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MODELING OF MOTOR TRANSPORT EXHAUST POLLUTANT DISPERSION

Petras Vaitiekūnas, Reda Banaitytė
Dept of Environmental Protection, Vilnius Gediminas Technical University, Saulėtekio al. 11, LT-10223 Vilnius, Lithuania. E-mail: vaitiek@ap.vtu.lt
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Abstract. Pollution is a major problem in all countries, even developed ones. It is the major environmental negative impact of anthropogenic activities affecting ecology. There are two major ways for assessment of negative impact of motor transport flow intensity and pollution level: monitoring the air or modeling pollutant dispersion. It is very important to estimate different unknown air modeling programs. In this work modeling is to be executed by the US EPA (United States Environmental Protection Agency) the so-called "the best possible existing software for strategic environmental assessment". That is also recommended by the Ministry of Environment of the Republic of Lithuania. In this work pollution modeling was executed for the northern part of Vilnius (the network of streets Geležinis Vilkas – Ozas – Kalvarijos). For motor vehicle pollution mathematical modeling, it is necessary to evaluate meteorological parameters like temperature, humidity, the wind direction and speed. Modeling software can also estimate relief conditions. Pollution emission measurements were used, and pollution dispersion modeling was performed. The main target was to evaluate pollutant dispersion from motor transport in the analysed area of Vilnius. During investigation maximum hourly, daily and annual concentrations of carbon monoxide, nitrogen oxide, sulphur dioxide, volatile organic compounds and particulate matter were observed.

Keywords: motor transport, air pollution, pollutants, dispersion, model "ISC-Aermod View", concentration.

1. Preface

Urban air pollution from road transport is a growing concern in a large number of developing country cities. With rising income, the use of motorized transport is expected to continue to increase in the coming years, potentially worsening the air quality. According to the data published in 1999 and 2005, motor transport pollution increased from 70 % to approximately 85 % [1, 2].

It is very important to identify problematic pollution points in cities, to analyse motor vehicle flows. All these facts play an important role in acceptance of decisions on particular urban areas. Subsistent pollution background determines possible locality's development tendency and opportunities [3, 4].

Motor vehicles spread pollutants into the air in four main ways: from exhaust pipes of vehicles through which combustion residues are emitted (65 % of all transport caused pollution); from a crankcase (20 %) and during hydrocarbons volatilization from carburettor (9 %), avd pump (6 %). The atmosphere is also polluted because of dust caused by tyre wear – annually up to 1,6 kg per vehicle of asbestos dusts, cadmium [3, 5].

Motor vehicles exhaust the biggest amount of pollutants into the atmosphere during initial start-up, braking and slow moton [3, 5].

A motor vehicle is the cause of major environmental problems affecting our environment globally, nationally and locally. Vehicle emissions are also a major contributor to pollution in terms of carbon monoxide (CO), nitrogen dioxide (NOx), volatile organic compounds (VOC) and particulates [6].

A large number of different motor vehicles, crossing this area to reach their destination, use either gasoline or diesel and emit gases full of different toxic substances, including SO_2, CO, lead and particulates and etc [6, 7].

Pollution is a major problem in all countries, even developed ones. It is the major environmental negative impact of anthropogenic activities affecting ecology. Specifically in this study air pollution modeling was performed using the program AERMOD accepted in USA and approved by US EPA (United States Environmental Protection Agency) and recommended by the Ministry of Enviroment of the Republic of Lithuania. This methodology could be adopted under Lithuania's circumstances. Usable software demands a large amount of data, like meteorological parameters, relief, emission factors, ect. Despite this all information can be set manually [4].

2. Pollutant dispersion modeling program

The pollutant dispersion modeling program "ISC-Aermod View" can evaluate meteorological parameters, relief, transport flows, short-term and long-term concentration measurement evaluation [4].

The Industrial Source Complex (ISC) short-term model provides options to model emissions from a wide range of sources that might be present at a typical industrial source complex. The basis of the model is the straight-line, steady-state Gaussian plume equation, which is used with some modifications to model simple point source emissions from stacks, emissions from stacks that experience the effects of aerodynamic downwash due to nearby buildings, isolated vents, multiple vents, storage piles, conveyor belts, and the like. Emission sources are categorized into four basic types of sources, i e point sources, volume sources, area sources and open pit sources. The volume source option and the area source option may also be used to simulate line sources [4, 8].

