VEHICULAR EMISSIONS

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Contents

Summary

The worldwide vehicle population is growing rapidly and the environmental problems due to vehicle emissions are becoming more and more serious. In this section, some information about the types, sources, environmental effects and health effects of vehicle pollutants is presented, and finally, some strategies for controlling vehicle emissions are introduced.

1. Vehicle Population

Since the early twentieth century, the world vehicle population has been growing rapidly. In 1950, the worldwide vehicle population totaled about 70 million, and by 1996 that number had increased to more than 700 million (as shown in Figure 1). USA contains one third of all the vehicles in the world, and Europe has another 1/3 of the world's total.

From 1980, the annual growth rate of the global vehicle population has been about 3%, while in some developing countries this rate is much greater. For example, in China the annual increase in vehicle population has been up to 15% in recent years.

In 1960 the more developed countries accounted for nearly all of the world's vehicles. Today, the number of vehicles in developing countries has grown to nearly 30% of the world total (see Figure 2). The number of vehicles in the world is expected to reach 1.1 billion in 2020, with developing countries accounting for 44% of the total. However, at 78 vehicles per 1000 persons, the number of vehicles per driving age population in developing countries is currently well below the 954 vehicles per 1000 in more developed nations. According to projections, these ratios will remain largely unchanged in 2020.

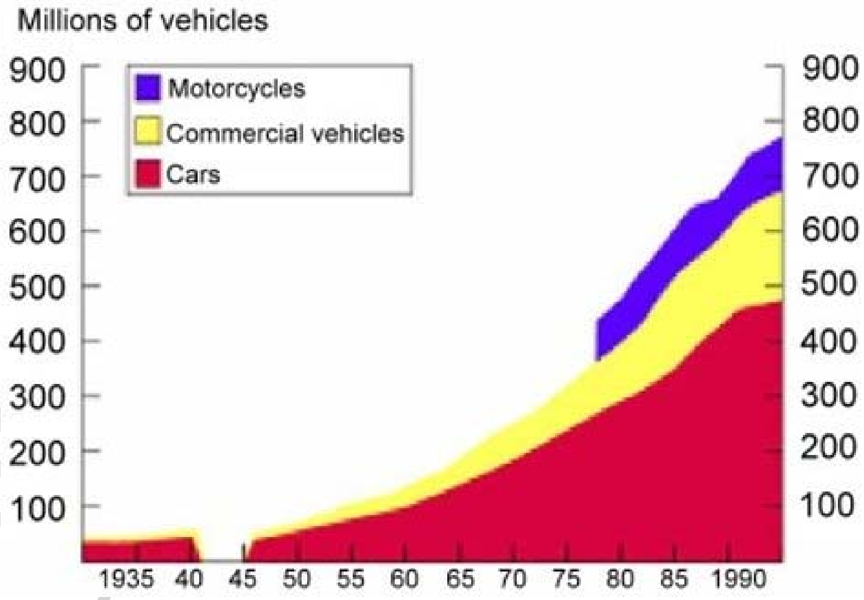

Figure 1: Global Trend in Motor Vehicles

Vehicle populations in urban settings are much larger than those in rural areas, and as a result, vehicle pollution is a more serious problem in urban environments.
Emissions from individual cars are generally low in relation to the smokestack image many people associate with air pollution. But in numerous cities across the world, personal automobiles are the single greatest pollution source, as emissions from millions of vehicles on the road add up. Driving a private car is probably a typical citizen's most "polluting" daily activity.

