EXPERIMENTAL EVALUATION AND THEORETICAL PREDICTION OF AMBIENT PARTICULATE MATTER AND SULPHUR-DIOXIDE CONCENTRATIONS DUE TO POWER PLANT STACK EMISSION IN DELHI REGION

by

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CERTIFICATE

I, the undersigned, certify that the thesis entitled "EXPERIMENTAL EVALUATION AND THEORETICAL PREDICTION OF AMBIENT PARTICULATE MATTER AND SULPHUR-DIOXIDE CONCENTRATIONS DUE TO POWER PLANT STACKS EMISSION IN DELHI REGION" which is being submitted by Mr. Krishna Pal, in fulfilment of the requirements for the award of the degree of "Doctor of Philosophy" in the Faculty of Engineering of the Indian Institute of Technology, New Delhi, is a record of candidate's own bonafide research work carried out under my guidance. The matter embodied in this thesis has not been submitted in part or full, elsewhere for the award of any degree.

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ABSTRACT

In the present work an air quality dispersion model for particulate matter and sulphur dioxide from a power plant in Delhi has been evolved. The power plant under study is situated at Delhi about 1 km^2 inland on the west bank of Jamuna river. To the east of the power station are green fields beyond the bank of Jamuna river while in the west lies the populated urban complex. In north and south of it is a mixed topography of fields and urban devellings.

The power plant is a coal find plant of 284 MW capacity. Samples of coal used in the plant were analysed at the time of pollutant measurement and it was observed that sulphur and ash contents of coal used were 0.5 to 0.6 and 31.0 per cent respectively. The calorific value of coal was experimentally determined with the help of Bomb Calorimeter as 4784 K.cal/kg on an average. On an average the boilers had fuel consumption figures of 2872.3 tonnes of coal and 46.7 tonnes of oil per day. The oil had sulphur content 3.0 per cent with a calorific value 10230K.cal/kg.

Emission rates of both the pollutants under study namely particulate matter and sulphurdioxide were experimentally determined at the source. Concentrations of particulate matter in the flue gases from each of the five boilers was measured at three locations namely before and after electrostat percipitator and at the top of stack in isokinetic conditions

while sulphurdioxide concentrations was measured at last two locations.

At each of these locations samples were collected at fifteen different points to get a representative concentration values. This was repeated at each of the three locations for each of five boilers under different operating conditions.

Particulate matter was measured with the help of an equipment known as 'Thimble Sampling Train'. For isokinetic conditions pressure temperature and velocity at sampling points were also observed with the help of a manometer fitted with the pilot tube. From the experimental data collected the average concentrations of particulate matter increased at higher loads for each of the five boiler. The stack emission was influenced by the efficiency of electrostatic precipitator.

Concentrations of sulphurdioxide were measured using "West and Gaske Technique". In the experimental set-up specially fabricated for its measurements, sodium tetrachloromercurate was used for absorption of sulphurdioxide. The colour was developed with the help of pararosaline dye. A standard graph was plotted for sulphurdioxide with the help of sodium metabisulphate. With the help of spectrophotometer optical density was measured to calculate the sulphurdioxide concentrations using the standard graph. Samples of sulphurdioxide were collected in isokinetic conditions at the points as measured earlier in the case of particulate matter. From the experimental data collected the average concentrations of sulphurdioxide increased with higher loads. From the experimental data average values of particulate matter and sulphurdioxide were calculated as 2942.3 gm sec^{-1} and 112 gm sec respectively from the plant on average operating conditions. These values were used for an air quality dispersion model formulation.

In the second phase of work plume rise formulation and optimization of stack height was looked into. For plume rise the experimental work involved determination of the plume rise under various conditions over a period of time, using instrumental technique. The instrument used was a theodolite and the visible technique of height measurements was adopted to measure plume rise. Some 348 sets of observations were recorded under various conditions of operation of plant and six stability classes of environment taken over period of time spread over six months, July through December, 1980. The top and bottom of plume were taken to be the heights of highest and lowest peaks observed. The mean height was taken midway between the top and bottom of plume.

The principal factors affecting plume rise namely wind speed, velocity of effluent, temperature of source and environment were measured with the help of wind anemometers and thermocouples respectively. The observed values of plume rise were compared with those values obtained from previous formulations available in the literature. It was observed that all the available formulations over estimated the plume rise.

