (CNG) and gasoline using the chassis dynamometer method. They found that the CNG engine had higher NO_x emissions and lower HC, CO and CO_2 emissions compared to the gasoline engine. Aslam et al. (2006) presented test results of the performance, fuel consumption and exhaust emissions under steady state operating conditions in a retrofitted car engine fueled by gasoline and CNG with a chassis dynamometer. The same results were observed as in the study of Jahirul et al. (2010). Zhang et al. (2011) compared the emissions emitted from in-use, light-duty, flexible-fuel vehicles fueled by gasoline and CNG based on the ECE 15 driving cycle in a laboratory. Compared with the emission levels measured for gasoline, the values for CNG were reduced on average by 7%–30% for CO, HC and NO_x. In addition, Jayaratne et al. (2009) measured the particulate and gaseous emissions from CNG and ultra-low-sulfur diesel-fueled buses at four engine loads using a chassis dynamometer. Based on the results of the above lab studies, it was found that CNG-fueled engines can cause an increase in NO_x or CO_2 emissions under certain conditions. For this reason, more studies on emissions from the rapidly increasing numbers of NGVs should be conducted.

In recent years, more researchers have begun to study vehicular emissions using the portable emission measurement system (PEMS), a test method that is rapidly increasing in popularity. This method has advantages over traditional laboratory measurements, which may not reflect actual emissions. However, most on-board emission tests have focused on diesel and gasoline vehicles (Huo et al., 2012a, 2009; Yao et al., 2011; Yao et al., 2007; Chan et al., 2007; Wang et al., 2005; Frey et al., 2003; Tong et al., 2000). As for CNG vehicles, Xie et al. (2011) studied the real-world emission characteristics of natural gas-gasoline bi-fuel vehicles. Additionally, other studies of CNG vehicles have focused on heavy-duty vehicles, such as transit buses and refuse trucks (Zhang et al., 2014; Lou et al., 2013; Fontaras et al., 2012).

In this work, the objective was to examine the real-world emission characteristics of light-duty CNG vehicles in China. To achieve this goal, we used a PEMS to monitor emissions from natural gas-gasoline bi-fuel vehicles currently in use as taxi cars fueled with CNG in Yichang, China. In total, 20 taxis, which included vehicles with Euro 2 and Euro 3 emission control technologies, were tested. Using the test data, we analyzed how the driving cycles influenced the CO_2, CO, HC and NO_x emissions, and we compared the emissions from the tested vehicles with those previously reported for light-duty gasoline vehicles (LDGVs) from China. In addition, we also compared the normalized emission factors of the tested vehicles with emission standards. The results of this study will improve the control of vehicle emissions and the development of NGVs in China.

2. Experimental section

2.1. Equipment

In this study, a PEMS manufactured by Sensors Inc. (Ann Arbor, MI, USA) was used; this system has been widely used in our previous studies throughout the last several years (Huo et al., 2012b; Liu et al., 2009). The system primarily consists of a SEMTECH-DS gaseous analyzer and an EFM-2 exhaust mass flow meter. The SEMTECH-DS analyzer can instantaneously measure gaseous pollutant emissions, including CO_2, CO, THC (total hydrocarbon) and NO_x, at a 1-s resolution. The SEMTECH-DS analyzer measures CO_2 and CO with infrared absorption technology, NO_x with ultraviolet absorption technology and HC with a flame ionization detector. In addition, a temperature/pressure sensor and a GPS device were connected to the SEMTECH-DS analyzer to monitor the environmental conditions and instantaneous location and speed.

To ensure the accuracy of the testing results, the SEMTECH-DS analyzer was purged with pure nitrogen before each test. The analyzer was calibrated with an NO_2 standard gas and mixed standard gases of CO_2, CO, NO and propane prior to the first test of the day. The GPS data were validated based on the length of the test route.

2.2. Test vehicles

At present, the majority of CNG vehicles in China are natural gas-gasoline bi-fuel taxis. In Yichang, which is located in Midwestern China, the number of CNG vehicles has increased rapidly due to the relatively abundant natural gas supply. In total, there are approximately 1700 natural gas-gasoline bi-fuel taxis, and all of them are fueled with CNG due to its low cost. In this work, we randomly selected CNG-fueled bi-fuel taxis driven on urban roads in Yichang. All of the taxis were driven under normal operating conditions and were rented from the private owners of the taxis. Detailed information on the tested taxis is listed in Table 1. All of the test vehicles had four-cylinder engines and manual transmissions. The CNG fuel used in the tested cars was from a station in Yichang and met national standards.

In total, 20 CNG-fueled bi-fuel taxis were tested, including 15 Euro 2 and 5 Euro 3 vehicles. In China, this type of bi-fuel car must be certified both for CNG and for gasoline. Both the Euro 2 and Euro 3 CNG-fueled bi-fuel taxis are stoichiometric engines with three-way catalysts.

2.3. Test route and method

For the test, the PEMS was installed in each taxi car to measure the emissions from the car itself. The tested taxis were driven by the drivers who normally operate them using a car-chasing technique to follow another taxi or car in a pre-designed, fixed test route (Wang et al., 2008b). In this study, a test route with a length of 27.8 km was selected, which included the main urban roads and a highway (the airport highway) in Yichang city, which are the typical roads that taxis often travel. The test route roughly reflected the urban and highway driving behavior of taxis in Yichang. The length of the urban roads was 12.0 km, and the length of the highway was 15.8 km. During the measurements, the taxis were not in service, and an assistant was engaged in the taxis to check the emissions equipment. The total weight of the emission equipment was approximately 80 kg. Before the test, all of the test vehicles were acclimated for approximately 2 h under environmental conditions with the engine off. All of the tests were performed at the end of April 2010, during which time the environmental temperature varied from 25 to 31 °C. In total, the average sample size for the per-vehicle measurements was approximately 45 min. In this study, we focused on the hot stabilized emission characteristics of the tested vehicles, and thus the first 200 s of test data were removed during data processing.