Jordan Journal of Civil Engineering, Volume **3**, No. **3**, **2009**

Assessment of Air Pollutants Emissions from a Cement Plant: A Case Study in Jordan

Bashar M. Al Smadi [1)], ***Kamel K. Al-Zboon*** [2)] ***and Khaldoun M. Shatnawi*** [1)]

[1)] Assistant Professors, Water and Environmental Engineering, Civil Engineering Department, The University of Jordan, Amman, Jordan
E-mail: b.alsmadi@ju.edu.jo (corresponding Author)
[2)] Environmental Engineering Department, Al-Huson University College, Al-Balqa Applied University, Irbid, Jordan, e-mail:kalzboon@yahoo.com

ABSTRACT

This paper presents predictions of air pollutants (dust, SO_2, NO_x and CO) emitted from a cement plant that will be constructed in Wadi Alabyad area located about 100 km south of Amman, Jordan. The Gaussian air pollution model is used and the predicted concentrations of the air pollutants are compared with the Jordanian air quality standards (JS 1140/2006). It is found that the month of September represents the worst-case scenario where the atmospheric stability condition is classified as A and the average wind speed is 1.7 m/s. The predicted SO_2 hourly and the 24-hour concentrations -when using fuel oil- reached 0.8 ppm and 0.42 ppm, consequently, at a distance of 750 m from the plant, which exceed the standard values of 0.3 ppm and 0.14 pmm, consequently. In case of natural gas as source of energy, the SO_2 concentration is predicted to be negligible. The hourly concentration of NO_x is 0.32 ppm at a distance of 750 m from the plant exceeding the standard limit of 0.21 ppm. It is found that the maximum TSP 24-hour concentration will be expected to reach 359.61 µg/m^3 exceeding the standard value of 260 µg/m^3. The TSP, PM_{10} and $PM_{2.5}$ concentrations exceeded the values set by the standard near the vicinity of the cement plant at a distance closer than 300 m. The proposed mitigation measures should limit the ambient air pollutant concentrations to be in compliance with the standard values.

KEYWORDS: Air pollution, Cement, Stake emission, Gaussian model, SO_2, Dust.

INTRODUCTION

The construction sector has bloomed during the past few years in Jordan. Many projects are being constructed including multi-stories residential buildings, high-rise commercial buildings as well as many other infrastructure projects. Due to the availability of raw materials necessary for the manufacturing of cement and measures taken by the government of Jordan to encourage and facilitate investments in the country, many of the cement plants are planned as well to meet the increasing demand for cement.

Concrete is second only to water as the most consumed substance on earth. Cement is the critical ingredient in concrete, locking together the sand and gravel constituents in an inert matrix; it is the "glue" which holds together much of modern society's infrastructure (Ian Marlowe and David Mansfield, 2002). Cement is produced from geological materials that contain CaO, SiO_2, Al_2O_3 and FeO in certain proportions to define the main properties of cement (Pacific Northwest National Laboratory, USA, 2003).

The main environmental issues associated with cement production are emissions to air and energy use.

Accepted for Publication 15/7/2009.

The energy used by cement industry is estimated at about 2% of the global energy consumption; 5% of global man-made carbon dioxide emissions originate from cement production (Hendriks et al., 1998).

One of the most critical impacts of cement manufacturing is the dust generated during transport, storage, milling, packing,… etc. (NGHI Son Cement Corporation Project, 1996). Atmospheric dust is an important source of air pollution particularly in dry climates. Mineral dust contains high concentrations of many metals known to have toxic effects not only on plants and animals but also on humans (Branquinho, C. et al., 2008; Shukla et al., 1990; Hirano et al., 1995). It has been reported that 1 kg of cement manufactured in Egypt generates about 0.07 kg of dust in the atmosphere (Hindy et al., 1990).

Table (1): Major sources of the main pollutants of the cement manufacturing building.

Emission	Specific pollutant	Source classification	Location
Gas	SO_2	Point sources	Raw mill and kiln stack exit
	NO_x		
	CO		
Dust	TSP, PM_{10} and $PM_{2.5}$	Point sources	Clinker cooler and cement mill stacks exit
		Volume sources	Outlets through dust control devices

Table (2): Summary of the average weather conditions data and the stability class representing the period from 1986 to 2006.

Month	Average wind speed (m/s)	Average wind direction (degrees from north)	General average wind direction	Average radiation	Stability class	Average temperature (^oC)
January	2.44	225.6	SW-NE	Slight	C	8.0
February	2.88	243.0	SW-NE	Slight	C	8.8
March	2.8	261.9	SW-NE	Moderate	B	11.6
April	2.63	279.6	NW-SE	Strong	B	16.7
May	2.50	267.8	SW-NE	Strong	B	20.8
June	2.66	280.1	NW-SE	Strong	A	23.1
July	2.7	298.9	NW-SE	Strong	A	24.9
August	2.11	300.1	NW-SE	Strong	A	24.9
September	1.70	305.8	NW-SE	Strong	A	23.1
October	1.54	272.6	NW-SE	Moderate	B	19.3
November	2.19	191.7	SW-NE	Moderate	B	14.0
December	2.34	194.1	SW-NE	Slight	C	9.5

Table (3): The expected pollutants' emission concentrations at the process stack exits and from the volume sources of the cement plant building versus fuel type.

		Fuel type	
		Fuel oil	Natural gas
Amount burnt (ton/day)		375	400
Sulfur content (%)		3.77	Negligible
Gas flow rate at the stack exit (Nm^3/hr)	-	309893	309893
SO_2 (mg/Nm^3)	Predicted emission (calculated based on the amount of the fuel to be burnt and its sulfur content)	3802	Negligible
	The maximum allowable limit set by the Jordanian standards	6500	6500
NO_x (mg/Nm^3)	Predicted emission (EPA AP-42)	1019.8	2243.4
	The maximum allowable limit set by the Jordanian standards	1800	1800
CO (mg/Nm^3)	Predicted emission (EPA AP-42)	161.1	169.5
	The maximum allowable limit set by the Jordanian standards	250	250
TSP (mg/Nm^3)	Predicted emission (Carlo Tozzi, 2006) General Kiln Clinker cooler Cement mill Volume source	 5 - 200 118.49 (10.2 g/s) 91.11 (8.5 g/s) 56.24 (1.6 g/s) 4.6 (g/s)	 5 - 200 118.49 (10.2 g/s) 91.11 (8.5 g/s) 56.24 (1.6 g/s) 4.6 (g/s)
	The maximum allowable limit set by the Jordanian standards	150	150

Table (4): Modeling results for the SO_2 gas.

Month	Stack exit temperature (^oC)	Downwind distance at which the maximum concentration exists (m)	Predicted ambient SO_2 concentration (ppm)		
			Hourly	24-hour	Annual
September	90 based on the maximum allowable stack exit concentration	750	0.8	0.42	0.018
	90 using fuel oil	750	0.47	0.25	0.011
	130	750	0.78	0.41	0.018
December	90	2000	0.54	0.29	0.013
	130	2000	0.48	0.25	0.011
(JS 1140/2006) maximum limit			0.30	0.14	0.04

Table (5): Modeling results for the NO_x gas.

Month	Stack exit temperature (^oC)	Downwind distance at which the maximum concentration exists (m)	Predicted ambient NOx concentration (ppm)		
			Hourly	24-hour	Annual
September	90	750	0.32	0.17	0.007
	130	750	0.3	0.16	0.007
December	90	2000	0.21	0.11	0.005
	130	2000	0.183	0.1	0.004
(JS 1140/2006) maximum limit (NO_2)			0.21	0.08	0.05

Table (6): Modeling results for the CO gas.

Month	Stack exit temperature (^oC)	Downwind distance at which the maximum concentration exists (m)	Predicted ambient CO concentration (ppm)	
			Hourly	8-hour
September	90	750	0.072	0.048
	130	750	0.068	0.045
December	90	2000	0.048	0.032
	130	2000	0.042	0.028
(JS 1140/2006) maximum limit			26	9

Table (7): Cumulative ambient concentrations of TSP resulting from all stacks, the volume source vent, the background concentration and the area sources as predicted by the air pollution model.

