IMPACT OF A GAS BASED POWER PLANT ON THE AIR QUALITY OF DELHI, INDIA

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ABSTRACT

A Power plant situated in the middle of a mega city affects drastically towards the level of different pollutants. The present work focuses on the impact assessment of main air pollutants emitted by Pragati Power Plant, Delhi (India) within a radius of 10 km. Simulations are carried out by using Industrial Source Complex Short Term (ISCST3) model for all seasons. NO_x is considered to be the main pollutant emitted by the power station, as it is gas based power plant. The meteorological variables as wind speed; wind direction and ambient temperature data recorded by Indian Meteorological Department (IMD) for 2011-12 have been used for concentration computations. For this study period Westerly winds are found to be dominating. The maximum concentration 15.484 µg/m^3 of NO_x is found to be at 1 Km. downwind towards West, in which the wind is also found to be dominated.

Key Words : ISCST3, Wind speed, Seasons, Pollutants, NO_x
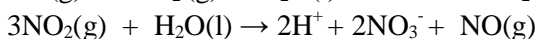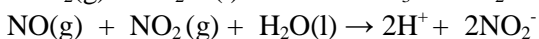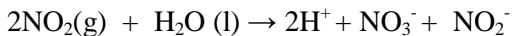
INTRODUCTION

Power plant is an industrial facility for the generation of electric power. Power consumption is one of the main indicators of development of state/country. In other words power development is key element in the development of the economy. Most power stations in the world burn fossil fuels such as coal, oil, and natural gas to generate electricity. Coal based power plants have the maximum contribution as 41%, which is followed by gas, hydro, nuclear, oil and other renewable based power plants as 21%, 16%, 13%, 5% and 3% respectively in total power generation of world. India suffers from a severe shortage of electricity generation capacity. Indian power sector has made significant progress over the last few decades. According to the World Bank, roughly 40 percent of residences in India are without electricity. In addition, blackouts are a common occurrence throughout the country's main cities. It has found that 68% of total power generation is based on coal in India. However, India's domestic coal is low in quality and emits more pollutants in environment. Therefore, there is need of an alternative of coal. It is expected that the share of natural gas in India's power generation will expand from 11 percent in 2008 to 16 percent in 2035. So it is necessary to find out the effect of gas based power plants on air environment especially on fog or smog. The international definition of fog is a visibility of less than 1 km and smog is a type of air pollution; the word smog was made in the early 20th century as a portmanteau of the words smoke and fog to refer to smoky fog. The role of pollutants as aerosols/gaseous in fog formation was recognized by Mensbrugghe who stated, aqueous vapor condenses in the air only in the presence of solid particles around which the invisible vapor becomes a liquid. The degradation of visibility caused by anthropogenic pollutants and their subsequent products is one of the most annoying air pollution problems. By using simultaneous measurement of light-scattering coefficient and ambient aerosol composition in the Los Angeles Basin it has been determined that sulfates and, to a lesser extent, nitrates, are much more effective light scatters on a per mass basis than other particulate components. They conclude that sulfates may be responsible for about half the light extinction in Los Angeles, while nitrate contributes one quarter.

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The scavenging of NO_2 and SO_2 from the atmosphere leads to the formation of NO_3^- and SO_4^{2-} by liquid phase oxidation. The reactions for aqueous-phase disproportionate of NO_X to form nitric and nitrous acid are :

$$2NO_2(g) + H_2O (l) \rightarrow 2H^+ + NO_3^- + NO_2^-$$
$$NO(g) + NO_2(g) + H_2O(l) \rightarrow 2H^+ + 2NO_2^-$$
$$3NO_2(g) + H_2O(l) \rightarrow 2H^+ + 2NO_3^- + NO(g)$$

These reactions would be major contributors to the droplet chemistry if allowed to reach equilibrium. However at the low partial pressures of NO_X found in the atmosphere they are very slow and not so important on the time scales for a fog or a cloud.

