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Health Risk Assessment among Adult and Children on Potential Air Pollutants Released from the Petrochemical Plant in Malaysia: The Result of Air Modelling

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ABSTRACT

Malaysia is the world's third largest exporter of liquified natural gas and the second largest oil and natural gas producer in Southeast Asia, following Indonesia. The potential air pollutants released from the industry may affect the health of the population. The primary objective of this study was to determine the potential health risk among the population in the zone of impact. This was a comparative case study between controlled and uncontrolled emissions based on the air dispersion modelling. Hazard quotient (HQ) was used to assess non-carcinogenic risk, while lifetime cancer risk (LCR) was used to assess carcinogenic risk. All ambient air pollutant levels were within permissible levels and adhered to the standard. The HQ for hydrogen sulphide and benzene was less than one in all scenarios. The LCR for benzene was acceptable in all scenarios. Advanced pollution prevention equipment should be installed within the gas emission system to treat the final emission to meet prescribed permissible limits. Continuous ambient air monitoring and effective control measures should be practiced to ensure the sustainability of clean air. The health risk assessment showed no risk of developing malignancy and non-cancer disorder among the workers and general population living surround the petrochemical plants. This allows the development of the petroleum refinery plants to be continued.

Keywords: Air modeling, health risk assessment, oil refinery, petrochemical plants, pollutants

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INTRODUCTION

Oil was first discovered in the Miri district of Sarawak in the early 1900s by one of the biggest oil and gas (OG) companies in the world. The oil exploration offshore

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of Sarawak found success in 1962, followed by the very first oil field discovery offshore of Peninsular Malaysia in 1971 (Hamdan et al., 2005). That oil discovery promoted opportunity and encouraged more companies to invest in the upstream, midstream and downstream oil industries, including Malaysia's proud OG company, Petroliam Nasional Berhad, which was formed in 1974 in accordance with the Petroleum Act of 1974 (Federal Government Gazette, 1974). The government of Malaysia has contributed significantly towards policy and macroeconomic planning to secure the sustainable and long-term success of the oil and gas industry.

Malaysia is the world's third largest exporter of liquified natural gas and the second largest oil and natural gas producer in Southeast Asia, following Indonesia. As of January 2017, Malaysia held proven oil reserves of 3.6 billion barrels, the fourth largest reserve in Asia Pacific after China, India and Vietnam. Petroleum and other liquid production in 2016 was estimated to be 744,000 barrels per day, a 15% increase since 2013 (U.S Energy Information Administration, 2017). One of the petrochemical plants located in Peninsular Malaysia has the capacity to produce 300,000 barrels per day (Rahman, 2018). With the addition of petrochemical plants, total production of specialty petroleum products will be 3.15 million metric tonnes per year (Malaysian Petrochemicals Association, 2016).

Benzene is a simple cyclic organic compound that occurs naturally in crude oil and is a constituent of petrol (Duarte-Davidson et al., 2001). The petroleum refinery industry is a major source of benzene in the environment. Previous studies have shown the association between exposure to benzene and potential adverse health effects involving the reproductive system (including pregnancy outcomes), respiratory system, nervous system, haematological system and immune system (Gist & Burg, 1997; Marchetti et al., 2011; Protano et al., 2012; Reutman et al., 2002; Smith, 2010). Benzene is a known human carcinogen (IARC, 2018). There is sufficient evidence to support the association between benzene exposure and haematopoietic malignancy, acute myeloid leukaemia, myelodysplastic syndromes, and lymphoma and childhood leukaemia (Smith, 2010). In fact, these malignancies can even occur at low benzene concentrations (Rinsky et al., 1987).

Hydrogen sulphide is a colourless gas with a characteristic odour of rotten eggs that can be found at low concentrations in the petroleum refining industries. The impurities in crude oil include oxygen, sulphur, nitrogen and other heavy metals (Jafarinejad, 2016), while in petroleum products, almost all of the sulphur content comprise hydrogen sulphide, carbonyl sulphide and carbon sulphide (Stumpf et al., 1998). Previous human studies suggested that the respiratory and nervous systems were the most sensitive targets of hydrogen sulphide toxicity (ATSDR, 2016). Exposure to lower concentrations can result in less severe neurological and respiratory effects. Reported neurological symptoms include headache and fatigue and effects on concentration, balance, memory, cognition, motor function and mood (depression). Reported respiratory effects include nasal irritation, sore throat, cough, dyspnoea and alteration in lung function tests (Bahadori, 2014; Lewis &

Copley, 2015; Lim et al., 2016). Hydrogen sulphide is considered a non-human carcinogen because of limited human and animal studies available to prove the carcinogenicity of the substance (ATSDR, 2016).