Distance (m)	Source	Predicted ambient TSP concentration ($\mu g/m^3$)		
		Hourly	24-hour	Annual
250	All stacks and volume vent	364.54	193.06	8.47
	Area source	152.1	80.55	3.53
	Maximum 24-hours background concentration (measured during 5 days)	-	86	3.77
	Total	**-**	**359.61**	**15.7**
500	All stacks and volume vent	217.25	115.06	5.05
	Area source	25.53	13.52	0.59
	Maximum 24-hours background concentration (measured during 5 days)	-	86	3.77
	Total	**-**	**214.58**	**9.41**
750	All stacks and volume vent	109.62	58.07	2.55
	Area source	7.24	3.83	0.17
	Maximum 24-hours background concentration (measured during 5 days)	-	86	3.77
	Total	**-**	**147.9**	**6.49**
(JS 1140/2006) maximum limit		**-**	**260**	**75**

Al-Khashman and Shawabkeh (2006) studied the metal distribution in soils around a cement factory in southern Jordan and found that all of the metals were concentrated on the surface of the soil, and highest metal concentrations were found close to the cement factory.

The typical gaseous emissions to air from cement manufacturing plants include nitrogen oxides (NO_x), sulphur dioxide (SO_2), carbon oxides (CO and CO_2) and dust (Pregger et al., 2009; Kampa and Castanas 2008; Egyptian Environmental Affairs Agency EEAA, 2005).

Air pollution has potentially harmful or nuisance effects on human beings, animals, plants, their biological communities and habitats and on the soil (World Business Council for Sustainable Development, 2005)

The objective of this paper is to present an assessment of the emissions from the cement plant that is expected to produce 5000 tons/day. This plant is planned to be constructed at Wadi Alabyad area, located about 100 km south of the city of Amman, Jordan. The predicted emissions are compared with the Jordanian standards of ambient air quality to check their compliance and to propose the necessary mitigation measures in case of violations.

BACKGROUND

There will be three processes stacks installed for the manufacturing building of the cement plant. These three

stacks are: (1) the raw mill and kiln, (2) the cooler clinker, and (3) the cement mills. Dust [which includes (Total Suspended Particulates (TSP), Particulate Matter smaller that 10μm (PM_{10}) and Particulate Matter smaller than 2.5 μm ($PM_{2.5}$)], SO_2, NO_x and CO are expected to exit from the raw mill and kiln stack. Dust is the only expected emission from the cooler stack and the cement mills stack.

The sources of the pollutants from the manufacturing building –studied here– are classified as: (1) point sources which are the stacks exits at the manufacturing building, (2) volume sources which are the spaces within the manufacturing building, and the pollutants from these spaces usually exit the building through controlled outlets. Table (1) presents a summary of the major sources and classification of the main pollutants of the cement plant.

METHODOLOGY

The Gaussian model (Equation 1) for air quality is used to evaluate the concentrations of the emissions from the cement plant area in the ambient air at a height of 1.6 meter (the average height of human nose) above the ground level (Noel de Nevers, 2000). The ambient air concentrations are calculated along a distance of 10 km from the stack in the downwind direction and along a distance of 1 km in the crosswind direction where the pollutant source is at the centerline of this distance.

$$c = \frac{Q}{2\pi u \sigma_y \sigma_z} \exp -0.5\left(\frac{y}{\sigma_y}\right)^2 \left[\exp -0.5\left(\frac{Z-H}{\sigma_z}\right)^2 + \exp -0.5\left(\frac{Z+H}{\sigma_z}\right)^2\right] \quad \text{.....(1)}$$

where:

c = pollutant concentration, g/m^3

Q = pollutant emission rate, g/s

π = pi, 3.14159

u = mean wind speed, m/s

σ_y = standard deviation of horizontal plume concentration, evaluated in terms of downwind distance x, m

σ_z = standard deviation of vertical plume concentration, evaluated in terms of downwind distance x, m

exp = base of natural logs, 2.71828183

H = effective stack height, m

x = downwind distance along the plume mean centerline from point of source, m

y = crosswind distance from the centerline of the plume, m

Z = height of the point (at which the ambient concentration is estimated) above ground surface, m

The plume rise was calculated by the known Holland's formula (Equation 2), (Noel De Nevers, 2000):

$$\Delta h = \frac{VsD}{u}\left[1.5 + (0.00268)(PD)\left(\frac{Ts - Ta}{Ts}\right)\right] \quad \text{……. (2)}$$

where:

Δh = Plume rise in m

Vs = stack exit velocity in m/s

D = Stack diameter in m

u = mean wind speed in m/s

P = pressure in millibars

Ts = stack gas temperature in K

Ta = atmospheric temperature in K

In order to be able to compare the 1-hour concentration of pollutants predicted by the model with the Jordan Air Quality Standards, the 24-hour and the annual average equivalent values are calculated. An atmospheric stability dependent formula (Duffee, O'Brien and Ostojic 1991 sited by SENES, 2003) (Equation 3) for time conversion from a 1-hour to 24-hour period is used.

$$C_o = (C_1)\left(\frac{t_1}{t_o}\right)^n \quad \text{…… (3)}$$

where:

t_1 = the longer averaging time, hr

t_o = the shorter averaging time, hr

n = the stability dependent exponent, 0.2

C_1 = the concentration at the longer averaging time, μg/m^3 or ppm

C_o = the concentration at the shorter averaging time, μg/m^3 or ppm

For converting from a 24-hr timeframe to timeframes of up to 1-year, the time conversion equation by Beychok (1984), sited by SENES (2003) is used (Equation 4).

Table (8): Cumulative ambient concentrations of PM_{10} resulting from all stacks, the volume source vent, the background concentration and the area sources as predicted by the air pollution model.

Distance (m)	Source	Predicted ambient PM_{10} concentration ($\mu g/m^3$)		
		Hourly	24-hour	Annual
250	All stacks and volume vent	182.7	96.53	4.24
	Area source	76.05	40.28	1.77
	Maximum 24-hours background concentration (measured during 5 days)	-	43	1.89
	Total	**-**	**179.81**	**7.9**
500	All stacks and volume vent	108.63	57.53	2.53
	Area source	12.77	6.76	0.3
	Maximum 24-hours background concentration (measured during 5 days)	-	43	1.89
	Total	**-**	**107.29**	**4.72**
750	All stacks and volume vent	54.81	29.04	1.28
	Area source	3.62	1.92	0.09
	Maximum 24-hours background concentration (measured during 5 days)	-	43	1.89
	Total	**-**	**73.96**	**3.26**
(JS 1140/2006) maximum limit		**-**	**120**	**70**

$$C_1 = (C_o)(\frac{t_o}{t_1})^{0.53} \qquad \text{……(4)}$$

The symbols are as defined for Equation 3.

The predictions of PM_{10} are estimated based on the assumption that they are equal to 50% of the TSP. Also, the $PM_{2.5}$ are assumed to be 50 % of the PM_{10} (Carlo Tozzi, 2006).

The needed meteorological data to be used for the input of the model were obtained from Qatraneh weather station which is the nearest station located about 16 km from the proposed cement plant location. The data regarding the physical parameters of the stacks and the fuel type were provided by Al-Shamil Engineering and are used in the model.

Meteorological Data Used for Air Quality Modeling

The model input climate data include: (1) average monthly temperature (2) average monthly solar radiation (3) average monthly wind speed and (4) The average prevailing wind direction (degrees from true north). These average values are presented in Table (2). These data are for the period from 1986 to 2006.The stability class presented in Table (2) is determined based on the atmospheric stability-category classification given by Turner (Noel De Nevers, 2000).