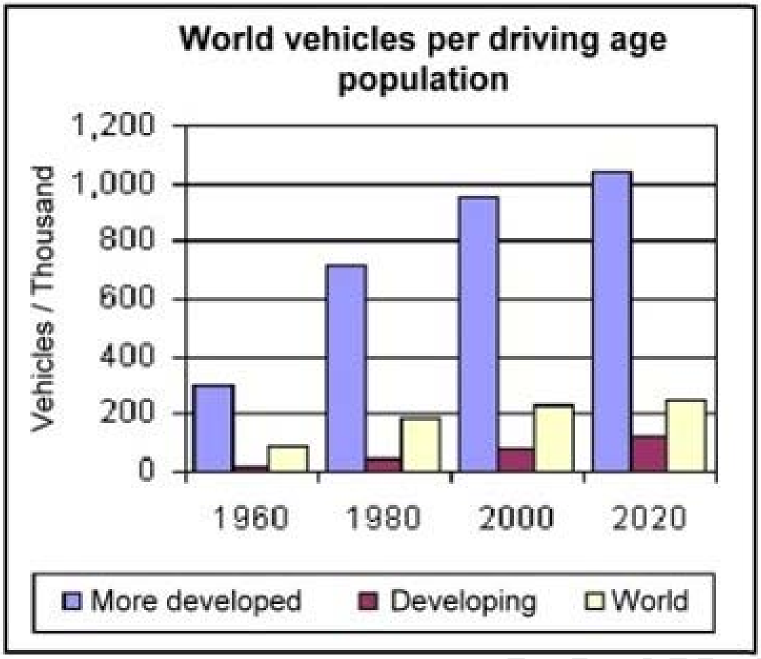

Figure 2. Comparison between vehicles in developed countries and developing countries

2. Vehicle Emissions

2.1 Pollutants

Carbon monoxide

Carbon monoxide (CO) is a toxic gas formed in combustion chambers that results from an insufficient supply of oxygen. The principal source of atmospheric carbon monoxide (accounting for nearly 90%) is exhaust from gasoline engines, with bonfires, forest fires and waste treatment and disposal processes contributing a large part of the remaining 10%.

Carbon monoxide is one of the most dangerous pollutants to human health because it causes a reduction in the oxygen-carrying capacity of the blood, resulting in headaches, fatigue, respiratory problems, and in some cases even death. Since the gas is odorless, tasteless and colorless, there is often no warning to the exposed person. It is therefore important to safeguard against the build-up of carbon monoxide in living spaces, such as that caused by poorly maintained indoor heating systems.

Carbon monoxide gas itself typically survives in the atmosphere for four weeks, during which time it is gradually oxidized to carbon dioxide. In recent years, much has been done to reduce carbon monoxide in the exhaust of gasoline engines through the extensive use of three-way catalysts, which convert the gas to carbon dioxide. The most efficient catalysts can reduce levels of CO in exhaust gases by 90%. Thus, carbon monoxide should soon become a pollutant of the past.

The major concern about CO pollution is in urban areas, particularly in countries with a low percentage of modern three-way-catalyst gasoline vehicles. Here, gasoline vehicles spend a good deal of time idling in traffic, frequently with cold or poorly maintained engines. The pollution problem is made worse in cold winter still-air conditions, because the pollutant cannot disperse.

Nitrogen oxides

The term 'nitrogen oxide (NOx)' refers to both nitric oxide (NO) and nitrogen dioxide (NO_2), since both of these compounds are always found together in the atmosphere. While there are natural sources of NOx, such as electrical storms and forest fires, the major source is the combustion of fossil fuels. Emissions from road transport account for some 50% of NOx worldwide, with power stations accounting for almost 20%. Indoor sources of nitrogen oxides include tobacco smoking and the use of gas and oil-fired appliances.

The problem of nitrogen oxides pollution is very much associated with urban regions, and road transport is considered to be the main cause. Pollution problems from nitrogen oxides can become acute in winter still-air conditions. This is a problem that must to be dealt with at its source.

Nitrogen oxides react with hydrocarbons in bright sunlight to form ozone, which is one of the most important secondary pollutants in the atmosphere. Another photochemical reaction in the atmosphere converts nitrogen dioxide into nitric compounds and nitrates, both of which can be transported by winds and combine with water to form acid rain. Some of the nitrates formed also remain in the atmosphere as very fine particles of less than 10 microns in diameter (PM10), which means that nitrogen oxides can contribute a substantial proportion of secondary particles.

Nitric oxide is not harmful to human beings when inhaled at concentrations normally present in the atmosphere. However, nitrogen dioxide, a reddish brown gas, does have serious health effects when inhaled at higher concentrations, and can cause acute inflammation of the air passages at moderate concentrations, particularly in persons with asthma. The atmospheric lifetime of nitrogen dioxide is typically one day, after which time it is converted into nitric acid and other chemical compounds.

