CFD Analysis of Brick Klin Flue Gases and its Health Impact: A Case Study of Northern Part of Dhaka, Bangladesh

Shahriar Shams*, M Hamidur Rahman, and J. N. Sahu

***Abstract*—The northern part of Dhaka city in Bangladesh has contributed to air pollution due to a large number of brick kilns especially operating during the manufacturing season starting from October to March. The study looks at the distribution pattern of emission coming out from the chimneys of brick kilns through computational fluid dynamics (CFD) analysis and its possible impact on the surrounding environment. CFD analysis shows that when wind velocity is more than 3 m/s with increased exit velocity varying from 7.5 to 9 m/s the flow pattern of pollutants are more or less the same and surrounding buildings and vegetation are very likely to be affected. Whereas, if the wind velocity is less than 1 m/s with increased exit velocity varying from 6 to 17.5 m/s, the flow pattern of pollutants are rather dispersive and gradually more inclined towards its height of the chimney and very unlikely the surrounding buildings and areas are directly to be affected.**

***Keywords*—Flue gases, Brick kiln, Computational fluid dynamics (CFD), Air pollution.**

I. INTRODUCTION

Air pollution is one of the major environmental threats to human health in many towns and cities in the developing countries. Particulate emission is mainly responsible for increased death rate and respiratory problems for the urban population [1], [2] . This problem is acute in Dhaka city with 1200 brick kilns located on the periphery and the northern part of the city contributing to the air pollution significantly. They are mainly based in Gabtali, Savar, Ashuliya, Keraniganj, Narshingdi, Gazipur and Manikganj. Brick manufacturing industry is responsible for producing mainly 28.8% of SO_2 and 8.8% NO_2 etc. Brickfields have been blamed for increasing air pollution, especially during the dry season. During the dry season (November to April, which coincides with the kilns operating period), they are citys main source of fine particulate pollution and are responsible for 38 percent of the total fine particulate mass, followed by motor vehicles (19%) and road dust (18%) [3]. As Dhaka is one of the most polluted cities in the world addressing the impact of emissions from kilns and finding alternative options is very important. There are around 5,000 registered brick kilns in the country with the total annual production of 12 billion. The industry is growing with more than 5% annually. It is estimated 25 to 26 % of the country's wood production are used for burning bricks every year, causing deforestation. The firing of a brick kiln to produce 100,000 bricks requires, in just cycle in the year, to burn over 52,000 trees, worth of firewood [4]. Only 26 brick kilns located in Dhaka use natural gas, while others consume 20 lakh tonnes of low quality coal and 20 lakh tonnes of firewood along with tires and rubbers annually despite the fact that the law restricts the use of wood in the brick kilns [5].

Even though brick fields are one of the major sources of air pollution in Dhaka city, most of the research activities regarding air pollution in Dhaka deal with vehicle and industrial pollution. Department of Environment (DOE), Bangladesh Council of Scientific and Industrial Research (BCSIR) and Bangladesh Atomic Energy Cent-re (BAEC), Dhaka are the main organizations working on air pollution, but none of the organizations were studying brickfields earlier. By

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the implementation of the national court order 2003, stack height of brick kilns have now been increased to 120 ft. The brick kiln manufacturing season runs from October to March, during which the northerly winds enhance the contribution of their emissions to the Dhaka air quality. From some survey results, it has been seen that the air pollution near Dhaka city increases to a large extent during the dry season [6]. As brick fields are operated during the dry season, it is clear that brick fields have large contribution to the air pollution. To support an effective urban air quality management in Dhaka and in other cities in Bangladesh, there is limited understanding of the dispersion pattern of brick kiln emission [7] . Therefore, study looks at the dispersion pattern of emission resulting from brick kilns. The study looks at the distribution pattern of emission coming out from the chimneys of brick kilns through computational fluid dynamics (CFD) analysis and its possible impact on the environment. CFD analysis helps to simulate the temperature profile of the brick kilns, the mass flow fractions of CO_2 and NO_x emissions at outlet, and also the air velocity profile inside the kiln [8]. The simulated temperature generated in a tunnel kiln is found to be between 1300 K and 300 K. CO_2 and NO_x volume generated inside the kiln is estimated as 1.01 m^3/s and 0.108 m^3/s respectively [8].