Table (9): Cumulative ambient concentrations of $PM_{2.5}$ resulting from all stacks, the volume source vent, the background concentration and the area sources as predicted by the air pollution model.

Distance (m)	Source	Predicted ambient $PM_{2.5}$ concentration ($\mu g/m^3$)		
		Hourly	24-hour	Annual
250	All stacks and volume vent	91.35	48.27	2.12
	Area source	38.03	20.14	0.89
	Maximum 24-hours background concentration (measured during 5 days)	-	21.5	0.95
	Total	**-**	**89.91**	**3.96**
500	All stacks and volume vent	54.32	28.77	1.27
	Area source	6.39	3.38	0.15
	Maximum 24-hours background concentration (measured during 5 days)	-	21.5	0.95
	Total	**-**	**53.65**	**2.37**
750	All stacks and volume vent	27.41	14.52	0.64
	Area source	1.81	0.96	0.05
	Maximum 24-hours background concentration (measured during 5 days)	-	21.5	0.95
	Total	**-**	**36.98**	**1.64**
(JS 1140/2006) maximum limit		**-**	**65**	**15**

The prevailing average wind direction is 50 % of the time from northwest to southeast and 50 % of the time from southwest to northeast (Table 2). Therefore, one month representing each wind direction is modeled. The worst case is when the stability condition is classified as A and the wind speed is lowest for the same class. For the case of the wind direction from northwest to southeast, the lowest wind speed associated with stability condition classified as A, was for the month of September. Therefore, the month of September represents the worst-case scenario for this wind direction. In fact, the month of September represents the worst-case scenario during the year. Hence, the results of the case of the month of September are discussed.

For the wind direction from southwest to northeast, some of the months represent class B stability condition and others represent class C stability condition. Class C was chosen arbitrarily to be modeled. The month of December was modeled because it has the lowest wind speed (worst case scenario) among the months that have class C stability condition.

Stacks Emission Modeling Input

The input data to the model include the following:

1. Raw mill and kiln stack data including:
   a. Stack physical height of 93 m,

b. Stack exit diameter of 3 m,
c. Stack exit gas temperature of 90 ^{o}C in combined operation, and
d. Stack exit gas temperature of 130 ^{o}C in normal operation.

2. Pollution source data for the raw mill and kiln stack including:
   a. The expected gas flow rate from the stack is 309893 Nm^3/hr,
   b. Fuel type to be used. The cement company considers two alternatives: fuel oil and natural gas.
   c. The amount of the fuel to be burnt per day during operation is shown in Table (3) for each type of fuel.
   d. Tow scenarios were used to obtain the stack exit gas concentrations to be used in the model: (1) the gas concentrations were calculated based on the fuel type or (2) they were obtained from the EPA and the European inventories. In most cases, the calculated and the estimated stack exit gas concentrations were below the values set by the Jordanian standards (JS 1189/2006). However, the company is committed to comply with the standards of the gas emissions at the stack exit (i.e. JS 1189/2006) and because these values were higher than those calculated or estimated ones. The values set by the standards represent the worst-case scenarios and thus they were used for the model input.
3. Cooler clinker stack data including:
   a. Stack physical height of 30 m
   b. Stack exit diameter of 3.2 m
   c. Stack exit air temperature of 192 ^{o}C
4. Cement mill stack data that including:
   a. Stack physical height of 40 m
   b. Stack exit diameter of 1.5 m
   c. Stack exit air temperature of 106 ^{o}C

Therefore, the pollutant emissions from the stacks and from the volume sources of the cement plant building modeled are as follows:

(I) SO_2 modeling input: the sulfur content of the tow fuel types is available as well as the amount of each fuel to be burnt every day. Therefore, the concentration of SO_2 at the stack exit could be calculated and used in the model.
   a. In case of fuel oil, it is found that the predicted SO_2 concentration at the stack is 3802 mg/Nm^3 (Based on burning 375 tons/day of fuel oil that has 3.77 % sulfur content, Table 3) which is less than the value set by the Jordanian standard of 6500 mg/Nm^3, and hence it was used to predict the ambient air concentration for the month of September with the case where the stack exit gas temperature was 90 ^{o}C (Figures 1.1.c and 1.1.d)
   b. In case of natural gas, the sulfur content is negligible and consequently, the SO_2 ambient concentration is predicted to be negligible as well and is not significant.

(II) NO_x modeling input:
   a. In case of fuel oil, it is found that the predicted NO_x concentration at the stack exit according to EPA AP-42 is 1019.8 mg/Nm^3 (Table 3), which is less than the value set by the Jordanian standard at stationary sources of 1800 mg/Nm^3. Therefore, the value set by the Jordanian standard is the worst-case scenario and it is used for the model input.
   b. In the case of natural gas, it is found that the predicted NO_x concentration at the stack is 2243.4 mg/Nm^3 based on the EPA AP-42 (Table 3), which is higher than the value set by the Jordanian standard of 1800 mg/Nm^3, but the company shall not violate the standard regulating the emission at the source (JS 1189/2006) and it is obligated to take mitigation measures that insure the compliance with the standard. Therefore, the value set by the Jordanian standard is considered as the worst-case scenario used for the model input.

(III) CO modeling input:

In the cases of natural gas and fuel oil, it is found that

the predicted CO concentration at the stack exit is 169.5 and 161.1 mg/Nm^3, consequently, (EPA AP-42) (Table 3), and in both cases it is less than the value set by the Jordanian standard of 250 mg/Nm^3. Therefore, the value set by the standard is the worst-case scenario used for the model input.

(IV) TSP modeling input:

a. In case of the raw mill and kiln stack, it is found that the predicted TSP is 118.49 mg/Nm^3 (according to the European Emission Inventory), (Carlo Tozzi, 2006) (Table 3), which is less than the value set by the Jordanian standard of 150 mg/Nm^3. Therefore, the standard value is modeled for the two months of September and December as it is the worst-case scenario. Also, the predicted value is modeled for the month of September.
b. In case of the cooler clinker stack, it is found that the predicted TSP value is 91.11 mg/Nm^3 (Carlo Tozzi, 2006) (Table 3), and it is modeled for the month of September.
c. In case of the cement mill stack, it is found that the predicted TSP value is 56.24 mg/Nm^3 (Carlo Tozzi, 2006) (Table 3), and it is modeled for the month of September.
d. In case of the volume sources, it is found that the predicted TSP value is 4.6 g/s (Carlo Tozzi, 2006) (Table 3), and it is modeled for the month of September.

RESULTS AND DISCUSSION

The modeled air quality parameters are: SO_2, NO_x, CO and TSP for the two months of September and December. Also, the two temperatures (90 ^oC and 130 ^oC) for the stack exit gas effluent are studied for each of the two months.

Raw Mill and Kiln Stack Emission Modeling Results

The results of the air quality parameters ambient concentrations are shown graphically in Figures similar to Figures (1.1.a through 1.4.b) (shown here for the SO_2). The other figures for the rest of pollutants are not shown here, but their main findings are reported in Tables and discussed for each of the pollutants. As explained before, all of the results presented in this study (except for the case of SO_2 emission resulting from using fuel oil (Figures 1.1.c and 1.1.d) are based on the worst-case scenario which is to assume that the concentrations of all of the studied parameters at the stack exit equal the maximum limits set by the Jordanian standard (JS 1189/2006). This was simply done because the values set by the standard are higher than those predicted ones in most of the cases and because the company is obligated to comply with the standard at the stack exit. Therefore, this worst-case scenario is not particular to any type of fuel, which means that the model output presented in all of the Figures (except Figures 1.1.c and 1.1.d) is applicable to any fuel type.

The SO_2 Modeling Results

The SO_2 results are shown in Figures (1.1.a through 1.4.b). The Figures display the results by two ways; one is by using an X-Y axis using Excel spread sheet and the other one is by using contour lines using Surfer 6 software.

