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Particulate pollution in Delhi due to Indraprastha power plant

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ABSTRACT. Particulate deposition in Delhi due to Indraprastha Power Plant within a radius of 15 km from it are computed employing the long period concentration equation recommended by American Society of Mechanical Engineers. Ten years (1966-75) data of wind speed, wind direction, atmospheric pressure, surface temperature recorded at Safdarjung airport are used for plume rise and concentration computations. An elaborate computer programme is developed to compute stability, wind and temperature at the stack level, and concentrations and depositions at every 1 km upto 15 km due to each stack. The total contribution due to the power plant is obtained as a cumulative of the individual stacks. The same procedure is extended in all directions. Isolines delineating zones of low and high deposition are drawn on monthly and annual maps.

Zones of high deposition/concentration exceeding U.S. Environmental Protection Agency (EPA) secondary standard located at about 1 km from the power plant oscillates between east and southeast in the year except in monsoon months (June to September) when it lay at a distance of 1 km between west and westnorthwest covering areas like Daryaganj, Ferozshaw Kotla, Irwin Hospital. The total deposition in the winter period is high. The total annual deposition over the area of 15 km radius is $69 \cdot 864 \times 10^{10}$ micrograms. Considering the years as a whole the area bounded by the EPA threshold value lies in the southeast between 0·7 and 1·7 km.

It is found that in the absence of any background pollution, particulate pollution in the zone under consideration can be limited to EPA values by increasing the stack levels to 90 metres. With any increase of background pollution the stack height also is to be further raised.

1. Introduction

Air pollution is defined as the undesirable addition to the atmosphere of substances (gases and liquids and solids particles) either that are foreign to the "natural" atmosphere or in quantities exceeding their natural concentrations. Thermal power plants are sources of sulphur dioxide and flyash. While gaseous pollution (sulphur dioxide) problems are dealt by many, particulate (*e.g.*, flyash) pollution is rarely studied because several techniques of analysis have been developed to a higher degree for gases than particulates (Bosanquet *et al.* 1950, Riehl *et al.* 1974). Secondly the technique for analysis differs since short period exposure is more important for gases but for particulates the accumulated deposition over a period of time is of primary interest. Particulates (under 500 microns in diameter) can injure surfaces within the respiratory system and affect climate, visibility, building materials, textile fibres and vegetation. Realising these adverse effects, much concern has been expressed of late of the nature of air quality in and around the Indraprastha power plant in Delhi. This power plant is situated at about 1 km inland on the west bank of *Jamuna* river. To the east of the power station is the *Jamuna* river, to the west, north and south lie the populated urban complex and shopping centres of Delhi (Fig. 1). In the present paper temporal and spatial distribution of particulate deposition within a radius of 15 km from the power plant is presented.

2. Plant characteristics

The total capacity of Indraprastha Power plant varies from 100-250 MW depending upon the requirements but the maximum capacity is 284 MW. It has three stacks with the following characteristics.

Item	*Stack 1*	*Stack 2*	*Stack 3*
Emission rate $\times 10^7$ (μgm/sec)	17.65	35.27	35.27
Stack exit velocity (m/s)	4.2	16.2	16.2
Internal diameter of the chimney at the top (m)	3.27	3.96	3.96
Stack gas exit temperature (°C)	130	130	130
Height of the stacks (m)	61.0	62.53	62.53
Distance between stacks (m)	67.06	54.86	
Efficiency of dust collector	>90%		

