Environmental assessment of atmospheric dioxin dispersion from a Municipal Wastes Power Plant (MWPP), Indonesia

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Abstract. *We assess the environmental effect of the dioxin dispersion from the municipal waste power plant (MWPP) covering, characteristics of the dispersion, and health risk in Indonesia. The dispersion studies through modelling which is done with the following steps: 1) estimate dioxin emissions from incinerator processing, 2) design the dioxin dispersion by literature review, 3) calculate health risk of communities based on the dispersion modelling. The results show that the dispersion of dioxin is represented in the form of a non-Gaussian solution of the advection-diffusion equation with taking into account the settling and deposition velocity. In the case of MWPP with capacity, 80 tonnes per day produce a concentration of 0.04 pg TEQ/Nm3 in residential areas, which are located 200 m from a chimney. Inhalation exposure resulting is 5.28 pg 1-TEQ/(kg-day) to adults and 6.95 pg 1-TEQ/(kg-day) to children. The strategy took to adjust by WHO environmental quality standard 4 pg 1-TEQ /(kg-day), we increase the reduction of Air Pollution Control (APC) 25%. The calculation of emissions based on combustion processes shows that the dioxin concentration of MWPP is still below the WHO's threshold.*

INTRODUCTION

In the last few decades, it has been realized that the burning of plastic produces pollutants that are called dioxin (Hoogenboom *et al*., 1995). Dioxins also called polychlorinated dibenzo-para-dioxins (PCDDs), are chemical compounds consisting of two benzene rings connected with oxygen (O) atoms which are formed due to by-products from incomplete combustion or other chemical processes (when chlorine, carbon, hydrogen, and oxygen are together in hot conditions) and often occur at temperatures of 400-640°C (Lali, 2018). Today the source of dioxin comes mainly from human activities (anthropogenic), namely large-scale industry and the use of chemical chlorine, combustion (incineration of domestic waste, sludge waste, medical waste, and hazardous waste), combustion of various fuels such as coal, wood, and products petroleum products, as well as high-temperature sources such as cement kilns, and uncontrolled combustion (Mc Kay, 2002). Chlorine is the principal reactant for the formation of dioxin. For example, the municipal waste contains 0.5-1% chlorine mass of the total waste mass (Lali, 2018; USEPA, 1999).

It is intensifying the infrastructure development of MWPP in 12 cities in Indonesia. To produce electricity, municipal waste must be burned at a minimum temperature of 850°C to produce superheated in the boiler to drive the turbine (Winanti, 2018). Burning municipal waste, which contains a lot of plastic, will produce dioxins. But the residence time of the combustion gas is designed to be a minimum of 2 seconds in the chamber burning thus dioxins can be destroyed. In the operational MWPP, we cannot guarantee that this condition always occurs. In fact, not all MWPP is safe from dioxin emissions, especially when starting up and shutting down the engine with a greater concentration during stable conditions. An example, the dioxin dispersion from Hangzhou MWPP with a capacity of 800 tons per day give air concentration around 0.39 pg/Nm^3 at a distance of about 100 m from the chimney higher than WHO requirements 0.11 pg TEQ/Nm^3 (toxic equivalent pentagrams per standard cubic meter) (Ma *et al*., 2012). In some European countries, the use of MWPP has met WHO standards. Measurements of dioxin concentrations in soils, vegetation and air around the Portugal Catalonia MWPP showed concentrations of 0.06 ng I-TEQ kg^{-1}, 0.58 ng I-TEC kg$^{-1,}$ and 0.01 pg/Nm^3, respectively (Vilavert *et al.*, 2012). The ambient dioxin concentration of 85 large and 39 small MWPP in France showed MSWI is operated well below the EU and French standard of 0.1 pg/Nm^3 (Nzihou *et al.*, 2012).

