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Research Article

GLC Prediction of Dioxin-Furan and Metals Emissions from a Hazardous Waste Incineration Plant

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Abstract
Spatial prediction and evaluation of pollutants emissions from incineration plant can be assessed by using air dispersion models. This study was to evaluate the impact of emission of selected pollutants generated by an incineration plant in Malaysia. The SCREEN3 dispersion model was used to simulate the ground level concentration (GLC) of heavy metals and dioxin-furan emitted from the incinerator up to within 5 km surrounding it. The model was run based on its actual and maximum allowable emission rates. None of the predicted maximum GLCs of the pollutants based on the actual emission rates as well as based on emission limits imposed on the incineration plant exceed more that 1% of their respective limits. The effect of gas exit temperature (80°C and 160°C) was also analyzed in predicting the pollutants GLC. Results showed that the maximum GLC of pollutants fall within 600 m and 800 m from the stack under lower and higher gas exit temperature, respectively, while pollutant concentration decreases with the distance and higher exit stack gas temperature reduces the predicted GLCs of pollutants. The predicted maximum GLC for metal pollutants at exit gas temperature of 160°C was 75% of that observed at 80°C. While for dioxin-furan, this was much more i.e 10% of the 80°C. Comparing the predicted GLC level with the recommended ambient air quality guidelines, the incinerator does not seem to contribute a significant air pollution problem in the area.
Keywords: Pollution dispersion, Incinerator, Heavy metals, Dioxin Furan.

Introduction

There are different methods for the disposal of industrial wastes; an incineration is one of the available options. Although this method of treatment reduces the volume of solid wastes significantly and possibly with thermal energy recovery, it is susceptible to emit toxic emissions (Yaghmaeian et al., 2014; Chang et al., 2000). Among different emissions caused by incineration, heavy metals are of most concern in air pollution matters (NRC, 2000). The identification of heavy metals levels emanated from incinerators have been investigated in several studies (Kuo et al., 2008; Begoña Zubero et al., 2010; Javied et al., 2008). The high levels of exposure due to heavy metals emissions such as Pb, Cd, As and Hg from this process

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is important due to their negative health and environmental effects (Natusch, 1974; Hlavay et al., 1992).

The World Health Organization (WHO) International Agency for Research on Cancer has considered the carcinogenic effects of As, Cr and Cd (IARC, 1990; IARC, 1993; IARC, 2012) and the neurotoxicity effects of Pb and Hg. In addition, dioxins and furans are released into the atmosphere from combustion processes, which belong to the most hazardous environmental contaminants and again can cause serious public health problems (Schuhmacher and Domingo, 2006). Coudon et al. (2019) presented that up to 2005, Incineration was the leading source of pollution, due to the emission of dibenzo-p-dioxins and dibenzofurans in France, while Barjoan et al. (2020) evaluated the cancer incidence in the vicinity of a waste incineration plant in the Nice area, France between 2005 and 2014. The measurement and deposition of dioxins and furans from the industries i.e a power plant and a steel mill plant have been presented by some studies. The studies concentrated on the negative health effects of dioxins and furans posed by the industries (Schuhmacher and Domingo, 2006; Onofrio et al., 2014). Drooge et al. (2021) in the study of the qualitative and quantitative changes evaluation of PCDD/Fs in traffic and waste incineration in urban air and soils demonstrated the necessity of decreasing the concentration of PCDD/Fs and their toxicity.

Thus, regulations imposed on industrial emissions are necessary in human and environmental health protection. Dispersion models are used to determine air pollutant exposure and are mainly used for estimating air pollution levels in the outside areas. The spatially distributed outdoor pollutants concentration is presented through dispersion models. Fortunately, air dispersion models are available to assess and evaluate the impact of these industrial sources into the surrounding environment. The receptor models are mostly applied in the cases where their first assessment has been previously done using a dispersion model (Monticelli et al., 2021). Studies have shown that air pollution dispersion models are accurate and suitable in forecasting pollutant dispersion in managing air quality (Rao et al., 1980; Sharma et al., 2004; Lin et al., 2021).

