Analysis of Effectiveness of Stack in the Dispersion of Air Pollutants by using Gaussian's Plume Model at Indo Gulf Fertilizers Ltd., Jagdishpur, U.P., India

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Abstract— The main objective of this work was to ascertain out whether stack can disperse atmospheric pollutants away from city or surroundings where the boiler is installed emitted under different conditions of mass flow rate at the exit and ambient cross flow velocity by using Gaussian's plume model. Dispersion modeling includes means of calculating ambient ground level concentrations of emitted substances, considering the information like meteorological data and pollutants flow rates.

Key words: Atmospheric Pollutants, Mass Flow Rate, Ambient Cross Flow Velocity, Gaussian's Plume Model, Dispersion Modeling, Ground Level Concentrations, Meteorological Data

I. INTRODUCTION

Air pollutants are introduced in the surrounding from the variety of sources that changes the composition of the atmosphere and affect the living species of environment. The concentration of the air pollutants depend not only on the quantities which are emitted from pollution sources but also depends upon the ability of the atmosphere to either absorb or disperse these pollutants. The concentration of air pollutants vary spatially and temporarily causing the air pollution to change with different positions and time due to changes in meteorological and topographical condition. The sources of air pollutants are automobiles, industries, domestic sources and natural sources. Due the presence of high amount of air pollutants in the air, the health of the people and the property is getting adversely affected.

The ambient air quality monitoring observing system includes estimation of various air contaminations at number of areas in the nation to meet targets of the checking Air quality checking system additionally includes choice of poisons, determination of areas, fixation and the kind of toxins in the environment through different normal sources, called regular urban air toxins, for example, Suspended Particulate Matter (SPM), Respirable Suspended Particulate Matter (RSPM), Sulfur dioxide (SO2), Oxides of Nitrogen (NOx), and Carbon Monoxide (CO) and so on.

II. GAUSSIAN'S DISPERSION MODEL

The Gaussian model which uses the Gaussian distribution equation to simply calculate the variations of pollutant concentrations away from the centre of the plume. This equation calculates the ground level pollutant concentrations depend upon time-averaged atmospheric variables.

$$C_{x,y} = \frac{Q}{\pi u \sigma_z . \sigma_y}\left(e^{-\frac{1}{2}\left(\frac{H^2}{\sigma_z{}^2}+\frac{y^2}{\sigma_y{}^2}\right)}\right)$$

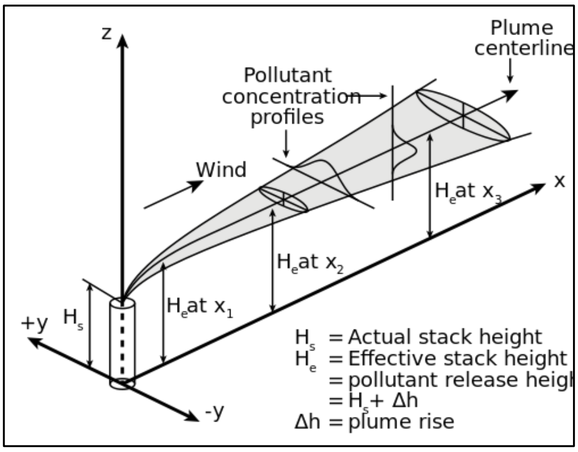

Fig. 1.1: Schematic diagram of Gaussian's distribution model [Source]

When concentration is required only along x-direction, i.e. in the downwind horizontal direction along the centre line of the plume, then naturally y=0. Then equation becomes

$$C_{x,0} = \frac{Q}{\pi u . \sigma_z \sigma_y} e^{-\frac{1}{2}\left(\frac{H^2}{\sigma_z{}^2}\right)}$$

III. DATA & READINGS

Meteorological data of Jagdishpur on visit day (24th October 2k18):

- Temperature: 22°C to 37°C
- Humidity: 71%
- Wind speed: N 2km/h to 7km/h
- Precipitation: 0mm
- Pressure: 1013hPa to 1015hPa
- Visibility: 3km
- UV Index: 5
- Air quality: 286 at PM 2.5 (Poor)
- Data of fuel used at Indo Gulf Fertilizers Ltd.
- Fuel type: 79.44% natural gas and 20.56% naptha fuel
- Fuel quantity: 0.228 million standard cubic metres/day.

