POLLUTION CONTROL IN TRANSPORTATION

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Summary

Transportation is a major component of modern civilization in the “global village”.

Transportation is also the heart of modern industrial systems, which pumps in resources and means for their transformation, pumps out products and provides links between the different parts of the “industrial organism” as a vital part of commercial activities.

Transportation is also a source of major anthropogenic contribution to environmental pollution.

In 1997, the emissions generated in the USA from mobile sources were roughly 30, 4, and 67 per cent of the generated in the USA carbon dioxide (CO_2), methane (CH_4), and nitrous oxide N_2O, respectively. Total emissions of nitrogen oxides (NO_x) from mobile sources represented 49 per cent of national emissions, while carbon monoxide (CO), non-methane volatile organic compounds (NMVOC) and sulfur dioxide (SO_2) emissions contributed approximately 81, 40 and 7 per cent, respectively. Emissions of particulate matter in the USA for the same year are reported as particulate matter smaller than 10 microns (PM10) – 2.569 thousand tons and total particulate matter (PT) – 5.489 thousand tons.

The topic discusses pollution and pollution control technologies for the most widely used present modes of transportation. Internal combustion engine vehicles – their advantages and disadvantages, energy efficiency, major pollutants and how they are formed, the present and future of these engines, etc., occupy a significant part of the topic. The problems and promises for future radical changes of pollution and zero emissions from transportation through the introduction of battery driven and hybrid electric vehicles, fuel cell vehicle technologies, etc. are also a major issue. Specific problems of the pollution control of heavy transport and non-road vehicles, marine engineering, railway systems and aeronautical engineering are also discussed here, though they have not been covered in the chapters of the topic.

1. Introduction

Transportation is a major component of modern civilization. It brings people together, catalyses exchanges of ideas and sharing of common views, exposes common problems, discovers new territories and ways of life, etc. and is essential in the “global village”.

Transportation is also in the heart of modern industrial systems. It brings in resources and means for their transformation, distributes products and provides links between different industries as a vital part of commercial activities (see *Pollution Control in Industrial Processes*).

Transportation is also the mobile source of major anthropogenic contribution to environmental pollution, which emits pollutants around the globe.

In 1997, the emissions generated in the USA from mobile sources were roughly 30, 4, and 67 per cent of the generated in the USA carbon dioxide (CO_2), methane (CH_4), and nitrous oxide N_2O, respectively. Total emissions of nitrogen oxides (NO_x) from mobile sources represented 49 per cent of national emissions, while carbon monoxide (CO), non-methane volatile organic compounds (NMVOC) and sulfur dioxide (SO_2) emissions contributed approximately 81, 40 and 7 per cent, respectively. Emissions of particulate matter in the USA for the same year are reported as particulate matter smaller than 10 microns (PM10) – 2.569 thousand tons and total particulate matter (PT) – 5.489 thousand tons.

The primary driving forces of the present transportation activities are the internal combustion engines (ICE). ICE operate by burning fossil fuel derivatives. Exhaust emissions are their major contribution to environmental pollution. Typical emissions contain primary greenhouse gases and all criteria pollutants. Toxic compounds include benzene, butadiene, aldehydes and lately – ethers, methanol, etc. In many countries exhaust emissions still contain lead and/or manganese (as lead replacement). Halogen containing gases and hydrocarbons emitted as evaporative emissions are additional pollutants. Odor and noise pollution are typical for heavy-duty engines.

Environmental pollution from transportation is not only limited to engine pollution. Pollutants are emitted to air, water and soil in vehicle production, maintenance and service, in their final demolition. The environment is polluted also in construction and maintenance of roads, stations and ports; from cargo in normal transportation and in accident, from disposal of old vehicles and obsolete transportation infrastructure and so on.