Some pollutants are emitted in small quantities, however, the modeling of their dispersion helps to verify if their concentrations exceed the threshold limit, especially in the surrounding residential area. The highest pollutants concentrations are found at a location of less than 10 km and mostly less than 5 km from the plants in different directions (Abdul-Wahab and Alsubhi, 2019). Abdul-Wahab and Alsubhi modeled hydrogen fluoride pollution from an aluminum smelter located in Oman and indicated that the concentrations were well below the allowable concentrations, in the distance of less than 10 km in the north-south and less than 5 km in the east-west direction (Abdul-Wahab and Alsubhi, 2019). Wang et al. (2022) analyzed the concentration distribution of fine particulate matter produced by in-situ burning of spilled oil in the northwest Arctic area of Canada using a steady-state Gaussian plume model. They showed that the dispersion pattern is affected by the spatial and temporal distribution of emission sources. They presented that there is few health risks to technical staff adjacent to the burning areas when they are more than 20 km away from the nearest community.

Lin et al. (2020) evaluated temporal variations and environmental impacts of PCDD/Fs in soils in the vicinity of a hazardous waste incinerator in China. They showed generally limited impact on soils within 7.5 km from the incinerator. Although they indicated relatively minor impacts of the incinerator on surrounding soils and major roles of other sources including open burning, traffic, and cement plant for PCDD/Fs accumulation, it is necessary to recognize the noticeable impact on area downwind from the stack in short distance (e.g., within 0.5 km).

Patel and Kumar compared between SCREEN and ISC dispersion models for mercury releases and concluded that ISC model predicts emission dispersion was better. However, authors found that SCREEN presented a more conservative result when considering the worst case scenario (Patel and Kumar, 1998). Mehdizadeh and Rifai evaluated the effects of industrial

plume travelling at high altitudes for four power plants using SCREEN and ISC dispersion models and found that the predicted concentrations from SCREEN3 corresponded better with observed values over long distances. But, the model over predicted the ground level pollutants concentrations within few distances from the stack suggesting that SCREEN presented a more conservative prediction (Mehdizadeh and Rifai, 2004). Taha et al., estimated the depletion of measured passive and active bio-aerosols release during green waste composting by use of SCREEN model and found that there was a reduction in background concentration within 10 m of this site (Taha et al., 2006).

This paper presents a study to evaluate the impact if any of an incineration plant on the Ground Level Concentration (GLC) of selected pollutants. The SCREEN3 dispersion model was used to simulate the emission of heavy metals i.e As, Cd, Pb and Hg, and dioxin-furan emissions based on both the actual and standard emission rates conditions. In addition, the effect of gas exit temperature and velocity were investigated in the modeling exercise.

Material and Methods

Description of the Incineration Plant

The incineration as a waste treatment process is used for dealing with toxic-hazardous and medical waste in the most environmentally friendly way. The ability to treat a wide variety of wastes, lower down time, operation and maintenance cost are the principles of designing and building on an incineration plant. Different equipments such as a unit of fabric filter along with lime and activated carbon injection as the flue gas cleaning agent and a wet scrubber system are applied in the design of the incinerator. The feeding system, combustion, heat reduction and recovery, and the air pollution control system i.e dry and wet system are the four main sections of the incineration plant (Figure 1). The nominal capacity of the incineration plant is 120 tons per day.

