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THE MAIN CONCEPTS OF THE PolEmiCA TECHNIQUE FOR STATIONARY SOURCES OF EMISSION IN AIRPORTS

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КОНЦЕПТУАЛЬНІ ПІДХОДИ ОЦІНКИ СТАЦІОНАРНИХ ДЖЕРЕЛ ЕМІСІЇ АЕРОПОРТІВ ПРОГРАМНИМ КОМПЛЕКСОМ PolEmiCA

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КОНЦЕПТУАЛЬНЫЕ ПОДХОДЫ ОЦЕНКИ СТАЦИОНАРНЫХ ИСТОЧНИКОВ ЭМИССИИ АЭРОПОРТОВ ПРОГРАММНЫМ КОМПЛЕКСОМ PolEmiCA

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Introduction. Aircraft engine emission in combination with other important sources of air pollution provides the impact on environment inside and around the airports, somewhere potential, mostly defining air quality locally, less regionally and at in different way globally. Sources of air pollution at airports include emissions from aircraft (during approach, landing, taxiing, take-off and initial climb of the aircraft, engine run-ups, etc.), individual mobiles, service vehicles, motor vehicles, stationary sources, such as heating plants, fuel storage facilities, and so on. In most cases under consideration aircraft engine pollution is dominant inside airport area. There is a need to implement models and method for assessment of air pollution produced by aircraft engine emission. Main purpose of the model PolEmiCa is to provide the dispersion (Pollution) and inventory (Emission) calculations for the aircraft engine emission during the landing-takeoff cycle of the aircraft in the airport area. It includes the aircraft emission from start-up procedures and also APU and GSE emissions. The current version of PolEmiCa combines the calculation for the main stationary sources and road vehicles inside the airport area for the following pollutants : CO, HC, NO_x, SOx, PM and fuel vapors (HC). Usual practice for the Former SU countries, in particular in Ukraine today, is that the air pollution must be calculated, first of all, for the stationary sources using the OND-86 method [1], which is used for administration purpose of air quality control, including the definition of the boundaries of sanitary protection zones around the sources of air pollution, airport is among them. The OND-86 method provides 20-30 minutes averaged concentrations, which are used as limits in domestic normative regulations.

In PolEmiCa a mixed Gaussian/Eulerian approach is implemented to describe dispersion processes of the pollutants in the atmosphere. The choice of the approach was set by existing and widely used models in most of the FSU countries according to the national standard OND-86, which provides the main calculation expressions on the basis of the analytical solution of the semi-empirical equation for turbulent diffusion in the atmosphere with a vertical wind profile of the form $U_{w0}(z/z_0)^c$. Wind velocities U_w and coefficients of atmosphere turbulence K_x, K_y, K_z describe the state of the atmosphere (depending on stratification or stability class). The significant material was assembled according to parameters of wind velocities and turbulent diffusion factors depending on atmospheric stability class (meteorological parameters), time of the day, season, and geographical arrangement of the location under the research. It means that the coefficients of atmospheric diffusion (K_x, K_y, K_z) are predefined as initial data for the dispersion calculation in dependence

to these meteorological parameters.

For this reason the dispersion for the stationary sources in PolEmiCa is calculated by the algorithm of OND-86. For the purposes of the CAEP MDG evaluation the 20-30-minutes averages of concentration (results of OND-86) were transformed into 1-hour averages using Addendum to the OND-86 “Method of calculation averaged over a long period, concentrations of harmful substances emitted into the atmosphere”. For stationary point sources the transformation coefficients are dependent from wind velocity and direction dispersions for specific atmosphere stability class mostly, for moving point sources transformation coefficients are near to relation of intervals of averaging of the calculated concentration because of their minor dependence from atmosphere parameters.

The main concepts of the OND-86 technique

Since 1962 in Soviet Union the regulatory diffusion models have been based on techniques developed by a team of specialists from the Main Geophysical Observatory (MGO) in cooperation with other scientific research institutes of the former USSR [2-7]. Concentration fields, calculated with these dispersion models, should be compared with ambient air quality standards called "maximum permissible concentrations" (MPCs). Two lists of MPCs were established (each one containing several hundred pollutants), which correspond to short-term (20-30 min) and long-term (up to one year) averaging times. Short-term MPCs are considered as more restrictive than long-term ones, that is why all other regulations in new independent (former USSR) states for environment protection are based these short-term MPCs. In that number the calculation technique OND-86 [1] (an abbreviation OND-86 means "National Regulatory Document introduced in 1986") is based on determining the short-term worst-case concentration fields. In such a sense, OND-86 can be compared with known SCREEN2 and SCREEN3 models, or other American screening models [2] which also predict short-term worst-case concentrations and cannot be used for estimations of the long-term averages, at least directly.

OND-86 technique [1] provides only short-term worst-case concentration fields and cannot be used for estimation of long-term *(e.g.,* annual) concentrations (this drawback is now eliminated with the newly developed MGOLT model, which is intended, in particular, for applications in health risk assessment).

The technique is based on the following assumptions:

– The pollutant dispersion in the atmosphere is affected by meteorological parameters (wind velocity and direction, temperature-stratification of the atmosphere and air temperature);

– The ground-level concentration of pollutants depends on the parameters of the emission source and composition of the air-gas mixture.

Unlike the majority of western regulatory dispersion models (mostly the types of Lagrangian models), the OND-86 model does not use Gaussian formulae and is based on analytical approximations of the numerical solution of the advection-diffusion equation (ADE) – it is known as the Eulerian approach in solving the equation for mass conservation of a single pollutant species. This equation can be solved analytically under special simplifying assumptions. This solution, which in fact is the Green function of the ADE, is also used to describe concentration fields from multiple, line and area sources as a superposition of concentration fields from single sources. Coefficients in ADE are parameterized using surface meteorological data (wind speed, wind direction and temperature gradient). The obtained solution was generalized to the cases of complex terrain and building environments using results of a number of numerical, field and laboratory experiments.

The model, as shown in Fig. 1, predicts the plume characteristics (dimensions) such as its maximum distance downwind the stack (x_m), maximum width (y_m) as well as maximum height (z_m). Calculations also predict the temperature distribution for the gases emitted from the stack, concentrations of gaseous and particulate pollutants emitted from an industrial single point stack.