The need to control engine emissions was recognized as early as 1909. The first engine exhaust gas treatment devices were introduced in 1976. The upper limits per kilometer of the US car legislation at that time were: CO – 9.3 g, HC – 0.93 g and NO_X – 1.93 g. The Tier 2 standards implemented after 2003, require light duty vehicles and trucks to emit per kilometer less than 2.1 g CO, 0.047 g non-methane organic gases (NMOG), 0.04 g NO_X and 0.005 g aldehydes (HCHO).

In 1990, the California Air Resources Board in the US outlined for the first time a strategy towards the total elimination of vehicle emissions. The zero emission vehicles (ZEV) concept is based on the development of non-polluting electric vehicles. The share of ZEVs in California in 2003 was planned to be ten per cent of all new vehicles delivered to the market by the major manufacturing companies.

These examples illustrate the steep road towards sustainable development of one of the privileges of modern civilization – fast and in comfort physical mobility. Neither previous successes nor ambitious future environmental goals can be achieved without adequate investments and efforts for development of advanced technologies for pollution control. Engine modifications, cleaner fuels, catalytic devices, devices to control evaporative emissions, etc. and the optimized application and maintenance of all options, play the essential role in the control of the pollution from internal combustion engines.

Zero emission vehicles are the vision for the future. Their mission can be achieved with the involvement of electric power in transportation. The latter maybe stored (i.e. EVs) and/or produced on-board (FCHEVs). Only electric power maybe used to satisfy all requirements of the vehicle or it may be combined with power generated from a fossil fuel.

2. Control of Exhaust Emissions from Internal Combustion Engines

2.1. Environmental Pollution from Internal Combustion Engine Vehicles

Internal combustion engines may be classified by different criteria. An appropriate classification from the point of view of combustion chemistry and air pollution will divide them into two major groups. The first group includes engines in which combustion is performed periodically in a chamber of changing volume (i. e. reciprocating piston engines). In the second group combustion is taking place continuously (steady flow) in a chamber of constant volume.

The first group may be further divided into spark ignition (SI) and compression ignition (CI) engines, although there are engines combining both principles. Spark ignition engines may be classified as two stroke and four stroke engines, CI engines – as direct injection and indirect injection engines.
The second group includes the jet engines, which can use a gas turbine, liquid fuel, air as oxidation agent and eventually - a turbo compressor (aircraft jet engines), and the rocket jet engines, which have chemical agents as fuels and oxidizers.

Another useful distinction between internal combustion engines is the fact that only in SI engines the fuel is evaporated and mixed with the oxidizing agent before the ignition takes place. In most other designs, the fuel is sprayed in the combustion chamber, in the form of drops of different size.

Quantitative estimation of the contribution of ICE vehicles to greenhouse gases and criteria for pollutants was given above. Vehicles in the US in 1990 provided also 45 per cent of the benzene, 41 per cent of the butadiene and 37 per cent of the aldehydes in the national toxic emissions. Leaded gasoline was banned in the USA in 1995. Brazil and Japan eliminated leaded gasoline in the 1980s. The first European country, which prohibited leaded gasoline (in 1993), was Austria. Still around one third of the gasoline consumed worldwide is leaded. In some countries manganese additives are permitted as substitutes for tetra ethyl lead. Figure 1 shows the main emission sources of a passenger car.