At the indo gulf fertilizers limited the main stack is connected with two boilers by (BOILER 605 & BOILER 606) which the pollutants are flowing towards the stack, thus the readings of that boilers are as follows:

A. BOILER 605

T_a = 32°C = 32 + 273 = 305K
T_s = 137°C = 137 + 273 = 410K
Pressure of water vapours in stack, ΔH = 11.5, 12.3, 11.9, 11.2, 12.2, 12.3, 11.7, 12.5, 12.2, 11.2, 12.1, 12.2, 13.3, 14.2, 16.3, 17.2, 16.1, 15.2
Mean ΔH = 13.08 mmH_2O

Plume velocity, $v_1 = 0.1995\sqrt{T_s \times \Delta H} = 14.61$m/s

B. BOILER 606

T_a = 32°C = 32 + 273 = 305K
T_s = 130°C = 130 + 273 = 403K
Pressure of water vapours in stack, ΔH = 14.2, 15.3, 16.9, 13.2, 17.7, 15.5, 18.2, 15.9, 18.3, 17.2, 15.1, 16.2, 18.5, 17.1, 17.9, 16.2
Mean ΔH = 16.63 mmH_2O
Plume velocity, $v_2 = 0.1995\sqrt{T_s \times \Delta H} = 16.33$ m/s
Mean plume velocity, v_s = 15.47 m/s
Pressure = 1014 milli-bars
Fuel quantity: 0.228 million standard cubic metres/day
Density of fuel = 0.712 kg/m^3
As we know, density = mass/volume
Therefore, mass = 6764 kg/h

$$CO_2 \text{ produced/h} = 6764 \times \frac{1}{100} = 67.64 \text{ kg}$$

$$\text{Nitrogen produced/h} = 6764 \times \frac{5.5}{100} = 372.02 \text{ kg}$$

Emission rate for $N_2 = \frac{372.02 \times 1000}{60 \times 60} = 103.34$ g/s
Emission rate for $CO_2 = \frac{67.64 \times 1000}{60 \times 60} = 18.79$ g/s
Height of stack, h = 110m
Diameter of stack = 3m
Wind velocities we have, 2km/h, 3km/h, 4km/h, 5km/h, 6km/h and 7km/h

IV. METHODOLOGY

The values of x and σ_y is been evaluated by the help of the value of σ_z, with the help of graph in the figures 1.2 and 1.3.

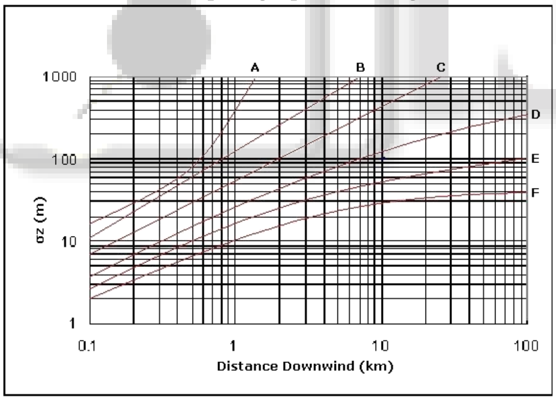

Fig. 1.2: Graph of plume's standard coefficient in vertical direction[Source]

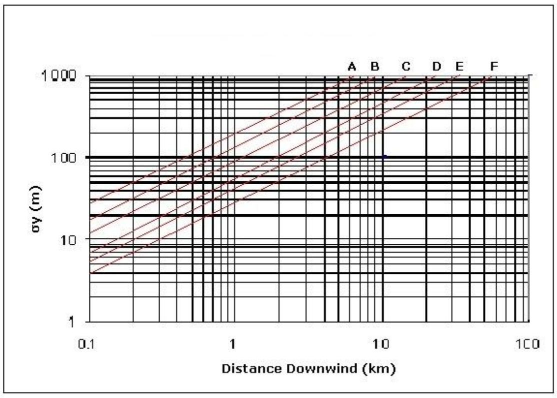

Fig. 1.3: Graph of plume's standard coefficient in cross-wind direction[Source]

A. For wind velocity, u = 2km/h

u = 0.56 m/s
by using formula,

$$\Delta h = \frac{v_s.D}{u}\left[1.5 + 2.68 * 10^{-3} P.D\left(\frac{T_s - T_a}{T_s}\right)\right]$$

we get the height of plume,

$$\Delta h = 293.02\text{m}$$

Effective height of stack is given by,
H = h + Δh = 110 + 293.02 = 403.02m
σ_z = 0.707*H = 284.94m