Without a doubt, controlling nitrogen oxide emissions remains one of the greatest challenges in improving urban air quality worldwide, particularly because this pollutant is a major chemical source contributing to the formation of secondary pollutants such as ozone and particulates.

Volatile organic compounds (VOCs)

Volatile organic compounds, or VOCs, range from hydrocarbons (alkanes, alkenes, and aromatics), to halocarbons (e.g., trichloroethylene) and oxygenates (alcohols, aldehydes, and ketones). They exist as vapors in the atmosphere, and are also classified as pollutants. Volatile organic compounds contribute substantially to the formation of secondary pollutants such as ozone as a result of their reaction with nitrogen oxides in sunlight.

The most abundant hydrocarbon in the atmosphere is methane, which accounts for the formation of some 15% of European ozone, and has a very long lifetime. Although the reactivity of methane is very slow, there is such an enormous amount of methane in the atmosphere that it can be regarded as an unchanging source of ozone. As such, it makes the greatest contribution to background levels of ozone. Other VOCs such as benzene and 1,3-butadiene receive much more public attention because of their carcinogenic properties.

VOCs originate from many places, including mobile, stationary, and natural sources. Trees and plants are natural (biogenic) sources of VOCs, and emit one of the most reactive hydrocarbons in terms of ozone formation—isoprene. In Europe, emissions from trees and plants accounted for at least 18% of total VOC emissions in 1990, with greater percentages occurring in countries with heavily forested regions. In USA, the percentage of biogenic VOC sources account for more than 25% of total VOCs, and in the USSR, 66% of VOCs come from biogenic sources.

The largest source of VOC emissions is gasoline-powered vehicles, with road transport accounting for 32% of the total mass in USA, compared to 35% in Europe. Solvents used in paints and other household and industrial products account for 27% of U. S. VOC sources, compared with 25% in European countries.

VOCs are of increasing concern to technical managers in industry, who are carefully monitoring their products. Vehicle manufacturers and oil companies carry out speciated exhaust and evaporative emission measurements on vehicles, whereby the gases are analyzed in terms of each hydrocarbon component. Chemical manufacturers are revising the composition of their products (for example, decorative paints and vehicle finishing) with a view to improving air quality.

Although VOCs are of particular concern in summer months because of their photochemical reactions that generate ozone, some hydrocarbons are of concern all year round, particularly benzene and 1,3-butadiene, because of their impacts on human health.

Particles

Particulate matter is a general term for the mixture of solid particles and liquid droplets found in the air. Particulate matter includes dust, dirt, soot, smoke and liquid droplets. It can be emitted into the air from natural and manmade sources, such as windblown dust, motor vehicles, construction sites, factories, and fires. Particles are also formed in the atmosphere by condensation or the transformation of emitted gases such as sulfur dioxide, nitrogen oxides, and volatile organic compounds.

The World Health Organization is expressing considerable concern about the impact on human health of particulate matter in the atmosphere. These particulates are classified according to their size or diameter. Those of particular concern to human beings are of 10 micrometers diameter or less (PM10). These particles include those emitted from the tail pipes of diesel engines, which are usually less than 2.5 micrometers in diameter, and dust arising from coal extraction, coal combustion, and dust generated by moving road traffic, all of which are larger than 2.5 micrometers in diameter.

Particles are further divided into two different classifications according to their sources. Primary particles are emitted from sources directly into the atmosphere and have an immediate impact on the PM10 concentration without undergoing any further chemical reactions. Secondary particles arise from the photochemical oxidation of sulfur dioxide and nitrogen dioxide to form mainly ammonium sulfates and nitrates, as well as the formation of secondary organic aerosols from the chemical degradation of hydrocarbons. These particles are often less than 2.5 micrometers in diameter.

The source distribution of particles is still being researched, but in urban regions of Europe during summer months, a first approximation is that one-third of all PM10 in the atmosphere originates from exhaust emissions from diesel engines; another one-third originates from dusts and sprays, and the remaining third are secondary particles. During winter months in urban regions, the major source of particles is from diesel engine exhaust.

In USA, the distribution is different because there is a smaller proportion of diesel vehicles and a much lower proportion of coal is used, suggesting that secondary particles are the main source of PM10 in summer months.

