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SIMULATION METHODS FOR TRAFFIC AND POLLUTION ASSESSMENT

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Abstract: *One of emission sources in the urban area have been identified as coming from the road traffic. Therefore, several simulation methods for traffic and pollution assessment are presented. There were analyzed the three main methods used for assessing the atmospheric air quality and the classification of air pollution models depending on multiple criteria. The mathematical models are used to describe the correlations between the meteorological conditions and the level of atmospheric concentrations of the pollutant emissions, analysis and interpretation of the experimental data. The primary objective of some specialised operational models is meant to supply a fast but still realistic assessment of the pollutant dispersion for the emissions due to the road traffic. The microscale numerical modelling offers the opportunity for a detailed simulation of the impact of various scenarios of urban planning, in order to establish and optimise the related strategic decisions.*
Keywords: *air quality, traffic, simulation, pollution, model, urban*

INTRODUCTORY CONSIDERATIONS REGARDING THE AMBIENT AIR QUALITY ASSESSMENT METHODS

There are three main methods (instruments) for assessing the atmospheric air quality: the environmental monitoring (analysis), the physical-mathematical modelling (simulation) and the measurement/inventory of the pollutant emissions.

The final purpose of the monitoring activities is not only the simple collecting of the testing data. It also means furnishing the necessary information required by the researchers, statesmen and planners in order to take certified decisions regarding the management and the improvement of the quality of atmosphere. The monitoring evidently stands for a central role within this process, providing the scientific base necessary for a long-term development, as well as for the definition of the priority objectives, the analysis of the existing situation conformity as related to the planned tasks, as well as the assessment of the efficiency of the used measures. Still, the limits specific for the monitoring activities taken separately must be recognised as such. Thus, no monitoring programme, no matter how well designed and financed, cannot hope to be able to deeply quantify the complex characteristics in space and time of the air pollution. In many cases, the isolated measurements acting as case studies might not be enough or might not be clear in order to be able to fully define the level of the epidemiological exposal of the resident population of a city, region or country. This is why very often it is needed to use the monitoring together with other objective assessment techniques, including the numerical modeling, emission measurement and inventory, use of some interpolate and mapping procedures of the environmental information. In the best case, the monitoring supplies with an incomplete but useful image related to the current quality of the environment.

On the other side, assessing the status of environmental factors only based on the modeling is not recommended either. Even though the numerical models can offer a strong instrument for data interpolation, predictive calculations and optimization of environmental control strategies, they can become useless when looking at their credibility until they are not adequately checked and validated by comparison with extended sets of experimental data as a result of monitoring "the real world". At the same time, it is also important *that the used methods to be according to the local conditions, emission sources and topography, as well as to be selected taking into account the compatibility with the available sets of meteorological and emission data. This last aspect most of the times represents a limiting factor because the multiple refined types essentially depend upon the availability of some high-quality input data which are hard to get and operatively assessed.*

A full inventory of emissions from an urban area, region or country must include detailed and documented information with respect to all the categories of sources (point, area and mobile). Moreover, in certain cases, there is also necessary to take into consideration and to assess the pollutants transported from other regions towards the field to be studied (e.g., the cross-border pollution). The emission inventories most of the times appeal at representative emission factors studied by means of measurements for various categories and types of sources coming from different areas of activity. At the same time, they use surrogate statistics such as the density of population, the fuel consumption, the distance travelled by vehicles or the levels of industrial production. Still, in this field, there are also informational limits caused by the availability of emission measurements, often restricted to the large industrial point sources or to several representative categories of vehicles tested under standard driving conditions (functional trial cycles).

Thus, the three instruments used for environmental assessment synthetically described above prove to depend one on another as purpose and as functional applicability. Consequently, the monitoring, the modeling and the inventory of emissions must be seen as complementary elements within any integrated approach in order to assess the exposal to the environmental insalubrity factors or to the determination of conformity with the criteria related to the air quality.

CLASSIFICATION OF AIR POLLUTION MODELS

Through the phenomenon of atmospheric dispersion of the pollutant emissions one can understand the ensemble of their diffusion and transportation phenomena. Because the phenomena of air pollution are basically influences by the atmospheric processes, the most used type of classification is according to the space scales that belong to them. This way, the distinction between the microscale (under 1 km), mesoscale (between 1 km and 1000 km) and macroscale (over 1000 km) is generally accepted. If in the case of modelling according to the microscale (often called as local scale) the transportation phenomena can usually be considered as insignificant as compared to the ones with atmospheric diffusion, in the case of mesoscale and especially for the macroscale, the situation is reversed, the dispersion of the pollutant emissions being dominated by the atmospheric transportation phenomena under the impact of wind fields distribution [1].