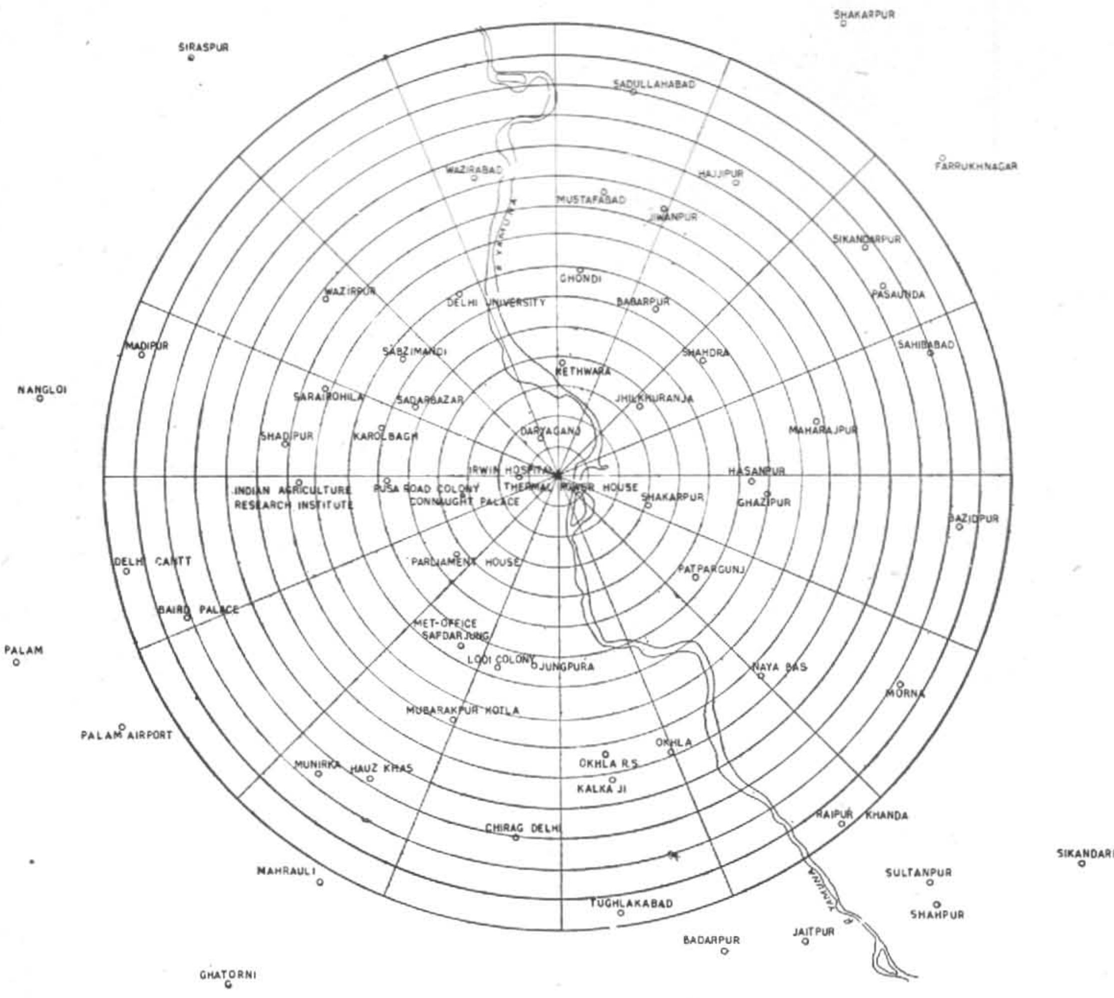


Fig. 1

Item	*Stack I*
Density of flyash (gm/cm^3)	2.1
Size of particulates (diameter in microns)	16

3. Symbols used

χ — Short period (1 hour) ground concentrations in (gm/m^3)
Q — Emission rate ($\mu gm/sec$)
u — Mean wind speed (m/sec) at stack height
x,y— Distances down wind (x) and cross wind (y) from the stack in metres
z — Vertical distance from the ground (metres)
H — Physical height of stack (metres)
Δh— Plume rise (m)
h — Effective stack height ($H+\Delta h$) in metres
σ_y, σ_z—Standard deviations (m) of plume concentration along y and z.

4. Basic equations

The ground level concentrations of gas or aerosols (particles less than about 20 microns diameter) from an elevated continuous source are provided by the Gaussian distribution. The short term concentration (1 hour) at the ground is given by

$$\chi = \frac{Q}{\pi u \ \sigma_y \ \sigma_z} \exp \left[-\frac{1}{2} \left(\frac{y^2}{\sigma_y{}^2} + \frac{h^2}{\sigma_z{}^2} \right) \right]$$

In this expression it is assumed that there is no diffusion in the x- direction.

Over extremely long periods (such as one month) there is simple adaptation of the basic dispersion equation that can be used. Although the form given is not a rigorous mathematical development, it is satisfactory for rough approximations (Smith 1968).

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

where ϕ is the angular width of direction sector (deg) and f is percentage frequency of occurrence of winds in a particular direction, wind group stability and period of interest.

Whenever the mass median diameter of airborne particles is less than 20 μ as is usually the case when any dust collection device precedes the emission (in the present case particle diameter is 16μ), a rough approximation of deposition may be obtained by multiplying the dispersion equation by deposition velocity V_g giving deposition in units/m^2/sec.

5. Evaluation of the parameters

The crux of the problem in computation of concentration lies in evaluating dispersion coefficients and plume rise.

