Jurnal
Teknologi

Full Paper

HEALTH RISK ASSESSMENT DUE TO EMISSIONS FROM MEDICAL WASTE INCINERATOR IN MALAYSIA

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Article history
Received
19 May 2015
Received in revised form
24 March 2016
Accepted
1 May 2016

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Graphical abstract

Pollutants	Concentration of Pollutant in Ambient Air (ug/m^3)	Inhalation unit risk factor (URF) (ug/m^3)$^{-1}$	Excess lifetime cancer risk (LCR)
Cd	<0.01	1.8 x 10^{-3}	1.8 x 10^{-5}
Pb	0.03	1.2 x 10^{-5}	3.6 x 10^{-7}
	Total		1.84 x 10

Abstract

In this research, health risk assessment due to the emission of pollutants from a medical waste incinerator located within industrial estate in the northern part of Malaysia was presented. The influence of pollutants emission in the vicinity of the incineration plant was the main concern in this research. The measured emissions of pollutants from the stacks of the studied plant that may pose risk to human health and the environment are compared against the acceptable limit as in the Environmental Quality (Clean Air) Regulation 2014. Next, the levels of pollutants in ambient air are assessed in comparison with the guideline established by the Malaysia Ambient Air Quality Guideline (MAAQG). The health risk assessment was then conducted by calculating the quantitative risk for non-carcinogenic and carcinogenic pollutants. The study reveals that the total cancer risk due to emission of carcinogenic pollutants from the incinerator is 1.84 x 10^{-5}, which indicates risky circumstances as the calculated risk is higher than the benchmark of acceptable risk of 1 x10^{-6}. Meanwhile the health risk calculated due to emission of non-carcinogenic pollutants ranges between 0.000286 and 0.1, indicating acceptable risk. The result shows that the non-carcinogenic pollutants emitted from the studied medical waste incinerator are within the acceptable exposure limits. However, for carcinogens, the released amounts may cause human health risk, and therefore demands for further attention to reduce the concentrations as low as reasonably practicable, at least in compliance with the established guidelines.

Keywords: Medical waste, incineration, emission, risk assessment, health risk.

Abstrak

Dalam kajian ini, penilaian risiko kesihatan yang disebabkan oleh pelepasan bahan pencemaran dari insinerator sisa perubatan yang terletak di dalam kawasan industri di utara Malaysia dibentangkan. Kesan pelepasan bahan pencemaran di sekitar insinerator tersebut merupakan kebimbangan utama dalam kajian ini. Pelepasan bahan pencemaran dari cerobong kilang tersebut mungkin menimbulkan risiko kepada kesihatan manusia dan alam sekitar dan akan dibandingkan dengan had yang telah ditetapkan dalam Environmental Quality (Clean Air) Regulation 2014. Seterusnya, tahap pencemaran pada udara ambien pula dibandingkan dengan garis panduan yang telah ditetapkan oleh Malaysia Ambient Air Quality Guideline (MAAQG). Penilaian risiko kesihatan yang telah dijalankan dengan mengira risiko kuantitatif bagi bahan pencemar bukan karsinogenik dan karsinogenik. Kajian ini mendedahkan bahawa jumlah risiko kanser yang disebabkan oleh pelepasan bahan pencemar karsinogenik dari insinerator adalah 1.84 x 10^{-5}, yang menunjukkan nilai tersebut mempunyai risiko yang lebih tinggi daripada had risiko yang boleh diterima iaitu 1 x10^{-6}. Sementara itu, risiko kanser yang disebabkan oleh pelepasan bahan pencemar bukan karsinogenik adalah antara 0.000286 and 0.1, menunjukkan nilai tersebut boleh diterima. Hasil kajian menunjukkan bahawa bahan pencemar bukan karsinogenik dari kawasan kajian ini adalah dalam had yang dibenarkan. Walau bagaimanapun, bagi bahan pencemar karsinogenik, jumlah yang dilepaskan boleh membawa risiko terhadap kesihatan manusia, dan oleh itu perhatian dan tindakan yang sewajarnya diperlukan untuk mengurangkan pelepasan daripada pencemar tersebut dapat dilaksanakan, atau sekurang-kurangnya dapat mematuhi had pelepasan yang telah ditetapkan

