REGIONAL DISTRIBUTION OF VEHICULAR EMISSIONS

Lixin FU and Yang CHEN
Department of Environmental Sciences and Engineering, Tsinghua University, Beijing, P. R. China

Keywords: Motor vehicle, traffic, emission control, air pollution, transport, mobile source, dispersion, distribution, urban atmosphere, ambient concentration, megacities, photochemical smog, contribution rate, emission standards, attainment, air quality, monitoring, particulates, vehicle population, urban transportation, mobility, atmospheric dilution, local topography, street canyon.

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Summary

Motor vehicle-related air pollution is a worldwide problem. This article begins with an introduction to global motor vehicle population growth and its resultant emissions, together with some basic features of vehicular pollution and its regional distributions. Then an overview of vehicle emissions and the evolution of control technologies are presented for the USA, Japan, Europe, and Hong Kong. The third part of the article gives a more extensive picture of motor vehicle emissions and their environmental impacts for 20 megacities worldwide, both in developed and developing countries. The next part presents a general description of some modeling approaches for detailed distribution considerations of vehicular emissions in urban areas. Finally, the authors look into the future for global trends on motor vehicle emissions and their control, and propose a comprehensive strategy to cope with vehicular pollution problems from both social and technical viewpoints.

1. Introduction

The use of motor vehicles has increased enormously all around the world since the 1940s. On-road motor vehicles have dominated the markets for passenger and freight transport both in developed and developing countries. It is estimated that between the years 1950 and 1990 the world car population rose tenfold, from around 40 million to 400 million, and it is forecast to reach 536 million in the year 2000. Although a mixed mode of transport should be encouraged, motorized road vehicles are likely to keep their overwhelming dominance of the transport sector in the foreseeable future. One consequence of this has been a growth in the importance of motor vehicles as a source of atmospheric pollution.

The amounts of pollutant emissions from motor vehicles are dependent on the vehicle population, the technologies used for emission control for in-use vehicles (i.e. the resultant composite emission factors of the fleet), and the mileage driven by each category of vehicle. This may vary a great deal from region to region, and from city to city. Owing to their rapidly increasing numbers and limited use of emission control technologies, motor vehicles are emerging as the largest source of urban air pollution in the developing world. In developed countries, non-attainment of urban air quality standards is still largely related to motor vehicle emissions. Although great efforts have been made to control these emissions, the continuously growing vehicle population and the growth in mileage driven by each vehicle have somewhat offset these benefits. Air pollution caused mainly by motor vehicle emissions is a common problem for large cities around the world.

Motor vehicle-related air pollutants are unevenly distributed in the urban atmosphere. Most of the direct emissions are concentrated along highways and major roads inside cities. This is especially the case where streets are surrounded by tall buildings on both sides (normally referred to as 'street canyons'). Air pollutants from road traffic such as CO, NO_x, VOCs (volatile organic compounds) and fine particulates will be transported

virtually throughout the whole urban area, causing region-wide air quality deterioration. Furthermore, VOCs and NO_x in the atmosphere can form photochemical smog when there is sufficient solar radiation, resulting in severe secondary air pollution. Since the 1970s, there have been many studies about the dispersion and distribution of traffic-related air pollution, which will be discussed in a later section.

2. Global Distribution of Vehicular Emissions

2.1. U.S.A.

In the United States, concerns about air pollution from motor vehicles first arose in southern California in the late 1940s because of the smog problem in the Los Angeles basin. For the whole country, transportation accounts for over two-thirds of total carbon monoxide emissions, over one-third of volatile organic compounds, about half of the oxides of nitrogen, less than 5% of the oxides of sulfur, and about 17% of airborne particulates (mostly from diesel engines). In large cities, motor vehicle emissions are especially noxious, in part because they tend to comprise a higher fraction of total emissions and because those emissions are released in the middle of crowded urban environments. Before 1990, the use of leaded gasoline by motor vehicles contributed most of the ambient lead to the environment, and this is very harmful to children. Lead additives in gasoline will eventually be eliminated worldwide.

In 1947, when photochemical smog first became a serious problem, the state of California put in place basic legislation authorizing local jurisdictions to control it; however, its origin was not identified. When other sources of pollutants were gradually controlled without any significant improvement in Los Angeles' smog, it became clear that motor vehicles were a major contributor. The state of California was the first authority in the world to develop motor vehicle emission standards and, due to the poor air quality problems in Los Angeles, it remains the only state in USA having the power to establish its own emission standards for motor vehicles. These standards are considered the most innovative in the world; they are usually adopted later at the federal level, and over time by many other countries.

Environmental pressure on the motor industry resulted in the first positive action in 1959, when crankcase blowby (ventilation gas from the crankcase) was first identified as a major source of emissions. In 1961, manufacturers voluntarily installed positive crankcase ventilation devices on all new cars sold in California. Subsequently, the state government made the installation of these devices to all new cars mandatory starting with the 1964 model year. Meanwhile, a report of the US Surgeon General to Congress and public pressure for action resulted in the Clean Air Act in 1963, which directed the development of emission control technology and appointed a liaison committee to work with the industry. The Clean Air Act was amended in 1965 to provide the Secretary of Health, Education and Welfare with authority to set and enforce national standards limiting gaseous emissions from new vehicles.. This move was strongly opposed by the auto industry. Federal standards for crankcase emissions, carbon monoxide and hydrocarbon exhaust emissions, together with procedures for compliance with the standards were adopted the following year, applying to all 1968 model year cars and light-duty vans. The resultant emission reductions at this stage were far from satisfactory

to meet the requirements needed for improving air quality.

