1. Mathematical modelling of air pollution from stationary sources

Mathematical modelling of air pollution effectively recruits our information about air pollution level and it is efficient tool in the smog monitoring and control system and for elaboration and control of projects for air sanitation in the areas with individual extra protection.

In Czechoslovakia so-called SKT methods [1] that facilitate calculation the field of harmful substance concentration for particular source was issued in the 1968. It means that with help of SKT methods to it was possible to determine such parameters of the source (mostly height of chimney) that the harmful concentration in the place of maximum was under allowed hygienic standard. As a rule the sources of harmful substances are built in towns where already exist the whole set other sources of harmful substances that are necessary to take into account. For the solution of such question is unavoidable to have in disposal mathematical model for multiple sources of harmful substances. First such model not only in Slovakia but in Czechoslovakia that has facilitated calculation of harmful substances concentrations was elaborated in the year 1973 [8]. Model was successfully used for calculation of $\text{SO}_2$ field concentration in Bratislava. In Czech Republic was similar model elaborated only after some years later. Conception of both models was similar. However both models have been different in the nature - with used classification of stability category. Slovak version so-called GAMOD (stationary Gaussian model) model was established on seven class Uhlig classification, as the Czech version was established on five class Bubnik-Koldovský classification. From the difference of various numbers stability categories comes out incompatibility of scattering parameters. Due to this reason the result of the models unification effort could remain only one solution - choose one model and such model propose as state-wide methodologies. For such purposes was selected Czech version of the air pollution model, that was in the year 1979 authorised as federal methodologies, known with the name MLVH methodologies [2].

MLVH methodologies was used in Slovakia as official methodologies till the year 1995. For the calculation of pollutant concentration from the stationary sources in Slovak Republic is used from the year 1995 all-state methodologies that is elaborated on the bases of American model methodologies from Industrial Source Complex Dispersion Models (ISC2) [9], issued from Environmental Protection Agency in the year 1992. The main aspect for elaboration of new methodologies was the incompatibility of MLVH methodologies with standard models and with parameters of sources used in the world. The additional aspect of the demand was necessity to provide efficient instrument for the environmental offices that could be used for recognition of impact from particular sources of harmful substances on the air quality.

On the basis of methodologies made in the Ministry for Environment of Slovak Republic that is intended for mathematical modelling of air pollution (short term version) was elaborated users oriented software product with the name MODIM: Gaussian scattering model for the ground surface field determination the concentrations of gaseous pollutant substances in the air and the solid particles to 20 micrometers - area and point sources. Model calculates supplies from the particular sources to the distance 50 km. Maximum dimension of the calculation network is 51 x 51 grid points and 100 selected points. It is possible to calculate with 250 sources. Influence of orography is solved with using more wind roses that are representative for the concrete region where are particular groups of sources.

Methodics was used at re-edition of the law No. 35 from the year 1967 for the calculation of minimal hight of chimney for providing sufficient dispersion of harmful substances in the air.

MODIM serves for calculation of short and long-term concentrations of harmful substances in residential and non-residential regions as an effective tool for determination of minimal hight of chimney in special cases. It makes possible to calculate short and long-term critical concentrations of pollutants and overfulfilment the set threshold values. To be possible to use model for the calculation of harmful substance concentration field over the larger area where is deformed the field of the wind due the influence of orography, was elaborated version with possibility of using more wind roses. The whole area was divided onto regions in which one wind rose was dominated. To the sectors were assorted harmful substances sources. Such model was successfully used for the calculation of the baseline air pollution matters concentration field in the whole Slovakia area. Modeling result of the NO$_x$ (1998 - average) for the area of the city Kosice in the basin of river Hornad is at the attached Fig. 1. In this event was applied six wind roses for each part of the city.
Fig. 1. Distribution of NO\textsubscript{x} concentration in Košice.

Within the project PHARE EU/93/AIR/22 the comparative modelling calculations of ground level pollutant concentrations from selected stationary point sources between MODIM and ISC2 were made. Obtained results provide total view about the quality of ground air level in the most exposed areas in Slovakia.

