AIR POLLUTION AT MIZUSHIMA INDUSTRIAL AREA
——SIMULATION OF SO_x CONCENTRATION——

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Abstract

In this study, it is purpose to establish a forecasting method for conditions of air pollution at a seaside industrial area. Using the data in Mizushima industrial area, we investigated the relation between weather conditions and SO_x concentrations on the ground level. The distributions of SO_x concentration were calculated by the plume model at the weather condition in which this area was polluted. And the optimum parameters for the plume model by which the error between measured and calculated SO_x concentration became smallest were obtained. It was found that the optimum parameters could be correlated by the wind velocity.

Introduction

Since the air pollution caused by SO_x or NO_x become to the serious social problems in Mizushima area, the environment department of Okayama Prefecture has considered the various counterplan. The forecasting system of air pollution is in force by this department and has the purpose to prevent the air pollution from occuring.

The various models that estimate the concentration distribution of air pollution materials have been reported already. These models estimate the average concentration over the periods of one year or one season, and estimate hardly the place, the time and the concentration which the serious air pollution occur.

In this study, to develop the method forecasting the concentrations of air pollution materials, SO_x concentrations are simulated by using the plume model. Using

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the data measured at the monitoring stations (M. T.), the relation between weather conditions and SO_x concentrations has considered. As the result the characteristics of air pollution in this area became clear. The optimum diffusion parameters of the plume model are determined. And the effects of season, number of effluent sources and meteorological conditions for these parameters are investigated.

If the estimating method of the diffusion parameters is established, the forecasting system at Mizushima becomes more effective by using this method.

The measured values of the wind directions and velocities and SO_x concentrations in 1973 and SO_x effluent rates in December of 1972 were used in this study.

1. Air pollution caused by SOx at Mizushima

1. 1 Topography and effluent sources

Mizushima is located at the north side of center of Seto inland sea and the topography of this area is shown in **Figure 1.** The industrial area being used by many factories is about 42,000,000 m^2 and there are 90 factories in this area now. There are some plants of petroleum refinery, petrochemistry, iron and steel, electric power, motorcar, heavy machine etc.. And the effluent sources of SO_x above 0.1 Nm^3/hr are 333. The