Kata kunci: Sisa perubatan, incinerator, pelepasan, penilaian risiko, risiko kesihatan

1.0 INTRODUCTION

Medical waste is any waste that generated from industry of health care such as pharmacy, hospitals and medical laboratories. Apparently it is hazardous waste and requires serious attention because it is harmful to the environment and public health. According to Lee *et. al*, medical waste have been classified into two types; general waste that include potential dangerous waste which does not require special handling and special waste including chemical waste, infectious waste, and radioactive waste which is very difficult to be managed and hence special handling, treatment and disposal are required [1]. In Malaysia, there are three companies involved in managing medical wastes:

a) Faber Medi-Serve Sdn Bhd serves 79 government-owned hospitals and 500 smaller clinics in the states of Perlis, Kedah, Penang, Perak, Sarawak and Sabah.

b) Radicare Sdn Bhd serves 47 other hospitals in Kuala Lumpur, Putrajaya, Kelantan, Pahang and Terengganu.

c) Pantai Medivest Sdn Bhd, a subsidiary of Pantai Holdings Berhad, manages the clinical waste from 22 hospitals in the remaining three states of Johor, Negeri Sembilan and Melaka.

Table 1 presents the average of medical waste composition from FMSB report on medical waste incineration plant in Malaysia (FMSB, 2008). The composition is compared to those from three other different countries under three categories; low-income country, middle-income country and high-income country as shown in Table 2. Vietnam represents the composition of medical waste from low-income countries, followed by Turkey represents middle-income countries and Italy represents high-income countries. This distinction in the income category is useful because the management of this type of medical waste and the studies done in that countries is different. Based on Table 1 below, the predominant components of medical waste in Malaysia is plastic which about 40% is. This is similar to percentage of plastic waste in Turkey and Italy which is around 41-46% as shown in Table 2. Apart from these two components, all countries showed the same trend for the remaining components. The next major components in the medical waste are gloves, mixed paper, absorbents, surgical garments and other. It is important to have a data on the waste composition since such data will provide insight in strategizing efforts controlling the pollutants emissions to the ambient air environment and managing the residues generated.

Table 1 Composition of medical waste in Malaysia (Faber Medi-Serve Sdn. Bhd. (FMSB), 2008)

Constituent	wt %
Mixed paper	14.1
Plastic	39.2
Gloves	15.6
Diapers	7.3
Surgical garments	11.1
Absorbent	12.6

Table 2 Composition of medical waste from three different countries

Vietnam[2]		**Turkey**[3]		**Italy**[4]	
Constituent	**wt %**	**Constituent**	**wt %**	**Constituent**	**wt %**
Paper	2.9	Paper	16	Paper	34
Wood, plaster	8.8	Carton	5	Plastics	46
Plastic	0.9	Plastic	41	Glass	8
Glass	2.3	Glass	7	Metal	0.4
Metals	0.7	Metal	2	Anatomical	0.1
Organic waste	52.7	Food	17	Liquids	12
PE bottles, bags, PVC	10.1	Textiles	10		
Hospital material	0.6	Other	3		
Other solid waste	21.0				

All the infectious wastes as presented in Tables 1 and 2 should be treated prior to disposal as it may cause spreading of infectious diseases as well as pollution to the environment. Due to such requirement, incineration is deemed as the most proper way to dispose medical waste. Incinerator has been widely adopted for such purpose and it may handle medical waste in a bulk quantity with high combustible content besides able to kill microbes and destroy contaminated materials effectively [5]. The incineration of medical waste involves the generation of particulate matter (PM), carbon monoxide (CO), sulfur dioxide (SO_2), hydrogen fluoride (HF), hydrogen chloride (HCl), nitrogen oxides (expressed as NO_2), dioxin and heavy metals such as cadmium, mercury, lead, dioxin and furan. The emissions of pollutants from the medical waste incinerator into the atmosphere shall not exceed the regulated emission limits as listed in Table 5. Meanwhile the ground level concentration of pollutants should be below the ambient air quality guidelines as listed in Table 6. As mentioned in Table 1, the major component of medical waste in Malaysia is plastic. This is parallel to the studies conducted by Connett, stated that greater amount of plastic in medical waste which is often used in sterile packaging and for non-reusable items and much of this plastic is chlorinated (e.g. PVC) [6]. Chemically, the burning of waste in form of polyvinyl chloride (PVC) and other chlorinated compound is bounded with chlorine to form HCl [7]. In fact, Swedish studies also have found that 60 to 65 percent of the fuel-bound chlorine in medical waste is converted to HCl. Therefore for medical waste incineration process, HCl pollutant should be of the main concern [7].

