Modeling of propagation of the hazardous impurities emitted by automobiles in traffic jams

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1 Introduction

Every day a great number of cars crowd the roads of big cities during rush hours. Pollutants that come from by-products of a combustion process are emitted by the cars into the atmosphere. Emissions from an individual car are generally low relative to the smokestack image many people associate with air pollution. But in numerous cities, the personal automobile is the single greatest polluter, as emissions from many thousands of vehicles on the road add up. Driving a private car is probably a most "polluting" daily activity for a typical town-dweller. It is rather a frequent occasion when long-term traffic jams arise in the streets. Many emitted pollutants are hazardous for human health and the environment and may cause numerous adverse effects and diseases.

In the present work an analysis of the distribution of the pollutants emitted by cars was performed on an example of one of the streets of the city of Minsk. The calculation of ground level concentrations of pollutants was carried out with the use of the well-known computer program STAR (version 3.10) that operates by solving the governing differential equations of the flow physics by numerical means on a computational mesh, for quite general circumstances [1].

2 Vehicle emissions

Pollution from cars comes from by-products of a combustion process (exhaust) and from evaporation of the fuel itself. Gasoline and diesel fuels are mixtures of hydrocarbons, whose compounds contain hydrogen and carbon atoms. The combustion process is not "perfect," and automobile engines emit several types of pollutants, among which are hydrocarbons, various nitrogen oxides, collectively known as NO_x, carbon monoxide (CO), and particulate matter.

In recent years, ecologists have started to view carbon dioxide, a product of "perfect" combustion, as a pollution concern. Carbon dioxide does not impact directly on human health, but it is a "greenhouse gas" that contributes to the potential for global warming.

Cars that use leaded petrol as a fuel emit also lead compounds in the form of organic particles (predominantly lead alkyls that escaped combustion) and inorganic particles. The widespread introduction of unleaded gasoline resulted in considerable reductions in ambient lead levels, which in turn alleviated many serious environmental and human health outcomes associated with lead pollution.

Inhalation exposure to lead, benzene, and benzpyrene causes cancer of different localizations. Particulate matter, nitrogen oxides, carbon monoxide, and some other chemicals are responsible for toxic effects and may be the reason of such health outcomes as asthma attack, bronchitis, etc.

Table 1 presents idle emission factors, in grams per hour (g/hr) of idle time, for volatile organic compounds (VOC), carbon monoxide (CO), and oxides of nitrogen (NO_x). Idle emissions of particulate matter (PM_{10}) are provided for heavy-duty diesel vehicles only; PM_{10} emissions from gasoline-fueled vehicles are negligible, especially when the elimination of lead in gasoline and reductions of sulfur content are accounted for. The data of Table 1 that contains idle emission factors can be used to obtain first-order approximations of emissions under idle conditions (e.g., drive-thru lanes). As with driving emissions, idle emissions are affected by a number of parameters that are not taken into account in the emission characteristics presented.

Table 1 Emission characteristics for different categories of vehicles (summer conditions, [2]).

Pollutant	Units	LDGV	LDGT	HDGV	LDDV	LDDT	HDDV	MC
VOC	g/hr	16.1	24.1	35.8	3.53	4.63	12.5	19.4
CO	g/hr	229	339	738	9.97	11.2	94.0	435
NO_x	g/hr	4.72	5.71	10.2	6.50	6.67	55.0	1.69

LDGV: Light-duty gasoline-fueled vehicles, up to 6000 lb Gross Vehicle Weight (GVW) (gasoline fueled passenger cars)
GT: Light-duty gasoline-fueled trucks, up to 8500 lb GVW (includes pick-up trucks, minivans, passenger vans, sport-utility vehicles, etc.)
HDGV: Heavy-duty gasoline-fueled vehicles, 8501+ lb GVW (gas heavy-duty trucks)
LDDV: Light-duty diesel vehicles, up to 6000 lb GVW (passenger cars with diesel engines)
LDDT: Light-duty diesel trucks, up to 8500 lb GVW (light trucks with diesel engines)
HDDV: Heavy-duty diesel vehicles, 8501+ lb GVW (diesel heavy-duty trucks)
MC: Motorcycles (only those certified for highway use; all gasoline-fueled)

Particulate emissions are observed to be relatively insensitive to temperature, and so "winter" and "summer" emission factors for idle PM_{10} are the same. For example, average of all heavy-duty diesel engines emission of particulate matter PM_{10} is 2.59 g/hr.
In the present paper the data contained in Table 1 were used to calculate emission by vehicles in a traffic jam.