This difference in values was perhaps because the correlation were based on the data of plant operating conditions, physical factors and environmental conditions that were far different from those prevailing in this country. Hence these 348 observations collected in various environmental conditions were used for the formulation of a new plume rise equations. For this observed data was classified into six stability categories based on wind speed i.e. 0-2, 2-4, 4-5, 5-6, 6-7 and above 7 $m.sec^{-1}$. During the experiments wind velocities were measured at two vertical stations located at 8m and 40 m height. The value of stability coefficients were between 0.8 to 0.3 depending upon the stability class.

Multiple regression calculations were made using all the data (384 observations) and also using six sets of data for different stability categories. Using a computer programme the values of emprical constants a, b, c were calculated for each of six categories of environmental conditions. In this manner plume rise equations were developed for each stability class.

It was observed that plume rise decreased with the increase of wind speed. It showed a downward trend at lower load factors while the plume rise was found to be more when the plant was operating at higher loads for all categories of environmental stability. Plume rise was found to be directly proportional to effluent velocity and inversely proportional to wind velocity.

Plume rise and stack height are among the principal factors effecting ground level concentrations. So for the plant under investigation stack optimization study was carried out. The mathematical approach employed was based on the Gaussian plume formulation. This formulation was modified for deposition. The particulate matter samples collected in first phase of the work were analysed for particulate matter distribution. For the determination of partile size the 'Scanning Electron Microscope' and 'Thermal Electron Microscope' were used. The values of particulate density were also calculated from experimental data. It was observed that particles size had mode, median and mean values of the order of 0.5 ,3.5 and 17.5 respectively. The data analysis showed that particle size (diameter) values were left skewed, double-log-normally distributed.

These values were used to compute settling velocity which was found to be 0.0139 $m.sec^{-1}$. These values were also used in Gaussion dispersion plume equation with the earlier determined emission rates of 1476.0 gm sec^{-1} for particulate matter and 56.0 gm sec^{-1} for sulphurdioxide. Computations were made for two typical categories of atmospheric conditions 'B' and 'F' viz. the unstable and moderately stable conditions respectively. For these stability conditions σ_y and σ_z

observed values were used. The computations were made for release heights of 0,60,100,160,200,260,300 m. A typical wind speed of 0.5 m sec^{-1} for F and 6 m sec^{-1} for B condition of atmospheric stability were considered. Calculation were made for two velocities of deposition of pollutants, $V_g = 0$; $V_g = 0.0139$ m sec^{-1} and it was observed that deposition was important in the design of optimum stack height. In the case under study it was found that under stable atmospheric condition (Class F), the optimum stack height for the present plant was 200 m while actual height of stack was well below the optimum value.

In the third phase of this work the horizontal and vertical dispersion of pollutant stream was observed experimentally and predicted theoretically. For the observations, visible technique of measurement was adopted. These observations were collected at 500, 1000; 2000; 5000; 10,000; 15,000; 20,000 m away from source, in sixteen directions and six stability conditions as describe earlier. For analytical prediction the steady state of diffusion equation for a continuous point source was used incorporating topographical, physical and meteorological parameters. The above mentioned equation was solved with the help of finite difference method. The values obtained theoretically and experimentally were tested with the help of X^2-test. The values were observed true at 3 per cent level.

In fourth phase of work measurement of ambient pollutant concentrations were carried out at a distance of 500; 1,000; 2,000; 5,000; 10,000; 20,000; m from stack at ground level by collecting samples at hourly intervals. Ambient concentrations were also analytically predicted using Gaussian plume equation and taking into account the source concentrations, plume rise, horizontal and vertical dispersions determined earlier. The experimentally observed and theoretical calculated results were true with in 5 per cent level when tested with the help of Chi-square test.

In the fifth phase of the work meteorological data of 5-year duration for the region was collected. This data was recorded at hourly intervals. The recorded data over a month was classified in sixteen directions and seven velocity intervals namely 0; 1-3; 4-7; 8-12; 13-18; 19-24; 25-30 km hr^{-1}. Monthly 'Wind Rose Diagram' for a period of five years were plotted and it was observed that maximum frequency of wind was from north-west being 18 per cent and maximum wind speed range was 8-12 km hr^{-1} being 22.58 per cent based on five years data. During these five years 21.3 per cent calm values were recorded.

In the last phase of the work isopelth for average monthly concentrations of particulate matter and sulphurdioxide were evolved. Monthly deposition of particulate matter was observed. These could be used to predict the concentrations of these pollutants at any location and during any month of a year. Relation were developed for critical concentration, wind speed, height, and the place of maximum concentration from source.

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