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Estimation of long term concentrations of SO_2 from Mathura refinery with Gaussian diffusion model

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सार — मथुरा तेल शोधक कारखाने के आस पास चारों ऋतुओं में सल्फर डाई ऑक्साइड का क्षेत्रीय वितरण प्राप्त करने के लिए भूतलीय दीर्घ कालिक सांद्रता($\mu g/m^3$) अभिकलित कर ली गई है । इसके लिए बिन्दु स्रोतों के लिए वैध स्थायी दशा विसरण निदर्श प्रयुक्त किया गया है । तेल शोधक कारखाने के चालू होने से पूर्व तथा बाद में विभिन्न दूरियों पर विभिन्न क्षेत्रों में चार बिन्दुओं पर इकट्ठे किए गए सल्फर डाईऑक्साइड के मॉनीटरीकृत आंकड़ों का भी उपयोग किया गया है । ऐसा देखा गया है कि तेल शोधक चालू होने के बाद से सल्फर डाईऑक्साइड की सांद्रता में कोई विशेष वृद्धि नहीं हुई है तथा निदर्श भी इस बात की पुष्टि करता है कि मॉनीटरिंग स्टेशनों पर शोधक के कारण होने वाली दीर्घकालिक सांद्रता महत्वहीन है ।

ABSTRACT. The ground level long term concentrations ($\mu g/m^3$) to obtain spatial distribution of sulphur dioxide around the Mathura refinery have been computed for all four seasons using steady state Gaussian diffusion model valid for point sources. The monitored data of sulphur dioxide at four points in different sectors at different distances collected prior to and after the commissioning of the refinery have also been utilised. It is seen that there is no significant increase in sulphur dioxide concentration after commissioning of the refinery and the model also confirms that the long term concentrations due to refinery are insignificant at the monitoring stations.

1. Introduction

Ground level concentrations at Agra due to Mathura Refinery by Gaussian Model were presented earlier by Ministry of Petroleum, Chemicals & Fertilizers (1978) and by Padmanabhamurty and Gupta (1978) but these data were not validated. In the present study are estimated ground level concentrations by the Gaussian diffusion model with the oil refinery at Mathura as the source of sulphur dioxide and the Taj Mahal at a distance of 40 km in the southeast at Agra and the Ghana bird sanctuary at Bharatpur nearly at a distance of 30-35 km in the southwest as receptors. Concentrations of sulphur dioxide at three places between Mathura oil refinery and the monuments at Agra and one at Bharatpur bird sanctuary are continuously monitored prior to and after commissioning of the refinery to study the impact of the refinery on the monuments at Agra and at Bharatpur bird sanctuary. These data have been compared with Gaussian diffusion model values.

Diffusion is a random process and the distribution from such motion could be in some statistical form which can be considered as Gaussian. Gaussian distribution obeys equation of continuity but does not either drop to zero at any distance nor allow for any wind shear in the surface layer. The former is not of much practical importance as the Gaussian curve tapers off extremely rapidly within a few σ crosswind. Owing to its simplicity Gaussian distribution is widely used. Gaussian distribution, however, predicts higher values over short periods of time but approaches closely to monitored values over longer periods. Hence, in the present study, the ground level long term concentrations of sulphur dioxide due to refinery are computed for all the four seasons making use of meteorological data collected at Mathura refinery observatory during the period 1981-82 and compared with monitored data corresponding to the same period.

2. Methodology

The ground level long term concentration ($\mu g/m^3$) for period over a month or more has been computed by:

$$\chi_{(x,o,f)} = \frac{360 f Q}{\varphi\, \pi^{3/2}\, 2^{1/2}\, \sigma_z\, \bar{u} x} \exp\left\{- \frac{1}{2} \frac{h^2}{\sigma_z^2}\right\}$$

$\chi_{(x,o,f)}$ = Long term concentration ($\mu g/m^3$)

f = % frequency with which the combination of meteorological condition of interest together with winds in that sector.

φ = Angular width of direction sector (degrees).

Q = Emission rate of sulphur dioxide ($\mu g/sec$) from the top of the stack.