5.1. *Dispersion characteristics*

5.1.1. The dispersion characteristics σ_y and σ_z depend upon the turbulent structure of the atmosphere. From the measures of horizontal and vertical motions of the air made with a bivane σ_y and σ_z can be estimated. Also from wind speed and cloudyness stability can be estimated hence σ_y and σ_z from the nomograms (Pasquill 1961). Turner (1970) introduced insolation as a function of solar altitude into Pasquill's classification and removed much of the subjectivity. The fluctuations of wind direction are used to indicate stability classification at Brookhaven National Laboratory (Slade 1968). In our study too the fluctuations of wind direction, in any hour are used to indicate the stability.

5.1.2. To study the impact of pollution arising from Mathura Oil Refinery, temperature, wind speed and direction are being recorded continuously over a mast at two levels. The average ranges of wind direction fluctuations in an hour are classified into "very unstable", "unstable", "neutral" and "stable" types. These stabilties with corresponding ranges of wind direction fluctuations are given below:

Range of wind direction fluctuations (*R*)	*Stability*
$R < 25°$	Stable
$25° \leqslant R \leqslant 45°$	Neutral
$45° \leqslant R \leqslant 60°$	Unstable
$R > 60°$	Very unstable

5.1.3. The values of σ_z and σ_y are obtained according to the power laws suggested by Mc Elroy (1969) for urban areas.

$$\sigma_z = b x^q$$

$$\sigma_y = a x^p$$

The values of the parameters (a, b, p, q) are given in the following table.

Numerical values of a, b, p, q

Stability	a	p	b	q
Very unstable	1·459	0·714	0·00555	1·54
Unstable	1·518	0·687	0·037	1·17
Neutral	1·358	0·674	0	0·945
Stable	0·791	0·667	0·4	0·672

5.2. *Plume rise*

5.2.1. Plume rise can be calculated as a function of source parameters, such as buoyancy and meteorological conditions. Techniques for doing this have been developed by several people and organisations but hardly any of them agree, either with each other or with new observations if they go outside the range of variables of observations the techniques were originally made to fit (Briggs 1975, Guldberg 1975).

5.2.2. One inadequately answered question is whether single source plume rise is augmented by the presence of nearby plumes ? This question is of decreasing importance to the tall stack problem since the trend has been to combine as much effluent as possible into one or two tall stacks which assumes the maximum possible plume rise. A general approach is that if the sources are very close to each other the plumes will combine and if they are very far apart the plumes will rise separately (Briggs 1974). In the present study as the stacks are separated by a distance equal to their height they are considered as independent sources.

5.2.3. Of the several formulae in literature Briggs model (1969, 71, 72) predicts best the observed plume rise during periods of low wind speed and at higher wind speeds the TVA : 1972 model suggested by Montgomery *et al.* (1972) performed best. As the parameters demanded by the formulae are not readily available, in the present computations Holland's (1953) equation derived from experimental data from large sources (stack diameters from 1·7 to 4·3 metres and stack temperatures from 82° to 204°C) is used as it has been developed with characteristics similar to Indraprastha power plant, Holland's equation is :

$$\triangle h = \frac{V_s\, d}{u}\left(1.5+2.68\times10^{-3}p\ \frac{T_s-T_a}{T_s}\, d\right)$$

where,

$\triangle h$: the rise of the plume above the stack (m)

V_s : stack gas exit velocity (m/sec)

d : inside stack diameter (m)

u : wind speed (m/s) at stack level

p : atmospheric pressure (mb)

T_s : stack gas temperature (°K) at stack level

T_a : air temperature (°K) at stack level, and $2\cdot68\times10^{-3}$) is a constant having units of $mb^{-1}m^{-1}$.

Holland suggested that a value between 1·1 and 1.2 times the $\triangle h$ from the equation should be used for *unstable* conditions and a value between 0·8 and 0·9 the $\triangle h$ from the equation should be used for *stable* conditions. In our study the constants used for unstable and stable conditions are 1·15 and 0·85 respectively.

V_s, d and T_s are obtained from power plants authorities. Average hourly pressure, surface wind and surface temperatures over a ten-year period (1966-75) recorded at Safdarjung airport are utilised. Although air temperature at the stack level is needed surface air temperature only is used in the equation in stable cases. In unstable and neutral cases air temperature at stack level was obtained by adopting dry adiabatic lapse rate.