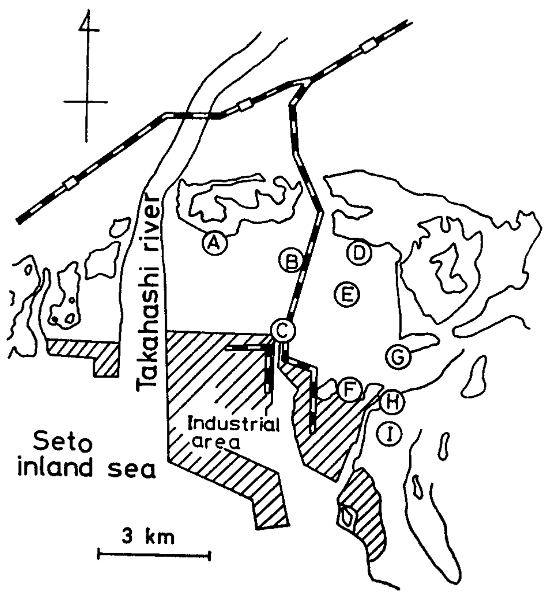

Fig. 1 Topography of Mizushima industrial area and monitoring stations

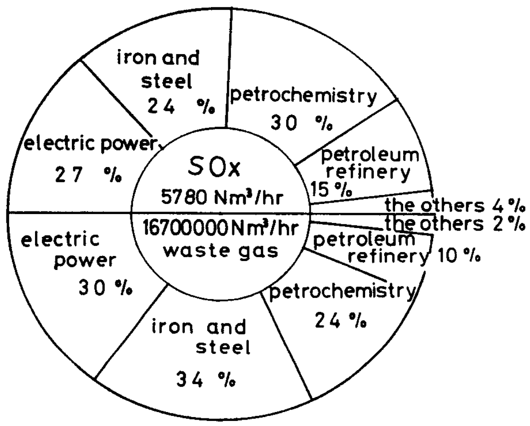

Fig. 2 Effluent volumes of waste gas and SO_x

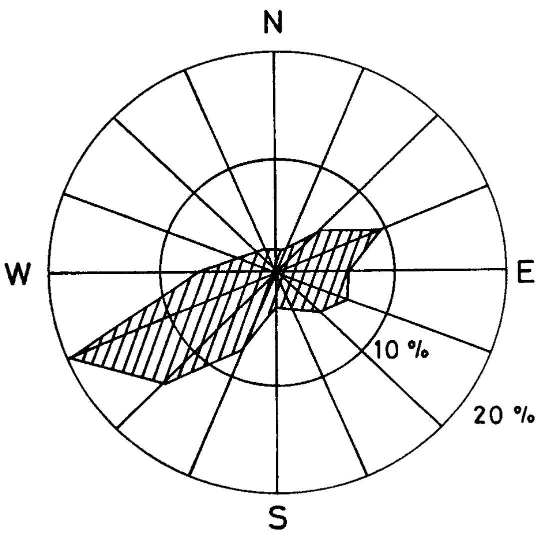

Fig. 3 Wind rose in July of 1971

effluent volumes of waste gas and SO_x are shown in **Figure 2.**

1. 2 Relation between weather conditions and SOx concentrations

In Mizushima, the monitoring of weather conditions and SO_x concentration is enforced at the M. T. being shown in Fig. 1. As Mizushima is situated at seaside, the sea breeze develops regularly in the daytime from Spring to Summer. **Figure 3** shows the wind rose at the M. T.- E in July of 1971. The appearence of the land and sea breeze is remarkable. The velocities of the sea breeze are 3~4 m/sec and of the land breeze are 2~3 m/sec.

SO_x effluented from many sources at the seaside industrial area is carried to the inland area by the sea breeze (SSE~WSW) and the high concentration of SO_x appears in this area. SO_x concentrations over 0.1 ppm have been measured in the M. T. -E at 34 days extending from July to August of 1973. In these days, the relations among the average values of SO_x concentrations, the wind directions and the wind velocities are shown in **Figure 4.** The land breeze appears from 20

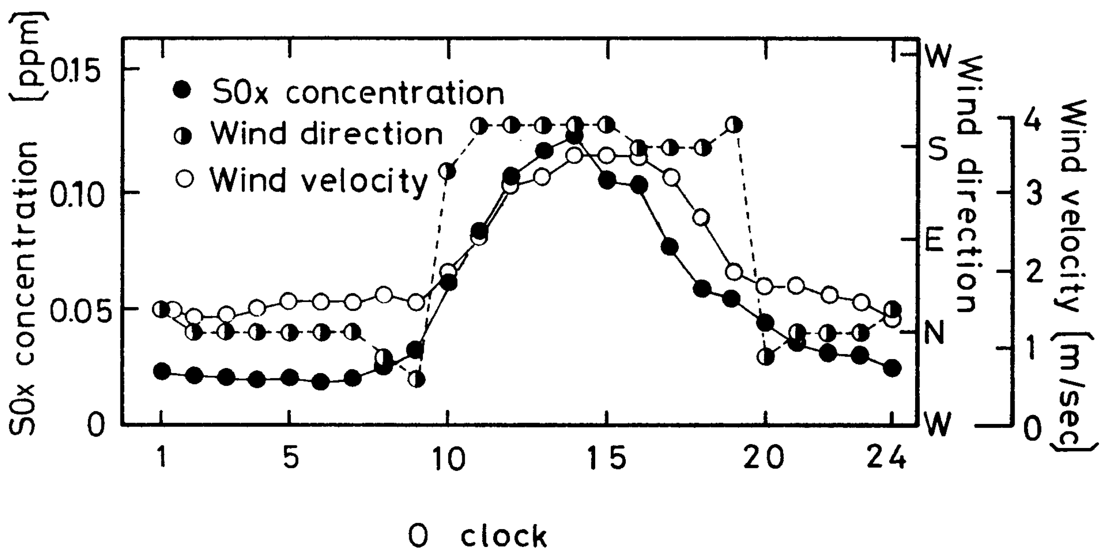

Fig. 4 Daily changes of SO_x concentration, wind direction and velocity at monitoring station E in July and August of 1973 (>0.1 ppm)

o'clock to 9 o'clock at the next morning and the sea breeze appears during the rest. The average SO_x concentrations are nearly constant (about 0.02 ppm) during the land breeze and however increase during the sea breeze, over 0.12 ppm at 14 o'clock. It is clear that the high concentration of SO_x relates intimately the sea breeze.