Children can be considered as a specific subgroup within public health regulations that are more sensitive than the average adult. With regard to susceptibility to toxicants, differences between children and adults may result from a combination of toxicokinetic, toxicodynamic and exposure factors (Schwenk et al., 2003). Children have a faster ventilation rate than adults, and they have relatively greater lung volume compared to body surface area. Chemical disposition including lipid and water content of the body and quantity of plasma protein binding sites differs between children and adults and tends to increase the volume of distribution for many chemicals, leading to lower blood concentrations and longer chemical half-lives (Daston et al., 2004). Young children are also not fully developed in terms of metabolic and renal clearance. Taking into consideration these unique characteristics found in children, their health risk assessment is different than that for adults.

In one of the states in Peninsular Malaysia, the residential areas are now in close proximity to the petrochemical plants, providing an opportunity to evaluate the health effects of a single source of pollution. These petrochemical refinery plants are the only large pollution source in the region of these residential areas. Therefore, the primary objective of this study was to determine the potential health risk for the people at the project site as well as at the surrounding residential areas by measuring the quantitative risk assessment for potential air pollutants using an air dispersion model for controlled and uncontrolled emission.

METHODS

This is a comparative case study between controlled and uncontrolled emissions based on the air dispersion modelling done for a new proposed petrochemical and refinery integrated plants project (Figure 1) from the detailed environmental impact assessment (DEIA) conducted in the year 2012.

Baseline ambient air monitoring was carried out at a total of 14 monitoring stations at the project site, site boundaries and sensitive receptors within a 5 km radius in November 2012. A total of 10 parameters was monitored: total suspended particulates (TSP), particulate matter (PM_{10}), sulphur dioxide (SO_2), nitrogen dioxide (NO_2), mercury (Hg), hydrogen chloride (HCl), chlorine gas (Cl_2), hydrogen sulphide (H_2S), carbon monoxide (CO) and benzene (C_6H_6). The ambient air samples were collected by drawing air from the surrounding area through an absorbent media via a pre-calibrated portable pump stationed at the monitoring point. The high-volume sampler method was used to collect the air samples for TSP and PM_{10}. The air samples were then sent for laboratory analysis.

Figure 1. Location of petrochemical and refinery plants. Place (A): Village LB, place (B): Village RBB, place (C): Residence RJ, place (D): Village RSK. Places A, B, C and D are the areas with the highest predicted pollutant concentration during normal and abnormal operation simulations based on air dispersion modelling.

The point sources of air emissions during the operational phase were identified. A total of 68 stacks consisting of heater stacks, specific process stacks, steam and power generation stacks, and flaring stacks will release a variety of air pollutants. The major components of the air pollutants released from the proposed project are total suspended particles, nitrogen dioxide, sulphur dioxide, hydrogen sulphide and benzene. The simulation for air pollution exposure was carried out; one was done at a location close to the proposed project site, and another was done near 28 residential areas. Residential area is defined as a land use in which housing or residences predominate, which may also be used for the purpose of administrative, commercial, education, medical, sanitary, entertainment, or any purpose which the State Authority may think fit to authorize (Department of Environment Malaysia, 2012). Residential areas in this study include villages and residences surround the proposed project site within 5 km radius zone of impact.

Two emissions scenarios were simulated for each location which are:

(a) Normal operation - The exposure when the air pollution control device is functioning (controlled emission).

(b) Abnormal operation - The exposure to air pollution without the control device (uncontrolled emission).

The model used was the U.S American Meteorological Society/Environmental Protection Agency Regulatory Model (AERMOD) for pollution aerial dispersion (Seangkiatiyuth et al., 2011). The Gaussian Dispersion Model was used to estimate the pollutant dispersion distance based on the variation of the stack heights. To cover all receptors within a 5 km radius from the project site boundary, results in contours were illustrated on an 18 km × 10 km cartesian grid with 200 metre spacing. The results of the modelling are presented in an air pollutant contours diagram for different parameters with average times and scenarios for development. The air dispersion results were a secondary data that published for the project and were compared with the regulation guidelines. The reliability of the model had been endorsed by the Department of Environment Malaysia.

Specific guidelines were used as a reference for ambient air level monitoring. The guidelines used herein were the Recommended Malaysia Ambient Air Quality Standard 2015 (Department of Environment Malaysia, 2013), the Arizona Ambient Air Quality Guidelines 1999 (Arizona Department of Health Services, 1999), Ontario's Ambient Air Quality Criteria 2012 (Ontario Ministry of the Environment, 2012), and the WHO Air Quality Guidelines for Particulate Matter, Ozone, Nitrogen Dioxide and Sulphur Dioxide 2005 (World Health Organization, 2005).