The two level temperature and wind records at Mathura Refinery site again are utilised to obtain the law of variation of wind in the vertical under different stability conditions. Mostly the cases could be categorised either as unstable or stable and very few occurred in neutral class. However, the coefficients of power law of wind came close to those suggested by Sutton (1947). Hence in the present study wind speed at the stack level is obtained by Sutton's power law.

$$u = u_1\,(z/z_1)^{n/(2-n)}$$

where, u_1, and u are the wind speeds and z_1, (lower) and z (higher) levels and n=0·2 (unstable) n=0·25 (neutral), n = 0·5 (stable)

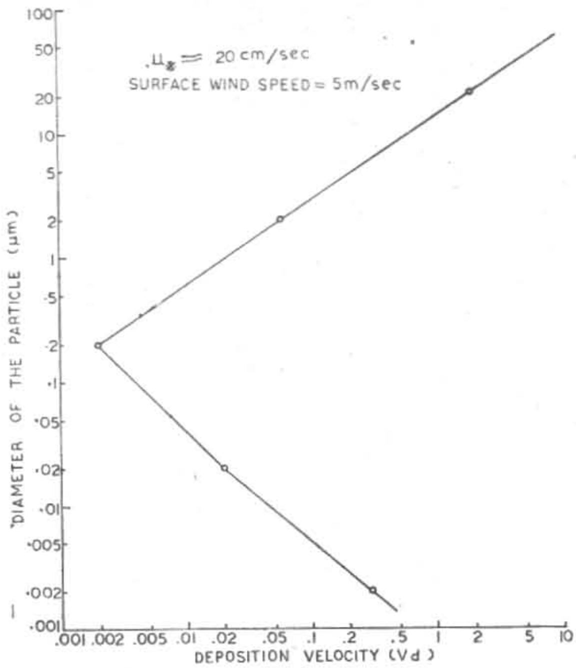


Fig. 2. Variation of deposition velocity *versus* particle diameter

6, Deposition velocity (V_g)

Deposition velocity varies with particle size and surface roughness. Particles of diameter between 1 and 200 microns settle with constant velocity (Sheehy *et al.* 1968), according to Stoke's law.

$$V_g = \frac{2r^2}{9}\ g\,\frac{(S_1-S_2)}{\eta}$$

where,

V_g=Velocity (cm/sec)
r=radius of particle (cm)
g=acceleration due to gravity (cm /sec^2)
S_1=density of particle (gm /cm^3)
S_2=density of air (gm/cm^3)
η=viscosity in poises=$1\cdot814\times10^{-4}$ gm/cm/sec.

Gregory (1945) in analysing the deposition of spores concluded that the deposition rate was proportional to the immediate ground level pollution concentration. Winchester and Nifong (1970) had assumed an average deposition velocity of 0·5 cm/sec regardless of particle size. Sehmel *et al.* (1973) have determined deposition velocities for various diameters of particles of density 2 gm/cm^3, u_x (frictional velocity) 20 cm/sec and surface wind speed 5 m/sec. The value of deposition velocity for the size of particles (16μm) under study is 1·4 cm/sec from the nomogram (Fig. 2) (the particle density

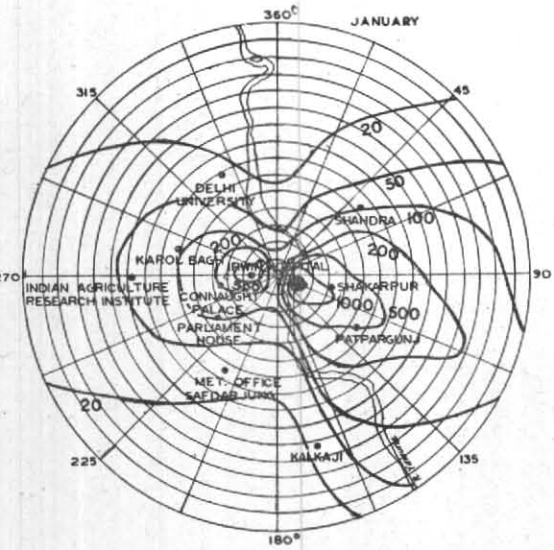
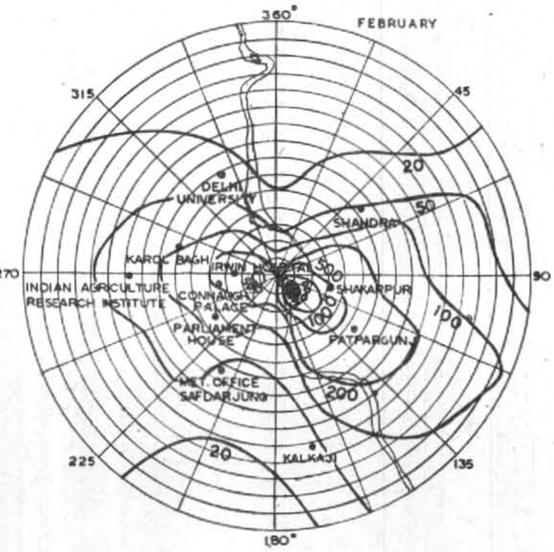