Due to dioxins being solid in form with a density slightly higher than NO$_2$, the Gaussian dispersion model commonly used to describe the distribution of pollutants is not appropriate. The measurement results in industrial and urban areas in Taiwan show a linear relationship between PM$_{10}$ (particles with a density of 2 g/cm^3) with dioxin concentration that is *y= 0.0052x-0.021* with *R^2= 0.998* where *x* is the concentration of PM$_{10}$ and *y* is the concentration of dioxin (Chandra *et al*., 2015, Lee *et al*., 2016). When away from the chimney, dioxin is not in the gas phase but in the particulate phase, which has a settling and deposition velocity (Lohman and Seigneur, 2001). The dioxin dispersion model used is based on the Gaussian model, which does not consider the settling and deposition rates. For example, the calculation of the Gaussian model of iron and non-iron smelting plants in the Cilegon industrial area with an activity of around 2 million tons per year or 6.3 kg/s produces dioxins of 150 000 pg TEQ/m^3 at a distance of 10 km (Warlina *et al*., 2008). Furthermore, emissions of 96 165 pg TEQ/m^3 will produce an ambient concentration of 0.73 pg TEQ/m^3 (Warlina *et al*., 2008, Warlina, 2015). This value far exceeds the WHO threshold of 0.11 pg TEQ/m^3 in 1990 and changed to 0.023 pg TEQ/Nm^3 starting in 1999 (Ma *et al*., 2012). As a comparison, the measurement of ambient air in an industrial area in Taiwan has an ambient air concentration of 0.043-0.053 *pg/Nm^3* (Lee *et al*., 2016).

What is the most appropriate model for describing the dispersion of dioxin in the atmosphere? How can we determine the health risks of the community in affected areas? This question will be answered in this paper. This paper develops the calculation method (modelling) of atmospheric dioxin dispersion from municipal waste power plant activities. Because there is no measurement of dioxin concentration in the Indonesian atmosphere, the model validation will be done by comparing the results of the model with the observation that has been made in other countries by including the model factors as close as possible to the existing conditions.

METHODOLOGY

In this chapter, we show step by step the modelling of atmospheric dispersion of dioxin for environmental impact studies. Because there is no primary data from laboratory analysis of dioxin concentrations in both chimney emissions and ambient air, we use secondary data obtained from the literature. The combustion process is obtained from a waste incinerator. The explanation is as follows.

The Concept of Atmospheric Dispersion of Dioxin

The dispersion of dioxins in the atmosphere behaves differently than other pollutants. Physically dioxin has a small density of 1.8 g/cm^3 while NO_2 gas is 1.45 g/cm^3 and SO_2 is 2.63x10^{-3} g/cm^3 but dioxin can be classified in non-gas particles. Dioxin is chemically classified as inactive (non-decay) and undergoes dry deposition (particles that fall to the ground) at a speed of about 0.2-0.5 cm/s in Greece (Olie *et al*., 1977), 0.27-0.28 (coastal), 0.19-0.24 (mountain), 0.148-0.162 (industrial estate), 0.49-0.98 (urban) in Taiwan (Chandra *et al.*, 2015, Lee *et al*., 2016, Zhu *et al*., 2017). For dioxins in the atmosphere, dry deposition is more dominant than wet deposition (Wu *et al*., 2009, Huang *et al*., 2011, Chandra *et al*., 2015, Lee *et al*., 2016).

The ambient air samples' measurements around municipal solid waste incinerators (MSWI) ranging from near the chimney mouth to away from the chimney mouth show the dioxin close to chimney behaves as a gas phase and far from the chimney gradually behave into particles through the absorption process. Dioxin will be bound by particulates so that it will be deposited to the soil surface following the deposition behavior of dust particles (Chao *et al*., 2004, Chandra *et al*., 2015). When dioxin is in the gas phase, the deposition will not occur because there is a balance between buoyancy and gravity so that the gas phase will always float in the atmosphere (Ryan, 1993; Mohan, 2016). Based on the above conditions, the dioxin dispersion generated by a chimney can be constructed in Figure 1.
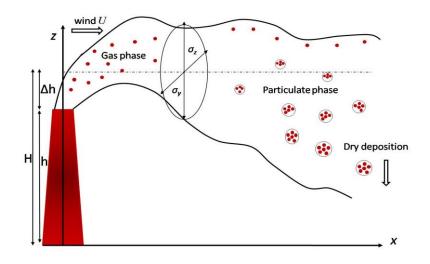

