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Pollutant dispersion over industrial sub-urban area (Helwan)

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सार — हेलवान औद्योगिक क्षेत्र में सीमेंट उत्पादन की राष्ट्रीय कम्पनी की एक चिमनी से छोड़े गए प्रदूषकों की सांद्रता का आकलन किया गया। ये आकलन जून 1988 से मई 1989 की अवधि के गाउसिन पिच्छक निदर्श पर आधारित है। इस विधि में क्रमश: क्षेतिज और उर्ध्वाधर दिशाओं में विसर्जित प्राचलों σ_y और σ_z के आकलन को प्रस्तुत किया गया है। यह विधि, पवन वेग और तापमान दोनों के दो-स्तरीय प्रेक्षण पर निर्भर है। प्रभावी विसर्जित शिखर (स्टैक शिखर और पिच्छक उन्नत) के आकलन के लिए ब्रिगस द्वारा संस्तुत पिच्छक उन्नत संशोधन को अपनाया गया है। विभिन्न शिखरों और उनके स्थिति निर्धारणों के लिए अधिकतम सांद्रता मानों का आकलन किया गया।

ABSTRACT. The concentration of pollutants released from one chimney of the National Company for cement production in Helwan industrial area has been calculated. The calculations are based on the Gaussian plume model covering the period June 1988-May 1989. A method has been presented to calculate the dispersion parameters σ_y and σ_z in horizontal and vertical directions respectively. The method rely on two-level observation of both wind velocity and temperature. The plume rise correction recommended by Briggs has been adopted to calculate the effective release height (stack heights *plus* the plume rise). The maximum concentration values for different heights and their locations have been calculated.

Key words — Gaussian plume model, Dispersion parameters, Air pollution, Stack height, Wind roses, Stability parameters

1. Introduction

In recent years, a number of models have been developed to predict the dispersion of contaminant in urban atmosphere. Understanding of the dispersion characteristics of the atmosphere is a pre-requisite for a successful control of air pollution problems. In impact analysis studies associated with the siting of major industrial plants, the two most important parameters required are the wind velocity at release height (stack height) and the dispersion parameters in lateral and vertical directions σ_y and σ_z. These are seldom available at the height of interest. Most important analysis use 10 metres wind roses (Raghavan aud Basu 1988) and Pasquill's dispersion parameters (Pasquill 1961), which are combined with a power law profile to give the input parameters. This approach is limited in its applicability, since ten metre windroses and Pasquill stability parameters are time-averaged quantities. While these may yield reasonable estimates of annual mean concentrations, they would yield short term concentrations that would be grossly in error. Turner (1964) modified Pasquill's method by using informations of daytime, latitude and seasons to estimate the maximum possible insolation, and then modifying this estimate according to cloud cover and ceiling height. The results are then combined with wind speed information to determine the stability parameters.

In this paper, and in view of the integral form of Businger *et al.* (1971) wind profile, later reviewed by El-Shahawi (1984 a & b), the atmospheric dispersion parameters have been estimate using a method of two-level observations of wind velocity and temperature. The method has been applied to study the dispersion of contaminants released from one chimney of National Company for cement production in Helwan industrial area (24 km southeast of Cairo).

2. Two-level observation method

This method is used to estimate the standard derivations of the plume concentration distributions in horizontal and vertical directions σ_y and σ_z respectively. It can be applied when temperature and wind velocity at two levels are available. It is assumed that Monin-Obukhov scale L is known, from which the finite difference of the non-dimensional wind velocity u_n at the two levels of observation z_2 and z_1 is determined using the following formula :

$$u_{nz}=4+z/L+2\tan^{-1}[4L/(z+4L)]+\ln[z/(z+8L)]+C \quad (1)$$

The finite difference of temperature and wind velocity, $\triangle\theta$ and $\triangle u$ at z_2 and z_1 are given by :

$$\triangle\theta = -(H/\rho c_p u_*)\triangle u_n \quad (2)$$

and

$$\triangle u = (u_*/k) = \triangle u_n \quad (3)$$

where, H is the sensible heat flux, ρ is the air density c_p is the specific heat of air, u_* is the friction velocity and k is the Von-Karman constant ≈ 0.4.