The OND-86 technique is currently approved at the state level (licensed by Ministry of Environment Protection of Ukraine) and recommended for use to calculate the emission dispersion in the air while rationing and limiting maximum permissible emissions (MPE) for the sources of air pollution. Few classes of sources are considered: surface sources with $H \leq 2$ m, and low sources with $2 < H \leq 10$, high sources with $H > 50$ m, and medium height sources with $10 < H < 50$ m. Buildings are also taken into account, which can practically be important for the sources with $H \leq 50$ m. However, this technique is difficult to use for scenario and forecast calculations under specific meteorological conditions for specific emission sources, for example such as aircraft. The OND-86 technique does not fully takes into account the type of the underlying layer over the ground surface, etc.

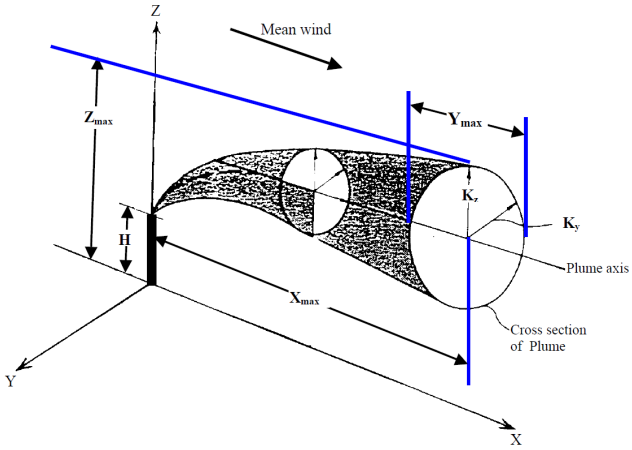

Figure 1 – Basic dimension of the plume

Main fundamental solution used for OND-86

In general, the problem of air pollution forecast can be defined mathematically as a solution under certain initial and boundary conditions of the following equation [2, 3]:

$$\frac{\partial q}{\partial t}+\sum_{i=1}^{3}u_i\frac{\partial q}{\partial x_i}=\sum_{i=1}^{3}\frac{\partial}{\partial x_i}k_i\frac{\partial q}{\partial x_i}+\alpha\times q\,, \tag{1}$$

where q is a pollutant concentration; t – time; x_i – coordinates; u_i – velocity vector components; k_i – the turbulent diffusion coefficients (i=1, 2, 3); α – coefficient, which takes into account the air pollutant transformation (calculated from chemical reactions). Wind velocities u_i and coefficients of atmosphere turbulence k_x, k_y, k_z describe the state of the atmosphere (depending on stratification or stability class of the atmosphere). The significant material was assembled according to parameters of wind velocities and turbulent diffusion factors depending on atmospheric stability class (meteorological parameters), time of the day, season, and geographical arrangement of the location under the research. It means that the coefficients of atmospheric diffusion (k_x, k_y, k_z) are predefined as initial data for the dispersion calculation in dependence to these meteorological parameters.

The fundament for OND-86 calculation technique is a solution of the atmospheric diffusion equation for stationary source of emission and air pollution [2-4]:

$$\sum_{i=1}^{2}u_i\frac{\partial q}{\partial x_i}=\sum_{i=1}^{2}\frac{\partial}{\partial x_i}k_i\frac{\partial q}{\partial x_i}+\alpha\times q \tag{2}$$

or for directly defined horizontal and vertical components of the wind velocity and atmosphere turbulence coefficients in a form:

$$u\frac{\partial q}{\partial x}+w\frac{\partial q}{\partial z}=\frac{\partial}{\partial y}k_y\frac{\partial q}{\partial y}+\frac{\partial}{\partial z}k_z\frac{\partial q}{\partial z}+\alpha\times q \tag{3}$$

where i=1,2 for are horizontal and vertical components u and w of the wind velocity respectively; k_y and k_z are horizontal and vertical components of the atmosphere turbulence coefficient; α is a factor of pollutant transformation; z = 0 corresponds to the level of the underlying ground surface.

For the calculation the pollutant concentration with sufficient accuracy, it is almost enough to adopt, that [2, 3, 5]:

$$u=u_1\frac{\ln z/z_0}{\ln z_1/z_0};$$
$$k_z=\nu+k_1 z/z_1 \quad \text{for } z\le h;\quad k_z=\nu+k_1 h/z_1 \quad \text{for } z>h \tag{4}$$
$$h=\frac{0.05k_1}{\varpi_z\cdot z_1}$$

where z_0 — the roughness of the underlying surface, h – height of the surface layer, ϖ_Z - the vertical component of the angular velocity of the Earth.

So, k_z increases linearly with height z in the surface layer $z<h$ and remains constant for $z>h$. In the case of a surface inversion, according to similarity theory a logarithmic/linear change with z is taken for u, and a linear-fractional change for k_z.

Berlyand [2, 5] found analytical solution of the equation (3) to calculate the maximum concentration

of harmful substances from point emission source for the case, that the wind speed varies with power law and the coefficient of turbulent diffusion linearly increases:

$$u = u_1 \times \left(\frac{z}{z_1}\right)^n, \; k_z = k_1 \times \left(\frac{z}{z_1}\right). \tag{5}$$

Equations describing pollutant rise above industrial sources of emission due to the initial escape and overheating of discharged gases resulted the expression $H_e = H + \Delta H$ for the effective source height H_e, where H is a geometrical source height, and

$$\Delta H = \frac{1.5 \cdot w_0 \cdot R_0}{u} \cdot \left(2.5 + \frac{3.3 \cdot g \cdot R_0 \cdot \Delta T}{T_a \cdot u^2}\right) \tag{6}$$

where w_o and ΔT are velocity and temperature excess of the exhaust gases from a stack with orifice radius R_o, g is the acceleration of gravity, u is wind velocity at the height z = 10 m, T_a is atmosphere temperature in K.

So, maximum concentration is calculated in following way for volatile (7) and non-volatile (8) PM [3]:

$$q_m = \frac{0.116 \times (1+n)^2 \times M}{u_1 \times H^{1.5\times(1+n)}} \sqrt{\frac{k_1}{k_o u_1}} \tag{7}$$

$$q_{\omega m} = \frac{0.063 \times (1+n)^2 \times M}{u_1 \times H^{1.5\times(1+n)}} \sqrt{\frac{k_1}{k_0 u_1}} \frac{(1.5+\omega)^{1.5+\omega}}{\Gamma(1+\omega) e^{\omega}} \tag{8}$$

where u_1 – wind velocity and k_1 – coefficient of turbulent diffusion at height z_1 both; n – temperature stratification of the atmosphere; M – emission rate; H – height of the emission source; ω – characteristics including the sedimentation rate of non-volatile PM:

$$\omega = w / k_1 \cdot (1+n) \tag{9}$$

where w – sedimentation (fall) rate, which is calculated according to Stokes law:

$$w = \frac{10^{-8} \cdot d_g^2 \cdot \rho \cdot g}{18 \cdot \mu} \tag{10}$$

d_g – diameter of particles, μ – dynamic viscosity of air, g/cm·s, or by Stokes law in simplified form:

$$w = 1{,}3 \cdot 10^{-2} \rho_d r_d^2,$$

where w is defined in cm/s, ρ_d – density of the dust particles, g/cm^3, r_d – their radius, μm.

