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The Sensitivity of Harp Model on Atmospheric Boundary Mixing Heights

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Abstract

The HARP software had been created and applied as a part of the California Air Resources Board (CARB) to help the Board and industry to evaluate the health based risk assessment from a given activity. The model determines the hourly ground level pollutant concentrations based on the atmospheric dispersion models ISCST3, and simultaneously characterizes human exposure surrounding the facility. A standardized epidemiological exposure-response, and toxicological dose response functions are used to calculate the health based risk impact on the receptors. The height of the atmospheric boundary layer or known as mixing height, serves as one of the inputs in the model. This paper presents the influence of different atmospheric boundary mixing heights on the sensitivity of the HARP, modeled on dioxin-furan emission from a 500kg/hr capacity clinical waste incineration plant. Result showed the mixing height can be represented by a constant value of 500m in local context replacing Holzworth's mixing height formula as hourly estimates of mixing height with a deviation less than 5%. The influence of different mixing height on the final result to find a stable boundary layer within HARP avoids the complexity of mixing height calculation at the same time obtain a good model result and reduces the impact of mixing height influence on modeling variation.

Keywords: Risk assessment, Mixing height, Dioxin, Dispersion Modeling, Exposure-response function

0.0 Introduction

The Hotspots Analysis and Reporting Program or HARP, created by California Air Resources Board is considered the most advanced multimedia, multi receptor and multi-pathway hotspots analysis program. Among the key input for HARP includes the meteorological data to compute the transport, dispersion and removal of pollutants. Although the dispersion of pollutants depends mostly on atmospheric turbulence, turbulence measurements are not routinely performed by meteorological services. Thus, dispersion characteristics are either inferred from basic meteorological parameters such as wind, temperature and radiation using parameterization schemes or from the output of numerical model.

Globalization requires transparent and comparable assessments method to accommodate the need of standardization of legislation between different countries. One of the steps taken is the inter comparison of meteorological preprocessors embedded in some of the air quality models. The

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action can be divided into four working groups; surface energy balance, mixing layer height, vertical profiles of mean and turbulence quantities and complex terrain [1]. Thus, a report of sensitivity analysis of the HARP model to identify an adequate range of values of mixing height was investigated in this study.

0.1 Models Description

HARP is a tool that assists with the programmatic requirement of the Air Toxics "Hot Spots" Program. HARP combines the tools of emission inventory database, facility database, facility prioritization, air dispersion modeling and risk assessment analysis. All of these tools are tied to a single database allowing information to be shared and utilized. The software maybe used to assess the potential health impacts from a single or multiple facilities in proximity to each other, where a single meteorological data set is appropriate for all the included facilities.

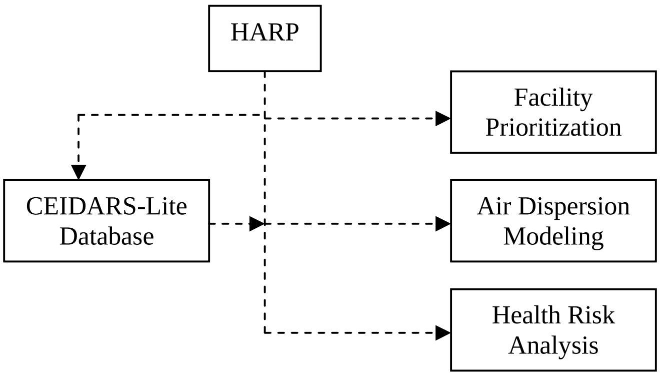

Figure 1 Organization of HARP.

The main component of HARP is the CEIDARS-Lite database from which all analysis tools are connected. The database is called CEIDARS-Lite due to its similarity to CEIDARS II, a database developed by the CARB used to track statewide pollutant emissions. Unlike CEIDARS II, the CEIDARS-Lite database includes additional tables containing data necessary for air dispersion and health risk analysis.

The Air Toxics "Hot Spots" Information and Assessment Act requires local air districts to prioritize facilities to determine which facilities must perform a health risk assessment. HARP calculates facility prioritization scores according to guidelines of Air Toxics "Hot Spots" Program, Facility Prioritization Guidelines developed by the California Air Pollution Control Officers Association (CAPCOA) [2, 3].

The third component of HARP is the air dispersion analysis tool. This feature allows easy utilization of facility and receptor data from the CEIDARS-Lite database to build the air dispersion analysis input file and perform the air dispersion analysis. The model used in the software is the ISCLT3 that is the leading air dispersion model.

