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Evaluating the emission status of light-duty gasoline vehicles and motorcycles in Macao with real-world remote sensing measurement

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ABSTRACT

Roadside remote sensing measurement was used to explore the real-world emission status of light duty gasoline vehicles (LDGVs) and motorcycles in Macao. Both fuel-based and distance-based emission factors were derived using the mass balance method. The emission concentration profile of LDGVs illustrated the benefits of tightening emission standards at the source country or region of import. The distance-based emission factors for CO, HC and NOx of LDGVs registered before 2000 were 8.00, 1.04 and 1.36 g/km, respectively. The distance-based emission factors for CO, HC and NOx of LDGVs registered in or after 2000 were 1.16, 0.15 and 0.18 g/km, respectively. The fuel-based CO emission factors of light duty motorcycles (LDMCs) and heavy duty motorcycles (HDMCs) registered before 2000 were about 10 times higher than those of LDGVs of the same age group. As the emissions of LDGVs decreased more quickly after 2000, the gap widens for newer vehicles. The distance-based HC emission factors of LDMCs and HDMCs registered before 2000 were 4.81 and 2.91 g/km, respectively. The distance-based HC emission factors of LDMCs and HDMCs registered in or after 2000 were 3.52 and 0.93 g/km, respectively. The poor emission performance of motorcycles and their larger share in the traffic flow will cause them to be the major contributor to traffic CO and HC emissions. LDMCs, especially two-stroke models, should be the priority for vehicle emission control efforts in Macao.

Introduction

Macao is composed of the Macao Peninsula, Taipa Island and Coloane Island. It has an area of 29.7 km^2 and a population of 582.0 thousand. By 2012, the total vehicle population in Macao reached 217,335, with an ownership rate of about 373 vehicles per 1000 people. As a comparison, the ownership rate in Beijing was 251 vehicles per 1000 people in 2012. Light duty vehicles and motorcycles account for about 97% of the total vehicle population in Macao (Macao Statistics and Census Service, 2013a). Fig. 1 shows the distribution of vehicles by first registration year for both motorcycles and other vehicles at the end of 2010. The in-use fleet still consists of a large share of older vehicles. For example, motor vehicles registered before 2000 account for 12% and 25% of motorcycles and other vehicles, respectively. The trend is expected to continue because no scrappage program is being implemented. Motor vehicle emissions are considered to be the most important local air pollution source in Macao since the region is not directly influenced by other local industrial emissions (Wu et al., 2002). Furthermore, local air pollution may also be

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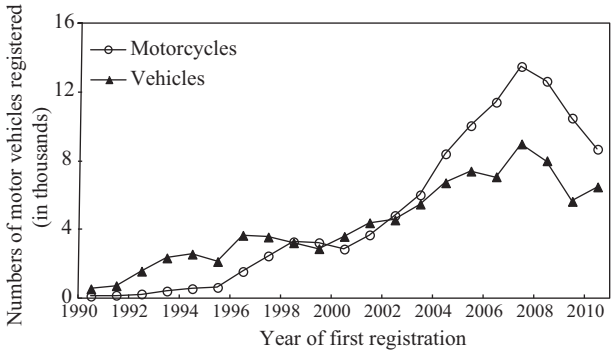

Fig. 1 – Distribution of first registration year of motorcycles and vehicles in Macao in 2010.

amplified by the "street canyon" effect (Tang and Wang, 2007). Ozone, considered as a key secondary air pollutant formed by the presence of NO_X and HC, has a relatively high concentration on Taipa Island. The highest daily average O_3 concentration in 2012 at the ambient monitoring station located on Taipa Island was 133.4 μg/m^3 (Macao Statistics and Census Service, 2013b), much higher than the 8-hr average O_3 threshold (100 μg/m^3) of the updated 2005 WHO air quality guidelines.