The mathematical modeling of the phenomena related to the dispersion of pollutant emissions consists in the assessment through numerical simulation of the pollutant concentration at the ground level and above, according to the characteristics of the sources of emission, of the meteorological and orographic (topographic) conditions, of the atmospheric processes of physical and chemical transformation, as well as of the processes developed at the interface between the atmosphere and lithosphere (the ground). In fact, the numerical modeling of dispersion of pollutant emissions in the atmosphere requires three fundamental categories of data entries [2]:

- *An emission inventory, containing all the necessary information related to the pollutant sources; the characteristic data can be introduced in the dispersion model, in order to simulate the pollutant behavior in the atmosphere;*
- *Data related to the dispersion model construction, allowing the adapting of its application to cases and conditions belonging to certain geographical (topographical) areas;*
- *Meteorological data, having an essential character because they mainly establish the behavior of emitted atmospheric pollutants.*

For a long time, the "classical" problems of atmospheric pollution were represented by the local ones, that is, the ones related to the environmental impact coming from some isolated sources of *emission. Still, during the last decades, the policy of protecting the environment faced more and more regional problems, often with a cross-border impact, such as the acidification, the eutrophication, the forming of photo-oxidiser compounds (especially the tropospheric ozone), the urban pollution or the one created by the atmospheric emissions of the highly-toxic substances and with problems that affect the entire world, i.e. the world climatic changes caused by the gas emissions that produce the greenhouse effect or the impact on the stratospheric ozone layer.*

The atmospheric pollution models can be classified taking into account multiple criteria, such as:

- *according to the space scale: local, local to regional, regional to continental and global (planetary);*
- *according to the time scale: episodic types and long-term statistics types;*
- *according to the way of treatment for the transportation equations: Eulerian types, Lagrangean types and types with "particle wreath" ("puff");*
- *according to the way of treatment of the different atmospheric processes: chemical reactions, dry and wet deposition;*
- *according to the complexity of approach: Gaussian types, semi-empirical types, grid types.*

The studies performed at the urban level probably represent the most important examples of modeling the dispersion phenomena that take place at the local to regional level, practically corresponding to the urban (sub)mesoscale. The mesoscale atmospheric models require a large number of meteorological input information. With this purpose, during the past years, currently there where two different approaches: the diagnostic calculation of the wind field in conjunction with the empirical parameterisation of the intensity of atmospheric turbulence and the prognostic calculation of the wind field as well as of the measures that define the turbulence. The first approach implies the availability of some very detailed sets of meteorological measurements that should allow an accurate reconstruction of the wind field. But more often, this endeavour still represents only an illusion. This is why, currently, the last way of approach, i.e. the numeric simulation of the wind and atmospheric turbulence characteristics from the area of interest is generally preferred [3].

Taking into account the above-mentioned aspects, a mesoscale air quality model represents currently a modelling system consisting in linking a diagnostic or a wind prognostic model to a diffusion model. In case of inert pollutants that do not change due to the atmospheric conditions at the space and time scale taken into consideration, one can use Eulerian models, as well as Lagrangean ones.

An Eulerian dispersion model can be is easily included in a prognostic wind model, this combination being often named a prognostic model of atmospheric pollution at the mesoscale. The Eulerian dispersion models are predominant in the case of reactive pollutants, typically the ozone and its precursors (especially the nitric oxide and the volatile organic compounds). The usual practice in these conditions consists in firstly applying the wind model and then the photochemical dispersion model.

In case of the regional-continental scale, the air quality models have as an object of study the long-distance transportation of the atmospheric pollutants, mostly with the purpose of:

- *quantifying the level of primary atmospheric and photo-oxidant pollutants (especially the ozone);*
- *assessing of the combustion deposits on various elements of the ecosystems crossed by the contaminated masses of air;*
- *understanding the physical and chemical processes coming from the formation, the transport and the deposits of these compounds.*

The winds, the clouds, the rainfalls, the characteristics of the underside surfaces and the chemical mechanisms are elements that determine the large-scale dispersion of the pollutant emissions. The final exits of the models consist of mean concentrations or deposits for square grids whose size varies currently between 50 x 50 km^2 and 150 x 150 km^2.

At the regional-continental scale, currently the Lagrangean models and the Eulerian models are both being used. The Lagrangean models, also *named "trajectory models", allow the performance of some prognoses regarding the concentration of pollutants along a path of the masses of air that consists of the pretty simple numerical treatment of the transportation within the equation of mass balance: the transportation is determined by the paths of the air flows. The use of such models, especially in case of some large chemical or nuclear accidents (like the Chernobyl accident from 1986), consists of the fact that, by coupling the atmospheric models used in an operative way within the weather forecast activity, with the method of effective calculation of the pollution concentrations along the forecast paths, one can obtain information necessary for taking decisions with respect to the protection of the population in such cases of environmental crisis. But due to their main disadvantage, i.e. the fact that it is very difficult to take into consideration the changing processes between the masses of air and the wind shear, the 3D models of Lagrangean type are still not considered to be very reliable (trust-worthy). In this case, the main advantage of the Eulerian models consist of a well-defined 3D formula, evidently necessary for approaching some atmospheric pollution problems more and more complex, such as the ones characteristic for the European regional scale in the future years. The Eulerian long-distance transportation models allow the determination of the contribution of external pollutant sources over the global pollution level from a country or the assessment of the contributions of internal sources to the cross-border pollution with the main atmospheric pollutants (sulphur dioxide, sulphates, nitric oxides, etc.). Taking into account the international conventions for reducing the pollutant emissions that determine the environmental processes at planetary level, such as climatic changes and the rainfall acidification, obtaining such information is mandatory. The Eulerian models also include the physical processes such as the dry and wet deposition or the non-linear chemical reactions between the pollutants emitted in the atmosphere which brings to a time of calculation so large that they can currently be run only for a relatively limited period of time. Still, the development of the computing technique is so fast that, in the near future, it is predictable the fact that these models will be used in an operative regime.*

Such an actual subject for research and development consists in the development of a methodology for linking the mesoscale prognostic models to the 3D microscale models. This way, one can appreciate that the predisposition for using some types of air quality models more and more sophisticated and precise will inevitably lead to the abandonment of the conventional rigid separation of the atmospheric processes according to the individual scales. The multiple-scale integrated approaches will be mandatory in the near future, while the refining of the digitisation techniques on grid mesh is necessary in order to extend the capability of combining the models developed for certain individual scales for the description of the processes, being extended to multiple space and time scales.