Analysis of the expressions indicates that the concentration varies inversely proportional to the wind velocity u_1 and directly proportional to the vertical component of the turbulent exchange coefficient k_1/u_1. The impact of the horizontal component of the turbulent exchange coefficient is determined by $k_0 = k_y/u$. The difference between the values of q_m and x_m for fine-particle and for heavy monodispersed pollutants increases with the increase of the dust fall rate w. It follows from the calculations that dependence of the concentration q on u_1 and k_1 is similar for both heavy and light pollutants. The decrease of k_1 is equivalent to the increase of w, and vice versa.

Expressions derived in Berlyand *et al.* [3] result from an analytical approximation of a previously tabulated numerical solution of the equation of atmospheric diffusion with a logarithmic wind profile and a linear eddy diffusivity profile truncated by a constant value at the top of the surface layer [6]. This solution depends mainly on wind speed and direction, as well as on a stability parameter λ, which is a ratio of the eddy diffusivity at the given height z_1 (for example, 1 m) to the product of z_1 and wind speed at the same height (λ is related to the Richardson number or to the Monin-Obukhov stability parameter). Distribution of the surface concentration is characterized by its maximum q_m, which is obtained at a distance x_m from the source, as well as by functions describing its horizontal variations.

The distance x_m from emission point source, at which the concentration will obtain the maximum value, is calculated according to formulas (11) correspondingly for volatile and non-volatile PM [3]:

$$x_m = \frac{2}{3} \frac{u_1 H^{1+n}}{k_1 (1+n)^2}, \quad x_m = \frac{u_1 H^{1+n}}{k_1 (1+n)^2 (1.5+\omega)} \tag{11}$$

It was found, that the maximum concentration of nvPM (A7) is higher than volatile one (A6), while the distance x_m is less. The difference in q_m and x_m values increases for volatile and non-volatile PM with increasing of particle sedimination rate.

Concentration of non-volatile PM (q_ω, $q_{\omega m}$) is related with concentration of volatile PM (q, q_m) by following way at the distance x from emission source with height H [2, 3]:

$$q_{\omega} = q\chi(\frac{w}{k_1}, \frac{k_1 x}{u_1}, H) \tag{12}$$

$$q_{\omega m} = q_m \chi_m(\frac{w}{k_1}, H) \tag{13}$$

Differences in concentrations of volatile and non-volatile PM are caused mainly by the dimensionless parameter w/k_1. At same value of w the sedimentation rate of PM will be different depending on the atmospheric turbulence intensity. In strong turbulence, for example, in the case of well-developed convection, the differences in the sedimentation velocity w are manifested mainly for large x.

The mentioned features for nvPM distribution are included by functions (χ, χ_m), which are determined by formula (14) on the basis of numerical solution of the equation (1):

$$\chi = \frac{\left[\frac{u_1}{(1+n)^2 k_1}\right]^{\omega} H^{\omega(1+n)}}{\Gamma(1+\omega) \times x^{\omega}} \tag{14}$$

Berlyand and Onikul [7] found the following dependences for χ and χ_m on w/k_1 and height H (Fig. 2). Analysis of analytical and numerical investigations highlighted that the maximum concentration of nvPM is always higher and appropriate distance to the emission source is less than for volatile PM. Additionally, the dependence was obtained for χ_m on height H for $w/k_1 = const$. As it is shown in Fig. 2, the χ_m is practically independent of the height of emission source, which are displayed in surface layer. However, for higher emission sources, the value of χ_m increases relatively quickly with height H.

From the calculations it follows that variations in the dispersion of dust result in separation of downwind concentration maxima for different fractions and thus contributes to a decrease of the total concentration maximum. In addition, X_m for the surface concentration maximum depends on the source height H considerably less than in the case of a monodispersed pollutant. However, its value still increases somewhat with larger values of H, especially for H> 300m.

One of the major particularities of accidental emissions is the necessity to take into account non stationarity, that is to introduce the nonstationary term, dq/dt, into Eq. (1). However, if in this case the equation is integrated over time t, it is possible to retrieve the formula for stationary conditions, where concentration is replaced by dose, $D = \int_0^t q dt$. This is the base on which recently a method of forecasting the scale of contamination with poisonous substances following accidental releases on chemically dangerous installations and during transportation has been developed.

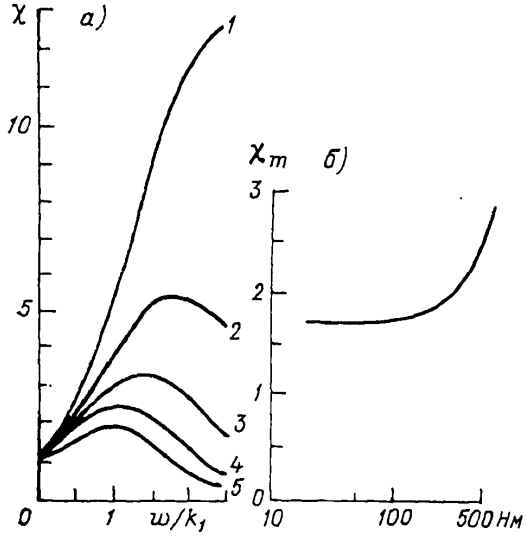

Figure 2 – Dependence coefficients χ and χ_m on w/k_1 and height H: curves are shown for k_1x/u_1 = 300 (1); 400 (2); 500 (3); 600 (4); 700 (5) [2]

When modelling dispersion of emissions from cars, they were considered as surface sources with values of concentrations and emissions averaged over the lowest layer of the depth z_h = 2 m [4]. For a highway of a width do with wind velocity u perpendicular to it, pollutant concentration is determined with the formula:

$$q = \frac{1.24 \cdot M}{d_o \cdot \lambda \cdot u} \ln \frac{\lambda \cdot x \cdot \sqrt{z_h^2 + \lambda^2 \cdot x^2}}{z_h \left[\lambda (x - d_0) - z_h + \sqrt{z_h^2 + \lambda^2 (x - d_0)^2} \right] \theta (x - d_0)} \tag{15}$$

where $\lambda = k_1 / u_1$ and $\theta(x - d_0)$ is the unit step function.

