DETERMINATION OF VARIABLE LAW OF THE TURBULENT DIFFUSION PARAMETERS WITH TIME INTERVAL IN THE AIR ENVIRONMENT IN VIETNAM

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ABSTRACT

Determination of variable law of the turbulent diffusion parameters with time interval in the air environment in Vietnam. Models of air pollutant transportation have been used popularly for evaluating air environmental state and forecasting air pollution in urban and industrial areas. However, the parameters used in the above mentioned models are all developed under foreign country conditions then the specialties of the monsoon tropical climatic region in Vietnam have not been reflected.

The paper presents the method of improving the turbulent diffusion parameters responding to climatic condition in Vietnam. The results are indicated to be high exactitude after having been tested by monitoring data.

Keywords: Atmospheric dispersion, improvement of turbulent diffusion parameters, tested calculation for urban areas.

Introduction

Models of air pollutant transportation have been used popularly for evaluating air environmental state and forecasting air pollution in urban and industrial areas. However, the parameters used in the above mentioned models were all developed under foreign country conditions then the characteristics of the monsoon tropical climatic region in Vietnam have not been reflected.

The paper presents the method of improving the turbulent diffusion parameters in Gauss and Sutton models through determination of size of horizon turbulent diffusion Ko in Berliand model. The authors have established the variable law of Ko with averaged time interval in inertia interval and out of balance interval. At the same tine, the series of meteorological observation data within three continual years (97-99) in Hanoi, Hue and Hochiminh City was also used to evaluation the accuracy and to determine proportional coefficients of established theoretical formulas. The tested results show that the theoretical curves correspond competently experimental ones. So, if semi-experimental formulas established by authors (in which proportional coefficients of theoretical formulas determined from tested measured data) is replaced in Berliand, Sutton and Gauss models then it is very convenient to apply these models for evaluation, prediction of transportation of air pollutants in air environment in Vietnam.

Establishment of variable law of the turbulent horizontal diffusion coefficient K_y with time interval τ

There are often 2 kinds of motions existing in atmosphere as follows:

- Turbulent motion
- Layer motion

However, turbulent motion is most important in bringing about vertical transportation and diffusion of particles (suspended dust and air pollutants...) in the air. Turbulent diffusion is characterized by turbulent diffusion coefficients of K_x, K_y, K_z, in the three spatial directions OX, OY, OZ, which is related with the travel distance of Plant in the theory of modern statistic turbulence. So, the variable law of Ky can be established based on this theory. In addition, it is noted that the authors have indicated in the works {1} the relation between K_y and R_y determined by the following formulas:

$$Ky(\tau) = \int_0^{\tau} R_y(\tau)d\tau \qquad (1)$$

In which:

K_y: Turbulent diffusion coefficient in axis crossing the wind direction
$R_y(\tau)$ - Correlation function of velocity component with y- axis
τ - Time interval ($\tau=\Delta t$)

Consider 2 cases:

(1) For the size of averaged time which is out of the balance interval $\tau>\tau^*$ (τ^* is the external size of turbulent diffusion).

In this case, according to the structural law of turbulent diffusion then structural function of time $D_y(\tau)$ is proportional linearity to the Iundin Law. It means:

$$D_y(\tau)=\alpha,\tau \qquad (2)$$

Where: α is proportional coefficient

Using the formula relating between the correlation function and structural function for process of turbulent diffusion considered as stationary, we have:

$$R_y(\tau) = \frac{1}{2}\left[D_y(\infty) - D_y(\tau)\right] \qquad (3)$$

Where: $D_y(\tau)$ is the saturated value of structural function
From (1-3), it was brought out that:

$$Ky(\tau) = \frac{1}{2}D_y(\infty).\tau - \frac{1}{4}\alpha\tau^2 = a.\tau - b\tau \qquad (4)$$

Set here: $a = \frac{1}{2}D_y(\infty)$, $\quad b = \frac{1}{4}\alpha$ are proportional coefficients.

In this case, it means horizontal diffusion coefficient Ky varies with τ, *responding to law of parabola*
(2). The size of average time τ belonging to the inertial interval $\tau_0<\tau<\tau^*$, τ is the internal size of turbulent diffusion).

