Study of Dispersion of HCl from Waste-To-Energy Plant at Different Receptor and Chimney Height at Taman Beringin, Kuala Lumpur

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Combustion of solid waste from waste-to-energy (WtE) plant emits a variety of air pollutants that may be hazardous to the environment and health. In order to control these hazardous air pollutants, regulation and emission limits has been established. The emission of these air pollutants can be control but not eliminated by implementing air pollution control (APC) devices. The emitted air pollutants will then be dispersed base on local weather. In Malaysia, the Malaysia Ambient Air Quality Guideline (MAAQG) is referred to ensure that the concentration of pollutants does not exceeds limit. For parameters that are not included in the MAAQS, other standard from other nation such as the Alberta's Ambient Air Quality Objectives and Guidelines (AAQOG) is referred. Ground level concentrations (GLC) are commonly reported. In a developing city where new high-rise building may be constructed in the future, it is important that the concentration of pollutants at the higher height to be reported as well. In this study, Taman Beringin, Kuala Lumpur, Malaysia is taken as a case study for studying the air pollutants concentration at different height for a 1,200 t capacity WtE plant. This study is performed using an air dispersion software preferred by the United State (US) Environmental Protection Agency (EPA) known as AERMOD atmospheric dispersion modelling system. Based on the local weather pattern of Taman Beringin and a chimney stack height of 60 m, the maximum height of a building at the location of N 3° 13' 31.61" E 101° 39' 36.59" is about 80 m.

1. Introduction

All waste-to-energy (WtE) plants need an efficient gas cleaning for compliance with the legislative air emission standards (Vehlow, 2014). Air pollutants from waste plant without proper control can cause severe environmental impact, such as acid rain phenomena, global warming, photochemical smog occurrence, damage surrounding building and structures and even health impact to surrounding residence (Gu and Yim, 2016). The rate of gas emission can be controlled and complied to the standards by implementing air pollution control (APC) devices (Dal Pozzo et al., 2016).

Typical modern APC systems comprise multiple stages for the removal of fly ashes, inorganic and organic gases, heavy metals, and dioxins from the flue gas (Vehlow, 2015). Pollutants are often removed through physical and chemical processes using separation technologies such as wet scrubber, semi-dry scrubber, and dry scrubber and selective catalyst reduction (SCR) for chemical processes and cyclones, electrostatic precipitator, fabric (bag) filter, and sand bed filter for physical processes (Gu and Yim, 2016).

These separation technologies cannot fully remove the pollutants and a small portion of the pollutants will escape from the plant as the flue gas where it will be dispersed into the environment. In a common case, to ensure that the WtE plant does not bring harm to the surrounding, the concentration of pollutants is often studied via air dispersion modelling and simulation, where the ground level concentration (GLC) is reported. The GLC should be lower that the stated limit in the Air Quality Standards such as the Malaysia Ambient Air

Quality Guideline (MAAQG), and the Alberta's Ambient Air Quality Objectives and Guideline (AAQOG). It is noted that different countries may have different standards and guidelines, and not all guidelines have the specification for all pollutants. In such cases, cross referencing is usually practiced.

In this study, Taman Beringin, Kuala Lumpur, Malaysia is taken as a case study for the study of air pollutant dispersion from a 1,200 t in capacity WtE plant. As the plant is located inside a city, there may be a lot of high-rise building built or to be built (in the future) around the WtE plant. Reporting of the GLC itself is therefore insufficient to indicate the air quality of the surrounding. Pollutant concentration is expected to be higher above ground. This study studies the concentration of hydrogen chloride (HCl) (signature pollutants of a WtE plant due to high presence of organic chloride) at height above ground level. The air dispersion modelling and simulation is done using AERMOD atmospheric dispersion modelling system, an integrated modelling system that is preferred by the United States Environmental Protection Agency (US EPA, 2009). The effect of increasing chimney height is also discussed.

2. Air Dispersion Modelling

Air dispersion modelling is the mathematical simulation of how air pollutants disperse in the ambient atmosphere. The dispersion models are used to estimate or to predict the downwind concentration of air pollutants or toxins emitted from sources such as industrial plants, vehicular traffic or accidental chemical releases. The perfect air concentration model will estimate the concentration emitted from any specified set of pollutant, at any location, at any period of time and with high confidence levels in our prediction. The models are typically employed to determine whether the ambient air is in compliance with the guideline.

