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Isopleths of Sulphur Dioxide in the Neighbourhood of Thermal Power Station-II at Neyveli

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Abstract

The purpose of the present study is to describe the pattern of pollutant dispersion in the neighbourhood of the thermal power station-II in Neyveli, a township about 200 Km south west of Chennai. Neyveli Lignite Corporation houses two mines and two thermal power stations. Thermal power stations-II is designed for 7 numbers of boilers each producing electricity at 210 MW, using lignite as the fuel. Gaussian diffusion equation has been used for predicting ground level downwind concentrations. Meteorological data collected for a period of one month was chosen for predictions. A critical case was identified for assessing maximum ground level concentrations of SO_2 at downwind locations under various combinations of wind speeds and atmospheric stability classes. This work involved computations of short-term averages and long-term averages of SO_2 Concentrations. It has been observed that SO_2 isopleths for assessing adverse meteorological situations would determine future expansion prospects of Thermal Power Stations at Neyveli.

Introduction

The magnitude and severity of air pollution problems due to sporadic development of industries in India has attracted the attention of the public. This is due to the fact that the volume of pollutants emitted by these industries present a threat to human and animal health, plant life, property value and the environment. Realizing the necessity to adopt a sytematic procedure for knowing the dispersion pattern of pollutants emitted from each industry located in the area, in order to maintain ambient air quality in and around the industries within the safe limits, a system of Isopleths has been developed that would offer the necessary information for evolving the relationship between the emission rate and the resulting air concentration of a specifc pollutant on the spatial scale.

Study Site

Neyveli Lignite Corporation (NLC), an integrated industrial complex, situated at Neyveli with a massive campus of 480 sq. km area houses two Mines, two Thermal Power Stations such as Thermal Power Station I and Thermal Power Station II. It is located in India about 200 Km from south west of Chennai in Tamil Nadu. Presently, 17 million tonnes of lignite is mined and 2070 MW of power is generated. Thermal Power Station- I comprises of 9 numbers of boilers producing electricity at 600 MW capacities and consists of six sets of 50 MW each and three sets of 100 MW. Thermal Powers Station- I Expansion comprises of 2 numbers of boilers producing electricity at 500 MW capacities. Thermal power station - II comprises of 7 numbers of boilers producing electricity at 1470 MW capacity and each boiler producing 210 MW.

Thermal Power Station-II has been selected for the present studies.

Materials and Methods

Computer aided Gaussian dispersion equation has been used to estimate the instantaneous ground level down wind concentrations and long-term concentrations (Turner,1967 & 1994; I.S.0 ,1978 ; D.O. En ,1983).

Gaussian Dispersion Equation

Turner D.B (1994) presents the GDE selected for use in the model, which is

$$\chi(x,y,z;H)=\frac{Q}{2\pi\sigma_y\sigma_z u}\exp^*\left[-\frac{1}{2}\left(\frac{y}{\sigma_y}\right)^2\right]\left\{\exp\left[-\frac{1}{2}\left(\frac{z-H}{\sigma_z}\right)^2\right]+\exp\left[-\frac{1}{2}\left(\frac{z+H}{\sigma_z}\right)^2\right]\right\}\quad ...(1)$$

where,

Q: the pollutant emission rate of the source, (μg/sec).

u: the mean wind speed at stack level, (m/sec).
σ_Y and σ_Z: the horizontal and vertical dispersion co-efficient respectively, (m).
H: the effective stack height, (m).

For computing Ground Level Concentrations (GLC), put Z=0 in equation (1), now the equation 1 reduces to

$$\chi(x,y,0,H)=\frac{Q}{\pi U\sigma_y\sigma_z}\exp\left(-\frac{y^2}{2\sigma_z{}^2}\right)\exp\left(-\frac{H^2}{2\sigma_z{}^2}\right) \quad \ldots (2)$$

For computing Ground Level Concentrations (GLC) along with the center-line of the plume (i.e. Y= O; Z = O) equation 1 is further reduced to

$$\chi\,(z,0,0,h)=\frac{Q}{\pi u\sigma_y\sigma_z}\exp\left|-\frac{1}{2}\left(\frac{h}{\sigma_z}\right)^2\right. \quad \ldots (3)$$

While the basic features of the long term Gaussian Dispersion Equation have been extensively described by Slade (1968) as follows,

$$\chi(long-termaverage)=\left[\frac{2}{\pi}\right]^{1/2}\frac{0.01fQ}{U\sigma_z}\exp\left(-\frac{H^2}{2\sigma_z{}^2}\right)\ldots\ldots\ldots\ldots\ldots (4)$$

By using the above equations 3 and 4, instantaneous ground level concentrations and long-term ground-level centre-line concentrations were computed.

