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Implications of Sutton and Pasquill coefficients in modelling accidental releases of hazardous chemicals

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ABSTRACT

The modelling of the results of accidental releases of hazardous chemicals is important for the making of contingency plans, such as the evacuation of the public from affected areas. Meteorological conditions such as wind speed and the degree of cloudiness, and the quantity of such chemicals released, are the main input parameters to mathematical models for the prediction of directions about an accident center that can be affected by the resulting puff or plume and the general rates at which pollutants are dispersed into the atmosphere.

Gaussian plume models have proved to be reasonably successful in accounting for observed concentration patterns. The Sutton (1953) and Pasquill (1962) approaches are the most common examples of this basic model and they have been used in this study. Sutton's model has been applied frequently in reactor hazard analysis and air pollution studies and there has been considerable experience with Sutton's diffusion coefficients and good verification of diffusion predictions for distances up to several kilometres from a release site. Pasquill's approach is based on estimating diffusion in terms of the angular spread of a diffusing plume using more commonly observed weather parameters.

In this paper we report our comparative study using both Sutton and Pasquill models to simulate the consequences of accidental release of two hazardous gases (chlorine under pressure and refrigerated ammonia). The results are analyzed and assessed in the light of the specific features of each model.

INTRODUCTION

The technology of hazard management has evolved with the growth of concern in the public mind and government agencies about major accidents in the Chemical Industry which may result in the release of toxic chemicals, large-scale fires and explosions. The modelling of the spread of hazardous chemical vapours provides valuable information to authorities responsible for contingency planning and safety. During the last few decades the use of mathematical modelling to reproduce the transport and dispersion of air pollutants has become common. The advent of large computers has facilitated the sophistication of the models so that extensive meteorological data can be input as well as the quantities and characteristics of released pollutants with the result that accurate predictions can be made in many cases. But, there is still a place for simple models in preliminary assessments, emergencies and whenever the uncertainties of more sophisticated models, such as DEGADIS, limit their application to specific pollutants, or meteorological or topographical conditions.

Air-pollution models can be classified into two main groups, the statistical Gaussian or bell-curve models and the numerical models. The Sutton (1953) and Pasquill (1962) models are the most widely used models of the first class of air-pollution models which have been reasonably successful in accounting for observed concentration patterns in terms of the Gaussian plume equation. They are limited in lacking provision for time dependence and spatial variability in meteorological parameters and results are poor often for conditions of light winds or calm. Some of these limitations are overcome by incorporating into the models the recently developed segmented-plume approach (Benkley & Bass 1980) which breaks the plume into independent elements or segments that are functions of local time-varying emission rates and meteorological conditions. Other limitations can be overcome by using the Puff-model approach (Roberts *et al.* 1970) which is appropriate for conditions of low wind and calm.

The numerical models are based on material balance and mass-conservation equations which are solved, for example, using the finite element method. Such models, however, vary considerably in the degree to which important physical phenomena are reproduced and their general application is limited because of the many assumptions that often have to be made.

THE SUTTON MODEL

Sutton's model has been applied frequently in reactor hazard analysis and air pollution studies and there has been considerable experience with Sutton's diffusion coefficients. The value of the index n and the generalized diffusion parameter C were updated after Sutton by Clancey (1974). Good verification of diffusion prediction by Sutton's method has been obtained for distances of the order of several kilometers (Slade 1968). The basic equation derived by Sutton for an instantaneous point source release at ground level is given by

$$\chi\,(x, y, z, t) \;=\; 2q/[\pi^{3/2} C_x C_y C_z (ut)^{3/2(2-n)}]\,\exp\left[-(ut)^{n-2}\left(\frac{x^2}{C_x^2}+\frac{y^2}{C_y^2}+\frac{z^2}{C_z^2}\right)\right] \tag{1}$$

where C_x, C_y, C_z are diffusion parameters in downwind, crosswind and vertical (x, y, z) directions (m $1/2''$), n is the diffusion index, χ is the predicted concentration (kg m^{-3}), q is the mass released instantaneously (kg), u is the mean wind speed (m s^{-1}), t is the time (s) and the coordinates x, y, z are measured from an origin moving with the cloud at the mean wind speed u.

The Sutton equation for a continuous point source at ground level is

$$\chi(x, y, z) = 2q^*/[\pi\, C_y C_z u d^{2-n}]\,\exp\left[-d^{n-2}\left(\frac{y^2}{C_y^2}+\frac{z^2}{C_z^2}\right)\right] \tag{2}$$

where q^* is the continuous mass rate of release (kg s^{-1}) and d is the distance downwind in the x direction.

The above Sutton equations for instantaneous and continuous sources are models of the behavior of a "puff" and of a "plume" of gas, respectively. The equations are convenient in form for the calculation of various derived quantities and have been extensively used.

Some important quantities in the puff model of dispersion from a ground level source are: (a) concentration at center of cloud, and (b) dimensions of cloud. Equations (1) and (2) are frequently written with the assumption of isotropic conditions, for which the diffusion parameters are

$$C_x = C_y = C_z = C \tag{3}$$

For instantaneous point source at ground level use is made of Eqn (1) and Eqn (3). If the concentration is that at ground level $z = 0$, then

$$\chi(x, y, o, t) = 2q/[\pi^{3/2} C^3 (ut)^{3/2(2-n)}] \exp\left[-(ut)^{n-2}\left(\frac{x^2}{C^2} + \frac{y^2}{C^2}\right)\right] \tag{4}$$

The index n and the generalized diffusion parameter C are meteorological constants. The index n is a function of the stability conditions. The value of C is a function of the height above ground and of the stability conditions. Values of these constants have been discussed in detail by Sutton (1953) and given by Clancey (1974). They are included in Table 1.

