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Prediction of SPM, SO_2 and NO_2 Concentrations in The Vicinity of Cement Industry Using Gaussian Model.

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ABSTRACT

The burning of limestone creates sulphide emissions, a major contributor to acid rain. Limestone (primarily calcium carbonate) is converted to quicklime (calcium oxide) through prolonged exposure to high heat. This removes water and carbon from the stone and releases carbon dioxide into the atmosphere. In cement industry the coal is used for heating process. Combustion of coal along with lime stone is the main source for the emission of air pollutants. This study deals with the prediction of ground level concentration of Suspended Particulate Matter (SPM), Sulphur dioxide (SO_2), and Nitrogen dioxide (NO_2). By using Gaussian model at various receptor points from a point source of a cement plant. Basically pollutant dispersion model is the mathematical formulation to explain how pollutants from various sources disperse in the atmosphere. The point source selected for this work is Ultra Tech Cement Ltd Andhra Pradesh Cement Works is located at Bhogasamudram, 16 km. from Tadipatri mandal in Anantpur district, Andhra Pradesh, India. Concentrations of SPM, SO_2 and NO_X are predicted for annual and 24 hour averaging periods at various points and compared with National Ambient Air Quality Standards.

Keywords: cement industry; point source; Primary Pollutants; Gaussian model; Ambient Air Quality Standards.

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INTRODUCTION

Gaussian Equation

The Gaussian dispersion model is most widely used for the prediction of ground level concentrations of pollutants [4]. The simple form of Gaussian plume equation for solving pollutant concentration at a point in space is given [7]:

$$C(x,y,z)=\frac{Q}{2\pi u\sigma_y\sigma_z}e^{-\frac{y^2}{2\sigma_y^2}}\left(e^{-\frac{(z+H)^2}{2\sigma_z^2}}+e^{-\frac{(z-H)^2}{2\sigma_z^2}}\right)$$

Where

Q = emission rate of pollutant in gram/second
u = average wind speed in meter/second
σy = standard deviation,y direction in meter
σz = standard deviation,z direction in meter
x = downwind distance x in meter
y = cross wind distance y in meter
Z = receptor height z in meter
H = effective height of stack in meter

Back Ground of the cement industry

Ultra Tech Cement Ltd Andhra Pradesh Cement Works is located at Bhogasamudram, 16 km from Tadipatri mandal in Anantpur district Andhra Pradesh, India. Cement plant is located at the hill top (351.5 m. MSL) and the packing plant & wagon tippler are located down the hill (266.0 m. MSL/ Latitude15 1' 13" N, Longitude 78 0' 54" E). The plant is located at the border line between Kurnool & Anantapur districts, 70 km from Anantpur city. The nearest railway station is "Juturu" between Tadipatri & Gooty on the Guntakal-Chennai line. The grinding unit is located in Arakkonam in the Tamilnadu state (figure 1). This unit is not producing the clinker and it is taking the clinker from Ultra Tech Cement Ltd Andhra Pradesh Cement Works and manufacturing ordinary Portland cement (OPC) and Portland Pozzolana cement (PPC).

