



Emission factors of air pollutants from CNG-gasoline bi-fuel vehicles: Part II. CO, HC and NO_x

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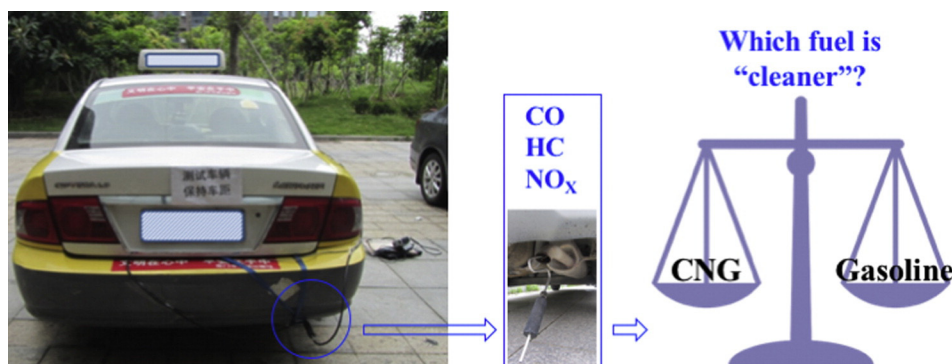
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HIGHLIGHTS

- Compared CO, HC and NO_x emissions from CNG/gasoline bi-fuel vehicles.
- Emission factors were measured on road for burning CNG and gasoline, respectively.
- Emission factors were compared under constant speeds and accelerating conditions.
- CO emission strongly correlates with vehicle speed.
- CNG is a more environmental friendly fuel in term of HC emissions.

GRAPHICAL ABSTRACT



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ABSTRACT

The estimation of emission factors (EFs) is the basis of accurate emission inventory. However, the EFs of air pollutants for motor vehicles vary under different operating conditions, which will cause uncertainty in developing emission inventory. Natural gas (NG), considered as a “cleaner” fuel than gasoline, is increasingly being used to reduce combustion emissions. However, information is scarce about how much emission reduction can be achieved by motor vehicles burning NG (NGVs) under real road driving conditions, which is necessary for evaluating the environmental benefits for NGVs. Here, online, in situ measurements of the emissions from nine bi-fuel vehicles were conducted under different operating conditions on the real road. A comparative study was performed for the EFs of black carbon (BC), carbon monoxide (CO), hydrocarbons (HCs) and nitrogen oxides (NO_x) for each operating condition when the vehicles using gasoline and compressed NG (CNG) as fuel. BC EFs were reported in part I. The part II in this paper series reports the influence of operating conditions and fuel types on the EFs of CO, HC and NO_x. Fuel-based EFs of CO showed good correlations with speed when burning CNG and gasoline. The correlation between fuel-based HC EFs and speed was relatively weak whether burning CNG or gasoline. The fuel-based NO_x EFs moderately correlated with speed when burning CNG, but weakly correlated with gasoline. As for HC, the mileage-based EFs of gasoline vehicles are 2.39–12.59 times higher than those of CNG vehicles. The mileage-based NO_x EFs of CNG vehicles are slightly higher than those of gasoline vehicles. These

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results would facilitate a detailed analysis of the environmental benefits for replacing gasoline with CNG in light duty vehicles.

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1. Introduction

Motor vehicle emissions contribute substantially to national and local emission inventories for hydrocarbons (HCs), nitrogen oxides (NO_x), and carbon monoxide (CO) (Liu et al., 2009; National Research Council, 2000; US EPA, 2012). They have serious impact on our urban air and public health. Hydrocarbons and nitrogen oxides are also the precursors of ozone. The ground level ozone can harm lung function and irritate the respiratory system (Jahirul et al., 2007; Lippmann, 1989). To figure out an adequate mitigation strategy concerning about these pollutants and their reaction products like ozone, it is necessary to obtain a reliable emission inventory for each pollutant. However, the reliability of emission profile of a vehicle can be affected by many factors such as fuel types, operating conditions and vehicle types. So, it is critical to accurately measure the vehicle emission when burning different fuels and under various operating conditions.

Alternative fuel has a profound future because it can reduce pollution at the very beginning and cost less compared to other emission reduction methods like engine control technology, exhaust after-treatment devices, and lower sulfur content of gasoline/diesel. Among all the fuels, natural gas (NG) is considered to be a promising one on the basis of its abundance, low pollution levels and high combustion efficiency. To quantify how much emission reduction can be achieved by burning NG, it is desirable to evaluate the actual net emission reduction of NG compared to other fuels. However, this information is scarce especially under real road driving conditions, which is necessary for evaluating the environmental benefits for replacing conventional vehicles with NGVs. Some work can be done by comparing the emissions produced by a fleet of NGV with emissions produced by an otherwise comparable fleet fueled with “conventional” fuel such as gasoline or diesel.