Fig. 3



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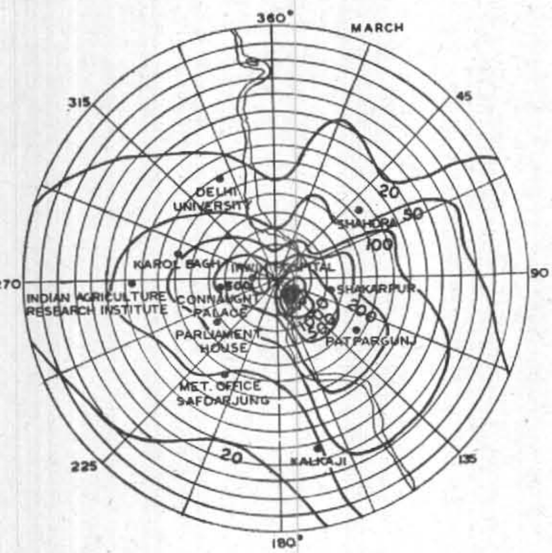

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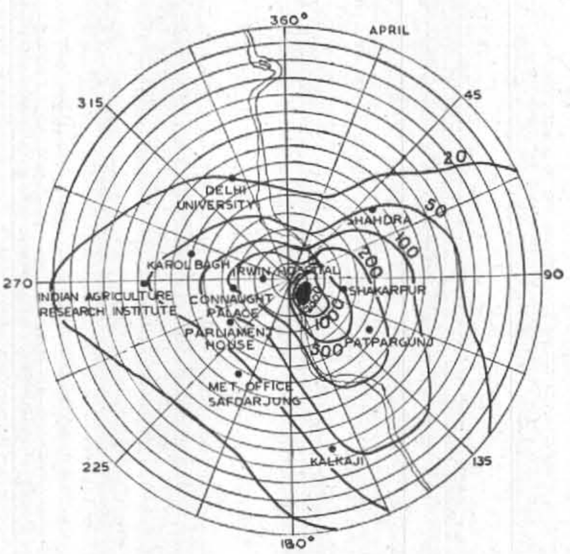


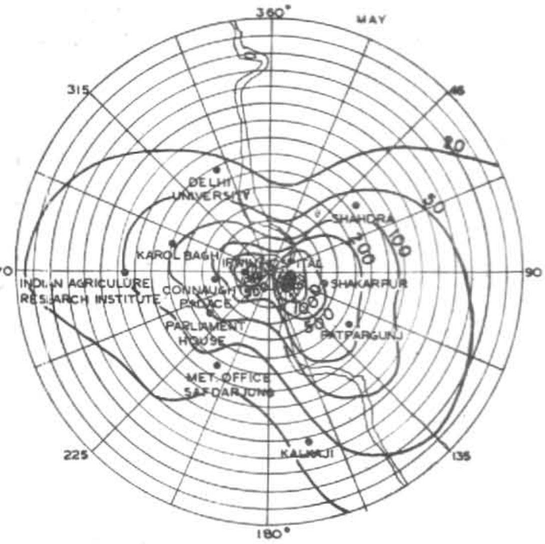
Fig. 6

Figs. 3-6. Monthly deposition of effluents emitted from Indraprastha Thermal Power House

is the same in both cases). The value of V_g computed by the above equation yielded a value of $1 \cdot 8$ cm/sec and used in our computations appears to compare reasonably with the value of Sehmel *et al.* (1973).

7. Concentration computations

Particulate concentrations are computed using the long term equation mentioned earlier. f is determined from the hourly wind roses prepared over a period of 10 years (1966-75) wind data recorded at Safdarjung airport. The mean value of the ranges of wind speeds in any particular direction are determined. Number of occasions in a particular wind group are also found out. Stability of the hour was determined by wind direction fluctuations recorded at Safdarjung only. Ground level concentrations in steps of 1 km from the power plant upto 15 km were computed using the values of f as derived above and using Q, ϕ, σ_z, u and h as given earlier. These concentrations were multiplied by deposition velocity. The contribution from each stack is added to yield total deposition from the plant (Stern 1968). The hourly values thus obtained are added up to yield total monthly deposition. The same procedure is adopted for all the 16 directions and for all months.