For the ground level concentration at the center of the cloud (χ_{cc}) $x = y = 0$, Eqn (4) becomes

$$\chi_{cc} = \chi(0, 0, 0, t) = 2q/[\pi^{3/2} C^3 (ut)^{3/2(2-n)}] \tag{5}$$

For the second quantity in the puff model, the conventional definition of the cloud is that the concentration at the cloud boundary χ_{cb} is one-tenth of that at the center as defined by Lees (1980).

$$\chi_{cb} = 0{\cdot}1\chi_{cc} \tag{6}$$

For the dimensions of the cloud at ground level, the cloud radius x is determined by calculating χ_{cc} from Eqn (5), χ_{cb} from Eqn (6) and x from Eqn (4) by setting $\chi = \chi_{cb}$.

Similar to the puff model, the important characteristics in the plume model of dispersion from a ground level source are: (a) concentration in axis of plume, and (b) dimensions of plume. Again, these quantities are mainly of interest at ground level.

For a continuous point source at ground level use is made of Eqn (2) with Eqn (3). If the concentration considered is that at ground level $z = 0$, then

$$\chi(x, y, 0) = 2q^*/[\pi C^2 u d^{2-n}] \exp\left[-d^{n-2}\frac{y^2}{C^2}\right] \tag{7}$$

Table 1. Values of *n* and *C* (Clancey 1974)

	Meteorological constants	
Stability condition	*n*	*C*
Lapse	0·17	0·20
Neutral	0·25	0·14
Inversion	0·35	0·09

For the ground level concentration on the axis of the plume (χ_{cl}) $y = 0$

$$\chi_{\mathrm{cl}} = \chi(x, 0, 0) = 2q^*/[\pi C^2 u d^{2-n}] \tag{8}$$

The concentration of the boundary of the plume χ_b, at a radius, r, in the y-direction, $z = 0$ & $y = r$, then

$$\chi_b = [2q^*(\pi C^2 u d^{2-n})] \exp\left(-d^{n-2}\frac{r^2}{C^2}\right) \tag{9}$$

The plume boundary concentration χ_{cb} may be defined as one-tenth of the axial concentration. Hence from Eqns (7)–(9) the radius of the plume in the y-direction is determined.

THE PASQUILL MODEL

An alternative form of the Sutton equation has been presented by Pasquill (1962). In this formulation, use is made of the relation

$$\sigma_x^2 = \tfrac{1}{2}C^2\,(ut)^{2-n} \tag{10}$$

Similar expressions apply for σ_y and σ_z, where σ_x, σ_y, σ_z are the standard deviations, or dispersion coefficients, in downwind, crosswind and vertical (x, y, z) directions (*m*). Values of σ_y and σ_z are estimated from the wind speed at a height of about 10 m. The values for instantaneous and continuous sources are given by Turner (1970). They are shown in Tables 2 and 3 respectively.

It should be emphasized that the values given for the dispersion coefficients are best estimates. These estimates are applicable only to open country. In stable and unstable conditions several-fold errors may occur in the estimate of σ_z. There are some circumstances, however, when the estimate of σ_z may be expected to be within a factor of 2. These are: (a) for all stability conditions at distances up to a few hundred meters, (b) for neutral or moderately stable conditions at distances up to a few kilometers, and (c) for unstable conditions in the lower 1000 m of the atmosphere with a marked inversion above at distances up to 10 km or more. The uncertainty in the estimation of σ_y is in general less than that in the estimation of σ_z.

The Pasquill equation for an instantaneous point source at ground level (for a puff of gas) is

$$\chi(x, y, z, t) = 2q/[(2\pi)^{3/2}\sigma_x\sigma_y\sigma_z] \exp\left[-\frac{1}{2}\left(\frac{x^2}{\sigma_x^2} + \frac{y^2}{\sigma_y^2} + \frac{z^2}{\sigma_z^2}\right)\right] \tag{11}$$

Table 2. Values of σ_y and σ_z for instantaneous sources given by Turner (1970) (based on unpublished work by D.H. Slade)

	$x = 100$ m		$x = 4000$ m	
Stable condition	σ_y (m)	σ_z (m)	σ_y (m)	σ_z (m)
Unstable	10	15	300	220
Neutral	4	3·80	120	50
Very stable	1·30	0·75	35	7

Table 3. Values of σ_y and σ_z for continuous sources (Turner 1970)