Figure 1 The dioxin dispersion coordinate system of a chimney (the red dot represents Dioxin), *h* is the height of the chimney, *Δh* is the height of the plume rise, and *σ(y, z)* is the dispersion coefficient

The Emission and Plume Rise

Because dioxin is a hazardous substance, activities must be treated in a chimney wherein it is categorized based on the ability to absorb dioxin. Emission factors are determined based on the chimney's treatment known as the Air Pollution Control (APC) which has four classes. Emissions= Production Capacity×Emission Factors, where the emission factors are represented as follows, Sophisticated APC has emission factors 0.5 μg TEQ/ton, Good APC 300.5 μg TEQ/ton, minimum APC 359 μg TEQ/ton and non APC has emission factors 3 500 μg TEQ/ton (Fiani *et al*., 2013). The calculation of pollutant emissions from the combustion process can be calculated based on the mass or volume of flue gas from combustion. Flue gas is a product of the combustion reaction of several components contained in the burned waste. Flue gas is calculated based on component combustion reactions obtained from the ultimate analysis of waste consisting of moisture (H_2O), carbon, hydrogen, sulfur, oxygen, nitrogen, and ash (Lee and Lin, 2007; Nzihou *et al*., 2012). The unit of waste component is converted to moles and calculated the product formed in

stoichiometry will produce a total mass of product flue gas as much as n kg of N kg of municipal waste that is burned.

The smoke that is emitted by the factory chimney depends on the initial burst velocity (V_a), the height of the chimney (H_0) and the temperature (T_a), and the diameter of the chimney (d), which can gush up and reach a height of more than ten times the height of the chimney. From the comparison of the data and the model, we recommend the Moses and Carson model for plume rise as follows (Carson and Moses, 1969).

$$\Delta h = \frac{V_s d}{U}\left(1.5 + 2.68 \times 10^3 Pd\left(\frac{T_s - T_a}{T_a}\right)\right)$$

(1)

Where U is downwind velocity, P is atmospheric pressure in the chimney, V_s is speed of smoke coming out of the chimney, T_s is gas temperature coming out of the chimney.

Mathematical Model of Atmospheric Dispersion of Dioxin

Modelling the dispersion of pollutants in the atmosphere is nothing else the problem solving of conservation of mass from a pollutant that disperses in the atmosphere. Because dioxin is a non-reactive pollutant, the source term or sink will be zero. Based on the dioxin dispersion construction as stated in Figure 1, we use a local scale model. For the local scale model, there are two basic phenomena, namely the dominant advection condition (strong winds), so that dispersion in the direction of the wind (downwind) can be ignored ($U \sim 0$). The second model is a weak wind condition so that the directional dispersion of the wind cannot be ignored.

High Wind Velocity Model

We solve steady state advection diffusion equation with settling velocity taken into account and by assumption as follow, the wind speed is constant and dominant in one direction, the source of pollutants is determined at a point with height $H = h + \Delta h$ with h the height of a chimney, and Δh is the immediate puff (boasting up) that depends on buoyancy. The boundary conditions are $\kappa \partial C/\partial x = 0$, $\partial C/\partial z = 0$ and $C(x, y, z \rightarrow \infty) = 0$. This yields the dioxin dispersion have an analytical solution as (Stockie, 2011; Ma *et al.*, 2012).

$$C(x, y, z) = \frac{Q}{2\pi U \sigma_y \sigma_z} \exp\left(-\frac{y^2}{2\sigma_y^2}\right) \times \Psi(x, z)$$

(2)

where

$$\Psi(x, z) = \exp\left(-\frac{W_s(z-H)}{2\kappa_z} - \frac{W_s^2 \sigma_z^2}{4\kappa_z^2}\right) \times \left[\exp\left(-\frac{(z-H)^2}{2\sigma_z^2}\right) + \exp\left(-\frac{(z+H)^2}{2\sigma_z^2}\right) - \frac{W_0\sqrt{2\pi}\sigma_z}{\kappa_z}\right.$$

$$\left. \times \exp\left(\frac{W_0(z+H)}{\kappa_z} + \frac{W_0^2}{\sqrt{2}\sigma_z}\right) erfc\left(\frac{W_0\sigma_z}{\sqrt{2}\kappa_z} + \frac{(z+H)}{\sqrt{2}\sigma_z}\right)\right]$$