The uniformity of wind direction at Mizushima is shown in **Table 1.** The number of hours observed the sea breeze at the M. T. -A, C, E and G from 9 o'clock

Table 1 Correlation of wind direction

	monitoring station			
	A	C	E	G
A	(259)	93.4%	95.9%	96.5%
C	71.4%	(198)	73.9%	75.7%
E	82.8%	82.8%	(222)	92.5%
G	84.2%	86.4%	94.1%	(226)
Ave.	79.3%	87.5%	88.0%	88.2%

to 20 o'clock in August of 1973 and the correlations of the sea breeze among these M. T. are shown in this table, respectively. For example, the sea breeze has been observed 198 hours at the M. T.-C, and the sea breeze has also been observed at the hours of 93.4% of these 198 hours at the M. T.-A and 82.8% at the M. T.-E.

2. Simulation of SOx concentration

2. 1 Calculation procedure

The plume from an elevated effluent source is assumed to have Gaussian distributions of SO_x both laterally and vertically, with standard deviation σ_y and σ_z. Wind velocity is taken to be constant with height, and it is assumed that the effect of the ground can be represented by an image source. The plume equation obtained by the above assumptions is applied to each effluent sources. The concentration at j-th M. T. is calculated by the next equation.

$$C_j = \sum_{i=1}^{n} \frac{350 Q_i}{\pi \sigma_y \sigma_z U} \exp\left\{-\frac{1}{2}\left(\frac{y_i^2}{\sigma_y^2} + \frac{H_{ei}^2}{\sigma_z^2}\right)\right\} \quad (1)$$

where n is the number of sources.

There are many equations for estimating the effective height of source (H_e), as the equations of CONCAWE[3], Briggs[2], TVA[8], Bosanquet I[1], etc.. In order to calculate H_e by using these equations, the data with atmospheric stability are necessary except CONCAWE equation. Therefore, CONCAWE equation is used in this calculation.

$$H_e = H + 0.175\, Q_H^{1/2} U^{-3/4} \quad (2)$$

The standard deviations are represented by next equations as the function of along-wind distance.

$$\sigma_y = k_y x^{\alpha}\ , \quad \sigma_z = k_z x^{\beta} \quad (3)$$

Sutton[7], Singer et al.[6] have represented σ_y and σ_z by the similar equation. In Pasquill-Gifford chart[4, 5], σ_y and σ_z have also been represented similarly.

Using the measured values of weather condition and SO_x concentration at 9 M. T., the optimum parameters of Eq. (3) are determined by the next performance function for various conditions.

$$\sum_{j=1}^{9} |C_{ob,j} - C_j| \longrightarrow \text{Minimum} \qquad (4)$$

where $C_{ob,j}$ represents the measured concentration at j-th M.T..

2.2 Conditions of simulation

In Mizushima, the effluent sources exhausted SO_x above 10 Nm^3/hr are 48 and the effluent volumes of SO_x occupy 93 % of the total volumes. One example of the comparison between the result of simulation using 333 sources and it using 48 sources is shown in **Table 2.** The average values of the days measured the sea breeze at the

Table 2 Effects of number of source and wind for estimation of diffusion parameters

							SOx concentration [ppm]								
N	W	α	k_y	β	k_z	$\frac{\Sigma \lvert C_{ob}-C \rvert}{\Sigma C_{ob}}$	A	B	C	D	E	F	G	H	I
48	E	0.80	1.15	0.60	2.85	0.193	0.021	0.093	0.118	0.092	0.099	0.089	0.052	0.045	0.043
333	E	0.80	1.55	0.60	3.05	0.162	0.036	0.087	0.109	0.087	0.101	0.089	0.061	0.054	0.038
48	Mean	0.80	1.55	0.60	2.05	0.280	0.019	0.045	0.074	0.078	0.093	0.052	0.089	0.065	0.023
Measured values							0.039	0.059	0.118	0.102	0.110	0.090	0.085	0.060	0.059

N : number of source W : wind direction and velocity

M.T.-E (13 o'clock in July and August of 1973) have been used as the measured values. The values of optimum parameters and the error of measured and calculated SO_x concentration are similar, and the computation times for 48 sources are a quarter for 333 sources.