Another type of dispersion model that has recently got a large use is the one with "particle wreath" ("puff"). Even though in the beginning they have been created and used for modelling the diffusion and atmospheric transportation phenomena of some accidental interrupted (sequential) emissions, the "puff" models are currently often applied extensively also for the continuous emissions, which are represented (digitised) in this case by series of wreaths of effluents later taken over by a variable wind field. By using these wreaths ("puffs") instead of the emission plumes, the changes induced by the change of the wind direction can be easily modelled.

URBAN SCALE MODELLING

The well-known and strong degradation of the air quality within the large cities is caused by the urbanisation phenomenon, which means the existence of some important masses of population characterised through high-mobility requirements within narrow areas, causing a strong increase of the traffic volumes. This fact has determined the scientific community to proceed to deep investigations over the urban atmospheric pollution, particularly with respect to the representative sources of emission.

The most relevant categories of emission sources in the urban area have been identified as coming from the road traffic, the residential heating systems *and, in some cases, as a result of the some specific industrial activities. The nature and relevance of the problems related to the quality of air from the urban areas are different from one case to another, depending upon the local topographic, climatic and meteorological conditions, the regulation of legislation in force for environment protection and the options for existing urban improvement and planning.*

The necessity of modeling the quality of urban air is a consequence of the increasing interest of the population with respect to those aspects related to the environmental protection and to the health of human communities, as well as to the overcongestion of the traffic flows. The modeling allows people to obtain some fields of atmospheric concentrations for different pollutants in a less expensive way, faster and with a superior space resolution as compared to the experimental monitoring by immission measurements. Consequently, the modeling of the urban air quality has become an essential instrument for:

- *determining the characteristics of the urban area pollution;*
- *modeling the evolution scenarios of the impact of pollution for the purpose of traffic management, e.g. the modernization or the construction of new traffic roads, parking lots for vehicles, a better administration of the existing road infrastructure by efficient packages of traffic engineering solutions (one-way streets, optimizing the cycles of traffic lights in order to relieve the traffic, etc.);*
- *showing the placement of air quality monitors;*
- *assessing the responsibility areas of the main categories of emission sources to the overall pollution impact induced on the air quality in the urban area.*

It is necessary to make a distinction regarding the adopted methodologies for studying the primary and secondary reactive pollutants, the primary non-reactive ones, respectively, to the space and time scale taken into consideration.

In order to make an adequate analysis of the physical and chemical processes that imply the secondary pollutants such as the ozone or the primary reactive pollutants such as the nitric oxides, one need to use the mathematical models applicable for the areas with linear dimensions generally between 50 – 100 km (regional mesoscale). Examples of such classic models are the UAM [4] with applications for multiple American cities [5] and CALGRID [6].

On the other side, for the non-reactive primary pollutants it is possible to reduce the space analysis scale. With respect to the determination of the space distribution of the fields of average concentrations in those respective urban areas, it is very useful to obtain information for scales between 5 and 20 km (urban (sub)mesoscale), with the basic steps of 250 – 1000 m.

The Gaussian dispersion model is the most well known approach world-wide in the field of studies related to the atmospheric impact of the pollutant emissions at this space scale [1]. The widespread and the success of the Gaussian model of dispersion are mainly due to the fact that it is easy to apply, the concept is attractive and it has a high level of confidence due to the great volume of comparison made in time with large sets of experimental data.

The Gaussian models are based on a sole and pretty simple mathematical formula which implies a constant wind speed and a total reflection of the emissions at the ground level, without chemical reactions or deposition (dry and wet) on the soil surface (see Fig. 1):

$$C(x,y,z) = (Q_S / (2\pi U \sigma_y \sigma_z)) \exp(-y^2/2\sigma_y^2) (\exp(-(z-h_S)^2/2\sigma_z^2)+\exp(-(z+h_S)^2/2\sigma_z^2)) \quad (1)$$

where: $C(x,y,z)$ *[g/m³] – the atmospheric concentration of the pollutant in a receptor point of coordinates (x,y,z);*

Q_S *[g/s] – the mass flow of the continuous emission of the point source;*

U [m/s] – mean speed of the wind at the height h_S*;*

$\sigma_y = \sigma_y(x)$ *[m] – the lateral dispersion parameter (horizontal – transversal);*

$\sigma_z = \sigma_z(x)$ *[m] – the vertical dispersion parameter;*

x [m] – the downstream distance along the central axis of the emission plume;

y [m] – the lateral distance against the central axis of the emission plume;

z [m] – the vertical coordinate;

h_S *[m] – the effective height of the emission, representing the sum of the physical (constructive) height of the source and the rise of the effluent cloud after the stabilization of its movement level.*