The ISC short-term model accepts hourly meteorological data records to define the conditions for plume rise, transport, diffusion and deposition. The model estimates the concentration or deposition value for each source and receptor combination for each hour of input meteorology, and calculates user-selected short-term averages. For deposition values, either the dry deposition flux, the wet deposition flux or the total deposition flux may be estimated. The total deposition flux is simply the sum of the dry and wet deposition fluxes at a particular receptor location. The user also has the option of selecting averages for the entire period of input meteorology [8].

The ISC short-term model uses a steady-state Gaussian plume equation to model emissions from point sources, such as stacks and isolated vents. This section describes the Gaussian point source model, including the basic Gaussian equation, the plume rise formulas, and the formulas used for determining dispersion parameters.

The ISC short-term model for stacks uses the steady-state Gaussian plume equation for a continuous elevated source. For each source and each hour, the origin of the source's coordinate system is placed at the ground surface at the base of the stack. The x axis is positive in the downwind direction, the y axis is crosswind (normal) to the x axis and the z axis extends vertically. The fixed receptor locations are converted to each source's coordinate system for each hourly concentration calculation. The hourly concentrations calculated for each source at each receptor are summed to obtain the total concentration produced at each receptor by the combined source emissions [8, 9].

2.1. Equation of Gaussian plume

For a steady-state Gaussian plume, the hourly concentration at downwind distance x (meters) and crosswind distance y (meters) is given by [10, 11]:

$$X = \frac{QKVD}{2\pi u_s \sigma_y \sigma_z} \exp\left[-0,5\left(\frac{y}{\sigma_y}\right)^2\right], \quad (1)$$

where Q – pollutant emission rate (mass per unit time); K – a scaling coefficient to convert calculated; concentrations to desired units (default value of 1×10^6 for Q in g/s and concentration in μg/m^3); V – vertical term; D – decay term; σ_y, σ_z – standard deviation of lateral and vertical concentration distribution (m); u_s – mean wind speed (m/s) at release height.

This equation includes a Vertical Term (V), a Decay Term (D), and dispersion parameters (σ_y and σ_z) as discussed below. It should be noted that the Vertical Term includes the effects of source elevation, receptor elevation, plume rise, limited mixing in the vertical, and the gravitational settling and dry deposition of particulates (with diameters greater than about 0,1 microns) [8].

The ISC model uses either a polar or a Cartesian receptor network as specified by the user. The model allows to use both types of receptors and multiple networks in a single run. All receptor points are converted to Cartesian (X, Y) coordinates prior to performing the dispersion calculations. In the polar coordinate system the radial coordinate of the point (r, 2) is measured from the user-specified origin, and the angular coordinate 2 is measured clockwise from the north. In the Cartesian coordinate system the X axis is positive to the east of the user-specified origin and the Y axis is positive to the north. For either type of receptor network, the user must define the location of each source with respect to the origin of the grid using Cartesian coordinates. In the polar coordinate system, assuming the origin is at $X = X_o$, $Y = Y_o$, the X and Y coordinates of a receptor at the point (r, 2) are given by [11]:

$$X(R) = r \sin \theta – X_0, \quad (2)$$

$$Y(R) = r \sin \theta – Y_0. \quad (3)$$

If the X and Y coordinates of the source are $X(S)$ and $Y(S)$, the downwind distance x to the receptor along the direction of plume travel is given by:

$$x = (X(R) – X(S))\sin(WD) – (Y(S))\cos(WD), \quad (4)$$

where WD is the direction from which the wind is blowing. The downwind distance is used in calculating the distance-dependent plume rise and the dispersion parameters. If any receptor is located within 1 meter of a point source or within 1 meter of the effective radius of a volume source, a warning message is printed and no concentrations are calculated for the source-receptor combination. The crosswind distance y to the receptor from the plume centerline is given by [10]:

$$y = (X(R) – X(S))\cos(WD) – (Y(R) – Y(S))\sin(WD). \quad (5)$$

The crosswind distance is used in Equation (1).