Practically, it is performed using computer programs that solved the mathematical equations and algorithm which simulate the pollutants dispersion. Typically, air quality models are used to predict ground level concentrations down point of sources. The object of a model is to relate mathematically, the effects of source emissions on GLC, and to establish that permissible level is not being exceeded. The study of the dispersion of pollutants in the atmosphere from different sources depend on the concepts of physics describing the movement of pollutants in the atmosphere and the effect of the boundary layer. The heart of any atmospheric dispersion model is to estimate the concentration of pollutant by calculating from some basic information about the source of the pollutant and meteorological condition. Most model for urban air pollution are based on Gaussian plume diffusion or Sutton's equations or the K theory and require digital computer. Gaussion plume models are commonly used for the air quality analysis and regulatory purposes. Besides that, this model are widely used, well understood, and easy to apply (Essa et al., 2014)

3. AERMOD

The AERMOD atmospheric dispersion modelling system is an integrated system that is preferred under the US EPA. In this assessment, the AERMOD View modelling package by Lakes Environmental (Version 8.2.0) is used. AERMOD includes three modules:

1. A steady-state dispersion model designed for short-range (up to 50 km) dispersion of air pollutant emissions from stationary industrial sources.
2. A meteorological data pre-processor (AERMET) that accepts surface meteorological data, upper air soundings, and optionally, data from on-site instrument towers. It then calculates atmospheric parameters needed by the dispersion model, such as atmospheric turbulence characteristics, mixing heights, friction velocity, Monin-Obukov length and surface heat flux (US EPA, 2004).
3. A terrain pre-processor (AERMAP) to provide a physical relationship between terrain features and the behaviour of air pollution plumes. It generates location and height data for each receptor location. It also provides information that allows the dispersion model to simulate the effects of air flowing over hills or splitting to flow around hills.

AERMOD is a refined dispersion model for simple and complex terrain for receptors within 50 km of a modelled source. AERMOD is a steady-state plume model. In the stable boundary layer (SBL), it assumes the concentration distribution to be Gaussian in both the vertical and horizontal. In the convective boundary layer (CBL), the horizontal distribution is also assumed to be Gaussian, but the vertical distribution is described with a bi-Gaussian probability density function. In the CBL, AERMOD treats "plume lofting," whereby a portion of plume mass, released from a buoyant source, rises to and remains near the top of the boundary layer before becoming mixed into the CBL. AERMOD tracks any plume mass that penetrates into the elevated stable layer, and then allows it to re-enter the boundary layer when and if appropriate. For sources in both the CBL and the SBL, AERMOD treats the enhancement of lateral dispersion resulting from plume meander. AERMOD incorporates current concepts about flow and dispersion in complex terrain. Where appropriate the plume is modelled as either impacting and/or following the terrain, thus AERMOD removes the need for defining

complex terrain regimes. All terrain is handled in a consistent and continuous manner while considering the dividing streamline concept in stably stratified conditions.

One of the major improvements that AERMOD brings to applied dispersion modelling is its ability to characterise the PBL through both surface and mixed layer scaling. AERMOD constructs vertical profiles of required meteorological variables based on measurements and extrapolations of those measurements using similarity (scaling) relationships. Vertical profiles of wind speed, wind direction, turbulence, temperature, and temperature gradient are estimated using all available meteorological observations. AERMOD is designed to run with a minimum of observed meteorological parameters. AERMOD requires only a single surface measurement of wind speed measured at between 10 and 100 m, wind direction and ambient temperature.

Unlike existing regulatory models, AERMOD accounts for the vertical in homogeneity of the PBL in its dispersion calculations. This is accomplished by "averaging" the parameters of the actual PBL into "effective" parameters of an equivalent homogeneous PBL.