The values of x and σ_y is been evaluated by the help of the value of σ_z, with the help of graph in the figures 3.7 and 3.8 in case of slightly unstable atmospheric conditions.
x = 6000m
σ_y = 545m

by using Gaussian's equation for the cross-wind distance of the centre line of plume, i.e. y=0

$$C_{x,0} = \frac{Q}{\pi u.\sigma_z \sigma_y} e^{-\frac{1}{2}\left(\frac{H^2}{\sigma_z{}^2}\right)}$$

Therefore after solving the equation wrt given values of the unknowns we get the values,
For N_2
C_{max} = 139 µg/m^3
And for CO_2
C_{max} = 25.3 µg/m^3

B. For wind velocity, u = 3km/hr

u = 0.83 m/s
by using formula,

$$\Delta h = \frac{v_s.D}{u}\left[1.5 + 2.68 * 10^{-3} P.D\left(\frac{T_s - T_a}{T_s}\right)\right]$$

we get the height of plume,

$$\Delta h = 197.7\text{m}$$

Effective height of stack is given by,
H = h + Δh = 110 + 197.7 = 307.7m
σ_z = 0.707*H = 218m

The values of x and σ_y is been evaluated by the help of the value of σ_z, with the help of graph in the figures 3.7 and 3.8 in case of slightly unstable atmospheric conditions.
x = 4000m
σ_y = 375m

by using Gaussian's equation for the cross-wind distance of the centre line of plume, i.e. y=0

$$C_{x,0} = \frac{Q}{\pi u.\sigma_z \sigma_y} e^{-\frac{1}{2}\left(\frac{H^2}{\sigma_z{}^2}\right)}$$

Therefore after solving the equation wrt given values of the unknowns we get the values,
For N_2
C_{max} = 178 µg/m^3
And for CO_2
C_{max} = 32.4 µg/m^3

C. For wind velocity, u = 4km/hr

u = 1.11 m/s
by using formula,

$$\Delta h = \frac{v_s.D}{u}\left[1.5 + 2.68 * 10^{-3} P.D\left(\frac{T_s - T_a}{T_s}\right)\right]$$

we get the height of plume,

$$\Delta h = 147.8\text{m}$$

Effective height of stack is given by,
H = h + Δh = 110 + 147.8 = 257.8m
σ_z = 0.707*H = 182m

The values of x and σ_y is been evaluated by the help of the value of σ_z, with the help of graph in the figures 3.7 and 3.8 in case of slightly unstable atmospheric conditions.
x = 3500m
σ_y = 335m
by using Gaussian's equation for the cross-wind distance of the centre line of plume, i.e. y=0

$$C_{x,0} = \frac{Q}{\pi u.\sigma_z \sigma_y} e^{-\frac{1}{2}\left(\frac{H^2}{\sigma_z^2}\right)}$$

Therefore after solving the equation wrt given values of the unknowns we get the values,
For N_2
C_{max} = 179 µg/m^3
And for CO_2
C_{max} = 32.5 µg/m^3

D. For wind velocity, u = 5km/hr

u = 1.39 m/s
by using formula,

$$\Delta h = \frac{v_s.D}{u}\left[1.5 + 2.68 * 10^{-3} P.D\left(\frac{T_s - T_a}{T_s}\right)\right]$$

we get the height of plume,
Δh = 118.05m
Effective height of stack is given by,
H = h + Δh = 110 + 118.05 = 228.05m
σ_z = 0.707*H = 161.23m

The values of x and σ_y is been evaluated by the help of the value of σ_z, with the help of graph in the figures 3.7 and 3.8 in case of slightly unstable atmospheric conditions.
x = 2600m
σ_y = 255m
by using Gaussian's equation for the cross-wind distance of the centre line of plume, i.e. y=0

$$C_{x,0} = \frac{Q}{\pi u.\sigma_z \sigma_y} e^{-\frac{1}{2}\left(\frac{H^2}{\sigma_z^2}\right)}$$

Therefore after solving the equation wrt given values of the unknowns we get the values,
For N_2
C_{max} = 212 µg/m^3
And for CO_2
C_{max} = 38.5 µg/m^3

