INFLUENCE OF THE ATMOSPHERIC AEROSOL AND AIR POLLUTION ON SOLAR ALBEDO OF THE EARTH

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ABSTRACT

The effect of increasing atmospheric aerosol and air pollutant concentration upon the solar albedo and consequently upon the heat budget near the earth's surface is studied. The magnitude of aerosol absorption coefficient to back-scattering coefficient B_{ab}/B_{bs} is calculated.This study will be used to estimate atmospheric stability categories and other meteorological parameters which are affected by thermal state and radiation balance of the atmosphere such as mixing and inversion height of Inshas nuclear reactor site. Consequently, concentration distribution of radiative release from Inshas site can be evaluated.

INTRODUCTION

The atmospheric aerosols and air pollutants affect the transfer of solar radiation between the earth-atmosphere system and outer space by reflection and absorption of incoming- and outgoing- solar radiation. These processes could either cause cooling or heating of the earth-atmosphere system depending on the relative magnitude of the aerosol or pollutant absorption and back-scattering coefficients.This attenuation of solar radiation ,by either reflection (scattering) or absorption, will influence the radiation balance and thermal state of the earth's surface.McCormick and Ludwig(1) suggested that an increasing concentration of air pollutant could increase the solar albedo and thus cool the earth. Charlson(2) reported that an increase in air pollutant concentration could either cause cooling or heating of the atmosphere depending on the pollutant physical characterstics. This view is a general one and is adopted by many investigators in later studies. Rehman et al(3) used an empirical scheme of parametrization to correlate solar radiative fluxes and atmospheric heating or cooling rates in the troposphere. Such empirical approach is found useful in planetary boundary layer modelling and in the evaluation of surface heat budget.

This study presents an investigation for the influence of air pollution on the solar albedo by the earth surface taking into account radiation absorption and back-scattering processes. The effect of air pollution upon the amount of energy absorbed by the earth-atmosphere system is studied. The present study will be extended in current research work to estimate various meteorological parameters that are essential for describing atmospheric dispersion calculations. Our future objective is to apply these results for evaluating the conditions of the Inshas nuclear reactor site.

EARTH-ATMOSPHERE HEAT TRANSFER EQUATIONS

Let us consider the effect of atmospheric pollutants and aerosols upon the amount of energy W absorbed by the earth-atmosphere system. This amount of energy is the sum of the absorption due to aerosol- diminished radiation by the earth's surface and by the atmosphere, i.e.,

$$W_{earth-atmos} = W_{surface} + W_{atmos} \qquad (1)$$

Expressing each of these terms as a function of atmospheric and surface properties, the first can be expressed as:

$$W_{surface} = S(1-A) \qquad (2)$$

where A is the solar albedo by the earth's surface (radiation reflected/ radiation incident),and S is the solar energy per unit time incident at the surface of the earth. In general, solar albedo of the ground surface is inversely proportional to the surface temperature, as clear from Figures (1) and (2) for Cairo city in two specific days (2 and 13 June 1966).Upon using the "flat earth approximation "(Mitchell(4)), one can express each of the two members of the right hand side of eq. (1) as:

$$W_{atmos} = S_o \left[1-\exp(-B_{ab} X)\right] \qquad (3)$$

and

$$W_{surface} = (1-A)\, S_o \exp\left[-(B_{bs}+B_{ab})X\right] \qquad (4)$$

where B_{ab} is the absorption coefficient of the aerosol or pollutants, X is the light path length through the atmosphere, and S_o is the energy per unit time incident on the atmosphere and B_{bs} is the back-scattering coefficient of the aerosol. Assuming that the fractional radiation absorption at the surface, (1-A), remains constant with varying atmospheric aerosol (pollution) concentration. Eq.(4) can be used to estimate whether particulate concentration will heat or cool the earth-atmosphere system. After approximating.the exponentials,that are occuring in the right hand side of eq.(4)up to the first order, one can re-write eq.(1), as

$$W_{earth-atmos} \simeq (1-A)S_o(1-B_{bs}X-B_{ab}X)+S_oB_{ab}X \qquad (5)$$

The difference in energy between the earth-atmosphere system with and without aerosols as given by eq(4) and (5) respectively reads

$$\Delta W_{earth-atmos} = S_oB_{ab}X-(1-A)S_o(B_{bs}+B_{ab})X \qquad (6)$$

A criterion which may be used to determine if the increase in aerosol heats or cools the earth-atmosphere system is:

$$\frac{B_{ab}}{B_{bs}} > \frac{1-A}{A} \quad \text{[heating the earth with increasing aerosol]} \qquad (7.a)$$

$$\frac{B_{ab}}{B_{bs}} = \frac{1-A}{A} \quad \text{[no change with increasing aerosol]} \qquad (7.b)$$

$$\frac{B_{ab}}{B_{bs}} < \frac{1-A}{A} \quad \text{[cooling the earth with increasing aerosol]} \qquad (7.c)$$

Figure (3) shows the relation between absorption to backscattering coefficient B_{ab}/B_{bs} and ground surface temperature, according to the first order expansion approximation.

