REDUCTION OF THE ENVIRONMENTAL CONCENTRATION OF AIR POLLUTANTS BY PROPER GEOMETRICAL ORIENTATION OF INDUSTRIAL LINE SOURCES

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Industrial line sources of air pollutants are frequently characterized by a relatively low height of release. Their contribution to the concentration of air pollutants in the environment may be significant and cause violation of the ambient air quality standards. Therefore, measures sometimes have to be taken to reduce the environmental concentration of air pollutants released by such line sources. Among the measures considered may be the reduction of the amount of pollutant at the source prior to release or the improvement of the atmospheric dispersion, either by increasing the height of release or, in the case of a line source, by changing the geometrical orientation of the individual sources.

A case study was undertaken of two line sources, one composed of 10 and the other of 20 individual sources. The height of release ranged from 15.7 to 39.6 m, with a uniform rate of release of a gaseous pollutant of 1 Ci/s for each source.

Average environmental concentrations of air pollutants were calculated for the original setting of the line sources and then compared with those obtained from other settings, in which the individual sources of the same physical height of release, were differently orientated geometrically. These concentrations were also compared with those obtained from a single source which released the total amount of pollutant (30 Ci/s) at a height of 70 m. The concentrations were calculated using a diffusion model in which the environmental conditions were represented by a three-dimensional matrix and were based on the Gaussian equation of the form (1):

$$\overline{\chi}(x_j,\theta_j) = \sum_{p=1}^{N_s} \sum_{r=1}^{N_w} \sum_{j=1}^{N_j} \frac{2.032 F_{pr}(\theta_j)\, Q_{ipr}(x_j)}{\sigma_p(x_j)\, u_r x_j} \exp\left(-\frac{h^2_{prj}}{2\sigma_p^2(x_j)}\right) \qquad (1)$$

where:

$\overline{\chi}(x_j,\theta_j)$ is the average ambient concentration, resulting from pollutant point sources j, at a downwind distance x, along a 22.5° arc θ, which includes both the source and receptor.

N_s, N_w, N_j are indices denoting, respectively, the number of atmospheric stability classes, wind velocity groups and point sources
$F_{pr}(\theta_j)$ is the fraction of the time during which the wind is in direction θ, for atmospheric stability class p and wind velocity group r
$Q_{ipr}(x_j)$ is the point source strength of a pollutant i, corrected for dry and wet deposition, occurring along a distance x
$\sigma_p(x_j)$ is the vertical dispersion coefficient at a distance x from source j, for atmospheric stability class p
u_r is the average velocity for wind group r
h_{pr} is the effective plume height for atmospheric stability class p and wind velocity group r.

A computer program, adapted for the Hebrew University CY74 computer, was written to solve equation (1).

Figure 1 shows the initial geometrical position of the two line sources and 16 ground level receptor points for which the average pollutant concentration was calculated.

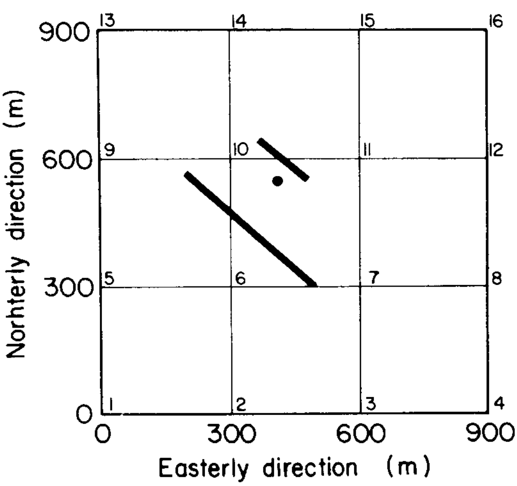

Figure 1. Initial geometrical position of the line sources and location of receptors 1-16 .
Line source
Rotation point

The 16 receptor points are distributed within a square 900 m x 900 m, at a distance of 300 m from each other. The computations of the average concentration of pollutant at the receptor points were performed for summer days, of characteristic joint atmospheric stability and wind velocity frequency (2).

