Global Journal of Environmental Sciences. Vol. 4, No. 2, 2005,: 147 - 149
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# MODELLING OF GROUND LEVEL PARTICULATE CONCENTRATION FROM AN INDUSTRIAL CHIMNEY

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(Received 13 July 2004; Revision accepted 1 November, 2004)

ABSTRACT

Increase in demand for cement has been created as a result of rapid industrialization.Cement production is not without its environmental pollution problems.The pollutants released in a cement industry include oxides of nitrogen, and sulphur, and particulates and volatile organic compounds.Elevated particulate concentrations in conjunction with oxides of sulphur is responsible for rises in respiratory tract diseases.To easily predict maximum ground level particulate concentrations in the atmosphere,models have been generated in this work.Six models having coefficient of determination ($r^2$) values ranging between 0.9735 to 0.9976 have been developed for a range of weather conditions for predicting maximum ground level particulate concentrations as a function pf chimney height.

**KEYWORDS:** particulates, cement industry, maximum ground level concentration, Gaussian plume model.

## INTRODUCTION

In the manufacture of cement ,calcium carbonate is the principal raw material. The dry process of cement manufacture is favored by modern designs although the choice depends on the nature of available raw material. Although cement is important, its production is not without its environmental pollution problems. The major constituents of gas effluent at a cement plant include oxides of nitrogen ($NO_x$),oxides of sulphur ($SO_x$),particulates and volatile organic compounds Masters(1991). Particulate matter is defined as any dispersed matter, solid or liquid in which the individual aggregates are larger than single small molecules(about 0.0002μm in diameter),but smaller than about 500μm.A number of terms are used to categorise particulates, namely aerosol, dust, fumes,mist,fog,smoke,soot and smog. Dust are solid particles caused by threshing, grinding or crushing operations. Elevated particulate concentrations in conjunction with oxides of sulphur is responsible for rises in respiratory tract diseases.Some particulates are especially dangerous because of their toxicity. .Large sized particulates come primarily from soil and other crustal materials. Combustion of fuels for power generation in industrial processes and for powering motor vehicles generates particulates. Lead-containing particulates are emitted from vehicles as black smoke(Wijetilleke and Karunaratne, 1995).The study of particulates is very important in domestic as well as agricultural sectors. Particulates may settle on leaves thereby interfering with normal photosynthetic activity in plants. Despite the above, little attention is being paid to this aspect of the environment in developing countries.

The monitoring of pollutants in the atmosphere is achieved using a model. The purpose of dispersion modeling is to obtain an estimate of downwind concentration without resorting to field sampling (Stiggins, *et al.*, 2003). The most important output of a diffusion model is the maximum concentration. Many methods including complex numerical dispersion models are available for pollutant concentration modeling (Zoumakis, *et al.*, 1992). Of all these, the Gaussian plume model is a straight forward and widely used approach for predicting concentrations of non depositing and non reactive air pollutants downward from a point source (Zoumakis, *et al*, 1992, Melli and Runca, 1979, Utah Division of Air Quality , 2000). In order to effectively manage the air quality, there is a need for monitoring and modeling of air quality parameters (IPAQMP, 2003). The Gaussian plume model has a wide variety of applications which include industries (Stiggins, *et al.*, 2003), weather conditions (IPAQMP, 2003), air crafts (Karol, *et al.*, 1996), as well as automobiles (Alili, *et al.*, 2001).

The Gaussian plume model is the most accepted computational approach for calculating the concentration of pollutant concentration. The transport and mixing of the pollutants are described in the model. There are several versions of the Gaussian plume model but a classical one is the Pasquill-Gifford model. The aim of this work is to show the effect of chimney height on maximum ground level particulate concentration .

The Pasquill-Gifford atmospheric classification system is the most commonly used method for estimating dispersion parameters associated with the Gaussian dispersion model (Stiggins, et al) The stability system classification system was introduced by Pasquill (1961), Gifford (1960) and Turner (1967). The stability classification for class A corresponds to a very unstable condition, B represents moderately unstable conditions, C corresponds to unstable and conditions associated with nighttime conditions, D: neutral ;E: slightly stable; F: stable also associated with nighttime conditions. The stability classes are important criteria used in calculating horizontal and vertical spread parameters ( respectively $\sigma_y$ and $\sigma_z$ ) utilized in the Gaussian model. The value of $\sigma_y$ and $\sigma_z$ used in this work were obtained from graphs in Masters (1991).