Due to the issues on medical waste incineration as discussed above, special attention should be given to this particular matter since the components of emissions from medical waste incineration are more critical than municipal solid waste incineration as there can be up to 50 times more mercury in medical waste [8]. According to Baseline National Toxics Inventory 1990 data, there are 50 tons of mercury was emitted from medical waste incinerator per year. The assessment of risk is the use of factual base to define the health effects associated with the operation of medical waste incinerator. However, NRC recommended that special attention need to be paid in future to health risks associated with emissions of nitrogen dioxide (NO_2), sulfur dioxide (SO_2), lead (Pb), cadmium (Cd), mercury (Hg), dioxins and furans because these pollutants have the greatest potential to cause carcinogenic and non-carcinogenic health effect [9]. This study also focused on the same pollutants as mentioned by NRC.

Based on extensive literature review, the studies of the medical waste management have been conducted by Malaysia Ministry of Natural Resources and Environment, Omar *et. al* , Ambali *et. al* and other research by consultation agency [10]; [11]. From the result of the studies, it shows that medical waste management in almost the entire hospitals studied in Malaysia is following the required standard and regulations. However, the studies emphasized on the impacts and management of medical wastes also the strategic measures taken by Malaysian government. Hence, there are some gaps in knowledge on health risk assessment in assessing the potential health risk and quantitative risk value of medical waste incinerator in Malaysia. In addition, there is no research has been conducted from the academic or researcher's point of view and no published article available regarding to this study in Malaysia.

2.0 METHODOLOGY

2.1 Description of Studied Medical Waste Incinerator Plant

The studied medical waste incinerator plant has been in operation in April 1997 and it is located at the northern part of Malaysia to incinerate 300 kg/h of medical waste having an average calorific value of 17.4 MJ/kg on a 24h/day basis. The descriptions of the studied plant are summarized in Table 3.

Table 3 Basic information of the studied medical waste incinerator

Incineration capacity (kg/h)	650 kg/h (max)
Auxiliary fuel	Natural gas
Air pollution control (APC) unit	ESP, Fabric filters + wet scrubber (limestone)
Number of stack	2
Stack height (m)	30
Stack diameter at sampling plane (m)	0.6
Velocity of stack (m/s)	11.2
Flow rate of flue gas (m^3/s)	2.2
Temperature of stack (˚C)	22

2.2 Analysis of Samples from Stack

The sample was collected for three times in order to increase the reliability of the data, and then the average values of the data have been computed to obtain the average concentration of each gaseous component and particulate matter. The equipment used during sampling are stack sampler, sampling pump, sampling probe, filter holder, sampling nozzle, impingers box, glass impingers and gas analyser. Glass fiber filters paper (Whatman GF) was used as a collection medium for particulate matter sampling. The difference in weight of the glass fiber filter paper signifies the amount of particulate matter collected on the filter media. Meanwhile for the sampling of gaseous emission, the measurements have been carried out in-situ by using portable gas analyzer (Telegan, Model 100).

2.3 Sampling Method of Ambient Air Monitoring

In this study, the ambient concentration of pollution released from the plant has been monitored from the specific location as shown in Table 4.

There are two sampling stations (A1 and A2) were setup to determine the existing ambient air levels of the following air pollutants:-

i) Particulate matters less than 10 microns (PM10)
ii) Carbon monoxide (CO)
iii) Nitrogen dioxide (NO_2)
iv) Sulphur dioxide (SO_2)
v) Hydrogen chloride (HCl)
vi) Cadmium (Cd)
vii) Mercury (Hg)
viii) Lead (Pb)

Table 4 Locations of ambient air quality monitoring

Site	Location	Description
A1	(N) 04°52.599' (E) 100°42.187'	Located at plant entrance
A2	(N) 04°53.013' (E) 100°42.362'	Located about 1 km north to the plant