Exposure Scenarios

Several exposure scenarios were simulated:

(a) Scenario 1 - Inhalation exposure of air pollutants among adults within project site during normal operation.

(b) Scenario 2 - Inhalation exposure of air pollutants among adults within project site during abnormal operation.

(c) Scenario 3 - Inhalation exposure of air pollutants among adults at surrounding residential areas during normal operation.

(d) Scenario 4 - Inhalation exposure of air pollutants among adults at surrounding residential areas during abnormal operation.

(e) Scenario 5 - Inhalation exposure of air pollutants among children at surrounding residential areas during normal operation.

(f) Scenario 6 - Inhalation exposure of air pollutants among children at surrounding residential areas during abnormal operation.

Risk Assessment of the Pollutant

Chronic Daily Intake for Inhalation. In general, the chronic daily intake of air pollutants through inhalation can be calculated by Equation 1 (United States Environment Protection Agency, 1989, 2009):

$$CDI_{inh} = C \times \frac{R_{inh} \times ET \times EF \times ED}{BW \times AT} \qquad [1]$$

Where,
CDI_{inh} = Chronic daily intake for inhalation (mg/kg-day)
C = Concentration of air pollutant (mg/m^3)
R_{inh} = Inhalation rate (m^3/day)
ET = Exposure time (hours/24 hours)
EF = Exposure frequency (days/year)
ED = Exposure duration (years)
BW = Body weight (kg)
AT = Averaging time (days)

The concentration value (C) is based on the air dispersion modelling results. This concentration value is first converted from units of µg/m^3 to mg/m^3 (United States Environment Protection Agency, 2005). There were certain assumptions made in this study, as shown in Table 1. Physiologically, children inhale less than adults because of lower lung volume capacity than adults. Inhalation rates (R_{inh}) are calculated by the amount of the carrier medium crossing the boundary per unit time, measured as m^3 of air breathed per day. The estimated inhalation rate for children is 5 m^3/day, and for adults is 15 m^3/day (Du et al., 2013; Hong et al., 2017). The average body weight (BW) for Malaysian children aged 6 and 10 years old (Sandjaja et al., 2018) and adults (Lim et al., 2000) are approximately 13 kg, 19 kg and 58 kg respectively. However, in view of the prevalence of obesity in Malaysia increasing over the years for both children and adults (Naidu et al., 2013; Tan et al., 2019), therefore, the estimated average body weights for children and adults in this study were 20 kg and 70 kg respectively.

The pollutant exposure among children was not calculated for the project site since they were neither working nor staying at the petrochemical plants. According to the Malaysian Employment Act of 1955, an employee cannot be required under his or her contract of service to work more than eight hours in one day and 48 hours in one week. As an example, one of the petrochemical plants on the east coast of Peninsular Malaysia runs 24 hours a day seven days a week, which requires four different shift groups with each shift period lasting for 12 hours and individual shift workers generally working four shifts per week (Bahrin et al., 2004). Therefore, the exposure time (ET) in this example is 12 hours per

Table 1
Specific assumptions for exposure

Factor	Definition	Standard Unit	Scenario Specific Assumption		
			Within Project Site	Surrounding Communities	
			Adult	Children	Adult
*During Normal Operation Simulation					
C	Concentration of the pollutant	$\mu g/m^3$			
R_{inhal}	Inhalation rate	m^3/day	15	5	15
BW	Average body weight	kg	70	20	70
ET_{proj}	Exposure time	hours/24 hours	12	24	24
EF_{proj}	Exposure frequency	days/year	208	350	350
ED	Exposure duration	years	25	6	30
$AT_{noncarc}$	Average time (Non-carcinogen)	days	ED x 365 days	ED x 365 days	ED x 365 days
AT_{carc}	Average time (carcinogen)	days	70 years × 365 days	70 years × 365 days	70 years × 365 days
*During Abnormal Operation Simulation					
R_{inhal}	Inhalation rate	m^3/day	15	5	15
BW	Average body weight	kg	70	20	70
ET_{proj}	Exposure Time	hours/24 hours	12	24	24
EF_{proj}	Exposure frequency	days/year	2	2	2
ED	Exposure duration	years	25	6	30
$AT_{noncarc}$	Average time (Non-carcinogen)	days	ED x 365 days	ED x 365 days	ED x 365 days
AT_{carc}	Average time (carcinogen)	days	70 years × 365 days	70 years × 365 days	70 years × 365 days

day, and exposure frequency (EF) is four days per week for 52 weeks, or 208 days/year. An abnormal operation is expected to occur at least two times (days) per year.

