CONTROL STRATEGIES TO REDUCE EMISSIONS

Lixin Fu and Jiaping Tang
Department of Environmental Sciences and Engineering, Tsinghua University, Beijing, P. R. China

Keywords: Motor vehicle, traffic, emission control, air pollution, transport, mobile source, fuel modification, emission standards, economic incentives, control strategies, regulation, I/M program, test procedure, particulate, cost-effective

Contents

Summary

Controlling emissions from motor vehicles has become a worldwide challenge in achieving better urban air quality. To address this problem, great efforts have been made since the 1970s and remarkable achievements have been attained in many industrialized countries. This chapter reviews the international evolution of emission standards and regulations for motor vehicles. Control technologies are also briefly introduced, these being developed along with increasingly stringent vehicular emission standards. As

newly produced motor vehicles are emitting less and less pollutants as a result of the adoption of new technologies, inspection and maintenance (I/M) programs for reducing emissions from in-use vehicles have become more and more important. Driven by the progress made in vehicle emission control technologies, motor fuels have also been significantly modified. Major improvements of fuels are discussed in the chapter, including alternative fuel use and electric car technologies. In addition to technical issues, economic policies and traffic management measures are also important constituents of a comprehensive control strategy for vehicular emissions abatement. Finally, the authors express their own viewpoint on future control strategies for motor vehicle emissions.

1. Introduction

The global efforts to combat emissions from motor vehicles date back to the mid-1960s, when vehicular emissions were identified as a major source of the precursor pollutants (NO_x and VOCs) of photochemical smog in Los Angeles, California, USA. The first emission controls prevented crankcase emissions from escaping from the car. In the early 1970's, CO and HC standards were set, followed by standards to control NO_x. More and more countries followed the U.S.A. in establishing their own emission standards and regulations to control motor vehicle emissions in the 1970s and 1980s. Since then, emission control technologies for motor vehicles have experienced dramatic improvements, driven by increasingly stringent emission standards. The overall amount of pollutants emitted from a modern car with advanced emission control technology is only 5% of those from a car before pollution controls were introduced.

Forced by the advances in vehicle emission control technology, fuel technologies have also been developed, and alternative fuels are becoming widely accepted, reducing exhaust emissions further. In addition to reducing emissions from new vehicles, the control of in-use motor vehicle emissions constitutes an important part of an overall pollutant reduction strategy. A well-functioning I/M (Inspection/Maintenance) program assures that cars will be properly maintained according to the manufacturer's instructions. Besides technical measures, economic instruments have also been widely adopted to help enforce challenging emission standards. As a result of the growing pressure to eliminate vehicular emissions, motor vehicles with zero emissions have appeared, such as electric cars and fuel-cell vehicles. The following sections will discuss these strategies.

2. Emission Standards and Regulations

Automotive exhaust emissions are regulated in most industrial and developing countries, although the degree of stringency varies greatly. Through the years, the number of regulated pollutants has increased, from CO, HC and diesel smoke in the early days of regulation, to include NO_x, PM, and other toxic components. The most comprehensive systems of vehicle emission standards and corresponding test procedures are those of North America, Japan and Europe. Emission standards and test procedures were originally adopted by the United States, which was the first country to set emission standards for vehicles. Generally, U.S. standards represent the most stringent in the world. These standards have been widely adopted by other countries and regions like Canada, Mexico, Brazil, Chile, Hong Kong, Taiwan (China), several western European countries, the Republic of Korea, and Singapore (for motorcycles only). The standards and test procedures established by the United Nations Economic Commission for Europe (ECE) are used voluntarily in some European Union countries, in a number of former Eastern bloc countries, and in some Asian countries like China. More recently, another system has been established in member countries of the European Union (EU, formerly European Community); that system uses mandatory EU Emission Directives instead of ECE regulations. Japan has also established a different set of emission standards and testing procedures that have been used by some other East Asian countries as supplementary standards.