Model parameterization

Guassian Dispersion Equation (GDE) involves various parameters such as wind speed at stack heights, dispersion coefficients, and plume rise etc. Many approaches are available for determining each of the above parameters. Each Air quality model utilizes separate equations for determining the parameter to predict Ground Level Concentrations (GLCs). The various parameters involved in the model such as wind speed at stack height, downwind distance, cross wind distance; σ_Y, σ_Z, effective stack height, etc have been selected from the following approaches.

Wind speed at Stack height

Power law has been used to find the observed wind speed, u_{ref}, from a reference measurement height, z_{ref}, to the stack or release height, h_s. The stack height wind speed, u_s, is used in the Gaussian plume equation (Equations 1 to 3):

$$U_s=U_{ref}\left(\frac{h_s}{Z_{ref}}\right)^P$$

where
p is the wind profile exponent, the default values of ' p' is 0.12 for unstable stability conditions, p: 0.14 for Neutral stability conditions and 0.24 for stable stability conditions.

Stability Class

Many investigators [Pasquill (1961), Turner (1964, 1994), Munn (1966), and Briggs (1973)] have made studies on classifying stability classes in the absence of any sophisticated observations. The meteorological conditions, defining Pasquill turbulence types, have been suitably modified to select stability class for the present study

Diffusion Co-efficient

Diffusion co-efficient is estimated through various approaches made by many researchers [Smith (1951); Smith (1968); Pasquill (`1961), Gifford (1961); Turner (1964); Carpenter et al. (1971); and

Briggs (1973)]. If the physical stack height is higher than 100 m, Briggs' interpolation schemes give better estimate. Therefore, Briggs' (1973) series of interpolation formulae have been used in the Gaussian diffusion equations for estimating σ_Y and σ_Z.

Plume Rise

Several investigators who have proposed formulae for the estimation of plume rise, are Briggs (1971), Gulberg (1975), Montgomeny *et al.* (1972), Holland (1975); Swamy, et al., (1996). Of all the formulae, the theoretical formula by Briggs (1971) yields the best results. Hence, this formula is used for estimating the plume rise.

Meteorological Data

To collect the meteorological data, a short- term meteorological monitoring was conducted for a period of 30 days at Neyveli from 2-8-1996 to 2 -9-1996. The anemometer was fixed at the roof top of a four-storied building at Neyveli, so that the observation height was about 12 m above the ground level. During the period of observations, wind velocity, wind directions, dry bulb temperature, wet bulb temperature, cloud cover etc., were measured. The wind rose diagram constructed from this data is shown in Figure 1.