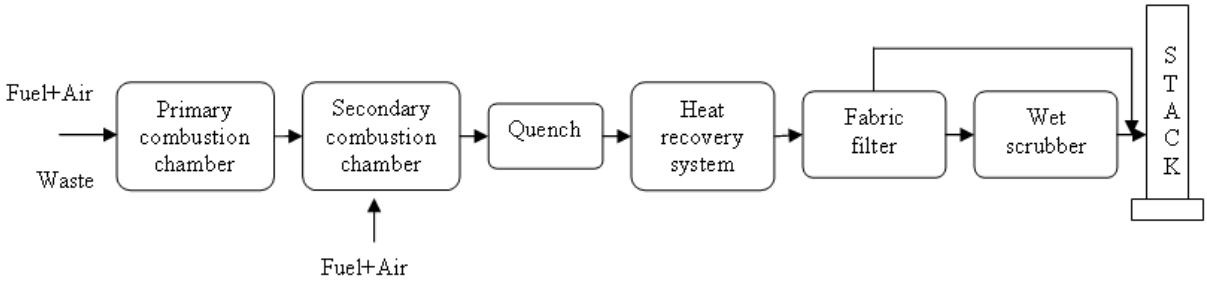

Figure 1. The schematic process flow diagram of the incinerator plant

The Emission Concentration

The emission concentration limits of selected pollutants imposed by the Department of Environment (DOE) on the incineration plant are presented in Table 1. The emission concentration limits were later used as the source input in the dispersion modeling exercise.

Table 1. Emission concentration limits imposed on the incineration plant

Pollutant	Limits, mg/Nm^3@corrected to 11% Oxygen
As	0.5
Cd	0.2
Pb	1.4
Hg	0.2
Dioxin-Furan (DF), ng/Nm3	0.1

The average concentration, standard deviation and range of pollutant concentration emissions from the plant, sampled for three consecutive years 2014 to 2016 are presented in Table 2. This study considered the selected pollutants concentrations including As, Cd, Pb, Hg and dioxin-Furan. On average, the concentration of As, Cd, Pb, Hg, and DF was 1%, 2%, 3%, 7% and 9% of their respective limits, respectively. However, any impact of these pollutants in the surrounding area was assessed and reported in the study.

Table 2. Emission concentration of pollutant measured on the incineration plant sampled from 2014-2016

Pollutants	Mean	Std Deviation	Min	Max
As	0.00392	0.00530	0.00138	0.00922
Cd	0.00391	0.00529	0.00138	0.00920
Pb	0.03667	0.00403	0.00361	0.07694
Hg	0.01368	0.01580	0.00212	0.02948
Dioxin-Furan (DF), ng/Nm^3	0.00883	0.00255	0.00628	0.01139

Note: Concentration is in mg/Nm^3 corrected to 11% O2 or otherwise stated.

Atmospheric Dispersion Modelling

Air dispersion models are widely used in air pollution study to assess and evaluate the probable impact from industrial sources. SCREEN3 model (USEPA, 1995) developed by the US Environmental Protection Agency (EPA), is a dispersion model used for estimating ground level ambient air pollution concentrations from a point source emission. The model can predict the pollution concentration of industrial sources up to 50 km for regulatory purposes.

In this study the SCREEN3 model was initialized to predict the air quality surrounding the incineration plant. The source parameters used as input in SCREEN3 model were as the followings:

- Stack inside diameter: 1.3 m
- Release height or stack height: 60 m
- Gas exit velocity: 15.3 m/s with Gas exit temperature: 80°C
- Gas exit velocity: 18.5 m/s with Gas exit temperature: 160°C.

The terrain surrounding the plant is flat, rural, and with no buildings or major emitters within 10 km distances. The most occurring atmospheric stability class in the study area is stability class A and the average wind speed was set as 1 m/s, a typical average wind speed found in many parts of peninsula Malaysia.

Results and discussion

The Predicted Maximum Ground Level Concentration

Figure 2 presents the typical concentration profile of predicted GLC of heavy metals emission from the incineration plant, where all pollutants exhibited a similar concentration pattern with downwind distance. The ground level concentration of different pollutants was predicted up to 5 km around the incinerator. The ground level concentration of pollutant was found to be significantly low further away from this distance. The results showed that the ground level concentration of the pollutants were significantly lower than the recommended ambient air quality concentration (as presented in the last column of Table 3). Seangkiatiyuth et al. (2011) evaluated the dispersion of NO2 from a cement complex in Thailand and presented less GLC of NO2 at distances of more than 5 km from the cement complex. Ma et al. (2013) investigated the ability of dispersion modeling in air quality simulation over an industrial area in Xuanwei,

China in the near future. They demonstrated the acceptable results of dispersion modeling while the maximum concentration of pollutants was predicted in the middle of simulation area around the emission sources. Wang et al. (2022) presented that there is few health risks to technical staff adjacent to the burning areas of an incinerator when they are more than 20 km away from the nearest community.