II. Impact of Brick kilns on the surrounding Environment

According to the Department of Agriculture Extension (DAE), the presence of the brickfields has made agriculture impossible in 2000 acres of land in Savar area near Dhaka. Crop production has reduced from 70% to 80% in 3000 acres of land affected by the emission of the gases from the brickfields. The emission resulting from brick kilns also reduces pollination by keeping away the pollinators like bees, butterflies and bats away from the crop fields.

The clusters of brick kilns lying north of Dhaka contribute 40% of the measured fine particulate materials pollution [9]. Growing construction activity is leading the demand for brick kilns and burning of biomass and low quality coal is resulting in pollution [10]. The incremental pollution of 40 g/m^3, due to the brick kilns in the north, translates to an increase in 5,000 premature deaths annually in the Dhaka city [9]. Gupta and Narayan [11] studied the long term impacts, associated with Brick kiln industry and found soil being affected with loss of vegetation [12], variations in species diversity [13] and productivity [14], [15].

According to the Department of Environment (DoE), the density of airborne particulate matter (PM) has reached 247 micro grams per cubic meter (mcm) in Dhaka which is nearly five times the acceptable level of 50 PM per mcm set by the National Ambient Air Quality Standard (NAAQS) of Bangladesh. Airborne particulates are considered more harmful when they are 10 micrometers or smaller in diameter and in Dhaka the density of PM which is 2.5 micrometers or smaller has been found to be 9 times higher than the NAAQS recommendation [16]. An estimated 15,000 premature deaths a year are attributed to poor air quality in Dhaka, according to an Air Quality Management Project (AQMP), funded by the government and the World Bank [17]. Brickfields have been blamed for increasing air pollution, especially during the dry season. These gases also disturb pollination by keeping away the helpful insects from the crop fields. The pollution is caused by poor quality of fuel and improper design of chimneys. Ash, dust and sulfur dioxide gas pollute the areas surrounding brickfields. The brick kilns emit toxic fumes containing suspended particulate matters rich in carbon particles and high concentration of carbon monoxides and sulphur dioxide (SO_2) that are harmful to eye, lungs and throat. Brickfields also cause crop loss, corrosion of metallic content of soil and loss of soil fertility. Burning in kiln makes the land unusable for cultivation for several years. According to the Department of Agriculture Extension (DAE), the presence of the brickfields has made agriculture impossible in 2000 acres of land in Savar area near Dhaka. Crop production has reduced from 70% to 80% in 3000 acres affected by the emission of the gases from the brickfields.

No accurate information is available on the population exposed to PM_{10} and $PM_{2.5}$ from the brick industry. This is estimated by multiplying the total population of 14.6 million in the metropolitan Dhaka area [18] by a coefficient of exposure. It is sometimes argued that all people in Dhaka are exposed to these pollutants due to north-south winds during the brick season. Because of data uncertainty, it is assumed that about 90 % of Dhakas total population or 13.1 million is exposed. Emission of individual air pollutant varied significantly during a firing batch (7 days) and between kilns. Average emission factors per 1,000 bricks were 6.3512.3 kg of CO, 0.525.9 kg of SO_2 and 0.641.4 kg