2.4 Quantitative Health Risk Assessment (QHRA)

In health risk assessment, Firstly, risk must be assessed by describing and identifying step before an attempt to minimize it. As stated by Hashim and Hashim, health risk assessment is can be estimated in two forms; quantitatively and qualitatively [12]. For health risk, quantitative assessment is preferred. The definition of quantitative health risk assessment (QHRA) as given by NAS is characterization of the potential adverse health effects of human exposures to environmental hazards [13]. It is used to compute the risk or safety of chemical exposure by numerical measurement. It contains four steps; hazard identification, dose-response assessment, exposure assessment, and risk characterization in only quantitative terms such as mutagen or carcinogen:

2.4.1 Hazard Identification

First and foremost, hazard from the emission source need to be identified to identify whether the exposure can cause severe health condition such as cancer, birth defect, skin irritation and and respiratory problem.

2.4.2 Dose-response Assessment

There are two important parameters used to evaluate the toxicological; Reference Dose (R_{fD}) and Reference Concentration (R_{fC}). The R_{fD} is used to estimate daily oral exposure of a toxicant, while the R_{fC} is used to estimate daily concentration of a toxicant in air. The R_{fD} and R_{fC} also can be referred to as safe level on dose and concentration of toxicant exposure which to ensure it below the safe level so that carcinogenic health effect will not be detectable. Data of R_{fC} and R_{fD} can be reffered to Table 8 below. When R_{fC} is not available, R_{fD} can be used to estimate it by the following equation [15]:

$$\text{Inhalation } R_{fc}\left(\frac{\mu g}{m^3}\right) = \frac{\text{Oral } R_{fD}\left(\frac{mg}{kg}.\text{day}\right) \text{x 70 kg body weight x 1000 } \mu g/mg}{20\frac{m^3}{day}\text{ inhalation rate}} \quad (1)$$

2.4.3 Exposure Assessment

For the third step, exposure assessment is the beginning to risk management through minimization of exposure. When the exposure is to be experienced, thus the health effect will be predicted. Hence, to compute the health effect and ensure either it is consider as acceptable or tolerable concentration will be discussed further in section of risk characterization. According to Louvar and Louvar, through the comparison between costs, benefits and alternative risk particularly on those that have been reviewed and accepted previously, a compromise on acceptable risk should be achieved [15]. The hazard of pollutants due to medical waste incinerator will be presented by using air dispersion modelling. The risk assessment study requires input data from air dispersion modeling which provides data on how the pollutants may travel from the emissions source to the receptor of interest within certain distances under specific atmospheric condition.

2.4.4 Risk Characterization

Risk characterization is used to compute the non-carcinogenic and carcinogenic risk differently. For the non-carcinogenic health effects, hazard quotient (HQ) is due to the inhalation exposure to the existing air pollutants from the proposed incinerator in the impacted area. It is obtained by taking the ratio of exposure air concentration (EC) to the reference concentration (R_{fC}) [16]; [17].

$$HQ = EC / R_{fC} \quad (2)$$

Where,
HQ = Hazard quotient (dimensionless)
EC = Exposure air concentration (mg/m^3)
R_{fC} = Reference concentration (mg/m^3)

For carcinogenic health risk due to inhalation, the lifetime cancer risk (LCR) is estimated as follows [16]; [17]:

$$LCR = EC \text{ x } URF \quad (3)$$

Where;
EC = exposure air concentration ($\mu g/m^3$)
URF = unit risk factor $(ug/m^3)^{-1}$

3.0 RESULTS AND DISCUSSION

3.1 Measure Stack Emission Concentration

The study found that the pollutants concentrations in Table 5 are well below the limits as in Environmental Quality (Clean Air) Regulation 2014.