The last component of HARP is the risk analysis tool. This portion of the program performs health risk analysis, which follows The Air Toxics Hot Spots Program Guidance Manual for

Preparation of Health Risk Assessments developed by OEHHA. The risk analysis tool integrates the CEIDARS-Lite database and the results of air dispersion analysis so that the risk functions can be performed within the same program. The impact and damage assessment at local scale is important because plants such as biomedical incinerators have strong public reaction around the area. A regional scale for concentration estimation and a local scale model is necessary to assess the impact of primary pollutants and the micro pollutants such as heavy metals, dioxins and furans.

2.0 Materials and Methods

2.1 Determination of the Required Atmospheric Variables at a Local Condition.

Atmospheric dispersion modeling at a regional scale requires meteorological data for every given hour of the considered year. Data usually needed in an air dispersion modeling are: Wind direction, wind speed, ambient temperature, stability class, rural or urban mixing height, wind profile exponent, and vertical potential temperature gradient.

The wind speed and direction parameters and the ambient temperature are usually measured at 10m from the ground level. The stability class, the wind profile exponent and the vertical potential temperature gradient are often not easily obtained. If field measurements are not possible, the stability class can be determined alternatively based on the Pasquil-Gifford classification [4]. The potential temperature gradient and wind profile exponent can be determined as a function of the stability class by employing some of the common correlation suggested by USEPA [5] as in Table 1.

Table 1 Vertical potential temperature gradient and wind profile exponent as a function of stability class as suggested by USEPA.

	A	B	C	D	E	F
Potential temperature gradient (K/m)	0	0	0	0	0.020	0.035
Rural wind profile exponent	0.07	0.07	0.10	0.15	0.35	0.55
Urban wind profile exponent	0.15	0.15	0.20	0.25	0.30	0.30

Practical determination of mixing height is often debatable among consultants and authorities that are involved in regulatory modeling. The height *h* of the mixing layer is a key parameter for all air pollution models. It determines the volume available for the dispersion of pollutants and is involved in many predictive and diagnostic methods or models to assess pollutant concentrations, and it is also an important parameter in atmospheric flow models. The mixing height can be determined by profile measurements and parameterization and simple models, which require input data from numerical weather prediction models. Remote sounding system data such as radiosondes, lidars, sodars and wind profiling radars offers a promising way towards the direct and continuous monitoring of the evolution of the mixing height through the complete diurnal cycle [6].

In this paper, hourly mixing height was calculated by using Holzworth equation [7] for estimation of the mixing height under convective conditions. In this method, the maximum mixing height that usually occurs in the early afternoon is obtained by drawing the dry-adiabatic lapse rate through the maximum temperature at the surface and the environmental lapse rate. The minimum mixing height normally occurs before sunrise and is obtained by adding excess temperature due to the heat island effect to minimum surface temperature. According to this approach the wind speed taken at 10m from surface is used as the main parameter. Holzworth mixing height formula can be simplified as;

$$\boldsymbol{h = 320\, u_{10}} \tag{1}$$

Sham stated that the urban mean mixing height in Malaysia was approximately 369m in the morning and 696 m at noon throughout the year [8]. The highest recorded mixing depth was at 914 m and the lowest was recorded at 379m. While it is recognized that there may be some problems of interpretation with it results to the recommendation of 500m in the morning and 1500m in the afternoon by U.S derived forecasting technique and that comparisons between tropical and mid-latitude cities may be prejudiced by the different characteristics of weather conditions and emission properties.

The sensitivity analysis is carried out in order to draw some conclusions on the influence of the mixing height on the results of the HARP model based on a local scale. Therefore, the purpose is to demonstrate if the constant value of mixing height could be utilized to assess the impact while avoiding the need for detail field measurements.

2.2 Case Study Data

Four case studies on the incineration facility were performed to test the sensitivity analysis of the HARP model. Table 2 listed the parameters for the 4 cases.

Table 2 Parameters for the 4 cases

Parameters	Case 1	Case 2	Case 3	Case 4
Flue gas temperature (K)	430 K	430 K	450 K	430 K
Stack height (m)	10 m	15 m	10 m	10 m
Stack diameter (m)	0.8 m	0.8 m	0.8 m	0.8 m
Rate (Nm^3/h)	36524	36524 Nm^3/h	36524 Nm^3/h	42475 Nm^3/h

The meteorological data used in the study was provided by the Malaysian Meteorological Services. The data include hourly values of wind direction, wind speed and ambient temperature for entire year of 2003. The hourly data of wind speed was used to estimate the atmospheric mixing height based on Holzworth's equation. The calculated minimum and maximum mixing height using the method was 421 and 2720 m, respectively. Figures 2 and 3 showed the wind speed distribution and the wind rose pattern of the study site, respectively.