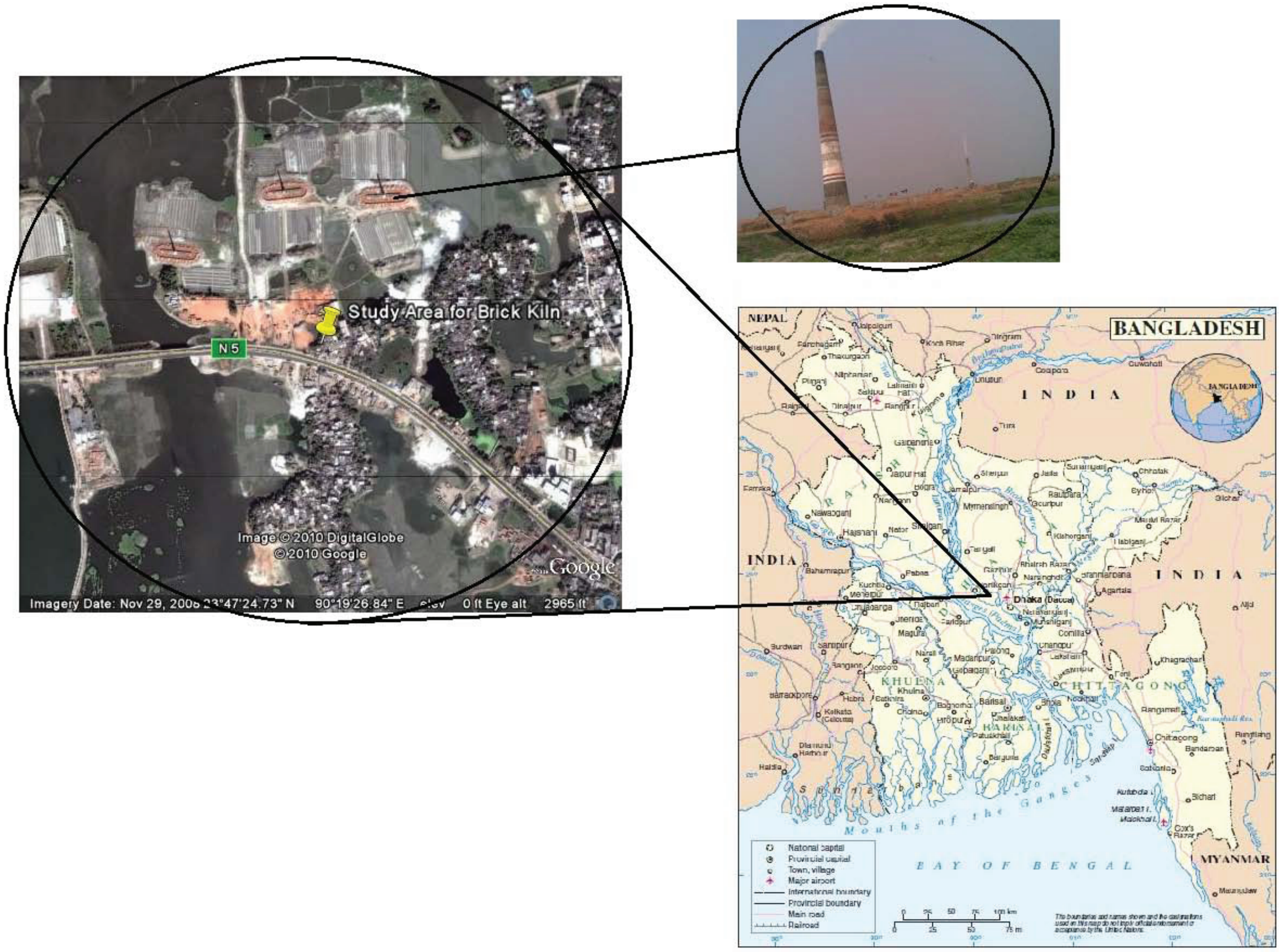


Fig. 1: Location Map of the Study area at Salehpur, Amin Bazar beside the Dhaka - Aricha Highway, Aminbazar. (Source: UN, 2004)

of particulate matter (PM) [19].

III. Case Study

The northern part of Dhaka city particularly Amin Bazar area has deteriorating air quality due to large number of brick kilns densely located to each others. The most of the brick kilns are located on the low lying and agricultural land, which gets submerged during rainy season. The average area occupied by each brick kiln is 13000 sq. m. and on average 30000 bricks are produced daily from each brick kiln. The selected area is Salehpur, Amin Bazar beside the Dhaka - Aricha Highway, Aminbazar and there are some houses and establishments on the south-western part of the study area which are likely to have environmental and health impact due to deteriorating air quality resulting from the brick kilns. The location map of the study area is shown in Figure 1.