The pH of the fog water is found to be in the range of 2.2 to 4.0. There are two dominant processes condensation and evaporation of water vapor, which control the fog water chemistry on pre-existing aerosol and scavenging of gas phase nitric acid. Fog water samples were found to be more acidic and concentrated with respect to chemical composition than the cloud and rainwater samples. It is found that the concentrations of the major chemical components in the fog samples were significantly higher than in previously collected samples of fog cloud and rainwater. In the case of SO_4^{2-}, NO_3^-, NH_4^+ and H^+, the observed concentrations were 10-100 times higher than the previous reported values. The dominant ions in the fog water NH_4^+, H^+, NO_3^- and SO_4^{2-} and their peak concentration were observed after days of dense haze. During the early phase of the Lennox fog, these ions comprise more than 90 % of the total ionic concentration. This indicates that the pre-existing aerosol is the major determinant of the chemical composition of fog water. Fogs also scavenge aerosol particles and it also accelerates their removal from the atmosphere. Suspended substances in the atmosphere contribute to the composition of fog. The chemical composition of fog water can vary as function of droplet size, due to the inhomogeneous chemical composition of cloud condensation nuclei, differences in the rate of soluble gas uptake by small and large drops, and other factors. In nearly all the case the dominant ions in the fog samples were NO_3^-, SO_4^{2-} and NH_4^+, which are the major components of secondary aerosols in Los Angeles. In particular the highest concentration was observed when the fog was preceded by smoggy days. The fraction of NO_3^- and SO_4^{2-} neutralized by NH_3 (in terms of NH_4^+) which determine the acidity of the fog. It is also observed that late night and early morning fogs, which form more easily in particle-laden atmosphere, appear to accelerate and increase smog production, visibility reduction and particulate sulfate levels during the subsequent day.

It is observed in the case of Shanghai; the pH of the fog water is governed by the balance between acidic and basic inputs. The induction of the large amounts of local ammonia and calcium in the environment raises the pH of fog water in shanghai, which is one of the most polluted city in the world.[1] According to a convention, fog is considered acidic when pH is below 5.0. In case of shanghai total concentration of measured cations exceeded that of anions in all fog water sample. High concentration of cations like NH_4^+, Na^+, K^+ were found and likely due to agricultural activities, human waste, and traffic emissions.[2] Similar outcomes were found in an experiment done in the case of Nanjiang city in China.[2] The concentrations of NO_3^- and SO_4^{2-} were found to be higher in shanghai and Nanjiang city. The concentrations of NO_3^- and SO_4^{2-} were higher in comparison of observed values. The ratios of NO_3^-/SO_4^{2-} were also found to be much higher in comparison of other environments in case of these two cities, which is in agreement to the experiments done in Los ageless, Mt. Fuji (Japan). High NO_2^- concentrations have also been observed in high pH urban fogs in California.[3,4]

Higher concentration of NO_X in fog can be derived from its emissions from varieties of combustion sources, high ratio of NO_3^-/SO_4^{2-} clearly suggest the important contributions from vehicular emissions. In the experiment done in the Nanjiang NO_2^- concentration showed the positive correlation with the visibility, which suggests the variation pattern. That is the NO_2^- concentration was low when the fog was dense. Simultaneously at the same time the basic natures of the fog water sample were found to be high in comparison to the

other places and the ratio of NO_3^-/SO_4^{2-} were relatively low. This indicates the low concentrations of the anions compare to the other places. Agricultural pattern, human waist and vehicular emission were found to be the main reason behind the increased concentration of cations like NH_4^+, K^+, and Na^+ etc. Particularly the excessive use of fertilizers increases the basic nature of soil, which is further supported by the vehicular emissions. Whereas in the case of Shanghai, Los Angeles, Mt.Fuji(Japan), Mt sierra Nevada, Mt. Norikura etc fog sample were found to be highly acidic and having higher concentration of NO_X. The results of the observation also suggest that NO_3^- in fog water was increased by the scavenging of HNO_3 gas. It is clearly suggested by the previous studies done at Mt. Norikura that the processes responsible for highly acidic nature of fog water samples were, (1) nucleation scavenging of $(NH_4)_2SO_4$, NH_4HSO_4, NH_4NO_3 particles, (2) absorption of HNO_3 gas by fog droplets and (3) oxidation of SO_2 to SO_4^{2-} in fog droplets.[5,6]