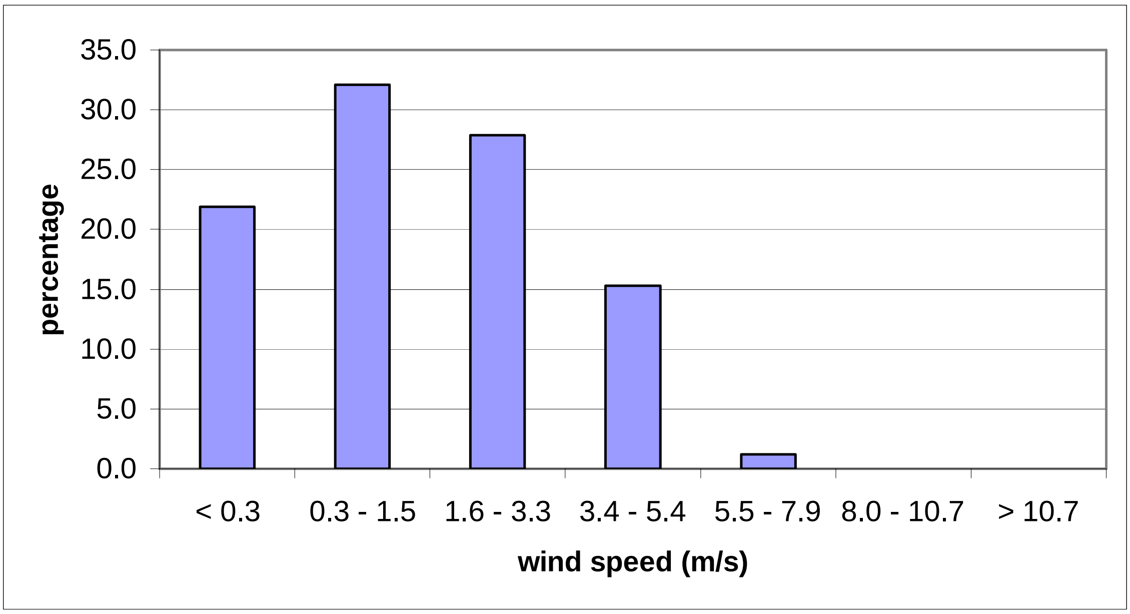

Figure 2 Wind speed distribution for the study site

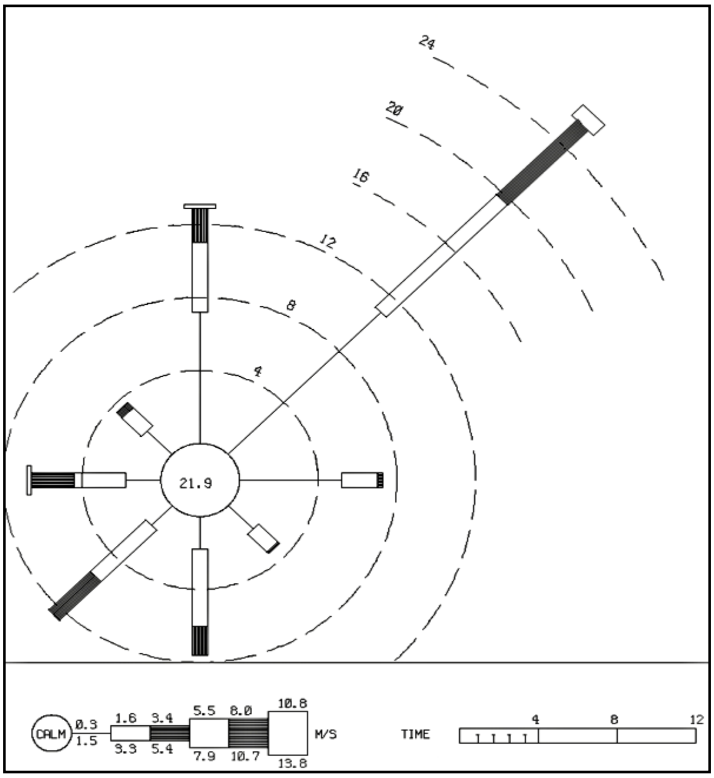

Figure 3 Wind rose for the study site

2.3 Sensitivity Analysis

A sensitivity analysis is performed in this paper in order to determine the influence of the mixing height on the results of the HARP model based on local meteorological conditions. The results were based on the four different cases mentioned earlier. The impact on human health due to dioxin-furans was selected in this paper due to the fact that it is one of the major pollutants of concern from a clinical waste incineration plant.