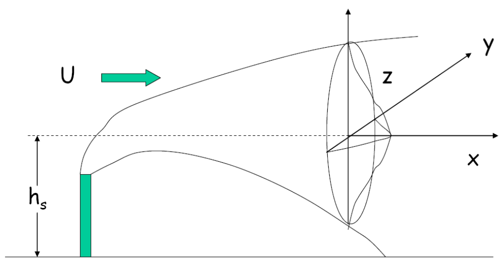

Figure 1. The scheme of the idealized pollutant emission plume with profiles of concentration described by the Gaussian distributions

Such a model type for the urban mesoscale is one of the most renown European dispersion models for the urban point (industrial) sources and area (stationary and mobile) sources, i.e. the OML-Multi model [7]. Developed within the Department of Atmospheric Environment of the National Environmental Research Institute – NERI from Denmark, the Operational Meteorological Model for Air Quality (OML) uses a new generation Gaussian plume approach, where the dispersion parameters are calculated as continuous functions of physical parameters of the planetary boundary layer, obtained through a meteorological pre-processing system (the OML pre-processor) which represents a separate software package [8].

The OML dispersion model requires hourly data regarding the pollutant emissions, the meteorological parameters and the regional background concentrations, as well as information regarding the receptors and the sources, the sizes of buildings placed next to the sources and the field topography. Because the emission data are generally obtained as annual average values, a series of time factors are used in order to identify the fraction of the annual value related to a specific period of time within a year. This type of information depends on the typical hourly, daily, weekly or monthly timeline variations of the emission flows. Such a series of time factors that can be set up are included in the sections of a special developed emission module of the OML-Multi model.

During the studies performed by the Research Department of the Romanian Automobile Register (RAR), the OML model has been applied on a rectangular grid of 20 km x 14 km, covering the most urbanised area and with the most dense road infrastructure within the Bucharest metropolitan area, totally using 315 (21 x 15) receptors for every 1 km towards the East and North, respectively, in order to calculate the fields of concentrations [9], [10], [11]. The OML model has been used for the following pollutants: CO, benzene, NOx, NO_2, O_3 and PM-10 (suspended inhaling particulates with an aerodynamic diameter under 10 μm). Based on the temporal dynamic series of concentration that are issued during the model run for the receptor points chosen by the user (grid nodes or other points of interest), the OML model allows the extraction of some statistics regarding the daily, monthly or yearly time average in order to compare them with the limit values and with the assessment thresholds of the EU Directives, these statistics being presented also as a graph of pollution maps. The OML model has also the important capability of parameterising in an operative way the kinetics of the main tropospheric chemical reactions at the space and time urban scale for modelling the transformations $NOx/NO_2/O_3$.

In order to model the urban background levels with the help of the OML-Multi model, the road traffic emission sources have been considered as diffuse area sources, placed in each of the grid meshes of the adopted digitisation system.

The predictive performance assessment for using the OML model for the Bucharest urban agglomeration has been carried out by comparing the modelling results with some sets of measured data, provided for the years 2004-2006 by the air quality automatic network belonging to the Bucharest Regional Agency for Environmental Protection. A general good quantitative and qualitative agreement has been observed between the modelling and measured data [10], [11].

The numerical simulations with the urban mesoscale models like OML represent an important alternative for the assessment of the urban background pollution levels from Bucharest and from other Romanian urban agglomerations. The space distributions of the most important and representative pollutants for the urban road traffic provide important information for assessing and forecasting the pollution level that can be reached within those agglomerations.

At the same time, one should also take into account the main natural removal mechanisms of the atmospheric pollutants, by the dry deposition to the *ground surface as a result of the gravitation fall (sedimentation) and by the adsorption phenomenon (by inertial impact) to the soil, vegetation or buildings, as well as for the wet deposition caused by the cleaning ("washing") of the air by means of different types of precipitation. For urban mesoscale modelling, the dry and wet deposition phenomena are taken into consideration especially in the case of particles (suspended powders), taking into account the gravitational effects and the different characteristics of their atmospheric transport as compared to the gas pollutants.*

STREET SCALE MODELING

The further reduction of the space scale of the concentration fields to several meters (street microscale) is also proved to be important. Thus, it is possible to settle the concentration peaks for the urban microstructures (pavements, different floors of the buildings, parks, etc.), as related to the micro-meteorological and emission varying conditions. This analysis is useful mainly for the pollutants with severe harmful effects, such as the carbon monoxide (CO). Moreover, like this it is possible to determine the space representativeness for the unique fixed points for measurement within the monitoring networks of the urban air quality.

In the case of the mobile road traffic emission sources, from the methodological point of view related to the modelling of the air quality at a certain receptor point, in order to assess by means of numerical simulation the total atmospheric concentration of an inert generic pollutant from the chemical point of view at an urban space and time scale, it is necessary to link the dispersion model at the street microscale with a model at the urban mesoscale. The total atmospheric concentration (C) can be obtained by adding the additional local street contribution (C_S) to the background concentration (C_B), representing the mesoscale contribution of all the background sources – coming from the road traffic, as well as from other types of anthropogenic emission sources (industry, residential heating, off-road vehicles, etc.) and natural ones (biogenic and mineral emissions).