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TABLE 1

The value of maximum concentration C_m and its location X_m at different height z, for the effective source heights H=116 m, 107.3 m and 95.1 m

	H=116m		H=107.3m		H=95.1 m	
Z(m)	X_m(m)	C_m (g/m³)	X_m(m)	C_m (g/m³)	X_m(m)	C_m(g/m³)
2	7305	3.0941×10^{-3}	6250	3.6164×10^{-3}	4910	3.0695×10^{-3}
10	4730	9.3824×10^{-4}	4030	1.0980×10^{-3}	3140	9.3424×10^{-4}
20	2840	7.3964×10^{-4}	2385	8.6989×10^{-4}	1800	7.4760×10^{-4}
30	1820	6.8720×10^{-4}	1450	8.1954×10^{-4}	980	7.2788×10^{-4}
40	1010	7.1232×10^{-4}	740	8.8714×10^{-4}	460	8.6492×10^{-4}
50	550	8.5095×10^{-4}	410	1.1247×10^{-3}	250	1.2086×10^{-3}
60	330	1.1235×10^{-3}	240	1.5747×10^{-3}	130	1.9063×10^{-3}
70	200	1.6046×10^{-3}	130	2.4401×10^{-3}	60	3.5929×10^{-3}
80	110	2.5399×10^{-3}	60	4.4084×10^{-3}	20	9.6223×10^{-3}
90	50	4.7350×10^{-3}	20	1.0574×10^{-2}	4	6.8271×10^{-2}
100	20	1.2202×10^{-2}	4	5.8744×10^{-2}	2	8.6172×10^{-2}

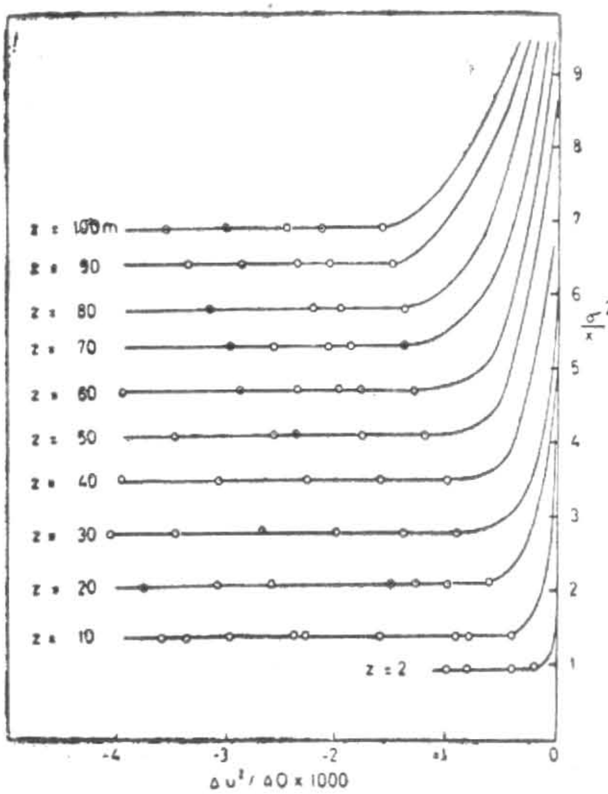

Fig. 1. The relation between σ^2/x and $(\triangle u)^2/\triangle\theta$ at different heights up to 100 m

From the definition of Monin-Obukhov length scale L (Kenneth 1973) :

$$L = -u^3_* \theta \rho c_p/(kgH) \tag{4}$$

and employing Eqns. (2) and (3) we can derive the following relation :

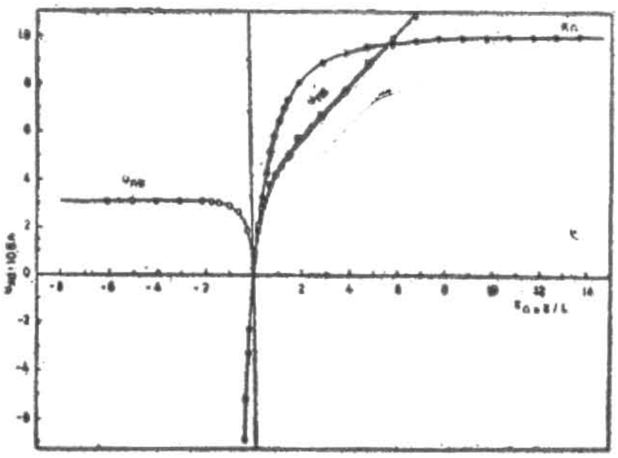

Fig. 2. The relation between ($z_n = g/L$) and both K_n and u_n

$$(g/\theta)L\triangle u_n = (\triangle u)^2/\triangle\theta \tag{5}$$

The dimensionless eddy diffusivity K_n is given by :

$$K_n = 1 - [4L/(z+4L)]^4 \tag{6}$$

while the eddy diffusivity K_z and wind velocity u_z are given by :

$$K_z = ku_* LK_n \tag{7}$$

$$u_z = (u_*/k)u_n \tag{8}$$

Thus we can write :

$$K_z + \triangle u = k^2 LK_n/\triangle u_n \tag{9}$$

$$u_z/\triangle u = (u_{nz} - u_{no})/\triangle u_n \tag{10}$$

where u_{no} is the dimensionless wind velocity at the level z_0 $(z >> z_0)$. Employing Eqns. (9) and (10),