Most of the comparisons between NG and “conventional” fuel were conducted on a dynamometer, where emissions from vehicles are measured under laboratory conditions during a driving cycle that simulates vehicle operation on a real road (National Research Council, 2000). This method has been widely used to investigate the characteristics of vehicle exhaust emission. A previous comparative analysis was performed on a gasoline and compressed natural gas (CNG) fueled retrofitted spark ignition car engine by dynamometer (Jahirul et al., 2010). The results showed that CNG engine had higher NO_x emissions and lower HC, CO and CO_2 emissions compared to the same engine fueled with gasoline. The same results were also observed in another dynamometer study (Aslam et al., 2006). However, Jayaratne et al. found that the NO_x emitted from CNG fueled engines varied widely with engine loads (Jayaratne et al., 2009). So, a more accurate emission profile should be measured based on various engine loads. Furthermore, the various engine operating conditions such as engine loads in these previous lab experiments cannot represent the real road driving conditions. Therefore, some studies began to focus on using on-board measurement system/portable emission measurements systems (PEMS) to monitor the real time motor vehicle emission because of the recent improvement in this technology. Most on-board emission tests focused on diesel and gasoline vehicles (Frey et al., 2003; Huo et al., 2012, 2011; Liu et al., 2009; Tong et al., 2000; Yao et al., 2007).

However, few studies were conducted on the real road to measure the emission from CNG fueled vehicles not mention compare it with conventional fueled vehicles under different operating conditions. Yao et al. used a PEMS to monitor emissions from CNG bi-fuel vehicles to investigate the influence of driving cycle on the emission characteristic (Yao et al., 2014). Only the emission from CNG fueled vehicles were measured in this study. The comparison of emission between CNG and

gasoline was based on different studies, which may bring uncertainties to the comparison as the emissions measured by PEMS vary with different environment conditions. Furthermore, the operating conditions in this study were restricted to urban driving cycle and highway driving cycle only. The average speeds of these 2 cycles were 26.7 km/h and 66.1 km/h. However, the measured emission results may vary under different operating conditions such as different constant speeds and acceleration/deceleration. To investigate the impact of using different fuels, more detailed study should be conducted by making all the conditions are same except fuel types.

The emission and comparison of black carbon (BC) and gaseous pollutants (i.e., CO, NO_x and HC) from CNG/gasoline bi-fuel vehicles were conducted. This paper reports the emissions of CO, HC and NO_x from CNG/Gasoline bi-fuel vehicles. The results of this study can help to improve the accuracy of emission inventory estimations by directly measuring CO, HC and NO_x from vehicles under different operating conditions and give insight into the advantages and disadvantages of utilizing CNG as an alternative fuel. The results of BC emission are reported in the part I of the paper series (Part I reference).

2. Methodology

An online, in situ system was introduced to measure the emission from nine CNG bi-fuel vehicles under 8 different operating conditions, including 7 constant speeds (20, 30, 40, 45, 55, 65, 75 km/h) and acceleration on the real road. A comparative study was performed for the emission factors of CO, HC and NO_x for each operating condition when the vehicles using gasoline and CNG as fuel. All the engines of the test vehicles are 1.8 L, 4 cylinders. The injection types are multipoint fuel injection (MPI) and the after-treatment devices are 3-way catalyst. For Hyundai vehicles, the maximum horsepower (HP) is 129 Ps. For KIA vehicles, the maximum horsepower (HP) is 128 Ps. More details of test vehicles are shown in Table 1.

2.1. Online, real-time and in situ measurement system

In this study, the EFs of CO, HC and NO_x were measured by an online, real-time and in situ measurement system, which consisted of an Aethalometer, a vehicle exhaust analyzer and a portable global positioning system device (GPS). This method was described in Wang et al.'s research (Wang et al., 2016). Detailed instruments picture can be found in the Part I of the paper series (Part I reference). The main components of

Table 1
Specifications of test vehicles.

No.	Model	Year of manufacture	Mileage ^b (km)
HYUNDAI 1 ^a	BH7183FMY	Mar. 2012	166,398 + 52.64
HYUNDAI 2	BH7183FMY	Mar. 2012	90,586 + 57.23
HYUNDAI 3	BH7183FMY	Mar. 2012	222,540 + 67.01
HYUNDAI 4	BH7183FMY	Mar. 2012	208,446 + 53.22
HYUNDAI 5	BH7183FMY	Sep. 2011	243,378 + 66.34
KIA 1	YQZ7180E3	Aug. 2010	413,148 + 61.31
KIA 2	YQZ7180E3	Feb. 2011	335,889 + 60.64
KIA 3	YQZ7180E3	Aug. 2010	358,929 + 59.75
KIA 4	YQZ7180E3	Aug. 2010	369,216 + 60.85
KIA 5	YQZ7180E3	Aug. 2010	380,514 + 56.67

^a HYUNDAI 1 is not included in this paper because of the emission data of three gaseous pollutants is not completed since this was the first time of this measurement campaign.

^b The number in the column of mileage for each vehicle represent the mileage before experiments and after experiments. For example, 166,398 km is the mileage of HYUNDAI 1 before experiments while 166,398 + 52.64 km is the mileage after experiments.

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