The maximum hourly concentrations in the ambient air at the 1.6 m above ground level calculated by the model for the SO_2 are presented in Table (4). These are compared with the maximum limits set by the Jordanian Standards (JS 1140/2006). Also, the equivalent daily and annual concentrations are calculated from their corresponding hourly values and they are presented in Table (4) as well.

The maximum hourly ambient concentrations of SO_2 range from 0.48 ppm (at a distance of 2 km) for the month of December (Figures 1.4.a and 1.4.b) to 0.8 ppm (at a distance of 750 m) for the month of September (Figures 1.1.a and 1.1.b). In all of the studied cases, the hourly and the daily ambient SO_2 concentrations exceeded the allowable limits of the Jordanian standard of 0.3 ppm and 0.14 ppm (Table 4). These high predicted concentrations are due to the fact that the maximum allowable stack exit concentrations set by the standard –

the worst case scenario- are used, and these results are also based on the assumption that no emission control devices are installed at the stack and no other mitigation measures are implemented. Therefore, the cement company shall implement the necessary mitigation measures to control SO_2 emissions.

Another fact will contribute to lower SO_2 emissions; the SO_2 gas is expected to be in contact with the calcined raw material at 800-1000 ^oC, and is expected to be absorbed by calcium oxide and other basic oxides to form calcium sulfate and calcium sulfite, therefore, only trace amounts of SO_2 will be emitted from the 93 m stack. As a result, the cement company can easily achieve a much lower SO_2 emission value than the Jordanian standard limit.

The annual ambient SO_2 concentrations range from 0.011 ppm to 0.018 ppm and all of these values are lower than the annual average set by the standard of 0.04 ppm (Table 4).

The NO_x Modeling Results

The NO_x results were plotted in figures similar to those shown in (Figure 1.1.a through 1.4.b) and are not shown here. The maximum hourly concentration calculated by the model and the estimated equivalent daily and annual concentrations in the ambient air at 1.6 m from the ground level for the NO_x are presented in Table (5) and are compared with the maximum limits set by the Jordanian Standards (JS1140/2006).

The maximum hourly ambient concentrations of NO_x range from 0.183 ppm (at a distance of 2 km) for the month of December to 0.32 ppm (at a distance of 750 m) for the month of September. The hourly ambient NO_x concentration exceeded the allowable limit of the Jordanian standard of 0.21 ppm for the month of September only. In all cases presented in Table (5), the 24-hr NO_x concentrations exceeded the value of 0.08 set by the standard. These high predicted concentrations are due to the fact that the maximum allowable stack exit concentration set by the standard were used and also these results were based on the assumption that no mitigation measures are implemented. Therefore, the cement company shall implement the mitigation measures discussed later to control NO_x emissions.

The annual ambient NO_x concentrations range from 0.004 ppm to 0.007 ppm and all of these values are lower that the annual average set by the standard of 0.05 ppm.

The CO Modeling Results

The maximum hourly concentration calculated by the model and the estimated equivalent 8-hour concentration in the ambient air at 1.6 above the ground level for CO are presented in Table (6) and are compared with the maximum limits set by the Jordanian Standards (JS 1140/2006). All of the calculated values are lower than those set by the standards.

TSP, PM_{10} and $PM_{2.5}$ Modeling Results

The largest emission source of dust is the kiln operation, which includes the feed system, the fuel firing system, the clinker burning, cooling and hauling systems. (Egyptian Environmental Affairs Agency EEAA, 2005).

Due to the complexity of evaluating the amounts of dust emission during the construction and the operation phases of cement plants, it is the usual practice to focus on the mitigation measures to reduce the negative impacts of dust emissions. The mitigation measures should ensure the compliance with the standards (World Business Council for Sustainable Development, 2005).

The cumulative ambient concentrations of the particulate matter were modeled and calculated at different distances from the cement plant. In the case of dust, the background concentrations as well as the area sources (not included in Table 1) are significant in contrary to the other air pollutants. Therefore, the measurements obtained during the 5 days monitoring period and the dust emissions from the area sources are presented and added to dust emissions from the plant. Tables (7 through 9) show the ambient cumulative dust concentrations from all sources. The background concentrations were determined on a 24-hour basis by measuring the PM_{10} during the 5 days interval (March 2nd through March 6th / 2008). The maximum measured concentration during the 5 days period was used in the

calculations. It is shown that the ambient concentrations beyond a distance of about 300 meters from the cement plant are in compliance with the Jordanian Standard (JS 1140/2006).

For distances less than 300 m near the vicinity of the plant, the cement company shall implement the recommended mitigation measures to control the emissions of dust components.

MITIGATION MEASURES

The control of dust resulting from hauling materials can be a difficult challenge and can be even a greater cause of air quality degradation than mill and kiln exhausts. However, the control and minimization of fugitive dust from cement plant operations require high cost technological solutions. Well-planned management of activities (e.g. in the methods of loading and material transfer) can reduce the generation of dust significantly and with relatively little additional cost. Options for controlling dust from other operations include: the use of covered or enclosed conveyers, crushers, material transfer points and storage areas; installation of dust collectors and/or bag filters where needed; paved roads; vacuum sweepers for plant roads; sprinklers for plant roads and storage piles; latex stabilizing sprays for storage piles; and site landscaping and vegetation (World Business Council for Sustainable Development, 2005).

If natural gas is used as the energy supply, then the flue gas sulfur dioxide will be undetectable as sulfur is very low and almost undetectable in natural gas fuel. The carbon monoxide concentration in the exhaust gas is expected to be low as natural gas undergoes almost complete combustion in the calciner.

The control of NO_x could be achieved using low NO_x emitting burners, by firing limestone under reducing atmosphere, and by recycling of kiln fuel gases for use in the pre-heaters and pre-calcinators (Obajana Cement PLC, 2005).

To minimize CO_2 emissions; an important greenhouse gas not studied here, from cement plants, three ways for improvement have been identified: (1) increased energy efficiency in order to consume less energy, (2) using alternative fuels (e.g. biomass) to replace conventional fuels, and (3) greater use of cementious additions such as slag and fly ash (World Business Council for Sustainable Development, 2005).

CONCLUSIONS

As the demand for cement increases in Jordan to meet the development requirements, the number of planned cement plants to be constructed in the near future has increased. Even though cement manufacturing industry has many advantages such as providing the local society with job opportunities and contributing to the enhancement of the economical development, it has some negative impacts on humans and on the environment if not managed in the suitable way. This paper presents a case study of a cement plant planned to be constructed at Wadi Alabyad located about 100 km south of the city of Amman, Jordan. The focus of the paper is on the assessment of the air pollutants from the factory. The Gaussian air pollution model is used to predict the ambient concentrations of air pollutants including dust, SO_2, NO_x and CO. The predicted values are compared with the Jordanian air quality standard (JS 1140/2006) and in the case of violations, mitigation measures are recommended to minimize the negative impacts of the air pollutants emitted from the cement plant being studied.

ACKNOWLEDGMENT

The authors are thankful to Dr. Abd-Alaziz Wishah from Shamil Engineering, Amman, Jordan, for providing the data and the opportunity to accomplish this study.