4. AERMOD Model Input and Case Study

There has been a long ongoing debate on the construction of a 1,200 t WtE plant at Taman Beringin due to concern on air pollution effecting the surrounding environment and residence's health. Recently, a 20th-storey residential flat (Projek Perumahan Rakyat Kepong) with height about 60 m was constructed at the South East region of the site (planned for WtE plant development) and about 400 m away. This rises concern that the air pollutants from the chimney may be directly blown toward the residential flat. In order to study the impact toward the residential flat, air dispersion study was performed to reveal the concentration of HCl (1 h average) above ground level for every 20 min up to 120 min using AERMOD. As the MAAQG does not indicate a specification for HCl, the AAQOG is referred where the concentration limit of HCl is 75 µg/m^3.

The summary of the input data is as below:

i) Emission Rate of HCl

The emission rate from the WtE plant are based on two scenarios, typical case where the flue gas is treated to remove air pollutants, and worst case where the flue gas is untreated.

(a) Scenario 1 (Waste Case Scenario - Untreated):
Unlikely event when plant faces an emergency shutdown due to power failure. Flue gases release after the emergency is not treated up to 30 min. HCl concentration, 157.8 µg/m^3.
(b) Scenario 2 (Typical Emission):
The flue gas is treated with APC Devices, lime scrubber. HCl concentration, 2 µg/m^3.

ii) Meteorology Data

Windrose at Taman Beringin can be illustrated as in Figure 1 below.
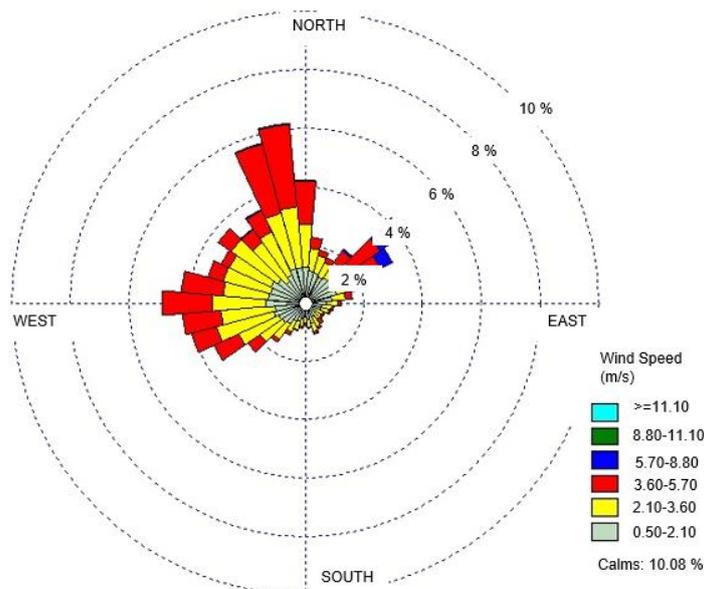
Figure 1: Windrose at Taman Beringin

The windrose is obtained from MM5 and the information of the data is as shown below:

Date: 1st January 2010 to 31st December 2012
Latitude: 3.230203 N
Longitude: 101.658486 E
Datum: WGS 84
Site Time Zone: UTC + 8
Closest City: Batu Caves
Country: Malaysia
Anemometer Height (m): 14
Station Base Elevation (m): 143
Upper Air Adjustment: -8 h(s)

iii) Dispersion Environment

The application of the model requires characterisation of the local (within 3 km) dispersion environment as either urban or rural, based on a US EPA-recommended procedure that characterises an area by prevalent land use. For this analysis, the 3 km area surrounding the proposed facility is approximately 50 % is urban. Thus, urban option was selected.

iv) Local Terrain

Local topography plays an important role in the selection of the appropriate dispersion model. Available dispersion models were formerly divided into two general categories: those applicable to terrain that is below stack top (simple terrain) and those applicable where the terrain is above stack top (complex terrain). However, AERMOD, which has been extensively evaluated on many terrain types, removes this distinction and allows a seamless treatment of project impacts on terrain both above and below stack top elevation.
In this analysis, as the project site is located near to FRIM and Batu Caves which is hilly, the effect of terrain on dispersion was accounted for in the modelling. The terrain data is retrieved from WebGIS (STRM1/3) and processed using AERMAP.

v) Receptor

In this analysis, the 20 storey residential flat is taken as a discrete receptor with the coordinate of N 3° 13' 31.61" E 101° 39' 36.59".