The influence of the geometrical orientation of the line sources on the pollutant concentration at the 16 receptor points was investigated by veering both line sources from the original position 45^o at a time around a given point A (Fig. 1). Figure 2 shows the average pollutant concentration at the receptor point 3 as a function of the rotation angle of the line sources.

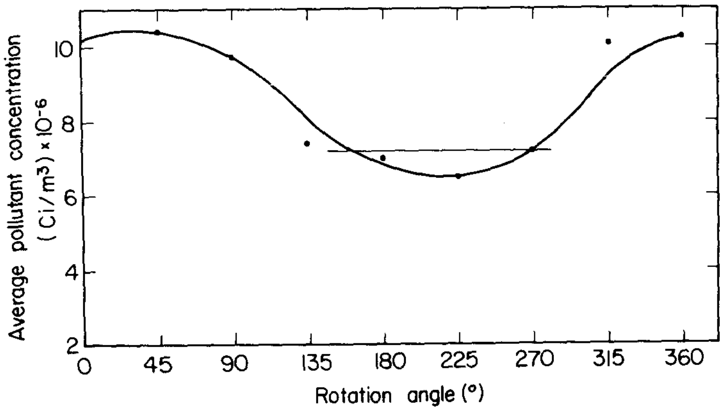

Figure 2. Average pollutant concentration at receptor point 3 as a function of the rotation angle of the line sources. The horizontal line shows the concentration of pollutant caused by a single source of 70 m height, the strength of which is equivalent to that of the line sources.

It is seen that at a given rotation angle, the average pollutant concentration is at a minimum at a certain receptor point. Similar results are obtained for all receptor points. The reduction of the pollutant concentration by a particular rotation of the line sources may attain values of up to about 50% as compared with the concentration obtained from the original position of the line sources.

Calculations were also made to compare the environmental pollutant concentration from given settings of the line sources, with the concentration caused by a single source of a height of 70 m, assuming that the strength of the single source is equivalent to that of the line sources. Figure 2 shows that at certain rotation angles of the line sources, the environmental concentration is lower even as compared with a single high source. In the case shown in Fig. 2 the minimum concentration obtained by rotating the line sources is about 10% lower than that caused by a 70 m high integrated source. However, for other receptor points and for other rotating angles, up to a 3-fold reduction of the average environmental concentration may be obtained by rotating the line sources, as compared with the concentration caused by a 70 m high integrated source.

The minimization of the average environmental concentration by rotating the line sources is different for each receptor point and calculations have to be performed to optimize the reduction of the pollutant concentration for all the receptor points in the area of interest, as related to each discrete point source of which the line sources are formed. The influence of a discrete point source on a given receptor point does not depend only on the reciprocal geometrical configuration of the source and receptor. It also depends on the atmospheric conditions, such as wind parameters and atmospheric stability, of which the plume width and height are functions, and on the probability of the receptor point being within the sector of influence of the source. Because the probability function $F_{pr}(\theta_j)$ is a discrete statistical parameter, there is no analytical procedure to find the minimum average concentration for all receptor points as a function of the rotation angle of the line sources. Numerical calculations therefore have to be performed to optimize the configuration of the line sources in order to get the minimum average concentration for all the receptor points in the area of interest.

A given geometrical orientation of the line sources can thus be found which minimizes the pollutant concentration both as compared with the original setting of the sources and with a single higher source integrating all the given point sources. Considering the substantial increase in cost of augmenting the height of release of pollutants as a means of reducing the air pollutant concentration, determining the proper geometrical orientation of the line sources should be considered as an economical means of improving the environmental air quality.

REFERENCES

1. Culkowski, W.M. and Petterson, M.R. (1976): A Comprehensive Atmospheric Transport and Diffusion Model, Atmospheric Turbulence and Diffusion Laboratory NOAA, Oak Ridge, Tenn. ATDL - 77/23, Contribution File No. 7612, p. 59.
2. Manes, A., Rindsberger, M., Segal, M., Zur, Y. and Zur I. (1976): Air Pollution Meteorology in Israel, National Survey, Part I, Israel Meteorological Service.