The wind power law is used to adjust the observed wind speed, u_{ref}, from a reference measurement height, z_{ref}, to the stack or release height, h_s. The stack height wind speed, u_s, is used in the Gaussian plume Equation (1), and in the plume rise formulas described in [12]. The power law equation is of the form [12]:

$$u_s = u_{ref}\left(\frac{h_s}{z_{ref}}\right)^p, \quad (6)$$

where p is the wind profile exponent. Values of p may be provided by the user as a function of stability category and the wind speed class. The values of p are presented in Table 1.

Table 1. Values of p depending on the category of stability

Category of stability	Rural area	Urban area
A	0,07	0,15
B	0,07	0,15
C	0,10	0,20
D	0,15	0,25
E	0,35	0,30
F	0,55	0,30

A particular description of usable software is given in the final work.

2.2. Modeling of pollutant dispersion from motor transport

The analysed part of Vilnius holds both commercial and residential communities and is considered as a vital area in the city (Fig 1). Streams of cars were calculated at assigned points, motor vehicles were classified as light cars, trucks, minibuses, buses, motorcycles and trailers. They cross this area to reach their destination; these motor vehicles use gasoline and gas or diesel [6].

For developing a straight pollutant dispersion model, it is necessary to know transport flow intensity at present and in the future. Also, we have to know motor transport flow composition (according to used fuel types and weight), different fuel consumption per vehicle and pollutant emission factor. That is the quantity of pollutants spread into the ambient air from a motor vehicle per unit of fuel (kg/t). If we have all the data, we can settle the quantity of pollutants spread into the ambient air from a motor vehicle per date For correct computation of uneven daily pollutant dispersion, we have to evaluate motor transport flow intensity (Table 2) [9, 12].

Fig 1. Studied area in northern part of Vilnius (network of Geležinis Vilkas – Ozas – Kalvarijos str)

2.2.1. Composition of motor transport flows

Motor vehicle flows on different streets are varied. However, according to percentage, the difference is insignificant. That is why we can use an approximate (average) composition of motor transport flows during model development. In accordance with accomplished study, the composition of motor transport flows is: light cars – 87,5 %; minibuses – 6,61 %; tracks – 3,04 %; buses – 2,03 %; motocycles – 0,32 % [6, 11].

Table 2. Motor transport flows in studied area during rush-hours

No	Name of street or street section	Length of street (m)	Area of street (m^2)	Amount of vehicles (unit/h)
1	Geležinis Vilkas st, section between Žalgiris and Ozas st	985	32780	2505
2	Geležinis Vilkas st, section between Ozas and J. Kazlauskas st	1190	34800	2270
3	Geležinis Vilkas st, section between J. Kazlauskas and Didlaukis st	660	18175	2400
4	Ozas st, section between Gelvonai and Geležinis Vilkas st	905	28100	3340
5	Ozas st, section between Geležinis Vilkas and Kalvarijos st	1115	33680	3010
6	Kareiviai st, section between Kalvarijos and Verkiai st	570	14160	2590
7	Kalvarijos st, section between Lukšis and Ozas st	170	3950	2425
8	Kalvarijos st, section between Ozas and Žvalgai st	815	19550	1710
9	Kalvarijos st, section between Žvalgai and J. Kazlauskas st	150	3845	2670
10	Kalvarijos st, section between J. Kazlauskas and Didlaukis st	260	10290	2350
11	Žvalgai st	675	13100	1170
12	J. Kazlauskas st	835	14125	407
13	Kernavė st	995	9590	250

Considering the given data by road direction, the stock of motor vehicles in Lithuania according to usable type of fuel and dominant trends during model development embraced [6]:

- A part of light cars with a gasoline engine – 50 %. Average fuel consumption – 10 l/100 km;
- A part of light cars with a dieseline engine – 30 %. Average fuel consumption – 8 l/100 km;
- A part of light cars with a liquid gas engine – 20 %. Average fuel consumption – 12 l/100 km;
- All minibuses, buses and trucks with a dieseline engine – less than 100 % but still predominanting. Fuel consumption, respectively, is: minibuses –
- 11 l/100 km; buses – 20 l/100 km; trucks – 35 l/100 km;
- All motorcycles with gasoline engines. Average fuel consumption – 8 l/100 km.

