EnviroInfo 2009 (Berlin)
Environmental Informatics and Industrial Environmental Protection: Concepts, Methods and Tools

Applying Fixed Box Model to Calculate the Temporal Variance of the Concentration of PM10 in Thanh Xuan District, Hanoi (Vietnam)

Pham Ngoc Ho, Duong Ngoc Bach, Vu Van Manh
Research Center for Environmental Monitoring and Modeling,
Faculty of Environmental Sciences, Hanoi University of Science, Vietnam National University, Hanoi
334 Nguyen Trai Street, Thanh Xuan District, Hanoi, Vietnam
hopn@vnu.edu.vn
bach_tnt@yahoo.com
fesvvm@yahoo.com

Abstract

This report presents the initial research results of applying the Fixed Box Model to calculate the temporal variance of the concentration of particulate matter of 10 micrometers (PM_{10}) one of the air pollutants that most commonly affects people's health. The input parameters (area source capacity of PM_{10}, wind speed, mixing height, size of area source) were estimated based on the area source emission inventory results including: road source, mobile source, construction source, industry source and household domestic source in Thanh Xuan District. This emission inventory project was carried out from 9/2007 to 3/2008 by Hanoi Center for Environmental and Natural Resources Monitoring and Analysis (CENMA) and Research Center for Environmental Monitoring and Modeling (CEMM) - Hanoi University of Science, of which, CEMM played a consultative role. The project was sponsored by the Swiss - Vietnamese Clean Air Program (SVCAP). The results show that:

- The graph describing the temporal variance of the concentration of PM_{10} has an exponential function, rising gradually until it reaches a saturated state.
- Concentration of PM_{10} C(t) is in inverse proportion to wind speed (U) and mixing height (H) at a fixed box length (L) and area source capacity (M_s).
- There exists a specific time constant τ for life time of pollutants in each case.
- The results from the Fixed Box Model are verified by real data get high accuracy.

Keywords: *Particulate Matter, Fixed Box Model, Emission Inventory*

1. Theoretical background of the Fixed Box Model

(P.N.Ho, V.V. Manh *et al.* 2005, P.N.Ho, D.N.Bach 2006)

Area source is the set of emission sources in a large area unit such as the toxic vapor dispersion from transportation activities, manufactures, households' cooking activities, dust from coal and sand banks, etc. If an area source is created from some point sources which are not very large, mathematical models can be used to calculate for each point source and then their results will be aggregated to infer the concentrations of pollutants at the investigated points. Also, the surface area can be divided into a set of parallel road sources. Calculating formulas will be used for each road source and their results will also be aggregated.

Besides the above methods, we can also use a fixed box model in order to estimate the level of atmospheric pollution caused by area sources (districts, cities, mine areas, etc.). The advantage of the fixed box model in comparison with the dispersion models of point sources and line sources is able to solve a non steady state problem. Its content is as follows:

Assuming that the air block at the studied area has a parallelepiped shape with length L(m), width d(m), and height H(m) which is often the height of atmospheric turbulent mixing layer. Capacity of area source is M_s (mg/m^2.s); the wind whose direction is perpendicular to the width has the average speed U (m/s); the wind takes a pollution flow which has the concentration C_v (mg/m^3)t; the concentration inside the parallelepiped is equal C (mg/m^3) (see figure 1.1):

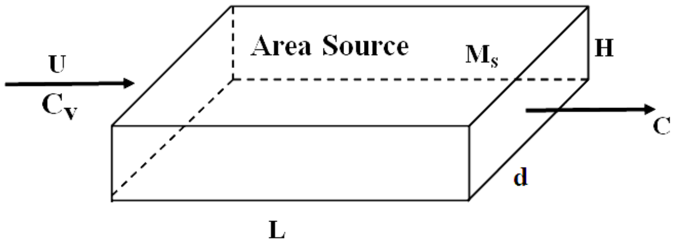


Figure 1.1. Parallelepiped characterizing the air block at the studied area

Suppose that pollutants do not diffuse through 2 boundary slices parallel with wind direction as well as with top and bottom slices, it will create the identical average concentration of pollutants in the air box. According to the law of mass balance, we must have:

$$LdH\frac{\partial C}{\partial t} = M_s Ld + dHuC_v - dHuC \qquad (1.1)$$

It means that: the variation speed of pollutants in the box = total of pollution level inside the box – pollution level going out of the box.