More accuratelly, we shall expand the exponential terms in eq.(4) up to the second order ,equation (5) takes the form:

$$W_{earth-atmos} = (1-A)S_o\left[1-B_{bs}X-B_{ab}X+\frac{(B_{bs}+B_{ab})^2X^2}{2}\right]+$$

$$S\left[1-1+B_{ab}X-\frac{B_{ab}^2X^2}{2}\right]$$

$$= S_o-S_oB_{bs}X-S_oB_{ab}X+\frac{S_o(B_{bs}+B_{ab})^2X^2}{2}-AS_o+AS_o$$

$$B_{bs}X + AS_oB_{ab}X - \frac{AS_o(B_{bs}+B_{ab})X^2}{2}+S_oB_{Ab}X-\frac{S_oB_{ab}^2X^2}{2}$$

In this case, eq.(6) may be written as:

$$\Delta W_{earth-atmos} = W_{earth-atmos} - (1-A)S_o$$

$$=AS_oB_{bs}X - S_oB_{bs}X + \frac{S_oB_{bs}^2X^2}{2}+S_oB_{bs}B_{ab}X^2+$$

$$AS_oB_{ab}X-\frac{AS_oB_{bs}^2X^2}{2}-AS_oB_{bs}B_{ab}X^2-\frac{AS_oB_{ab}^2X^2}{2}$$

Requiring no change i.e $\Delta W=0$ we get:

$$\frac{B_{ab}^2}{B_{bs}^2}+\left(2-\frac{2}{X\,B_{bs}^2}-\frac{2}{A}\right)\frac{B_{ab}}{B_{bs}}+\left(1-\frac{1}{A}+\frac{2}{AXB_{bs}^2}-\frac{2}{XB_{bs}^2}\right)=0$$

we get after approximating $B_{bs}=c$

$$\frac{B_{ab}}{B_{bs}} = \frac{-M \pm \sqrt{M^2-4N}}{2}$$

where $M=2-\frac{2}{XC}-\frac{2}{A}$ and $N=1-\frac{1}{A}+\frac{2}{AXC}-\frac{2}{XC}$

Neglecting the positive value which gives unrealistic values,we have

$$\frac{B_{ab}}{B_{bs}} = \frac{-M - \sqrt{M^2 - 4N}}{2}$$

After re-substituting the abbreviations given above,the final form may be written as:

$$\frac{B_{ab}}{B_{bs}} = \frac{1-A}{A} + \frac{1}{XC} - \sqrt{\frac{1}{X^2C^2} - \frac{1}{A} + \frac{1}{A^2}} \qquad (8)$$

Figure (4) illustrates the same relation as in Fig.(3), but for the case of second order expansion approximation.where C is a constant, its value depends on the surface type upon which the solar radiation is absorbed or scattered. Our derived equations (7) and (8) are applied to calculate B_{ab} / B_{bs} for different surface type. Table 1 gives the result of calculation taking an average value for light path length through the atmosphere X=0.2

Table 1.Comparison of critical absorption to backscattering ratios for different surface types as derived in the report using eqn.(7) and eqn.(8)

surface type	Albedo A	Critical ratio eqn.(7)	Critical ratio eqn.(8)
Urban area	0.2	4	3.8
Deserts	0.3	2.3	2.2
Prariries and grassland	0.2	4	3.8
Forests	0.16	5.2	4.9
Oceans	0.08	12	10.1
snow-fields	0.7	0.43	0.4

STABILITY CLASSIFICATION ACCORDING TO SOLAR RADIATION

The interaction of air pollution with the thermodynamics of the atmospheric mixing layer occurs radiatively, and thus we should incorporate the radiation budget analysis in the problem of air quality pollutant dispersion models. The problem is associated with the estimation of energy budget components:net radiation, latent heat flux, ground heat flux, sensible heat flux, cloud cover, and water vapour. Manju et. al(5) proposed a model predicting the long range air quality for the dispersion of air pollutants emitted from an area source. The model input parameters are the routine meteorological observations which are used for the computations of: sensible surface heat flux, mixing height depth, friction velocity ,wind speed and diffusivity profiles. These results can be used to obtain atmospheric stability and consequently the pollutant concentration pattern.

The solar altitude (SA) is first determined from the meteorological station latitude and longitude, time of the day and season. An insolation class number (ICN) is then determined as indicated in table (2).

Table 2. Insolation Class from Solar Altitude

Solar Altitude	Insolation cLASS Numbers
$SA \leq 0^{o}$	ICN=0
$0^{o} < SA \leq 15^{o}$	ICN=1
$15^{o} < SA \leq 35^{o}$	ICN=2
$35^{o} < SA \leq 60^{o}$	ICN=3
$60^{o} < SA$	ICN=4

The insolation class is then modified according to the ceiling height and pollution or aerosol cover (whether cooling or heating the earth- atmosphere system,eqns. (7) or (8). and the net radiation index is computed

Once the net solar radiation index is determined the stability classes can be identified from the categories presented in Safety Series NO.50-SG-S3$^{(6)}$. The categories are presented in tables (3) and (4),for day and night respectively.