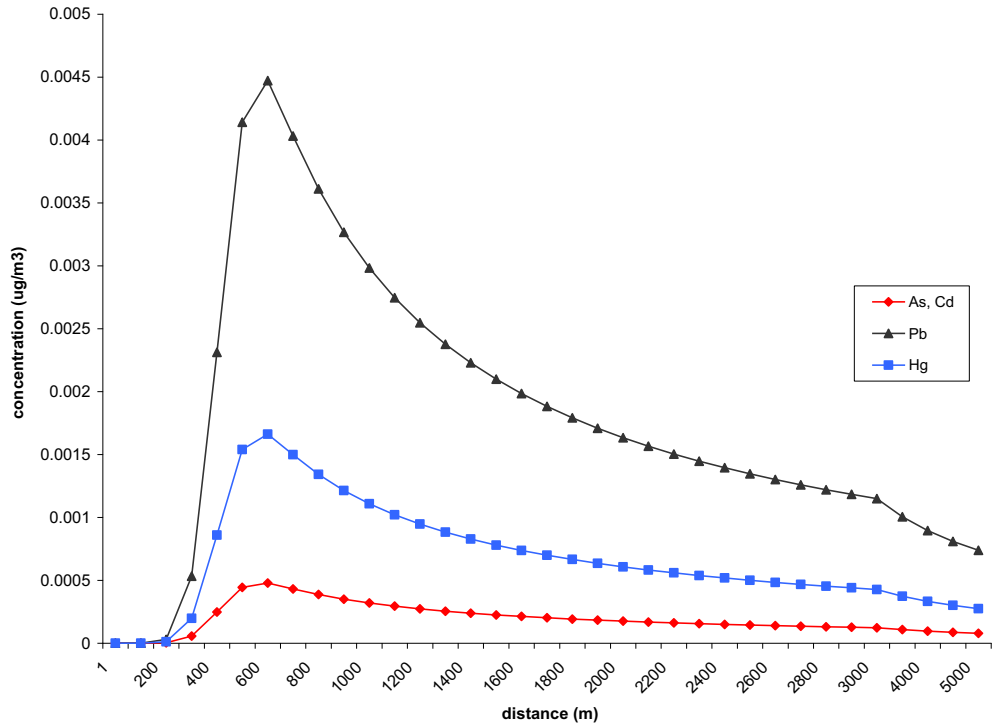

Figure 2. Concentration profile of predicted GLC of heavy metals near the incinerator based on actual emission rate

Table 3 presents the predicted maximum GLC of pollutants concentration based on the actual emission rates for different exit gas temperatures (i.e 80°C and 160°C), compared to the recommended ambient air quality guidelines established by the DOE or elsewhere in the world, According to Table 3 the contribution from the plant was significantly low with respect to the recommended ambient limits. None of the predicted maximum GLCs of the pollutants exceed more that 1% of their respective limits in both cases for different exit gas temperatures. Bhaskar et al. (2008) studied the measurement and modeling of PM10 and lead over Madurai, India. They manifested that the concentration of pollutants does not exceed the Indian air quality standards and were found in the similar concentration of most other Indian urban areas.

As expected, the predicted maximum GLC of pollutants decreases, whenever the gas exit temperature increases. A higher exit gas temperature presents a higher exit gas volume and thus, increases the exit gas velocity of a given source, where everything else (i.e physical stack height and diameter) remains constant, as in this modeling exercise. As shown in Table 3, the predicted maximum GLC for metal pollutants at exit gas temperature of 160°C was 75% of that observed at 80°C. While for dioxin-furan, this was much more i.e 10% of the 80°C. Thus, the strategy of increasing the exit stack gas temperature to reduce the pollutant GLC around the plant is not necessary as the GLCs for all the pollutants were significantly low even at 80°C. Thus, the plant operator does not need to consider any additional 'buoyancy effect' on the plume to further reduce the pollutants GLCs as the predicted concentrations are significantly low in both cases of the exit gas temperatures.