Where Q is discharge rate (kg/det), $\sigma_{y,z}$ is dispersion coefficient, κ is zonal difusivity coefficient, H is initial emission height, (x,y,z) are zonal, meridional and vertical coordinate system. $W_0 = W_d - 0.5 W_s$, $\kappa_z = 0.5 U$ $d\sigma_z/dx$, $r_{(y,z)} = \sigma_{(y,z)}^2/2$, $erfc$ is a complementary error function. The dioxin unit's unit of concentration commonly used is a nanogram ng/Nm^3 (1 $ng = 10^{-9}$ g) or pg/Nm^3 (1 $pg = 10^{-12}$ g). N means normal where the gas is measured under normal conditions, for EPA-USA normal is a gas at the temperature 25°C and the pressure 101.325 kPa. This paper will follow the EPA-USA rules where the dioxin unit is measured in pg/Nm^3.

Based on the linear relationship between PM_{10} and dioxin concentration [Chandra *et al.*, 2015; Lee *et al.*, 2016] we use the settling velocity and dry deposition PM_{10} (a particle with diameter $\leq 10 \times 10^{-6}$m) i.e. the settling velocity of 2.9 mm/s and the dry deposition speed of 5.2 mm/s (Okubo and Kuwahara, 2019) The relation between the coefficient of dispersion in the zonal wind direction is given by,

$$\sigma_y^2(x) = \frac{2}{u}\int_0^x \kappa_y(\eta)d\eta \quad ; \quad \sigma_z^2(x) = \frac{2}{u}\int_0^x \kappa_z(\eta)d\eta \tag{3}$$

The coefficient of dispersion or standard deviation $\sigma_{(y, z)}$ depends on the stability of the atmosphere which has a general form $\sigma_{(y,z)} = a_{(y,z)} x^{b(y,z)}$ with $x > 0$ (Seinfield and Pandis, 2016). For an atmospheric scale of less than 5 km, the coefficient is represented in a table called the Briggs sigma table (Briggs, 1973). Generally, in Indonesia, the atmospheric conditions are convective then we use $a_y = 0.34$, $b_y = 0.82$, $a_z = 0.75$ dan $b_z = 0.82$. Equation 2 states that the wind direction is parallel to the x-axis. If the wind direction has an angle θ relative to the x-axis then the coordinate transformation is performed as follows, $x \rightarrow x' = x \cos(90-\theta) + y \sin(90-\theta, y \rightarrow y' = -x \sin(90-\theta) + y \cos(90-\theta)$, thus dioxin dispersion is obtained for arbitrary wind direction, according to wind rose data (Sulaiman and Sadly, 2014).

Low Wind Velocity Model

Whereas for winds smaller than 1.5 ms^{-1}, the dioxin dispersion in parallel to the wind (*x*-direction) is significant enough so that the zonal U velocity and the dispersion coefficient (κ_x) in the zonal direction cannot be neglected. Analytical solutions based on the Fourier analysis method and by taking into account the deposition rate yields,

$$C(x, y, z) = \int_0^\infty \frac{Q}{4\pi\sqrt{2\pi}\sigma_x\sigma_y\sigma_z} e^{-\frac{(x-Ut)^2}{2\sigma_x^2}} dt \times \exp\left(-\frac{y^2}{2\sigma_y^2}\right) \times \Psi(x, z) \tag{4}$$

Thus Equation 2 and Equation 4 represent dioxin's dispersion in the local-scale atmosphere by considering synoptic wind speeds. The integrals in Equation 4 can be solved by a Gaussian integral $\int_{(-\infty,\infty)} exp(-ax^2+bx+c)dx = \sqrt{(\pi/a)}exp[(b^2/4a)+c]$.