Pasquill stability category	Dispersion coefficients		Range at distance (d)*
	σ_y (m)	σ_z (m)	
A	$\sigma_y = 0{\cdot}493d^{0{\cdot}88}$	$\sigma_z = 0{\cdot}087d^{1{\cdot}10}$	$100 < d < 300$
		$\log \sigma_z = 1{\cdot}67 + 0{\cdot}902 \log d + 0{\cdot}181 (\log d)^2$	$300 < d < 3000$
B	$\sigma_y = 0{\cdot}337d^{0{\cdot}88}$	$\sigma_z = 0{\cdot}135d^{0{\cdot}95}$	$100 < d < 500$
		$\log \sigma_z = 1{\cdot}25 + 1{\cdot}09 \log d + 0{\cdot}0018 (\log d)^2$	$100 < d < 2 \times 10^4$
C	$\sigma_y = 0{\cdot}195d^{0{\cdot}9}$	$\sigma_z = 0{\cdot}112d^{0{\cdot}91}$	$100 < d\ 10^5$
D	$\sigma_y = 0{\cdot}128d^{0{\cdot}9}$	$\sigma_z = 0{\cdot}093d^{0{\cdot}85}$	$100 < d < 500$
		$\log \sigma_z = 1{\cdot}22 + 1{\cdot}08 \log d - 0{\cdot}061 (\log d)^2$	$500 < d < 10^5$
E	$\sigma_y = 0{\cdot}091d^{0{\cdot}91}$	$\sigma_z = 0{\cdot}082d^{0{\cdot}82}$	$100 < d < 500$
		$\log \sigma_z = 1{\cdot}19 + 1{\cdot}04 \log d - 0{\cdot}07 (\log d)^2$	$500 < d < 10^5$
F	$\sigma_y = 0{\cdot}067d^{0{\cdot}90}$	$\sigma_z = 0{\cdot}057d^{0{\cdot}8}$	$100 < d < 500$
		$\log \sigma_z = 1{\cdot}91 + 1{\cdot}37 \log d - 0{\cdot}119 (\log d)^2$	$500 < d < 10^5$

*d is the distance in the x direction.

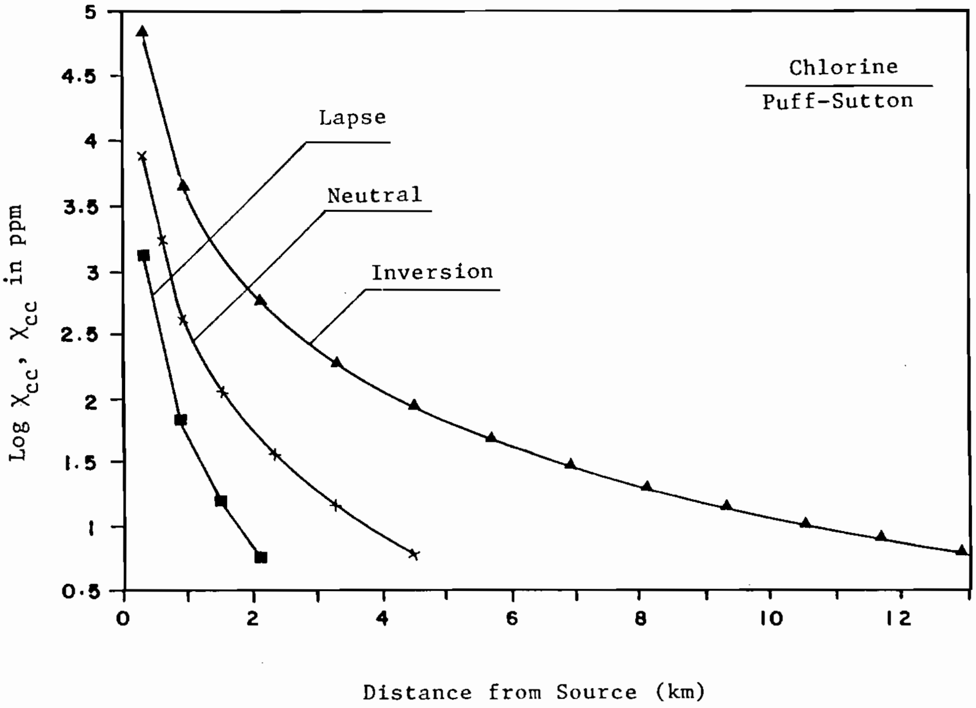

Fig. 1. Concentration of chlorine *v.* distance under various stability conditions.

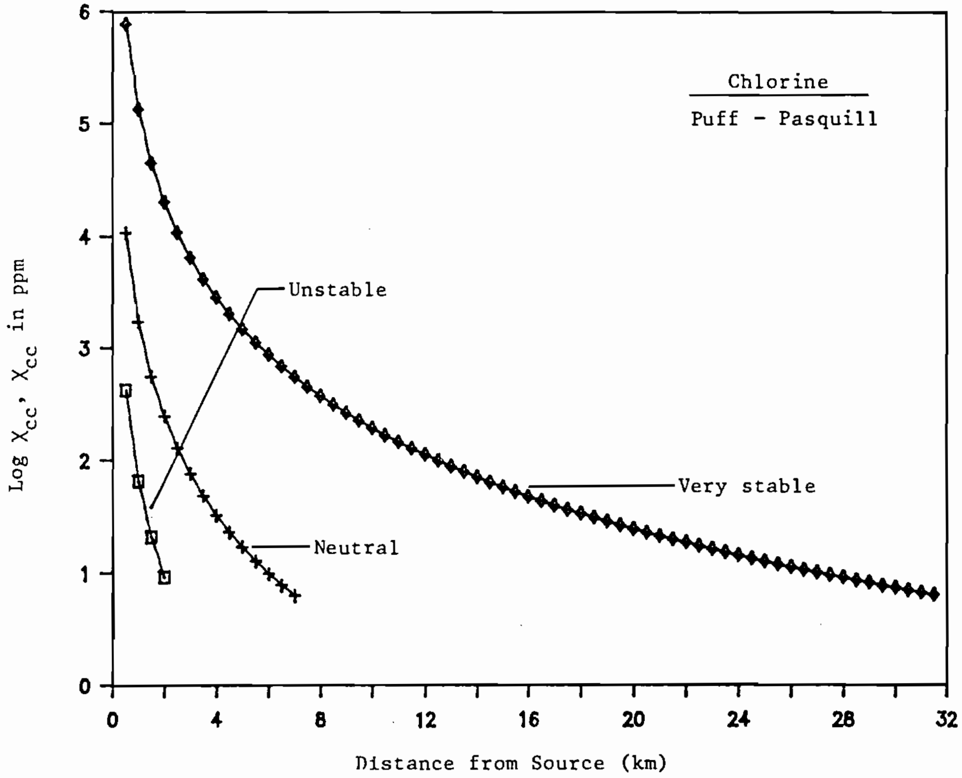

Fig. 2. Concentration at center of chlorine cloud *v*. distance under different stability conditions.

where the coordinates x, y, z are measured from an origin moving with the cloud at the mean wind speed u.