Fig. 3 presents results of the comparison of calculations (using eq. 13) with observations near a highway during five field studies [4]. Research has also started on the effects of photochemical transformations of cars exhaust, transformation of NO into NO_2, forming of ozone, etc. From the requirement for the concentration at the edge of an urban roadway not to exceed MPC, it is possible to establish permissible emissions from the roadway, and from there permissible intensity of traffic on the roadway. For the cases of unfavorable meteorological conditions it is possible to indicate how much to reduce the traffic on the roadway or in other streets, and when necessary allover the city. In contrast to the Gaussian model for a stationary point source

$$q = \frac{M}{2 \cdot \pi \cdot \bar{u} \cdot \sigma_y \cdot \sigma_z} \left[\exp\left(-\frac{(z - H_e)^2}{2 \cdot \sigma_z^2} \right) + \exp\left(-\frac{(z + H_e)^2}{2 \cdot \sigma_z^2} \right) \right] \cdot \exp\left(-\frac{y^2}{2 \cdot \sigma_y^2} \right) \tag{16}$$

which enables one to estimate the most probable (modal) value of the concentration under given meteorological conditions, the MGO model calculates an upper (1-2%) quantile C of the concentration distribution, which corresponds to the stability parameter 2 being varied under given values of other meteorological parameters.

The duration of the time interval for which concentrations were calculated from solution of the diffusion equation, and the length of the sampling time for experimental estimation of concentrations are very important for comparison of calculated and measured concentrations. This is also essential because air pollution effects on the environment (living organisms, vegetation, coatings, etc.), depend not only on the instantaneous pollutant concentration but also on the time of exposure. Accordingly, the maximum permissible concentrations are established in terms of time of exposure and pollutant properties.

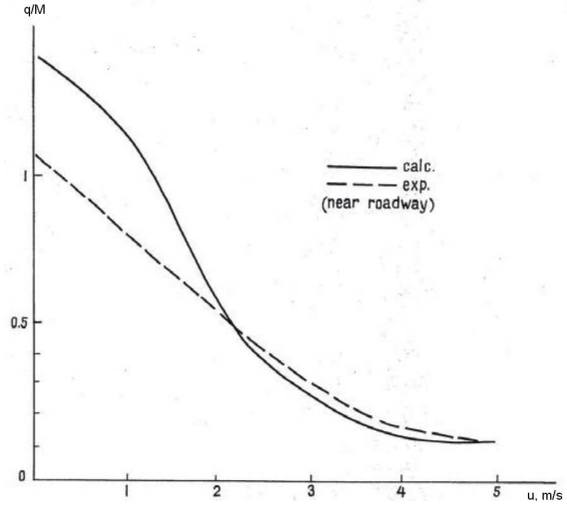

Figure 3 – Normalized concentrations as a function of wind speed [4]

In view of the above, studies have been made of the effect of the averaging period for the concentration field described by the initial equation, with a proper choice of values for diffusion coefficients and winds. Such investigations encounter considerable difficulties due to the necessity of taking into account the influence of a wide spectrum of eddies typical of atmospheric turbulence. A tentative approach to solving this problem was developed by Berlyand [2]. They suggested taking into consideration the averaging period for exchange coefficients and wind speed components in the analysis of turbulent diffusion. In the above solutions k_y and k_z were assumed to be determined by Eulerian parameters of micro scale structure of meteorological elements and to be independent on Lagrangian characteristics of the process.

In [3] it was assumed in the estimation of k_y that above the surface layer $k_y \sim k_z$. Under such a condition the characteristic time scale τ' of eddies that determine k_y and k_z is estimated from fluctuations of the horizontal and vertical wind speed components u' and w', as well as from the mixing length l of the eddies, so that:

$$\tau' = \left. \frac{1}{\sqrt{u'w'}} \right|_{z=h}$$

Numerical estimations indicate that τ' is usually 2-3 minutes. Thus, the concentration field q described by the initial turbulent diffusion equation (1) with the above values of k_y and k_x is determined by small scale eddies with τ' of about 2-3 minutes. The x axis in this case should be directed along the wind direction averaged over the period τ'. Estimates suggest that a calculation based on the above formulae will agree, to some extent, with experiments when air samples are taken within a few minutes at comparatively small distances from the source, i.e., with a short pollutant travel time. The solutions obtained are thus valid mainly for the calculation of maximum concentrations from comparatively low sources over small distances. Experimental values for concentrations are considerably lower than calculated concentrations for higher sources and for sampling periods of 20-30 minutes. The greater the distance from the source, the larger the difference.

Berlyand [3] found the expressions for averaged concentration by including the fluctuation of atmospheric turbulence coefficients and wind velocity impact. For the horizontal component of the coefficient k_y it follows that $k_y = \varphi_o^2 u$, where φ_o^2 is dispersion of wind direction oscillations for the time interval for which the concentration q is averaged.

So, the expressions of maximum averaged concentration $\overline{q_m}$ for volatile PM and the distance $\overline{x_m}$ from emissions source, where maximum will be obtained, take form:

$$\overline{q_m} = \frac{0.216 \cdot k_1 \cdot (1+n)^3 \cdot M}{\varphi_0 \cdot u_1^2 \cdot H^{2\cdot(1+n)}} \quad \overline{x_m} = \frac{u_1 \cdot H^{1+n}}{2k_1 \cdot (1+n)^2} \tag{17}$$

Considered expressions (17) are similar to formulas (7, 9). Analysis of the expressions indicates that the averaging effect causes the reduction of the maximum concentration and of the distance where it is achieved. Also it was observed, that averaged concentration is more sensitive to the height.

And the expressions for non-volatile PM take form:

$$\overline{q_{\omega m}} = \overline{q_m} \cdot F' \quad \overline{x_{\omega m}} = \overline{x_m} \cdot \mathrm{N}' \tag{18}$$

where F', N' – dimensionless coefficient, F'>1, N'<1.

From these formulas (B17, B18) it follows that the averaged concentration increases with decreasing of wind oscillations. Therefore, the increase of φ_o due to unstable atmospheric conditions under weak wind velocity reduces the concentration value.