Health Risk due to Dioxin Exposure

In this paper, the health risks of dioxin exposure will be calculated based on the Nouwen equation. This risk is measured by dioxin exposure per day per person (adults and children). The formulation is given as follows (Nouwen *et al.*, 2001).

$$INH = \frac{V_r \times C_{atm} \times f_r \times t_r}{BW} \tag{5}$$

Where *INH* is daily dioxin exposure level (*ng I-TEQ/(kg-day)*), V_r is average ventilation (20m^3/d for adults and 7.6 m^3/d for children), C_{atm} is dioxin concentration in the air (*pgTEQ/Nm^3*), f_r is alveolar fraction in the throat (0.75 adults/children), t_f is fraction time (0.616 adults and 0.457 children) and *BW* is weight (in this case we make an average of 70 kg adults and 15 kg children). This formula is known as inhalation exposure which is caused by emissions from a factory with the assumption every individual is exposed 24 hours per day with the same concentration both inside and outside the home.

RESULT AND DISCUSSION

We review the case of MWPP in Bantargebang, Indonesia (Thohiroh and Mardiati, 2017). MWPP has a chimney with a height of $H_0 = 30$ m, gas flow velocity in the chimney mouth $V_s = 3.17$ m/s, chimney diameter 0.38 cm, atmospheric pressure P= 1 000 Pa, the temperature in the mouth of the chimney $T_s = 623$K and

ambient air temperature at T_u= 300K. MWPP has an activity that is stated by the production capacity of 80 tons/day, the resulting emissions based on the calculation of emission factor are 40 *µg TEQ/day* for Sophisticated APC, 2 400 *µg TEQ/day* for Good APC, 28×10^3 *µg TEQ/day* for minimal APC and 28×10^4 *µg TEQ/day* for non-APC. In contrast, the calculation of emissions based on the combustion process is more complicated by sorting the waste composition. We calculate the concentration of C, H, O, N, S, and ash from each component to determine the total C, H, O, N, S, and ash from the waste. For example, it is assumed that the total amount of 100 kg of waste with organic waste has a moisture content (MC) of 70%, then the dry weight of organic waste is 53.7501-(0.7)x(53.7501)= 16.12503 kg. From the dry weight will be obtained the amount of C organic waste 0.48x16.12503= 7.74 kg, H= 1.03 kg, O= 6.06 kg, N= 0.41 kg, S= 0.06 kg, Ash= 0.81kg, and H_2O= 37.63 kg. The calculation shows that the results of the ultimate analysis consisted of carbon 26.19 kg, hydrogen 3.35 kg, oxygen 16.29 kg, nitrogen 0.57 kg, sulfur 0.1 kg, water 38.95 kg, and ash 13.97 kg burned using air which has a composition of 0.05% CO_2, N_2 76.10%, O_2 23.06%, H_2O 0.79% with excess 80% at a combustion temperature of 900ºC. The unit of waste component is converted into mol (n) where n is the mass (m) divided by the molecular weight (BM) then the product formed in stoichiometry is calculated. It yields a total mass of product flue gas of 210 614 kg from 100 kg of waste burned.

The combustion reaction showed the O_2 requirement to burn 100 kg of waste is 107 264 kg, so that the total air needed with excess oxygen 80% is 837.14 kg. Previous studies conducted by (Ujam and Eboh, 2012) take 8.66 kg of air to burn 1 kg of trash with excess oxygen by 80%. If the waste incinerator can process waste up to 80 tons per day, the flue gas will produce 976 016 m^3 (220ºC) per day. These calculation results are the same as calculations made by (De Vivo *et al.*, 2017). The dioxin emissions in the volume of flue gas production are 1.48×10^{-5} *µg TEQ/s* for Sophisticated APC, 1.48×10^{-3} *µg TEQ/s* for Good APC, 1.03×10^{-2} *µg TEQ/s* for minimal APC, and 1.03 *µg TEQ/s* for non-APC. Calculations with emission factors have a higher value of two orders. For example, the sophisticated APC with emission factors having a 40 µg TEQ/day value while calculations with the combustion process produce emissions of 0.013 µg TEQ/day. Thus, the measure with emission factors has a high enough error. For studies with worst-case scenarios, the emission factors method is acceptable.