If the concentration considered is that at ground level $z = 0$, then Eqn (11) becomes

$$\chi(x, y, o, t) = 2q/[2\pi)^{3/2}\sigma_x\sigma_y\sigma_z] \exp\left[-\frac{1}{2}\left(\frac{x^2}{\sigma_x^2} + \frac{y^2}{\sigma_y^2}\right)\right] \tag{12}$$

For the ground level concentration χ_{cc} at the center of the cloud $x = y = 0$, and it is normally assumed that σ_x is equal to σ_y as defined by Lees (1980).

$$\chi_{cc} = 2q/[(2\pi)^{3/2}\sigma_y^2\sigma_z] \tag{13}$$

The boundary concentration, χ_{cb} of a cloud having a radius, r (i.e. $y = r$), is given by

$$\chi_{cb} = 2q/[(2\pi)^{3/2}\sigma_y^2\sigma_z] \exp\left[\frac{1}{2}\left(\frac{r^2}{\sigma_y^2}\right)\right] \tag{14}$$

Assuming the boundary concentration in a cloud, χ_{cb}, as one-tenth the concentration at the center as defined by Lees (1980), the radius of the cloud could be calculated from Eqn (14).

The Pasquill equation for a continuous point source at ground level (for a plume

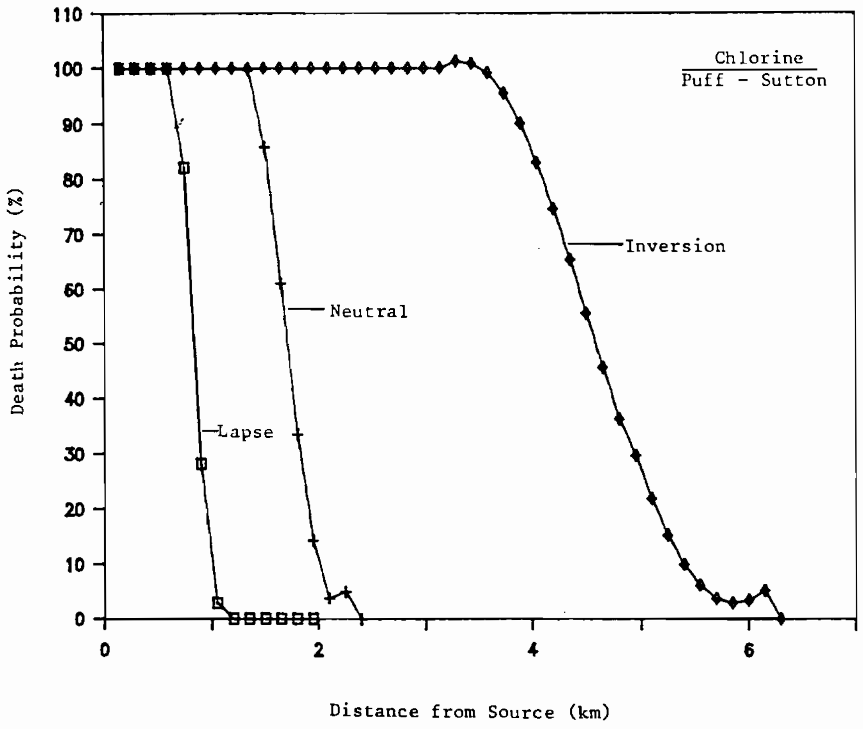

Fig. 3. Probability of death *v.* distance under different stability conditions.

gas) is

$$\chi(x, y, z) = (q^*/\pi\sigma_y\sigma_z u)\exp\left[-\frac{1}{2}\left(\frac{y^2}{\sigma_y^2}+\frac{z^2}{\sigma_z^2}\right)\right] \tag{15}$$

Following the same steps as for Pasquill model for an instantaneous point source, the concentration along the axis of the plume at ground level χ_{cl}, the concentration at the boundary of the plume χ_b and the radius of the plume r are calculated for any stability category A, B, C, D, E & F given in Table 3.

DISPERSION AS PUFFS AND PLUMES

The dispersion situations which occur in practice often correspond not to the puff or to the plume model but to the intermediate case. The puff model is preferable if the diffusion in the downwind, or x direction is large relative to the length of the plume. A measure of diffusion in the downwind direction is the dispersion coefficient σ_x, where this is evaluated using puff data, and a measure of the length of the plume is the group ut, where u is the wind speed and t the time for total discharge or evaporation of the gas. The coefficient σ_x is evaluated using the puff data at $ut/2$. The plume model is undefined for zero wind speed, is inaccurate for low wind speeds and therefore is not recommended for use at wind speeds less than 2 m/s.