One example of the comparison between the result of simulation using the average wind direction and velocity at 5 M.T. and it using the values at the M.T.-E is also shown in Table 2. If the measured values of the M.T.-E are used, the errors of measured and calculated SO_x concentration are smaller than the other.

2.3 Estimation and correlation of diffusion parameters

In order to investigate the effects of time and season, the diffusion parameters at the sea breeze were estimated in January, April, July to August and October of 1973, respectively. The average SO_x concentrations at each o'clock (from 9 o'clock to 20 o'clock, 9 M.T.) that measured the sea breeze at the M.T.-E were used as the measured values.

The coefficients and exponents of Eq. (3) are varied over the wide ranges and

SO_x concentrations of each M.T. are calculated by Eq. (1). Then the optimum parameters that satisfy Eq. (4) are determined. There are the several sets of α, k_y and β, k_z that satisfy Eq. (4). Therefore, authors adopted the average values of each o'clock as α and β. The optimum values of k_y and k_z have been shown in **Figures 5** and **6,** respectively. The optimum values of α and β are shown in figures. The

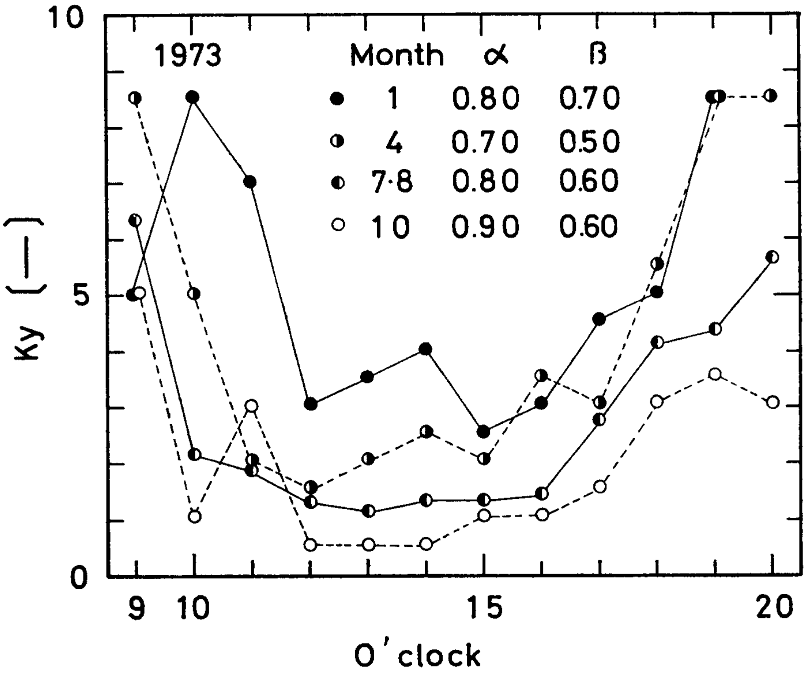

Fig. 5 Estimation of k_y

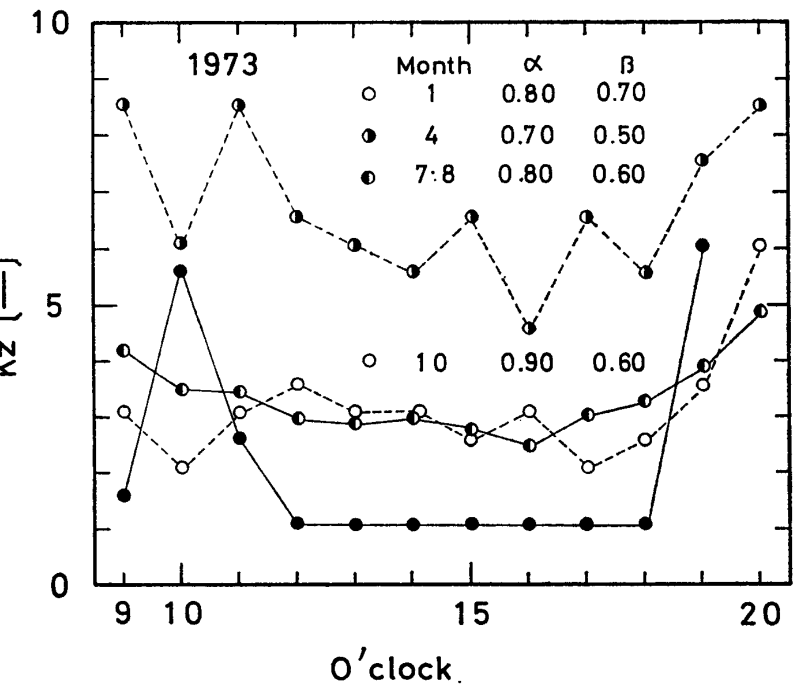

Fig. 6 Estimation of k_z

values of α agree approximately with it of Pasquill-Gifford chart[4,5] and the values of