OND-86 main calculation formula

From the integrated solution of Eq. (2), taking into account the initial rise (6) and the condition that $\frac{\partial^2 q}{\partial x \cdot \partial u} = 0$ and $\frac{\partial^2 q}{\partial x \cdot \partial k_z} = 0$, the expression for the maximal value of the short-time average concentration (20 min) q_{mu}, at the distance x_{mu} from a single point emission source under the critical wind velocity u_m and an unfavorable stratification (for elevated sources under unstable conditions) was obtained [1]:

$$q_{mu} = \frac{A \cdot M \cdot F \cdot m \cdot n \cdot \eta}{H^2 \sqrt[3]{V_1 \cdot \Delta T}} \tag{19}$$

where q_{mu} is measured in mg/m^3; A is a dimensionless coefficient that depends on the temperature-stratification of the atmosphere; M is the mass of the pollutant emitted into the atmosphere per unit time, g/s; F is a dimensionless coefficient that takes into account the rate of pollutant sedimentation in the atmospheric air; m, n are dimensionless coefficients that take into account the conditions of the air-gas mixture yield from the mouth of the emission source; η is a dimensionless coefficient that takes into account the effect of the land topography; H is the height of the emission source above the ground level, m; V_1 is the volumetric flow rate ($V_1 = \pi R_o^2 w_o$) of the air-gas mixture, m^3/s; $\Delta T = T_g - T_a$ is the differential temperature of the discharged air-gas mixture T_g and the ambient air T_a, ºC.

The coefficient η in (19) incorporates terrain effects. For an even surface η =1. For terrain with elongated hills or valleys, maximum values of η depend on source location and the point of concentration measurement.

In particular, the expression for q_{mu} (19), including the relationship between initial plume rise and meteorological parameters, is tested for its extreme in u and λ. The obtained results were employed to construct a maximum ground-level ("worst case") concentration q_{mu}, which represents the value for critical

wind speed $u=u_m$ and critical stability parameter $\lambda = \lambda_m$. The MGO model can also be used to calculate concentrations from single and multiple sources at given receptor points, wind speeds, and wind directions.

Definition of the concentration under unfavorable stratification (19) means that it permits to minimize the initial meteorological information necessary for the calculations, confining the choice to the indicated values of A for different climatic areas. Often this is sufficient, because to require that the maximum concentration under unfavorable conditions must satisfy air quality standards, also concentration standards under all other meteorological conditions will be satisfied. Coefficient $A = 0.3(K_1/\varphi_o u_1)$ is determined from data on spatial-temporal distribution of turbulent parameters (Climatic characteristics). If q is expressed in mg/m^3, M in g/s, V in m^3/s, and H in m, then the value of A over the territory of the former USSR will vary from 140-160 for zones with moderate turbulence, located in the Central and Northern halves of the European part of the country to 250 for zones with the most intensive turbulent exchange in subtropics of Central Asia and in Transbaikal region [1-3]. For other countries it is recommended to establish A according to similarity of climatic conditions.

The values m and n are derived from the graphs in fig. 4 and 5 accordingly; they depend on the following auxiliary parameters:

$$f = 1000\frac{w_0^2 \cdot D}{H^2 \cdot \Delta T} \quad V_m = 0.65\sqrt[3]{\frac{V \cdot \Delta T}{H}} \tag{20}$$

$$V_m' = 1.3\frac{w_0 \cdot D}{H} \quad f_e = 800 \cdot (V_m')^3 \tag{21}$$

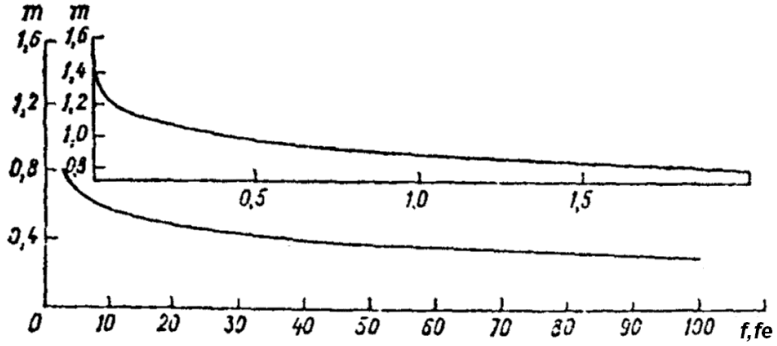

Figure 4 – Dependence of dimensionless coefficient m on parameters f, f_e

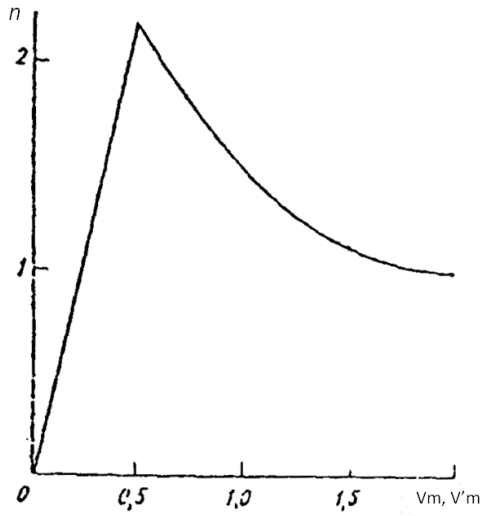

Figure 5 – Dependence of dimensionless coefficient n on parameters V_m, V'_m

The distance x_{mu} from a single point emission source, at which a ground-level concentration will obtain the maximum value q_{mu} under unfavorable meteorological conditions:

$$x_{mu} = \frac{5-F}{4} d \cdot H \tag{22}$$

where d is a dimensionless coefficient, defined by exhaust velocity, height of emission source and temperature difference. For hot emissions (f < 100), d is calculated by following way:

- for $V_m \leq 0.5$: $d = 2.48\left(1 + 0.28 \cdot \sqrt[3]{f}\right)$
- for $0.5 \leq V_m \leq 2$: $d = 4.95 \cdot V_m\left(1 + 0.28 \cdot \sqrt[3]{f}\right)$ (23)
- for $V_m > 2$: $d = 7 \cdot V_m\left(1 + 0.28 \cdot \sqrt[3]{f}\right)$

The unfavorable (critical value) wind velocity u_m depends on parameter V_m:

- for $V_m \leq 0.5$: $u_m = 0.5$
- for $0.5 \leq V_m \leq 2$: $u_m = V_m$ (24)
- for $V_m > 2$: $u_m = V_m\left(1 + 0.28 \cdot \sqrt{f}\right)$

Coefficient F in (19) determines the effects of pollutant sedimentation (fall) rate w. It varies from unity for gases and light pollutants to 2-3 for heavy particles and depends on the efficiency of dust cleaning. In case if sedimentation rate w is known the coefficient F is equal to:

- 1, if $w/u_m \leq 0.015$, where u_m –unfavorable wind velocity.
- 1.5, if $0.015 \leq w/u_m \leq 0.030$
- 2.0 – 3.0, if $w/u_m > 0.03$, with taking into the emission purification factor (EPF): if EPF is at least 90%, F = 2; if EPF is in the range 75-90%, F=2.5; F = 2; if EPF is less than 75%, F=3.