$\bar{u}$ = Mean wind speed at stack height (m/sec)

x = Downwind distance from the stack (m)

H = Physical stack height (m)

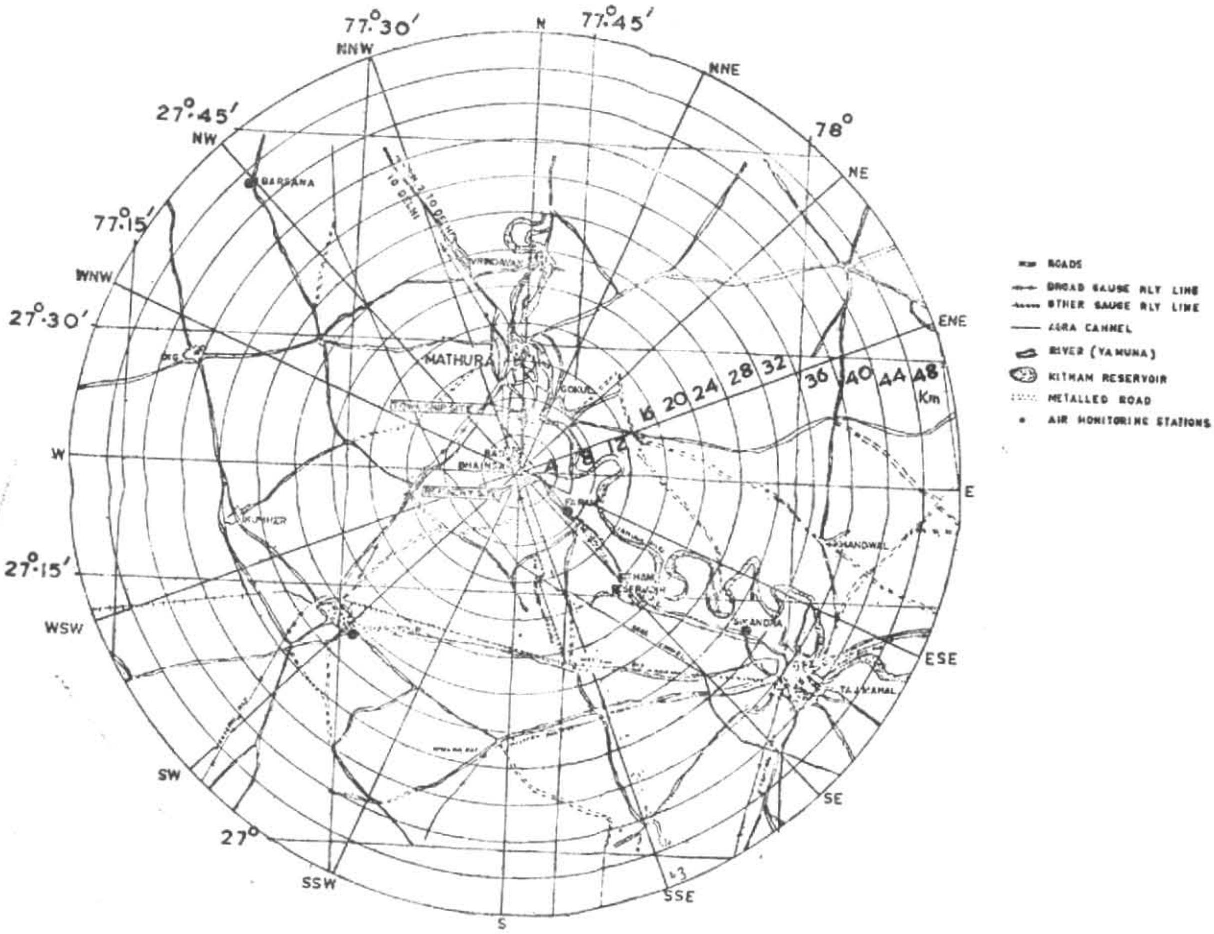

Fig. 1. Locator map showing the positions of Agra, Mathura, Bharatpur, Mathura refinery etc.