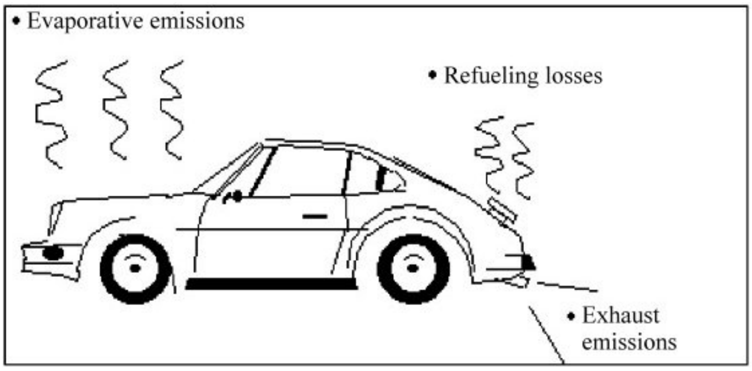

Figure 1: Typical Emission Sources from a Passenger Car

2.2. Formation of Pollutants in ICE and Their Estimation

Chemical elements under ideal conditions should burn to the corresponding oxides, so CO_2 and water are the most likely products to be expected from oxidation of hydrocarbons. However, conditions in engineering applications of combustion reactions are not ideal. If the air quantity is higher than the stoichiometric the flames are called "lean", if it is lower - "rich". In a real combustion chamber, flames may be both. Other important factors include flame temperatures, gas residence time at high temperatures and combustion chamber turbulence. None of these factors is at its most favorable values, throughout the whole chamber space. The fuels are in fact mixtures of compounds with different molecular masses, volatility, diffusion coefficients, etc. Under the non-ideal conditions in the chamber, they undergo thermal and oxidation pyrolysis, prior to reaching the flame propagation zone. The mode of ignition of the fuel, and the intermediate products through which it passes in combustion reactions are very important for the type and the relative quantity of pollutants formed.

Pollutants in exhaust emissions from ICE can be divided into two main groups. Hydrocarbons, toxic compounds and particulate matter originate from the transformation of fuel hydrocarbons into different organic molecules. A considerable amount of hydrocarbons can be unconverted. Oxides are the final conversion products of all chemical elements contained in the original fuel molecules. An intermediate group, typical for heavier fuels, containing metals, consists of compounds built by combination of metals with other chemical elements (e.g., sulfates in particulate matter of diesel emissions).

Estimation of emissions from ICE starts with measurement of the emission rates of the particular polluting effluents in standard tests. Typically, two types of tests are used for estimation of emissions from vehicles – laboratory driving tests and fleet driving tests. Testing of aircraft, locomotive and marine engines apply more or less similar procedures.

Sophisticated statistical modeling is involved in the development of emission factors from vehicles. It includes creating of representative fleets, averaging traveling activities, typical driving patterns, etc.

2.3 Control of exhaust emissions from ICE

Engine exhaust emissions depend on the organization of the combustion process in terms of air-fuel ratio and mixing, timing of fuel injection, ignition and combustion, etc.

Control of exhaust emission of *four-stroke SI engines* can be achieved through a sophisticated combination of engine modifications. Typical solutions include central or multi-port electronic fuel injection, timing of the initial spark, flexible electronic ignition systems, automatic chokes and inlet heaters, idling emission controls and fuel cut –off systems, lean-burning. Engine modifications for the *two stroke SI engines*, which control exhaust emissions, involve direct fuel injection systems, skip firing, exhaust charge controls, ignition timing.

Modern CI engines use moderately retarded injection timing to reduce NO_X emissions, and high injection pressure to limit the negative timing effect on particulate matter and fuel efficiency. Regulation of the temperature of the compressed air charge is practiced in advanced diesel engine designs. It influences positively NO_X and particulate matter. Inter cooling of air charge is typical for modern turbo charged designs.

Compression ratios are inherently high in the diesel engine technology. Modern designs try to sustain the appropriate compression ratio for the particular engine.

Modern designs of nozzles spraying the fuel in the combustion chamber are directed towards limiting or eliminating the small amount of fuel kept for some time in the nozzle, thus reducing hydrocarbon and PM emissions.

New combustion chamber designs minimize parasitic volumes formed by the geometry of piston, cylinder head and cylinder walls. They can also optimize in-cylinder air motion and intake air swirl to minimize smoke and PM, while not allowing increase of NO_X, hydrocarbons and fuel consumption.

Lubricating oil largely contributes to emissions of hydrocarbons and particulate matter. Its presence in the chamber can be limited by improving the quality of the surface and the roundness of cylinders, optimization of piston ring tension and shape, redesigning of valve stem seals, turbocharger oil seals, and similar potential leak points.