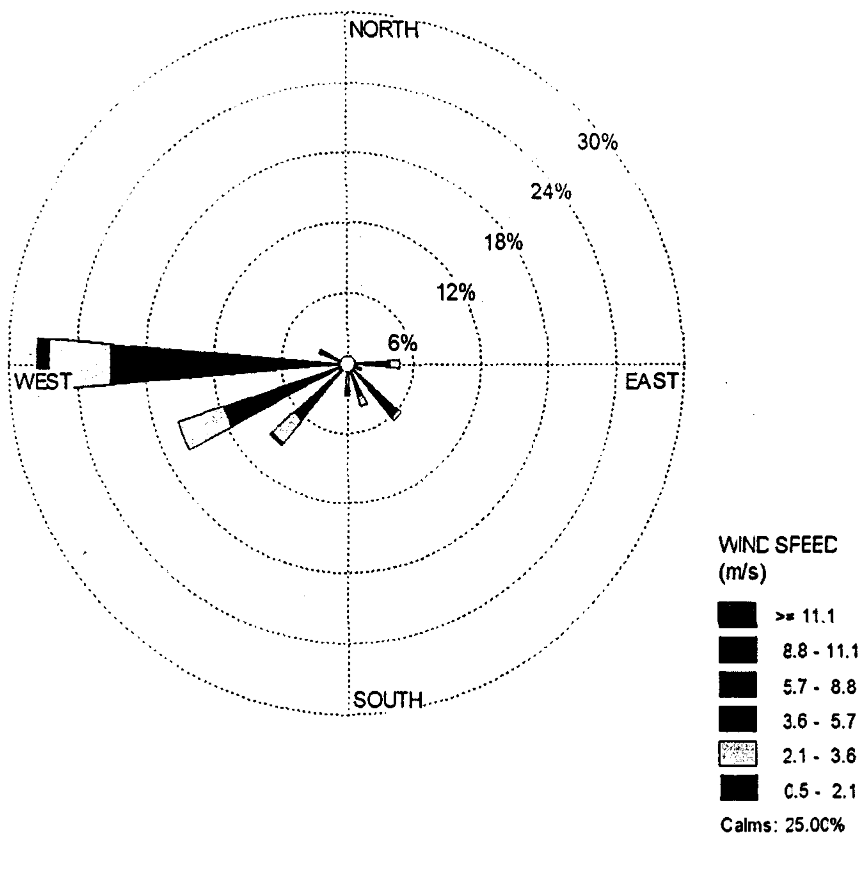

Figure 1: Wind Rose Diagram

It may be seen from Figure 1 that the most predominant wind during the period of study was westerly wind. Wind speeds of < 2.1m/sec, 2.1- 3.6 m/sec, and 3.6 – 5.7 m/sec had prevailed 21.11 %, 5.27 % and 1.11 % respectively. Another major wind was from WSW. Wind speeds of 0.5 – 2.1 m/sec, 2.1 – 3.6, and 3.6 - 5.7 m/sec had prevailed 11.66%, 2.51%, 0.30% respectively. Calm conditions had prevailed for about 25 % of the time periods. Could-cover varied between 1/8 to 8/8.Based on the meteorological data, stability rose has been drawn (Figure 2).

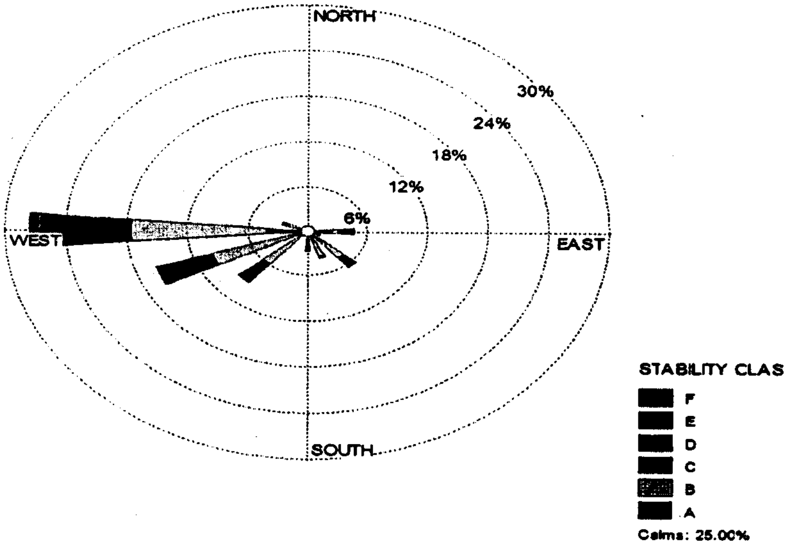

Figure 2: Stability Rose Diagram

Air Pollutant Dispersion Pattern

Meteorological and source emission data collected at site have been used to study the dispersion pattern of SO_2 in the neighbourhood of Neyveli Power Plant-II employing Gaussian Dispersion equation as discussed above. Table1 presents downwind SO_2 concentrations (10-minute averages) under various wind speed and relevant stability classes. This table corresponds to 210 MW power plant using lignite as fuel. As the accuracy of prediction becomes limited for downwind distances beyond 25000 meters (25.0 Km), it was concluded that the most adverse air pollution situation would result if high concentrations occur at downwind distances less than 25.0Km.