In this case, structural function $D_y(\tau)$ is proportional to τ with 2/3-exponent (the Conmogonop Obukhop 's law of 2/3), it means:

$$D_y(\tau) = \beta.\tau^{2/3} \qquad (5)$$

From (1), (3) and (5) the following law was brought out:

$$K_y(\tau) = \frac{1}{2}D_y(\infty).\tau - \frac{3}{5}\beta\tau^{5/3}$$

or

$$K_y(\tau) = A\tau - \frac{3}{5}\beta\tau^{5/3} \qquad (6)$$

In which: $A=\frac{1}{2}D_y(\infty),\quad B=\frac{3}{5}\beta$ are proportional coefficients

The formularies (4) and (6) expresses the variable law of horizontal turbulent diffusion coefficient Ky with averaged time interval τ and presents the law of Ko with τ at the same time.

Determination size of horizon turbulence K_0

In order to calculate the concentration of air pollutants with Berliand model, the coefficient Ko need determining and can be determined by the following formula:

$$K_0=K_y/U \qquad (7)$$

Where:

K_y is horizontal turbulent diffusion coefficient (m^2/s)

U is the averaged wind velocity taken measurement at the ground (or direct taken from meteorological observation data at the ground).

Determination of extended dispersion coefficients Cy and Cz in Sutton model

The parameters C_y and C_z in Sutton model are called extended turbulent dispersion coefficients of Sutton, related to coefficient Ko as follows:

$$C_y^2 = 4\,K_0 \qquad (8)$$

As it was assumed that diffusion process was a stationary one, turbulent field was considered non-isotropic and homogeneous, and due to Z only varied in the interval of $(0, +\infty)$, so it was considered as:
$C_z = 0.5\ C_y$. Therefore, when Ko is available, Cy and Cz will be determined directly.

Determination of dispersion coefficients of gauss σ_y, σ_z

The Gaussian dispersion coefficients of air pollutants in the direction of y and z, crossing the wind blowing direction (aligned in x-axis), for process of transportation of air pollutants considered to be stationary, can be directly calculated through the value of Cy and Cz (or Ko), determined by the following formularies:

$$2\sigma_y^2= C_y^2.x^{2-n};\qquad 2\sigma_z^2= C_z^2.x^{2-n}; \qquad (9)$$

$$2\sigma_y^2= 4K_0.x^{2-n};\qquad 2\sigma_z^2= K_0.x^{2-n}; \qquad (10)$$

From (10) it was brought out that $\sigma_z^2= 0{,}25\sigma_y^2$ or $\sigma_z= 0{,}5\sigma_y$. This can be explained to be similar to the case of $C_z = 0.5\ C_y$. It means that in the case of dispersion of air pollutants in the air near ground surface corresponding to law of standard contribution and the emission sources keep constant over the time (the stationary diffusion process), then dispersion coefficient σ_z (with z varies in the interval from $0\div\infty$) is an half of dispersion coefficient σ_y (with y varies in the interval from $-\infty\div+\infty$).

Those above diffusion parameters are expressed via $K_0=K_y/U$, in which the variable law of $K_y=f(\tau)$ was determined by the formula at the item (1). So, only when proportional coefficients a, b in formula (4) is determined corresponding to climatic conditions of research areas, can we calculate the turbulent diffusion parameters with the averaged time interval τ, corresponding to the environmental standard regulation of Vietnam 1995 (for example: the averaged time interval for toxic gas concentration is 1, 8, 24 hours).

