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THE COMPLEX EVALUATION OF TRAFFIC POLLUTION DISPERSION NEAR ROADWAYS

Nijole Astrauskiene[1], Valdas Spakauskas[2]

[1, 2]*Vilnius Gediminas technical university, Saulėtekio ave. 11, LT-10223 Vilnius, Lithuania.*
E-mail: [1]Nijole.Astrauskiene@vgtu.lt

Abstract. Nowadays environmental issues concerning traffic become more important since it is well known that the transport sector is the major source of noise and numerous air pollutants. The transport sector is the fastest growing consumer of energy and producer of greenhouse gases in the EU. The reduction of transport pollution and the environment quality improvement can be achieved more easily knowing the present situation and factors determining its current state. The paper considers the mathematical models which can be used to describe and predict the roadside pollution.

Keywords: traffic, mathematical models, pollution, aerosol particles, roadside.

1. Introduction

Recent studies have shown a dramatic decrease of the number concentrations of ultrafine particles with increasing distance from busy freeways, thereby demonstrating that vehicular pollution is a major source of ultrafine particles and that high number concentrations can be a localized phenomenon, on scales of 100–300m (Zhu *et al*. 2002). Epidemiological studies (Peters *et al.* 1997; Chia-Pin Chio and Chung-Min Liao 2008; Balmes *et al.* 2009) have demonstrated a higher association between health effects and exposures to ultrafine particles compared to accumulation mode or coarse particles.

The XXI century can be called the century of computers and motor vehicles. There were 11 thousand vehicles all over the world in 1900, while in 2010 – already 800 million. According to the forecast of the Independent Analytical Agency of Economic Development „Global Insight“, 3 billions of vehicles will be motoring on Earth's roads in 2035. In Lithuania, the number of motor vehicles began to increase rapidly some decades ago. During the 1965–2000 period the number of vehicles in Lithuania increased even 20 times. At the beginning of 2010 the car fleet in Lithuania comprised 2133720 vehicles.

It is clear that the vehicle pollution remains large because the average vehicle age is 14 years, and the most advanced technologies are not able to reduce the pollution. It is known that the transport pollution near a roadway reaches up to 500 meters, i.e. the 1-km wide roadside is polluted. Therefore, it is important to determine the regularities of such pollution so that effective measures would be taken to reduce this pollution.

The main problems that should be clarified are the following: 1) what is the present environment pollution; 2) how to reduce the environment pollution; 3) what is the pollution impact on the environment, especially on ecological processes; 4) the prediction of pollution and its impact on the environment and ecological processes. The problem of the present pollution and its impact on the environment having the modern research methods and technologies, ecological evaluation methods and criteria of the assessment of environmental impact does not pose principal difficulties. When the forecast of pollution and its impact is necessary, we apply some theoretical models. It is especially important to determine the conservation value of the territory where roads will be built or repaired. Depending on the territory conservation value the environment impact assessment should be differentiated taking into account the worldwide used methods and criteria.

2. The traffic pollution and its dispersion

In modeling the transport pollution impact on the environment, the concentrations of CO, NO_2, NO, NO_X, SO_2 and particles are most often investigated because emissions only of these pollutants can be estimated sufficiently accurately. The emission amount of these pollutants can be determined when the consumed fuel or run of vehicles is known (Teršalų emisijos...1993; Gkatzoflias *et* *al.* 2007), latest program (Copert 4) is widely used in the EU.

It is more convenient to use typical emissions determined by the World Health Organization (International Institute… 2002), Fig 1 and Fig 2.