Table (3) Stability Classification using Solar Radiation

wind speed ($m.s^{-1}$) at 10 m	Stability class,day with solar radiation R_D (langleys.h^{-1})			
	$R_D \geq 50$	$50 > R_D \geq 25$	$25 > R_D \geq 12.5$	$12.5 > R_D$
$U < 2$	A	A-B	B	D
$2 \leq U < 3$	A-B	B	C	D
$3 \leq U < 4$	B	B-C	C	D
$4 \leq U < 6$	C	C-D	D	D
$6 \leq U$	C	D	D	D

Table (4) Stability Classification using Solar Radiation

wind speed ($m.s^{-1}$) at 10 m	Stability class,night with net radiation R_N (langleys.h^{-1})		
	$R_N > -1.8$	$-1.8 \geq R_N > -3.6$	$-3.6 \geq R_N$
$U < 2$	D	-	-
$2 \leq U < 3$	D	E	F
$3 \leq U < 4$	D	D	E
$4 \leq U < 6$	D	D	D
$6 \leq U$	D	D	D

where the stability conditions are divided into six classes designated A(extremely unstable) ,B,C,D,E AND F(moderately stable).

Finally, the stability parameters σ_y and σ_z used in the pollutant concentration distribution may be calculated from the formulae:

$$\sigma_y = p_y \, x^{q_y} \tag{9}$$

$$\sigma_z = p_z \, x^{q_z} \tag{10}$$

where p_y, q_y, p_z and q_z are emperical constants having the values given in Table (5) (Safety Series No.50,1980)

Table (5) The coefficients p,and q for different stability classes and two emission heights

Emission height (meter)	Stability class	Coefficients p and q for the calculation of σ_z and σ_y p_y	q_y	p_z	q_z
50	A	0.87	0.81	0.22	0.97
50	B	0.87	0.81	0.22	0.97
50	C	0.72	0.78	0.21	0.94
50	D	0.62	0.77	0.20	0.94
50	E	1.69	0.62	0.16	0.81
50	F	5.38	0.58	0.40	0.62
100	A	0.23	1.00	0.10	1.16
100	B	0.23	0.97	0.16	1.02
100	C	0.22	0.94	0.25	0.89
100	D	0.22	0.91	0.40	0.76
100	E	1.69	0.62	0.16	0.81
100	F	5.38	0.58	0.40	0.62

CONCLUSIONS

The effect of aerosol and air pollution on albedo of the earth is studied . We get two formulae, eqns.(7) and (8), for B_{ab}/B_{bs}, which can be used to determine whether the aerosol will cause heating or cooling the earth -atmosphere system. These results can be used for classifying stability classes and the stability parameters σ_y and σ_z may be estimated. Concentration of pollutants are then computed from appropriate formulae.

The stability parameters given by eqns.(9) and (10) are the most widely used in case of release from nuclear power plants. The proposed technique in this paper will be adopted to estimate the diffusion parameters, mixing and inversion heights and hence the dispersion from the Inshas Nuclear reactor, Egypt. The procedure given in this paper is general and could be easily adopted and used for any site where meteorological observations are available.

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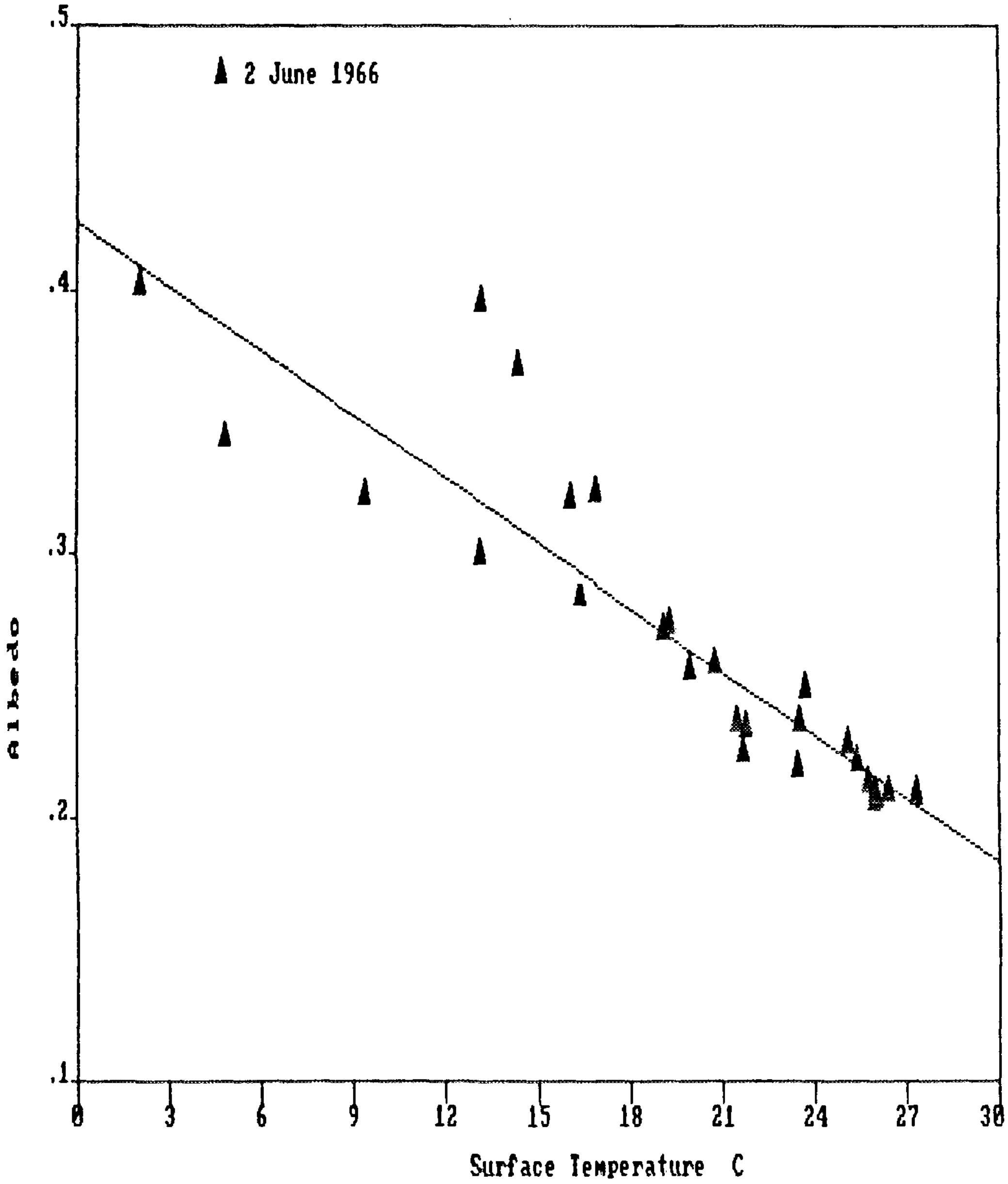
Fig.1 Half Hourly Rel. Bet. Albedo & Surface Temp.