Determination of proportional coefficients a, b in the formula expressing variable law of horizontal turbulent diffusion coefficients K_y with time interval τ

We used the method of minimal square in order to determine coefficients a, b.
Set square deviation:

$K_y(\tau_i) = y_i = a\tau_i - b\tau_i^2$, we find square deviation as:

$$Y=\sum_{i=1}^{n}\delta_i^2=\sum_{i=1}^{n}\left[a\tau_i-b\tau_i^2-y_i\right]^2 \qquad (11)$$

In order to get the minimal value of this deviation, then:

$$\frac{\partial Y}{\partial a}=\frac{\partial Y}{\partial b}=0$$

We obtained following equation system from calculating above ones:

$$\begin{cases}(\sum_{i=1}^{n}\delta_i^2)_a{}'=\sum_{i=1}^{n}2\tau_i\left[a\tau_i-b\tau_i^2-y_i\right]=0\\(\sum_{i=1}^{n}\delta_i^2)_b{}'=\sum_{i=1}^{n}2\tau_i^2\left[a\tau_i-b\tau_i^2-y_i\right]=0\end{cases} \qquad (12)$$

Solution of above equation system (12) were:

$$\begin{cases}a=\dfrac{\sum_{i=1}^{n}y_i\tau_i+b\sum_{i=1}^{n}\tau_i^3}{\sum_{i=1}^{n}\tau_i^2}\\ b=\dfrac{(\sum_{i=1}^{n}y_i\tau_i^2).(\sum_{i=1}^{n}\tau_i^2)-(\sum_{i=1}^{n}y_i\tau_i).(\sum_{i=1}^{n}\tau_i^3)}{(\sum_{i=1}^{n}\tau_i^3)^2-(\sum_{i=1}^{n}\tau_i^4).(\sum_{i=1}^{n}\tau_i^2)}\end{cases} \qquad (13)$$

In order to determine a, b, we need to calculate the horizontal turbulent diffusion coefficients $K_y(\tau_i)=y_i$ corresponding to the values of (τ_i) based on the meteorological observation data at the research areas.

Pilot calculation for 3 areas of Hanoi, Hue, Hochiminh City was carried out step by step as follows:

Calculating Data

Data on wind speed and direction, frequencies of wind at the meteorological observation station characterized for the surveying area were used for calculation. Series of data were taken within 3 years to assure statistic stability. Data were taken with 4obs, corresponding to times point of observations: 1,7,13, 19. Thus, the sequent time interval for the values of wind velocity is τ=6h. Series of data were divided into 4 seasons for each year: spring (months of II, III, IV), summer (months of V, VI, VII), autumn (months of VIII, IX, X), and winter (months of XI, XII, I). Beside, the series of within 3 years were used to calculate of parameters characterized for entire year.

With each wind direction, the formula used for calculating values of V_i is:

$$V_y=\left|\vec{V}\right|.\sin(\varphi) \qquad (14)$$

Where:

φ is the deviation angle of vector of wind velocity $\vec{V}$ with x axis
$|\vec{V}|$ is module of wind velocity at time point of observation
(*): in some material, φ is also called open angle of horizontal turbulent diffusion.

Calculation of turbulent diffusion coefficient K_y

In meteorology, the analytical expression of random process does not always exist but only its diagram is taken by autograph or its garbage value table with the intermittent value of time is tabulated. In that case, the approximated integral can be altered by sum of values.

$V_y(t)$ is given as a "reality" of process of random. V(t) is egodic in the interval [0, T]. The interval [0, T] was subdivided into n the equal parts and this equals τ

$$T=N.\tau \qquad (15)$$

It will be make great errors if these data are not been treated. Therefore, this data need interpolating and extrapolating before calculation at the same time with making series of data smooth following the method presented in (4)

Basing on the formula $V_y = |\vec{V}|.\sin(\varphi)$ we could calculate the components of V_y corresponding to the angles of $\varphi=5^0$, 10^0, 15^0 and 20^0, $22,5^0$. After that, the values of correlation function, standardized correlation function were calculated by the components of wind velocities V_y for each season.