The most frequent, due to the relative simple and direct applicability for estimations at local scale, for the assessment of atmospheric dispersion of emissions close to a traffic road, there were used different versions of the Gaussian model for the linear pollution sources [1].

The main roads with an intense traffic can be treated from the microscale modeling point of view as infinite linear sources, characterized through an emission mass flow for the unit of length Q_L [g s^{-1}m^{-1}]. The established Gaussian model of the linear emission source is based on the superposition principle (effect overlapping), according to which the concentration for a certain reception point can be obtained by adding up the contribution of all the infinitesimal point sub-sources that make up the respective linear source. At the same time, one can consider that the diffusion mechanism for each point sub-source is not linked to other sub-sources that make up the emission line. With this hypothesis, an analytical solution can be obtained by integrating the equation (1) for the point sources relative to the lateral distance y.

The solution of the Gaussian model for the downstream pollutant concentration from an infinite linear source of traffic belonging to a road that makes up an angle Φ with the wind direction is the following [1], [15]:

$$C(x,z) = (Q_L / (\sqrt{2\pi}\,(U \sin\Phi)\,\sigma_z))\,(\exp(-(z-h_S)^2/2\sigma_z^2)+\exp(-(z+h_S)^2/2\sigma_z^2)) \qquad (2)$$

If we note with d the perpendicular distance from the receptor point where we calculate the concentration to the traffic road, then the x distance on the wind direction used for computing the vertical dispersion parameter σ_z will obviously be $d/\sin\Phi$. We also mention the fact that in the equation (2) there is no y, due to the fact that for any value of it the concentration is the same for a given x. Also, the horizontal dispersion parameter σ_y is missing because we supposed that the side dispersion for a segment of the linear source is compensated by the side dispersions to opposite directions for the side segments. The equation (2) should use the wind speed (U) measured or assessed for a height of about 2 m for downstream distances from the linear source of some hundreds meters, while the angle Φ between the wind direction and the traffic line should not be less than about 45°, and the effective height h_S of emission is considered to be about 2 m. Taking into account the fact that the average physical height related to *the discharge ends of the car mufflers that make up the road traffic line is about 0.3 m, consequently we take into consideration a rise of the exhaust gas plumes of about 1.7 m.*

The validity of the hypothesis taken for the deduction of relation (2) regarding the independence of individual diffusion mechanisms for each point source as part of the traffic line becomes objectionable when the linear emission source comes with its own turbulence that is created by the car movement, like in the real case of the road traffic and which overlaps the local atmospheric turbulence. Moreover, the performed approximation by applying the overlapping principle becomes in turn arguable and in the long run insufficient in the case of some small angles between the wind direction and the traffic road axis whose impact over the environment is under study.

It is true that when the wind direction becomes parallel with the traffic linear source, that is the wind blows along the road, the angle Φ heads towards 0, which becomes a numerical singularity for the equation (2) for which the concentration heads towards the infinite ($\sin\Phi \rightarrow 0$ as the nominator in that relation). From the point of view of mathematical formulation of the calculation hypotheses, this fact is normal because we took into consideration a modelling by means of a linear emission source with an infinite length that is consequently characterised by an emission flow which is also infinite.

A way to avoid this singularity can be reached by taking into consideration a linear emission source with a finite length, by admitting a computing error which cannot be major due to the fact that the decrease of concentrations from the maximum one to the infinite minimum one, especially when close to the source, takes place following a very lean curve. The linear source with a finite length, for $\Phi=0$, heads to the characteristics of the point source with an infinite number of exhaustion points along the wind direction. In this case, the computing of concentrations can be done by using the equation (1) for the point source, by conventionally placing the emission point exactly in the centre of that limited linear source. The emission flow for the equivalent point source is obtained by multiplying the emission flow of the linear source with its limited length.

The most renowned approaches of this type at the worldwide level include the American models HIWAY2 [12], CALINE4 [13], [14] and SLSM [15]. For the HIWAY2 and CALINE4 models, the fields of atmospheric concentrations for the pollutant forecast by using a Gaussian equation of the linear emission source for an arbitrary wind direction are calculated by using a numerical integration procedure. This procedure divides (digitises) the roadway in a series of elements whose concentrations are individually calculated and then added up. Both models allow introducing in the calculation of a finite mixing height.

As opposed to these ones, the American model ROADWAY [16] is based on the flux-gradient approach, due to the obvious advantages regarding the numerical simulation in a more natural way of the interaction between the atmospheric diffusion processes and the chemical transformations of the pollutant emissions [1].