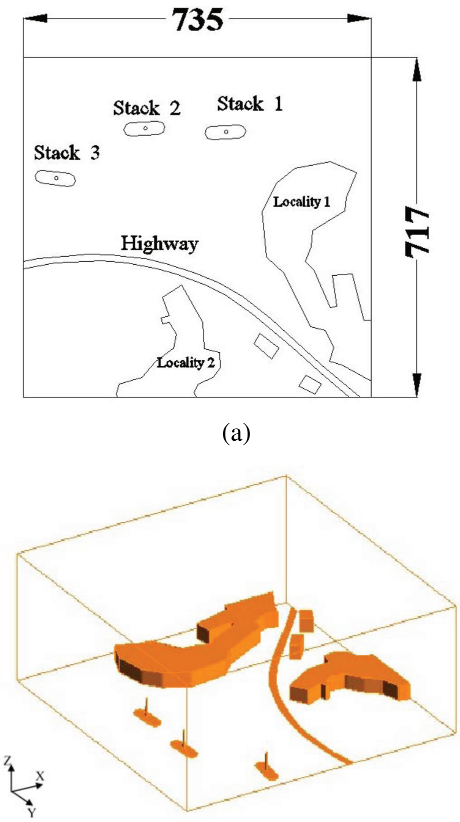
The production of bricks in the brick kiln involves intensive energy process [20], [21]. Each kiln consuming an average of 240 tons of coal to produce one million bricks. Almost all the coal being used is a low-grade coal imported from the Indian State of Meghalaya. This type of coal has a calorific value of 4,000 kcal/kg producing 25.8 tonnes of carbon, which is equivalent to 94.4 tonnes of CO_2 per T J (IPCC default value for bituminous coal). Each kiln therefore produces 760 tonnes of CO_2 per year. Total annual CO_2 emissions from the 5,000 kilns are, therefore, over 3.8 million tonnes. Derivation of the CO_2 emissions per kiln is shown on the following Table 1. Various types of brick kilns emit CO_2 at different rates as shown in Table 2. However, Hoffmann kiln emits lowest value of CO_2 (30 tonnes) as compared to FCK and Zigzag Klin. It has been stated that replacing

TABLE 1: Energy consumption particulate and CO_2 emissions for existing technologies [23], [24]

Caloric value of coal	4000 kcal/kg
Coal consumption per 100000 bricks	20 to 24 Tonnes
Brick weight	3.5 kg
Specific for fuel consumption	4.0E 6TJ/brick
Carbon emission factor for fuel	25.4 tC/TJ
Carbon to CO2 conservation factor	3.66

TABLE 2: CO_2 emission from various types of brick kilns [23], [24]

Kiln Type	Coal per 100,00 bricks (t)	Particu-lates (mg/m^3)	CO_2 emitted per 100,000 bricks (t)	Reduction in CO_2 emis-sions (%)
FCK	20-22a	1,000+	50	n.a.
Zigzagb	16-20	500-1000+	40-45	10-20
Hoffmann (natural gas)	16,000 m^3	16,000 m^3	30	40



(a)

(b)

Fig. 2: (a) Plan view of the case study area, (b) 3D view of the case study area.

the brick cluster north of Dhaka with VSBKs would reduce current premature mortality by more than 60% [22].

IV. Results and Discussion

An analysis of brick kilns as shown in Figure 2 is done using CFD for various emission scenarios.

CFD analysis shows that when wind velocity is more 3 m/s with increased exist velocity varying from 7.5 to 9 m/s as shown in Figure 3(a) and Figure 3(b), the flow pattern of pollutants are more or less the same and it is going to affect the surrounding localities. Whereas if the wind velocity is less 1 m/s with increased exit velocity varying from 6 to 17.5 m/s, the flow pattern of pollutants are rather dispersed and gradually more inclined towards its height of the chimney and very unlikely the surrounding buildings are to be affected. The results demonstrate the influence of wind in dispersion of pollutants. It also evident from the analysis that dispersion of pollutant decreases with increased value of smoke exit to wind inlet ratio as shown in Figure 4(a), 4(b) and 4(c). It is also noticeable that pollutant dispersion takes funnel shape as shown from 3D analysis.

The most noticeable effect of air pollution in the case study area is the reduction of visibility particularly during the winter season where many accidents occur on the Dhaka-Aricha Highway. It is noticed that around the case study area one can feel unusual odors and irritation in the eyes. The air pollution affects the surrounding areas with increased fog formation and reduced solar radiation.