If the time span is infinite (t→ ∞) the variation of pollutant reaches the stable equilibrium: $\frac{\partial C}{\partial t} = 0$ (steady state), from the equation (1.1) we have: $C_\infty = \frac{M_s.L}{u.H} + C_v$ (1.2)

From the equation (1.2) it can be found that if the air going inside the box is clean (C_v=0) the stable pollutant concentration will be in direct ratio to the capacity of emission source M_s and in reverse ratio to coefficient uH. If wind flows takes pollutants with it ($C_v \neq 0$) then the effect of wind, which increases the pollutants in the parallelepiped, must be added in.

In case of transient state: $\frac{\partial C}{\partial t} \neq 0$

Considering C_0 as the concentration of pollutant in the air box at the studied area at the time t=0, solving the differential equation (1.1) we will have the following result:

$$C(t) = \left(\frac{M_s L}{uH} + C_v\right).\left(1 - e^{\frac{-ut}{L}}\right) + C_0 e^{\frac{-ut}{L}} \qquad (1.3)$$

If wind flow blows into the box does not take pollutants with it and C_0=0, the equation (1.3) becomes:

$$C(t) = \frac{M_s L}{uH}\left(1 - e^{\frac{-ut}{L}}\right) \qquad (1.4)$$

When t = τ = L/u is called time constant, which characterizes the residual time of pollutant in the box, the formula (1.4) becomes:

$$C(u) = \frac{M_s L}{euH}(e-1) \qquad (1.5)$$

2. Calculation

2.1 Calculating the input parameters of the model based on the real data of emission inventory in Thanh Xuan District

(P.N.Ho, V.V. Manh *et al.* 2007, CENMA 2008)

2.1.1 Dimension of the box

Length L (maximum): 5310 m; Width d (maximum): 3130 m

2.1.2 Calculating the capacity of area source Ms of PM_{10}

Area sources in this case are the emission sources such as road sources (42 roads), mobile sources (emission from vehicles on 42 roads), construction sources (4 areas of civil construction and construction of 105 households), emission sources from manufactures (22 sources) and household domestic sources (47094 households).

2.1.2.1 Calculating the emission capacity of PM_{10} from road sources

- Emission of PM_{10} from a type of vehicles on road is calculated according to the following formula:

M_{PM10} = (Ef x Sum of VKT x365)/1000000 (ton/year) (2.1)

- VKT (Vehicles Kilometers Traveled) is the number of km which vehicle travels in one day;
- Ef: is the road emission coefficient of PM_{10} emitted by each vehicle (g/km).

In which: **Ef=k(sL/2)0.65(W/3)1.5(1-P/4N)** (AP42, EPA, 1999).

- k: coefficient considering the dimension of PM (g/km); sL: quantity of alluvia on the road surface (g/m^2) varying from 0 - 300g/m^2; W: average weight of vehicle (ton); P: total rainy days in year; N: number of days in year, N=365 days.

The concretely calculated parameters are in the following table:

Vehicle type	4-16 places	24 places and over	Lorry	Container truck	Bus	Motorbike
W (ton)	3	5	5	25	10	0.12

k (PM_{10})	sL	P	N
4.6	10,20,30	86	365

Table 2.1. Parameters of vehicle and parameters related to road source

- The emission capacity of PM_{10} from road sources in Thanh Xuan District (calculating for all of 42 roads in Thanh Xuan District) is estimated as follows: 2438.88 (tons/year).

2.1.2.2 Calculating the emission capacity of PM10 from mobile sources

- Emission of PM_{10} from exhaust of vehicle is calculated according to the formula (2.1), in which:
- Ef: is emission coefficient of PM_{10} caused by exhaust of each type of vehicle, given in table 2.2.
- The emission capacity of PM_{10} from mobile sources in Thanh Xuan District (calculating for all of 42 roads in Thanh Xuan District) is estimated as follows: 148,79 (tons/year).

Vehicle types	Emission coefficient of PM_{10} (g/km)
4-16 places	0.10
24 places and over	0.15
Lorry	0.23
Container truck	3.28
Bus	1.97
Motorbike	0.10

Table 2.2. Emission coefficient of PM_{10} from mobile sources (AP42)

2.1.2.3 Calculating the emission capacity of PM_{10} from construction sources

- Emission of PM_{10} from construction activities is calculated according to the following formula:

M_{PM10} = S x t x Ef (ton/year) (2.2)

- S: The area of construction surface (m^2); t: duration of construction (month/year); Ef: emission coefficient = 0.025 kg/m^2.month (AP42)
- The emission capacity of PM_{10} from construction activities in Thanh Xuan District (including 4 concentrated civil construction areas and individual construction of 105 households) is as follows: 299.93 (tons/year).