Within the performed project it was not possible to use all facilities provided by ISC2 due a non-complex input data. Problem of non-complex input data is consisting mainly in the absence or incompleteness of data that are possible to summarise into the following domains:

- absence of mixing layer data
- no fully representative stability class data for evaluated area
- wind roses are determined on the basis of insufficient long sequel of observations and from the data observed in climatic terms, respectively assigned from non representative standing of meteorological station in the term of localisation air pollution sources.
- incomplete technical data of stacks
- underestimated supplied emission data, respectively incomplete registration of escaping pollution substance into the air at the source.

Modelling results from this project, in spite of limitation due incompleteness of input data, provide in general very good results in comparison with sampled data in respective area. This is the evidence of very responsive approach to the solution of the problem and about the effort to know particularity of individual locations.

Modelling results calculated in the framework of the project are very valuable material for recruitment the complex vision of the ground level air pollution quality in Slovakia and the fact that the official model used in Slovakia is fully compatible with used model is permitting a broad field for using submitted results in the future for evaluation of air pollution in Slovakia.

Development of methods for mathematical modelling will run in Slovakia even in the future. In the nearest 2-3 years the process of creation methods for the standards of calculation air pollution in Slovakia will continue. In the years 1999-2002 should be elaborated users version of methods for calculation non-stationary air pollution in conditions of complex terrain.
Together with elaboration of methods for air pollution calculation it is necessary to devote attention to the study of new non traditional, but reliable methods, of mathematical modelling air pollution.

2. Mathematical modelling of air pollution from mobile sources

The first version of the method was elaborated in 1984 [4]. The method was issued in 1985 [5] by the Ministry for Forestry and Water Management of Slovak Republic as the official computational method. In 1993 the method was modified and adopted for the personal computers and issued by the Ministry for Environment of Slovak Republic as the whole state method for air pollution calculation from the road traffic [6]. The method is nowadays used mainly for the regulatory purposes. It is used to compute the contribution of new built or reconstructed communications, highways to the air pollution, to asses the efficiency of the regulatory decisions handling the air pollution problem from the car traffic in the city. The method is indirectly used by the assessment of the contribution of new built parking-places, collective garages and tunnels to the air pollution. The reliability of the method was verified by the calculating of air pollution in two biggest cities of Slovakia-Bratislava and Košice [7].

In the first approximation the street can be considered as a line source of pollutants. The dispersion of the pollutants from the line source is described by the stationary two-dimensional partial differential equation of turbulent diffusion

\[ U \frac{\partial C}{\partial x} = K_x \frac{\partial^2 C}{\partial x^2} + K_z \frac{\partial C}{\partial z} \]  

The first boundary condition simulates the reflection and absorption respectively of the pollutants on the walls of the buildings on both sides of the road. If the built-up area round the road is interrupted, instead of absorption we consider the passage of the pollutant between the buildings. The coefficient \( \nu \) can be expressed by the relation

\[ \nu = \frac{PK_x}{100D}, \]  

where \( D \) is the width of the pavements on the both sides of the road. Coefficient \( P \) is the percentage of not built-up space round the road on both sides of the road. If the road is surrounded by the continual built-up area \( P=0 \), if the road is free of the buildings \( P=100 \).

The second boundary condition expresses the production of pollutants over the road and the third boundary condition expresses the perfect reflection of pollutant on the ground surface and on the top of mixing layer of the atmosphere.

The fourth and fifth boundary conditions allow to determine the pollutant concentration at the boundary of the calculation domain in the free atmosphere between the roofs of buildings and the height of the mixing layer.
Except the calculation of the pollutant concentration distribution in a street canyon, the model calculates the pollutant concentration distribution over the city in the free atmosphere. The method is again based on the numerical solution of the boundary problem

\[ \frac{U}{\partial x} \frac{\partial C}{\partial x} - \frac{\partial}{\partial z} K(z) \frac{\partial C}{\partial z} = 0, \]  

with the boundary conditions

\[ K(z) \frac{\partial C}{\partial z} \bigg|_{z=0} = 0, \]

\[ C \bigg|_{z=H} = C_k(z). \]

\( C_k(z) \) is the vertical profile of pollutant concentration over the \( k \)-th street, laying against the wind direction from the given street.