TABLE 1

Ambient air monitored values of sulfur dioxide concentrations

Station	Season	Long term concentration ($\mu g/m^3$): Prior to the commissioning of refinery, *i.e.*, 1981	After the commissioning of the refinery (*i.e.*, during 1982)	Remarks
Farah	Summer	—	6.4	Started
	Monsoon	—	6.1	from
	Post monsoon	—	N.A.	Jan'82
	Winter	—	4.2	
Keetham Lake	Summer	1.7	2.3	Started
	Monsoon	1.7	1.8	from
	Post monsoon	3.8	1.6	Apr'81
	Winter	2.8	2.2	
Sikandara	Summer	5.4	6.2	Started
	Monsoon	5.3	5.5	from Oct' 80
	Post monsoon	11.2	—	
	Winter	5.9	9.1	
Bharatpur	Summer	—	3.1	Started
	Monsoon	2.6	3.1	from June' 81
	Post monsoon	3.1	N.A.	
	Winter	3.0	1.7	

$\triangle h$ = Plume rise (m)

$h = H + \triangle h$ = effective stack height (m)

σ_z = Standard deviation of plume concentrations along z (m).

The above equation assumes that the effluent is uniformly distributed in the horizontal within the sector and also the absence of turbulent diffusion in the direction of transport (Smith 1968; Turner 1970). It is also considered that the pollutants are passive and the Agra-Mathura-Bharatpur region is located on a flat terrain.

Plant characteristics — A single stack of 80 m height has been considered with the following actual emission rate since January 1982:

Rate of emission of sulphur dioxide = 400 kg/hr
Emission of heat (Q_H) = 20.5 MW.

Stability conditions — Wind direction fluctuations were used to evaluate σ_θ as a measure of stability (Slade 1968). Limits of σ_θ corresponding to Pasquill classification (Turner 1970) of stabilities were determined from the wind data collected at Mathura refinery observatory (Padmanabhamurty and Gupta 1979). These values only are used for stability classification in the present paper.

Pasquill stability type	Mean value of σ_θ at 10 m
(A) Highly unstable	12.0
(B) Moderately unstable	10.5
(C) Slightly unstable	8.0
(D) Neutral	6.0
(E) Moderately stable	4.0
(F) Highly stable	2.0

Dispersion characteristics

The dispersion characteristics σ_y and σ_z depend upon the turbulent structure of the atmosphere and the downwind distance. As the transport is over a flat country, the equations (Gifford 1976) recommended by Briggs for computing σ_y and σ_z valid for flat terrain have been used. Though the equations are valid upto