2.1.2.4 Calculating the emission capacity of PM_{10} from domestic cooking activities

- Emission of PM_{10} from domestic cooking activities is calculated according to the following formula:

M_{PM10} = Mass of fuel used x Emission coefficient Ef (ton/year) (2.3)

- Emission coefficient from coal burning: Ef = 2.32 kg/ton ; Emission coefficient from gas burning: Ef = 0.0001 kg/ton
- The emission capacity of PM_{10} from domestic cooking activities in Thanh Xuan District (47094 households) is as follows: 45.11 (ton/year).

2.1.2.5 Calculating the emission capacity of PM_{10} from point sources

The formula of calculating the emission capacity of PM_{10} from small point sources:

- If the fuel used is coal:

M_{PM10} = Fuel amount x Emission coefficient Ef x ash coefficient of coal (ton/year) (2.4)

Ef= 0.357 kg/ton; Ash coefficient of coal: 3.125 kg/ton

- If the fuel used is petroleum and gas, the formula (2.3) can be used to calculated, in which: Ef = 0.2 kg/m^3 for petroleum and Ef = 0.000027053 kg/ton for gas; Ef coefficients in formulas (2.3) - (2.4) come from (AP42, PREIS 2004)
- The emission capacity of PM_{10} from small point sources in Thanh Xuan District (22 manufactures) is as follows: 20.14 (ton/year).

2.2 Adjustment of the calculated results of emission capacity in the studied area

At present, there is no standard emission coefficient for the above types of studied sources in Vietnam, United States emission coefficients (according to the document AP-42, EPA and PUNE project, India, 2004) (PREIS 2004) were used during the calculating process. Therefore, it is necessary to adjust the calculated results in order to obtain a relative accuracy. The adjustment principle is based on the surveys of each specific source to correct and estimate the emission capacity M for the studied area, the results are showed in table 2.3:

Emission sources	Calculated capacity M* according to document AP-42 and PUNE (ton/year)	Adjustment coefficient (d)	Adjusted capacity (ton/year) $M = M^*(d+1)$
	PM_{10}		**PM_{10}**
Household construction	179	0.2	214.8
Civil construction	120.93	0.3	157.21
Domestic cooking	45.11	0.15	51.88
Road source	2438.88	0.35	3292.49
Mobile source	148.79	0.15	171.11
Manufacture	20.14	0.2	24.17
Total	**2952.85**		**3911.65**

Table 2.3. Estimation of emission capacities of PM_{10}, from emission sources in Thanh Xuan District in 2007 with the adjustment coefficient d

2.3 Calculation Scenarios

2.3.1 The input parameters of fixed box model based on the table 2.3

- Emission capacity of area source M_s = 0.0136mg/m^{2}s ;
- The length of the box: = 5310 m; - The width of the box = 3130 m
- Mixing height: H_1= 120 m; H_2 = 200 m

Mixing height is the height H in the atmospheric boundary layer where the turbulent coefficient Az = KZζ = const with z > H; Of which, K_z is the vertical turbulent coefficient, ζ is the average density of the studied atmospheric layer.

The researches of Obukhov and Budyko (L.D.Quang, P.N.Ho 2006) showed that Profile of A_z (or turbulent coefficient K_z) in the atmospheric border layer has a linear dependence on the distance of vertical movement of turbulent cycle $l_z = \chi z$ (χ- Karman constant ≈ 0.4) in the equilibrium condition to the height $H=l_{zmax}$, corresponding with the height Z_{max} varying from 300-500m. Therefore, the height H can be estimated varies from 120-200m.

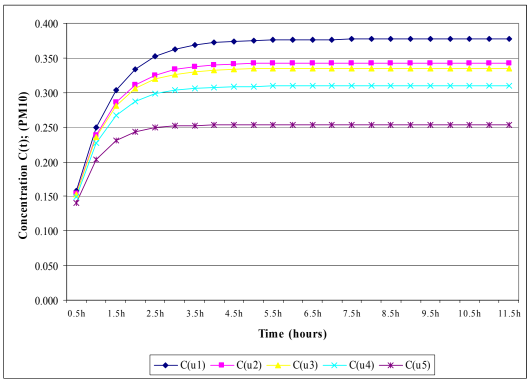
- Wind speed: wind speed and frequency are shown in the table 2.4.