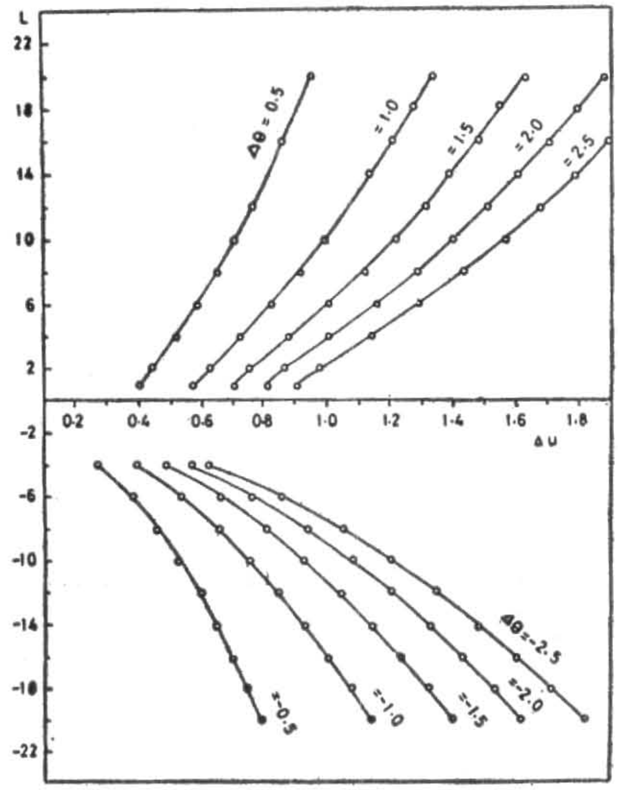

Fig. 3. The relation between L and Δu for different stability classes (different values of $\triangle\theta$)

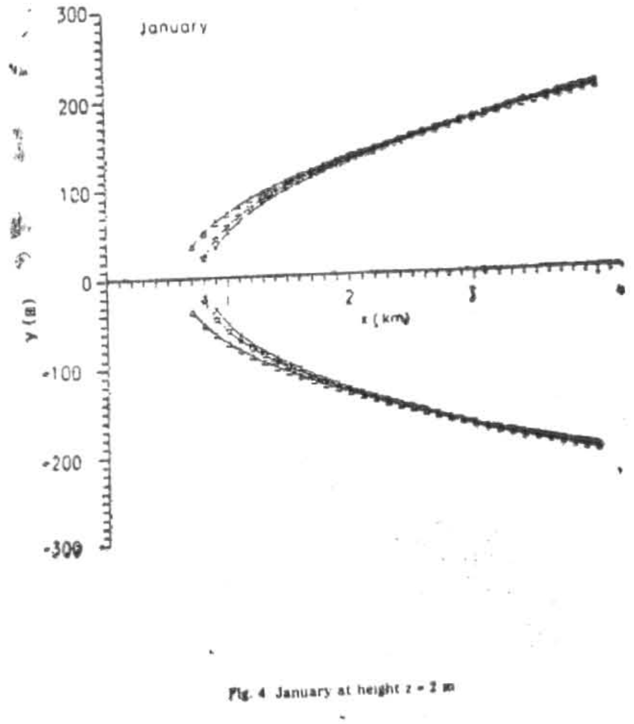

Fig. 4. The isopleth curves of equal concentration for different wind velocities and temperature difference between the plume released and that of the ambient atmosphere

$\triangle$: U_{2m}=2.4 m/s, $\triangle T$=32.8°K,* : U_{2m} = 1.2 m/s, $\triangle T$ = 32.9°K and x : U_{2m} = 1.2 m/s, $\triangle T$ = 40.2° K

the eddy diffusivity and wind speed at the investigation height z can be calculated.