It is noteworthy to note that the pollutants emission rates used in the prediction (i.e as model input) for the higher exit gas temperature was assumed to be the same as those observed in the lower exit stack gas temperature. In the latter case, the emission rates obtained were based on when both the dry-wet air pollution control system were in operation during the emission testing performance (as presented in Table 2). With dry-wet system in placed during plant operation, the exit stack gas temperature is 80°C due to the wet scrubber unit while in the case of a dry system (i.e only with fabric filter unit with lime and activated carbon injection system), the exit gas temperature is approximately double. Thus, actual emission rates when merely dry air pollution control system is applied should be used and tested in the modeling exercise. However, to simulate this set of condition and taking into consideration of a worst case scenario, emission rates based on the limits imposed on the plant was used instead in the modeling exercise (see Table 1) and the results based on the exit gas temperature of 160°C are presented in Table 4.

Table 3. Predicted pollutant maximum GLC based on actual emission of the incineration plant for different exit gas temperatures compared to the ambient air quality guidelines

Pollutant	Maximum GLC based on temperature 80ºC and velocity 15.3m/s	Maximum GLC based on temperature 160ºC and velocity 18.5m/s	Ratio of Maximum GLC at 160ºC /80ºC	Ambient air quality guidelines
As	0.000479 (0.15%)	0.000356 (0.11%)	0.75	0.3
Cd	0.000478 (0.02%)	0.000355 (0.017%)	0.75	2
Pb	0.004472 (0.30%)	0.003322 (0.22%)	0.75	1.5
Hg	0.001662 (0.08%)	0.001234 (0.061%)	0.75	2
DF (pg/m^3)	0. 007893 (0.15%)	0.000801 (0.016%)	0.10	5

Note: Concentration is in ug/m^3 or otherwise stated; ( ) is percent of ambient air quality guidelines.

As in Table 4 the predicted maximum GLCs based on emission limits imposed on the incineration plant for all the pollutants were still significantly low compared to the ambient air quality guidelines, representing less than 1% of the respective limits. The finding suggests that the existing air quality level surrounding the plant will not be significantly influenced by the emission from the incineration plant, even though its emission concentrations were at the maximum allowable emission limits. The prediction was performed based on the consideration that the actual pollutant emission concentration when only dry air pollution control system with exit gas temperature of 160°C was not available for the simulation. Evidently, based on the results of the simulation the impact of the emission from the incineration plant assuming maximum allowable emission limits for the dry air pollution control system in operation, do not seem to present any significant deterioration on the level of air quality surrounding the plant. In a study by Morra et al. (2009), it was demonstrated that the impact of air pollutants on human from a municipal solid waste incinerator and landfill was acceptable. Lin et al. (2020) indicated relatively minor impacts of PCDD/Fs from an incinerator on surrounding soils, however they presented that it is necessary to recognize the noticeable impact on area downwind from the stack in short distance (e.g., within 0.5 km).

Table 4. Predicted pollutant maximum GLC based on emission limits imposed on the incineration plant for exit gas temperature of 160ºC compared to the ambient air quality guidelines

Pollutant	Maximum GLC based on exit stack gas temperature of 160ºC with velocity of 18.5m/s	Ambient air quality guidelines
As	0.045395 (0.15 %)	0.3
Cd	0.018158 (0.009 %)	2
Pb	0.127106 (0.084 %)	1.5
Hg	0.018158 (0.009 %)	2
DF (pg/m3)	0.00908 (0.0018%)	5

Note: Concentration is in ug/m^3 or otherwise stated; ( ) is percent of ambient air quality guidelines.

Downwind Distance of Maximum Ground Level Concentration

Figure 3 presents the pollutant GLC concentration profile against downwind distance of a selected pollutant for different exit gas temperatures (i.e 80°C and 160°C) which showed that the distance where the maximum concentration occurred for the higher exit gas temperature was further away compared to the lower one. The effect of buoyancy and momentum terms due to the hotter plume is dominant and causes the pollutant to fall further away downwind from the incinerator. The maximum GLC for the 80°C and 160°C exit gas temperature was within 600 and 800m away, respectively. Further falling distance means that the concentration of pollutant will be diluted and resulted in lower GLC downwind. As discussed previously, the predicted maximum GLC for the 160°C plume has been reduced to 75% and 10% for metals and dioxin-furan at this distance, respectively, when compared to 80°C plume. The influence of a higher exit stack gas temperature obviously plays a considerable role in reducing the predicted GLCs of pollutant further distance away from its source. This technique is considered as an option, which can be adopted if necessary, to reduce the impact of air pollution from a source onto the surrounding area. Rafiei studied the dispersion modeling of the two stacks of cement industry. She pointed to the positive effect of options such as increasing the exhaust gas temperature to improve the emission of gaseous pollutants. She also demonstrated that the pollutants fall further away downwind from the industrial source (Rafiei 2018).