The coefficient F depends from w/u_m as shown in Fig. 6.

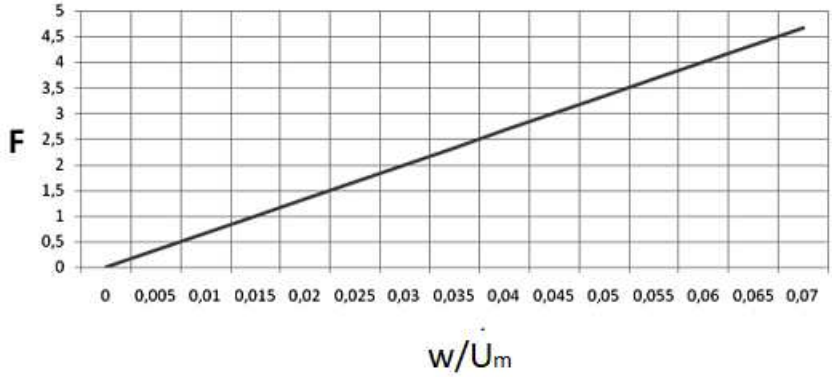

Figure 6 – Dependence of dimensionless coefficient F coefficient on w/u_m

The calculation of spatial distribution of the pollutant concentration implies the calculation of the three basic parameters: the maximum ground-level concentration q_{mu}; critical wind velocity u_m; the distance from the emission source to the point of maximum ground level concentration $x_{mu.}$

The highest concentration of the pollutant in the air q_{mu} for a given emission source appears in case of critical wind velocity and only at a certain distance x_{mu} in streamwise direction.

In general case for a grid of points under the control we may use the formula:

$$q = q_m \cdot r \cdot s_1 \cdot (x/\rho \cdot x_m) \cdot s_2 \cdot (u, y/x) \quad (25)$$

where $r = r(u/u_M)$ and $\rho = \rho(u/u_M)$, with $r(1) = p(1) = 1$ and $s_1(1) = s_2(u,0) = 1$, and the graphs for s_1 and s_2 determining are shown in fig. 7 and 8.

Dispersion Modelling for CAEPport

Emissions Dispersion for CAEPport was calculated by PolEmiCa for the following emission sources: Aircraft during LTO cycle; Start-up procedures, GSE; APU/GPU; Power plants; Fuel Farms; Landside vehicle traffic and Parking Facilities. Power plants and fuel farms are the typical stationary sources of air pollution in airports. The Fuel Farm consists of 5 kerosene tanks with a diameter of 40 m and a height of 15 m each. They all have a sealed internal floating roof and contain on average 18 million litres of kerosene each (~24% of the tank volume). Calculated emission HC (fuel vapor) into atmosphere for fuel farm is 0.3136 g/s. The Power Plant has two oil burners of 40 MW performance each. Their fuel consumption (oil) is 3,600 kg oil/hour (1 kg oil/s in total) and their operating time is 3000 hours per year each. Power Plant provides all heating/cooling requirements of the passenger terminal, maintenance, and cargo buildings.

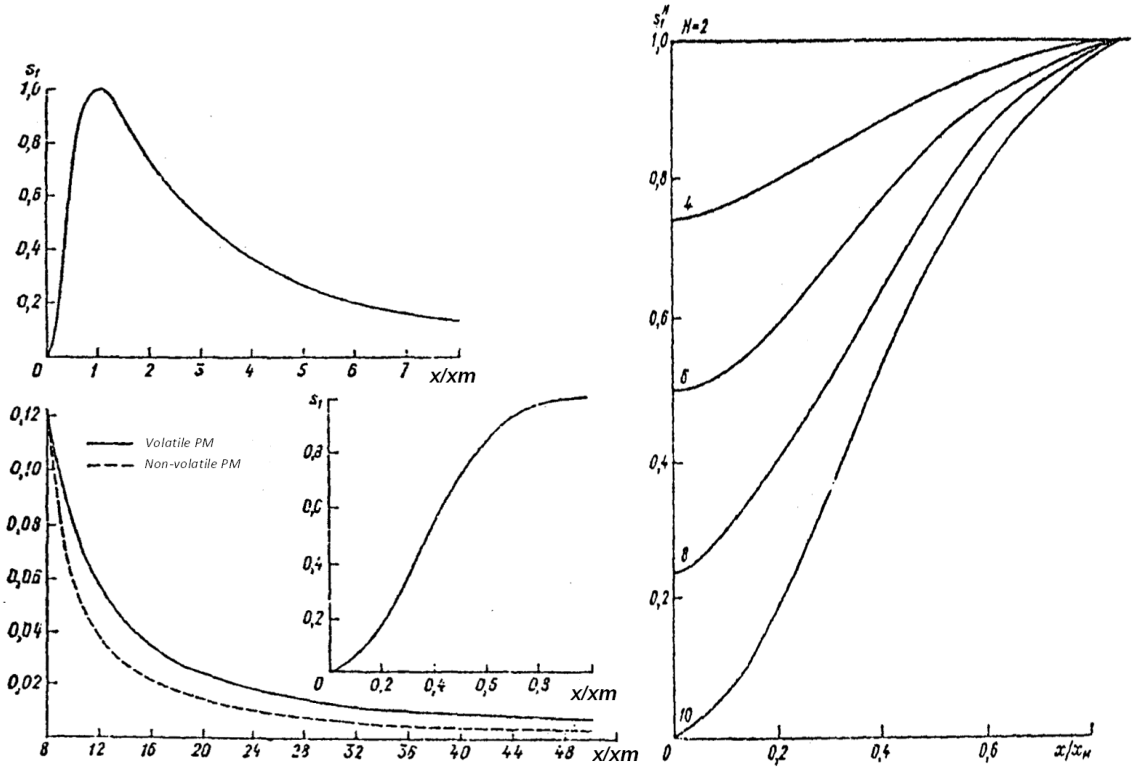

Figure 7 – Dependence of dimensionless coefficient s_1 on distance from point emission source for volatile and non-volatile substances