The first boundary condition expresses the perfect reflection of the pollutant from the surface on the roofs level, where the origin of the coordinate system has been shifted and at the height of the mixing layer of the atmosphere.

The second boundary condition expresses the influence of the streets laying against the wind on the background pollutant concentration.

Both boundary problems referred to have been solved by the method of finite differences. This is an implicit method and thus unconditionally stable. It consists of the fact that instead of functions of continuous argument, the functions of discrete argument are considered, whose values are given in the grid points.

The calculation domain is constructed so that the whole canyon is divided into three columns of the boxes in the horizontal direction and into ten boxes in the vertical direction, e.g. the pollutant concentration is calculated in thirty grid points. The calculated pollutant concentration in a grid point presents the mean concentration in the box, in the centre of which the grid point is situated. The mean pollutant concentration in a given box will therefore depend on the dimensions of the box. The algorithm of the solution both boundary problems may be found in treatise (Hesek, 1984).

### 2.1. The emission of the road

The specific emission of the communication \( Q \) is calculated by means of the emission factors \((EP)\) and numbers of the passenger cars \((NP)\) and duty vehicles \((ED, ND)\), which pass the road in the time \( T \) by the relation

\[ Q = \frac{EP \cdot NP + ED \cdot ND}{3600 \cdot T \cdot S}. \]

Emission factors \( EP, ED \) are given in \( \text{mg m}^{-1} \text{car}^{-1} \), numbers of passenger cars and duty vehicles \( NP \) and \( ND \) are given in \( \text{car h}^{-1} \), time \( T \) is given in \( h \) and width of the road \( S \) in \( m \).

The emission factors were determined on the basis of the COPERT90 Program, elaborated by the Corinair working group [3]. The method for calculating of the emissions from the motor vehicles in the European Union Countries is very detailed and it enables determination of the emission factors depending on the velocity of the vehicle practically for each type of the moving vehicles.

The graphic and analytic dependences of the CO, NOx, VOC, and particular matters (PM) for all categories of passenger cars are given in COPERT90 Program. On the basis of the present vehicle park composition for Slovak Republic the weighted arithmetical mean emission factors for passenger cars and duty vehicles according to COPERT90 Program were calculated. For the urban regime of drive the speed of 20 km h\(^{-1}\), for the rural regime the speed of 60 km h\(^{-1}\) and for the highway 100 km h\(^{-1}\) speed was assumed. The results are shown in Table 1.

<table>
<thead>
<tr>
<th>Pollutant</th>
<th>Urban regime</th>
<th>Rural regime</th>
<th>Highway regime</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>passenger cars</td>
<td>duty vehicles</td>
<td>passenger cars</td>
</tr>
<tr>
<td>CO</td>
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<td>15.29</td>
<td>19.00</td>
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<td>NOx</td>
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<tr>
<td>VOC</td>
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<td>2.92</td>
</tr>
<tr>
<td>PM</td>
<td>0.14</td>
<td>0.80</td>
<td>0.30</td>
</tr>
</tbody>
</table>

Tab. 1. Emission factors, calculated on the basis of COPERT90 Program for urban, rural and highway regime of drive.
2.2. The output data

In the modules KALIB and STREETS the distribution of the pollutant concentration in the street canyons is calculated. The pollutant concentration at 1.5 m height and at the top of the buildings on both sides of the street is printed out. The module KALIB does it only on one chosen street (where the calibration measurement is done) and for the actual meteorological parameters given interactively through the screen of the computer. In the module STREETS it is done for the mean meteorological parameters for 8 basic wind directions. In both modules the contributions of the individual streets and the resulting pollutant concentration from all streets being situated against the wind direction are calculated.

The pollutant concentration at the height of 1.5 m in modules GRID and GRIDMAX is calculated. If the calculation domain is built-up then the height of calculation is 1.5 m over the roofs of buildings. In the module GRIDMAX the maximum pollutant concentration in all grid points is printed out. Except the pollutant concentration the emission of the pollutants on all streets is printed out.

REFERENCES