These models allow the assessment of atmospheric dispersion of the pollutant emissions due to the mobile sources for a great variety of geometric configurations of the road infrastructure and topographies of the studied area:

- *at-grade roads, ramps, slopes, fill sections, depressed sections, bridges, parking lots;*
- *aligned road sections, bends, rural and mountain curved alignments (serpentines);*
- *multiple perpendicular, inclined, T-form, Y-form crossroads, roundabouts;*
- *out-of-level crossroads, traffic routing and splitting isles, complex geometrical configurations;*
- *road infrastructure side areas – with an opened and levelled topography, canyons, quays, hill peaks, bunds, etc.*

Modeling the turbulence caused by the road traffic is vital for the cases of atmospheric calm and of the low-speed winds. The mechanical turbulence due to the traffic mainly depends on the driving average speed, on the size of the cars considered as elements of mobile roughness, as well as on the speed of the wind and on the angle between the wind direction and the road axis, taking into account for this last case the overlapping of mechanical turbulence *caused by the traffic over the local atmospheric turbulence.*

Moreover, it is mostly important to model the thermal increased height of the pollutant emission plume, the exhausted gas raising up due to its own thermal flux that supports them and raises them somehow just like the Archimedes force. This thermal (convective) component mainly depends upon the heat emission of the exhausted gas that can be calculated according to the traffic density, the specific consumption of fuel, the average energetic content of the car fuels and the thermal efficiency of the car engines.

The highest levels of pollution are registered on the canyon-type of streets ("street canyons") where the exhaust gas dilution is greatly limited by the presence of high buildings along the pretty narrow roads. This aspect is very important because architecturally speaking the street canyons represent one of the basic structures of the urban topography [17].

The special peculiarities of the flow and the dispersion conditions from the urban street canyons suppose the fact that the traditional (conventional) modeling methods are hard to apply in this case. Thus, with respect to the urban pollution caused by the road traffic, one should take into account the fact that there is no model capable enough to cover all the actual street configurations. Even the most modern and sophisticated models based upon numerical solutions of the flows from the fields of wind and on the scalar dispersion equations find it difficult to treat the extreme initial and the cross-border conditions. An "exact" mathematical description of the pollutant emissions dispersion in the street canyons is consequently impossible to be put into practice. The necessary simplifications of the "real world" conditions often imply restrictions over the field of applicability of models. From the regulation point of view though, for the studies regarding the impact over the environment, the most important is if and where the pollution levels exceed the specific norms of the air quality.

As a principle, there are two major interdependent ways of approaching the studies regarding the pollution specific to the street canyons: by means of physical modeling, consisting in the performance of some scale tests within the aerodynamic tunnels using the similarity criteria of the aerodynamic flows and by the mathematical (numerical) modeling.

The physical modeling, in case of neutral stratification, has been very often used for visualizing the flows and the pollutant concentrations, and for the speed measurements above and within some scaling of street canyons, taking into account at the same time the peculiarities of the side urban roughness. These studies that use a physical model offer a reliable base for validation and testing of the numerical models of urban dispersion, by strictly applying some special elements in order to ensure the quality of data, by supporting at the same time further development and improvement of mathematical modeling by computerized simulation [1].

The urban street canyon geometry does not only lead to the decrease of pollutant emission dilution. It also causes a significant change of the flowing conditions of the airflow led by the wind [1], [2]. Thus, one of the most remarkable characteristics of the flow within the street canyons consists in the creation of a vertical wind vortex (horizontal-axis rotor), for the fact that the direction of the wind at the street level is opposed to the one related to the level above the roofs of the nearby buildings. This aspect can be seen in the Figure 2.

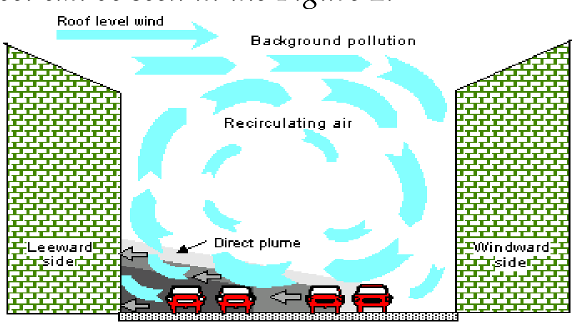

Figure 2. The scheme of wind and pollutant emissions circulation within the street canyon

This peculiar form of the airflow in the street canyons takes us to the creation of those important transversal concentration gradients relative to the traffic roadway. The levels of the pollutant concentrations on the upstream (leeward) side of the road are highly superior to those registered for the downstream (windward) side, directly "blown" by the wind, according to the suggestive graph from the Figure 3.

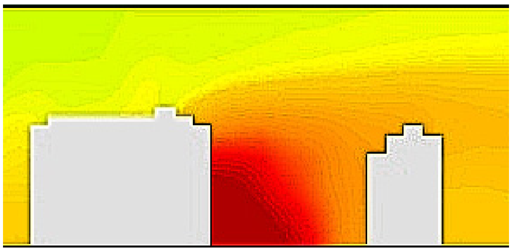

Figure 3. Vertical transversal section through the specific concentration field of the street canyon

The dependence on the wind direction is caused by the formation of the turbulent helical circulation specific for the street canyons. The numerical simulation offers an excellent explanation of this characteristic. The well-known effect of the street canyon is extremely obvious: the upstream concentrations are larger than the downstream ones. A receptor point placed on the downstream side of the street canyon is exposed to the background pollution and only indirectly to the local street traffic emissions which are significantly diluted by the circulating vortex specific to this urban topographic configuration, different from the case of placement on the upstream side which is directly exposed to the emissions caused by the nearby traffic mobile sources (see Fig. 2), so that in this case, the level of concentration is highly raised (see Figure 3).