Countries outside Europe and USA have different sources contributing to PM10, and the first task is to quantify the sources of particulate matter for both summer and winter seasons.

Health concerns focus on PM10 because these small particles reach deepest into the lung. Increased concentrations of particles have been associated with higher daily mortality rates in USA due to lung diseases. The current school of thought is that the number of particles, and hence smaller particles, are more damaging to the lung than the chemical composition of the PM10 fraction. The World Health Organization (WHO) and the United Nations Economic Commission for Europe (UNECE) have concluded that it is the fraction of small-sized particulate matter (rather than large particles) that are considered responsible for most of these health effects.

It may not be long before PM2.5 is considered to be the particulate size of importance, which will take dusts and sprays out of the particle inventory, and so place the focus entirely on the exhaust from diesel engines and on secondary particles.

It should be noted that, as nitrogen oxides and sulfur dioxide levels decline to conform to U.S. and European standards, so also will the levels of secondary ammonium nitrates and sulfates. This may well focus public attention on the diesel engine, though it is likely that any future PM2.5 standard could be met in summer by a corresponding decline in secondary particles. Diesel exhaust control technology may well be sufficient to ensure that future PM standards in winter months can be met. The automobile engineer has a real challenge in ensuring that the diesel engine can return to its early "lean and green" image.

Ozone

Ground-level ozone is formed in the atmosphere from the chemical reaction of hydrocarbons and nitrogen oxides in the presence of sunlight in spring and summer months. Ozone is formed by the recombination of molecular and atomic oxygen, the main source of the atomic oxygen being from the photolysis of nitrogen dioxide.

Ozone is the most important secondary pollutant, and moves across international boundaries with wind fields. Since the precursors of ozone (VOCs and NOx) are often generated from mobile and stationary sources, the ozone problem needs to be addressed at its source by industries on a state and national basis.

The science of ozone formation, transport, and accumulation is very complex. Ground-level ozone is produced and destroyed in a cyclical set of chemical reactions involving NOx, VOC, heat, and sunlight. As a result, differences in NOx and VOC emissions and weather patterns contribute to daily, seasonal, and yearly differences in ozone concentrations and differences from city to city. Many of the chemical reactions that are part of the ozone-forming cycle are sensitive to temperature and sunlight. When ambient temperatures and sunlight levels remain high for several days and the air is relatively stagnant, ozone and its precursors can build up and produce more ozone than typically would occur on a single high temperature day. Further complicating matters, ozone also can be transported into an area from pollution sources found hundreds of miles upwind, resulting in elevated ozone levels even in areas with low VOC or NOx emissions.

Furthermore, ozone formation depends on the relative ratios of VOCs to NOx. A low ratio (high NOx levels) in cities or heavy industrialized states will result in less ozone formation, since NOx will inhibit ozone creation. The strategy for reducing ozone in any given state or country, whether NOx or VOC reduction or both, will depend upon the relative VOC to NOx ratios of each area. In practice, mathematical models that take into account chemical reactivity and meteorology are used to predict the emissions reductions that are needed to meet a specified ozone concentration.

It is of critical importance to have detailed statistics of VOC distributions for each country, and for all sectors. We must have detailed VOC speciation for both gasoline engine exhaust and evaporative emissions, and from diesel and liquefied petroleum gas (LPG) engines, as well as from other industrial sectors. Only then can we be sure that our ozone air quality model will accurately predict control strategies.

Ozone is a powerful irritant causing inflammation of the lung passages. There is evidence to show that long-term exposure can cause a chronic decline in respiratory function. However, there is only scant evidence to suggest that those suffering from asthma will find a worsening of their condition in ozone episodes. When ozone encounters a solid surface, it degenerates into oxygen, and for this reason, in high ozone episodes, it is safer to remain indoors.

Carbon dioxide

Carbon dioxide is increasing in the atmosphere due to combustion processes involved in the burning of oil, coal, and gas. It is one of the most abundant greenhouse gases, comprising 72% of the total by weight, the others being methane, chlorofluorocarbons (CFCs), and nitrous oxide.

The Earth is kept warm by solar energy trapped by the atmosphere. It is becoming widely accepted that the temperature of the Earth is increasing by approximately 1 ^{o}C every thirty years—a process widely known as global warming.