## MATERIALS AND METHODS

### Measurement of particulates

Particulate samples were taken at the most accessible part of the system. Thus, two holes of about 100mm diameter were drilled into the chimney at the entrance (after the precipitator) and at a height of 7m above the ground. Prior to any measurement ,a standard pitot tube was inserted into the chimney to measure the velocity of the gas at the sampling point. With the aid of a calibration chart, the pressure drop required across the sampling probe to ensure sampling at the same velocity as in the chimney was obtained. The pitot was then replaced by a sampling probe to

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which sunction was applied from a pump. The sunction was regulated by a valve to give the correct pressure drop .The inlet for the dust laden gas points upstream in the chimney and the gas entering it passed tangentially into the probe. The resulting swirls spon the grit and dust into the hopper of the sampler and the dust free gas was removed through the suction pump. At the end of the sampling period, the content of the hopper was weighed.

**Modeling Pollutant Concentration in the atmosphere**

The ground level particulate concentration from a cement factory was obtained using the Guassian-point source dispersion equation(Masters ,1991). The form of the equation applicable to z=0 in the coordinate system is

$$C(x,y)=\frac{Q}{2\pi\sigma_y\sigma_z U}\left(\exp\frac{-H^2}{2\sigma_z^2}\right)\left(\exp\frac{-y^2}{2\sigma_y^2}\right) \quad (1)$$

where C(x, y)=concentration at ground level at the point (x,y)μg/m$^3$
Y=horizontal distance from the plume center line in metres (m)
Q=emission rate of particulate (μ g/s)
H=effective stack height (x) in metres (m)
U=average wind speed at effective stack height (m/s)
$\sigma_y$ =horizontal dispersion coefficient (standard deviation) in metres (m)
$\sigma_z$ =vertical dispersion coefficient (standard deviation) in metres (m)

**Atmospheric Stability Classification**

The Gaussian plume model - the Pasquill-Gifford version(Pasquill, 1961,Gifford,1960) was used to predict the ground level particulate concentration for a cement industry. Power equations were also used to represent the curves generated using the plume model having ground level particulate concentration(y) as a function of chimney height(x). The prediction was performed for all the weather condition (A-F).

**Regression Models**

Regression models of the form y=ax$^n$ were generated having stack height as the independent variable and ground level particulate concentration for each stability classification namely A=very unstable; B=moderately unstable; C=slightly unstable; D=neutral ;E=slightly stable; F=stable as dependent variable( Masters, 1991).

## RESULTS AND DISCUSSION

**Plot of particulate concentration against stack height**

Figure 1 shows the plot of maximum downwind ground level concentrations of particulates against chimney height for the six weather classifications under consideration(A-F). The maximum concentration shown in the figure with the value of 11966.381μg/m$^3$ was obtained for weather classification F and it was also evident that at a chimney height of above 70m, the maximum particulate concentration released into the atmosphere was at a tolerance level of below 30 μg/m$^3$(Wijetilleke, *et al.*,1995) for all the weather conditions.The implication of this is that chimney heights of above 70m are safe for particulate dispersion considering emission rates less than or equal to that used in the work..

**Simple Regression**

This is a form of equation with one dependent and one independent variable. The regression form used in this study is

$$Y = ax^n \quad (2)$$

Where y= particulate concentration (μg/m$^3$).
x= stack height(m)
n = power coefficient of stack height.

This regression was performed using the power function of Microsoft excel .Table 1 shows the power function models determined for each weather condition. In condition A, the coefficient of determination was $R^2$ = 0.9735 with an overall F of 440.8 and a t value of 19.166 at 95% confidence interval. Conditions B and C models also have high coefficients of determination of 0.9939 and .9974 respectively. The highest coefficient of determination of 0.9976 was for the model for predicting ground level