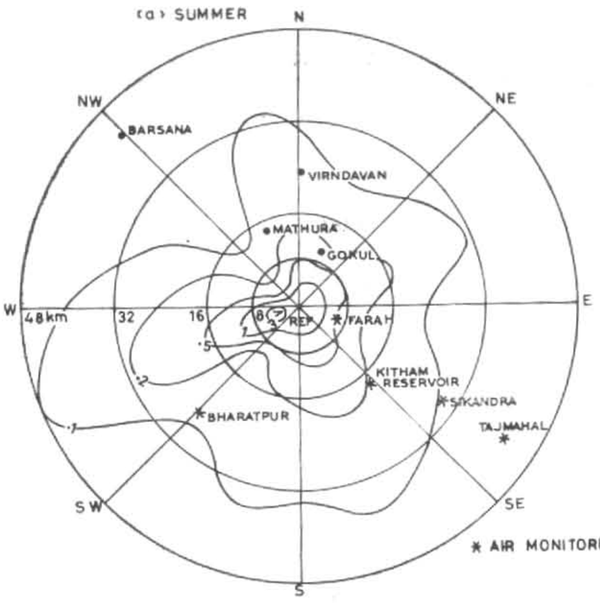

Fig. 2

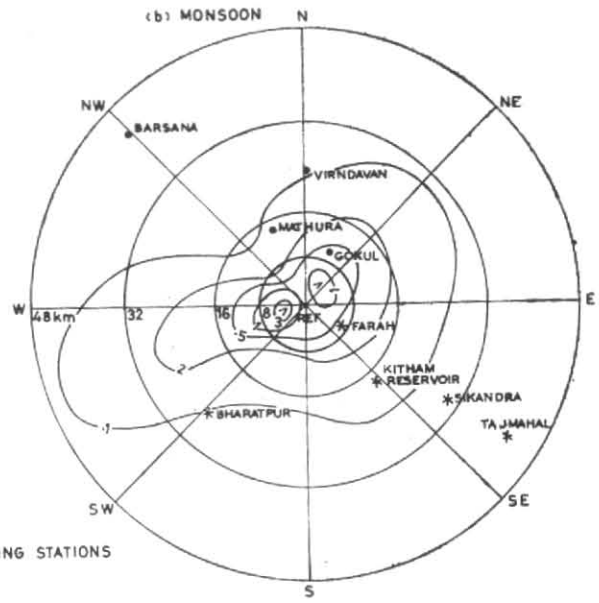

Fig. 3

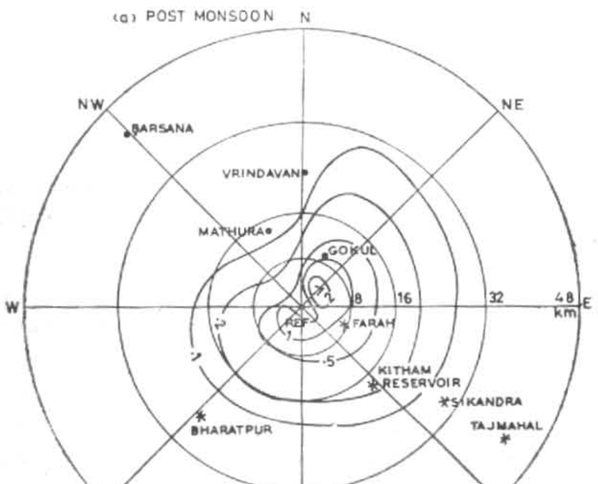

Fig. 4

Fig. 5

Figs. 2-5. Isopleths of ground level long term concentration ($\mu g/m^3$) of SO_2 released from a refinery during summer season of 1982 (Fig 2); Monsoon (Fig. 3); Post monsoon (Fig. 4) and Winter season (Fig. 5)

10 km, Briggs (Gifford 1976), however, mentioned that these equations could be used upto 30 km, hence used in the present study.

Plume rise

The rise of the plume over the stack may be calculated as a function of source parameters, such as, buoyancy, momentum and other meteorological parameters. Numerous formulae have been developed for plume rise, but no two formulae agree with each other or with new observations to which they refer (Guldberg 1975). In the present study, plume rise was obtained by Lucas formulae as modified by Padmanabhamurty & Gupta (1978). This requires minimum data which are conveniently recorded at several meteorological stations. The accuracy often claimed by sophisticated formulae is not lost by the use of these expressions. Plume rise equations used in the present study are :

$$\triangle h = \frac{60 + 5H}{u} Q_H^{0.25} \quad \text{(for unstable and neutral conditions)}$$

$$\triangle h = 116 \frac{Q_H^{0.25}}{u} \quad \text{(for stable atmosphere and low wind speed)}$$

$$\triangle h = 160 \frac{Q_H^{0.25}}{u} \quad \text{(for stable atmosphere and high wind speed)}$$

For wind at stack level, a power law derived from continuous observations was used as $u_2 = u_1 \left(\frac{z_2}{z_1}\right)^p$ where u_1 and u_2 are wind speeds at z_1 (lower) and z_2 (higher) level and

$p = 1/7$ (unstable and neutral conditions)

$p = 1/3$ (stable)