In all the experiments mentioned above concentration of SO_4^{2-} dominates over the concentration of NO_3^-. This indicates that SO_4^{2-} primarily contributed to the acidity of fog water samples. However, the concentration of NO_3^- dominated over the concentration of SO_4^{2-} in some places, probably due to the characteristics of pollutants. Atmospheric concentration of NO_3^- in fog water at the early stage of fog formation was found to be about 25 times larger than that in aerosols before fog event. Possible cause of this increase are the following processes: (1) Liquid phase oxidation of NO_X (2) hydrolysis of N_2O_5 on the surface of droplets and (3) HNO_3 gas scavenging. Therefore we can say that, HNO_3 scavenging is the biggest cause of NO_3^- increase in the fog samples.

AIMS AND OBJECTIVES

To assess the impact of a newly gas based power plant on the air quality of Delhi, especially near Indira Gandhi International (IGI) airport, will open up a new option as a substitute of traditional power plants, which uses coal as fuel.

MATERIAL AND METHODS

The air dispersion model used is Industrial Source Complex Short Term (ISCST3), developed by the US Environmental Protection Agency (US EPA) and recommended by Ministry of Environment and Forests (MoEF). The impact of stack emission on the ground level concentration (GLC) of NOx in the ambient air has been predicted through this model.For a steady-state Gaussian plume, the hourly concentration at downwind distance x (meters) and crosswind distance y (meters) is given by :

$$\chi = \frac{QKVD}{2\pi u_s \sigma_y \sigma_z} \exp\left[-0.5\left(\frac{y}{\sigma_y}\right)^2\right] \qquad (1)$$

Where Q = pollutant emission rate (mass per unit time)
K = a scaling coefficient to convert calculated concentrations to desired units (default value of 1×10^6 for Q in g/s and concentration in $\mu g/m^3$)
V = vertical term
D = decay term
σ_y, σ_z = Standard deviation of lateral and vertical concentration distribution (m)
u_s = mean wind speed (m/s) at release height.
The hourly micro-meteorological data was recorded by Indian Meteorological Department (IMD). These hourly meteorological data like wind direction, wind speed and ambient temperatures have been used for dispersion modeling.
The site-specific mixing depth data are not available. Therefore, in the present study the hourly mixing depth has been derived on the basis of the data presented in a CPCB publication Spatial Distribution of Hourly Mixing Depth over Indian Region.

RESULTS AND DISCUSSION

In order to achieve the above objective, for protection point of view of IGI Airport, the real time hourly visibility and meteorological variables data of the years 2006 to 2011 at IGI Airport is acquired from India Meteorological Department (IMD) and the air quality data of NOx for the same period has been taken from CPCB, Delhi. The peak winter months as December 2010 and January 2011 are

considered as study period in the present study. These months have been chosen due to frequent occurrence of fog in these months.

Prediction of NO$_x$ concentration at ground level around the proposed Pragati II power plant, Bamnauli

The ISCST3 model has been used to predict the hourly NOx concentrations during the months Dec 2010 and Jan 2011 (winter season). These months have been chosen due to frequent occurrence of fog in this period. The wind rose, based on wind pattern of fog

days over these months, is shown in **Fig. 1**. The maximum wind speed is found to be 4 m/s and is blowing mostly in the W, WNW and E directions. However, the wind is calm (< 1.0m/s) nearly 40% of the times.