The residential areas surrounding the project site are mostly villages, and the residents typically spend most of their lives in their village. Local activities involve agriculture, livestock, forestry, fisheries, culture, the local economy and tourism. The estimated exposure frequency for village residents in this study was 350 days per year, taking into account the period that the residents spend time outside of the area for activities such as vacation and festival celebration. The exposure duration (ED) was estimated at 30 years for non-carcinogen effects, so the average time (AT) was the number of days in 30 years. For carcinogenic effects, the risk is expressed as the excess probability of developing cancer over a lifetime, which is approximately 70 years by default.

Inhalation Reference Dose. The reference concentration (RfC) is an estimation of the maximum permissible risk to the human population through daily exposure, taking into consideration sensitive groups during a lifetime. The threshold RfC value can be used to indicate whether there are adverse health effects during a human lifetime. RfC is typically expressed as the chemical weight (mg) per volume (m^3) of air. Since the units for CDI_{inh} are in mg/kg-day, the RfC should be converted to reference dose (RfD_{inh}) in order to calculate the unitless hazard quotient (HQ). The risk screening environmental indicator (RSEI) method uses the standard adult human exposure factor for inhalation rate (20 m^3/day) and a body weight of 70 kg to convert the RfC (mg/m^3) to dosage units (mg/kg-day). The RfC value for each air pollutant is based on the United States Environment Protection Agency's Integrated Risk Information System (IRIS) as shown in Table 2. The conversion is calculated by the following Equation 2 (United States Environment Protection Agency, 2015):

$$RfD_{inh} = RfC \times \frac{1}{BW} \times R_{inh} \qquad [2]$$

Where, RfD_{inh} = Inhalation reference dose (mg/kg-day)
RfC = Reference concentration (mg/m^3)
BW = Body weight (kg)
R_{inh} = Inhalation rate (m^3/day)

Inhalation Cancer Slope Factor. The inhalation unit risk (IUR) is the upper-bound excess lifetime cancer risk estimated to result from continuous exposure to carcinogens at a concentration of 1 mg/m^3 in the air. The IUR is obtained from the database of the United States Environment Protection Agency's IRIS (United States Environment Protection Agency, 2005). The IUR is given in units of $\mu g/m^3$, which must be converted into units of mg/m^3 (multiplication by 1000). Similar to the RfC, the IUR expressed in units of exposure

Table 2
RfC values for potential air pollutants released from the industry

Air Pollutants	RfC (mg/m^3)	Reference
Total Suspended Particle (TSP)	Not available	-
Sulphur Dioxide (SO_2)	Not available	-
Nitrogen Dioxide (NO_2)	Not available	-
Hydrogen Sulphide (H_2S)	0.002	US EPA's IRIS 2003
Benzene (C_6H_6)	0.030	US EPA's IRIS 2003

RfC: Reference concentration
US EPA's IRIS: United States Environment Protection Agency's Integrated Risk Information System

(mg/m^3) must be converted to units of dose (mg/kg-day) for the calculation of toxicity relative to weight. An inhalation rate of 20 m^3/day and a body weight of 70 kg are used in Equation 3 (United States Environment Protection Agency, 2015):

$$CSF_{inh} = IUR \times BW \times \frac{1}{R_{inh}} \qquad [3]$$

Where, CSF_{inh} = Inhalation cancer slope factor (1/(mg/kg-day))
IUR = Inhalation unit risk (1/(mg/m^3))
BW = Body weight (kg)
R_{inh} = Inhalation rate (m^3/day)

Hazard Quotient Estimation. For non-carcinogenic health effects of air pollutants, the risk is expressed as HQ, which is the average daily exposure divided by the reference dose. An HQ of less than 1 is considered safe, and adverse effects are unlikely even for sensitive populations (Equation 4) (United States Environment Protection Agency, 2009).

$$HQ = \frac{CDI_{inh}}{RfD_{inh}} \qquad [4]$$

Where, HQ = Hazard quotient (unitless)
CDI_{inh} = Chronic daily intake for inhalation (mg/kg-day)
RfD_{inh} = Inhalation reference dose (mg/kg-day)

Lifetime Cancer Risk Estimation. Since benzene is the only confirmed human carcinogenic (category A) pollutant among the potential pollutant emissions in this study, the slope factor was used to calculate the cancer risk. The lifetime cancer risk (LCR) indicates the probability that an individual will develop cancer over a lifetime (70 years by default) as a result of exposure to a specific carcinogen. A cancer risk of one in a million (1×10^{-6}) means that if one million people are exposed, one cancer case would be expected. The United States Environment Protection Agency considers values within the range of 1×10^{-6} to 1×10^{-4} to be acceptable cancer risk for regulatory purposes. The LCR is calculated as in Equation 5 (United States Environment Protection Agency, 2009):

$$LCR = CDI_{inh} \times CSF_{inh} \qquad [5]$$

Where, LCR = Lifetime cancer risk (unitless)
CDI_{inh} = Chronic daily intake for inhalation (mg/kg-day)
CSF_{inh} = Inhalation cancer slope factor (mg/kg-day)$^{-1}$