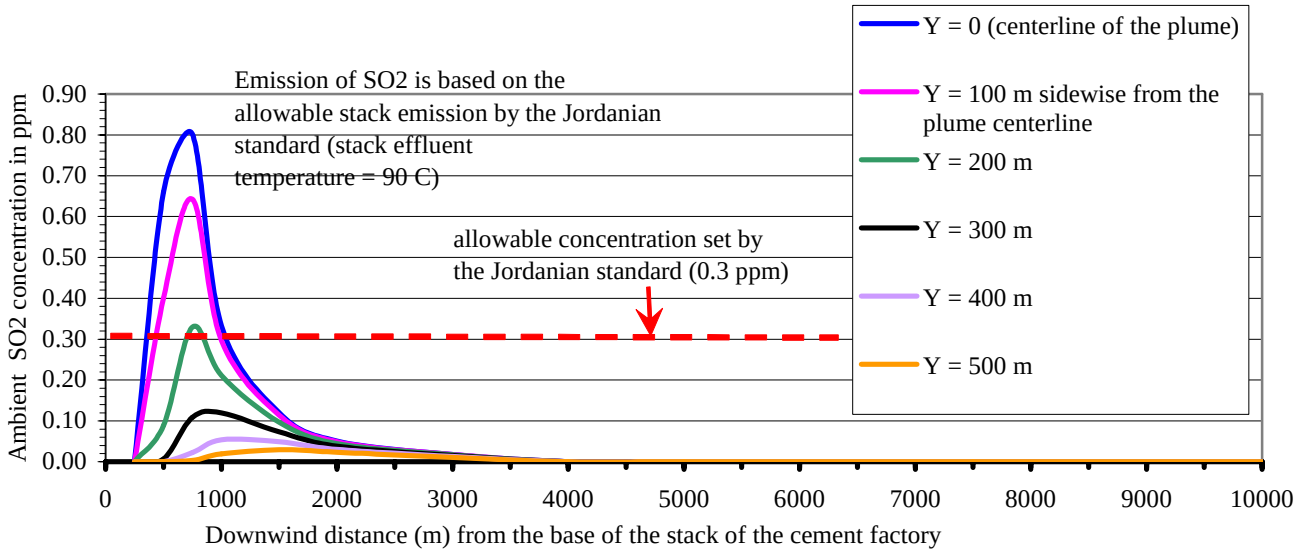

Figure (1.1.a): One hour ambient concentration of SO_2 estimated by modeling at stability class A, wind speed of 1.7 m/s in the direction of 305.8 degrees from north, during the month of September, based on the allowable stack emission by (JS 1189/2006).

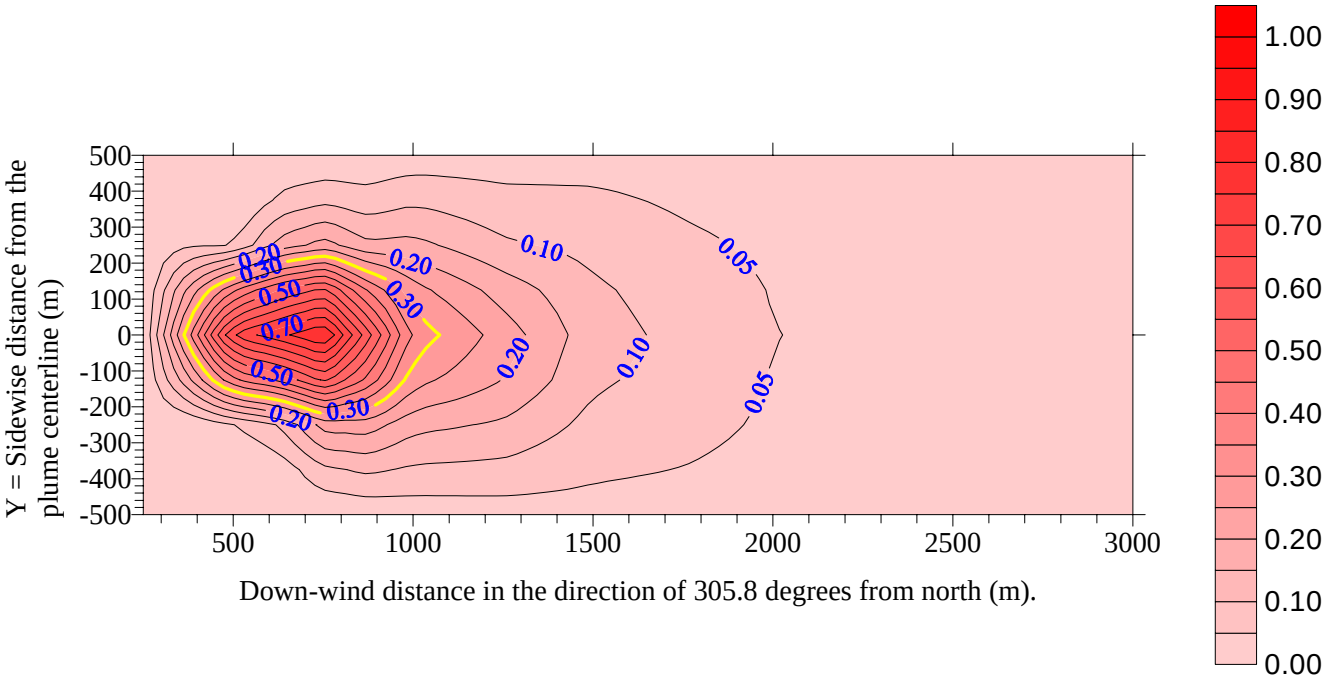

Figure (1.1.b): One-hour ambient concentration contour lines of SO_2 at stability class A, wind speed of 1.7 m/s in the direction of 305.8 degrees from north, stack exit gas temperature of 90°C during the month of September, based on the allowable stack emission by (JS 1189/2006).

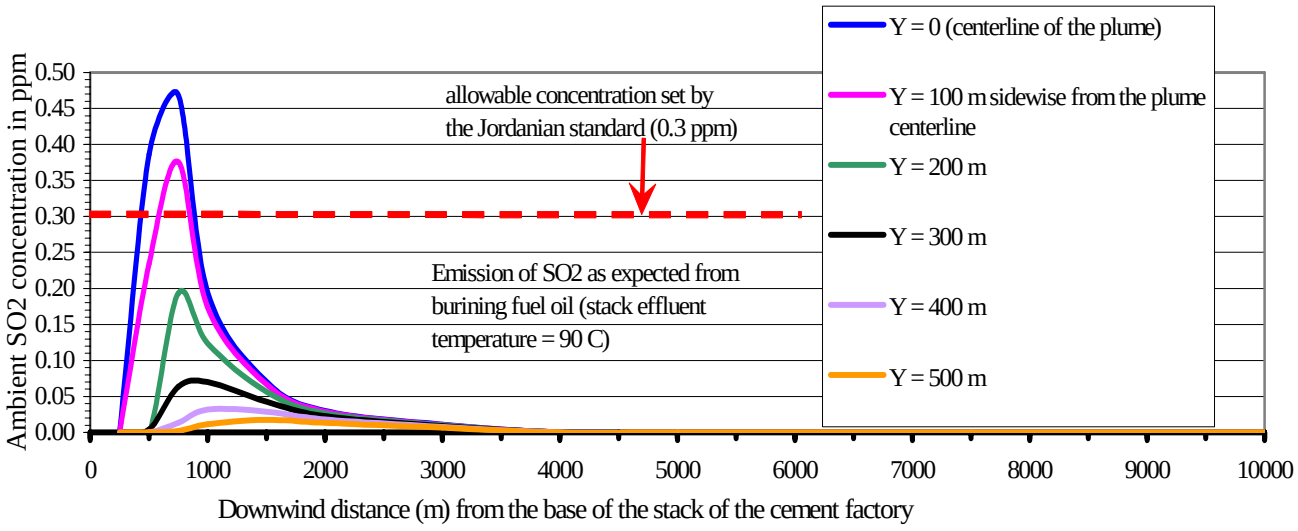

Figure (1.1.c): One hour ambient concentration of SO_2 estimated by modeling at stability class A, wind speed of 1.7 m/s in the direction of 305.8 degrees from north, during the month of September, expected from burning fuel oil.