E. For wind velocity, u = 6km/hr

u = 1.67 m/s
by using formula,

$$\Delta h = \frac{v_s.D}{u}\left[1.5 + 2.68 * 10^{-3} P.D\left(\frac{T_s - T_a}{T_s}\right)\right]$$

we get the height of plume,

$$\Delta h = 98.26m$$

Effective height of stack is given by,
H = h + Δh = 110 + 98.26 = 208.26m
σ_z = 0.707*H = 147.24m

The values of x and σ_y is been evaluated by the help of the value of σ_z, with the help of graph in the figures 3.7 and 3.8 in case of slightly unstable atmospheric conditions.
x = 2260m
σ_y = 225m

by using Gaussian's equation for the cross-wind distance of the centre line of plume, i.e. y=0

$$C_{x,0} = \frac{Q}{\pi u.\sigma_z \sigma_y} e^{-\frac{1}{2}\left(\frac{H^2}{\sigma_z^2}\right)}$$

Therefore after solving the equation wrt given values of the unknowns we get the values,
For N_2
C_{max} = 219 µg/m^3
And for CO_2
C_{max} = 39.8 µg/m^3

F. For wind velocity, u = 7km/hr

u = 1.94 m/s
by using formula,

$$\Delta h = \frac{v_s.D}{u}\left[1.5 + 2.68 * 10^{-3} P.D\left(\frac{T_s - T_a}{T_s}\right)\right]$$

we get the height of plume,

$$\Delta h = 84.58m$$

Effective height of stack is given by,
H = h + Δh = 110 + 84.58 = 194.58m
σ_z = 0.707*H = 137.57m

The values of x and σ_y is been evaluated by the help of the value of σ_z, with the help of graph in the figures 3.7 and 3.8 in case of slightly unstable atmospheric conditions.
x = 2100m
σ_y = 205m

by using Gaussian's equation for the cross-wind distance of the centre line of plume, i.e. y=0

$$C_{x,0} = \frac{Q}{\pi u.\sigma_z \sigma_y} e^{-\frac{1}{2}\left(\frac{H^2}{\sigma_z^2}\right)}$$

Therefore after solving the equation wrt given values of the unknowns we get the values,
For N_2
C_{max} = 221 µg/m^3
And for CO_2
C_{max} = 40 µg/m^3

V. RESULTS & DISCUSSION

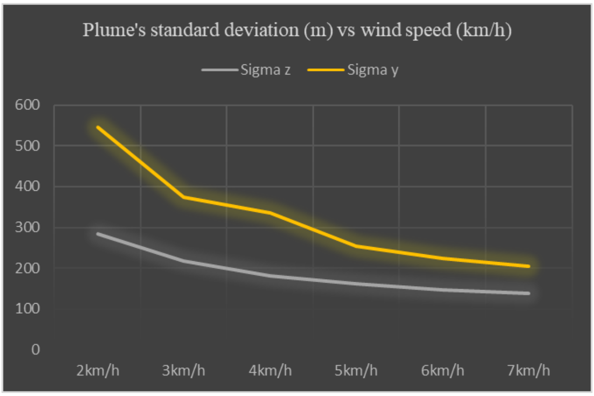

Fig. 1.4:

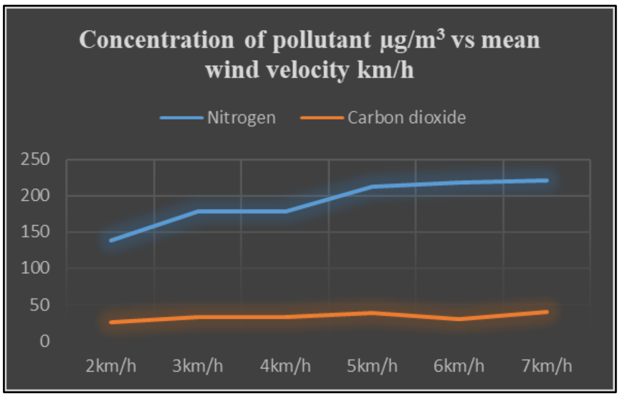

Fig. 1.5:

VI. CONCLUSIONS

From the results we figured out that when the wind velocity is low then the pollutant concentration on the ground is low and at the high wind velocity the pollutant concentration is increased. To avoid this behaviour,

Stack velocity is to be increased in such a manner that the wind velocity should be much less than that of stack velocity.

We can also have numbers of stack in the industry of different dimensions which can give the different velocities of gases from stack as per required.

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