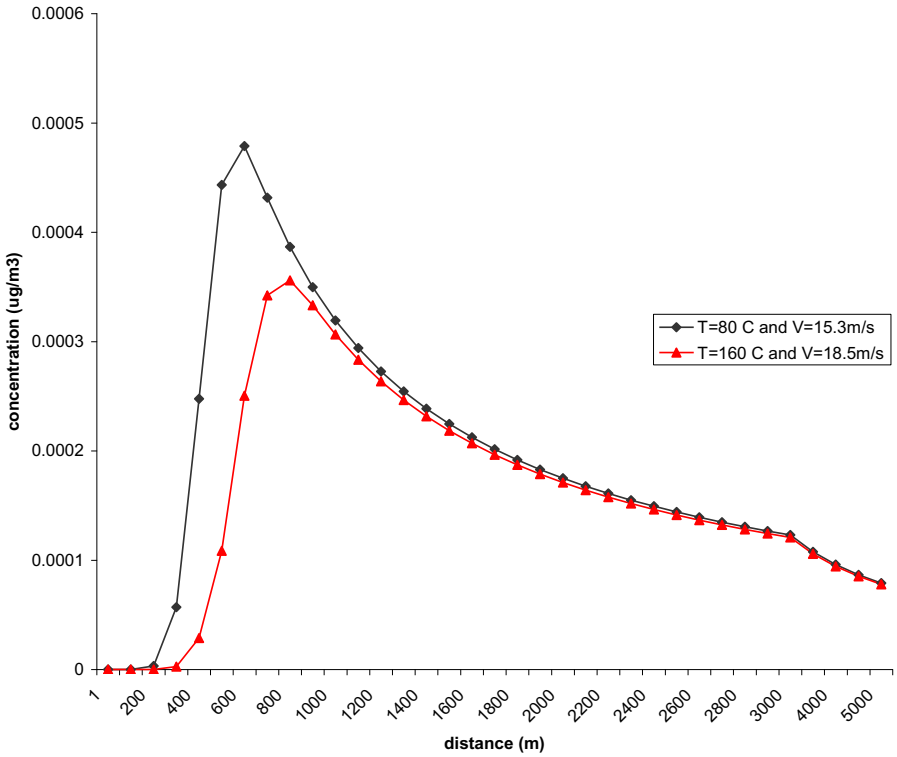

Figure 3. Predicted Pollutants GLC against downwind distance based on different gas exit temperatures

Average Cumulative Predicted Ground Level Concentration

Table 5 presents the average cumulative predicted GLC of pollutants based on actual plant emission compared to the ambient air quality onsite measurement near the incinerator and air quality guidelines which showed that the average cumulative of each of the pollutants concentration was significantly low compared to both the actual on site measurement and air quality guidelines. The results showed that none of the concentration of the modeled pollutant

was exceeding more than 1% of their respective ambient air quality guidelines. The average cumulative pollutant concentration represents the potential exposure concentration to the population at large vicinity the plant. It is based on the sum of a particular pollutant's predicted GLC at each distance up to 5 km away from the stack and averaged up accordingly to the number of points taken over that distance. Presumably, it gives a better representation of the average concentration of pollutant contributed by the incinerator spread out all over the area up to 5 km away.