RESULTS

Ambient Air Monitoring

The results of the ambient air monitoring are shown in Table 3. For each air pollutant, despite the highest ambient air level chosen from the ambient air monitoring station locations (total of 14 stations), the concentration level was within permissible levels and adhered to the guidelines. The highest ambient air level for most of the air pollutants were recorded at monitoring station (AN1), located at the north-western boundary of the project site. The highest ambient air level for ammonia nitrogen (0.344 mg/m^3) and benzene (0.008 mg/m^3) were recorded at monitoring station (AN8), located one km north of the project site. The highest ambient air level for hydrogen chloride (0.208 mg/m^3) was recorded at the project site.

Predicted Maximum Ambient for Air Pollutants from Air Dispersion Modelling

The predicted maximum levels during normal and abnormal operation were predicted using air dispersion modelling at two different locations; the proposed project site and surrounding residential areas located within a 5 km radius (Table 4). Sulphur dioxide, nitrogen dioxide and hydrogen sulphide concentration levels were found to be higher than permissible levels during the abnormal operation simulation at the proposed project site with values

Table 3
Ambient air levels for air pollutants

Air Pollutants	Unit	Averaging Time (Hours)	Highest Ambient Air Level	Permissible Level
Total Suspended Particle (TSP)	µg/m^3	24	66.000[a]	260.000*
Particulate Matter (PM_{10})	µg/m^3	24	59.000[a]	150.000*
Sulphur Dioxide (SO_2)	ppm	24	<0.001[a]	0.100#
Nitrogen Dioxide (NO_2)	ppm	24	<0.001[a]	0.100#
Mercury (Hg)	µg/m^3	24	<0.001[a]	2.000#
Ammonia Nitrogen (NH_3N)	mg/m^3	8	0.344[b]	100.000#
Hydrogen Chloride (HCl)	mg/m^3	8	0.208[c]	20.000#
Chlorine Gas (Cl_2)	mg/m^3	8	<0.001[a]	10.000#
Hydrogen Sulphide (H_2S)	ppm	8	<1.000[a]	7.000#
Carbon Monoxide (CO)	ppm	8	<5.000[a]	10.000*
Benzene (C_6H_6)	mg/m^3	8	0.008[b]	Not available

The highest ambient air level for each air pollutant was chosen among 14 monitoring stations (AN1 until AN14) at the project site, site boundaries and sensitive receptors within a 5 km radius for the purpose of ambient air monitoring.
a: Location AN1- At north-western boundary of the project site
b: Location AN8- Approximately 1.0 km north of the project site
c: Location AN9- Within the project site, near the existing dump site
*: Recommended Malaysia Ambient Air Quality Standard 2015
#: Ontario's Ambient Air Quality Criteria 2012

of 106.4 µg/m^3, 190.7 µg/m^3 and 47.2 µg/m^3 respectively. A similar pattern was found at surrounding residential areas where nitrogen dioxide and hydrogen sulphide concentrations were found to be higher than permissible levels during the abnormal operation simulation in village RSK and village RBB with values of 96.8 µg/m^3 and 19.1 µg/m^3 respectively. The predicted maximum ambient air for all air pollutants were acceptable at all areas (within project site and residential areas) during normal operation.

Non-Cancer Risk Assessment

HQ for each air pollutant was calculated based on simulated scenario given (Scenario 1 to 6) as shown in Table 5. In general, the HQ for hydrogen sulphide and benzene were less than one in all scenarios indicating that the non-carcinogenic risk for human exposure to both air pollutants are deemed as acceptable. The highest HQ for hydrogen sulphide was 8.0×10^{-2} in scenario 5. The lowest HQ for hydrogen sulphide was 3.9×10^{-2} in scenario 4. The highest HQ for benzene was 3.9×10^{-1} in scenario 5. The lowest HQ for benzene was 3.2×10^{-3} in scenario 2. The HQ for children (scenario 5 and 6) was higher than adult (scenario 3 and 4) due to difference in body weight between these children and adult. The HQ for other air pollutants (total suspended particles, sulphur dioxide and nitrogen dioxide) cannot be calculated since the RfC of these air pollutants were not available in the database.