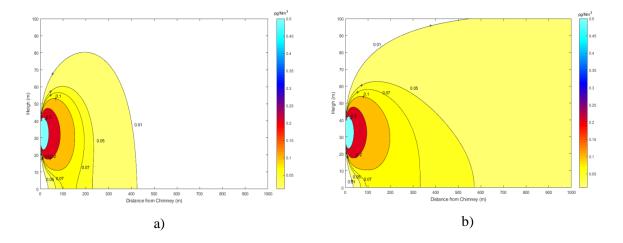a)   b)

Figure 2 Dispersion of dioxins in the vertical direction with emission sources for sophisticated APC conditions and chimney height of 30 m and wind speeds of 2.5 m/s where a) Solution of Equation 4 and b) Gaussian Solution (w_d=w_s=0 in Equation 4)

First, we simulate dioxin dispersion in the (*x-z*) direction to see the dioxin dispersion's vertical behaviors and compare it to the Gaussian model. In this simulation, we use the wind in October that blows to the southeast at a speed of 2.5 m/s. The winds head to the residential area so that the possibility of the settlement is quite large. With a velocity of 2.5 m/s, the dispersion will meet Equation 2 with type-C stability

conditions. Dioxin dispersion in the vertical direction is depicted in Figure 2a. In MWPP conditions equipped with water pollution control with a sophisticated scenario, then at a distance of 30-230 m from the chimney will be exposed to 0.05 pg/Nm^3 dioxin. While at a distance between 100-170 m will be exposed to dioxin by 0.07 pg/Nm^3. Exposure concentrations of 0.1 pg/Nm^3 are only at elevations above 10 m and disperse as far as 150 m. If using the Gaussian model (Figure 2b), dioxin will spread to a wider area. For example, dioxin with a concentration of 0.05 pg/Nm^3 will disperse as far as 80 m to 580 m. The concentration of 0.01 pg/Nm^3, disperse over an area of more than 1 km and altitudes more than 100 m. The Gaussian model is suitable for dispersing gaseous pollutants (Alimuddin *et al*., 2018; Dewi *et al*., 2018; Assegaf, 2018). Measurement of ambient air in an industrial area in Taiwan has an ambient air concentration of 0.043-0.053 pg/Nm^3 (Lee *et al*., 2016), whereas, for urban areas, it has an ambient air concentration of 0.0039-0.0136 *pg/Nm^3* (Chandra *et al*., 2015). Quality standards for ambient air quality according to WHO around 0.11 pg/Nm^3 in 1990. Conditions with the assumption of sophisticated APC will produce dioxin concentrations that are still below WHO quality standards.

Some countries have measured ambient air concentrations for dioxin, for example in China had ambient air concentrations of 0.19 pg TEQ/m^3 before the presence of MSW incinerators and 0.495 to 3.03 pg TEQ/m^3 with the presence of MSW Incinerators (Xu *et al*., 2009). Modelling studies of dioxin dispersion with Gaussian models from the MSW plant with a capacity of 800 tons/day provide ambient concentrations of around 0.04 pg TEQ/m^3 at distances of 800 m for wind speeds below 1.5 m/s and 0.05 pg TEQ/m^3 at distances of 1 km for wind speeds of more than 1.5 m/s (Ma *et al*., 2012). If we calculate with Equation 2 and Equation 4 produce a concentration of 0.005 pg TEQ/Nm^3 at a distance of 800 m for wind conditions below 1.5 m/s and 0.001 pg TEQ/Nm^3 for wind conditions above 1.5 m/s. These results are consistent with the study in this paper, where the Gaussian model provides over-estimated results.
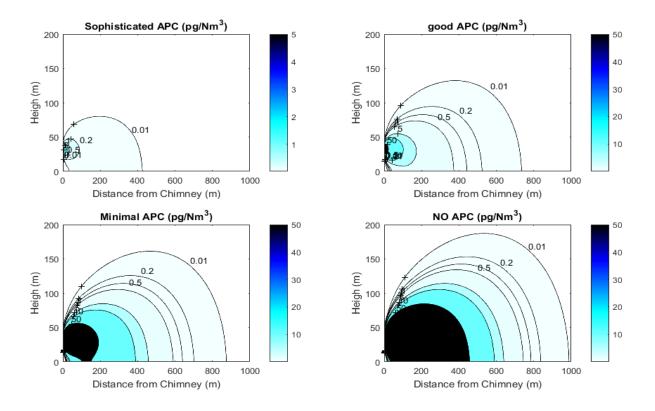