The standard deviations σ_y and σ_z have the formulae (Safety series 1980).

$$\sigma_y^2 = 2K_y\, x/u_z \quad , \quad \sigma_z^2 = 2K_z\, x/u_z \tag{11}$$

Assuming diagonal eddy diffusivity with element $K = K_y$ (horizontal) $= K_z$ (vertical) everywhere, then we have :

$$\sigma^2/x = \sigma_z^2/x = \sigma_y^2/x = 2K_z/u_z \tag{12}$$

Dividing Eqns. (9) and (10), and comparing the results with Eqn. (12) we get :

$$\sigma^2/x = 2k^2\, LK_n/(u_{nz} - u_{no}) \tag{13}$$

The concentration of the pollutants released from the factory chimney could be calculated by inserting the estimated values of σ_y and σ_z given by Eqn. (13) into the Gaussian plume model formula given by :

$$C(x, y, z) = Q/(2\pi u \sigma_y \sigma_z) \exp\{-0.5(y/\sigma_y)^2\} [\exp\{-0.5\{(z-H)/\sigma_z)^2\} + \exp\{-0.5\{(z+H)/\sigma_z)^2\}] \tag{14}$$

where, Q is the emission rate or source strength (g/sec), $C(x, y, z)$ is the pollutant concentration (g/m^3), x, y and z are the downwind, lateral and vertical coordinates, and H is the effective release height.

These computational processes are repeated for different assumed L and z values to provide the corresponding values of K_z/u_z as shown by Eqn. (12).

3. Input data and numerical calculations

Meteorological data has been obtained from the Egyptian Meteorological Authority. The values given below are the release characteristics of the National Company :

a — Stack height h_s=88 m,

b — Inside stack radius R_0=1.8 m.

c — Initial plume temperature T=320° K,

d — Emission rate Q=1160 g/sec,

e — Number of stacks=3,

f — Initial vertical speed of the plume w_0=1/10 of the corresponding wind velocity at the stack height.

The effective release height H is :

$$H = h_s + \triangle h \tag{15}$$

where, $\triangle h$ is the plume rise which can be calculated in view of Briggs formula (Briggs 1975)

$$\triangle h = 1.54\,(F_0/u u_*^2)^{2/3} \quad h_s^{1/3} \tag{16}$$

where F_0 the initial buoyancy flux given by :

$$F_0 = w_0 R_0^2 (g/T) \triangle T \tag{17}$$

u_* is the friction velocity and for neutral condition is written as :

$$u_* = 0,\ 4u_{10}/\ln(10)$$

$\triangle T$ is the difference between the initial plume temperature and the ambient temperature at the stack height.

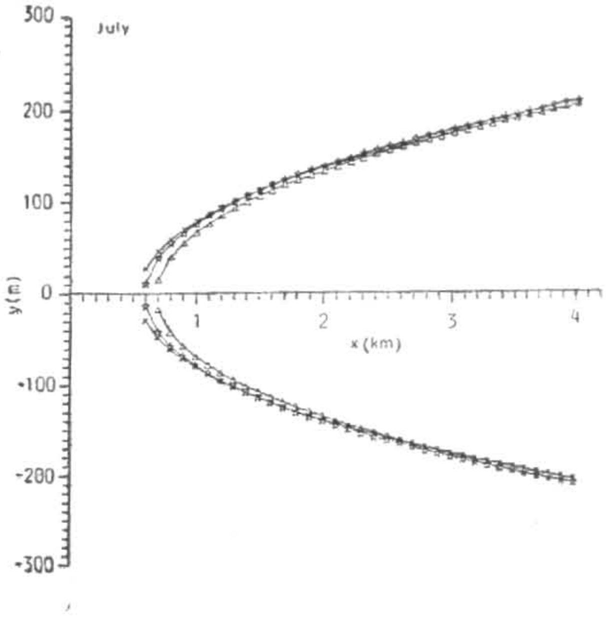

Fig. 5. The same as Fig. 4, with x : U_{2m} = 1.8 m/s, $\triangle T$= 11.5°K * : U_{2m} = 1.2 m/s, $\triangle T$ = 12.2° K and $\triangle$: U_{2m} = 1.2 m/s, $\triangle T$ = 23°K

