TYPES AND AMOUNTS OF VEHICULAR EMISSIONS

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Summary

This article assesses the types and amounts of main atmospheric pollutants from vehicles. Cars, trucks, buses, and other motor vehicles continue to play a dominant role in causing air pollution. They are major sources of carbon monoxide (CO), volatile organic compounds (VOCs) and nitrogen oxides, the precursors to tropospheric ozone formation, acid rain, and particulate matter in urban areas. Carbon monoxide, an odorless and colorless gas, is becoming a pollutant of the past because of the substantial reductions in CO levels achieved through modern gasoline vehicle technology. Nitrogen

oxides (NOx) and volatile organic compounds (VOCs), which are recognized pollutants and precursors for ground-level ozone formation, will be the main challenges in the next decade. While the presence of particulate matter in air pollution tends to focus public attention on diesel engine exhaust, secondary particles such as ammonium sulfates and nitrates form a substantial part of the particle inventory, and are likely to decline in the next decade. In this article, the formation mechanisms of each vehicle pollutants are introduced.

1. Introduction

Worldwide, cars, trucks, buses, and other motor vehicles continue to play a dominant role in causing air pollution. They are major sources of carbon monoxide (CO), volatile organic compounds (VOCs) and nitrogen oxides, the precursors to tropospheric ozone, acid rain, and particulate matter in urban areas. Air pollutants are classified in two categories: primary, if emitted directly into the atmosphere by a stationary or mobile source; and secondary, if formed in the atmosphere as a result of physical and chemical processes such as hydrolysis, oxidation, or photochemistry.

Among primary pollutants emitted from mobile sources are carbon monoxide (CO), hydrocarbons (HC) and other volatile organic compounds (VOCs), oxides of sulfur (SO_x), oxides of nitrogen (NO_x), particulate matter including dust and smoke, and compounds of lead. Secondary pollutants from mobile sources include nitrogen dioxide, the entire class of photochemical oxidants (including ozone), secondary particulate matter and acid rain. Carbon dioxide has no direct adverse effects on human health or public welfare but its build-up contributes to enhancement of the greenhouse effect.

The importance of highway-related pollutants has increased dramatically in the last forty years. Pollution of the environment is not new but it is only in recent years that transportation has made a major contribution. Since the Industrial Revolution, there has been an increase in the quantity of atmospheric waste products generated by industry and society. Control procedures involving technology and legislation have contributed to the reduction of emissions, particularly industrial and domestic emissions, in industrialized countries over the last forty years. As the same time as industrial and domestic emissions have reduced, motor vehicle use has increased rapidly with the result that transportation is now a major source of pollution, particularly in the urban environment. In 1950, there were less than 50 million cars worldwide and 85% of those cars were in USA. Between 1950 and 1990, the US car population increased by a factor of 3 and the worldwide car population increased by a factor of 8. Major population increases, particularly in Asia and South America, will probably be accompanied by increased urbanization as social factors force the majority of the added population into cities and away from rural areas. The overall effect of these trends is likely to be an increase in the number of cities experiencing major traffic-related pollution problems.

Motor vehicles are major emission sources of air pollutant in USA and Japan. In the densely populated north-eastern USA where the air pollution problem is especially severe, the Environment Protection Agency (EPA) has projected that highway vehicles will account for approximately 38% of the total NO_x inventory and 22% of the total VOC inventory in 2005, in spite of the introduction of tighter motor vehicle standards in the

1990 Clean Air Act. When focusing on emissions in congested city centers, the importance of vehicle emissions is even greater. One recent study used a chemical mass balance technique to determine the source of particulates on a midtown Manhattan street. In this instance, diesel bus emissions appeared to be the primary source.

In the European Union as whole, on and off-road vehicles are the largest sources of CO, NOx and non-methane hydrocarbons. Prior to the adoption of the Euro 3/4 requirements, forecasts indicated that vehicles would remain a major emissions source until 2010. In densely populated urban areas, vehicles can be a major source of exposure to particulates as well. Road vehicles currently account for 74% of nitrogen oxides and 94% of black smoke emissions in London. On their own, diesels account for 32% and 87% of total emissions (43% and 92% of vehicle emissions) for these two pollutants respectively.