3. Results and discussions

Locator map (Fig. 1) indicates the position of Agra Mathura, Bharatpur, Mathura Refinery, National Highway, monuments at Agra, bird sanctuary at Bharatpur, monitoring stations at Farah, Keetham Lake, Sikandara and Taj Mahal etc. Fig. 2 indicates the isopleths of ground level long term concentration ($\mu g/m^3$) of sulphur dioxide released from a refinery stack during the summer season of 1982. It can be seen that the ground level long term concentration of SO_2 due to refinery at the monuments at Agra is less than 0.1 to 0.2 $\mu g/m^3$. Similarly Figs. 3, 4 & 5 indicate the isopleths of ground level long term concentration ($\mu g/m^3$) of sulphur dioxide during monsoon, post monsoon and winter seasons respectively. In all cases ground level (long term) concentration is less than 0.1 $\mu g/m^3$ at the monuments at Agra except during winter when it is 0.1 $\mu g/m^3$. In all cases the concentrations are nearly 0.5 $\mu g/m^3$ at Farah, 0.2 $\mu g/m^3$ at Keetham lake and 0.1 $\mu g/m^3$ at Sikandara and Bharatpur bird sanctuary. These concentrations are so insignificant which are even not possible to measure with the help of automatic monitoring equipment. Table 1 shows the monitored values indicating long term concentrations ($\mu g/m^3$) at Farah, Keetham lake, Sikandara and Bharatpur bird sanctuary before (*i.e.*, during 1981) and after the commissioning of refinery, *i.e.*, during 1982 at Mathura. The monitored values clearly indicate that there is no significant change in ambient air quality before and after the commissioning of the refinery. Any small change observed may be due to local sources only. However, it may be mentioned that there was a significant reduction by as much as 75% in the concentration of sulphur dioxide in the ambient air, *i.e.*, from 23.03 $\mu g/m^3$ during January to March 1981 to 5.65 $\mu g/m^3$ during April to Sep. 1981 at Taj Mahal. This reduction has been achieved by closing two power stations, dieselisation of railway marschalling yards.

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APPENDIX

Sample calculation with northwesterly wind

Station : Mathura Distance : 30 km

Month : January Hours of observation : 05-06 IST

Year : Mean of 1976, 77, 78 & 79

Percentage frequencies of surface wind

Wind direction	Wind speed (kt) 1-3	4-6	7-10	11-16	17-21	22-27	>27
N	1	—	—	1	—		
NNE	—	—	—	1	—		
NE	2	—	1	2	—		
ENE	3	1	1	2	—		
E	—	2	—	—	—		
ESE	—	1	1	1	—		
SE	2	1	—	—	—		
SSE	1	1	—	—	—		
S	—	3	—	—	—		
SSW	1	—	—	—	—		
SW	—	2	1	—	—		
WSW	2	3	4	—	—		
W	1	4	3	9	1		
WNW	—	5	10	6	1		
NW	—	8	8	—	—		
NNW	—	1	2	—	—		

We know that

$$\chi_{(x,o,f)} = \frac{360 f Q}{\varphi \pi^{3/2}\, 2^{1/2}\, \sigma_z\, \bar{u} x} \exp\left\{ -\frac{h^2}{2\sigma_z^2} \right\}$$

The average value of σ_θ comes out to be less than 2.0 during the month of January between 0500 & 0600 IST and hence the atmosphere is considered to be highly stable.

The value of f when the winds are northwesterly, wind speed in the range of 4-6 knots and highly stable atmosphere is $= 8/100$ (refer above table)

Width of wind direction sector (φ) = 22.5 degrees

$$\text{Emission rate of } SO_2\ (Q) = \frac{100\times10^9}{3.6\times10^3} = 2.78\times10^7\ \mu\text{g/sec}$$

Down wind distance (x) $= 30\times10^3 = 30000$ m

Stack height (H) = 80 m

Heat emission rate (Q_H) = 20.5 MW

$$\text{Mean wind speed at 10 m} = \frac{4+6}{2} = 5 \text{ knots}$$

$$\text{Wind speed at 80 m} = \frac{5}{1.94}\left(\frac{80}{10}\right)^{1/3} = 10/1.94 \text{ m.p.s.}$$

$$\text{Plume rise } (\triangle h) = \frac{116\times(20.5)^{0.25}\times1.94}{10} = 48 \text{ m}$$

Effective stack height (h) $= 80+48 = 128$ m

σ_z at 30 km under highly stable

$$= 0.016\times30{,}000(1+0.0003\times30{,}000)^{-1} = 48 \text{ m}$$

$$\chi_{(30{,}000,\,o,\,f)} = \frac{360\times8\times2.78\times10^7\times1.94}{100\times22.5\times(3.1416)^{3/2}\times2^{1/2}\times48\times10\times30{,}000} \times e^{-\frac{128\times128}{2\times48\times48}} = 0.018\ \mu\text{g/m}^3$$

Similarly, one can compute long term concentration with other wind speed ranges and add up all together. This total will give likely long term concentration due to northwesterly wind during 05-06 hr. Likewise we can compute for all 24 hr.