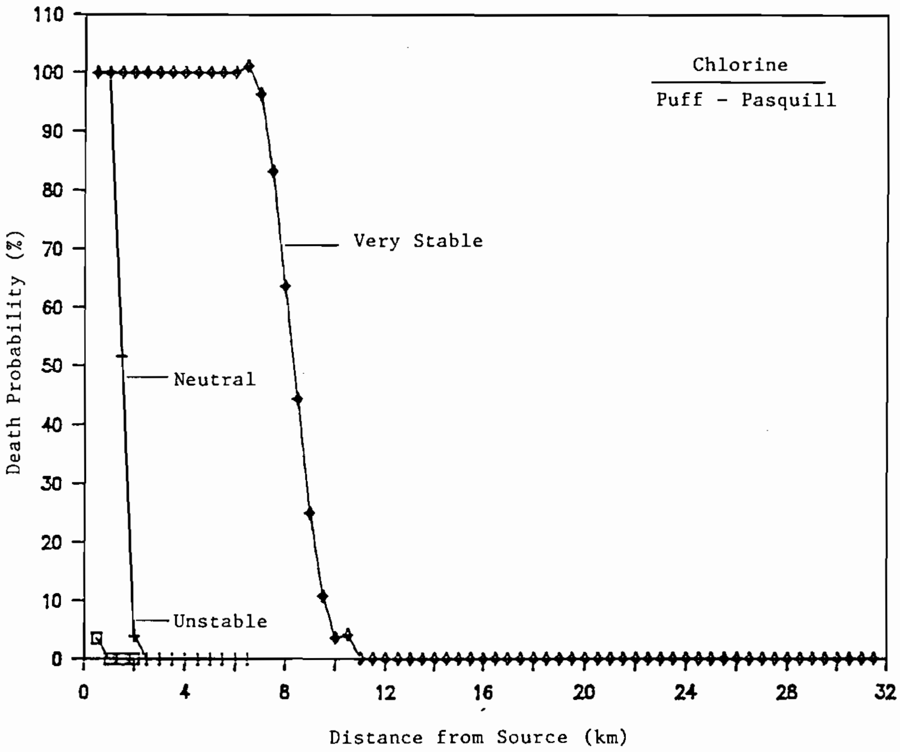

Fig. 4. Probability of death *v.* distance under different stability conditions.

CONSEQUENCES OF ACCIDENTAL RELEASE

The initial consequence of accidental release of hazardous liquids or liquefied gases is the vaporization that takes place before a cloud or plume is formed, at a certain rate depending mainly on the properties of the substance, storing or containment conditions, mode of release (instantaneous or continuous) and ambient conditions. The following vaporization situations can be distinguished for the hazardous chemicals under consideration:

- Chlorine is considered a refrigerated liquefied gas at a low temperature and under pressure.
- Ammonia is considered a refrigerated liquefied gas at low temperature, but at atmospheric pressure.

Using simple heat balance equation and thermodynamic principles the initial vaporized quantity of refrigerated liquefied chlorine stored under pressure and refrigerated liquefied ammonia is computed. Also the steady-state evaporation rate for chlorine and ammonia contained within the bund area is computed. Knowing the initial vaporized quantity and steady-state evaporation rate, the concentration of the center of the cloud and plume, the dimensions of the cloud and plume and maximum distance travelled by the cloud until it reaches the maximum permissible exposure limit, are computed using Sutton's and Pasquill's model.

To estimate the degree of injury or damage in terms of percentage death or

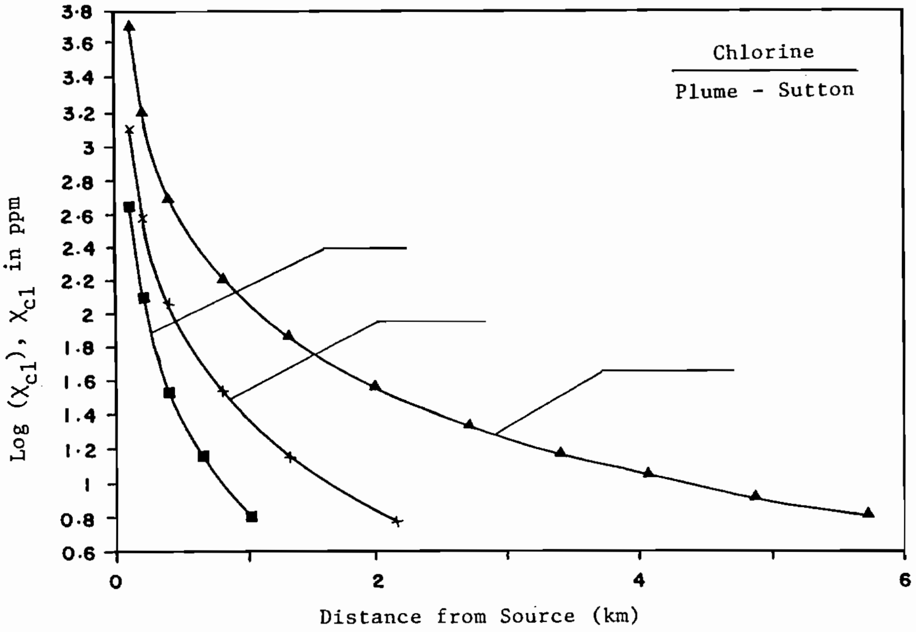

Fig. 5. Concentration of chlorine *v.* stability conditions.

casualties resulting from these releases the Probit Analysis method is used. A general form of the probit function is

$$Y = K_1 + K_2 \log_e V \tag{17}$$

where the probit Y is a measure of the percentage of the vulnerable resource which sustains injury or damage, and the variable V is a measure of the intensity of the causative factor which harms the vulnerable resource. The constituents K_1 and K_2 may be calculated from the data on the relationship between the intensity of the causative factor and the degree of harmful response; values are given by Eisenberg *et al.* (1975).