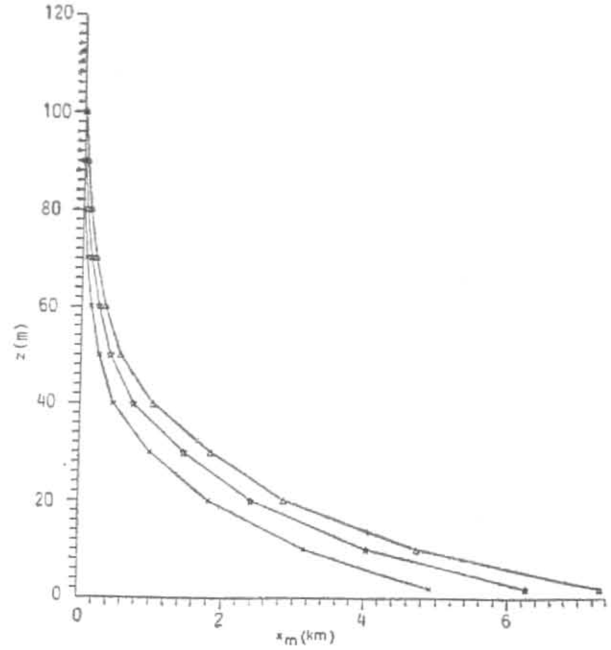

Fig. 6. The relation between the location of the maximum concentration (Xm) and the height (z) above the ground surface for different effective source heights, with $\triangle$: H=116 m, * : H=107.3 m and x : H=95.1 m

The numerical calculations covered the period June 1988-May 1989. For the heights above the ground surface ranging from 2 m to 10 m, the values of wind velocity u_z, friction velocity u_*, diffusivity K_z and dispersion parameters σ^2/x have been calculated. Set of illustrative graphs have been constructed. Fig. 1 shows the variation of σ^2/x as function of finite differences $(\triangle u)/^2\triangle\theta$. Also, the relations between $z_n=z/L$ and both K_n and u_n are plotted in Fig. 2. For different assumed values of $\triangle\theta$, a relation between L and $\triangle u$ is given in Fig. 3. Isopleth curves of equal concentration are plotted for the three heights of record 2 m, 10 m and 50 m. As an example, the result shown in Figs. 4 and 5 represent the two months January and July (for the two seasons winter and summer) for the height 2 m.

Employing the Gaussian plume model, the maximum value of pollutants concentration beneath the plume centerline is estimated, while the location of this maximum is then derived from the concentration formula of Gaussian plume model for different height z and beneath the centerline of the plume (*i.e.*, y=0). The results are represented in Table 1, for the three effective source heights H=116 m, 107.3 m and 95.1 m and illustrated graphically in Fig. 6.

4. Closing remark

The method of two levels observation was used to calculate the dispersion parameters in order to estimate the concentration of pollutants released from one chimney of the National Company for cement production in Helwan-Cairo. The method depends mainly upon easily obtainable data of temperature and wind speed differences between two chosen heights above the ground. The calculations give more accurate results since temperature and wind speed can be measured with higher accuracy than the input data of modified Turner method. It is obvious that the method avoids the non-generality in application and the uncertainty arising from the applications of empirical relations. Finally the method can be extended and used for a variety of diffusion problems such as flow over rough surfaces.

References

Briggs, G.A., 1975, "Plume rise predictions," Workshop proc. Boston, Mass, 29 Sept-3 Oct 1975, *Amer. Met. Soc.*, 59-111.

Businger, J.A., Wyngaard, J.C., Izumi, Y. and Bradley, E.F. 1971, "Flux profile relationships in the atmospheric surface layer," *J. atmos. Sci.*, **28**, 181-189.

EL-Shahawi, M.A., 1984(a), "A modified form of Gaussian plume model", *Bull Fac. Sci.*, Cairo Univ., **52**, 619-628.

EL-Shahawi, M.A., 1984(b), "The estimation of eddy diffusivity profiles for different thermal. structures" *Bull Fac. Sci.*, Cairo Univ, **52**, 629-673.

Kenneth, Ragland, W. 1973, "Multiple box model for dispersion of air pollutants from area sources", *Atmos. Environ.*, **7**, 1017-1032.

Pasquill, F., 1961, "The estimation of the dispersion of windborne materials," *Met. Mag.*, **90**, 33-49.

Raghavan, N. and Basu, S., 1988, "Prediction of wind speed, direction and diffusivity under neutral conditions for tall stacks," *J. appl. Met.*, **27**, 261-268.

Safety series N° 50-SG-3, 1980, Atmospheric dispersion in nuclear power plant siting, International Atomic Energy Agency, Vienna.

Turner, D.B., 1964, "A diffusion model for an urban area", *J. appl. Met.*, **3**, 83-91.