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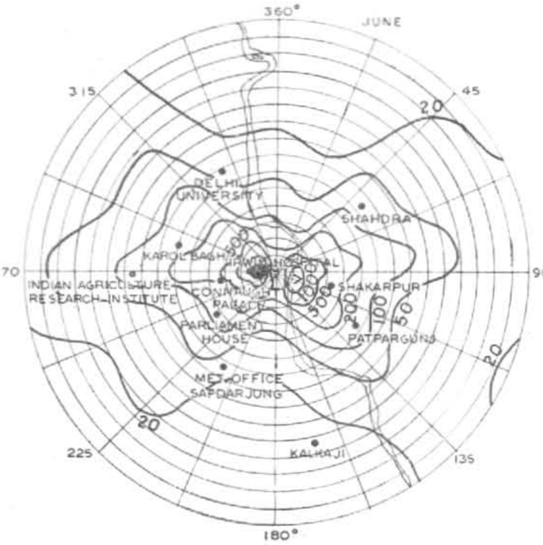

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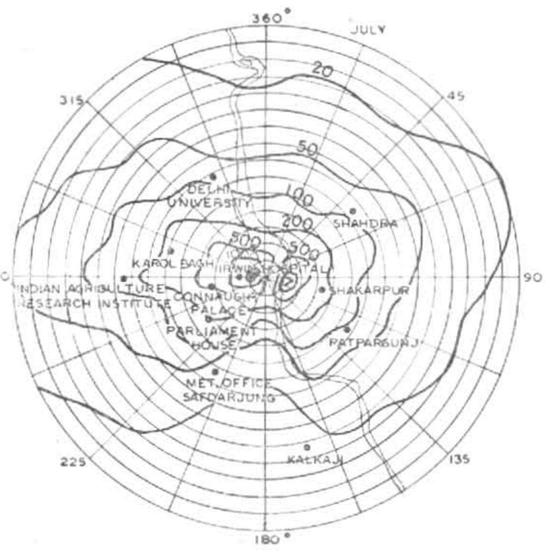

Fig. 9

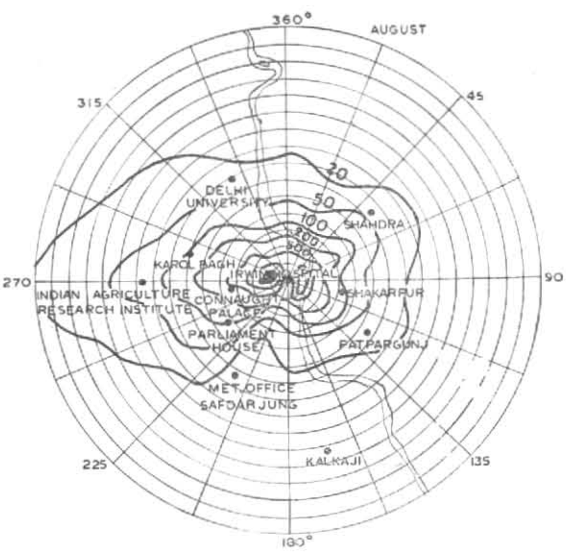

Fig. 10

Figs. 7-10. Monthly deposition of effluents emitted from Indraprastha Thermal Power House

The quantum of deposition of particulates are plotted on a base map (*refer* Fig. 1) at every km in all directions. Zone of deposition delineating 20, 50, 100, 200, 500, 1000, 2000 micrograms in each month are identified. On the annual map isolines of deposition 200, 500, 1000, 2000, 5000, 10,000 and 20,000 micrograms are marked.

8. Results and discussion

8.1. The spatial distribution of particulate deposition from January to December are presented in Figs. 3 to 14. Monthly, seasonal and annual deposition of particulates are also indicated in Table 1. The salient features are :

(*i*) The zone of high deposition (shaded in diagrams) lies at a distance of 0·8 to 1·6 km between east and eastsoutheast in January but moved to eastsoutheast to southsoutheast in February. In March it occupied wider area from eastsoutheast to south-southsoutheast or even beyond. Much change is not evident in April but in May a zone on the west between 0·8 and 1·5 km developed and strengthened in June between west and westnorthwest. In July this zone spread