Transformation of probit Y to percentage Pd or vice versa is given by Finney (1971). A mathematical expression was derived by regression (curve fitting) to obtain the percentage injury or damage Pd in terms of the probit Y. This expression is given by

$$\mathrm{Pd} = 4{\cdot}911 + 109{\cdot}17\,Y - 96{\cdot}47Y^2 + 29{\cdot}15y^3 - 3{\cdot}51Y^4 + 0{\cdot}148Y^5 \tag{25}$$

Equation (25) was tested, and error in estimating Pd did not exceed ±2%, which is considered acceptable.

The measure of the intensity of the causative factor V is basically dependent on the damaging or injury characteristics of the hazardous substance as well as the resulting consequences. In some cases the variable V is a single variable and in others it is a function of one or more variables. Thus Eisenberg *et al.* (1975) define V for death from toxic gases such as chlorine and ammonia as

$$V \leqq \sum \chi_i^m T_i \tag{26}$$

where χ_i is the gas concentration, T_i the time of exposure, and m an index; its value is given as 2·75 for both chlorine and ammonia (Eisenberg *et al.* 1975).

Table 4. Input data to the program for chlorine and ammonia

Parameters		Chlorine	Ammonia
Related to chemical characteristics			
W:	Stored liquefied mass, kg	70,000	30,000,000
q:	Quantity of gas released, kg	NA	NA
S:	Specific heat, cal g^{-1} °C^{-1}	0·274	1·07
V:	Latent heat of vaporation, cal g^{-1}	68·8	327·1
t_1:	Initial temperature, °C	−50	−33·4
t_2:	Normal boiling point, °C	−34·1	−33·4
t_3:	Ambient temperature, °C	50	50
d_1:	Specific gravity	2·4	0·59
d_3:	Density of gas, kg m^{-3}	NA	NA
mw:	Molecular weight	70·91	17·03
st:	max. permissible exposure limit, kg m^{-3}	0·000018	0·000054
barea:	bund area, m^2	250	6800
Related to probit analysis			
m:	Index related to probit analysis	2·75	2·75
K_1:	Constant related to probit analysis	−17·1	−30·57
K_2:	Constant related to probit analysis	1·69	1·385

NA: not applicable.

Two programs were written in BASIC using the above equations, the first based on Sutton's model and the second based on Pasquill's model. Both programs were then used to simulate the consequences of the same hypothetical accidental release of the selected chemical in turn. The input data for each of these chemicals are given in Table 4. The meteorological data for both Sutton and Pasquill models are kept constant for the sake of comparison.

RESULTS AND DISCUSSION

The study aims to serve two objectives. The first is to determine the magnitude of a toxic gas resulting from both instantaneous (puff) and continuous (plume) accidental releases at ground level by using Sutton and Pasquill models. The second objective is to compare the results obtained using Pasquill's model under the same release and meteorological conditions and to point out reasons for any identified differences. To achieve both objectives simultaneously, the models were then used to simulate the consequences of hypothetical accidental release of the selected chemicals. Chlorine exemplifies a toxic gas heavier than air, which is stored in liquefied form under pressure and refrigeration. Ammonia exemplifies a toxic gas, lighter than air which is stored under refrigeration.

The logs of the concentration of chlorine in the cloud center *v*. the distance from the source due to a hypothetical puff release is plotted in Fig. 1 for the Sutton model analysis and in Fig. 2 for the Pasquill model analysis. Significant differences in the analyses based on the models are evident in the data plotted, especially for very stable conditions (the inversion conditions of the Sutton model). In this case the safe distance for accidental exposure in the Sutton model is about one third that obtained using the Pasquill model. In neutral condition the Pasquill model safe distance is only

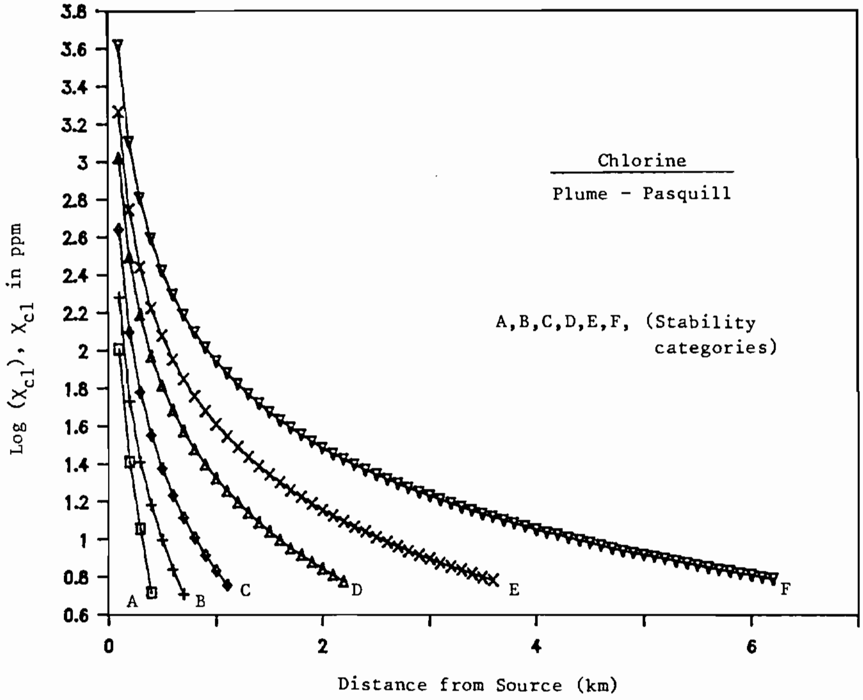

Fig. 6. Concentration along the centerline of chlorine plume *v.* distance under different stability categories.