Table 4

Air dispersion modelling for potential air pollutants released from the industry

Air Pollutant	Pollutant Concentration (µg/m^3)				
	Total Suspended Particle (TSP)	Sulphur Dioxide (SO_2)	Nitrogen Dioxide (NO_2)	Hydrogen Sulphide (H_2S)	Benzene (C_6H_6)
Averaging Time (Hours)	24	24	24	24	8
Guideline Value	260.000*	105.000*	75.000*	7.000#	Not available
At project site					
Existing Baseline	30.000	3.000	2.000	0.000	0.300
Normal Operation	35.100	27.600	53.300	0.470	14.600
Abnormal Operation	174.100	106.400	190.700	47.200	47.100
At surrounding communities					
Existing Baseline	97.000	3.000	2.000	0.000	6.700
Normal Operation	98.300[a]	20.700[b]	35.500[b]	0.190[b]	13.800[b]
Abnormal Operation	127.700[a]	61.300[c]	96.800[d]	19.100[b]	26.100[b]

The highest air pollutant level for each simulation (normal and abnormal operation) surround the project site was chosen among the 28 communities.

a: Village LB- Within 500 m south of the project site

b: Village RBB- Approximately 2 km east of the project site

c: Residence RJ- Approximately 700 m south-eastern of the project site

d: Village RSK- Approximately 3 km east of the project site

*: Recommended Malaysia Ambient Air Quality Standard 2015

#: Ontario's Ambient Air Quality Criteria 2012

Table 5

Hazard quotient for potential air pollutants released from the industry

Scenario	Total Suspended Particle (TSP)			Sulphur Dioxide (SO_2)			Nitrogen Dioxide (NO_2)			Hydrogen Sulphide (H_2S)			Benzene (C_6H_6)		
	CDI (mg/ kg-day)	RfD (mg/ kg-day)	HQ (Unit-less)	CDI (mg/ kg-day)	RfD (mg/ kg-day)	HQ (Unit-less)	CDI (mg/ kg-day)	RfD (mg/ kg-day)	HQ (Unit-less)	CDI (mg/ kg-day)	RfD (mg/ kg-day)	HQ (Unit-less)	CDI (mg/ kg-day)	RfD (mg/ kg-day)	HQ (Unit-less)
Scenario 1	2.1×10^{-3}	-	-	1.7×10^{-3}	-	-	3.3×10^{-3}	-	-	2.9×10^{-5}	5.7×10^{-4}	5.0×10^{-2}	8.9×10^{-4}	8.6×10^{-3}	1.0×10^{-1}
Scenario 2	1.0×10^{-4}	-	-	6.2×10^{-5}	-	-	1.1×10^{-4}	-	-	2.8×10^{-5}	5.7×10^{-4}	4.8×10^{2}	2.8×10^{-5}	8.6×10^{-3}	3.2×10^{-3}
Scenario 3	2.0×10^{-2}	-	-	4.3×10^{-3}	-	-	7.3×10^{-3}	-	-	3.9×10^{-5}	5.7×10^{-4}	6.8×10^{-2}	2.8×10^{-3}	8.6×10^{-3}	3.3×10^{-1}
Scenario 4	1.5×10^{-4}	-	-	7.2×10^{-5}	-	-	1.1×10^{-4}	-	-	2.2×10^{-5}	5.7×10^{-4}	3.9×10^{-2}	3.1×10^{-5}	8.6×10^{-3}	3.6×10^{-3}
Scenario 5	2.4×10^{-2}	-	-	5.0×10^{-3}	-	-	8.5×10^{-3}	-	-	4.6×10^{-5}	5.7×10^{-4}	8.0×10^{-2}	3.3×10^{-3}	8.6×10^{-3}	3.9×10^{-1}
Scenario 6	1.7×10^{-4}	-	-	8.4×10^{-5}	-	-	1.3×10^{-4}	-	-	2.6×10^{-5}	5.7×10^{-4}	4.6×10^{-2}	3.6×10^{-5}	8.6×10^{-3}	4.2×10^{-3}

CDI: Chronic daily intake
RfD: Reference dose
HQ: Hazard Quotient

Cancer Risk Assessment

For the cancer risk assessment, benzene was the only toxicant classified as a known human carcinogen in the United States Environment Protection Agency Classification and the IARC Classification. Therefore, the cancer risk assessment was calculated only for benzene as shown in Table 6. In general, the LCR for benzene was lower than value of 1 × 10^{-6} in all scenarios, indicating that the risk of developing benzene-related malignancy over a lifetime duration of 70 years is very minimal. The highest LCR for benzene was 3.3 × 10^{-8} in scenario 3. The lowest LCR for benzene was 8.4 × 10^{-11} in scenario 6. The HQ for children (scenario 5 and 6) was lower than adult (scenario 3 and 4) due to difference in exposure duration between these children and adult.