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THE REGRESSION POLYNOMIAL OF LINE  1 -

     ( 4.258E-01 ) + ( -8.082E-03 )*X
     THE VARIANCE -   5.816E-04
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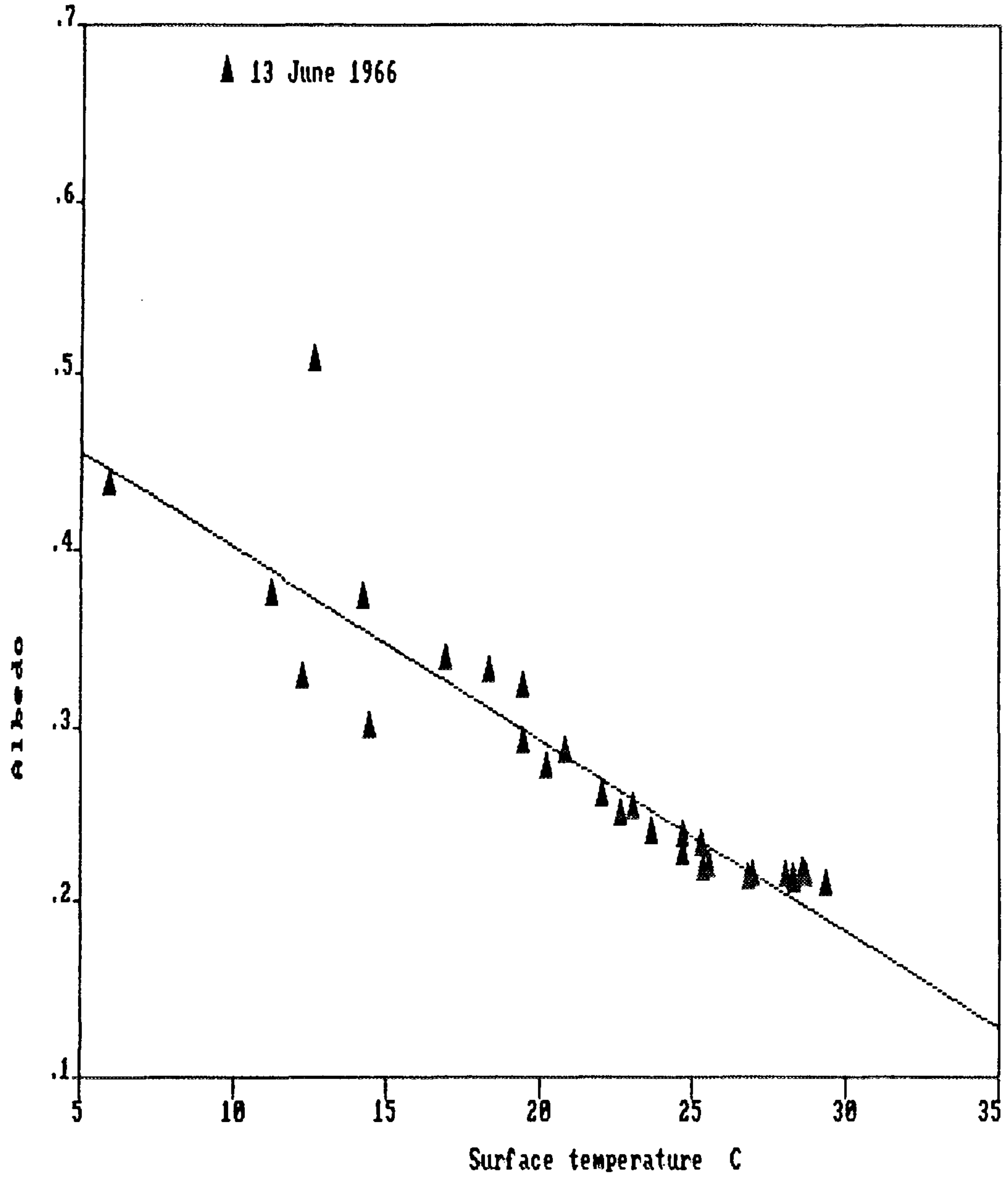
Fig.2 Half Hourly Rel. Bet. Surface Temp.& Albedo