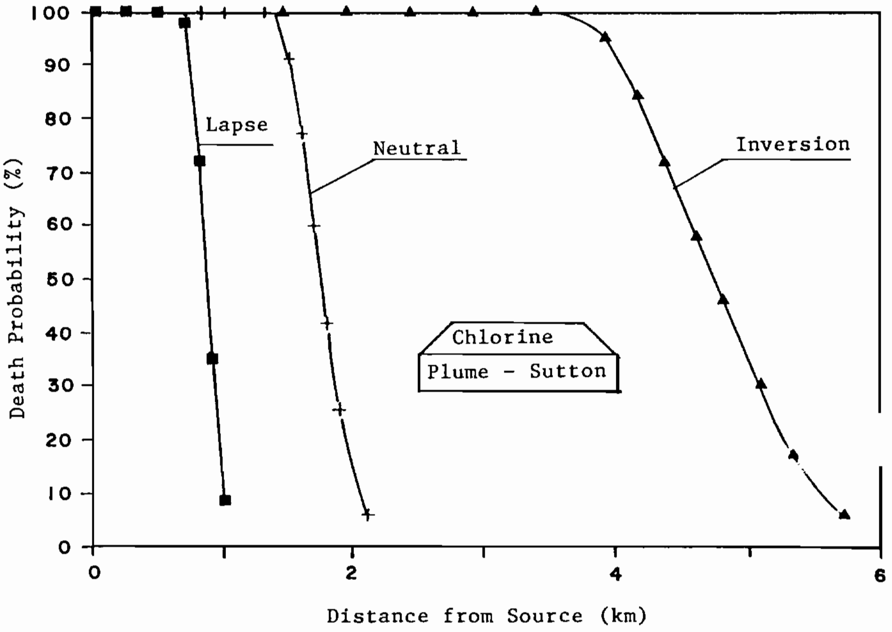

Fig. 7. Probability of death *v.* distance under various stability conditions.

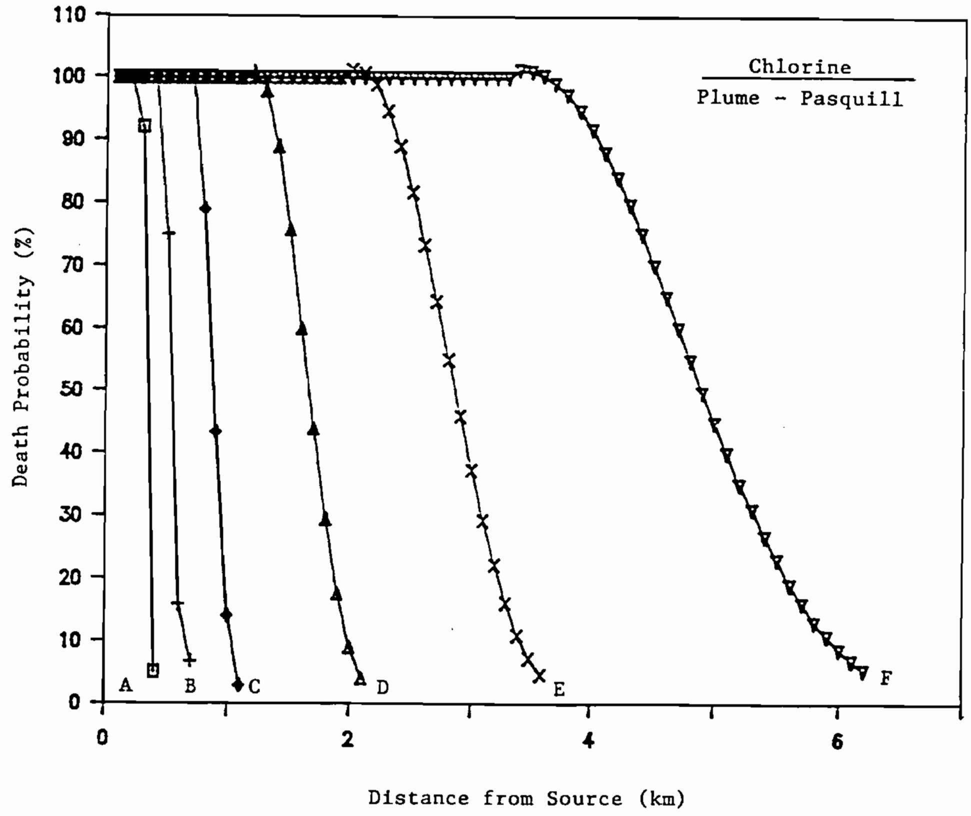

Fig. 8. Probability of death *v.* distance under different stability categories.

slightly higher than that obtained from the Sutton model-based analysis, while under lapse (Sutton) or unstable (Pasquill) conditions the safe distances are comparable. The probability of death based on toxicity and exposure is plotted *v.* distance from a source for puff release of chlorine using the Sutton model in Fig. 3 and the Pasquill model in Fig. 4. The results show that the probability of death using the Pasquill model under very stable conditions does not fall to zero until twice the distance from the source obtained using the Sutton model under inversion conditions. Under neutral and lapse conditions both models give similar results.