vi) Stack Information

As the WtE plant comprises of 2 separate lines (600 t in capacity each), the chimney also consists of 2 stacks coupled as one. The information of the stacks is shown below:
Stack Height and Diameter: 60 m, 80 m, 100 m (Height) and 2 m (Diameter)
Stack Location: 3 13' 49.86"N, 101 39' 31.44"E
Flue gas velocity and temperature: 16.2 m/s (velocity) and 150 °C (temperature)

5. Results and Discussion

Based on the data described above, using urban mode, the GLC contour of HCl for 1 h average is shown in Figure 2 for Scenario 1 (worst case) and Figure 3 Scenario 2 (typical case). The result shows that the concentration for both cases is within the limit of 75 µg/m^3. The maximum GLC for the worst-case scenario is 27.3 µg/m^3 and 0.346 µg/m^3 for typical case. The result shows that the emission from the waste to energy plant will not cause any adverse health effect to the surrounding communities. However, the concentrations of the pollutants are different when it is modelled above ground level. The results that reveal the concentration of the pollutants above ground level is shown in Figure 4 (a) and Figure 4 (b).
Figure 4 (a) and Figure 4 (b) shows that the concentration of HCl increases with increasing height. For Scenario 1, which will only occur when the waste to energy plant faces a sudden shut down and lasting for only about 30 min if occurs. For chimney height of 60 m, the concentration exceeds the limit at around 80 m and above. For chimney height of 80 m, the concentration exceeds the limit at around 100 m and above. For chimney height of 100 m, the concentration exceeds the limit at around 110 m and above. The correlation that can be deduce is that for the case of air dispersion in Taman Beringin, the allowance before the air pollution exceed the allowable limit is approximately 10 – 20 m above the chimney height. This indicates that, high-rise that is to be built at the surrounding area should not be 10 – 20 m above the chimney height. Therefore if higher building is anticipated for future development, the waste to energy plant's chimney should be design at

a greater height. It is also to be noted that the analysis may be different from different location around Taman Beringin.