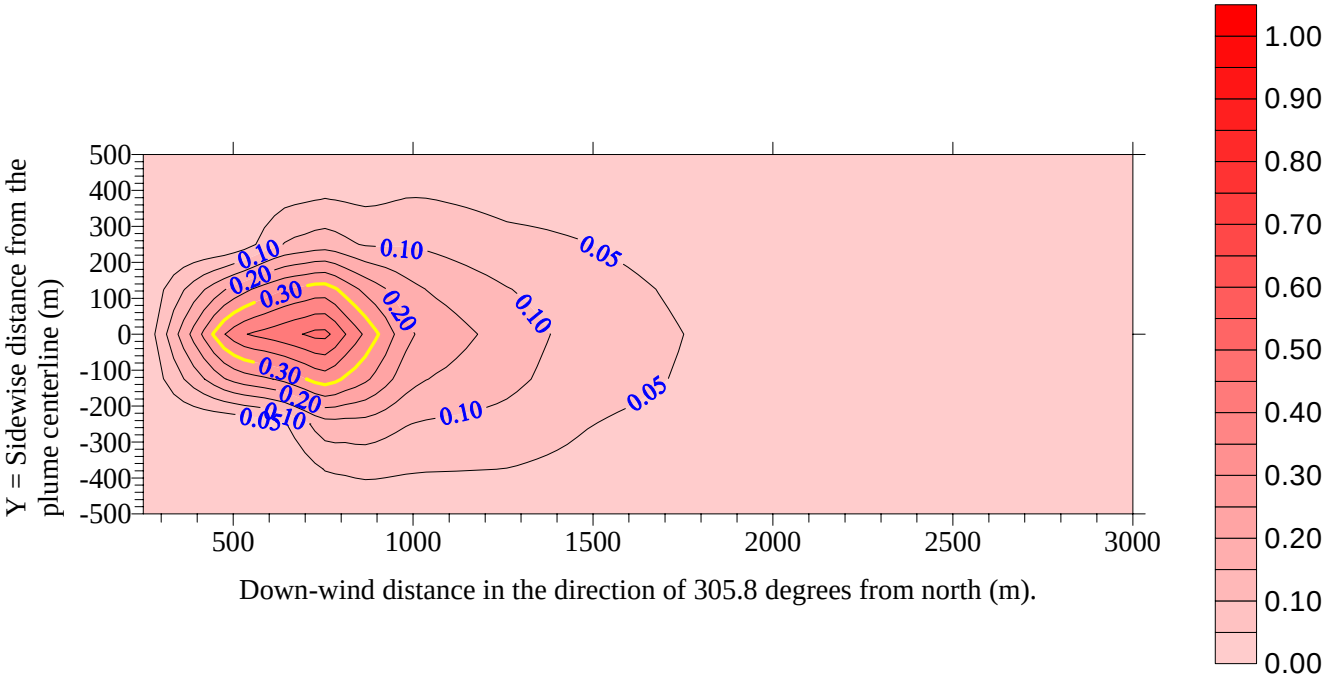

Figure (1.1.d): One-hour ambient concentration contour lines of SO_2 at stability class A, wind speed of 1.7 m/s in the direction of 305.8 degrees from north, stack exit gas temperature of 90°C during the month of September (emission from burning fuel oil).

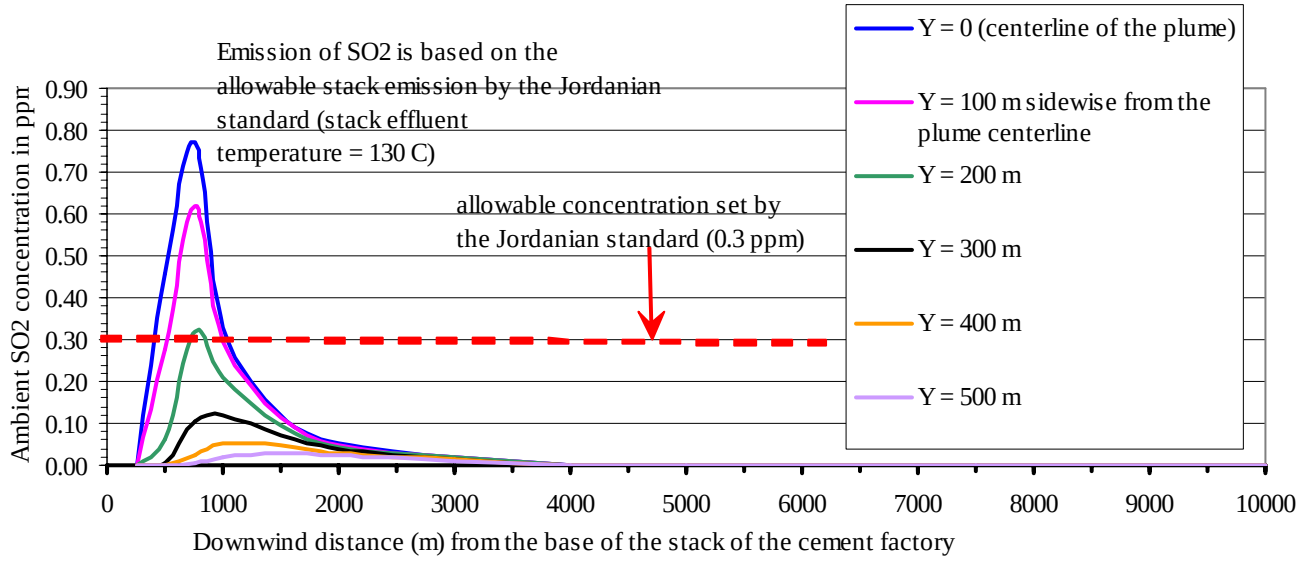

Figure (1.2.a): One hour ambient concentration of SO_2 estimated by modeling at stability class A, wind speed of 1.7 m/s in the direction of 305.8 degrees from north, stack exit gas temperature of 130°C, during the month of September.

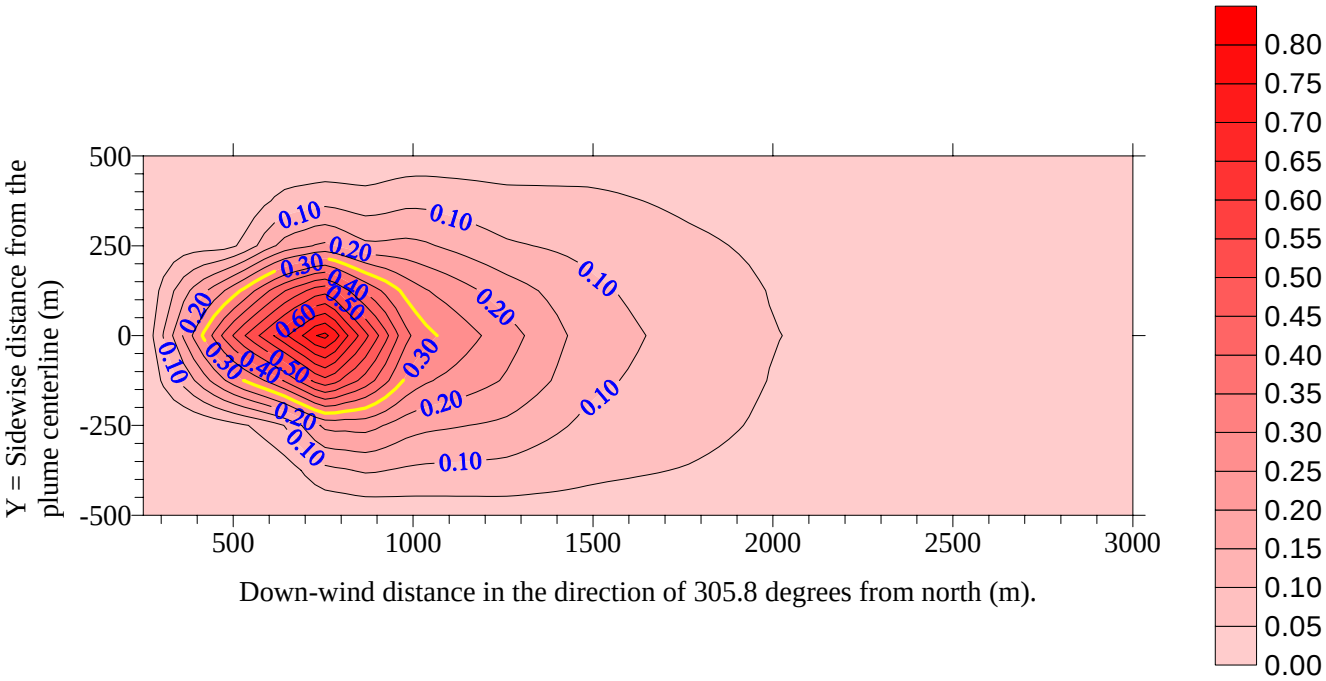

Figure (1.2.b): One-hour ambient concentration contour lines of SO_2 at stability class A, wind speed of 1.7 m/s in the direction of 305.8 degrees from north, stack exit gas temperature of 130°C, during the month of September.