Carbon dioxide is not a pollutant of concern to human health, but it is considered to be an environmental problem because of its contribution to global warming.

Currently, transportation accounts for 25% of total carbon dioxide emissions and the pressure to tackle increasing traffic volumes is enormous. In response, many national governments are taxing fuel in the hope of curbing the growth in vehicle ownership.

Local governments are encouraging the use of park-and-ride and alternative transportation systems in urban areas. The automobile engineer needs to be aware of the wider effects of pollution.

2.2 Formation of vehicle emissions

The power to move a car comes from burning fuel in an engine. Pollution from cars comes from by-products of this combustion process (exhaust) and from evaporation of the fuel (see Figure 3).

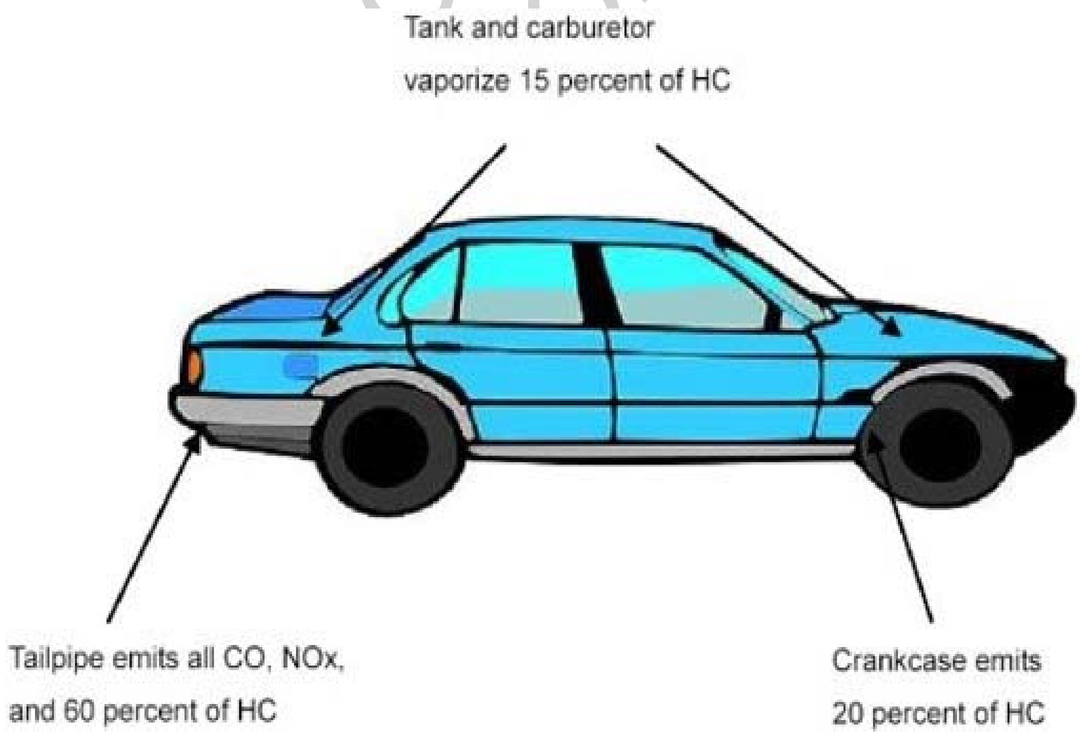

Figure 3. Sources of vehicle pollutants

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Biographical Sketches

Dr. HE Kebin is a Professor of Environmental Science & Engineering, and Director of the Office of International Cooperation and Exchange, Tsinghua University. Since receiving his Ph. D. in environmental engineering in 1990, he has been conducting research on air pollution, including coal-fired air pollution and vehicular emission, for over ten years. To date, as a principal investigator, he has finished more than 20 research projects and published more than 90 academic papers. He has been a senior visiting scholar at the Technical University of Denmark, Leeds University in the UK, and Harvard University in USA. He also serves as a Member of the Council for the China Energy Research Society, as the Senior Member of China Society of Environmental Science, a Member of the Pollution Control Working Group in China Council for International Cooperation on Environment and Development, a Member of the Air & Waste Management Association in the USA, and a Member of the Society of Automotive Engineering in the USA.

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