APPLICATION OF AIR DISPERSION MODEL FOR THE ESTIMATION OF AIR POLLUTANTS FROM COAL-FIRED BRICK-KILNS SAMPLES IN GUJRAT

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ABSTRACT: Air pollution is causing severe health and air quality problems in developing countries due to the use of low quality fuel in vehicles, industrial processes and other energy-derived products. Although, brick-kiln industry plays a major role in providing building material, its role in polluting quality of air is ignored. The brick-kiln industry in Pakistan usually exists in and around most of the urban centers. Most of the brick-kiln plants use a low quality coal or other solid waste material and thus results in the production of Sulfur-containing (SO_X), Nitrogen containing (NO_X), Carbon-containing (CO_X) compounds, and particulate matter (PM) along with many other organic pollutants due to burning of low-quality waste material. Therefore, with a rapid but uncontrolled development, emission from these sources is constantly increased and adversely affecting the environment. Yet pollution control efforts are traditionally focused on large industry, in part because the problems of the small scale sources are not well understood. It is therefore, necessary to estimate and monitor the pollutants from traditional brick kilns. In the present study quantification of various air pollutants in the brick kiln emission was carried out to calculate their distribution in the atmosphere by using Gaussian model of dispersion and flue gas analyzer (EPA, 2005). According to study, sampling of air pollutants was carried out around Brick Kilns located close to Gujrat City with a distance of 0.2, 0.4, 0.6, 0.8, 1.0, 2, 3, 4, and 5 km from the source (brick-kilns) following the wind direction. Samples were tested by using Industrial Source Complex Dispersion Model (ISCDM) (EPA, 2005). The observed concentration (g/s) of various pollutants at source (i.e. coil fired brick kiln) on the average were found to be 411, 530.82, 1800, 82.44 g/s for NOx, SOx, CO and Particulate Matter (PM), respectively. The results were compared with the samples with 5 different distances away from brick-kiln plants. The samples were compared with National Environmental Quality Standards (NEQS) and World Health Organization (WHO) values. Most of the air samples were found above WHO standards, however, samples far away from brick-kiln plants (4 & 5 kms) were below National Environmental Quality Standards (NEQS) and World Health Organization (WHO) Standards. Pollution control efforts are traditionally focused on large industry, in part because the problems of the small scale sources are not well understood. More studies are being designed to study the effects of brick-kilns in and around other larger cities. Furthermore, a contamination of other larger industrial emissions could synergize this pollution effect, studies are under-investigation.

***KEY WORDS:** Air Pollutants, Brick Kilns, Coal Fired Combustion, Industrial Source Complex Dispersion Model (ISCDM).*

INTRODUCTION

Industrialization and transportation is contributing towards unfavorable environment. The condition is severe in developing countries where low quality fuel is mostly used for burning purposes which poses great environmental threats. Pakistan, a developing country with a population of almost 180 million, has been facing the same air pollution problem.

Air pollution is the survival of one or more pollutants in the atmosphere which can cause hazard on public health and the atmospheric ecosystem depending on its amount and persistence [1]**.** There are many sources of air pollution. These sources are generally classified as point sources (e.g. stacks), line sources (e.g. roads) area sources (e. g. treatment plants) or volume sources (e. g buildings). About 60 % of the emission is from point sources [2-3].

Coal is one of major energy source which is contributing in world's energy systems with the share of 23.80% and 23.75% of production and consumption respectively [4-5]. In developing countries, however, unabated burning of coal and the use of fuel oils and automotive diesel with higher sulfur content are major sources of sulfur dioxide [6-7]. The majority of nitrogen oxides formed through this route is emitted as nitric oxide. A smaller amount, typically 5% of the total, is emitted as primary nitrogen dioxide, while the major proportion of atmospheric nitrogen dioxide is a secondary product of atmospheric chemistry [8]. Particulate matter (PM) impacts local, regional and global environments in many ways. Fine PM with diameters less than or equal to 2.5 µm ($PM_{2.5}$) has negative effects on human health [5, 9]. At global level, pollutants like CO_2contributes to the phenomena of global warming and climate in change [10]. Carbon monoxide adverse health effects of on the central nervous system examine high-level poisoning (CO-Hb levels of >10%). Such poisoning, results in symptoms ranging from common flu and cold (shortness of breath on mild exertion, mild headaches, and nausea) to unconsciousness and death [6, 8, 11-12]. Knowledge of the pollutant types and emission rates form the foundations of air pollution studies and control is necessary [13, 10].