For the wind speeds under 1 m/s, these differences are still far less, due to the diminishing up to the finishing of the helical eddy circulation. For these low wind speeds, the turbulence produced by the road circulation by means of the so-called advective traffic wave dominates the dispersion conditions inside the street canyon, so that the dependence on the wind direction is less obvious.

At the local level, the pollutant concentration is directly proportional with the emission flow of the street linear source Q_L [g/s/m] and inverse proportional with the wind speed at the roof level U [m/s], but amplified by adding a little correction term U_S (0.3 – 0.5 m/s), for taking into consideration the air movement mechanically induced through the wave of the road traffic. More exactly, the pollutant concentration is inverse proportional with the speed of the transversal wind component. This phenomenon is produced as long as the characteristic swirl is developed. When this thing does not take place, we can suppose that the pollutant emission dispersion is essentially due to the local atmospheric turbulence mentioned before. We can also see that when the speed of wind heads to zero (absolute atmospheric calm) or the direction of the wind is almost parallel with the axis of the street canyon, the concentrations on the two sides of the road become equal [18].

An approximate analytical solution of the Navier-Stokes flowing equations, for an incompressible fluid and specialised for the wind currents and the diffusion equation for the street canyons, has been deduced in 1973 by Hotchkiss and Harlow [21].

The expressions for the wind component U perpendicular on the axis of the street canyon and for the vertical wind component W, respectively, are the following:

$$U = \frac{A}{K}\left[e^{Km}(1+Km) - \beta e^{-Km}(1-Km)\right]\sin(Kx) \quad (3)$$

$$W = -Am\left[e^{Km} - \beta e^{-Km}\right]\cos(Kx) \quad (4)$$

where:

$$K = \pi / Lc \quad (5)$$

$$m = z - Hc \quad (6)$$

$$\beta = e^{-2KHc} \quad (7)$$

$$A = \frac{KU_0}{1-\beta} \quad (8)$$

and U_0 represents the wind speed over the central axis of the street canyon at the roof level, so in the coordinate point x = Lc/2 and z = Hc, where Lc is the width and Hc is the height (depth) of the street canyon.

The wind speed component parallel with the median (longitudinal) axis of the street canyon (V) can be described by using a logarithmic vertical profile, suggested by Yamartino and Wiegand [19], using the relation:

$$V(z) = V_r \frac{\lg[(z+z_0)/z_0]}{\lg[(z_r+z_0)/z_0]} \quad (9)$$

where V_r is the wind speed component parallel to the street axis, measured at a reference height z_r, and z_0 represents the roughness length.

Yamartino and Wiegand [19] have proposed the following values for the roughness z_0 for the street canyons: z_0 = 0.4 m when the characteristic swirl will not be developed, z_0 = 0.04 m if the swirl is manifested and z_0 = 400 m if one of the buildings of the street canyon is far larger than the others, thus disturbing the flow over the canyon. Evidently, z_0 = 400 m represents a physically impossible value *but this way the report of the logarithms heads toward z/z_r.*

Using the expressions (3) and (4) of the wind field, Hotchkiss and Harlow [21] have established, after some more extra approximations, the following calculation formula for the concentration field Cs:

$$Cs = S\left[\frac{1}{U_W} - \frac{V}{V_t}\right] -$$

$$-\frac{SU_n m}{4KV_t^2(1-\beta)}\left[e^{Km}(1-Km) - \beta e^{-Km}(1+Km)\right]cos(Kx) \quad (10)$$

where $S = Q_l/Lc$ represents the emission "density", which is the supposed to be uniform on the street transversal direction, and U_n represents the wind speed component on the top of the street canyon, perpendicular (normal) on the longitudinal axis of the traffic road.

In order to model the turbulent diffusivity (viscosity) V_t, Hotchkiss and Harlow [21] have proposed the use of a calculation relation where the turbulence speed scale is correlated with the speed of wind on the top of the street canyon (U_t) and the correction factor (U_S) of the speed due to the turbulence caused by the road traffic:

$$V_t = L\sqrt{(\alpha_1 U_t)^2 + U_S^2} \quad (11)$$

For the length scale L, they simply suggest using the Lc width of the street canyon, and a_1 is a constant empirically determined. As for the ventilation speed of the street canyon (Uw) which determines the concentration levels on the top of the canyon, the following calculation relation has been proposed:

$$U_W = (V_t\, U_t / Lc)^{1/2} \quad (12)$$

Chronologically speaking, a first model for the urban street canyon that creates an excellent combination between the operational characteristics and the scientific refinement which made it renown in the whole world was the American-German model CPB – "Canyon Plume-Box" (Yamartino & Wiegand, 1986) [19], [20]. Within this model, the pollutant concentrations are calculated by means of combining a subtype of dispersion by using the Gaussian emission plume formulation for the direct impact of the pollutants emitted by the road traffic, with a "box"-type of model which allows the assessment of the extra impact caused by the recirculating pollutants within the street canyon by eddy flow. The specific peculiarity of such a "box" approach consists in taking into consideration a limited vertical dispersion, in a finite volume of air. The wind field within the street canyon is defined by the Hotchkiss & Harlow rotor model [21] for the transversal components U and W, while the longitudinal component V (along the canyon) is represented by a vertical logarithmic profile which takes into account the roughness length variation according to the wind speed direction. In order to determine the turbulence parameters a_u, a_v and a_w, they use a parameterisation empirical model for the turbulence intensity; the used variables for this purpose include the mechanical component, induced by the wind at the roof level of the buildings next to the street canyon, as well as by the traffic advective wave and the thermal (convective) component, depending on the global solar radiation and the heat issued by the exhausted gases of the vehicles quantified according to the traffic flow (the number of vehicles within the time unit).