Table 6
Lifetime cancer risk for benzene released from the industry

	Benzene (C_6H_6)		
Scenario	CDI (mg/kg-day)	CSF $(mg/kg\text{-}day)^{-1}$	LCR (Unitless)
Scenario 1	3.2 x 10^{-4}	2.7 x 10^{-5}	8.7 x 10^{-9}
Scenario 2	9.9 x 10^{-6}	2.7 x 10^{-5}	2.7 x 10^{-10}
Scenario 3	1.2 x 10^{-3}	2.7 x 10^{-5}	3.3 x 10^{-8}
Scenario 4	1.3 x 10^{-5}	2.7 x 10^{-5}	3.6 x 10^{-10}
Scenario 5	2.8 x 10^{-4}	2.7 x 10^{-5}	7.7 x 10^{-9}
Scenario 6	3.1 x 10^{-6}	2.7 x 10^{-5}	8.4 x 10^{-11}

CDI: Chronic daily intake
CSF: Cancer Slope Factor
HQ: Hazard Quotient

DISCUSSIONS

National standards vary according to health risks, technological feasibility, economic considerations and various other political and social factors, which in turn depend on the level of development and national capability for air quality management (Vahlsing & Smith, 2012). In order to develop a national standard, epidemiological and toxicological studies from locations with similar population sizes and geographical and meteorological factors should be considered. Regardless of the specific values set at the global level (WHO) or in specific regions (United States, Canada and countries in Europe) for ambient air quality standards, Malaysia is an individual country that should design and implement its own national plans based on economic strategies, political wills, local laws and regulations (Green et al., 2002).

There is no fix rule on choosing which air quality standard in the environmental health impact assessment (EHIA). The selection of the air quality standard should consider geographical and meteorological background, economic stability, government policy, and social acceptance. The author decided to choose the Recommended Malaysia Ambient Air

Quality Standard of 2015 (Department of Environment Malaysia, 2013) and the Ontario's Ambient Air Quality Criteria 2012 (Ontario Ministry of the Environment, 2012) from the various established air quality standards and guidelines.

The air dispersion model is a desirable prediction model that can provide estimations not only for mean concentrations but also for peak time-average concentrations in any time interval (Efthimiou et al., 2011). The model is routinely used to provide reliable estimates of air pollutant concentrations over a variety of timescales and areas, including estimating short- and long-term concentrations at sensitive receptor sites. It is also used to provide evidence for predicted concentrations from relevant sources of pollution so that mitigation actions can be applied to areas that are potentially affected. The air dispersion model can allow regulators to assess emissions and evaluate the effectiveness of mitigation strategies prior to permitting operations, and can provide additional information to improve exposure assessments (Douglas et al., 2017).

As shown in the air dispersion modelling, the industry is predicted to release acceptable concentrations of potential air pollutants namely; total suspended particles, sulphur dioxide, nitrogen dioxide, hydrogen sulphide and benzene during normal operations when the control measures for air emissions are functioning adequately. However, if there is a failure in any component of air emission control, the concentration of certain potential air pollutants such as sulphur dioxide, nitrogen dioxide and hydrogen sulphide will exceed acceptable levels, especially at the project site. The employees should be aware and properly trained to mitigate this issue. The concern should be focused on the surrounding population as well because of concentrations of nitrogen dioxide and hydrogen sulphide exceeding the permissible level.

This detailed environmental impact assessment was made in view of the project operating throughout its lifespan which is approximately 30 to 50 years. Any changes in the petrochemical refinery process and operation would subject for a new impact assessment. Therefore, this article is relevant as assumption made that no changes of process taken place to date. The health risk assessment for exposure to toxic pollutants in this study was carried out based on predictions using air dispersion modelling. Hence, the individual health risk assessment could not be calculated since no personal air monitoring was conducted. The values of the HQ and LCR are a general estimation. The HQ for hydrogen sulphide and benzene showed no risk (values less than one) during both operation simulations among adult and children. The LCR value for benzene showed a very low risk of developing benzene-induced haematological malignancy.

Control of Air Pollutants Emission from Petrochemical Plants

The major air pollutants that will be emitted from the petrochemical plants include total suspended particles, sulphur dioxide, nitrogen dioxide, hydrogen sulphide and benzene.

Certain control actions should be performed by the project management. Advanced pollution prevention equipment such as low nitrogen oxide burners, de-nitrogen oxide equipment, de-sulphur oxide equipment and dust collection equipment should be installed within the gas emission systems to treat the final emissions and to meet prescribed permissible limits as stipulated in the Environmental Quality (Clean Air) Regulation of 2014 (Federal Government Gazette, 2014).