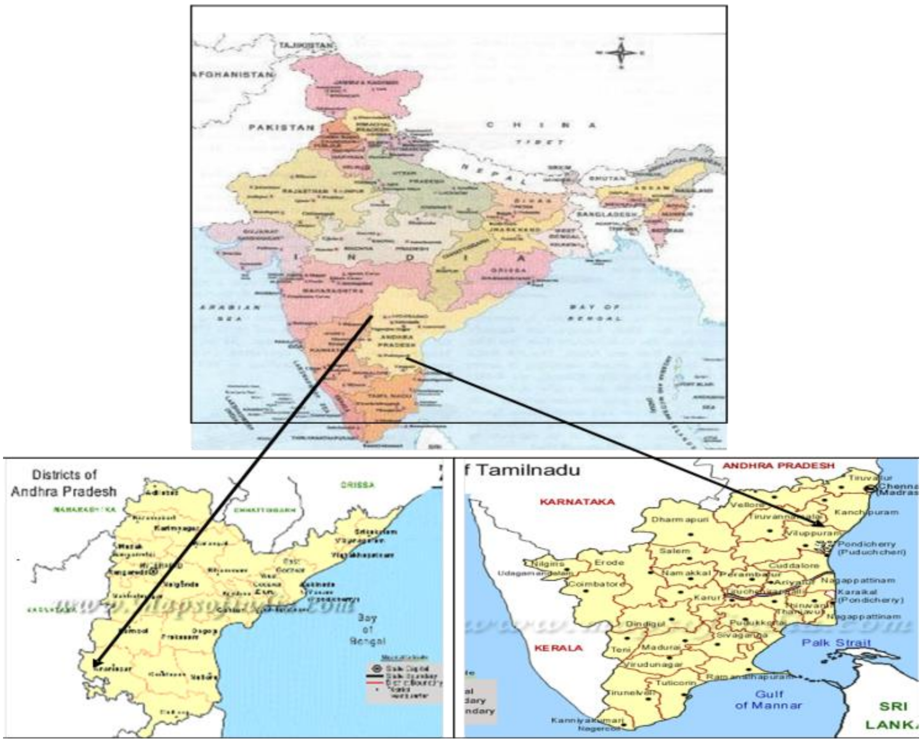

Figure 1: UTCL plant- location

Potential Air Pollutants Emitted

Potential air pollutants from stationary source of a cement manufacturing plant are criteria pollutants of Suspended Particulate Matter (SPM), Sulphur dioxide (SO_2), and Nitrogen dioxide (NO_2) [1]. All the pollutants produced are considered as photo toxicants [6]. They will show severe environmental impact on man, material, livestock and vegetation.

Methodology

Three point sources are integrated; emission rates and emission concentrations are calculated from emission inventory methodologies [10]. Prediction of ground level concentrations of Suspended Particulate Matter (SPM), Sulphur dioxide (SO_2), and Nitrogen dioxide (NO_2) are carried out by using Gaussian dispersion equation [4].

Gaussian Model

The Gaussian dispersion model is very old and the most widely used in the prediction of air pollutant concentrations in the ambient atmosphere [3]. It assumes that the dispersion of air pollutant is a Gaussian distribution; it means the pollutant distribution is a normal probability distribution. Gaussian models are used for predicting the dispersion of all types of plumes emitted from ground-level or elevated sources [7].

Plume rise on the basis of Holland's equation

$$\Delta H = \frac{Vsd}{u}\left(1.5 + 2.68 \times 10 - 3p.\frac{Ts - Ta}{TS}.d\right)$$

Where,

ΔH = the rise of the flume above the stack, m
V_S = stack gas exit velocity, m/s
d = the inside stack diameter, m
u = wind speed, m/s
p = atmospheric pressure, Atm.
T_s = stack gas temperature, ^{0}k
T_a = ambient air temperature, ^{0}k
Plume rise ΔH m
Source parameters are given in table 1.

Table 1: Different parameters of UTCL

Parameters(units)	Stack 1	Stack 2	Stack 3
ΔH(m)	1.5	1.5	1.5
H(m)	150	180	210
V_S (m/s)	12.5	21.3	25.7
d(m)	6.5	7.5	7.5
U(m/s)	20	20	20
P(Atm.)	1.0017	1.0017	1.0017
T_s(^{0}k)	240	315	460
T_a(^{0}k)	115	215	306
Effective stack height (Hs) = $\Delta H + H$	151.5	181.5	211.5

Gaussian Equation for pollutant concentration at ground level along the plume centreline.

$$C(x,0,0) = \frac{Q}{\pi u \sigma_y \sigma_z} e^{-\frac{H^2}{2\sigma_z^2}}$$

C = Downwind concentration

Input Variables

x = downwind distance in meters = 1500, 2000, 2500, 3000, 3500, 4000, 4500 and 5000

Q = emission rate in grams/sec
Emission of SPM in gm./s = 3587 (Emission control 99.5%)
Emission of SO_2 in gm./s = 1042.23
Emission of NO_X in gm./s =791.5
Pi =3.14159
u = average wind speed in meters/sec = 3.045
H = Effective stack height in meters
Wind speed measurement height in m. = 10(Anemometer height)

Based on the meteorological conditions of the project site, Atmospheric Stability class (A - F) is stable (A).

Sigma Values

Sigma values are fundamental to all Gaussian based air dispersion models [11]. They can be determined very roughly by reading off a graph (figures 2.1 and 2.2) or by the equations.