No.	Wind direction	Annual average speed (m/s)	Wind frequence (%)
1	North	1.95	22.62
2	Northern East	2.38	34.95
3	East	1.60	26.68
4	Southern East	1.76	51.2
5	Northern West	1.8	14.21

Table 2.4. The wind regime in the area of Hanoi in 2007 (Lang station)

2.3.2 Calculated results

Case 1: with H_1 = 120 m:



Case 2: with H_2 = 200 m:

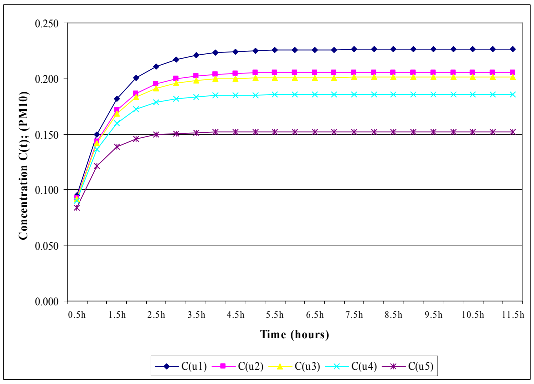


Figure 2.1. Temporal variance of PM_{10}

	u_1 = 1.6 m/s	u_2 = 1.76 m/s	u_3 = 1.8 m/s	u_4 = 1.95 m/s	u_5 = 2.38 m/s
τ (minute)	55.31	50.28	49.17	45.38	37.18
$C(mg/m^3);PM_{10}$	0.238	0.217	0.212	0.196	0.160

Table 2.5. Calculated results of pollutant concentration (C) corresponding to the residual time τ and the change of wind speed (H_1= 120m)

	u_1 = 1.6 m/s	u_2 = 1.76 m/s	u_3 = 1.8 m/s	u_4 = 1.95 m/s	u_5 = 2.38 m/s
τ (minute)	55.31	50.28	49.17	45.38	37.18
$C(mg/m^3);PM_{10}$	0.143	0.130	0.127	0.117	0.096

Table 2.6. Calculated results of pollutant concentration (C) corresponding to the residual time τ and the change of wind speed (H_2= 200m)

Parameter	u_5 = 2.38 m/s		u_1 = 1.6 m/s	
	t_∞(h)	C_{max} (mg/m^3)	t_∞(h)	C_{max} (mg/m^3)
PM_{10}	3.5	0.253	6.5	0.377

Table 2.7. Calculated results of concentration C_{max} corresponding to the time of starting saturation t∞ of pollutants in the case of H_1=120m

Parameter	u_5 = 2.38 m/s		u_1 = 1.6 m/s	
	t_∞(h)	C_{max} (mg/m^3)	t_∞(h)	C_{max} (mg/m^3)
PM_{10}	3.5	0.152	5.5	0.226

Table 2.8. Calculated results of concentration Cmax corresponding to the time of starting saturation t∞ of pollutants in the case of H_2=200m

In order to verify the calculated result of the model with the measured data, the measured data of PM_{10} at 3 points (50 Khuong Đinh – Thuong Đinh ; D_4 collective quarter VACVINA-Nhan Chinh and A_{11}- north of Thanh Xuan) in Thanh Xuan District together with the data of the emission inventory during 3 continuous days from 28-30/11/2007 have been used. The time of sampling: 4 times per day at 1h, 7h, 13h, 19h; the duration of sampling is 1h for each time, the measured data were averaged for each time, after that they were averaged for all of 4 times to get the specific values for 24h; and the value of concentration C_{max} from the saturate curves at t_∞ is considered as the average concentration of 24h which is taken to compare, the results are indicated in the table 2.9.

Parameter	Measured concentration (u = 2,2 m/s)	Calculated concentration of the model (H_1= 120m; u = 2,38m/s)	Relative error (%)	Measured concentration (u = 2,2 m/s)	Calculated concentration of the model (H_2= 200m;u = 2,38m/s)	Relative error (%)
PM_{10}	0,259	0,253	2,4	0,259	0,152	41,4

Table 2.9. Comparison between the calculated result of the model and the measured result (mg/m^3)

Table 2.9 shows that: the calculated result is closer to the measured result when $H_1<H_2$. Therefore, the estimation of mixing height suitable with the actual conditions plays an important role.