Table 5. Pollutant average cumulative predicted GLC based on actual plant emission compared to ambient air quality on site measurement near the incinerator and ambient air quality guidelines

Pollutant	Average cumulative GLC based on temperature 80ºC and velocity 15.3m/s	Ambient air quality on site measurement	Ambient air quality guidelines
As	0.00019 {<1.90%}(0.063%)	<0.01	0.3
Cd	0.00019 {<1.90%}(0.009%)	<0.01	2
Pb	0.00180 {4.50%}(0.120%)	0.04	1.5
Hg	0.00067 {<6.70%}(0.033%)	<0.01	2
DF (pg/m3)	0. 00044 {10.5%}(0.088%)	0.0042	5

Note: Concentration is in ug/m3 or otherwise stated; { } is the percent of onsite measurement; ( ) is percent of ambient air quality guidelines

The existing six monitoring stations, three stations located 100m radius within the boundary of the hazardous waste complex, while another three are located within 1.5km away outside the boundary of the complex were used for gathering the onsite ambient air quality data. The data were obtained in 2015 and unfortunately, reported to two decimal places with most of the elements had been found to be not detectable i.e below the detection limits, except for Pb and DF.

As in Table 5 average cumulative of each of the pollutants concentration was not exceeding 11% of their respective onsite ambient air concentrations. A commonly found element from any incineration process is Pb which appears in the highest concentration compared to other metals found in the ambient air. However, the low concentration of Pb (as well as the low concentration of other pollutants) in the ambient air vicinity the plant in comparison with the recommended air quality guidelines demonstrates its little impact to the local environment.

Conclusion

Heavy metals are of most concern among different emissions caused by incineration plant. In addition, dioxins and furans are among the most hazardous environmental contaminants as the results of combustion processes. Although some pollutants are emitted in small quantities, they are considered dangerous. Therefore, it is essential to model their dispersion to verify if their concentrations exceed the threshold limit, especially in the surrounding area. In this study a SCREEN3 air dispersion model was used to predict the ground level concentration (GLC) of heavy metals and dioxin-furan emission from a schedule waste incineration plant. The concentration profile of predicted GLC of heavy metals emission from the incineration plant up to 5 km exhibited a similar concentration pattern with downwind distance for all pollutants.

In this study the SCREEN3 model was initialized to predict the air quality surrounding the incineration plant based on the actual emission rates for different gas exit temperatures (i.e 80°C and 160°C). The comparison of the ground level concentration of the pollutants with the recommended ambient air quality concentration showed they are well lower than their recommended ambient air quality concentration. Examining the effect of gas exit temperature also showed that the predicted maximum GLC occurred within 600 and 800 m from the stack for different stack gas exit temperatures of 80°C and 160°C, respectively, which is a distance

away from the nearest residential area at the site. The predicted maximum GLC of pollutants decreases, whenever the gas exit temperature increases, because a higher exit gas temperature presents a higher exit gas volume and thus, increases the exit gas velocity of a given source. Therefore, the strategy of increasing the exit stack gas temperature is efficient in reducing the pollutant GLC around the plant. However, in another scenario of considering a worst case, emission rates based on the limits imposed on the plant were used instead in the modeling exercise.

The predicted maximum GLCs based on emission limits imposed on the incineration plant for all the pollutants indicated that they did not exceed the ambient air quality guidelines and suggested that the existing air quality level surrounding the plant will not be significantly influenced by the emission from the incineration plant, even though its emission concentrations were at the maximum allowable emission limits. Subsequently, the average cumulative predicted GLC of pollutants based on actual plant emission was compared to the ambient air quality onsite measurement near the incinerator (six monitoring stations within the boundary of the hazardous waste complex and within 1.5km away outside the boundary of the complex) and air quality guidelines and showed that the average cumulative of each of the pollutants concentration was significantly low compared to both the actual on site measurement and air quality guidelines. However, the impact of variation in other stack characteristics such as stack height may be considered and evaluated in the future work. Besides, the study may be performed using the other dispersion modeling to compare its simulation results with the present study. Generally, the findings indicated that the predicted GLC of all pollutants were significantly low compared to the recommended ambient air quality guidelines and that the probably impact due to the emission from the incineration plant onto the environment seemed remote. However, the modeling of various pollutants dispersion from any industrial complex should be considered to verify if their concentrations exceed the threshold limit, especially in the surrounding residential areas.

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