Graphical method:

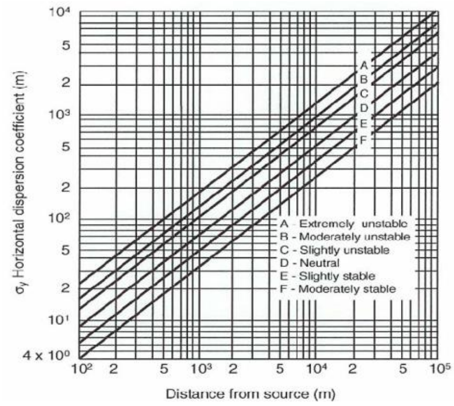

Figure 2.1. Horizontal Dispersion Coefficient (σ_y)

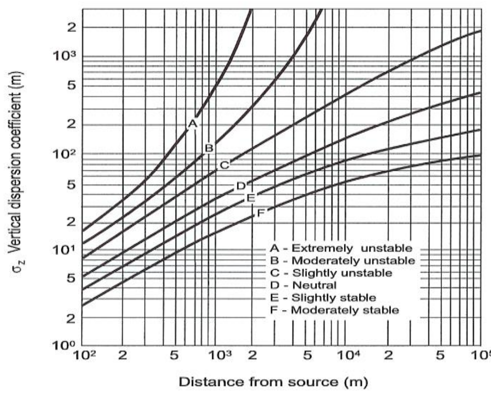

Figure 2.2. Vertical Dispersion Coefficient (σ_z)

Sigma values may be determined more accurately by the following equations:

$$\sigma y=ax^{0.893}$$
$$\sigma z=cx^{d}-f$$

The value of x is the distance downwind from the source. From experimental determination and amount to curve-fitting, a, c, d, and f values are determined. These values are shown in Tables 2 and 3. Using power function, a=1 and f=0 (i.e., the default values). To find a square root of x, c = 0.5.

As it is complicated to find the values of a, c, d, and f that correspond to study the atmospheric stability, various computer programs are used to determine these values. However, calculators can also be used to solve the above function.

Table 2: Calculation of values of sigma y

Sigma – y		
Stability class	**"a" value**	**other variables**
A	213	"x" = the distance downwind
B	156	"f" = 0
C	104	"c" = .894

D	68	
E	50.5	
F	34	

Table 3: Calculation of values of sigma z

Sigma z (x = distance downwind)						
Stability class	if x<1 km, then:			if x>1 km, then:		
	"a" is:	"c" is:	"f" is:	"a" is:	"c" is:	"f" is:
A	440.8	1.941	-9.27	459.7	2.094	9.6
B	106.6	1.149	-3.3	108.2	1.098	-2
C	61	0.911	0	61	0.911	0
D	33.2	0.725	1.7	44.5	0.516	13
E	22.8	0.678	1.3	55.4	0.305	34
F	14.35	0.74	0.35	62.6	0.18	48.6

In the present study, Ground Level Concentration of criteria air Pollutants and sigma values are predicted by using computer programs and are as presented in the proceeding section

Output values (predicted ground level concentration of air pollutants)

Predicted Ground Level Concentration of Air Pollutants **u**nder highly Unstable Condition is calculated. The table 4 presents ground level concentrations for highly unstable condition (Pasquill-Gifford Stability class – A).

Table 4: Ground Level Concentration of Air Pollutants

Downwind distance (m)	σ_y (m)	σ_z (m)	SPM ($\mu g/m^3$)	SO_2 ($\mu g/m^3$)	NO_X ($\mu g/m^3$)
1500	306.059	1064.907	576.183	167.41	127.139
2000	395.822	1952.997	242.927	70.58	53.60
2500	483.212	3121.966	124.483	36.169	27.46
3000	568.756	4577.797	72.12	20.95	15.91
3500	652.794	6325.492	45.47	13.21	10.03
4000	735.565	8369.321	30.50	8.86	6.73
4500	817.243	10713.034	21.44	6.23	4.733
5000	879.963	13359.977	15.65	4.54	3.45
5500	977.831	16313.175	11.77	3.42	2.59
6000	1056.938	19575.383	9.07	2.63	2.00

With reference to Environmental Impact Assessment report of UTCL site, background concentrations are given in the table 5.

Table 5: Background concentrations of UTCL

Parameter	Concentration
SPM	100
SO_2	15
NO_X	10

Table 6 represents the Ground Level Concentration of the Pollutants along with back ground concentrations.