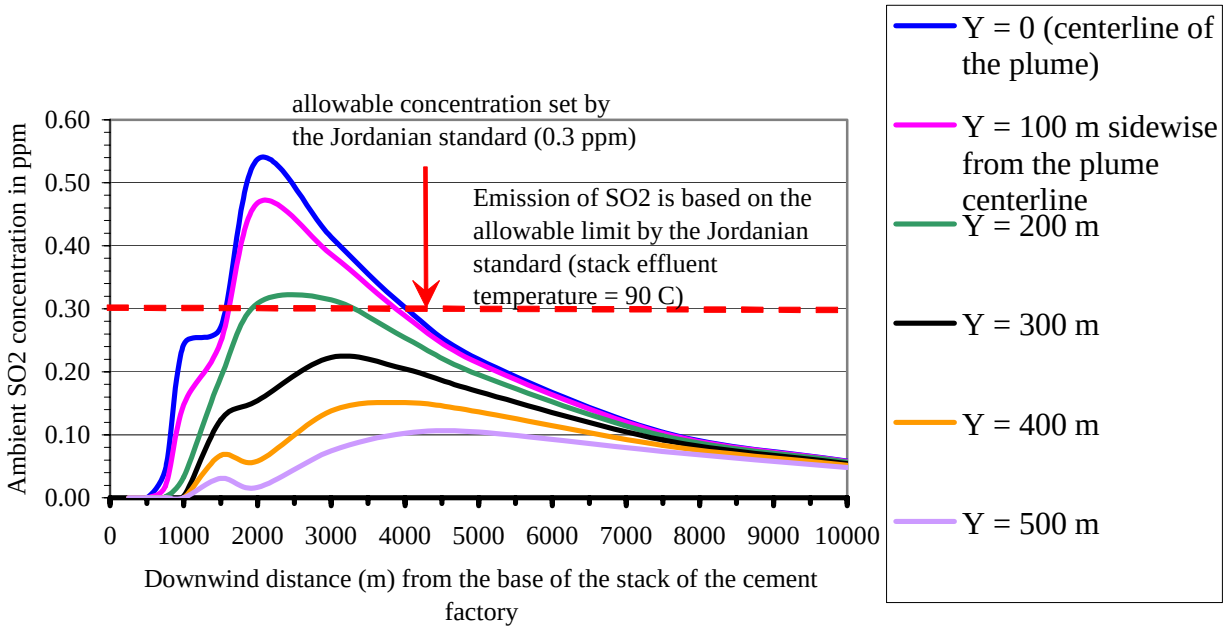

Figure (1.3.a): One hour ambient concentration of SO_2 estimated by modeling at stability class C, wind speed of 2.34 m/s in the direction of 194.1 degrees from north, stack exit gas temperature of 90°C, during the month of December.

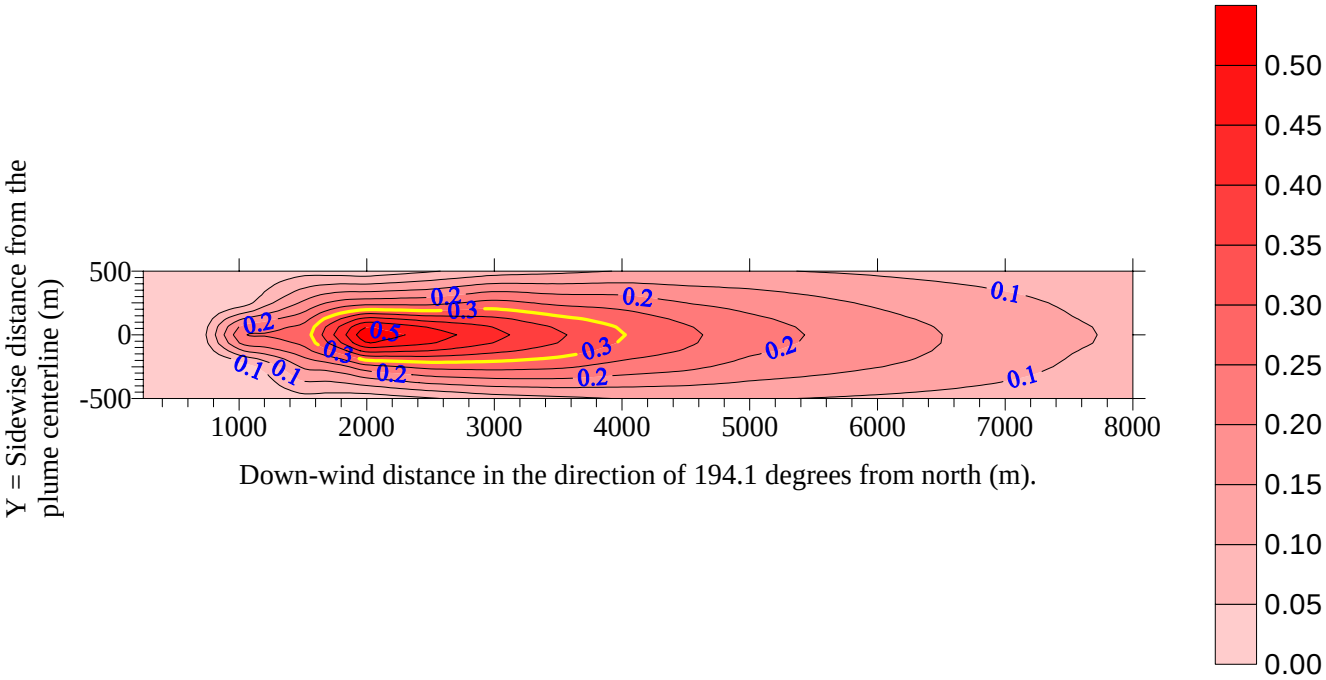

Figure (1.3.b): One-hour ambient concentration contour lines of SO_2 at stability class C, wind speed of 2.34 m/s in the direction of 194.1 degrees from north, stack exit gas temperature of 90°C, during the month of December.