The emission rate and stack characteristics of power plants with meteorology of Dec 2010 and Jan 2011 are used as input to ISCST3 model to predict the hourly averaged ground level concentrations (glc), which has been drawn in the form of isopleths of various concentrations the **Fig. 2**.
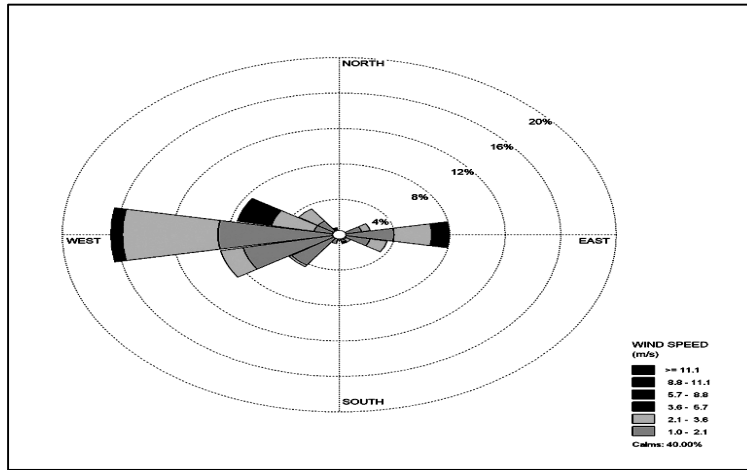

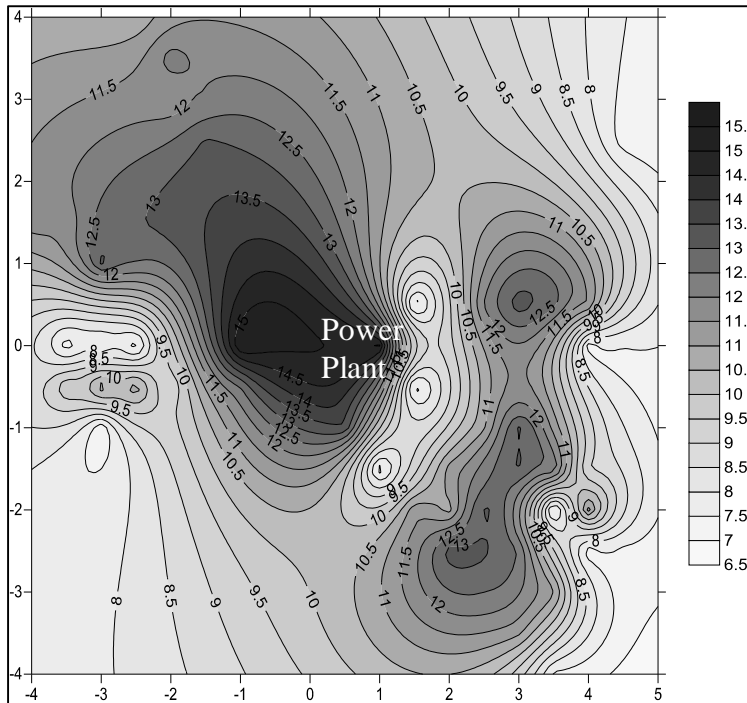**Fig. 1 :** Wind rose based on wind pattern of fog days over months

Fig. 2 : Model's predicted concentration of NOx (μg/m^3) in the form of isopleths of various concentrations within the radius of 5 km

It is noticeable that the model's predicted ground level concentration of NO_x is found to be maximum at the plant's site during the calm winds. The first 10 maximum hourly averaged models' predicted concentrations are shown below in **Table 1**. The above table shows that the maximum hourly concentration is at a distance of 1km in West direction of proposed plant. The IGI airport is located around 8 km in SE direction of the power plant. The maximum 10 hourly concentrations at a same distance in the same direction during winter season are shown in **Table 2**.