2.1. United States

Emission standards in the USA can be categorized into 3 stages: the initial stage (before 1977), the substantial reduction period (1978-1993), and the super-low emission stage (1994 onwards). The first emission regulations in the U.S.A., which eliminated crankcase emissions and limited exhaust concentration of CO and HC, were enacted in the state of California in 1959. The first federal standards under the Clean Air Act (CAA), which applied to 1968 model vehicles, were published in the Federal Register in 1966. These standards corresponded roughly to the values set in California in 1960. Successive amendments to the CAA in 1968 and thereafter converted the standards from pollutant concentration values to pollutant mass values. These values were expressed as amount of pollutant mass emitted per mile (unit distance) traveled, based on an adopted driving cycle. The Constant Volume Sample (CVS) method was used to collect and measure the emissions of pollutant mass corresponding to each driving cycle. The standards, which initially covered carbon monoxide and unburned hydrocarbon emissions, were extended to nitrogen oxides and particulates, which subsequently included diesel engines.

Model Year	CO	HC	NO_x
Pre-1968 (uncontrolled)	90.0	15.0	6.2
1970	34.0	4.1	-
1972	28.0	3.0	-
1973 - 74	28.0	3.0	3.1
1975 - 76	15.0	1.5	3.1
1977	15.0	1.5	2.0
1980	7.0	0.41	2.0
1981	3.4	0.41	1.0
1994 - 96 (Tier 1)	3.4	0.25	0.4
2004 (Tier 2)	1.7	0.125	0.2

Table 1: Progression of U.S. Exhaust Emission Standards for Light-Duty Gasoline-Fueled Vehicles (g/mile)

The 1990 Clean Air Act Amendments mandated implementation of federal emission standards identical to California Low Emission Vehicle (LEV) standards for light-duty vehicles. The federal Tier 1 emission standards require LEV emissions of volatile organic compounds to be 30 percent less than previous standards and emissions of nitrogen oxides to be 60 percent less.

In response to the severe air pollution problems in Los Angeles and other California cities, the CARB (California Air Resources Board) in 1989 established stringent, technology-forcing vehicle emission standards to be phased in between 1994 and 2003. These rules outlined a set standard 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).

2.2. Europe

The vehicle emission standards established by the ECE and incorporated into the legislation of the EU are not directly comparable to those in the U.S.A. because of differences in testing procedures. Light-duty vehicles were the first to be regulated, beginning in 1970, to conform to the original ECE Regulation 15. The regulation was amended four times for type approval (ECE 15-01, implemented in 1974, ECE 15-02 in 1977, ECE 15-03 in 1979, and ECE 15-04 in 1984). ECE 15-04 was applied to both gasoline and diesel-fueled light-duty vehicles. The emission limits included in these regulations were based on the ECE 15 driving cycle.Although ECE 83 was also adopted as European Community Directive 88/76/EEC, this regulation was not implemented in national legislation by any European country, in anticipation of the adoption of the Consolidated Emissions Directive, 91/441/EEC. This latter directive was adopted by the Council of Ministers of the European Community in June 1991. Under the Consolidated Emission standards, exhaust emission standards for passenger cars are certified on the basis of the New European Driving Cycle (NEDC), which is the combination of the ECE-15 (urban) cycle and the extra-urban driving cycle (EUDC). These limits became effective July 1, 1992 for new models, and on December 31, 1992 for all production. The equivalent emission standards (Ministerial Directive 93/59/EEC) were required for other light-duty vehicles (light trucks and commercial vehicles) in 1994 for EU member countries. Limit values in these standards are significantly reduced compared with those previously applied. There is also a durability requirement for these vehicles. Implementation of these emission standards by EU member States is mandatory and unlike previous directives, not left to the discretion of individual national governments.

	91/441/EEC		94/12/EC	
	Type approval	Conformity of production	Gasoline	Diesel
CO	2.72	3.16	2.2	1.0
HC+NOx	0.97	1.13	0.5	0.7
PM	0.14	0.18	-	0.08
Evap. Emission (g/test)	2.0	2.0	2.0	-

Table 2: European Union Emission Standards for Passenger Cars with up to 6 seats (ECE15+EUDC test procedure, g/km)

In March 1994, the Council of Ministers of the European Community adopted Directive 94/12/EC, which provides for more stringent emission limits for passenger cars from 1996 onwards. Equivalent standards in Directive 96/69/EC were then applied to light-duty trucks and commercial vehicles in 1997. These standards require further emission reductions from both gasoline and diesel vehicles. Production vehicles must comply with these type approval limits. The present European emission standards for passenger cars and light commercial vehicles are comparable to the U.S. standards adopted in the early 1990s.