Figure 3 Dispersion of dioxin in the vertical direction with emission sources for the four conditions of the APCS (Air Pollution Control Strategy) scenario and chimney height of 30m and wind speed of 2.5 m/s

In the same way, the simulations for the four APC scenarios are depicted in Figure 3. APC is a system that must exist in a process that involves combustion that functions to control dioxin residues. The APC system used in a factory depends on the type of incinerator and residual cleaning equipment installed. Incinerators involving dioxin have two types, namely dry (semi-dry) systems, and wet systems. Both types can minimize the release of dioxin into the atmosphere (Astrup, 2008). Sophisticated APS usually uses semi-dry lime scrubbing and filter bags equipped with activated carbon injection. This is an important series of preventing and minimizing dioxin emissions through the chimney. Figure 3 shows that in the sophisticated APC, the dioxin concentration was 0.01 pg/Nm^3 which is still included in the safe category (Abad *et al*., 2006). In this condition, we see no concentration of 0.2 pg/Mm3 below 10 m height (the height of houses in settlements is less than 10 m) so that the general public is not exposed to dioxin. For the cases without APC, produce dioxin concentrations at ground level, above 50 pg/Nm^3 at a distance of 50 m to 500 m from the MWPP chimney. While the area between 50 m to more than 800 m and altitude reaches 150 m, have concentrations above the WHO quality standard. The minimum APC, the area above the quality standard in the distance of 50 m to 700 m. The minimum condition of the APC with concentrations above 50 pg/Nm^3 occur between 100 m to 150 m from the MWPP chimney. The APC good scenario has an area exceeding the quality standard between 40 m to 500 m. The sophisticated APC is a must for getting dioxin exposure below the WHO quality standard from the above results.

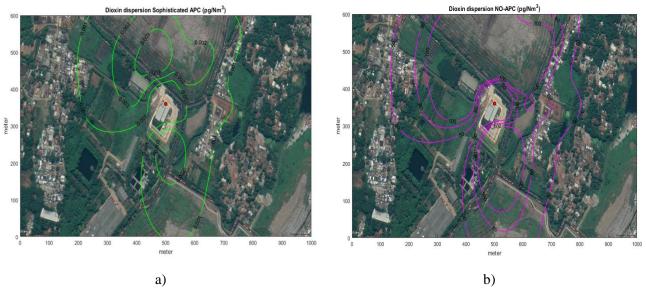a)   b)

Figure 4 Isopleths from the dioxin distribution in the horizontal direction of the MWPP Bekasi where emissions are calculated based on the combustion process, for the accumulation of one year with average monthly wind a) sophisticated APC, b) do not use APC

The calculation of emissions based on the combustion process produces a significant change where scenarios with sophisticated APC and without APC are depicted in Figure 4a and Figure 4b, respectively. With the presence of APC, the ambient dioxin concentration becomes 0.001 pg TEQ/Nm^3 at the residential location. Whereas the condition without APC will produce a concentration of around 50 pg TEQ/Nm^3. Calculation of emissions based on combustion processes has a much smaller ambient concentration than analyses using emission factors in order 10^{-1} or about ten times less. For studies that prioritize the worst-case scenario, then the calculation with emission factors is recommended, but in case of a favorable scenario, the calculation by using the combustion process is recommended.