According to the atmospheric emission census carried out by the Ministry of Environmental Protection (MEP) of China (MEP China, 2010), on-road motor vehicles contributed 31% of the NOx emissions in China in 2007. Among the vehicle fleet, the yellow-labeled (older and higher-polluting) vehicles contributed 60.4% of the HC emissions and 63.7% of the NO*x* emissions in 2011, respectively. (MEP China, 2012). Older motor vehicles without stringent emission control have become the most important targets for in-use vehicle emission control (Wu et al., 2011; Hu et al., 2012). There are substantial uncertainties regarding the vehicle emission status in Macao because no emission standards and corresponding type approval programs were implemented for newly registered vehicles until 2008. The first emission standards for motorcycles and other vehicles came into effect in 2008 and 2012, respectively. The emission standard for motorcycles is comparable to Euro 3 in the European Union. The emission standard for light duty vehicles and heavy duty diesel vehicles is comparable to Euro 4. In-use vehicle control becomes an important issue for reducing the vehicle emissions of the whole fleet when emission standards for new vehicles are adopted. It is important to understand the vehicle fleet emission characteristics to develop an effective in-use emission control program in Macao.

Since the 1990s, roadside remote sensing has been widely used as an effective tool to evaluate real-world fleet emission characteristics. Remote sensing can enable collection of a large number of samples under real-world driving conditions in a relatively short time at a low cost. Corley et al. (2003) used remote sensing data to evaluate the effectiveness of in-use vehicle I/M programs. Remote sensing can also be used to build emission inventories (Singer and Harley, 2000). Mass emission factors, which are more informative than emission concentrations, are derived from the volume-based concentrations measured by remote sensing. Remote sensing has also been used for reporting the general emission status of in-use fleets in typical cities, such as Beijing (Zhou et al., 2007) and Hangzhou (Guo et al., 2007a).

The purpose of this study is to analyze the real-world vehicle emission characteristics of in-use vehicles in Macao. Remote sensing measurements were carried out at 19 sites in Macao. The emission concentrations of CO, HC and NO of light duty gasoline vehicles (LDGVs) and motorcycles were collected. Fuel-based and distance-based mass emission factors were derived from remote sensing readings. The effects of vehicle category and registration year on the emission status in Macao were studied. This article aims to help policy-makers better understand the emission profiles of in-use motorcycles and LDGVs as an input for the development of vehicle emission control programs for Macao.

1. Materials and methods

1.1. Vehicle emission remote sensing

The vehicle emission remote sensing data used in this article were collected from March to April 2008 as part of a research program to evaluate the emission status of motorcycles and other vehicles in Macao. The concentrations of CO, HC and NO and CO_2 were measured in the exhaust plume of vehicles driving by a remote sensing measurement system at 19 road sites with a single traffic lane. The remote sensing system used in this study was a RSD4600, manufactured by Environmental Systems Products (ESP, Tucson, Arizona, the United States). The system uses non-dispersive infrared (NDIR) spectroscopy to measure CO and HC and dispersive ultraviolet spectroscopy to measure NO. All HC remote sensing measurements in this study are given as propane equivalents. In this system, the infrared and ultraviolet beams and the source detector module and vertical transfer mirror units are positioned on opposite sides of a single traffic lane. As vehicles drive into the test site, the beam passes through the exhaust plume from the tailpipe, which absorbs some of the light. The instrument was calibrated with a gas with a known blend of HC, CO, CO_2 and NO according to the manufacturer's instructions. An emitter bar and a detector bar were used for measuring the driving conditions of vehicles. The vehicle license plates were automatically captured by a camera and recognized by the software. The selection of the testing site was mainly based on the number of lanes, road grade, driving conditions, traffic flow and power supply availability.

Only records with valid emission information for all pollutants, speed, acceleration and identified vehicle license were used for further statistical analysis. Detailed vehicle information was achieved by matching the vehicle license with the vehicle registration database including vehicle category, vehicle model, fuel type, year of first registration and engine capacity. Table 1 summarizes the information of valid emission records collected for light duty motorcycles (LDMCs) with engine capacity at or lower than 50 cm^3, heavy duty motorcycles (HDMCs) with engine capacity higher than 50 cm^3 and LDGVs during the field measurement campaign. The average registration year of LDMCs was about 3 years older than HDMCs and LDGVs, which is partly due to the reduction in sales of two-stroke motorcycles. The fraction of the vehicles responsible for more than 50% of the total measured on-road exhaust emissions by remote sensing can be referred to as "gross polluters" (Zhang et al., 1995). Using this parameter, the low percentage of gross polluting LDGVs in Macao implies that a relatively small percentage of high emitting LDGVs contribute substantially to the total fleet emissions. Compared with LDGVs, the percentages of gross polluters in LDMCs and HDMCs are relatively high, which indicates that the potential ratio of high emitters in the