Jet engine designs, which control exhaust emissions, include a high number of small burners, operated near the optimum conditions throughout the whole process. They allow for better combustion and lower emissions of CO and hydrocarbons down to quite low equivalence ratios. Multiple burners also ensure lower NO_X emissions at low loads. Air assisted atomizers and pre-mixing of air and fuel in the primary zone provide intimate contact between combustion species and reduce emissions. Multiple staged combustion, like in power generation turbines is also practiced in low NO_X turbine engine designs.

Fuel options for control of emissions from ICE include the optimization and improving of the environmental compatibility of the composition of the traditional fuels, and their partial or entire replacement with alternative fuels. Reformulation of the fuel is usually the optimization of the composition that accommodates the incorporation of alternative components. Alternative fuels used as components, or for a total replacement of traditional fuels include hydrocarbon gases, methanol, ethanol, ethers, and biodiesel additives. Lubricants can be also replaced or reformulated in order to improve emission control. Typical options include the use of semi-synthetic or synthetic oils, new additives, and alternative biodegradable components.

3. Catalytic Converters and Other Emission Control Devices

Figure 2 shows the arrangement of the main emission controls in a car

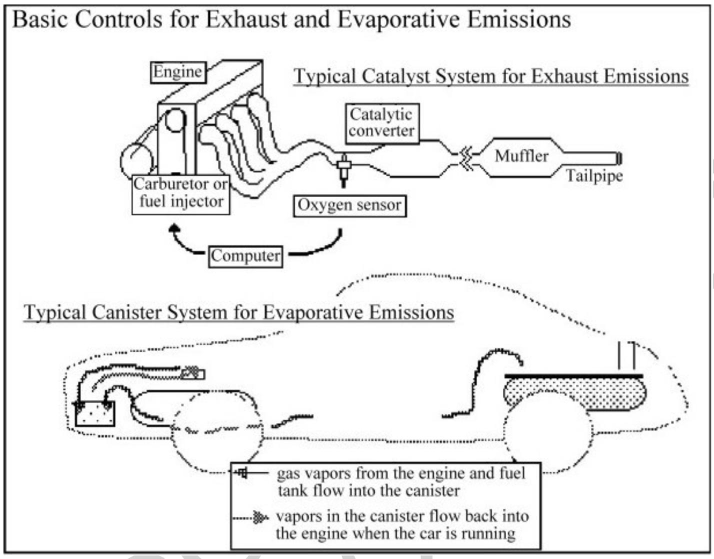

Figure 2: Typical Arrangement of Controls for Exhaust and Evaporative Emissions in a Passenger Car

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Biographical Sketch

Georgi St. Cholakov is Associate Professor at the University of Chemical Technology and Metallurgy in Sofia. He received his first hands-on experience of ecological problems during compulsory his military service as the Head of the Fuels and Lubricants Unit of an airbase. His PhD dissertation was on development of replacements for lubricant additives synthesized from the sperm oil, obtained from blue whales. He did a post doctoral specialization in tribology at the University of Birmingham, U.K. Later he specialized in effective and ecological processing and use of petroleum derivatives at Imperial College, London, the French Institute of Petroleum, and other leading universities. The scientific and research interests of G. St. Cholakov are centered around petroleum processing and petroleum derivatives – environmentally compatible processes and products, process and product design for the petroleum industry, chemistry of combustion and ecology, etc. He is teaching advanced courses in related academic disciplines – alternative fuels and lubricants, air pollution management, chemistry of combustion and ecology, additives for fuels and lubricants, technological computation in petroleum processing, etc. He has contributed more than 50 papers in refereed international journals and co-edited the Bulgarian edition of Miall's Dictionary of Chemistry. He is member and has served in elective positions in different Bulgarian and Balkan professional organizations. He has been member of the editorial boards of two journals, published in Bulgaria in the English language.