The study also deals with a comparison of the calculated ground concentrations in the case of estimated hourly mixing height values and in the case of constant mixing height values in particular the mean deviation of the concentrations is defined as in Equation 2:

$$D_c = \sum_{i=1}^{100} \left| C_i - c_i \right| / 100 \tag{2}$$

C_i represents the yearly mean ground concentrations at the highest concentration of the simulated grid which is calculated on the basis of the estimated hourly mixing height values. Meanwhile, c_i represents the concentrations of the highest point at constant mixing height values between 250m to 2000m with a 250m step size.

In order to perform the sensitivity analysis, method used in Brizio & Genon was applied to calculate the normalized mean ground concentration and the normalized concentration deviation at a local scale are normalized as in Equation 3 and 4 respectively [9].

$$\frac{c}{C} = \frac{\sum_{i=1}^{100} \frac{c_i}{100}}{\sum_{i=1}^{100} \frac{C_i}{100}} = \frac{\sum_{i=1}^{100} c_i}{\sum_{i=1}^{100} C_i} \tag{3}$$

$$\frac{D_c}{C} = \frac{\sum_{i=1}^{100} \frac{\left| C_i - c_i \right|}{100}}{\sum_{i=1}^{100} \frac{C_i}{100}} = \frac{\sum_{i=1}^{100} \left| C_i - c_i \right|}{\sum_{i=1}^{100} C_i} \tag{4}$$

3.0 Results and Conclusion

Nine simulations were performed for the sensitivity analysis by combining the four different cases from a single incinerator plant, so as to examine the models response to different source parameters and meteorology. Each simulation is identified by emission scenario at different mixing heights ranges between 250 and 2000m with a 250m step between each value. This way, the concentration at the ground level referring to dioxins-furans emissions were calculated by the HARP model, for every simulation, on the basis of the estimated hourly mixing height and mixing height set between 250m and 2000m.

According to Gaussian model algorithms, the calculated ground level concentration decreases as the mixing height increases because of the dilution in the mixed layers. Figure 4 shows the normalized mean ground concentration c/C versus the constant values of mixing heights in eight simulated cases. The result shows the predicted behavior with c/C increases in the beginning and slowly decreases with increase in the mixing height. This indicates there is an unstable boundary layer between 750m and 1500m. This situation can be explained considering the effective stack height, h_e, which is the sum of the stack height and the plume rise.

The study showed that varying emission stack height from 10m to 15m does not change the ratio of c/C as in Case 2 show a similar result to Case 1. However, the change in release temperature in Case 3 and volumetric flowrates in Case 4 influenced the ratio of c/C. As far as this phenomenon is concerned, it should mention that the ISCLT3 model, integrated in the HARP employs the Briggs plume rise formula. When the plume rise is buoyancy dominated, it chiefly depends on the flue gas volume and stack gas temperature of the facility [9]. Other known parameters that could affect the c/C ratio are the ambient air temperature and wind speed. Figure 5 shows that Dc/C generally reduces if the emission temperature increases while the Dc/C generally increases when the emission rate is increased.

The study suggests that the mixing height as an input parameter of the HARP model can be approximated by a constant value during the year without losing accuracy in the final result. The normalized concentration illustrates decreasing mean concentrations as a function of the mixing height (Figure 4). If one considered a constant value of mixing height approximately 500m, the normalized concentration is smaller than 5% and the deviation of concentration is almost zero.

Thus, in the case where real measurements are not available, the atmospheric stability class can be obtained by means of conventional classification such as the Pasquil-Gifford approach [4], whereas the wind profile gradient can be determined by simple correlation with the stability class. However, the mixing height estimates is based on a complex calculation procedure. In this study, the investigation on the influence of mixing heights on the result of HARP in order to avoid complexity of calculation had been presented, which indicates that the mixing height can be represented by a constant value between 500m and 750m without affecting the final results significantly.