3 Dispersion of pollutants

On an example of one of the streets of the town of Minsk named Oranskaya the modeling of the propagation of automobile fume was performed in a 3D geometry for the case of a traffic jam in this street. The location of buildings, trees, and fences in the street was taken into consideration to achieve better coincidence with the real geometry of the street. The trees in the street were modeled as objects with some transparency for gases and suspended particles. The emission sources were taken in the form of one or two linier sources, the intensity of which can be varied in accordance with the sort and number of vehicles in the street. The emission intensity was calculated on the base of the data presented in Table 1. The considered part of the street has a length of 200m. The stationary distribution of concentration of hazardous impurities emitted by cars was calculated and analyzed for different directions and velocities of the wind.
Some results of modeling automobile fume dispersion are presented in Fig.1 for the case of a 1 m/s north-west wind. It is seen from the figure that the concentration of the emitted gases can substantially vary in different parts of the street.
The distribution of low-level concentrations of the main hazardous impurities in gases and solid phases were analyzed to estimate the risk for human health associated with short-term inhalation exposure. It should be noted that though in many cases the concentrations of chemicals averaged over the street are relatively low the difference between the maximum and minimum values of concentrations may be extremely high. The calculations carried out for stationary task showed that as a rule the maximum of concentrations in the street can vary within rather a wide range, i.e., from 0.1 to 1.4 mkg/m^3 for VOC; from 0.2 to 30 mkg/m^3 for CO; from 0.15 to 2.2 mkg/m^3 for $NO_{x;}$; and from 0.01 to 0.1 mkg/m^3 for PM_{10}; The maximum values of concentrations depend on the number and kind of vehicles in the street and, as it is seen from Table 1, theses may achieve an order of magnitude.
The calculations performed allow a conclusion that there are some places in the street where the concentrations of hazardous substances may exceed the levels established for a short-term exposure. The exact location of these places depends on the direction of the wind. For example, in some cases extremely high concentrations of hazardous chemicals may be observed at the stop of public transport. A short-term exposure to hazardous substances may cause such health outcomes as asthma attack, bronchitis, especially for sensitive groups of population.

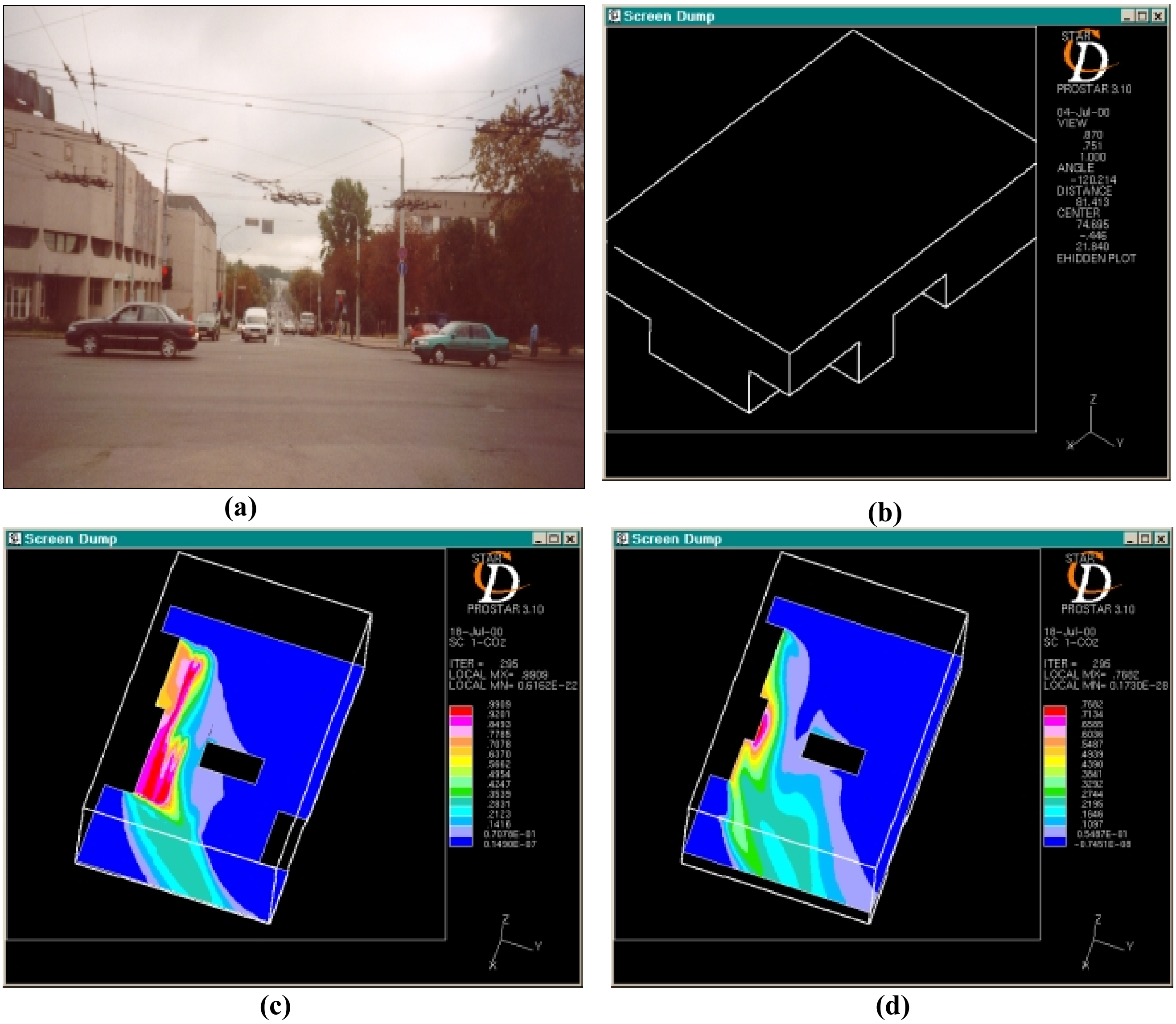

Figure 1. Distribution of concentration (relative units) over the street in a traffic jam (a-the view of the street, b- calculating domain, c –distribution of concentration at a height of 1 meter, d- at a height of 10 meter).

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References

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