2.3. Japan

In Japan, the first vehicular control measures concerning CO emissions were enacted in 1969 and then extended to HC and NO_x emissions in 1973. These standards involve both concentration and mass emission limits relative to driving cycles specific to Japan.

Japan revised its emissions test procedures for light-duty vehicles in 1991. The new test procedure, resembling the new ECE emissions test cycle, consists of a series of low- and moderate-speed accelerations and decelerations at 20 km per hour to 40 km per hour, as well as a higher-speed component reaching up to 70 km per hour. This procedure applied to passenger cars and light- to medium-duty trucks. The test procedure for heavy-duty engines has also been modified from the previous six-mode test to another steady-state, engine dynamometer test involving 13 operating modes. The units of measurement have also been changed, from grams per test and ppm to grams per kilometer and grams per kilowatt-hour, making it easier to compare Japanese standards with U.S. and ECE emission standards. In addition to these changes, emission limits on nitrogen oxides are to be further tightened, and limits on diesel particulate emissions have been introduced. Smoke limits were reduced by 20 percent in 1993 for light- and medium-duty diesel vehicles and more stringent smoke limits are expected for heavy-duty passenger vehicles.

3. Vehicle Technology for Controlling Emissions

Vehicle emission control efforts have a thirty-year history since their beginning in the 1960s. Technical measures to limit vehicular air pollution have been developed to enable new vehicles to comply with increasingly stringent emission standards. Legislation first addressed visible smoke, carbon monoxide, hydrocarbons and oxides of nitrogen. Reduction of lead in gasoline and sulfur in diesel fuel then received increasing attention. Eventually, limits on emissions of particulate matter from diesel-fueled vehicles were gradually tightened.

Carcinogens like benzene and formaldehyde are now being controlled. For light-duty vehicles, crankcase hydrocarbon controls were developed in the 1960s, and carbon monoxide and hydrocarbon exhaust standards were introduced later in that same decade. By the mid-1970s, most industrialized countries had implemented some form of vehicle emission control program.

3.1. Control Technology for Gasoline-Fueled Vehicles

Emissions from gasoline-fueled vehicles can be reduced through changes in engine design, combustion conditions and catalytic after-treatment. Some of the engine and combustion variables that affect emissions are the air-fuel ratio, ignition timing, turbulence in the combustion chamber, and exhaust gas re-circulation.

-
-
-

Bibliography

Chhatwal G. R., Mehra M. C. (1989). *Environmental Air Pollution and Its Control*, 284 pp. Anmol Publications, New Delhi, India. [Covers broad issues of traffic-related air pollution control.]

Davis M. L., Cornwell D. A. (1991). *Introduction to Environmental Engineering*.. McGraw-Hill, USA. [This book discussed basic engineering concepts involved with automotive pollution control.]

Elsom D. M. (1992). *Atmospheric Pollution - A Global Problem*.. Blackwell, USA. [This publication presents an overview of worldwide motor vehicle emissions regulations.]

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. [This publication presents a series of articles on the dispersion, environmental impacts of, and control strategies for motor vehicle emissions.]

Harrison R. M. (1996). *Pollution: Causes, Effects and Control*. 3rd Edition, Royal Society of Chemistry, U.K. [Presents a broad overview of control strategies for pollutant emissions from road traffic.]

Heinsohn R. J. and Kabel R. L. (1999). *Sources and Control of Air Pollution*. Prentice Hall, Upper Saddle River, New Jersey, USA. [Discusses technical and comprehensive measures to control traffic- related air pollution].

U.S. EPA. (1991). *The Steps of Air Quality Management*. Tier 2 Report to Congress, EPA420-R-98-008, U.S. Environmental Protection Agency. [Presents the steps used to control vehicular pollution in the U.S.A.]

Biographical Sketches

Mr. Lixin Fu is an associate professor in the department of Environmental Sciences and Engineering, Tsinghua University, Beijing, China. He was born on 4 May 1966 in Hunan Province of China, and received his Ph.D. degree from Tsinghua University in 1998.

Mr. Jiaping Tang is a doctoral degree research student in the Institute of Nuclear Energy at the same university; he was born on 14 July 1974 in Hunan Province, P. R. China.