Health risks from exposure to dioxin can be identified by looking at the exposed area is around 100 houses. Assuming that in one house, there are two adults and two children, there are 200 exposed adults and 200 exposed children. Each person has a risk of exposure to dioxin calculated based on Equation 5 as follows, INH_{adults}= 20×0.04×0.75×0.616/70= 0.00528 ng I-TEQ/(kg-day)= 5.28 pg I-TEQ/(kg-day) and $INH_{children}$= 7.6×0.04×0.75×0.457/15= 0.00695 ng I-TEQ/(kg-day) or 6.95 pg I-TEQ/(kg-day). WHO issued a dioxin exposure threshold of 10 pg I-TEQ/(kg-day) for all sources of exposure to dioxin (not just inhalation) (Hoogenboom *et al.*, 2001; WHO, 2000). This condition is indeed still below the WHO threshold. But we should remark that dioxin exposure not only comes from inhalation but also from vegetation, soil, water, food, and animals at the location of the activity. For example, chicken eggs in the MWPP have a high possibility be exposed to both meat and eggs.

Because of almost all studies showing that children are more vulnerable than adults, WHO suppresses the acceptable value or Tolerable Daily Intake (TDI) with a value of 1-4 pg I-TEQ/(kg-day), while Environmental Protection Agency (EPA)-USA has a TDI of about 1 pg I-TEQ/(kg-day) (Nouwen *et al.*, 2001). The results of a dioxin dispersion modeling study in the Hangzhou region with a capacity of 800 tons MSW per day will give human dioxin exposure around 15.63 to 3.81 pg I-TEQ /(kg day) at a distance of about 300 m from the chimney (Ma *et al.*, 2012). This value is above the TDI required by WHO. The ambient air concentrations must have a value of 0.023 pg TEQ/Nm^3 to follow with the WHO TDI requirements. Studies in Taiwan show that ambient dioxin concentrations in coastal (urban) areas are 0.0039-0.0136 pg TEQ/Nm^3 and in mountainous regions have 0.0016-0.0029 pg TEQ/Nm^3 (Chandra *et al.*, 2015). The air quality monitoring results in Hong Kong were 0.1 pg TEQ/m^3 in 1999 and 0.02 pg TEQ/m^3 in 2019 (https://www.aqhi.gov.hk). Some countries apply ambient air quality standards for dioxin differently. For example, in 1990, Connecticut-USA adopted standard 1 pg TEQ/m^3 (Rao and Brown, 1990). Japan applies annual standard 0.6 pg TEQ/m^3 [https://www.env.go.jp/en/air/aq/], Ontario Canada applies annual standard 0.1 pg TEQ/m^3 24-hour. Thus, the TDI standard from WHO is still higher than the natural ambient air concentration. We have seen that the ambient air concentration due to the presence of MWPP in the study area is 0.04 pg TEQ/Nm^3. This concentration will result in dioxin exposure of 5.28 pg I-TEQ/(kg-day) for adults and 6.95 pg I-TEQ/(kg-day) for children, which is still above the WHO TDI limit of 4 pg I- TEQ/(kg-day). The strategy that can be done based on Equation 4 or Equation 7 is to reduce production capacity from 80 tons per day to 60 tons per day or increase the APC from 0.5 µg TEQ/ton to 0.375 µg TEQ/ton.

CONCLUSION

The development of atmospheric dioxin dispersion produced by MWPP and its impact on human health have been given in-depth in this paper. Dioxins disperse in the atmosphere in two phases. When it is close to the mouth of the chimney, the dioxin disperses in a gaseous form. While far away from the chimney, the absorption process occurs by dust particles so that the dioxin will form into a particulate phase. It is about 10 percent not absorbed by dust particles and then disperses in the form of a solid-gas phase. We use the non-Gaussian solution of the advection-diffusion equation by considering the settling and deposition particle velocity. APS technology scenario is applied to simulate the dioxin dispersion from the MWPP. For the case of MWPP with a production capacity of 80 tons per day, it produces a concentration of 0.04 pg TEQ/Nm^3 in a residential area within 200 m of the emission source. The resulting inhalation exposure was 5.28 pg I-TEQ/(kg-day) for adults and 6.95 pg I-TEQ/(kg-day) for children. The strategy is taken to adjust to the WHO quality standard of 4 pg I-TEQ/(kg-day) reduces the production capacity to 60 tons per day, or increases the APC from 0.5 µg TEQ/ton to 0.375 µg TEQ/ton. Calculation of emissions based on combustion processes produces ambient concentrations ten times less than calculations using emission factors. We apply to MWPP and show that the dioxin concentration is still below the threshold required by WHO.

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