The pollutants discharged from the chimney of brick kilns depend on the meteorological conditions. Even though the total discharge of contaminants into the atmosphere in a given area remains constant from day to day, the degree of air pollution may vary widely because of differences in meteorological conditions. Therefore simulations have been carried out under different meteorological conditions such wind direc-

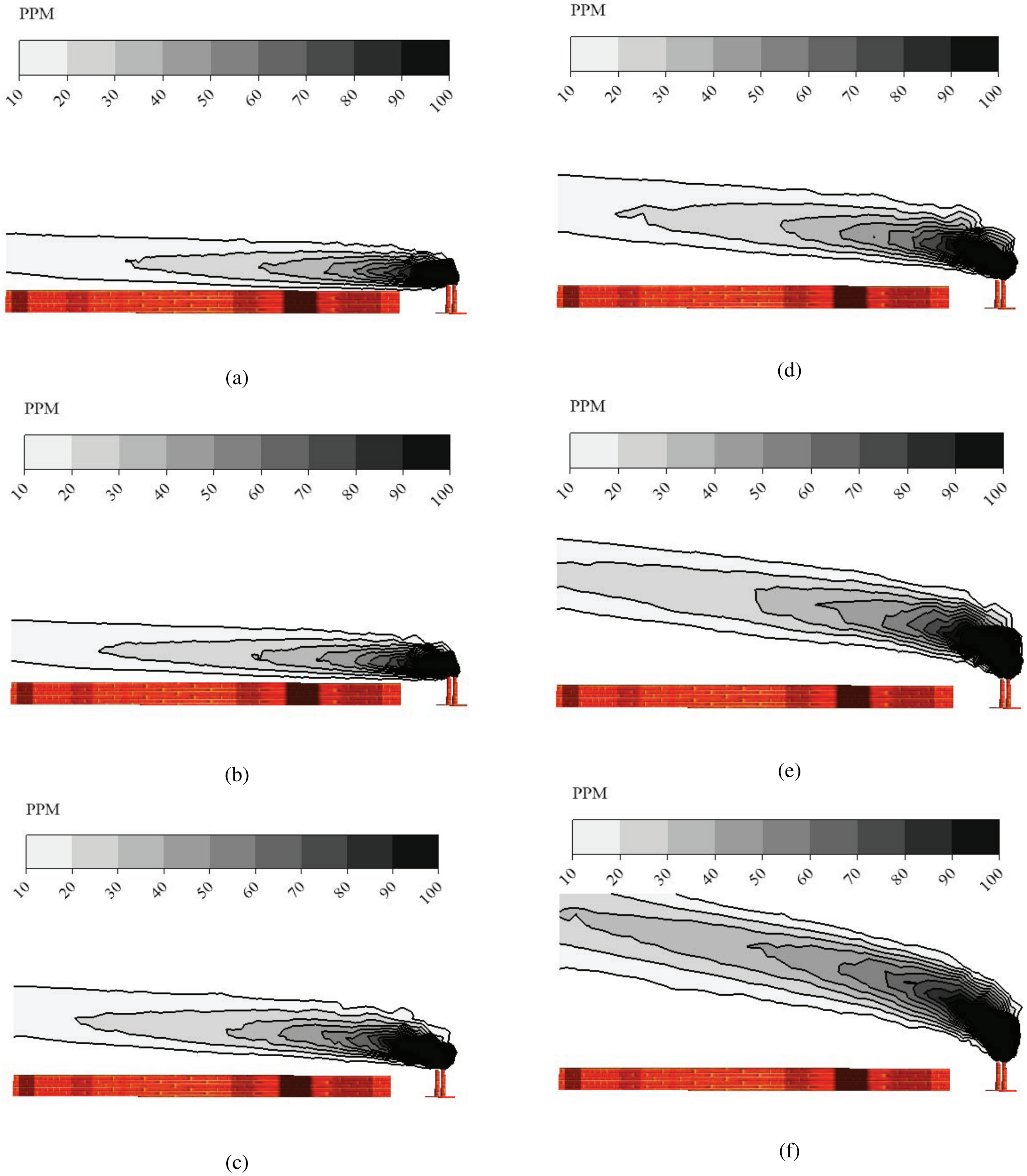


Fig. 3: (a) 3 m/s wind, 7.5 m/s exit velocity (b) 3 m/s wind, 9 m/s exit velocity (c) 1 m/s wind, 6 m/s exit velocity (d) 1 m/s wind, 8 m/s exit velocity (e) $1m/s$ wind, 12 m/s exit velocity, (f) 1 m/s wind, 17.5 m/s exit velocity.

tion and speed, temperature, atmospheric stability and mixing height. However, the secondary parameters such as precipitation, humidity, and solar radiation have not been considered during this simulation. The