Table 1: First 10 Maximum hourly concentration of NOx (µg/m^3)

S/N	NOx (µg/m^3)	Distance (km)	Direction
1	15.48	1.00	W
2	15.07	1.00	E
3	14.04	1.11	ESE
4	13.41	1.11	SE
5	13.22	3.04	ENE
6	13.18	3.20	SSE
7	13.11	3.20	SSE
8	13.10	3.20	SE
9	13.07	3.16	WNW
10	13.06	3.16	ESE

Table 2 : First 10 maximum hourly concentration of NOx (µg/m^3) at 8 km distance (IGI, Airport) in SE direction from power plant during Dec 2010 and Jan 2011 (winter)

S/N	NOx (µg/m^3)	X (m)	Y (m)
1	5.80	8000	0
2	5.10	8000	500
3	5.10	8000	-500
4	5.07	8000	-1500
5	4.72	8000	-1000
6	4.51	8000	1500
7	4.28	8000	-2000
8	3.82	8000	1000
9	3.39	8000	-4500
10	3.27	8000	2000

Reduction in visibility due to Bamnauli power plant at IGI airport

The maximum glc concentration of NO_x due to the power plant at IGI airport is found to be 5.80µg/m^3, which is used as one of the input parameter in regression equation (1) along with the models predicted concentration of NO_x to estimate the visibility. Firstly, hourly meteorological and air pollutant data for the Dec 2010 and Jan 2011 has been used to estimate the average visibility. After that the average visibility has been estimated using the added NO_x concentration with other air pollutants and meteorological variable. This difference has been shown below in **Table 3** shows that average visibility at IGI airport would be decreased at the maximum distance of 1.16 m due to proposed Pragati II power plant at Bamnauli. In the light of above study, one can see that the contribution of the power plant towards the concentration of NO_X is considerably small, which would not be significant for fog/smog formation and affects the visibility at IGI airport.

Table 3 : Reduction in visibility due to power plant during fog days in Dec 2010 and Jan 2011(winter)

Maximum 10 concentration of NO_X (µg/m^3) due to power plant at IGI	Limit of visibility without power plant	Limit of visibility with proposed power plant	Reduction in visibility due to power plant
5.80	1561.48 m	1560.32 m	1.16 m
5.10	1561.48 m	1560.46 m	1.02 m
5.10	1561.48 m	1560.46 m	1.02 m
5.07	1561.48 m	1560.47 m	1.01 m
4.72	1561.48 m	1560.54 m	0.94 m
4.51	1561.48 m	1560.58 m	0.90 m
4.28	1561.48 m	1560.64 m	0.84 m
3.82	1561.48 m	1560.72 m	0.76 m
3.39	1561.48 m	1560.80 m	0.68 m
3.27	1561.48 m	1560.83 m	0.65 m