2.2.2. Pollutant emission factor

Dispersion factor is designed to evaluate an environment in which pollution urbanization level originates. Two ways are possible: "rural" and "urban". If we select "urban" factor additionally, we have to point the population of the studied area [12].

Pollution source emission factor allows to evaluate uneven pollution emissions. This factor estimates variations of emissions. Emission factor can vary from 0 to 1. If pollution emission factor is equal to 1, a pollution source spreads into the air 100 % of indicated emission. If it is 0,5, a source spreads into the air 50 % of indicated emission. Sometimes it is advisable to point emission factor for each hour per day. For working hours, emission factor would be 1, and for the rest – 0. In this case the situation could be closer to reality [12].

With reference to the decree No 125 of 13 Jul 1998 accepted by the Ministry of Environment of the Republic of Lithuania, amounts of pollutants spread by internal combustion engines are shown in Fig 2.

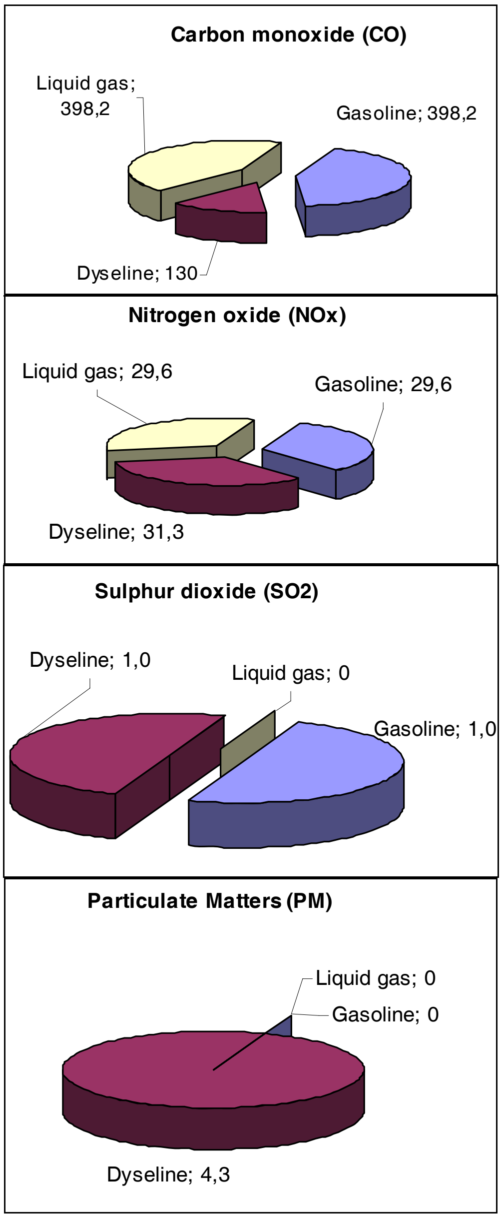

Fig 2. Emission factor according to usable fuel (kg/t)

For correct computation of uneven daily pollutant dispersion we have to evaluate motor transport flow intensity. Table 3 shows uneven flows of motor transport per day.

Construction evaluations are inconvenience because of plenty of buidings, business centres, housing. Therefore, we have to collet all the measurements of constructions, like length, width, height. This can be applied in the case of modelling for a small area [10].

Table 3. Intensity of motor transport flows during the day

Time	Intensity of motor-transport flows, %
6:00–7:00 a m	50
7:00–8:00 a m	95
7:30–8:30 a m	100
8:00–9:00 a m	95
9:00–10:00 a m	75
10:00–11:00 a m	70
11:00–12:00 a m	70
12:00–1:00 p m	70
1:00–2:00 p m	80
2:00–3:00 p m	75
3:00–4:00 p m	80
4:00–5:00 p m	90
5:00–6:00 p m	100
6:00–7:00 p m	90
7:00–8:00 p m	70
8:00–9:00 p m	60
9:00–10:00 p m	50
10:00–6:00 a m	12

2.2.3. Meteorological parameters

Usable software "ISC-Aermod View" needs very detailed meteorological parameters like temperature, humidity, precipitation, the wind direction and speed, nebulosity, etc. These meteorological parameters must be pointed for each hour per year. This model allows to estimate an average concentration for a selected day, week, month or season. Also, it can be used for evaluating annual concentration [4, 12].