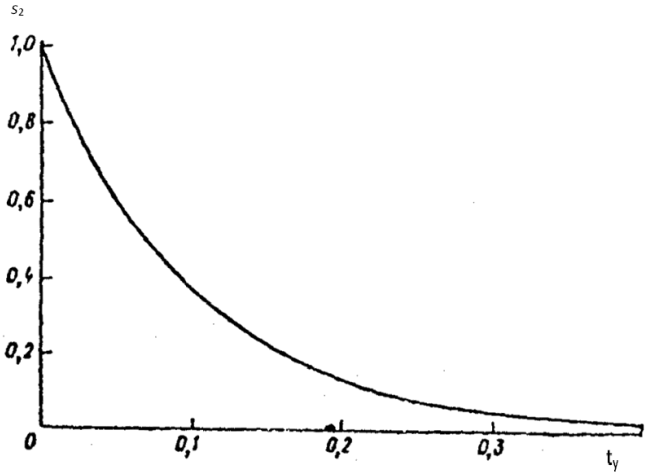

Figure 8 – Dependence of dimensionless coefficient s_2 on wind velocity and relation y/x

Calculated emission rates for power plant in atmosphere are the following:

Emission substance		Max emission factor, g/s	Annular emission, t/year
Code	Type		
301	NO (Nitrogen (IV) oxide)	5.7342372	61,929684
304	NO (Nitrogen (II) oxide)	0,9318136	10,063587
328	Soot	1,2753978	13,774296
330	SO2 (Sulfur dioxide)	7,6440000	82,555200
337	CO	5,4129816	58,460201
703	benz/a/piren (3,4-benzpiren)	0,0000027	0,0000292
2904	Fuel oil ash	0,063327	0,6839316

Dispersion calculations for total air pollution (all sources are included) by NOx emission is shown in Fig. 9. Maximum concentrations are observed at runway end, where 90 % of operations are provided. The contribution from stationary sources to this field is shown in fig. 10.

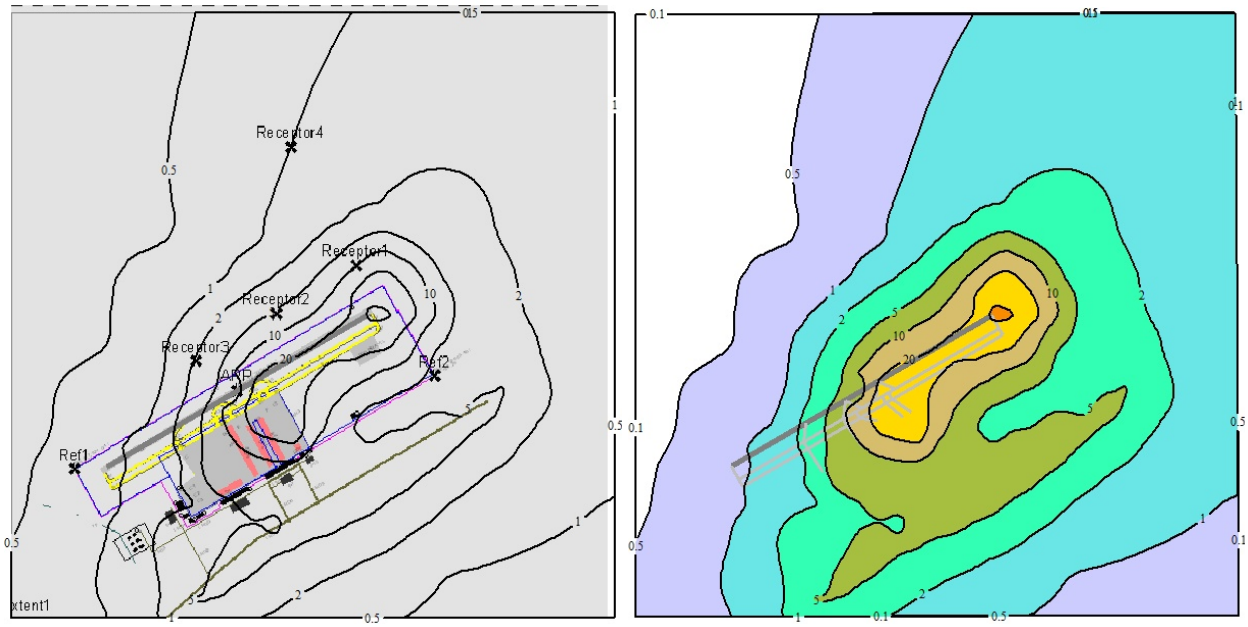

Figure 9 – CAEPort air pollution for NOx: a) concentration contours on a simplified map of the CAEPport in µg/m^3; b) the same concentration contours with colored area for specific values

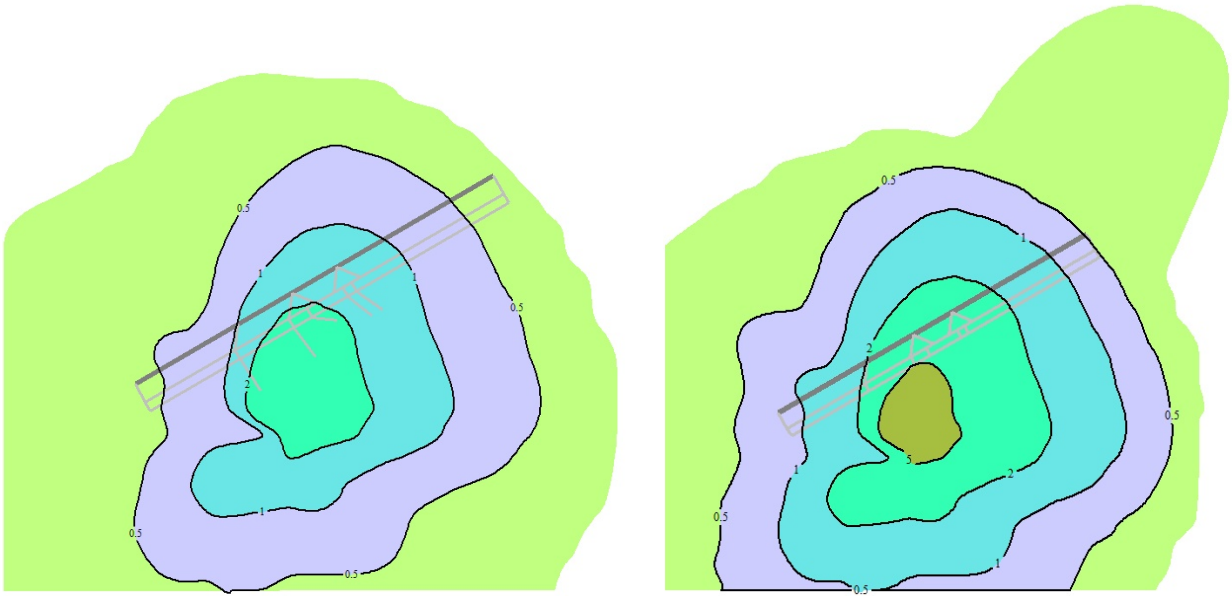

Figure 10 – CAEPort air pollution by Power Plant emission in µg/m^3: a) with emission rate for Power Plant, calculated by US method; b) with emission rate for Power Plant, calculated by Ukrainian method (shown in Table)

PolEmiCa is still developing in a number of directions, in that number via comparison with measurements of concentrations from aircraft engine emission in airports, made in Ukraine and worldwide.