The national effort to substantially reduce emissions from motor vehicles can be traced to the 1970 amendments to the Clean Air Act, which authorized the newly established US EPA (Environmental Protection Agency) to define separate standards for automobiles, light- and heavy-duty trucks and motorcycles, in order to help to meet NAAQS (National Ambient Air Quality Standards). The emission standards for automobiles required a 90% reduction in carbon monoxide and hydrocarbons by 1975 (as compared to 1970 emission rates), and a 90% reduction in nitrogen oxides by 1976. Provisions were made for EPA to authorize delays in implementing the target dates by one year if it was considered that technology to meet the standards was genuinely not available. Strong enforcement provisions to assure compliance with these requirements were also a part of the Amendments. During this period, emission control technologies experienced dramatic improvement.

Until 1990, there had been no change in Federal limits for gaseous exhaust emissions from cars, although allowable particulate emissions were reduced from 0.6 to 0.2 g mile^{-1} in 1988. There had been further reductions in limits for light- and heavy-duty trucks, although the stringent reductions for hydrocarbons and CO were deferred until 1987. Most of these standards are technology-forcing emission standards (which means new technologies are to be developed to meet the standards). Diesel particulate standards were also introduced for heavy-duty trucks, and exceptionally severe limits were proposed for such vehicles operating in urban areas beginning in 1990. Further amendments to the Clean Air Act were passed in 1990, further tightening vehicle emission requirements.

The population of motor vehicles in USA reached 201 million in the year 1999, accounting for 31% of the total number of motor vehicles in the world. These vehicles are driven much more than in other countries. Each U.S. vehicle owner drives an average of 15 500 km annually. Since USA is the country that made the greatest efforts to combat air pollution from motor vehicles, pollutant emission factors from individual cars have been decreased greatly compared to the uncontrolled levels in the 1960s. Table 1 illustrates the progressive change in emission factors of light-duty gasoline-fueled vehicles in USA. Although urban air quality has been improved correspondingly in most cities across the country, it is still not as good as people want. Ozone concentrations in Los Angeles and other cities frequently violate the NAAQS, leading to a further need to reduce motor vehicle emissions.

Model year	Carbon monoxide	Hydrocarbons	Nitrogen oxides
Pre-1968 (uncontrolled)	90.0	15.0	6.2
1970	34.0	4.1	Not regulated
1977	15.0	1.5	2.0
1981	3.4	0.41	1.0
1994 -96 (Tier 1)	3.4	0.25[a]	0.4
2004 (potential Tier 2)	1.7	0.125[a]	0.2

a. Non-methane hydrocarbons.

Table 1. Progression of U.S. exhaust emission factors for light-duty gasoline-fueled vehicle (grams per mile)

The new rules established by CARB (California Air Resources Board) defined a set of categories for low-emission vehicles, including transitional low-emission vehicles (TLEV), low-emission vehicles (LEV), ultra low-emission vehicles (ULEV), and zero-emission vehicles (ZEV). Beginning in 2004, diesel fueled light-duty vehicles are required to meet standards identical to those for gasoline-fueled vehicles for all pollutants except particulate matter. The requirements are being phased in between 1994 and 2003 in California, and a few other states that have adopted the California standards. These challenging emission standards will cause innovative technology to be developed by the vehicle industry in the near future.

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Bibliography

Faiz A., Weaver C. S., and Walsh M. P. (1996). *Air Pollution from Motor Vehicles: Standards and Technologies for Controlling Emissions*, 246 pp. The World Bank, Washington, D. C., USA. [This book presents worldwide standards and available technologies for controlling automotive emissions.]

Hamilton R. S., Harrison R. M. (1991). *Highway Pollution*, 339 pp. Elsevier Science Publishers, Amsterdam, Netherlands. [The book presents a series of articles on the dispersion, environmental impacts of, and control strategies for motor vehicle emissions.]

Hertel O. and Berkowicz R. (1990). *The Development of Operational Street Pollution Model (OSPM)*. NATC/CCMS ITM "Air Pollution Modeling and its Application", Vancover, Canada. [This paper describes the OSPM street-canyon automotive pollution dispersion model.]

Ministry of Machinery Industry of China (1997). *A Comprehensive Analysis on Automotive Industry of China* [in Chinese], 72 pp. [This publication presents the overall situation of the automotive industry in China, and motor vehicle populations worldwide.]

Tims J. M. (1990). *Vehicle Emissions*, pp148-160, in *World Guide to Environmental Issues and Organizations*, Edited by Brackley P. Harlow, Essex, U.K. [Discusses worldwide problems and controls associated with vehicle emissions.]

UNEP (1992). *Urban Air Pollution in Megacities of the World*. Blackwell Publishers, Oxford, UK. [Briefly summarizes major issues concerning air pollution conditions in 20 megacities around the world.]

Walsh M. P. and Shan J. J. (1997). *Clean Fuels for Asia*, 101 pp. The World Bank, Washington, DC., USA. [This publication addresses motor fuel technologies and their possible application in Asian countries.]

Yamatino R. J. and Wiegand G. (1986). *Development of CPBM Models for Urban Street Canyon.* Atmospheric Environment **20**, 2137-2156. [The paper describes the CPBM street-canyon automotive pollution dispersion model.]

Biographical Sketches

Mr. Lixin Fu is an associate professor in the department of Environmental Sciences and Engineering, Tsinghua University, Beijing, China. He was born in May 1966 in Hunan Province of China, and received his Ph.D. degree from Tsinghua University in 1998.

Mr. Yang Chen is a Master's degree research student in the same department. He was born in June 1974 in Zhejiang Province in China.