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THE REGRESSION POLYNOMIAL OF LINE  1 -

     ( 5.117E-01) + (-1.095E-02)*X
     THE VARIANCE -  9.443E-04
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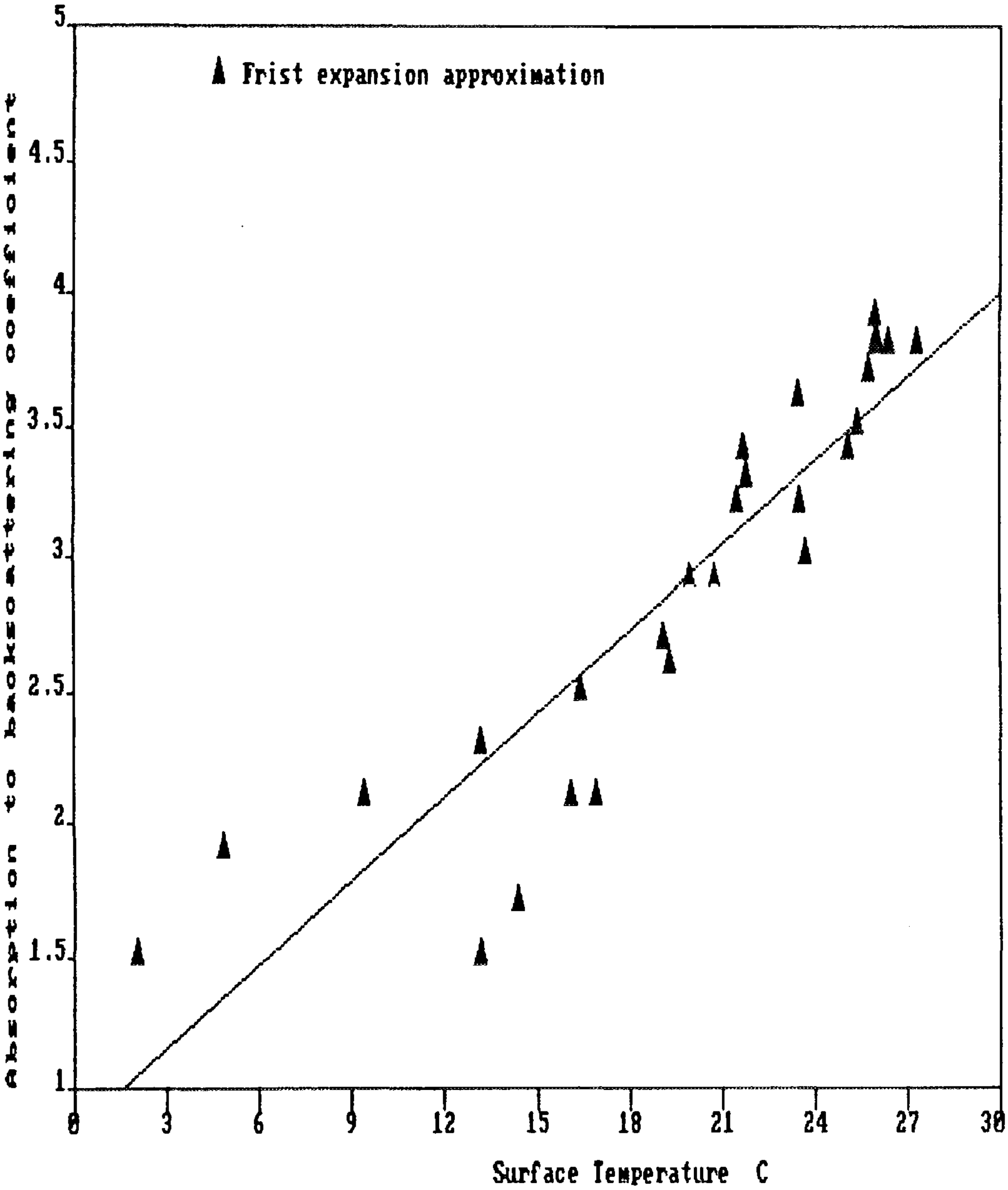
Fig.3 Month. Rel.Between Bab/Bbs and Surface Temp.