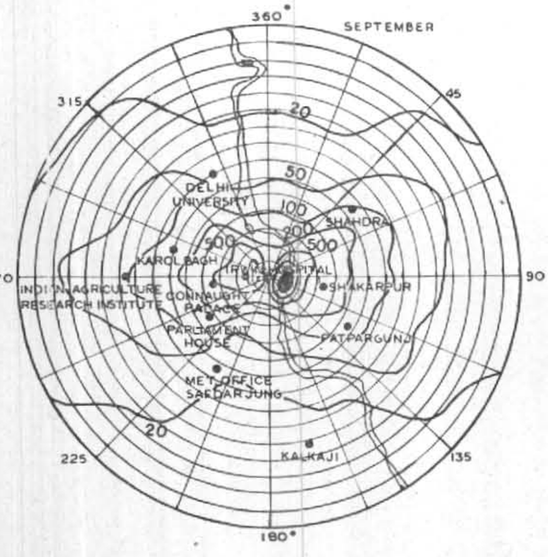

Fig. 11

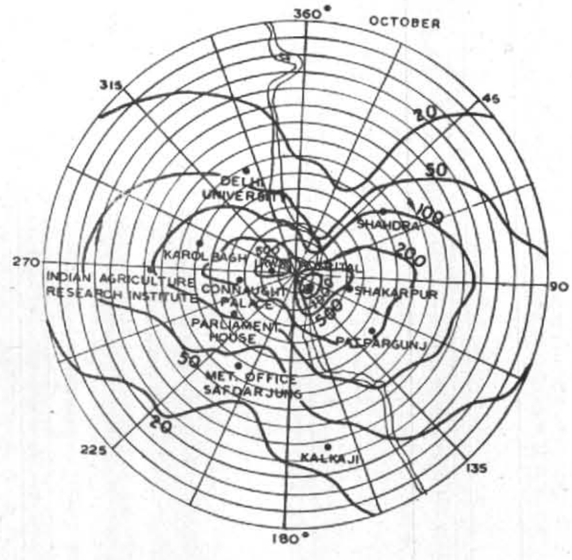

Fig. 12

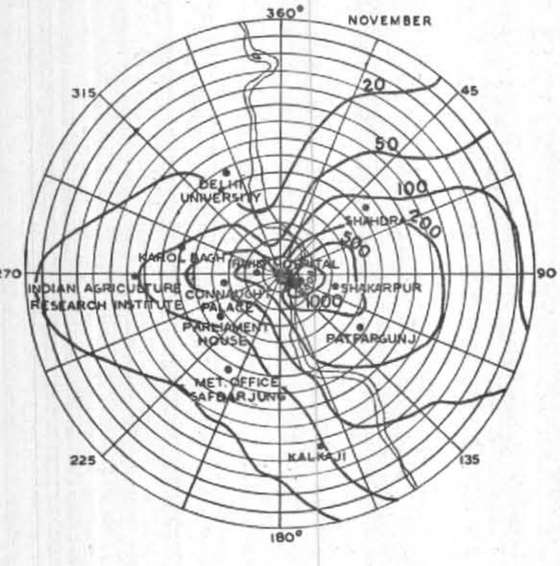

Fig. 13

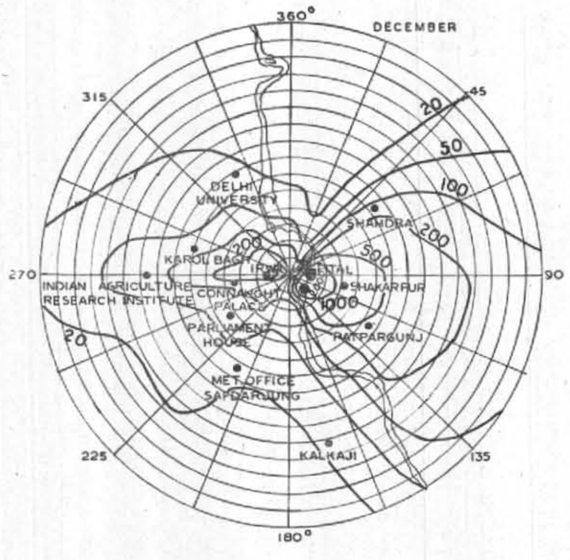

Fig. 14

Figs. 11-14. Monthly deposition of effluents emitted from Indraprastha Thermal Power House

from westsouthwest to northwest from 0·8 to 1·5 km while the zone in the east weakened. In August the deposition is confined to the same area and in September the zone in the east again strengthened extending from eastnortheast-southsoutheast. This zone in October is between 0·8 and 1·3 km in the southeast. November exhibits no different pattern. In December two pockets of high deposition—one on due east and another in southsoutheast at 0·8 to 1·3 km distance appear. On an annual basis (Fig. 15) a zone of deposition exceeding 20,000 micrograms between 0·8 to 1·8 km in the sector eastsoutheast appears. Also a zone of deposition greater than 10,000 micrograms appears between westwestnorthwest at a distance of 0·8-2·2 km.

Besides monthly, seasonal and annual deposition in Table 1 are given 24 hours average concentration over zones of deposition in excess of 2,000 micrograms in each month.

(*ii*) Generally the total deposition is higher in winter months from October to March.