B_1 or C of stability category of Singer et al.[6]. On the other hand, the values of β agree approximately with D or E of stability category of Pasquill-Gifford chart[4,5], that is, the values in conditions of neutral category to slightly stable category of atmospheric stability. The values of k_y and k_z vary considerably by the times and seasons and these are larger than those of the previous works. In the morning and the evening, as the wind direction is nonuniform and the wind velocity is small, the values of k_y and k_z are larger than the rest. In **Figure 7**, SO_x concentrations that

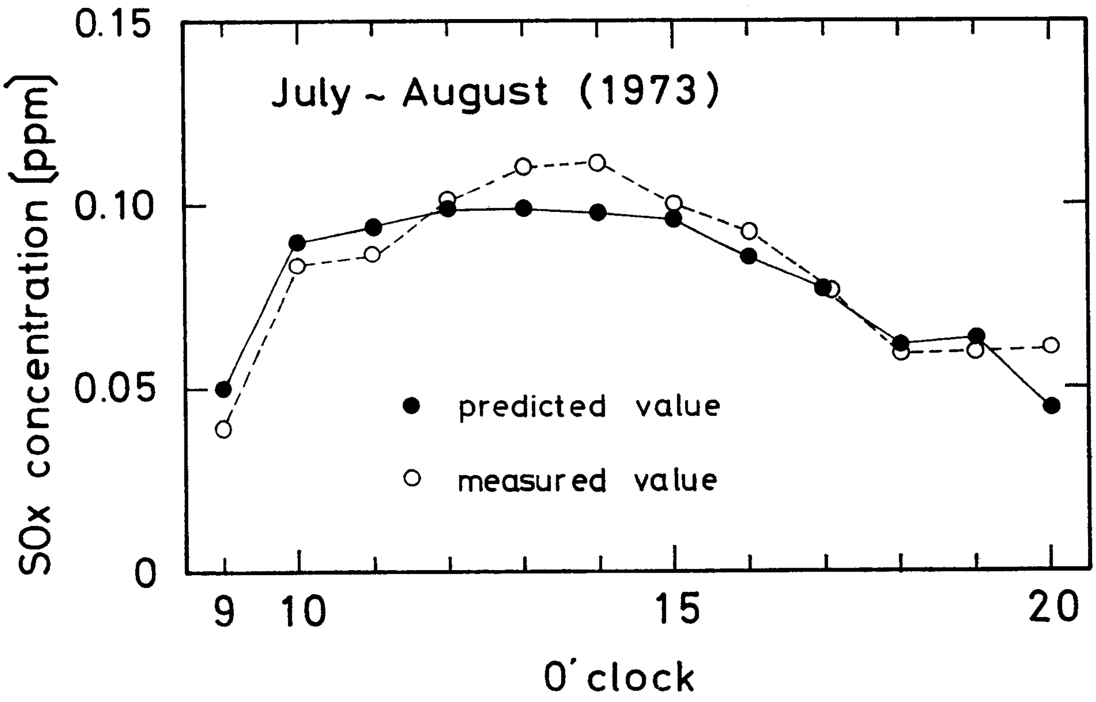

Fig. 7 Comparison of predicted and measured concentration of SOx

predicted by using the estimated parameters have been compared with the measured values.

The relations of k_y, k_z and the wind velocities (July and August of 1973) have been shown in **Figure 8.** The values of k_y and k_z decrease lineally with increase of the wind velocities. This is explained by the fact that the wind direction is steady and the diffusion of plume is controled both laterally and vertically, as the wind velocity increases. Therefore, k_y and k_z can be represented as follows.

$$k_y \text{ (or } k_z) = a\text{U} + b \qquad (5)$$

Table 3 shows a and b of Eq. (5) obtained by the method of least squares, the standard deviations and the correlation coefficients of each season. It is clear that the diffusion parameters can be correlated by the wind velocity at summer (July and August) that this area is polluted by SO_x.