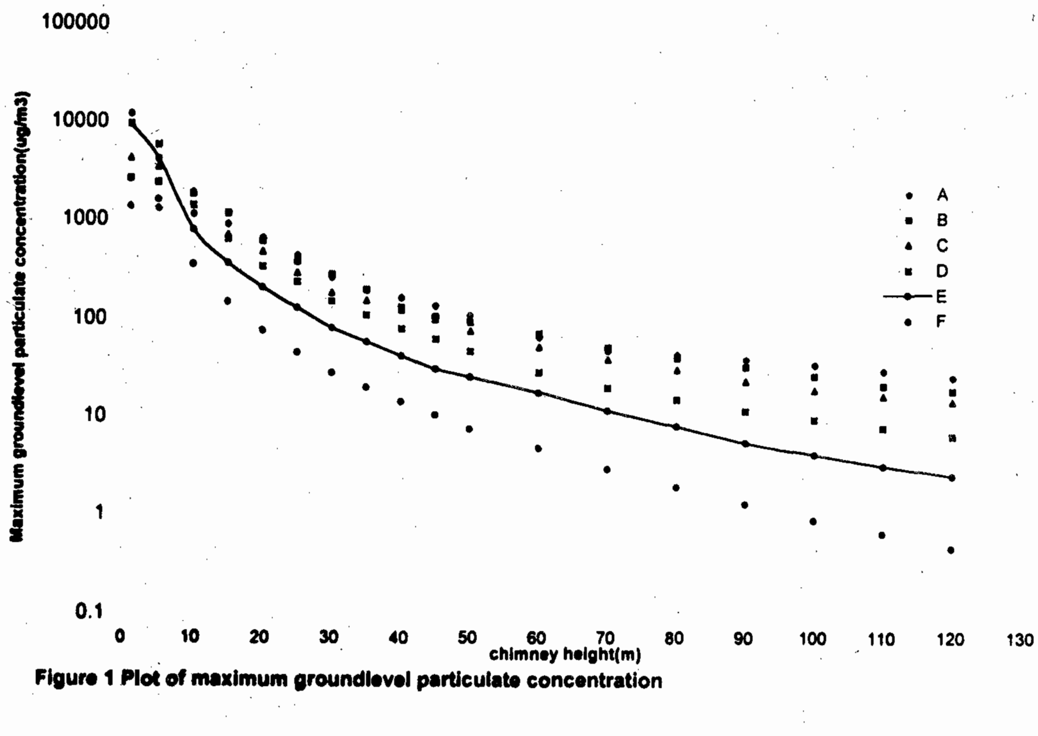


**Figure 1 Plot of maximum groundlevel particulate concentration**

**Table 1: Power function models for determining groundlevel particulate concentration(at 95%confidence Interval)**

| Weather conditions | Model | $R^2$ | F | t |
|---|---|---|---|---|
| A:very unstable | $Y=93368x^{-1.7389}$ | 0.9735 | 440.8 | 19.166 |
| B:moderately unstable | $Y=187291x^{-1.9353}$ | 0.9939 | 1955.2 | 40.339 |
| C:slightly unstable | $Y=160021x^{-1.9573}$ | 0.9974 | 4603.4 | 61.937 |
| D:neutral | $Y=253033x^{-2.2032}$ | 0.9967 | 3624.4 | 54.955 |
| E:slightly stable | $Y=150645x^{-2.2222}$ | 0.9976 | 4988 | 64.472 |
| F:stable | $Y=133255x^{-2.5043}$ | 0.9963 | 3231.24 | 51.8888 |

concentration for weather condition E .Considering the overall F values at 95% confidence interval, the models were adjudged valid for predictions at the individual weather conditions .The t-test to check the significance of the independent variable, the chimney heights from zero was obtained using the formula (Yevjevich, 1972).

$$t = \frac{r\sqrt{N-2}}{\sqrt{1-r^2}} \qquad (3)$$

Where $r$ = coefficient of correlation
N = Number of observations
$r^2$ = coefficient of determination
and the overall F was obtained using the formula

$$F = \frac{R^2}{1-R^2}\frac{(n-k-1)}{k} \qquad (4)$$

Where k = number of independent variables
n = number of observations

## CONCLUSION AND RECOMMENDATION

In this paper models have been generated for predicting ground level particulate concentration for all the weather conditions. Considering the measured value of particulate emission pollutant rate, Q, various values of ground level particulate concentration were calculated with different values of stack height. The calculated maximum values of ground level particulate concentrations and utilized stack height values were used to plot a graph of maximum values of ground level particulate concentrations and stack height for all weather condition (A-F).

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