The formula for calculating the above functions as follows:

$$R_y(k\tau) = \frac{1}{N-k}\sum_{i=1}^{N-k}(V_{y_{i+k}} - \overline{V_y})\ (V_{y_i} - \overline{V_y}) \qquad (16)$$

$$D_y(k\tau) = \frac{1}{N-k}\sum_{i=1}^{N-k}(V_{y_{i+k}} - \overline{V_{yi}})^2 \qquad (17)$$

$$r_y(k\tau) = \frac{R_y(k\tau)}{\delta^2 v_y} \qquad (18)$$

Where:

$R_y(k\tau)$: the values of time correlation function of wind velocity
$D_y(k\tau)$: the value of time structural function of wind velocity
$r_y(k\tau)$: the values of standardized correlation function of wind velocity V_y
$\delta^2 v_y$: Squared deviation of wind velocity V_y
N: Sum of the values of V_y responding to each season
k=1,2,3.... N-1; τ=6h

The calculation of value of turbulent diffusion coefficient Ky with averaged time interval τ based on the curves of correlation functions.

$$K_y(\tau) = \int_0^\tau R_y(\tau)d\tau \qquad (19)$$

Basing on the results of valuation of "stationary" and the curves of structural function D_y, it could be selected limit of variable interval of τ, then abscises was subdivided into n the equal Δτ intervals. Whereat, at the point of time of τ_i, we defined formula of calculation of horizontal turbulent diffusion coefficient as follows:

$$K_y(\tau_n) = \sum_{i=1}^{n} R_{yi}\Delta\tau_i \qquad (20)$$

with $n = \overline{1, m}$

Averaging values of Ky corresponding to angles of φ, we obtained mean value of Ky with time, characterized for each surveying season.

The values of a, b coefficients for the areas suiting with seasons within a year were computerized as follows:

Table 1.

Areas	Coefficient	Spring	Summer	Autumn	Winter
Hanoi	b	$5{,}50.\ 10^{-6}$	$3{,}62.\ 10^{-6}$	$1{,}56.\ 10^{-6}$	$4{,}61.\ 10^{-6}$
	a	$1{,}02.\ 10^{-2}$	$6{,}15.\ 10^{-3}$	$3{,}69\ .10^{-3}$	$7{,}14.\ 10^{-3}$
Hue	b	$8{,}29.\ 10^{-6}$	$5{,}87.\ 10^{-6}$	$1{,}27.\ 10^{-5}$	$1{,}31.\ 10^{-5}$
	a	$6{,}12.\ 10^{-3}$	$6{,}16.\ 10^{-3}$	$2{,}23.\ 10^{-2}$	$1{,}23.\ 10^{-2}$
Hochiminh city	b	$3{,}15.\ 10^{-6}$	$1{,}19.\ 10^{-6}$	$1{,}42.\ 10^{-6}$	$5{,}37.\ 10^{-6}$
	a	$5.03.\ 10^{-3}$	$2{,}60.\ 10^{-3}$	$2{,}24.\ 10^{-3}$	$1{,}53.\ 10^{-2}$

Valuation of errors

Values of average mean squared error: $\frac{1}{n}\sum_{i=1}^{n}\delta_i^2 = \frac{1}{n}\sum_{i=1}^{n}\left[a\tau_i - b\tau_i^2 - y_i\right]^2$ was calculated basing on a, b coefficients as follows:

Table 2.

Area	Spring	Summer	Autumn	Winter
Hanoi	0,003565	0,001983	0,002795	0,002474
Hue	0,001455	0,000930	0,002060	0,003657
Hochiminh City	0,000160	0,000040	0,002333	0,000503

From the above table, it can be found that errors vary from interval 10^{-2}-10^{-5}. This indicates that the theoretical curves corresponding competently to experimental ones.

After a, b coefficients were replaced in the formula of (4), we obtained semi-experimental formula which expresses the variable law of Ky with τ, responding to τ≥ 1h. The formula of (6) is only correct with τ<1h, so measured data of wind velocity by autograph with small inertia need using for determining proportional coefficients of A, B. However, Vietnam standard for permissible concentration of air pollutants only corresponds to averaged time interval $\tau \geq 1h$. So, if formulary of (4) with a, b - coefficients determined is replaced in Berliand, Sutton and Gauss models then it is very convenient to apply these models for evaluation, prediction of transportation of air pollutants in air environment. The other parameters such as turbulent index n, turbulent diffusion coefficient K_1 can be calculated through formulas expressing the variable law of wind velocity and temperature with height in the air layer near ground surface.

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