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THE REGRESSION POLYNOMIAL OF LINE  1 -

     ( 8.319E-01) + ( 1.056E-01)*X
     THE VARIANCE -  9.711E-02
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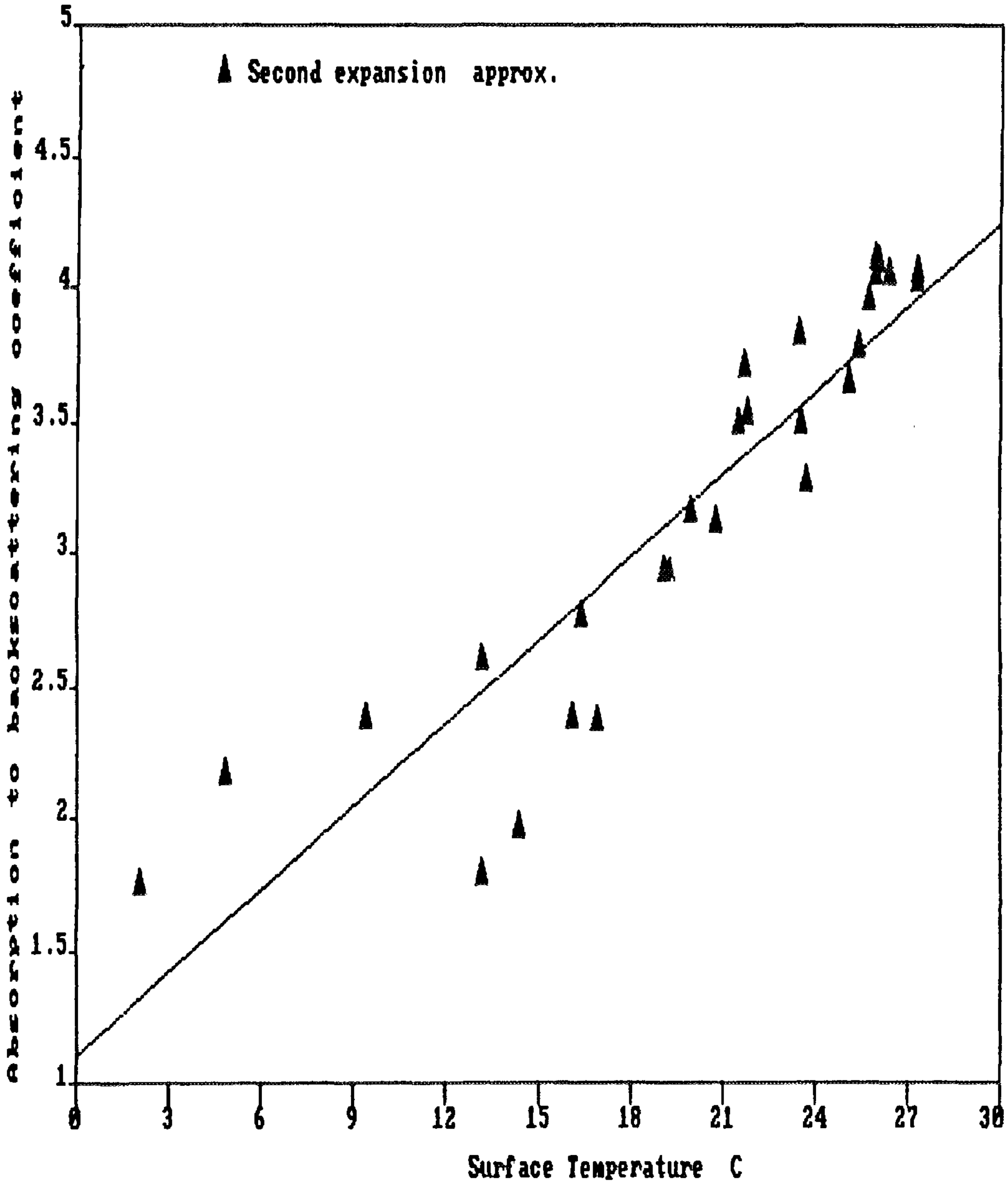
Fig.4 Month. Rel.Between Bab/Bbs and Surface Temp.



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THE REGRESSION POLYNOMIAL OF LINE  1 -

     ( 1.101E+00) + ( 1.046E-01)*X
     THE VARIANCE -  9.330E-02
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PLUME RISE AND GROUND LEVEL POLLUTION

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ABSTRACT

A theoretical model of ground level concentration of an inert pollutant released from a chimney has been formulated . The highest possible ground level concentration is obtained from the Gaussian plume model for power law forms of the dispersion coefficient . The results are disscussed for various sets of dispersion coefficient depending on stability categories .

INTRODUCTION

The Gaussian Plume Model (GPM) (Csanady , Smith , Turner) (1,2,3) provides the primary method for calculating concentrations of non - reactive pollutants from a point source. This model has found widespread application in design of stacks and environmental impact analysis . In the GPM formula for the concentration , the effective height of emission is an important parameter for ground level concentration calculations. Due to the initial kinetic energy of the released plume and its thermal energy when the plume temperature is above ambient air temperature, there will be an increase in the emission height of the plume. This increase is known as the plume rise Δh. The effective source height H is then given by (IAEA safety Guide)[(4)]

$$H = h_s + \Delta h \qquad (1)$$

where h_s is the physical stack height. In order to predict ground level concentration of pollutants, the plume rise should be taken into consideration. Pasquill [(5)] , Ragland [(6,7)]and others have obtained the maximum ground level pollution, taking into account the plume rise.

These treatments have assumed that the plume rise Δh is constant with the downwind distance x. In the present paper, we deal with the general case in which Δh is a function of x and we calculate, analytically, the profile of H in terms of the downwind distance. In case where Δh is constant, the worst ground level concentration was found.