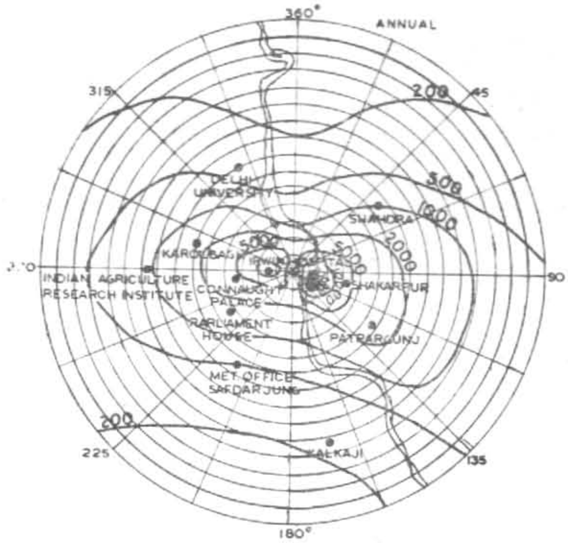

Fig. 15. Annual deposition of effluents emitted from Indraprastha Thermal Power House in micrograms

TABLE 1

Monthly deposition of particulates due to Indraprastha Power Plant over 15 km radius

(Washout not considered)

	Total deposition in micrograms $\times 10^{10}$	24-hr average concentration over the shaded portion (micrograms/m^3)
Jan	6·8876	165
Feb	6·1186	158
Mar	7·2372	168
Apr	5·4525	235
May	5·2266	179
Jun	4·7710	185
Jul	6·2970	162
Aug	3·4674	312
Sep	5·0446	128
Oct	5·3066	125
Nov	7·2440	157
Dec	6·8112	167

Total deposition during the year over 15 km radius $= 69·8643 \times 10^{10}$ Micrograms

Total deposition during Dec-Feb over 15 km radius $= 19·8174 \times 10^{10}$ Micrograms

Total deposition during Mar—May over 15 km radius $= 17·9163 \times 10^{10}$ Micrograms

Total deposition during Jun-sep over 15 km radius $= 19·5800 \times 10^{10}$ Micrograms

Total deposition during Oct-Nov over 15 km radius $= 12·5506 \times 10^{10}$ Micrograms

(*iii*) The areas affected are areas like Daryaganj, Irwin Hospital, Febrozshaw Kotla, Indraprastha Estate on the west and westnorthwest. In the east-southeast east *Jamuna* river appears to act as a sink for a major part of the pollutants.

8·2. The monthly deposition of particulates in all the 16 directions of compass with distance for a pre-monsoon month (March) is shown in Fig. 16. The maximum deposition occurs between 500 m and 1 km in different directions and decreased exponentially with distance. The pattern remains the same in all the months except for maximum deposition distance and direction.

8·3. Environmental protection agency of U.S.A. has defined particulate matter of 260 and 150 micrograms per cubic metre 24-hour concentration as primary and secondary standards respectively (E.P.A. 1972). Primary standards are designed to protect human health. Secondary standards are designed to protect against effects on soil, water, vegetation, minerals, animals, weather, visibility, personal comfort and well being. In Table 1, 24-hour average concentration in the heavily deposited (shaded in figures) areas are given. The levels of particulate pollution due to Indraprastha power plant are in excess of E.P.A. values in all months except in September and October and this pollution is likely to be a source of considerable discomfort to the population in these zones. Although August recorded very high concentrations—even detrimental to human beings—yet these figures may not be taken seriously unless washout which could be of the order of 60-70 per cent on global

Fig. 16. Monthly deposition of emitted particulates *versus* distance from Indraprastha Thermal Power House during March

scale (Bolin and Charlson 1976) is considered and the actual concentrations are arrived at.

9. Summary and conclusions

(1) Zones of deposition exceeding U. S. EPA Secondary Standard are located in the sector east to southsoutheast at a distance of 1 km in the year and on the west-northwest sector in the monsoon. Town planners and Public Health authorities may have to take cognizance of it in their developmental programmes.

(2) Particulate pollution in the zones under consideration can be limited to EPA values either by increasing the stack height or by "Meteorological Control". In the absence of background pollution in the present study a stack height of 90 metres or above appears to be optimum. Any addition of background pollution raises the height of stack.

(3) "Meteorological Control" is a technique of utilising the dilution capacity of the atmosphere to a maximum. This implies releasing effluents into the atmosphere under favourable conditions and restricting them under stagnation periods. This necessitates scheduling of emissions.

(4) Although tall stacks are an unavoidably useful palliative to aid in reducing the more evident effects of emission of large quantities of pollutants to the atmosphere, but the better long range solution is to reduce the emissions themselves (Pooler and Niemeyer 1970).

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