Table 5 Measure stack emission concentration of the studied medical incineration plant

Pollutants	Average concentration ± sd *	Limits ^
Particulate matter (PM)	85.67 ± 41.04	100
Nitrogen Oxides (expressed as NO_2)	44.67 ± 22.03	200
Sulfur Dioxide (SO_2)	<3.0 ± 0	50
Carbon Monoxide (CO)	37.43 ± 19.38	50
Hydrogen Chloride (HCl)	0.13 ± 0.04	50
Cadmium (Cd)	0.01 ± 0.006	0.5
Lead (Pb)	0.03 ± 0.01	0.5
Mercury (Hg)	0.04 ± 0	0.05

*Concentrations are in mg/Nm^3 <Means not detectable or below detection limit
^Limits as in Environmental Quality (Clean Air) Regulation 2014

3.2 Data of Ambient Monitoring

The ambient concentration of pollutants emitted from the studied medical waste incinerator plant was presented as in Table 6. Comparison of the level ambient air concentration with the Recommended Malaysia Ambient Air Quality Guideline (RMAAQG) has done to ensure the concentration of pollutants in acceptable limit for human and environment exposure.

Table 6: Table of Monitoring Ambient Concentration Compared with the Recommended Malaysia Ambient Air Quality Guideline (RMAAQG) (1989) and other guidelines

Pollutants	Concentration of Pollutant in Ambient Air*		Limits^
	A1	A2	
Particulate matter (PM) <10 µm (PM_{10})	48.0	43.6	260 @24 hr^
Nitrogen Oxides (expressed as NO_2) (1-hour average)	<1.0	<1.0	10 @24 hr^
Carbon Monoxide (CO**)	<1.0	<1.0	35 @1hr^
Sulfur Dioxide (SO_2) (24- hour average)	<2.0	<2.0	105 @24 hr^
Hydrogen Chloride (HCl) (24- hour average)	<2.0	<2.0	32 @24hr [b]
Cadmium (Cd)	<0.001	<0.001	0.025 @24hr [a]
Mercury (Hg)	<0.01	<0.01	2.0 @24hr [a]
Lead (Pb)	0.03	0.03	1.5 @3m^

*Concentrations are in mg/Nm^3
**Concentrations are in mg/m^3
<Means not detectable or below detection limit
^Based on limits imposed by Recommended Malaysian Ambient Air Quality Guidelines (1989)
[a] Ontario Ambient Air Quality Criteria (OAAQC), 2003 @ 24h
[b] Based on limit imposed on incineration plant

According to Table 7, the health risk assessment has computed by average value of ambient concentration from location A1 and A2. The hazard quotient value that is more than one (HQ>1) signifies that the pollutants from the studied medical waste incinerator plant could possibly cause health risk to the receptor exposed [15]; [16]. In this study, hazard quotient was measured at different concentration of pollutants. The hypothesis that can be made is the concentration of pollutant is not directly proportional to the calculated value of hazard quotient. Therefore, it proves that high concentration of pollutant does not indicate hazard risk of the pollutant. Based from the Table 7, the value of hazard quotient is lower than 1 that range between 0.000286 and 0.1. Hence, the calculated value of hazard quotient indicate that the pollutants would not cause non-cancer related disease to the population residing at 1 km from the point of source. However, it has shown that special supervision should be given for emission of mercury, Hg in the studied plant as the hazard quotient of Hg is in the red alert by approaching the limit (HQ~1) which is 9.52×10^{-3}.

Table 7 Table for assessment of non-carcinogenic health effects of pollutants from the studied medical waste incinerator plant

Pollutants	Concentration of Pollutant in Ambient Air (ug/m^3)	R_{fC} (ug/m^3)	Hazard Qoutient (HQ)
NO_2	<1.0	[c] 3500	2.86×10^{-4}
SO_2	<2.0	[b]28.2	0.071
HCl	<2.0	[a]20	0.10
Hg	<0.01	[c] 1.05	9.52×10^{-3}
Cd	<0.01	[c] 1.75	5.71×10^{-3}
Pb	0.03	[a]1.5	0.02

[a] Integrated Risk Information System (IRIS) by US EPA (http://www.epa.gov.iris)
[b] Agency for Toxic Substance and Disease Registry (ATSDR) (1998)
[c] R_{fC} estimated from oral R_{fD}

The similar study was conducted by Lonati and Zanoni on health risk estimation for Hg emissions from a municipal solid waste gasification plant [17]. The resulting hazard index value of Hg at the most impacted point in the study area was recorded as acceptable non-carcinogenic health risk of 1.26×10^{-4} for the adult and 3.77×10^{-4} for the child receptor. Nevertheless, the result of this study contrary to the study that has been conducted by Sun *et. al* [18]. They mentioned that hazard index of Hg in the dust from educational area posed a high non-carcinogenic risk on the children health. (Hazard index, HI = 6.89). Hence, health effects on the receptors in the studied area need further detailed investigation.