THEORETICAL TREATMENT

The concentration distribution from a single release is given by the GPM as :

$$\chi(x,y,z,H) = \frac{Q}{2\pi\sigma_y\sigma_z u}\exp\left[-\left(\frac{y^2}{2\sigma_y^2}\right)\right]\cdot\left\{\exp\left[-\frac{(z-H)^2}{2\sigma_z^2}\right]+\exp\left[-\frac{(z+H)^2}{2\sigma_z^2}\right]\right\} \qquad (2)$$

where Q is the emission rate, u the wind spead at stack height, σ_y and σ_z are the lateral and vertical dispersion coefficients. The ground level concentration below the centerline of the plume is btained by setting y=z=0 in equation (2), then we have :

$$\chi(x,0,0,H)=\frac{Q}{\pi\sigma_y\sigma_z u}\exp\left[-\frac{H^2(x)}{2\sigma_z^2}\right] \tag{3}$$

The standard deviations of the Gaussian distributions σ_y and σ_z are functions of downwind distance x and atmospheric stability , and they are expressed as (Turner (3)) :

$$\sigma_z = a\,x^b \qquad \text{and} \qquad \sigma_y = a\,x^d \tag{4}$$

where the coefficients a,b , c , and d depend on the atmospheric stability class , table 1 . (Ragland[6,7]).

Table 1. Standard deviations coefficient (recommended by U. S. Enviromental Protection Agency EPA) .

Stability	a	b	c	d
Very unstable	0.00022	2.1	0.59	0.85
Unstable	0.056	1.1	0.41	0.86
Slightly unstable	0.12	0.91	0.24	0.88
Neutral	0.73	0.55	0.14	0.89
Slightly stable	0.82	0.48	0.11	0.89
Stable	0.63	0.45	0.075	0.89

Eqution (3) then may be written as

$$\chi(x,0,0,H)=\frac{Q}{\pi\, u\, a\, c\, x^{(b+d)}}\exp\left[-\frac{H^2(x)}{2a^2x^{2b}}\right] \tag{5}$$

The maximum concentration occurs at the region where $\frac{\partial\chi}{\partial x}=0$. (Note that the maximum concentration of pollutant does not occur at a definite point or location on the ground , but it does occur over the whole range of x for which we find $\frac{\partial \chi}{\partial x} = 0$).

Upon differentiating equation (5) we get the following differential equation which specifies the variation of H as function of x .

$$xH(x)\frac{dH(x)}{dx} - bH^2(x) + a^2(b+d)x^{2b} = 0 \qquad (6)$$

Upon making the transformation

$$H = \left[xY'(x)\right]^b$$

We get the differential eqution

$$\frac{b}{a^2(b+d)}Y'^{2b-1}\frac{dY'}{dx} + \frac{1}{x} = 0$$

Its solution

$$\frac{1}{2a^2(b+d)}Y'^{2b} = \ln\frac{A}{x}$$

where A is the constant of integration .

On substituting back , we get the solution of eqution (6) as

$$H_m(x) = \left[2a^2(b+d)x^{2b}\ln\frac{A}{x}\right]^{1/2} \qquad (7.a)$$

which when substituted in equation (5) gives for maximum concentration for all x the value :

$$\chi_m(x) = \frac{Q}{\pi\, u\, a\, c\, A^{b+d}} \tag{7.b}$$

where x is the distance where the maximum concentration occurs . Equation (7) gives the variation of the effective source height H as function of downwind distance through the range where maximum concentration occurs . The constant of Intergration A could be determined from case study, namely , the emission from the research reactor in Inchas (Mayhoub et al$^{(8)}$) ,its stack height $h_s = 43$ m . For example A has the following numerical values :

A= 1882	m	(neutral)
A=4624	m	(slightly stable)
A=68082	m	(stable)

The explicit formula of χ can not-easily-be deduced analytically from equation (7) . The best fit of this relation was performed on the computer , which yields the following semi-empirical formula for the three above-mentioned stability classes

$$H_m(x) = c_1 x^2 + c_2 x + c_3 \tag{8}$$

where c_1, c_2 , and c_3 are constants , their values for different stability classes are given in table 2 .

Table 2 . The constants c_1 , c_2 and c_3 for different stability classes

Stability	c	c	c
Neutral	-76.12	69.93	29.63
Slightly Stable	-35.23	55.03	27.12
Stable	-27.44	59.39	23.27

Graphically , the relation between x_m and H is shown in Fig. 1 for the three stability classes , neutral, slightly stable and stable .

SPECIAL CASE

Considering the case where the effective height of the emission H is constant . Equation (6) in this case is simply reduced to

$$bH^2 = a^2(b+d)x_m^{2b}$$

or equivalently

$$x_m = \left[\frac{bH^2}{a^2(b+d)}\right]^{1/2b} \qquad (9)$$

In this case , x_m could be easily identified , and hence both σ_z and σ_y can be determined easily

$$(\sigma_z)_{\max} = \left[\frac{b}{b+d}\right]^{1/2} H \qquad (10)$$

Thus , the maximum concentration χ_m could be found

$$\chi_m = \frac{Q\exp\left[-\frac{b+d}{2b}\right]}{\pi\, u\, a\, c\left[\frac{bH^2}{a^2(b+d)}\right]^{(b+d)/2b}} \tag{11}$$

Moses ,1968 formulated the plume rise Δ h and its stability dependence on the following form

$$\Delta h = B/u \tag{12}$$

where B is a characterstic number for a particular stack and depends on stability to a certain extent .