Table-1: Maximum Instantaneous Concentration [Gaussian Model] Under Various Wind Speed and Stability Classes

CLASS	X	SY	SZ	UBAR	USTK	EFF.	max con
A	10000	1555.63	2000	0.25	0.36	5772.43	2.909
A-B	10000	1343.5	1600	0.25	0.36	5772.43	0.404
B	10000	1131.37	1200	0.25	0.36	5772.43	0.004
A	8400	1362.36	1680	0.69	1	2231.75	38.18
A-B	10000	1343.5	1600	0.69	1	2231.75	37.137
B	10000	1131.37	1200	0.69	1	2231.75	27.592
A	**4500**	**822.15**	**900**	**1.39**	**2.01**	**1218.64**	**56.645**
A-B	5600	851.88	896	1.39	2.01	1218.64	54.463
B	7600	916.59	912	1.39	2.01	1218.64	51.356
A-B	4000	642.32	640	2.1	3.04	881	65.443
B	5400	696.23	648	2.1	3.04	881	61.033
C	10000	777.82	461.88	2.1	3.04	881	31.32
E	10000	424.26	75	2.1	4.41	399.82	0.001
F	10000	282.84	40	2.1	4.41	399.82	0
A-B	3300	543.68	528	2.78	4.03	719.32	72.185
B	4400	586.67	528	2.78	4.03	719.32	66.896
C	10000	777.82	461.88	2.78	4.03	719.32	43.388
E	10000	424.26	75	2.78	5.84	383.77	0.002

F	10000	282.84	40	2.78	5.84	383.77	0
B	3800	517.56	456	3.47	5.03	620.03	70.594
B-C	5100	560.29	449.53	3.47	5.03	620.03	64.4
C	8800	705.99	423.76	3.47	5.03	620.03	48.124
D	10000	565.69	150	3.47	5.35	596.05	0.173
E	10000	424.26	75	3.47	7.29	372.1	0.004
C	7500	623.64	379.47	4.17	6.04	552.88	51.085
C-D	10000	671.75	305.94	4.17	6.04	552.88	33.217
D	10000	565.69	150	4.17	6.43	532.92	0.703
C	6600	563.49	346.65	4.86	7.04	505.62	52.979
C-D	10000	671.75	305.94	4.86	7.04	505.62	37.232
D	10000	565.69	150	4.86	7.49	488.5	1.653
C	6400	549.73	339.08	5.1	7.39	492.18	53.452
C-D	10000	671.75	305.94	5.1	7.39	492.18	38.115
D	10000	565.69	150	5.1	7.86	475.86	2.065
C	5800	507.57	315.71	5.83	8.45	458.1	54.433
C-D	10000	671.75	305.94	5.83	8.45	458.1	39.639
D	10000	565.69	150	5.83	8.99	443.82	3.477
C	5100	456.54	287.07	6.94	10.06	420.02	54.931
D	10000	565.69	150	6.94	10.7	408.02	5.753
C	4600	418.77	265.58	8.33	12.07	386.64	54.507
D	10000	565.69	150	8.33	12.84	376.65	8.283
C	4300	395.54	252.23	9.72	14.09	362.81	53.402
D	10000	565.69	150	9.72	14.98	354.25	10.214
Worst	Meteorological	Situation					
CLASS	X	SY	SZ	UBAR	USTK	EFF.	Max con
A-B	3300	543.68	528	2.78	4.03	719.32	72.185

A careful scrutiny of Table1 reveals that maximum 10-minutes SO_2 concentration of 72.18 µg/m^3 occurs at a distances of 3300 metres (3.3 Km), when a wind speed of 2.78 m/sec (10.0Kmph) prevails under stability class A-B. However since this wind speed occurs only at a frequency of 5.3 % from the most frequent wind direction, therefore it may be ignored.