2. Pollutants from Vehicles

2.1. Carbon Dioxide

The primary environmental concern here is related to carbon dioxide's possible climatic impact. Scientists generally view it as a major contributor to the exacerbation of the greenhouse effect and consequential global warming. CO_2 is emitted by the combustion of fossil fuels. Estimates suggest that about 15% of the world's total man-made emissions of CO_2 are generated by motor vehicles and in some OECD countries the figure may reach 70%.

Since CO_2 is a natural constituent of air (although only about 0.03%) it is not strictly viewed as a pollutant. Excess amounts of the gas have no direct detrimental effect on human health. The problem is that there is mounting, although some would argue not yet conclusive, evidence that high levels of CO_2 in the atmosphere, by preventing heat from escaping from the planet, will lead to global climate change. In particular, the retention of heat by the Earth and atmosphere is due to CO_2 in the air being 'transparent' to incoming short-wave radiation but 'opaque' to longer wave radiation that comes from the Earth. This is called the greenhouse effect because the glass in a greenhouse acts in a similar heat retentive way.

Western and Eastern industrialized countries contribute 80% to global CO_2 emissions, although their share of the world's population is only 25% of the total. Less developed countries, including the People's Republic of China, where 75% of the world's population lives, contributes only 20% to world totals of this pollutant.

Carbon dioxide is a normal end-combustion product of every fuel containing carbon (biomass, wood, coal and its variants, oil and petroleum derivatives) and a product of aerobic metabolism (respiration). On the other hand, it is reconverted to carbonaceous solids by the chlorophyll in plants. In 1983, carbon emissions from fossil fuel combustion were estimated at approximately 5 Gt (10^9 t) per year, with an equivalent amount being contributed by other human activities. Other studies have set the share of carbon emissions retained by the Earth's atmosphere at 2.9 Gt of the 5.8 Gt emitted annually from different sources. Emissions have since been re-assessed for 1990 at 26 Gt of CO_2, with 15% being attributable to road traffic.

Of the total industrial CO_2 emissions in France in 1986 (estimated by CITEPA at 326 Mt), the portion attributable to transportation (determined by adding only the contributions of regular- and premium-grade gasoline and diesel fuel combustion, since the contribution of LPG is still negligible in France) amounted to about 95.3Mt, or 29% of the total. A similar calculation for the entire world (excluding China, the ex-USSR, and Eastern Europe) attributes 4416 Mt to transportation, out of a total emitted tonnage of about 18 Gt of CO_2, or about 25% of the worldwide total.

2.2. Carbon Monoxide

CO is a colorless, odorless, and highly toxic gas, with a density close to that of air. It can have detrimental effects on health because it interferes with the absorption of oxygen by red blood cells. This may lead to increased morbidity and adversely affected fertility, and there is evidence that it affects worker productivity. CO is especially a problem in urban areas where synergistic effects with other pollutants means it contributes to photochemical smog and surface ozone formation. Concentrations of ozone even at low levels have implications for the respiratory system.

Carbon monoxide results from the incomplete combustion of fuel and is emitted directly from vehicle tailpipes. Incomplete combustion is most likely to occur at low air-to-fuel ratios in the engine. These conditions are common during vehicle starting when air supply is restricted ("choked"), when cars are not tuned properly, and at altitudes where "thin" air effectively reduces the amount of oxygen available for combustion (except in cars that are designed or adjusted to compensate for altitude).

As exemplified by the inventories, carbon monoxide is a pollutant closely associated with emissions from gasoline vehicles. Some 90% of all CO emissions in industrialized nations originate from the transport sector, and about 85% of that total is associated with automobile use. In urban areas, the contribution from motor vehicles to carbon monoxide pollution can exceed 90% of the total. Transportation is responsible for approximately 85% of CO emissions in the UK. In the USA, two-thirds of total carbon monoxide emissions come from transportation sources, with the largest contribution coming from highway motor vehicles. In urban areas where concentrations tend to be highest, motor vehicle traffic is responsible for about 98% of all emissions of carbon monoxide. The figure reaches 100% in the center of many densely developed areas.