Considering the feasibility of control technology, the most achievable control technology is recommended to reduce the emissions of the air pollutants that are anticipated to be produced from the project. The fuel source to be used for the proposed project is either the process gas, low-sulphur fuel oil, or natural gas, so the particulate matter produced from the waste gas is very low (McDonald et al., 2004). In addition, a scrubber or filter is installed to reduce the particulate matter in the waste gas emissions. In order to reduce the concentration of sulphur oxide emissions, process gas, low-sulphur fuel oil and natural gas are used as a fuel source for heater, cracker and boiler firing. Low nitrogen dioxide burners are employed for boiler and heater systems to reduce the flame temperature and hence decrease the generation of nitrogen oxides.

The process tail gas that contains hydrocarbons is treated in the recovery system before it is vented to the atmosphere. In emergency situations, any hydrocarbon in the unrecovered process tail gas is burned by flare. Hydrocarbon removal efficiency of up to 98% can be achieved in the flare burning process (Ismail & Umukoro, 2012). The flare system is equipped with a spare emergency electricity supply system and fuel to the flare system is transported via pressure force, so the efficiency of the flare system is affected during power failures (Bahadori, 2014). Regular maintenance of point sources of emissions should be done to ensure that the plant is operating at its optimum level and to comply with the emissions limits.

Continuous real-time stack emission monitoring by Department of Environment Malaysia should be done strictly as per required by the Environmental Quality (Clean Air) Regulation of 2014 at all point sources of emission in the petrochemical plants. The objectives of continuous monitoring are to ensure that the control devices function at full capacity, to ensure that the gases emitted from the stacks are below permissible level and to serves as the evidence for environmental legislation and enforcement.

Air Pollutants Mitigation

In the event of abnormal operations which may involve failure of the process equipment, the relevant plant should be temporarily shut down until it can resume normal operations. The project management should ensure that the project operation can be terminated within an hour. The failed equipment should then be repaired as soon as possible.

The monitoring of ambient air pollutant levels at the project site and at surrounding residential areas should be conducted and reported regularly by Department of Environment Malaysia. Health surveillance should be done by the nearest district health office to monitor the air pollutant related disease among the nearby population especially cardiovascular and respiratory morbidity and mortality. These data together with ambient air monitoring data are crucial to estimate the burden of disease among communities and to relate with potential air pollutant released from the petrochemical plants. The nearest government health clinic and hospital should be well-prepared and have strong capacity to cope with the unexpected numbers of patients.

During the event of uncontrolled emission of air pollutants, risk communication to the affected community should be delivered effectively. The community has right to know about the incident, the toxicant released, and the possible health risk to them. The company should be transparent not only to their stakeholders and investors, but also to the respective government agency, state authority, workers, public and the mass media. A good risk communication relieves the public panic and ensure effective mitigation action taken. Multi-agencies collaboration including District and State Authority, Department of Environment Malaysia, Ministry of Health Malaysia, Fire and Rescue Department of Malaysia, Royal Malaysia Police, Civil Defence Forces (*Angkatan Pertahan Awam*) and others is needed to ensure effective disaster management. Each agency has their specific function to provide necessary action.

Workers should comply with the safe work practice to minimize the risk to them and the surround people. They should wear appropriate and adequate personal protection equipment (PPE) while performing task at the petrochemical plants. Unsafe act should be avoided at the workplace such as smoking, not wearing appropriate respiratory protection while handling volatile organic compounds, not comply with standard operation procedure (Federal Government Gazette, 1994). The medical surveillance component of the health surveillance programme should be conducted among the workers periodically according to Occupational Safety and Health (Use and Standards of Exposure of Chemicals Hazardous to Health) Regulations 2000 (Federal Government Gazette, 2000) . In the same regulation, the worker should be removed from any work that exposed them to chemical hazardous to health.

Public have their role as well in this mitigation action. They should ensure good indoor air quality at home; avoid tobacco smoking, avoid use of household product-containing volatile organic compound, and others. Air cleaners for home use and office use can provide relief indoor but need to consider cost of purchasing and maintenance. The outdoor activities should be limited to reduce exposure towards the air pollutants. They should take care of their health and to seek medical attention if developed air pollutant-related diseases. Open burning should be prohibited. Public early warning system for example siren and alarm system at the petrochemical plants should be activated to alert the public when indicated.

CONCLUSIONS

In conclusion, the baseline ambient air concentrations for all air pollutants were found to be acceptable and below the permissible levels. The health risk assessment showed no risk of developing malignancy and non-cancer disorder among the workers and general population living surround the petrochemical plants. This allows the project to continue the development of the petroleum refinery plants and to operate at full capacity, providing advanced, efficient and well-maintained engineering control measures. Continuous monitoring by the oil and gas company and government authorities such as the Department of Environment of Malaysia should be done in areas prone to air pollution to fulfil the requirements of the laws and legislation. Oil and gas industries are very crucial to economic growth in Malaysia but should not forget the health complications that may arise from toxicant exposure if the emissions are not controlled.

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