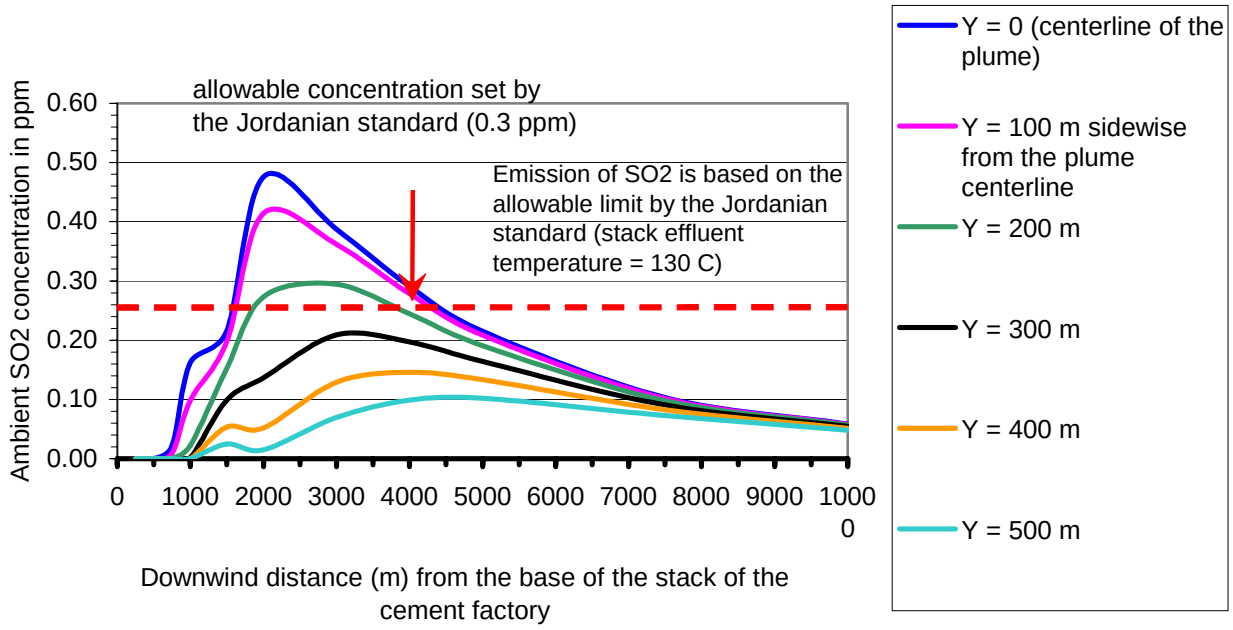

Figure (1.4.a): One hour ambient concentration of SO_2 estimated by modeling at stability class C, wind speed of 2.34 m/s in the direction of 194.1 degrees from north, stack exit gas temperature of 130°C, during the month of December.

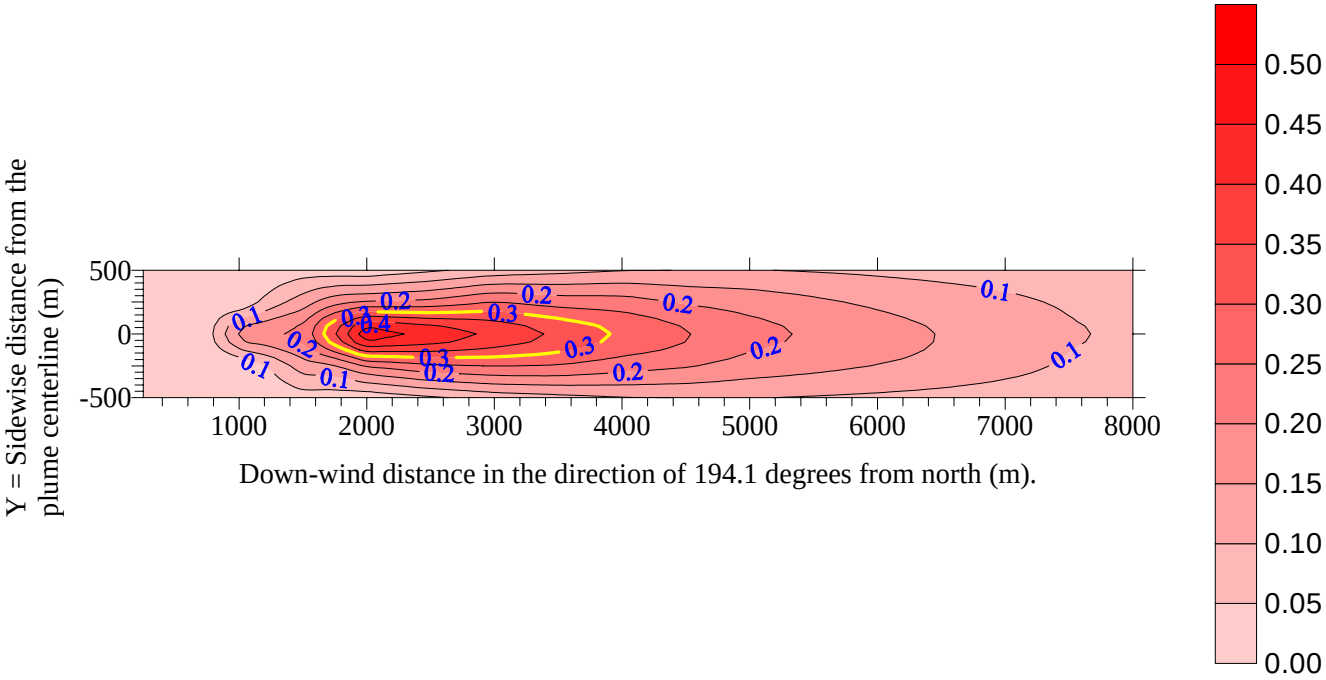

Figure (1.4.b): One-hour ambient concentration contour lines of SO_2 at stability class C, wind speed of 2.34 m/s in the direction of 194.1 degrees from north, stack exit gas temperature of 130°C, during the month of December.

REFERENCES

Branquinho, C., Giao-Oliveira, G., Auguto, S., Pinho, P., Maguas, C. and Correia, O. 2208. Biomonitoring special and temporal impact of atmospheric dust from a cement industry, *Environmental Pollution*, 151: 292-299.

Carlo Tozzi. 2006. European emission inventory guidebook B3311, Processes with Contact Activities, Cement 030311 and 040612, Roma, Italy.

Egyptian Environmental Affairs Agency EEAA. 2005. Environmental impact assessment guidelines for cement manufacturing plants, Ministry of State for Environmental Affairs.

EPA, US Office of Air Quality Planning and Standards. 1985. Compilation of air pollutant emission factors, Volume I: Stationary Point and Area Sources, 4th edition, AP-42, Research Triangle Park, NC 27711.

Hendriks, C. A., Worrell, E., Jager, D., Blok, K. and Riemer, Pierce. 1998. Emission reduction of greenhouse gases from the cement industry, Presented at the 4th International Conference on Greenhouse Gas Control Technologies, Interlaken, 30 August to 2 September.

Hindy, K. T., Abdel Shafy, H. T. and Farag, S. A. 1990. The role of the cement industry in the contamination of air, water, soil and plant with vanadium in Cairo, *Environmental Pollution*, 66: 195-205.

Hirano, T., Kiyota, M. and Aiga, I. 1995. Physical effects of dust on leaf physiology of cucumber and kidney bean plants, *Environmental Pollution*, 89: 255-261.

Ian Marlowe and David Mansfield. 2002. Toward a sustainable cement industry, environment, health and safety performance improvement, World Business Council for Sustainable Development, Substudy 10.

Kampa, M. and Castanas, E. 2008. Human health effects of air pollution, *Environmental Pollution*, 151: 362-367.

Nghi Son Cement Corporation Project. 1996. Summary environmental impact assessment in the Socialist Republic of Vietnam.

Noel de Nevers. 2000. Air pollution control engineering. Second Edition. McGraw Hill, International Edition.

Obajana Cement PLC. 2005. Executive summary, social and environmental impact assessment, subsidiary of Dangote Industrial, Limited.

Pacific Northwest National Laboratory, USA. 2003. Greenhouse gas emission inventory in Ukraine's cement sector, Advanced International Studies Unit, Kiev.

Royal Scientific Society. 2006. Environmental impact assessment- MCMC project, Amman, Jordan.

Pregger T. and Friedrich, R. 2009. Effective pollutant emission heights for atmospheric transport modeling based on real-world information, *Environmental Pollution*, 157: 552-560

SENES Consultants Limited and Al-Shamil Engineering. (June 2003). Technical support documents, environmental impact assessment for the proposed use of petcoke at Jordan cement plants.

Shukla, J., Pandey, V., Singh, S. N., Yunus, M., Singh, N. and Ahmad, K.J. 1990. Effect of cement dust on the growth and yield of *brassica campestris* L., *Environmental Pollution*, 66: 81-88.

World Business Council for Sustainable Development. 2005. Cement sustainability initiative (CSI), Environmental and social impact assessment (ESIA) Guidelines, Version 1.0.