For Scenario 2 (typical case) where the pollution is controlled by the air pollution control devices, the concentration of HCl remains relatively low even at higher level revealing that at most of the time, the concentration of the pollutants is well controlled. As the waste to energy plant has two line of operation producing electricity for its own operation, sudden shut down of the plant is unlikely to happen.
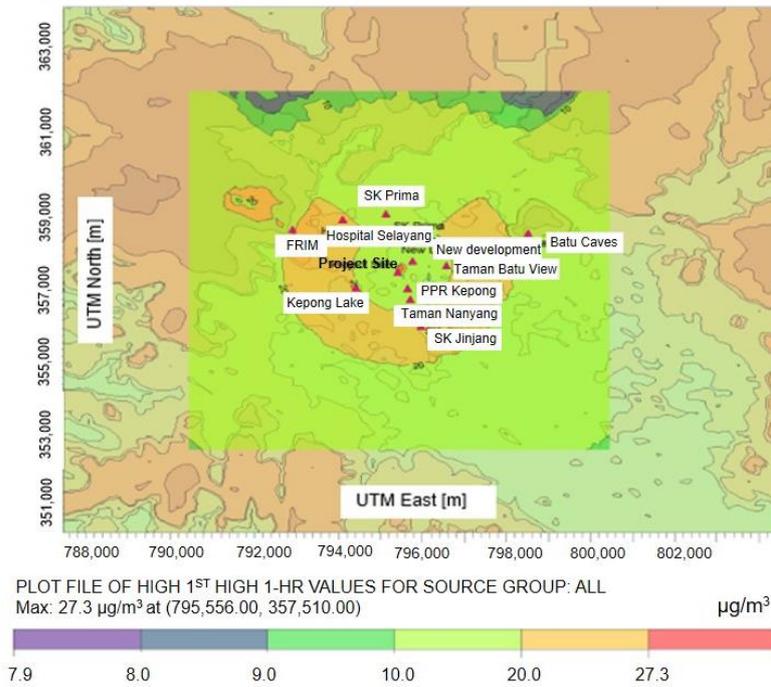
Figure 2: HCl 1 h average concentration for Scenario
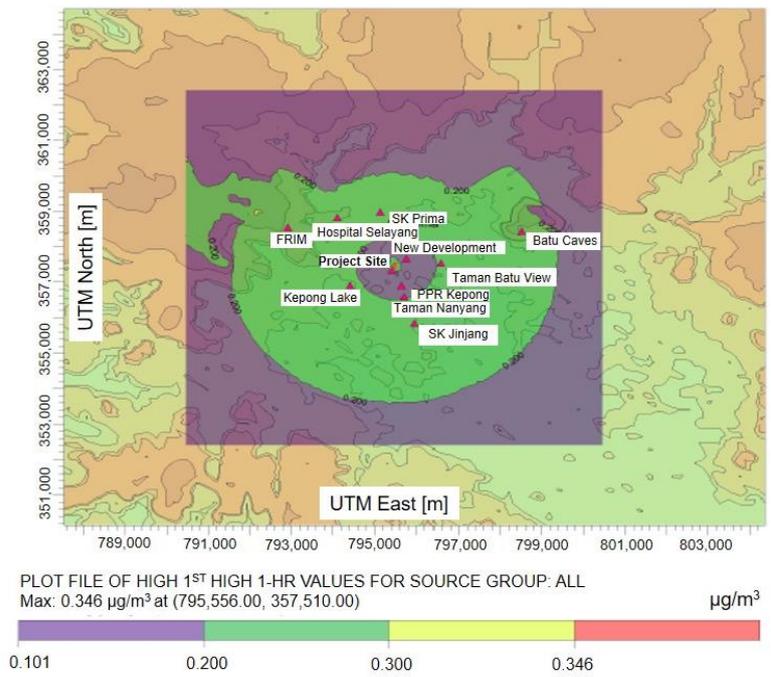
Figure 3: HCl 1 h average concentration for Scenario 2
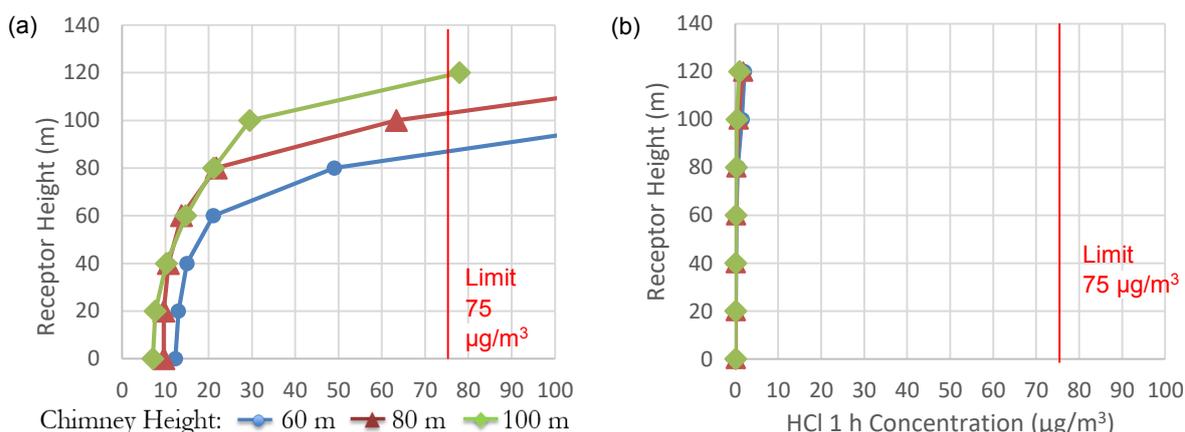
Figure 4: (a) HCl 1 h concentration at different receptor and chimney height (worst case); (b) HCl 1 h concentration at different receptor and chimney height (typical case)

6. Conclusion

In conclusion, the prediction of concentration for HCl exceeds limit only at about 10 - 20 m above the chimney height for Scenario 1 (worst case) in urban mode. Projek Perumahan Rakyat Kepong, which has a height of 60 m, are still within the limit and therefore significant impact to the residence would not incur. In fact, this indication is for the worst-case scenario that is unlikely to happen (as the WtE plant has two line in operation and supplies its own electricity). For the typical case, the concentration of HCl is well below the limit even at 120 m. However, as different location may result in different results due to variability in weather condition and terrain, the study should be repeated for studies of HCl concentration at different sites.

References

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