2.2.4. Receptors

Concentrations near the ground surface in studied territory are calculated at preestablished points. These points are called receptors (Fig 3). Usually receptors are settled as a network of measurements at a given distance from one another. The closer the preestablished points the more reliable the results. An optimal distance between receptors has to be chosen to get positive results, and modeling duration should not be long [10].

With reference to letter No 10-5-1373 of 4 Mar 2003 from the Ministry of Environment of the Republic of Lithuania, the height from the ground surface for calculating pollution emissions is equal to 1,5 meter. It is reputed human air aspiration height.

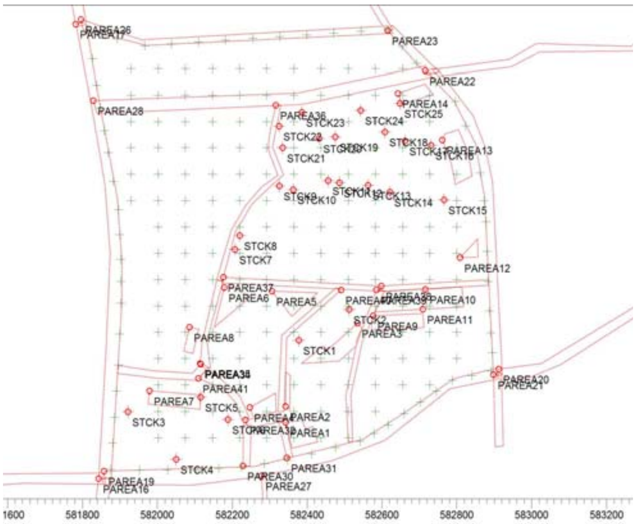

Fig 3. Pollution measuring points in studied area

2.2.5. Other parameters

"ISC-Aermod View" model can allow to evaluate an impact of neighbouring relief and constructions on pollutant dispersion. These parameters are not evaluated in the work because of the need of 3D visualization. The network of streets under consideration is in a conditionally flat area [10].

For percentiles, it is necessary to dispose of statistically unreliable modeling results. Percentiles can be diverse and indicate a part of statistically reliable measurements. The remainder is eliminated. In that case we can avoid inadequacy of results [10].

3. Modeling results and discussion

With an annually growing level of motorization in Vilnius, it should be noted that the air pollution level increases every year. According to the above data, the present situation can be defined with the help of pollutant dispersion modeling program "ISC-Aermod View".

During investigation maximum hourly, during working hours, daily and annual concentrations of carbon monoxide, nitrogen oxide, sulphur dioxide, volatile organic compounds and particulate matter were observed.

In consideration of numerous amounts of cars in Vilnius air pollution by motor vehicles increase every year. It causes growing pollutant dispersion. According to the Lithuanian requirements, the biggest permissible concentration of carbon monoxide (CO) is: onetime – 5,0 mg/m^3 and oneday – 3 mg/m^3 [10].

As we can see in the figures done with the help of the modeling program "ISC-Aermod View" (Fig 4) a maximum hourly amount of CO in the studied locality is 1,607 mg/m^3. The maximum during working hours is 1,375 mg/m^3 and a maximum dayly amount of CO is 1,233 mg/m^3. A maximum annual amount is 0,4649 mg/m^3. Comparing all these data with the biggest permissible concentrations of CO it is obvious that there is no excess.

Carbon monoxide (CO)

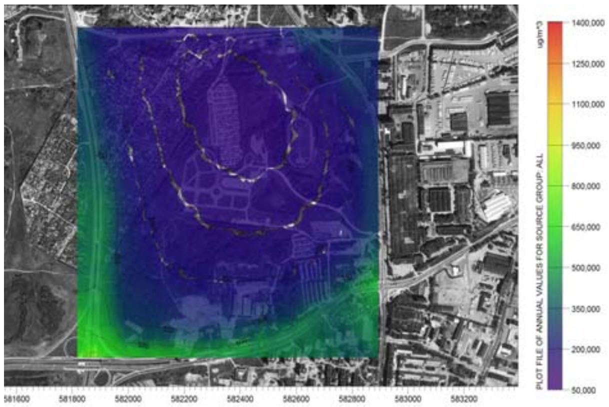

Fig 4. Graphic view of pollutant dispersion modeling (CO)