The logarithm of the concentration of chlorine along the centerline of the plume, due to a hypothetical continuous release of gas from a plant is plotted in Fig. 5 using the Sutton model and in Fig. 6 using the Pasquill model analysis *v.* the distance from the source until the concentration reaches the maximum permissible exposure limit. From a comparison of the two figures it can be seen that the results obtained using the Pasquill model under stability categories C, D and F are comparable with those obtained using the Sutton model under lapse, neutral and inversion conditions respectively. Stability category E of the Pasquill model appears to represent an intermediate situation between neutral and inversion conditions of the Sutton model. Stability category A and B of the Pasquill model represent conditions more extreme than the lapse condition of the Sutton model. Similar results (Figs 7 and 8) were obtained from both models for the probability of death as a function of distance from the source.

The results obtained for the modelling of the dispersion of ammonia vapour showed the same trends for instantaneous and continuous release as those for chlorine. The above analyses of the results obtained using the Sutton and Pasquill models indicate that both may be useful for the preliminary assessment of the magnitudes of potential hazards accompanying the release of dangerous vapours into the atmosphere. The Sutton model is simpler than the Pasquill one which provides for a wider range of stability categories and returns more information about a given event.

The results show that certain stability categories of the Sutton model are equivalent almost to those in the Pasquill model. For example, the lapse condition of the Sutton model is equivalent to the unstable condition of the Pasquill model, for puff release, while lapse, neutral and inversion conditions in the Sutton model are equivalent to stability conditions C, D, and F respectively of the Pasquill model for continuous release of a vapour.

The results of this preliminary hazard assessment using computer programs incorporating the Sutton and Pasquill models should be considered as providing conservative data for contingency planning and the establishment of control responses. Several accidental events have been analyzed successfully with these simple models for relatively low cost and time expenditure compared with the analyses obtainable using more sophisticated models.

REFERENCES

Benkley, C.W. & Bass, A. 1980. Development of mesoscale air quality simulation models, vol. 3. User's guide to MESOPUFF (Mesoscale Puff) model. EPA 600/7-80-058, U.S. Environment Protection Agency, Research Triangle Park, NC., U.S.A.

Clancey, V.J. 1974. The evaporation and dispersion of flammable liquid spillages. In: Chemical Process Hazards, vol. 5, p. 80.

Eisenberg, N.A., Lynch, C.J. & Breeding, R.J. 1975. Vulnerability model. A simulation system for assessing damage resulting from marine spill. National Technical Information Service Report No. AD-A015-245, Springfield, Va., U.S.A.

Finney, D.J. 1971. Probit analysis. Cambridge University Press, London.

Lees, F.P. 1980. Loss prevention in the process industries. Butterworths, London.

Pasquill, F. 1962. Atmospheric Diffusion. Van Nostrand, London.

Roberts, J.J., Croke, E.S. & Kennedy, A.S.K. 1970. An urban atmospheric dispersion model. Symposium on Multiple Source Urban Diffusion Models. Air Pollution Control Office Publication No. AP-86, pp. 6.1–6.72, Pittsburgh, Pa, U.S.A.

Slade, D.H. 1968. Meteorology and atomic energy. Technical Information Center, U.S. Department of Energy, Washington, DC.

Sutton, O.G. 1953. Micrometeorology. McGraw-Hill, New York.

Turner, D.B. 1970. Workbook and atmospheric dispersion estimates. Environmental Protection Agency, Office of Air Programs, Research Triangle Park, N.C., U.S.A.

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استخدام نموذجي ساتون وپاسكويل الرياضيين في محاكاة انتشار المواد الكيميائية الخطرة في الحالات الطارئة

ضاري العجمي ، فكري غبريال ، مها عزيز
معهد الكويت للأبحاث العلمية ، ص . ب ٢٤٨٨٥ ،
الصفاة ١٣١٠٩ ، الكويت

خلاصـــة

إن محاكاة انتشار المواد الكيميائية الخطرة يعتبر مهما من أجل أخذ الاحتياطات اللازمة في حالة انتشار هذه المواد في الحالات الطارئة ووضع خطط وقائية مثل خطة لإجلاء العامة من المناطق المتضررة . وتعتمد النماذج الرياضية للمحاكاة والتنبؤ باتجاه انتشار المواد الكيميائية الخطرة في الحالات الطارئة على عدة مدخلات منها الظروف الجوية مثل سرعة الرياح وكمية الغيوم بالاضافة إلى كمية المواد الكيميائية المنطلقة .

ولقد أثبتت النماذج الرياضية المبنية على نظرية جاوس نجاحها في التنبؤ بكيفية انتشار ملوثات الهواء الجوي . ومن أهم النماذج الرياضية الشائعة الاستعمال والتي تعتبر خير مثال لنظرية جاوس ، نموذج ساتون (١٩٥٣) ونموذج پاسكويل (١٩٦٢) . ولقد تم استخدامها في هذه الدراسة . ويشتمل هذا البحث على مقارنة بين نتائج نموذج ساتون ونموذج پاستكويل اللذين استخدما لمحاكاة كيفية انتشار غازين خطرين هما الكلور المضغوط والنوشادر المبرد .