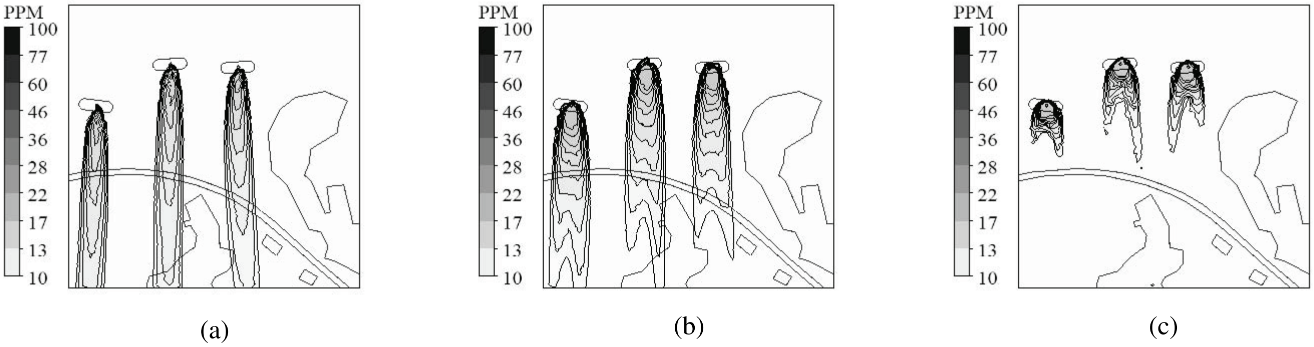


Fig. 4: (a) Smoke exit to wind inlet ratio 2.5, (b) Smoke exit to wind inlet ratio 6, and (c) Smoke exit to wind inlet ratio 12.

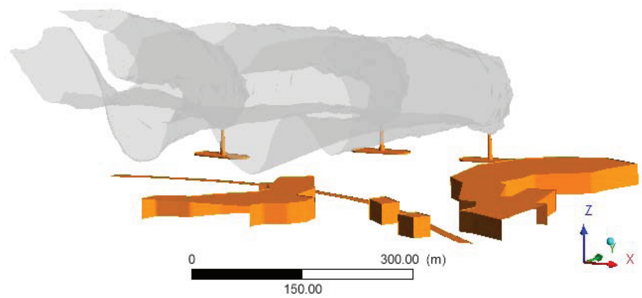


Fig. 5: Pollutant flow pattern 3D view.

direction and speed of surface winds govern the drift and diffusion of the air pollutants discharged near the ground. The higher the wind speed at or near the point of discharge of pollution, the more rapidly are the pollutants carried away from the source. On the other hand, when the wind speeds are low, pollutants tend to be concentrated near the area of discharge and longer the period of light winds the greater will be the pollutant concentrations.

The amount of air flow through the kiln controls combustion as well as heat distribution in the kiln. In general higher is the air flow rate higher is the fire travel in the kiln. The air flow in the kiln is achieved with the help of chimney. The hot gases inside the chimney are lighter than the ambient air outside the kiln, the difference in weight between the hot air column inside the chimney and outside air produces a pressure difference which is known as drought. This pressure difference results in air movement in the kiln. The setting in the kiln provides resistance to air flow and therefore the quantity of air flowing through a kiln depends both on the drought produced as well as resistance provided by brick setting, flue ducts and chimney. The temperature of flue gases, density and length of pre-heating and cooling zone should be further analyzed using CFD.

V. CONCLUSION

The application of dispersion theory and knowledge of local weather conditions are necessary to determine the required chimney height. The existing regulation for chimney height of 120 feet needs to be reviewed as most of the brick kilns are located on the wetland which is 30 to 40 feet below from surrounding area. It is observed through CFD analysis that with low air speed near the base of the chimney will have more direct influence on surrounding buildings and locality in terms of pollution. The seasonal production of bricks is the contributing factor to air pollution. The existing brick kilns use coal and wood and inefficient utilization of energy with conventional design and therefore more susceptible to emission. The new technology Vertical Shaft Brick Kiln (VSBK) may be used to reduce brick kiln emission. It is recommended that emissions standards for brick kilns under ECR97 should be revised with brick diversification (e.g., perforated or hollow bricks for partition walls), establish proper emission monitoring for brick kilns; impose an emission levy based on polluter-pay principle. A combination of government intervention such as regulations for phasing out traditional solid clay bricks and financial incentives through preferential tax policies on promoting new brick products can play an important role for saving land and energy.

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