In Pakistan, air pollution is causing severe health and air quality problems due to the use of low quality fuel in vehicles, industrial processes and other energy-derived products. Although, brick-kiln industry plays a major role in providing building material, its role in polluting quality of air is ignored. The brick-kiln industry in Pakistan usually exists in and around most of the urban centers. Most of the brick-kiln plants use a low quality coal or other solid waste material and thus results in the production of Sulfur-containing (SO_X), Nitrogen containing (NO_X), Carbon-containing (CO_X) compounds, and particulate matter (PM) along with many other organic pollutants due to burning of low-quality waste material. Therefore, with a rapid but uncontrolled development, emission from these sources is constantly increased and adversely affecting the environment. Yet pollution control efforts are traditionally focused on large industry, in part because the problems of the small scale sources are not well understood. It is therefore, necessary to estimate and monitor the pollutants from traditional brick kilns. Gujrat is a famous industrial city of Punjab, Pakistan. A large number of brick kilns in and around Gujrat use poor quality coal. Some brick-kilns also use rice husk, whereas, clay and silica are used as raw material for manufacturing of bricks. Due to their existence on smaller piece of land and the use of traditional vertical-stationary chimney, made of cement and silica for the exhaust of gases, brick-kilns and their emissions poses a great risk to air quality and human health.

In the present study, quantification of various air pollutants, i.e., SO_X , NOx, Cox, & PM, from brick-kilns around Gujrat city and its distribution in atmosphere was carried by using Gaussian model of dispersion.

MATERIALS & METHODS

Estimated levels of pollutants i.e. NO_x, SO_x, CO_x and particulate matter (PM) from Brick Kiln were used to evaluate their dispersion in air with respect to distance. Dispersion up to a distance of 10 kilometer from the source (Brick Kiln) was carried out using Gaussian ISC Model under neutral meteorological conditions (stability class D) (Table 1). Experiments were performed in triplicate on a coal fired Brick Kiln and the results are represented as mean values.

Sampling

Two different methods, i.e., *Flue gas analyzer* and *Air dispersion mathematical model*, for the estimation and monitoring of pollutants from coal fired brick kiln in air, were used [3].

Flue gas analyzer: flue gas analyzer (Calibrated Lancom, USA) was used. After powered on, the instrument was purged to avoid interference, and the knob was placed near that stack end which was emitting pollutants.

Air dispersion mathematical model: Model is view of reality. Mathematical modeling is also a tool for estimation of pollutants at different distances and determination of dispersion of pollutants in air. Mathematical modeling used the two types of data, i.e., Physical or Metrological data, and Mathematical model [3].

Meteorological data:

Meteorological data (e.g. Wind speed, environmental condition) was obtained from Pakistan Meteorological Dept. H-8, Islamabad (Table 1).

Mathematical model:

Gaussian model is the most accepted model to determine from the stack exiting the continuous plume. Gaussian plume dispersion model was used [3]. ISC (Industrial Source Complex Model) has been specifically developed to simulate air pollution due to an industrial plant, taking accurately into account the effect of high stacks on the behavior of the pollutant plume. Its numerous options allow computing the dry deposition of the pollutant downwind the stacks, to model the plume high accounting for the hydro dynamical effects, to simulate the impact of linear, area and volumetric sources. It works with non reactive pollutant, including particulate matter. The mathematical equation used is given as under:

C(x,y,z)

$$=\frac{Q}{2\pi u \sigma_y \sigma_z}\left\{\left(\exp\left(\frac{-(z-H)^2}{2\sigma_z^2}\right)+\exp\left(\frac{-(z+H)^2}{2\sigma_z^2}\right)\right)\right\}\left\{\exp\left(\frac{-(y)^2}{2\sigma_y^2}\right)\right\} \quad \textbf{(1)}$$

Where:

C (x,y,z) : Pollutant concentration as a function of downwind position (x,y,z).

Q Mass emission rate.

U Wind speed evaluated at "effective" release height.

σ_z, σ_y : Corresponds to disk area in simple model (values depend upon downwind distance, x).

H: Total height

$\left\{\left(\exp\left(\frac{-(z-H)^2}{2\sigma_z^2}\right)+\exp\left(\frac{-(z+H)^2}{2\sigma_z^2}\right)\right)\right\}$ = Distribution of mass in vertical dimension (z) at a given downwind distance, (includes the effect of surface reflection).