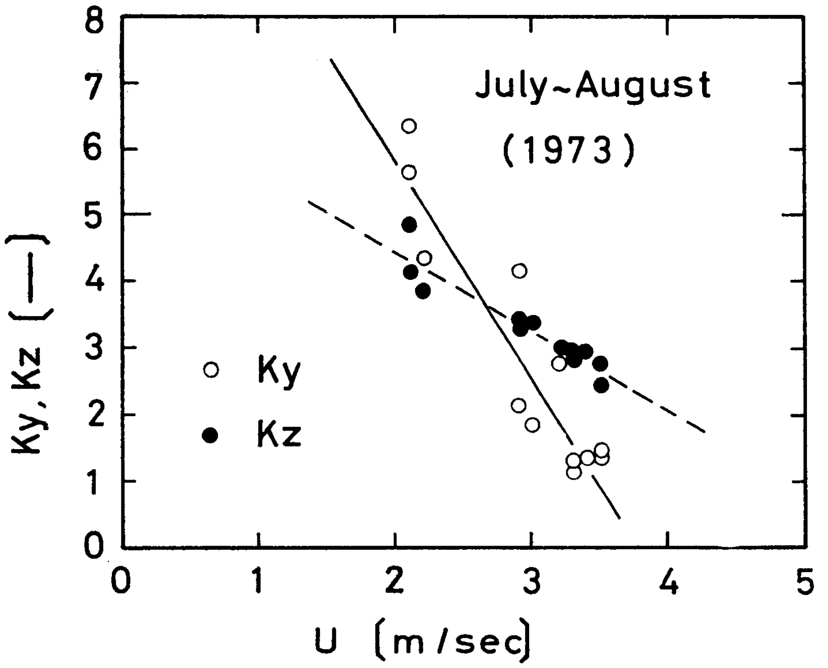

Fig. 8 Correlations of k_y and k_z

Table 3 Correlation of coefficients and constants of Eq. (5)

Month		a	b	σ	γ
1	k_y	−1.520	9.30	1.18	0.841
	k_z	−0.154	2.52	1.74	0.071
4	k_y	−2.700	13.30	1.12	0.891
	k_z	−0.979	9.92	0.97	0.676
7 ~ 8	k_y	−3.180	12.20	0.70	0.887
	k_z	−1.180	6.81	0.24	0.950
10	k_y	−2.140	11.80	1.79	0.744
	k_z	−0.054	4.24	2.90	0.310

Conclusion

In order to establish a forecasting method for conditions of air pollution at a seaside industrial area, the optimum parameters of the plume model by which the error between measured and calculated SO_x concentration became smallest were obtained by using data measured in Mizushima industrial area. The following knowledges were obtained.

1) The air pollution by SO_x occurs at the time measured the sea breeze in this area.
2) 48 effluent sources are used satisfactorily to the predicting calculations.
3) The measured values of wind direction and velocity at the M.T.-E are used in this simulation.
4) The values of α agree approximately with Pasquill-Gifford chart or the slightly unstable category of Singer et al.. On the other hand, the values of β agree

approximately with the neutral category or the slightly stable category. The values of k_y and k_z are larger than those of the previous works.

5) The values of k_y and k_z decrease with increase of wind velocity and can be correlated by Eq. (5) and Table 3.

Nomenclature

C = calculating concentration of pollutant gas in ground level [ppm]
C_{ob} = measuring concentration of pollutant gas in ground level [ppm]
H = stack height [m]
H_e = effective stack height [m]
k_y, k_z = coefficients defined by Eq. (3) [——]
Q_H = heat emission rate [cal/sec]
Q = emission rate of pollutant gas [g/sec]
U = wind velocity [m/sec]
x = co-ordinate in downwind direction [m]
y = co-ordinate in crosswind direction [m]
α, β = exponents defined by Eq. (3) [——]
γ = correlation coefficient [——]
σ = standard deviation [——]
σ_y = standard deviation of distribution of effluent gas in y direction at distance x from source [m]
σ_z = standard deviation of distribution of effluent gas in vertical direction at distance x from source [m]

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