A similar approach to the one used by the CPB model has been applied consequently also for the development of the not less established Danish dispersion model OSPM – "Operational Street Pollution Model" [22], [23], [24]. The atmospheric concentrations of the exhausted gases are also calculated by using a combination between the Gaussian subtype plume for the direct contribution and the "box" subtype for the recirculating part of the pollutants in the street canyon. This operational model uses a simplified empirical parameterisation of the flow and dispersion conditions inside a street canyon, still established through an extensive analysis of some very large sets of experimental data, the results of these tests being used for the improvement of the predictive performances, regarding especially different street configurations and meteorological conditions. The parameters considered for the quantification of the influence on the atmospheric turbulence structure are the global solar radiation, the wind speed at the roof level, the road traffic flow and the average speed of the vehicles, the sizes of the street canyon and the geometrical position of the receptor within the canyon. At the same time, it is supposed that the sizes of the turbulent swirl are given by the *geometrical sizes of the street canyon and especially by the directional variable height of the upstream buildings, while the speed characteristic for the turbulence process is within the standard deviations of the wind speed.*

The CPB and OSPM models have proved their good predictive performances as compared to the extended sets of timeline average concentrations, measured in various street locations from the multiple urban areas. The request of the input data on a timeline sequential basis (traffic, meteorological and background pollution data) can be often prohibiting but it is also possible to use this type of models with composite input data that simulate, for example, the worst conditions for dispersion or the long-term climatological statistics; the credibility of this last type of results is not considered to be lower than the "standard" regulatory applications.

An empirical approach has been used also for the development of the Dutch CAR model ("Calculation of Air pollution from Road traffic") meant for studying the atmospheric pollution caused by the road traffic [25]. Mainly, based on some experiments performed within aerodynamic tunnels [26], [27] and [28], a set of empirical correlations has been established between the wind direction and the concentration for various street configurations. The experiences within the aerodynamic tunnels have covered a set made of 49 different configurations according to the sizes, distances and forms of the streets and the nearby buildings, at the same time investigating the influences on the dispersion characteristics of the trees on the sides of the road. The results of these master experiments have been included in a type of Gaussian emission plume model, under the name of the TNO traffic model [26]) which form the basis for the final development of the more operational CAR model, where some of the more distinctive street configurations with respect to the dispersion conditions have been classified. For each type of street it is mentioned a relation between the source and the receptor according to the distance between the receptor point and the axis of that street. Only the annual average concentrations can be calculated, as well as other statistic long-term parameters, based on the empirical correlations coming from the measured data base of the Dutch national network for monitoring the atmospheric pollution, those correlations being updated every year. This operational model is currently applied for the studies related to the impact on the environment performed for the Dutch cities. At the same time, an international version, named CAR International [29], is available.

Finally, one should also mention the Japanese original model OMG [30] which allows for the microscale modeling of the atmospheric dispersion of the pollutant emissions outside the urban street canyon domain where they have been produced, taking into account the report between the built surface and the total surface of the area next to the road infrastructure on a distance of 100 m on the one side and the other of the studied traffic roadway. In this case, one should also take into account the fact that in the urban areas, the mechanical turbulence induced by the presence of buildings influences the car engines exhaust gas diffusion. This phenomenon can be modelled by using the concept of the volume source and quantified by introducing an initial dispersion of the pollutant emissions plume, caused by the turbulent mix from the street canyons and expressed according to the average height and the superficial density of the buildings (the report between the built area and the total available area). The total pollution concentration at a receptor point can be obtained by adding the additional street contribution to the urban background concentrations (regional background plus urban source background contribution), also taking into account the microscale pollutant impact induced by the traffic linear sources developed inside the street canyon next to the studied circulation road.

CONCLUSIONS

The mathematical models that have the capability to describe in an adequate way the correlations between the meteorological conditions and the level of atmospheric concentrations of the pollutant emissions represent at the same time excellent instruments used also for the analysis and the interpretation of the experimental data. It is supposed that the measurements provide with information related to the "real world" conditions, but sometimes it is not possible, only by using *these ones, to explain the apparition of a peculiar situation and its cause. The use of an adequate model can solve this problem. The primary objective of some specialized operational models is meant to supply a fast but still realistic assessment of the pollutant dispersion for the emissions due to the road traffic.*

The anticipated and desired perspective of the medium and long-term modernization and development of the Romanian road infrastructure, will involve in the most normal way, according to the European Union environmental legislation, the extension of application of many assessment procedures for the atmospheric impact caused by the road traffic.

In this context, the microscale numerical modeling offers the opportunity for a detailed simulation of the impact of various scenarios of urban planning, in order to establish and optimize the related strategic decisions. The broad list of the physical processes and the very important number of non-linear interactions lead to the impossibility to assess in a coherent way the consequences of the structural changes without making an appeal to the expert systems for advanced numerical modeling.

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