The excess lifetime cancer risk (LCR) of the carcinogenic pollutants from the studied medical waste incinerator plant are calculated to determine carcinogenic health risk associated with the medical waste incineration as shown in Table 8. Based on equation 3, exposure air concentration (EC) is the data from ambient air exposure in Table 6 multiply with inhalation unit risk factor (URF) which is the data from IRIS by US EPA and California Office of Health Hazard Assessment. The benchmark of $1x10^{-6}$ (i.e. 1 cancer case in a million populations) of excess lifetime cancer risk is often used to indicate acceptable risk [15]; [16]. However, the study reveals that the sum total of cancer risk due to emission of carcinogenic substances from the incinerator; LCR of Cd + LCR of Pb is 1.84×10^{-5}. This value indicates risky circumstances as the calculated risk is higher than the benchmark of acceptable risk of 1×10^{-6} which the estimated risk is almost entirely determined by cadmium, Cd with 1.8×10^{-5} while risk due to emission of lead, Pb is 3.6×10^{-7}. In fact, despite the higher concentration of Pb emitted to ambient air, the carcinogenic risk due to exposure of Pb is far lower than Cd. It strongly shows that the concentration of pollutant is not directly proportional to the excess lifetime cancer risk.

Based on literature studies conducted, Lonati and Zanoni in their study on emissions of carcinogenic pollutants (PCDD/Fs and Cd) from waste gasification plant, stated the same viewpoint that the emission control should focus on Cd rather than PCDD/Fs in order to reduce the carcinogenic risk [17]. They point out that the carcinogenic risk is approximately by 95% due to exposure of Cd. In contrast, Mari *et. al* reported air inhalation presented the minimum risk contribution to total heavy metals exposure as the acceptable risk for Cd and Pb is range from 1.49×10^{-8} to 5.87×10^{-8}, respectively [19]. However, the level of heavy metals in soil requires serious monitoring.

Table 8 Table for assessment of carcinogenic health effects from the studied medical waste incinerator plant

Pollutants	Concentration of Pollutant in Ambient Air (ug/m³)	Inhalation unit risk factor (URF) (ug/m³)⁻¹	Excess lifetime cancer risk (LCR)
Cd	<0.01	[a]1.8×10^{-3}	1.8×10^{-5}
Pb	0.03	[b]1.2×10^{-5}	3.6×10^{-7}
Total			1.84×10^{-5}

[a]Integrated Risk Information System (IRIS) by US EPA (http://www.epa.gov.iris)
[b]California Office of Health Hazard Assessment (http://oehha.ca.gov/tcdb)

4.0 CONCLUSION

The study focuses on the health risk assessment due to emissions from medical waste incinerator in Malaysia.Comparison of ambient concentration of pollutants emitted from the studied medical waste incinerator plant with limits imposed by Recommended Malaysian Ambient Air Quality Guidelines (1989) shows that receptors at 1 km from the studied medical waste incinerator plant are exposed to acceptable concentration of pollutant. Besides, the health risk assessment of pollutants emitted from studied medical waste incinerator plant shows that the pollutants would not cause health risk in term of non-carcinogenic health effect to the population residing at 1 km from the point of source because the calculated hazard qoutient value of the pollutants are ranges from 0.000286 to 0.1which lower than 1. However, the pollutants may cause health risk in term of carcinogenic health effect to the population residing at 1 km from the point of emission as the calculated excess lifetime cancer risk value is which is 1.84 x 10-5 ,being above the threshold value of 1x10-6. In this research, it is impossible to conclude that the studied area is exposed to the risk of cancer even though elevated concentrations of cadmium was calculated, since there is insignificant quantity of cadmium released compared to other pollutants due to medical waste incineration was presented in the environment. Nevertheless, special attention should be taken against the sensitive receptors, such as at nearby residences, hospitals and schools. Calculation of health risk associated with the operation of medical waste incinerator in Malaysia is needed to protect environment and human health.

Acknowledgement

The author would like to thank Malaysia Ministry of Higher Education (MOHE) for financial assistance while conducting this project.

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