$\left\{\exp\left(\frac{-(y)^2}{2\sigma_y^2}\right)\right\}$ = Distribution of mass in cross-wind dimension (y) at a given downwind distance (x)

Vertical distribution: Vertical distribution σ_z and cross wind distribution σ_y were calculated the with the help plume sigma formulas from EPA's ISC Model [3].

$\sigma_z = a\,x^b$ **(2)**

Where: x is in kilometers; σ_z is in meters; a, b depend on x.

Cross wind distribution: For stability class, Pasquill – Gifford table was used (Table 2). When started the analysis the stability class D was applicable i.e. neutral where the constants a, b, c, d and f depend on the stability class and their values are given in the tables 2,3. Stability class D and its constants were used to calculate σ_y and σ_z:

$\sigma_y = 465.11628\ x\ (\tan\theta)$ **(3)**

Where: x is in kilometers; σ_y is in meters; θ is in radians

RESULT & DISCUSSIONS

Concentrations of Pollutants at Source

Estimated levels of pollutants i.e. NO_x, SO_x, CO_x and particulate matter (PM) from Brick Kiln were used to evaluate their dispersion in air with respect to distance. Dispersion up to a distance of 10 kilometer from the source (Brick Kiln) was carried out using Gaussian ISC Model under neutral meteorological conditions (stability class D). Experiments were performed in triplicate on a coal fired Brick Kiln and the results are represented as mean values.

The observed emission rate (g/sec) of various pollutants at source (coal fired brick kiln) on the average was found to be: NO_x (411 g/sec); SO_x (530.82 g/sec), CO_x (1800 g/sec), and Particulate Matter (82.44 g/sec).

Table 1: Stack parameters and Meteorological Data

Sr. No.	*Stack parameter*	*Values*
1	Stack height	18.9 m
2	Stack diameter	0.75 m
3	Δh	1.94 m
4	Total height (H)	20.84 m
5	Stack velocity or gas flow rate	8.05 m
6	Down wind speed (u)	4.47m/s
7	Stability class	D (Neutral)

Observations regarding the concentration of NO_x, SO_x, CO_x and Particulate Matter emitted from brick kiln when operated at full capacity showed clear distribution/ dispersion of NO_x, SO_x, CO_x and Particulate Matter as we move away from the source point i.e. Brick Kiln both in vertical (σ_z) and cross wind (σ_y) directions (Figures 1).

On the average σ_z and σ_y values continuously increased with the increase in distance from the point source. For 0.2 to 5 kilometer distance σ_z and σ_y showed increase in distribution from 8.868 to 88.69 and 16.27 to 292.5 respectively.

Table 2: Distribution of pollutants in vertical (σz) and cross wind (σy) directions

Sr.#	Distance (Kilometer)	σ_z	σ_y
1	0.2	8.868	16.27
2	0.4	15.53	29.45
3	0.5	18.3	36.1
4	0.6	21.21	42.72
5	0.8	26.78	55.53
6	1	32.093	68.1
7	2	50.151	127.9
8	3	65.12	184.6
9	4	77.49	239.3
10	5	88.69	292.5

σz = distribution of vertical wind directions; **σy** = distribution in cross wind directions

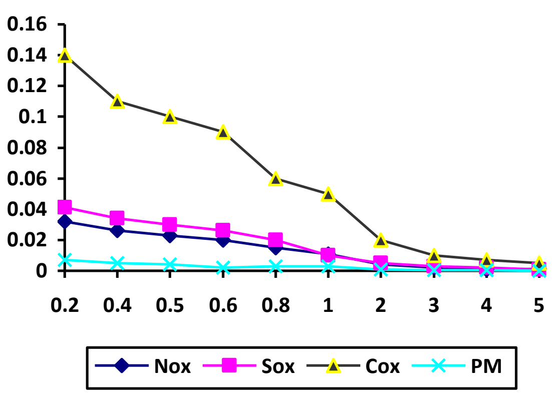

Figure 1: Distribution of NO_x, SO_x, COx and PM (g/m3) from source point to a 5 Km distance in wind direction

Distribution/Dispersion of NO_x with respect to distance from Brick Kiln:

The estimated emission rate of NO_x at the point source i.e. Brick Kiln on the average was 411 g/sec. After application of Gaussian ISC Model to evaluate the dispersion or distribution of NO_x in both vertical and cross wind direction, it is revealed that with increase in distance from the source i.e. Brick Kiln there is a gradual decrease in NO_x concentration when observed for a distance of 5 kilometer from the source. After every kilometer (Figure 1) from the source up to 10 kilometer the decrease in NO_x concentration was 0.032, 0.026 g/m^3, 0.023 g/m^3, 0.020 g/m^3, 0.015 g/m^3, 0.011 g/m^3, 0.004 g/m^3, 0.002 g/m^3, 0.001g/m^3, 0.0011 g/m^3 with standard deviation 0.011 respectively. As the σ_z and σ_y values increases with respect to distance as discussed earlier, therefore it is concluded that after every kilometer from the source, concentration of NO_x would decrease because of the increase in dispersion i.e. σ_z and σ_y.

Majority of nitrogen oxides (NOx) are formed through combustion of oil, gas, and coal, and are emitted as nitric oxide [8]. In human beings , NO_x with high concentrations (10-30 ppm) causes nose and eye irritation, pulmonary edema (swelling) , bronchitis, and even pneumonia. At low concentration, it can cause pulmonary fibrosis and emphysema [14]. NO_x including nitric oxide (NO) and nitrogen dioxide (NO_2) are known to have more severe impacts on vegetations as well [13, 15]. Some broad leafed plants can show necrosis and growth retardation [14]. Nitrogen oxides can also effects indirectly in the form of acid rain [16].

The concentration of NO_x at point source, i.e., zero point was found to be beyond the permissible limits as defined by National Environmental Quality Standard (NEQS) and World Health Organization (WHO). It means that NO_x concentration in the vicinity of source point are posing serious health impacts. As we move away from the brick kiln the threats of health problems diminishes because of the decrease in the NO_x level below the limiting value.

Distribution/Dispersion of SO_x with respect to distance from Brick Kiln:

The emission rate of SO_x was also estimated at zero point i.e. Brick Kiln. On the average the estimated concentration of SO_x at the point source i.e. Brick Kiln was found to be 530.82 g/sec (Figure 1).

Dispersion modeling of SO_x was carried out using Gaussian ISC Model and distribution/dispersion of SO_x was evaluated both in vertical and cross wind directions. A gradual decrease in SO_x concentration was observed with increase in distance from the point source i.e. Brick Kiln, to a distance of 10 kilometer away. After every kilometer from the source up to 5 kilometer the decrease in SO_x concentration was 0.041 g/m^3, 0.034g/m^3, 0.03 g/m^3, 0.026g/m^3, 0.02 g/m^3, 0.01g/m^3, 0.005g/m^3, 0.003g/m^3 0.002g/m^{3,} 0.001 g/m^3 with standard deviation 0.015 respectively as shown in Figure 1. As the σ_z and σ_y values increases with respect to distance as discussed earlier, therefore it is concluded that after every kilometer from the point source, the concentration of SO_x decreased because of the increase in dispersion i.e. σ_z and σ_y.

SOx exposures have adverse effects on the respiratory system of adults in general, and specifically in children, living in or near heavily industrialized areas [6, 11]. Long-term studies showed that it affects the cardiovascular and respiratory systems of elders and also cause sensitization to allergens [17]. Furthermore, Acid deposition, which occurs as wet deposition of oxides of sulpher and nitrogen with water in the form of acid rain , acid snow , or acid fog. Acid rain reacts directly with the stone surface in the presence of moisture and SO_2 caused carbonate – stone damage [18, 19].

When SO_x concentration was compared with the limiting values as defined by NEQS and WHO, it was found that the concentration of SO_x at source point i.e zero point was beyond the permissible limits as defined by National Environmental Quality Standard (NEQS) and World Health Organization (WHO). Results clearly show that SO_x concentration in the vicinity of source point are posing serious health impacts but as we move away from the brick kiln the threats of health problems diminishes because of the decrease in the SO_x level below the limiting value.