In USA, carbon monoxide has become less of a national air quality problem over the past twenty years as CO concentrations in the air have decreased by 60% nationwide. In 1997, only three counties (Los Angeles County, CA, Fairbanks, AK, and Imperial County, CA) had monitoring sites that failed to meet the NAAQS for CO. Carbon monoxide emissions from transportation fell by 41% between 1970 and 1997, compared to an 11% reduction in emissions from non-transportation sources over this same time period. Factors contributing to reduced CO emissions from motor vehicles include national standards for tailpipe emissions, new vehicle technologies, and use of oxygenated gasoline. Although the number of violations of the CO standard has fallen significantly, high concentrations of CO often occur in areas with heavy traffic congestion.

2.3. Sulfur Dioxide

Sulfur dioxide (SO_2) is a colorless, but strong smelling gas. It is the main sulfur compound emitted into the atmosphere. All combustion processes of products containing sulfur yield SO_2 emissions; hence, fossil fuels are mainly blamed for atmospheric SO_2. Emissions of this gas can result in bronchitis and other diseases of the respiratory system, and it is the major contributor to 'acid rain'. Transportation is directly responsible for about 5% of total SO_2 emissions (although in some countries it is as high as 17%), with diesel fuel producing more SO_2 per liter than gasoline. More importantly, coal-fired electricity generation is a major source of this gas, and there are further indirect environmental implications related to both the use of electronic rail transport and the manufacture of transport vehicles. The transportation share of sulfur-containing pollutants is primarily from engines running on diesel or home-heating oil containing 0.3% S (the upper limit of French specifications). Gasoline generally contains a maximum of 0.08% S, although the corresponding specifications allow for 0.15% (premium) to 0.20% (regular) S.

A calculation made from French consumption figures for 1987 indicate emissions of 30 000 tons of SO_2 comes from automotive fuels and 72 000 tons from diesel fuels. In Germany in 1982, annual SO_2 emissions due to transportation were estimated to be 100 000 t/year, accounting for 3.4% of total emissions. In 1985, truck emissions were estimated at 42 000 t/year, with an emission factor of 0.54g SO_2/kg of diesel fuel.

In USA, SO_2 is a less pervasive air quality problem compared to carbon monoxide, ozone, and particulate matter. During the period from 1978 to 1997, concentrations of SO_2 in the air declined by 55%. Fewer than 100 000 Americans lived in counties with air quality concentrations above the SO_2 NAAQS limits in 1997. Despite the small number of violations of the SO_2 standard, sulfur dioxide emissions remains an environmental problem, as SO_2 contributes to particulate matter in the atmosphere and acid rain. In USA, transportation is a relatively minor source of SO_2 emissions, contributing about 3% of total SO_2 emissions nationwide. Production and refining of petroleum for transportation also contributes about 2% of national SO_2 emissions. SO_2 emissions from transportation have trended upward through the 1970s and 1980s, largely due to increases in emissions by ships and boats. A substantial decline in heavy-duty vehicle emissions occurred, however, between 1992 and 1994. EPA recently promulgated a new rule that requires significantly lower sulfur content for gasoline, which in turn will help to reduce motor vehicles emissions of VOCs, CO, and NO_x since sulfur in gasoline inhibits the performance of the catalytic converters in modern vehicles.

Atmospheric sulfur dioxide is oxidized to form sulfuric acid. Sulfuric acid may be incorporated into rain or dry-deposition as fine particles and, in doing so, cause acidification of soils and surface waters. Such acidification processes have been associated with well-publicized problems falling under the all-embracing term of "acid rain". In Europe, such problems have been most acute in Scandinavia, which emits little sulfur dioxide, but which is subject to deposition of acidic compounds coming from emissions produced in other countries, such as those of Eastern Europe and the UK. In order to control sulfur dioxide, flue gas desulfurization equipment is being installed in major UK power plants. The process involves the use of a watery mixture (slurry) of limestone to 'scrub' the power plant waste gases of sulfur dioxide, but this process results in the production of large quantities of gypsum that require disposal.

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Biographical Sketches

Dr. HE Kebin is a Professor of Environmental Science and Engineering, Director of the Office of International Cooperation and Exchange, Tsinghua University. Since receiving his Ph. D. in environmental engineering in 1990, Prof. He has been conducting research on air pollution, including coal-fired air pollution and vehicular emission, for over ten years. Up to now, as a principal investigator, he has finished more than 20 research projects and published more than 90 academic papers. Dr. He has been a senior visiting scholar at the Technical University of Denmark, Leeds University in the UK, and Harvard University in USA. Dr. 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 USA, and a Member of the Society of Automotive Engineering in USA.

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