However, it can be concluded further that the commissioning of Bamnauli power plant will not diminish the visibility by more than 1.16m at IGI airport; Delhi. The maximum ground level concentration (glc) is shown through isopleths of various concentrations at different locations including the IGI airport in **Fig. 3**.
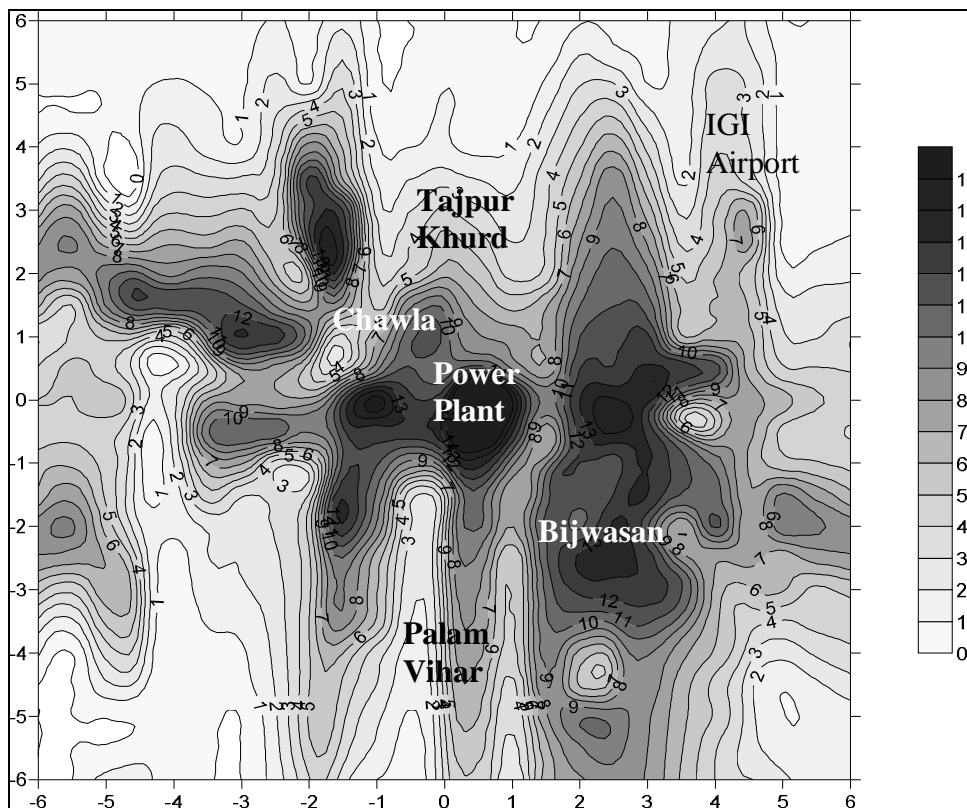

Fig. 3 : Model's simulated concentration of NOx (µg/m^3) in the form of isopleths at different locations including the IGI air port within 6 km radius of plan

Spatial distribution of NO_X in the above figure shows that the concentration of NO_X due to Bamnauli power plant at IGI airport is very small quantity, which is not enough to participate in the fog formation at IGI airport. Therefore, it is justifiable that the proposed plant at Bamnauli will not play any role in the formation of fog/smog at IGI airport. Further the model's predictions of spatial distribution of NO_X within 10 km radius of plant reveal that concentrations of NO_x due to Bamnauli power plant is negligible in and around IGI airport.

A study of NOx concentrations due to proposed power plant at four different locations namely Chawla, Tajpur Khurd, Palam Vihar, Bijvasan and background concentration without plant has been carried out to assess the air pollution status at plant site. The total concentrations of NO_X ($C_1+ C_2$) ($\mu g/m^3$) is the sum of the concentration (C_1) without proposed power plant/background and (C_2) with proposed power plant as shown in **Table 4**.

The total concentration in column 3 of above table shows the models predicted concentrations, after commissioning/operation of power plant, at different locations like Chawla, Tajpur Khurd, Palam Vihar and Bijvasan. The same has been compared with the NAAQS of NOx to assess the impact of power plant at these locations, which reveals that the concentrations of NO_x at all four locations in the periphery of power plant are well within the National Ambient Air Quality Standards (80 $\mu g/m^3$).

Table 4 : Ambient air quality levels of NOx at plant site

Location name	Avg. Concentration of NOx($\mu g/m^3$) (C_1) around plant	Concentration of NOx($\mu g/m^3$) due to power plant (C_2)	$C_1 + C_2$	NAAQS of NOx($\mu g/m^3$)
Chawla (NW)	32.0	5.16	37.16	80
TajpurKhurd (N)	27.0	0.26	27.26	80
Palam Vihar (S)	28.0	1.90	29.90	80
Bijvasan (SE)	29.0	10.89	39.89	80

CONCLUSION

From above results and discussion we can conclude that air pollutants emitted from proposed plant will not have any impact around the plant within a radius of 5 km.

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