Distribution/Dispersion of CO_x with respect to distance from Brick Kiln:

Distribution/ Dispersion behavior of CO_x was almost similar to the dispersion behavior of NOx and SO_x. The estimated emission rate of CO_x at the point source i.e., Brick Kiln on the average was 1800 g/sec. After application of Gaussian ISC Model to evaluate the dispersion or distribution of CO_x in both vertical and cross wind direction, it is revealed that with increase in distance from the source i.e. Brick Kiln there is a gradual decrease in CO_x concentration when observed for a distance of 5 kilometer from the source

From the source up to 5 kilometer after every kilometer (Figure 1) the decrease in CO_x concentration was 0.14 g/m^3, 0.11 g/m^3, 0.1 g/m^3, 0.09 g/m^3, 0.06 g/m^3, 0.05 g/m^3, 0.02 g/m^3, 0.01 g/m^3 0.007 g/m^{3,} 0.005 g/m^3 with standard deviation 0.05 respectively as illustrated in Figure 1. As the σ_z and σ_y values increases with respect to distance as discussed earlier therefore it is depicted that after every kilometer from the source point concentration of CO_x decreased because of the increase in dispersion i.e. σ_z and σ_y.

Carbon monoxide (CO) causes adverse health effects on central nervous system examine high-level poisoning (CO-Hb levels of >10%). Such toxicity results in symptoms ranging from common flu to cold (shortness of breath on mild exertion, mild headaches, and nausea) to unconsciousness and death [6,8,11]. Acidosis is caused by an overabundance of CO_2 in the blood. Under normal physiological circumstances, there is a higher concentration of CO_2 in the blood than in the lungs, forming a concentration gradient, where blood CO_2 diffuses into the lungs and then is exhaled. The excess CO_2 shifts the equilibrium toward the creation of more hydrogen ions, thus creating an acidic environment. During respiratory acidosis, the pH of the blood becomes less than 7.35 [20-21]. Increases in minor greenhouse gases (GHGs) are hypothesized to cause large increases in surface, lower atmospheric temperatures and causes significant global climatic warming and associated impacts [22-23].

The concentration of CO_x at source point i.e zero point was found to be beyond the permissible limit as defined by National Environmental Quality Standard (NEQS) and World Health Organization (WHO). It means that CO_x concentration in the vicinity of source point are posing serious health impacts but health ricks decreases as we move away from the brick kiln because of the decrease in the CO_x level below the limiting value.

Distribution/Dispersion of PM with respect to distance from Brick Kiln:

The estimated emission rate of particulate matter at the point source i.e. Brick Kiln on the average was 82.44 g / sec. After application of Gaussian ISC Model to evaluate the dispersion or distribution of particulate matter in both vertical and cross wind direction, it is revealed that with increase in distance from the source i.e. Brick Kiln there is a gradual decrease in particulate matter concentration when observed for a distance of 5 kilometer from the source (Figure 1).

After every kilometer (Figure 1) from the source up to 5 kilometer the decrease in particulate matter concentration was 0.007 g/m^3, 0. 005 g/m^3, 0.004 g/m^3, 0.002 g/m^3, 0.003 g/m^3, 0.0028 g/m^3, 0.0009 g/m^3, 0.0005g/m^3, 0.0003 g/m3, 0.0002 g/m^3 with standard deviation 0.002 respectively. As the σ_z and σ_y values increases with respect to distance as discussed earlier therefore it is depicted that after every kilometer from the source point concentration of particulate matter decrease because of the increase in dispersion i.e. σ_z and σ_y.

The effects of inhaling particulate matter (PM) have been widely studied in humans and animals and include asthma, lung cancer, cardiovascular issues, and premature death. The size of the particle is a main determinant of where in the respiratory tract the particle will come to rest when inhaled. Because of the size of the particle, they can penetrate the deepest part of the lungs [24]. Particle pollution that settles to the ground can also lead to environmental damage, including acidification of waters, soil nutrient depletion, and destruction of forests and crops aesthetically; particle pollution can stain and damage many materials, including buildings, statues, and monuments [25]. Vegetation exposed to wet and dry deposition of particulates may be injured when particulates are combined with other pollutants. Coarse particles, such as dust, directly deposited on leaf surfaces can reduce gas exchange and photosynthesis, leading to reduced plant growth [26].

The concentration of particulate matter at source point i.e zero point, was found beyond the permissible limits defined by National Environmental Quality Standard (NEQS) and World Health Organization (WHO), as well. However, as we move away from the brick kiln the threats of health problems diminishes because of the decrease in the particulate matter level below the limiting value.

CONCLUSION

Based on current study with application of Gaussian ISC Model to evaluate the dispersion or distribution of pollutants in both vertical and cross wind direction, it has been revealed that with increase in distance from the source i.e. Brick Kiln, there is a gradual decrease in pollutants concentration. Further analysis on such movement based wind direction and distance from the source is under-study.

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