Now considering the most frequent wind speed class, namely, 0.5 - 2.1 m/sec which occurs at a frequency of 21.11 % from the most frequent wind direction, computations were made for a wind speed of 1.39 m/sec (5.0Kmph) for which stability classes A or A-B or B are possible. This gives the maximum SO_2 concentration of 56.64 µg/m^3 (Table 2) at a downwind distance of 4500m (4.5 Km). Therefore, wind speed of 1.39 m/sec and stability class A, were chosen for calculating long-term concentrations (Table 3).

Table-2:Instantaneous Concentration [Gaussian Model] for Stability Class A

Distance x (m)	бy (m)	бz (m)	µbar	µstak	effect ht	Instantaneous SO_2 Con.(ug/m3)
500	107.35	100	1.39	2.01	1218.64	0
1000	209.76	200	1.39	2.01	1218.64	0
1500	307.73	300	1.39	2.01	1218.64	0.297
2000	401.66	400	1.39	2.01	1218.64	6.296
2500	491.93	500	1.39	2.01	1218.64	21.861
3000	578.86	600	1.39	2.01	1218.64	38.368
3500	662.71	700	1.39	2.01	1218.64	49.651
4000	743.74	800	1.39	2.01	1218.64	55.22
4500	822.15	900	1.39	2.01	1218.64	**56.645**

5000	898.15	1000	1.39	2.01	1218.64	55.546
5500	971.9	1100	1.39	2.01	1218.64	53.083
6000	1043.55	1200	1.39	2.01	1218.64	49.985
6500	1113.25	1300	1.39	2.01	1218.64	46.679
7000	1181.13	1400	1.39	2.01	1218.64	43.403
7500	1247.28	1500	1.39	2.01	1218.64	40.281
8000	1311.83	1600	1.39	2.01	1218.64	37.369
8500	1374.85	1700	1.39	2.01	1218.64	34.689
9000	1436.44	1800	1.39	2.01	1218.64	32.239
9500	1496.68	1900	1.39	2.01	1218.64	30.01
10000	1555.63	2000	1.39	2.01	1218.64	27.985

Isopleths of long-term SO_2 concentrations are shown in Figure 4 for a wind speed of 1.39 m/sec under stability class A in the downwind direction of East because winds blowing from the West would transport the plume towards East, while Figure 3 represents the Isopleths of SO_2 for an averaging time of 10-minutes. These results have been obtained by plotting the downwind centre line concentrations and the crosswind concentrations at various locations along the downwind direction (namely East) in this case.

Table 3: Long Term Average Concentration Based on Frequency of Wind Speeds and Direction

Distance x (m)	бy (m)	бz (m)	µbar	µstak	Effective ht	Gaussian long term over central line Con; (µg/m3)
500	107.35	100	1.39	2.01	1218.64	0
1000	209.76	200	1.39	2.01	1218.64	0
1500	307.73	300	1.39	2.01	1218.64	0.082
2000	401.66	400	1.39	2.01	1218.64	1.704
2500	491.93	500	1.39	2.01	1218.64	5.798
3000	578.86	600	1.39	2.01	1218.64	9.978
3500	662.71	700	1.39	2.01	1218.64	12.671
4000	743.74	800	1.39	2.01	1218.64	13.838
4500	822.15	900	1.39	2.01	1218.64	13.948
5000	898.15	1000	1.39	2.01	1218.64	13.448
5500	971.9	1100	1.39	2.01	1218.64	12.643
6000	1043.55	1200	1.39	2.01	1218.64	11.717
6500	1113.25	1300	1.39	2.01	1218.64	10.775
7000	1181.13	1400	1.39	2.01	1218.64	9.871
7500	1247.28	1500	1.39	2.01	1218.64	9.029
8000	1311.83	1600	1.39	2.01	1218.64	8.259
8500	1374.85	1700	1.39	2.01	1218.64	7.562
9000	1436.44	1800	1.39	2.01	1218.64	6.935

It may be seen that Figures 3 & 4 represent the same dispersion pattern, but with a difference that the averaging times are different. These SO_2 Isopleths would correspond to SO_2 emissions from a single unit of 210 MW. The actual impact of 7 such units will be 7 times the magnitude of the SO_2 concentration in each case, i.e., it will be 7 x 56.64 = 396.5µg/m^3 (10-minute average).