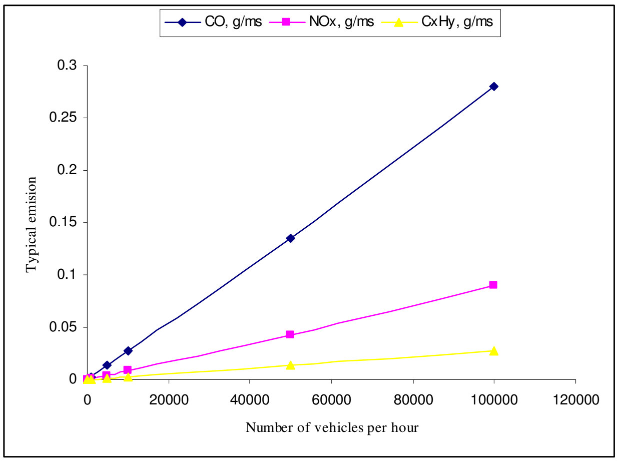

Fig 1. Typical road mean emission per hour

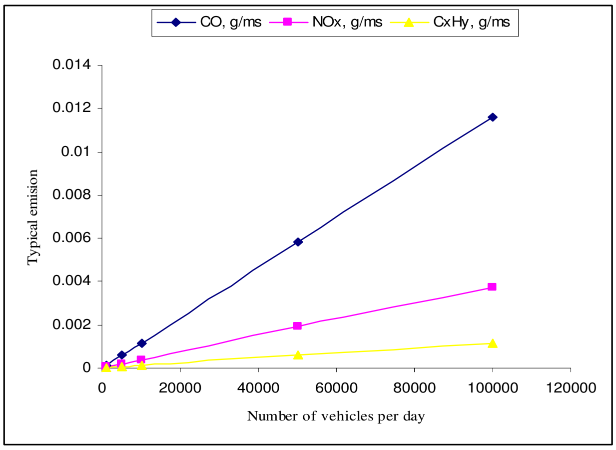

Fig 2. Typical road mean emission per day

The results of these emissions can be used in calculation of the pollution dispersion according to any standard program, but they do not allow determining concentrations of various metals.

For the determination of pollutant dispersion near a roadway a number of methods based on deterministic, numerical, statistical and artificial neural network techniques are developed (Nagendra and Khare 2002). Various model approaches such as Monte Carlo simulation (Liu *et al.* 1994), stochastic method (Karim *at al.* 1998) and regression technique (Fomunung 1999) have been used to describe the pollutant fluctuating properties during the dispersion process of pollutants.

Among the models of most common use are the models based on a Gaussian dispersion model. They are improved in various aspects, e.g. considering the turbulent kinetic energy due to the movement of vehicles on the road (Rao 2002).

However, it is well known that the roadside soil contains a lot of accumulated metals such as Ca, Na, Mg, K, Fe, Al, Ba, Cd, Co, Cr, Cu, Mn, Ni, Pb, Sb, Sr, Ti, V, Y, Zn, Mo, Zr, Pd, Pt, among which lead is the most dangerous. But their emission capability cannot be determined. Only sources of these pollutants can be determined (Ahu-Alaban *et al.* 2003; Cadle 1997) (Table 1).

Table 1. Main road pollution sources

Sources	Metals
Fuel	Pb
Lubricants	Zn, Cd, Ba, Co, Mo
Tyres	Ca, Zn
Catalysts	Pt, Pd, Cr, Ni
Protection equipment	Zn, Ca, Cr, Mn
Brakes	Zn, Ca, Cu, Cr, Mn
Road construction materials	Fe, Al, Mn, As
Resuspension of road dust	Pb, Fe, Al, Mn, Zn, Cu, Ni, Mo, As

For the evaluation of heavy metals the moss monitoring method, which was created and developed in Sweden, has been widely used lately (Rühling 1969). Another method widely used in Lithuania is the metal concentration determination in the roadside soil (Branval and Špakauskas 2007; Martinėnas e*t al.* 2006), but this method can help to determine only the present pollution and it is not suited for forecasting.

Metals in the soil may come from many different sources. Industrial plants emitted large amounts of metal in the past, but these amounts have been reduced considerably over the last few years. Therefore in assessments of the traffic pollution using the soil pollution as indicator it is essentially to determine the background pollution due to non-traffic sources.

The majority of particles from vehicle exhaust are in the size range of 20–130 nm for diesel engines and 20–60 nm for gasoline engines. It is known that the aerodynamic properties of fine and coarse particles are different, so their dispersion will be different too. Therefore the particles as usual are divided into fine $PM_{2,5}$ – particulate mater with an aerodynamic diameter less than 2,5 µm, coarse PM_{10} – ranging between 10 and 2,5 µm, and ultrafine – with an aerodynamic diameter less than 0,1 µm. The aerodynamic properties of the particles of ultrafine and fine fraction are very similar, therefore in this work, all these particles will be treated as belonging to one fine fraction.

It appears that besides different aerodynamic properties which determine the character of particle dispersion, various metals have the feature to spread with fine or coarse aerosols, and that must be taken into account in the modeling the dispersion of pollutants. It is determined that Fe is distributed mainly in coarse aerosols, and Pb, Zn, Mb, As are distributed mainly in fine aerosols. The resuspension of road dust can be considered to be a source of the crustal elements Fe, Al, Mn and As. Road dust becomes enriched with large amounts of Zn due to brake wear or tyre wear. The brake wear metals Cu, Ni, Mo, Zn can be considered to be a component of coarse aerosols. Driving conditions (stop and go or free cruising conditions, brake or acceleration) can also influence the total amount of metals emitted by transport fleet.

The vehicular exhaust jet plume rises due to the thermally induced upward motion which further enhances the pollutant dispersion process. In the far-wake region of vehicle, there is a gradual decay of the vehicle induced velocity and turbulence, and this model can be used to describe the pollutant behaviour in atmosphere (Martinėnas and Špakauskas 2010).

We propose the calculation of pollutant concentrations in soil using our developed models based on the experimental measurements:

$$c(x) = \sum_{i=1}^{i=2} c_0(i) e^{-m_i x^2}, \tag{1}$$

where $c_0(i)$ is the concentration on the road for the road length unit, x is the distance from the road, i = **1** for coarse and i = **2** for fine particles; m_i is the parameter depending on the particle diameter, density, coefficient of viscosity and the wind speed. The value of coefficient m corresponding to Lithuanian conditions is 0.013 for coarse particles and 0.00008 for fine particles.