Nitrogen oxide (NO_x)

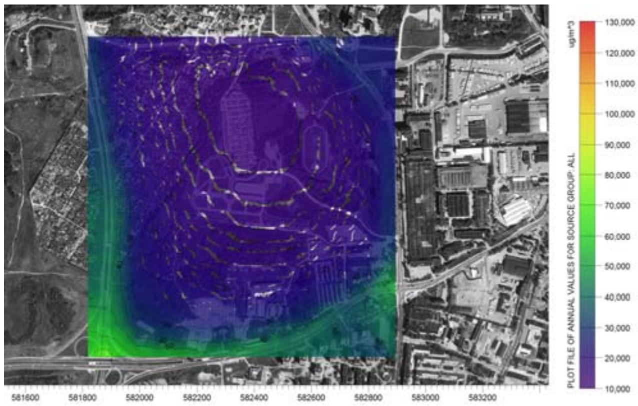

Fig 5. Graphic view of pollutant dispersion modeling (NOx)

According to the Lithuanian requirements, the biggest permissible concentration of nitrogen oxide (NOx) is: onetime – 0,085 mg/m^3 and oneday – 0,04 mg/m^3 [10].

Volatile organic compounds (VOC)

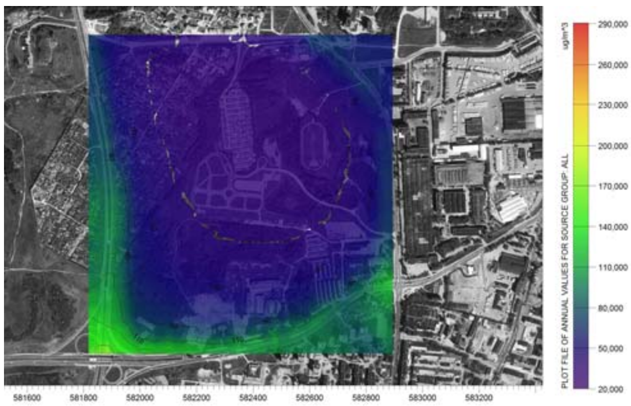

Fig 6. Graphic view of pollutant dispersion modeling (VOC)

As we can see in the figures done with the help of the modeling program "ISC-Aermod View" (Fig 5) a maximum hourly amount of nitrogen oxide (NOx) in the studied locality is 0,1731 mg/m^3. The maximum during working hours is 0,1482 mg/m^3 and a maximum one-day amount of NOx is 0,12105 mg/m^3. A maximum annual amount is 0,04983 mg/m^3. Comparing all these data with the biggest permissible concentrations of NOx, it is obvious that there is an excess. Some means is needed to reduce pollution with NOx.

According to the Lithuanian requirements the biggest permissible concentration of Volatile Organic Compounds (VOC) is: onetime – 100 mg/m^3 [10].

As we can see in the figures done with the help of the modeling program "ISC-Aermod View" (Fig 6) a maximum hourly amount of VOC in the studied locality is 0,362 mg/m^3. The maximum during working hours is 0,3099 mg/m^3 and a maximum one day amount of VOC is 0,2532 mg/m^3. A maximum annual amount is 0,1046 mg/m^3. Comparing all these data with the biggest permissible concentrations of VOC, it is obvious that there is no excess.

Particulate matter (PM)

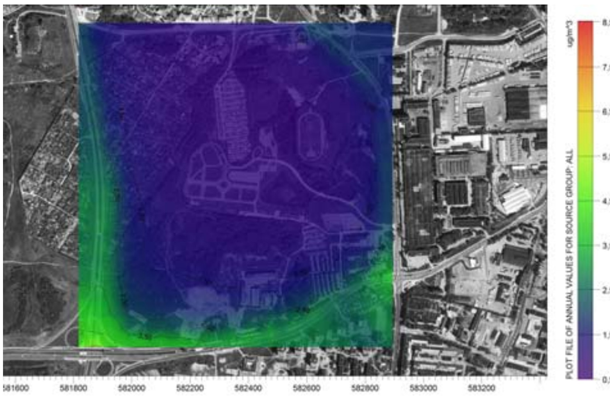

Fig 7. Graphic view of pollutant dispersion modeling (PM)

According to the Lithuanian requirements, the biggest permissible concentration of particulate matter (PM) is: onetime – 0,5 mg/m^3 and oneday – 0,15 mg/m^3 [10].