REFERENCES

1. *OND-86*. The method for calculating the concentration of harmful substances emitted by industrial enterprises into the atmospheric air // Berlyand, M.E., Gasilina, N.K., Genikhovich, E.L., Onikul, R.I. & Glukharev, V.A., Gidrometeoizdat, Leningrad, 1987, 94 p.

2. *Berlyand M. E. Contemporary Problems of Atmospheric Diffusion and Air Pollution,* Hydrometeorological Publishing House, Leningrad, 448 pp. (in Russian, Transl. into English: NEPC US EPA, Raleigh N.C., 1976; into German: Acad. Verlag, Berlin, 1982).

3. *Berlyand, M.E.* Forecast and control of air pollution, Gimiz, Leningrad, 1985, 272 p. [in Russian, Transl. into English: Kluwer Acad. publ., 1990, in press].

4. *Berlyand M. E.* Problems of industrial air pollution modelling considering soviet experience // Air

Pollution Modeling and Its Application VIII, Edited by Han van Dop and Douw G. Steyn, Proceedings of the Eighteenth NATO/CCMS International Technical Meeting on Air Pollution Modeling and Its Application, held May 13-17, 1990, in Vancouver, British Columbia, Canada. Springer Science+Business Media New York, 1991. pp. 1-16.

5. *Berlyand M. E. and Genikhovich E. L.* (1971) Atmospheric diffusion and air flow structure over inhomogeneous surface. In: *Meteorological Aspects of Air Pollution: Prec. Int. Symp.,* Leningrad, 1968, Hydrometeorological Publishing House, Leningrad, 49-69 pp. [in Russian].

6. *Berlyand M. E.* (1983) Forecasting of air pollution with emphasis on research in the U.S.S.R. WMO Environmental Pollution Monitoring and Research Programme, N 19, Geneva, Switzerland, 208 p.

7. *Berlyand M. E. and Onikul R. I.* (1977) Validation and comparison of methods of pollutants dispersion calculation. Transactions of the Main Geophysical Observatory, Leningrad, Vol. 387, pp. 23-26 [in Russian].

РЕФЕРАТ

Запорожець О.І. Концептуальні підходи оцінки стаціонарних джерел емісії аеропортів програмним комплексом PolEmiCA. // О.І. Запорожець, К.В. Синило // Вісник Національного транспортного університету. Серія «Технічні науки». Науково-технічний збірник – К.: НТУ, 2019. – Вип. 3 (45).

В статті виконано узагальнення та порівняння алгоритмів обчислення максимально-разових концентрацій забруднення повітря характерними джерелами в районі та околиці аеропорту.

Об'єкт дослідження – якість повітря навколо злітно-посадкових смуг аеропортів.

Мета роботи – визначення і обґрунтування методів обчислення характерних джерел викиду забруднювальних речовин навколо злітно-посадкових смуг аеропортів.

Метод дослідження – аналіз, узагальнення та порівняння наявних відомостей про джерела викиду забруднювальних речовин навколо злітно-посадкових смуг аеропортів.

Використання методів обчислення джерел викиду забруднювальних речовин і якості повітря аеропортів для обґрунтування санітарно-захисних зон навколо злітно-посадкових смуг аеропортів.

Результати статті можуть бути впроваджені в процесі експлуатації авіатранспортних систем.

КЛЮЧОВІ СЛОВА: АЕРОПОРТИ, ДЖЕРЕЛА ВИКИДУ ЗАБРУДНЮВАЛЬНИХ РЕЧОВИН, МІСЦЕВА ЯКІСТЬ ПОВІТРЯ АЕРОПОРТІВ

ABSTRACT

Zaporozhets O.I., Synylo K.V. The main concepts of the PolEmiCA technique for stationary sources of emission in airporst. Visnyk of National Transport University. Series «Technical sciences». Scientific and Technical Collection. Kyiv. National Transport University. 2019. Vol. 3 (45).

In the paper the synthesis and comparison of the available information on local air quality in the vicinity of the airports presented.

Object of study – the local air quality around the airport.

Purpose – to identify and study the prospects for local air quality in the vicinity of the airports.

Research methods – analysis and comparison of available information on local air quality in the vicinity of the airport.

The use of local air quality assessment to justify sanitary zones around runways of airports.

The results can be incorporated into the operation of aviation vehicles in intelligent transport systems.

KEYWORDS: AIRPORTS, STATIONARY SOURCES OF EMISSION IN AIRPORST, LOCAL AIR QUALITY

РЕФЕРАТ

Запорожец А.И. Концептуальные подходы оценки стационарных источников эмиссии аэропортов программным комплексом PolEmiCA / А. И. Запорожец, К.В. Синило // Вестник Национального транспортного университета. Серия «Технические науки». Научно-технический сборник – К.: НТУ, 2019. – Вып. 3 (45).

В статье выполнено обобщение и сравнение алгоритмов вычисления максимально-разовых

концентраций загрязнения воздуха характерными источниками в районе и окрестностях аэропорта.

Объект исследования – качество воздуха вокруг взлетно-посадочных полос аэропортов.

Цель работы – определение и обоснование методов вычисления характерных источников выброса загрязняющих веществ вокруг взлетно-посадочных полос аэропортов.

Метод исследования - анализ, обобщение и сравнение имеющихся сведений об источниках выброса загрязняющих веществ вокруг взлетно-посадочных полос аэропортов.

Использование методов вычисления источников выброса загрязняющих веществ и качества воздуха аэропортов для обоснования санитарно-защитных зон вокруг взлетно-посадочных полос аэропортов.

Результаты статьи могут быть внедрены в процессе эксплуатации воздушных систем.

КЛЮЧЕВЫЕ СЛОВА: АЭРОПОРТЫ, ИСТОЧНИКИ ВЫБРОСОВ ЗАГРЯЗНЯЮЩИХ ВЕЩЕСТВ, МЕСТНОЕ КАЧЕСТВО ВОЗДУХА АЭРОПОРТОВ

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