In the case of interest in the dispersion of the particles of a particular fraction, e.g. of the particles of ultrafine fraction (diameter less than 0.1 μm), which are possible causative agent attaching increase in human mortality and morbidity, the summation parameter i in eq. (2) is to be equalled to the number of fractions n:

$$c(x) = \sum_{i=1}^{i=n} \left(a_i e^{-m_i x} + b_i e^{k_i x} \right), \tag{2}$$

here the sum of a_i and b_i must be equal to the concentration of pollutants on a road; the first term in parenthesis expresses the effect caused by gravitational forces and the second term with exponent e^{kx} expresses buoyancy effect, which is characteristic for particles of 50–200 nm and occurs due to the thermally induced upward motion (Martinėnas and Špakauskas 2010).

For calculation of the total dispersion either metals or particles on roadsides it is convenient to use the following expression:

$$c(x) = c_f + c_0 e^{-kx}. \tag{3}$$

Here c_f is the background concentration, c_0 is the concentration on a road, and k = 0.05. The concentration on an exploitable road c_0 can be measured; in the case of road projection, the fleet of vehicles is predicted as usual. Knowing the fleet of vehicles and using the data in Table 2 and 3, it is possible to calculate the emissions of traffic pollutants caused by fuel combustion.

It is known what metals with what diameter of particles are transferred, but it is impossible to measure or calculate their concentrations on a road; so the modeling of their distribution on the roadsides can not be done. But knowing the emission of fuel combustion products and the percentage of metals in the total amount of freeway pollutants the dispersion of metal pollution on roadsides can be found.

We recommend calculating only the concentrations of such elements as Mn, Pb, Zn, Cu, Ni, Mo, and Cr, because they are considerably higher than the background ones. The concentrations of other elements are on the background level.

The major fraction of pollutants falls out on the range of 30 m from a freeway, and the fall out of these pollutants on the roadside is conditioned by coarse PM_{10} particles. These concentrations of pollutants can be calculated using the following regression formula:

$$PM_{10} = 2.2 + 7(\text{dies.exh.}) + 3.1(\text{pet.exh.}) + 4.4(\text{resusp.}) + 9(\text{tyre \& brake}) + 2.5(\text{roadsurf.}), \tag{4}$$

where dies.exh. is the exhaust by diesel engines, pet.exhaus. is the exhaust by petrol engines, resusp. is the resuspension of road dust, and roadsurf. is road surface emissions.

Table 2. Emission factors for PM_{10} particles

Source	Vehicle category	Emission factor, mg/km
Exhaust	LVD	13.9
	HVD	79.3
Resuspension	LVD	0.8
	HVD	14.4
Tyre & brake wear	LVD	6.9
	HVD	49.7
Road surface wear	LVD	3.1
	HVD	29.0

Table 3. $PM_{2.5}$ emission factors for tyre, brake wear and road abrasion

Transport category	Emission factor, g/km		
	Tyre wear	Brake wear	Road abrasion
Motorcycles	0.0001	0.0003	0.0016
Passenger cars	0.0003	0.0022	0.0042
Light duty vehicles	0.0003	0.0022	0.0042
Heavy duty vehicles and buses	0.0020	0.0071	0.0209

For calculations of the fall out of $PM_{2,5}$ particles on a roadside the data of Table 3 can be used. The presented emission factors must be multiplied by the number of vehicles and simply summed (International Institute… 2002).

For finding the concentration of a particular metal the fraction of this metal in the total pollution is to be known. These data are presented in Table 4.

Table 4. Heavy metal fraction of tyre, brake wear and road abrasion

Heavy metals	Tyre wear mg/kg	Brake wear mg/kg	Road abrasion mg/kg
As	0.8	10.0	0
Cd	2.6	13.2	1
Cr	12.4	669	40
Cu	174	51112	12
Ni	33.6	463	20
Pb	107	3126	15
Zn	7434	8676	35

The percentage composition of metal elements is known too: Mn – 24 %, Pb – 31 %, Zn – 5 %, Cu – 5.5 %, Ni – 3.5 %, Mo – 21.5 %, and Cr – 2 %. The latter data allow forecasting the emission of metals and the formulas (1) and (2) presented in this work enable to model the dispersion of metals on roadsides.

3. Conclusions

1. Knowing the data on total road emission and using equation (4) the pollutant concentration on the soil surface near roadways can be forecasted.
2. Knowing the particulate dispersion on a road it is possible to model the pollution of the roadsides by metals.
3. Knowing the emission of fuel combustion products and the percentage of metals in the total amount of freeway pollutants, the dispersion of metal pollution on roadsides can be found.

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