Sulphur dioxide (SO_2)

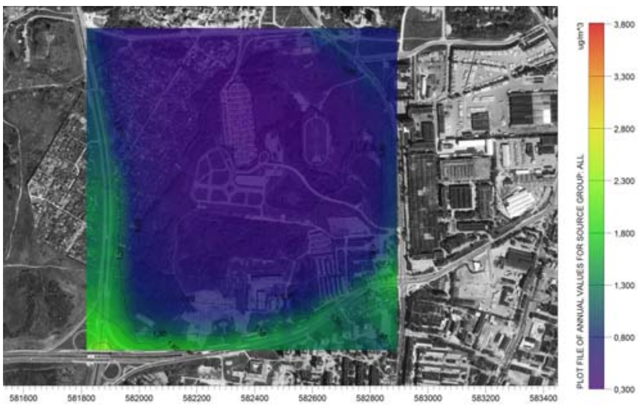

Fig 8. Graphic view of pollutant dispersion modeling (SO_2)

As we can see in the figures done with the help of the modeling program "ISC-Aermod View" (Fig 7) a maximum hourly amount of PM in the studied locality is 0,0107 mg/m^3. The maximum during working hours is 0,0091 mg/m^3, and a maximum oneday amount of PM is 0,0075 mg/m^3. A maximum annual amount – 0,0031 mg/m^3. Comparing all these data with the biggest permissible concentrations of PM, it is obvious that there is no excess.

According to the Lithuanian requirements, the biggest permissible concentration of SO_2 is: onetime – 0,5 mg/m^3 and oneday – 0,05 mg/m^3 [10].

As we can see in the figures done with the help of the modeling program "ISC-Aermod View" (Fig 8) a maximum hourly amount of SO_2 in the studied locality is 0,0048 mg/m^3. The maximum during working hours is 0,0041 mg/m^3, and a maximum oneday amount of SO_2 is 0,034 mg/m^3. A maximum annual amount is 0,0014 mg/m^3. Comparing all these data with the biggest permissible concentrations of SO_2, it is obvious that there is no excess.

4. Conclusions

1. There are two major ways for assessing negative impact of motor transport and pollution level – monitoring the air or modeling pollution dispersion.
2. "ISC-Aermod View" is a complete and powerful air pollutant dispersion modeling system which originated from a Gaussian plume model and is widely used to assess pollutant concentrations from a wide variety of sources.
3. Gasoline motor vehicles are the main source of lead aerosol and carbon monoxide, while diesel vehicles are a major source of heavy particles.
4. According to graphic pollutant dispersion modeling results, maximum amounts of pollutants from motor vehicles were estimated:
   - Carbon monoxide (CO) – 1,607 mg/m^3;
   - Nitrogen oxide (NO_x) – 0,1731 mg/m^3;
   - Volatile organic compounds (VOC) – 0,362 mg/m^3;
   - Sulphur dioxide (SO_2) – 0,0048 mg/m^3;
   - Particulate matter (PM) – 0,0107 mg/m^3.
5. According to increase of motor transport flows every year, new and applicable means for pollutant emission reduction are needed.