To find the worst wind velocity u_m under which , the ground level concentration has a maximum value , we find dχ/du . Applying this differentiation on equation (3) , taking into account that $H = h_s + B/u$, we get

$$u_m = \frac{d}{b}\frac{B}{h_s} \tag{13}$$

From which we can find the worst emmission height H_m which causes a maximum ground level concentration

$$H_m = \left(\frac{b+d}{d}\right)h_s \tag{14}$$

Finally substituting u_m and H_m back into equation (11) we get the worst ground level concentration χ_{worst}

$$\chi_{worst} = \frac{Qb\exp[-(b+d)/2b]h_s^{-d/b}}{\pi\, a\, c\, d\, B[b(b+d)/a^2d^2]^{(b+d)/2b}} \tag{15}$$

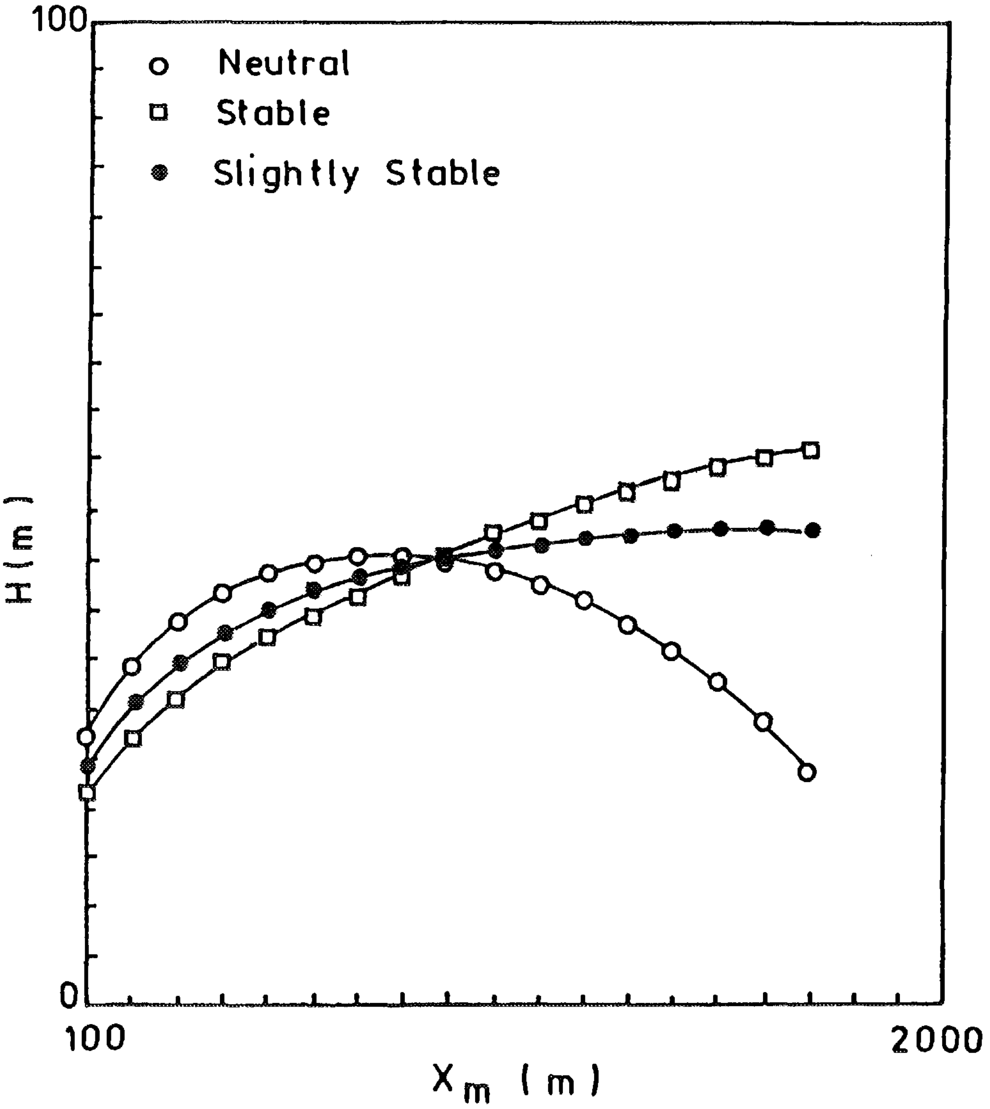

Fig. 1. Relation between X_m and H·

SUMMARY AND CONCLUSIONS

In this paper we present a theoretical study which provides a satisfactory desciption of ground level concentration in two cases : the plume rise Δ h is function of downwind distance and when it is not . In the second case we consider the variation of Δh with the wind velocity , and atomospheric stability. Equations (9-15) determine the maximum ground level concentration , its position , the worst wind velocity , dispersion parameters and emission height. In the first case , it was not easy to obtain such formulas due to the complexity of the problem . In equation (7) , it was difficult to express analytically the formula of x_m . It seems reasonable to draw these relations and get regression polynomials of three stability categories in case study , namely the emission from the research reactor in Inchas (Egypt) .

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