Table 6: Ground Level Concentration of the Pollutants with back ground Concentrations

Downwind distance (m)	σ_y (m)	σ_z (m)	SPM ($\mu g/m^3$)	SO_2 ($\mu g/m^3$)	NO_X ($\mu g/m^3$)
1500	306.059	1064.907	676.183	182.41	137.139
2000	395.822	1952.997	342.927	85.58	63.60

2500	483.212	3121.966	224.483	51.169	37.46
3000	568.756	4577.797	172.12	35.95	25.91
3500	652.794	6325.492	145.47	28.21	20.03
4000	735.565	8369.321	130.50	23.86	16.73
4500	817.243	10713.034	121.44	21.23	14.73
5000	879.963	13359.977	115.65	19.54	13.45
5500	977.831	16313.175	111.77	18.42	12.59
6000	1056.938	19575.383	109.07	17.63	12.00

Multiplying Factors

The Gaussian model generates 1-hour concentration estimates. The 1-hour averages may be converted to a longer averaging period using the guidance below.

Point Sources and Flares

For "points" and "flares," use the U.S. EPA multiplying factors shown in table7 to convert 1-hour concentration estimates from 1 hour to other averaging periods. Maximum concentration of primary pollutants for various averaging periods given in table 8.

Table 7: EPA Multiplying Factor for point Sources

Averaging Period	EPA Multiplying Factor for point Sources
3 hours	0.9
8 hours	0.7
24 hours	0.4
Annual	0.08

Maximum concentration of primary pollutants for various averaging periods

Table 8: Maximum concentration of primary pollutants for various averaging periods

Pollutant	Averaging period				
	1 hour	3 hours	8 hours	24 hours	Annual
SPM (μg/m^3)	576.183	518.56	403.32	230.47	46.09
SO_2 (μg/m^3)	167.41	150.66	117.18	66.947	13.39
NO_X (μg/m^3)	127.139	114.42	88.99	50.85	10.17

National ambient air quality standards

National ambient air quality standards are prescribed by the Central Pollution Control Board, the standards for criteria pollutants are specified in the table 9.

Table 9: National Ambient Air Quality Standards

S.NO.	Pollutant	Time Weighted average	Concentration in Ambient Air	
			Industrial, Residential, Rural and other Area	Ecologically sensitive area (notified by Central Govt.)
1	Sulfur dioxide (SO_2) μg/m^3	Annual* 24 hours**	50 80	20 80
2	Nitrogen dioxide (NO_2) μg/m^3	Annual* 24 hours**	40 80	30 80
3	Particulate Matter PM_{10} μg/m^3	Annual* 24 hours**	60 100	60 100
4	Particulate Matter $PM_{2.5}$ μg/m^3	Annual* 24 hours**	40 60	40 60
5	Ozone (O^3) μg/m^3	8 hours	100	100

		1 hour	180	180
7	Carbon Monoxide (CO) mg/m^3	8 hours	2	2
		1 hour	4	4
		24 hours**	400	400

The project location comes under the category of Industrial, Residential, Rural and Other Area. National Ambient Air Quality Standards; Central Pollution Control Board Notification, New Delhi, the 18th November, 2009 No.B-29016/20/90/PCI-L

In exercise of the powers conferred by Subsection -2: (h) of section 16 of the Air (Prevention and Control of Pollution) Act, 1981 (Act No. 14 of 1981) and in super session of the Notification No(s). S.O. 384(E), dated 11th April, 1994 and S.O. 935(E), dated 14th October, 1998, the Central Pollution Control Board hereby notifies the National Ambient Air Quality Standards with immediate effect, namely NAAQS.

Annual arithmetic mean of minimum 104 measurements in a year at a particular site taken twice a week 24 hourly at uniform intervals.

24 hourly or 8 hourly or 1 hourly monitored values, as applicable, shall be complied with 98% of the time in a year. 2% of the time, they may exceed the limits but not on two consecutive days of monitoring.

Note: Whenever and wherever monitoring results on two consecutive days of monitoring exceed the limits specified above for the respective category, it shall be considered adequate reason to institute regular or continuous monitoring and further investigation [12].

CONCLUSION

The study area falls under the category of Industrial, Residential, and Rural Area. From level 1 assessment it is predicted that

- The annual average of SO_2 concentration is 13.39 (µg/m^3) and 24 hours average is 66.94 (µg/m^3). These are within limits.
- The annual average of NO_X concentration is 10.17 (µg/m^3) and 24 hours average is 50.85 (µg/m^3). These are within limits.
- Predicted SPM values are the annual average of SPM concentration is 46.09(µg/m^3) and 24 hours average is 230.47 (µg/m^3). The 24 hr average value is greater than NAAQS, Predicted SPM concentrations of SPM exceeded NAAQS.

As the concentrations of pollutants (SPM, SO_2, NO_X) in level-1 assessment are more conservative less specific so the project is further proceeded to level-2 assessment of application of refined model i.e., AERMOD-9.1 with site specific hourly data.

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