Using the following power-law relationship, concentration known for one averaging time can be converted in terms of a new averaging time:

$$C1 = C0\left(\frac{t0}{t1}\right)^a$$

where

C_0 : Concentration recorded or predicted for original averaging time t_0,

C_1 : Concentration predicted for new averaging time, t_1, and a : Power-law constant,

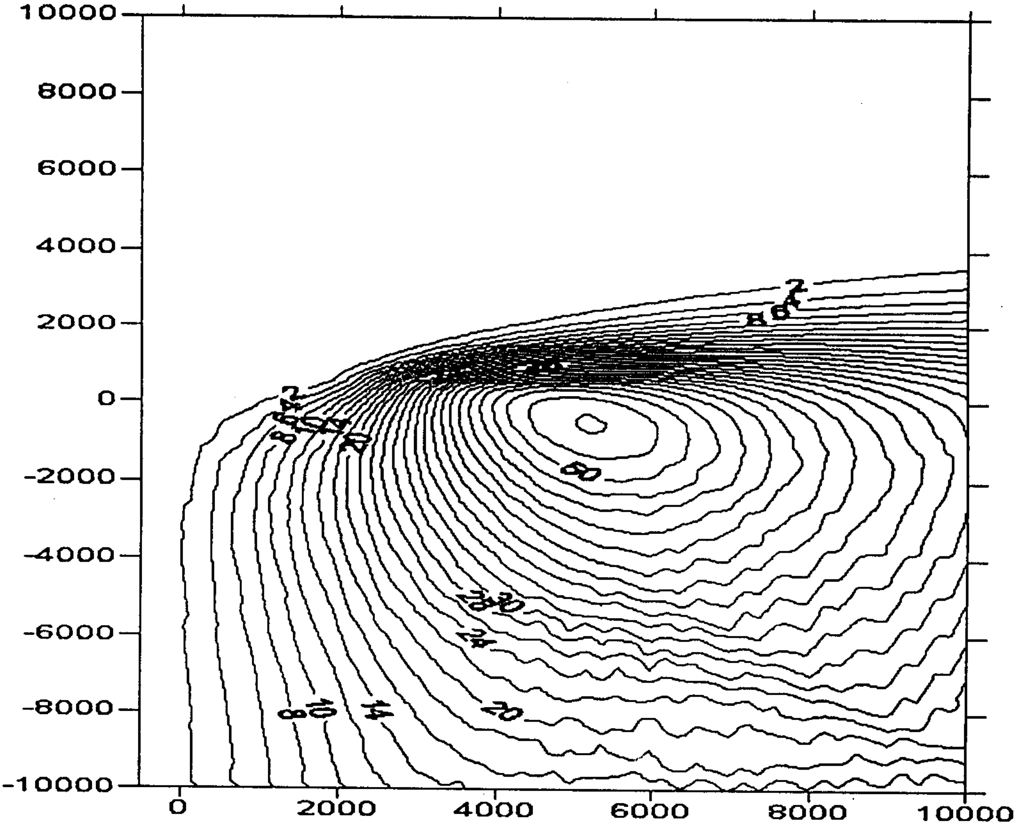

Figure 3: Isopleths of Instantaneous SO_2 Concentrations (2D View)