- The calculated results from the model that were smaller than the measured results corresponds with the physical significance because the measured concentration at the monitoring point is : $C_d = C_n + C_t + C_o$, of which: C_n is the existing foundation concentration, C_t is the calculated concentration of emission from area sources and C_o is the concentration generated by wind flow which takes pollutants from other areas into the box (this element has not been considered yet in the research).
- The calculated results from the model also indicate that there has been a scientific basic for the adjustment in emission inventory and the adjustment has obtained an acceptable accurate level.

3. Conclusions

- The above figures show that all of the lines of concentration of pollutant PM_{10} varying with time (corresponding to various wind speeds and mixing height) have the shape of exponential function, gradually increasing with time until a value t_∞ where the concentration reaches the saturation (the graph is parallel with the horizontal axis);

- The higher the wind speed is, the shorter the time of reaching saturation is. For example: in the case of calculating for u_5 = 2,38 m/s and H_1 = 120 m, the time for reaching the saturation state of PM_{10} is after 3,5 hours;
- Pollutant's concentration C(t) is in reverse ratio to wind speed U and mixing height H corresponding to the fixed box length L and area source capacity M_s;
- Defined the time constant τ, characterizing the residual duration of PM_{10} in the box corresponding to each studied case. The higher the wind speed is, the shorter the residual duration of pollutant is; With the wind speed varying from 1,6 – 2,38 m/s, the residual time τ of pollutant in the box is 55,31 - 37,18 minutes;
- Compared with the Vietnamese standard TCVN 5937-2005 (24h average), the concentration of PM_{10} is 1,6-2,5 times higher than the standard (in the case of wind speed 2,38 – 1,6m/s and mixing height H_1=120m). In the case of mixing height H_2=200m and wind speed = 1,6 m/s, the concentration of PM_{10} is 1,5 time higher than the Vietnamese standard.
- The calculated results from the model which were verified by the measured data indicated that the estimation of mixing height H = 120m gives the calculated result closer to the measured result;
- The initial result may have significance for studying the application of this fixed box model on evaluating the air quality in districts of Hanoi city in particular and urban areas of Vietnam in general.

Acknowledgement

The authors would like to express a sincere thank to the fund of the Swiss - Vietnamese Clean Air Program (SVCAP) as well as Hanoi Center for Environmental and Natural Resources Monitoring and Analysis (CENMA) who implemented the air emission inventory to get the measured data for serving the calculation in this report. Besides, the authors also sincerely thank the base study program that supported the finance for the research group to implement the base study project No.706206 in 2008.

References

AP-42: Compilation of Air Pollutant Emission Factors.

CENMA: Report of pilot emission inventory in Hanoi, Research Center for Environmental Monitoring and Modeling (CEMM) and Hanoi Center for Environmental and Natural Resources Monitoring and Analysis (CENMA), 2008.

EPA: Handbook for Criteria Pollutant Inventory Development, EPA-454/R-99-037,1999.

J.G.Kretzschamr: Some physical aspects of air pollution monitoring and modeling. E&M.RA 9601, VITO, Belgium, 1996.

Le Dinh Quang, Pham Ngoc Ho – Environmental dynamics of atmospheric boundary layer, Hanoi University of Science, Vietnam National University, Hanoi, 2006.

Pham Ngoc Dang – Air environment. Science and Technology Publishing House, Ha Noi, 2003.

Pham Ngoc Ho, Trinh Thi Thanh, Dong Kim Loan – Basic of air and water environment. Hanoi University of Science, Vietnam National University, Hanoi, 2007.

Pham Ngoc Ho, Hoang Xuan Co – Basic of meteorology. Science and Technology Publishing House, Ha Noi, 1991.

Pham Ngoc Ho, Vu Van Manh, Duong Ngoc Bach, Hoang Xuan Co, Dong Kim Loan, Pham Thi Viet Anh – Training document for air emission inventory. Swiss-Vietnamese Clean Air Programme (SVCAP), 1/2007.

Pham Ngoc Ho, Duong Ngoc Bach – Calculating the characteristics variable with time of PM_{10} generated from road and domestic sources in inner Hanoi. Science journal of Vietnam National University, Hanoi, Natural science and technology, Vol.XXII, No. 3BPT, 2006 (page 15-20).

Pham Ngoc Ho, Vu Van Manh, Pham Thi Viet Anh, Dong Kim Loan, Pham Thi Thu Ha, Duong Ngoc Bach and Do Manh Dung – The temporal statistical characteristics of air environment in urban areas of Hanoi. Proceeding of the 2nd National Conference on Environment, Hanoi, 4/2005.

PREIS: Pune Regional Emission Inventory Study, 2004.