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AUTOMOBILIŲ IŠMETAMŲ TERŠALŲ SKLAIDOS MODELIAVIMAS

P. Vaitiekūnas, R. Banaitytė

S a n t r a u k a

Didžiuosiuose Lietuvos miestuose žymus transporto priemonių skaičiaus didėjimas. Transporto priemonių spūstys neišvengiamai verčia ieškoti būdų aplinkos oro užterštumui mažinti. Transporto priemonių išmetamų dujų neigiamą poveikį ir užterštumo lygį galima įvertinti dviem būdais – oro taršos stebėsenos arba teršalų sklaidos modeliavimo būdu. Automobilių išmetamų teršalų modeliavimas naudojant JAV priimtą ir *US EPA (United States Environmental Protection Agency)* patvirtintą bei LR aplinkos ministerijos rekomenduojamą teršalų sklaidos aplinkos ore matematinį modelį *ISC3* atliktas Vilniaus miesto centrinėje dalyje (Ozo – Kalvarijų – Šiaurinės – Geležinio Vilko gatvių tinklas). Automobilių išmetamų teršalų skaitiniam modeliavimui atlikti būtina įvertinti meteorologines – atmosferos, reljefo, vėjo stiprumo ir krypties sąlygas. Remiantis turimais taršos emisijų duomenimis, atliktas jų sklaidos modeliavimas Gauso pasiskirstymo su empirinėmis pataisomis principu, nustatytos anglies monoksido, sieros ir azoto dioksido, lakiųjų organinių dalelių bei kietųjų dalelių maksimalios vienkartinės, paros, mėnesio ir metų vidutinės koncentracijos. Vienas iš darbo tikslų – įvertinti šios modeliavimo programos pritaikomumą Lietuvoje.

Reikšminiai žodžiai: automobilių transportas, oro tarša, teršalai, sklaida, *ISC-Aermod View* modelis, koncentracija.

МОДЕЛИРОВАНИЕ РАСПРОСТРАНЕНИЯ ВЫБРАСЫВАЕМЫХ ИЗ АВТОТРАНСПОРТА ЗАГРЯЗНИТЕЛЕЙ

П. Вайтекунас, Р. Банайтите

Р е з ю м е

В больших городах Литвы значительно увеличилось количество автотранспорта. Скопление автотранспорта вынуждает искать способы уменьшения загрязненности воздуха. Отрицательное воздействие выбрасываемых из автотранспорта газов и аэрозолей и степень загрязненности можно оценить двумя способами – мониторингом загрязнения воздуха или моделированием распространения загрязнителей в воздухе. Моделирование выбросов из автотранспорта с использованием принятой в США и утвержденной US EPA (United States Environmental Protection Agency), а также рекомендованной Министерством окружающей среды Литовской Республики математической модели ISC3 выполнено в центральной части города Вильнюса (в сети улиц Озо–Шяуринес–Гележинё Вилко).

При моделировании необходимо учитывать метеорологические условия (атмосферные, силу и направление ветра), а также рельеф местности. С использованием имеющихся данных об эмиссиях загрязнителей выполнено моделирование их переноса в приземном слое по Гаусовому принципу распространения с рядом эмпирических поправок; установлены максимальные, одноразовые, суточные, месячные и среднегодовые концентрации окиси углерода, диоксида серы и азота, летучих органических соединений и твердых частиц. Одной из целей работы было оценить пригодность этой программы моделирования в условиях Литвы.

Ключевые слова: автотранспорт, загрязнение воздуха, загрязнители, модель „ISC-Aermod View", концентрация.

Petras VAITIEKŪNAS. Dr Habil, Prof, Dept of Enviromental Protection, Vilnius Gediminas Technical University (VGTU).

Doctor Habil of Science, (energy and thermal engineering) 1999. Doctor of Science (1972), Laboratory of Fluid Dynamics in Heat Exchangers, Lithuanian Energy Institute, Kaunas. Employment: Professor (2002), Associate Professor (1997). Publications: author of 2 monographs, over 190 scientific publications. Work on probation: Prof. D. Brian Spalding, Con-

centration, Heat & Momentum Limited, Bakery House, 40 High Street, Wimbledon Village, London SW19 5AU, UK (PHOENICS 1.4 EP CFD, January – February 1996, and PHOENICS 3.1 VR CFD, April–May 1998). Membership: corresponding member of International Academy of Ecological and Life Protection Sciences. Research interests: hidrodynamics, convective heat transfer and thermophysics, computational fluid dynamics, modeling transfer processes in the environment.

Reda BANAITYTĖ. Master student (environmental protection engineering), Dept of Environmental Protection, Vilnius Gediminas Technical University (VGTU).

Research interests: environmental protection, pollution prevention, numerical modeling of pollutant dispersion.