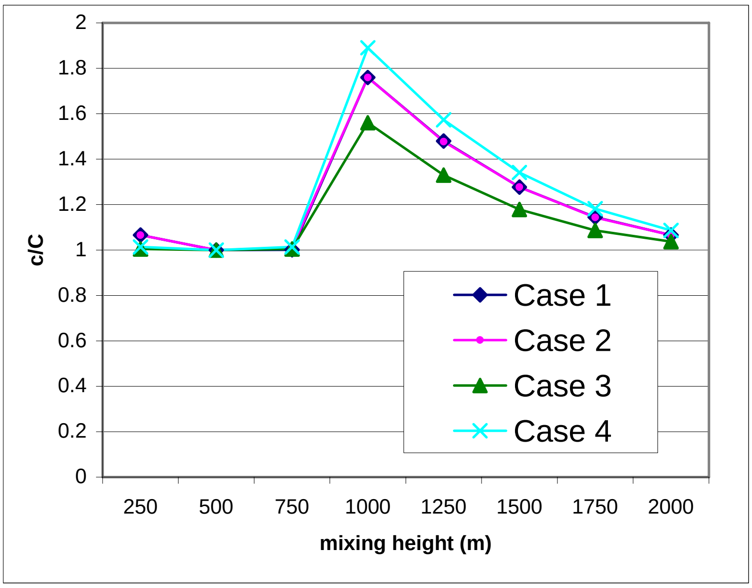

Figure 4 Normalized mean ground concentration as a function of mixing height

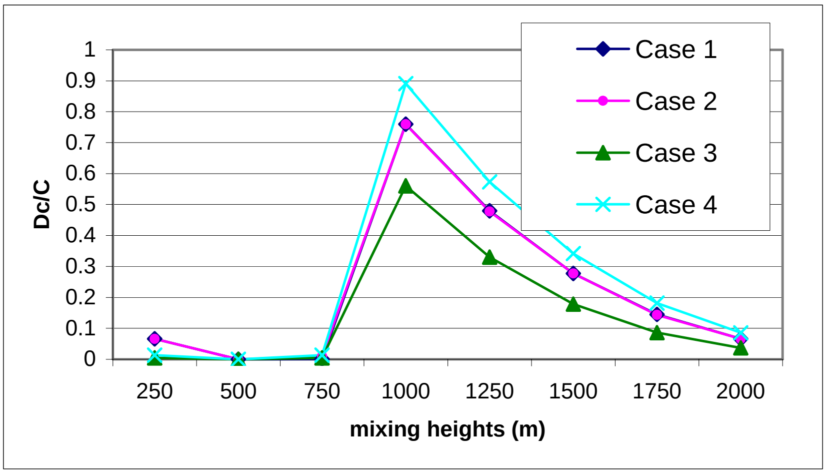

Figure 5 Normalized concentration deviation as a function of mixing height.

References

[1] Fisher, B.E.A, Erbrink, J.J., Finardi, S, Jeannet, P., Joffre, S., Morselli, M.G., Pechinger, U., Seibert, P., Thomson, D.J (1998). *COST Action 710-Final Report. Harmonization of the pre-processing of meteorological data for atmospheric dispersion models.* European Union Commission Luxembourg. EUR 18195 EN.
[2] CAPCOA. Air *Toxics "Hot Spots" Program, Facility Prioritization Guidelines*. California. July 1990.
[3] CAPCOA. *Air Resources Board's Emission Inventory Criteria and Guidelines Regulation.* California 2003.
[4] Pasquill, F. and Smith, F.B (1983). *Atmospheric Diffusion. Ellis Horwood Ltd.* Chichester.
[5] USEPA (1994b). *Draft Exposure Assessment Guidance for RCRA Hazardous Waste Combustion Facilities*. OSWER. EPA-530-R-94-021. April 22.
[6] Seibert, P., Beyrich, F., Gryning, S, Joffre, S., Ramussen, A. and Terceir, P (2000). Review and inter-comparison of operational methods for determination of the mixing height. *Atmospheric Environment.* 34:1001-1027.
[7] Holzworth, G.C (1972). *Mixing Heights, Wind Speeds and Potential for Urban Air Pollution Throughout the Contiguous United States.* Publication No. AP-101, U.S. Environmental Protection Agency, Research Triangle Park, North Carolina 27711.
[8] Sham S (1979). Mixing depth, wind speed and air pollution potential in the Kuala Lumpur – Petaling Jaya area, Malaysia. *Malayan Nature Journal* 7:2(215-222).
[9] Brizio, E. and Genon, G (2004). The influence of different mixing heights on ECOSENSE model results at a local scale. *Environmental Modeling & Software*. 20:9170933.