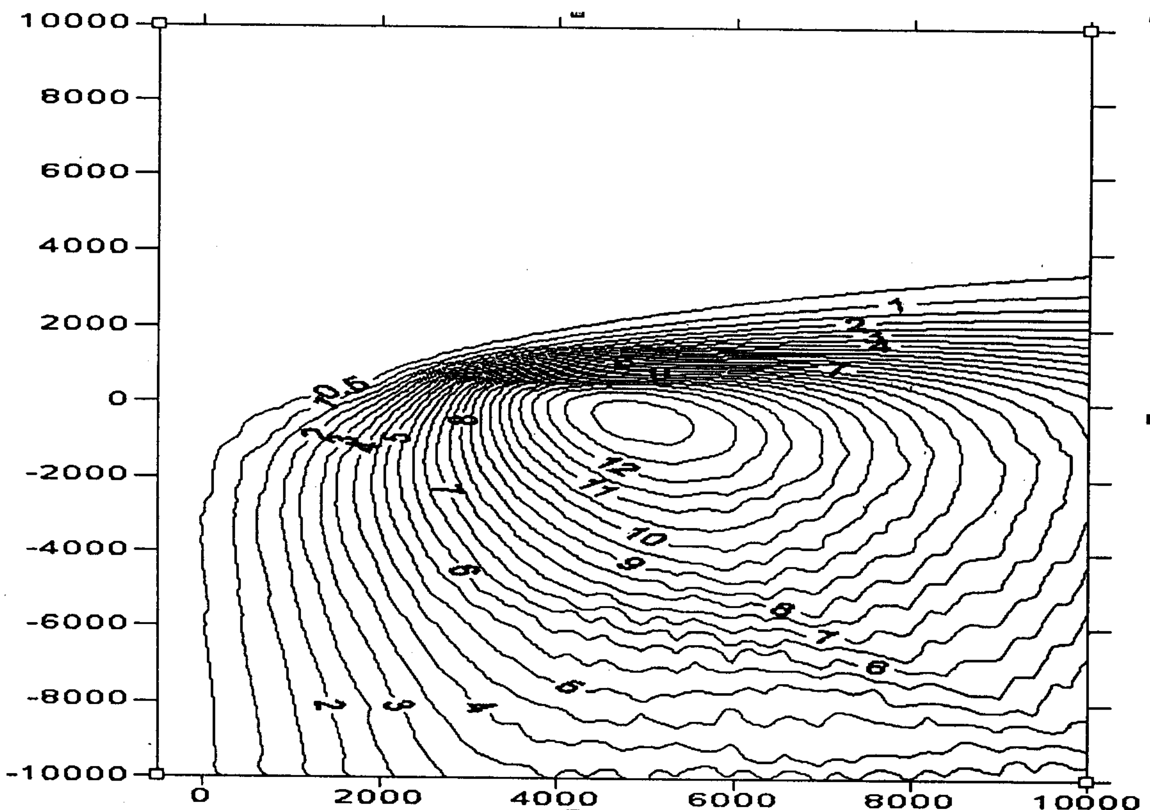

Figure 4: Isopleths of Long-Term SO_2 Concentrations (2D View)

a = 0.41 can be used for converting 10-minutes concentration to 1-hour concentration; and 1-hour concentration to 8-hour concentration, while value of a = 0.17 can be used for converting 8-hour concentrations to 24-hour concentrations.

Computations made as above show that SO_2 emissions from 7 x 210 MW units in TS-II at Neyveli would result in a maximum ground level SO_2 concentration of 81.09 $\mu g/m^3$, 67.28 $\mu g/m^3$ as 8-hour and 24-Hour averages respectively at a downwind distance of 4.5 Km from the source when a wind speed of 1.39 m/sec (5.0 Kmph) occurs under the stability class A. Since a wind speed of < 2.1 m/sec occurs during 21.11 per cent of the time of experimental duration, therefore it can be stated that wind speed of 1.39 m/sec (5.0 Kmph) holds good to occur over 21.11 per cent of observation time under stability class A or B or in between A and B (i.e., A-B). Equally distributing the probability of occurrence, stability class A can prevail for about 7.03 per cent of the time-periods yielding maximum SO_2 ground level concentrations as indicated above.

Conclusions

If 80.0 $\mu g/m^3$ of SO_2 is considered as the National Ambient Air Quality Standard, applicable to 8-Hour averaging time, it can be said that the prescribed standard for SO_2 would be violated for 7.03 per cent of the time-periods in the neighborhood of TS-II when all the 7 x 210 MW units are operated. However, if 80.0 $\mu g/m^3$ of SO_2 is considered as the National Ambient Air Quality Standard applicable to 24-Hour averaging time, it can be said that the prescribed standard for SO_2 would never be violated, as the predicted 24-Hour maximum concentration of SO_2 would be limited to a value of 67.28 $\mu g/m^3$ at a wind speed of 1.39 m/sec under stability class A. Thus SO_2 Isopleths indicated for assessing the most adverse meteorological situation can be used to throw further light on future expansion prospects of Thermal Station-II at Neyveli.

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