



Levels of Petroleum Hydrocarbons in Soil Near an Onshore Crude Oil Storage Facility in Malaysia

Kuok Ho Daniel Tang^{1*}, Chung Hieng Ithra Ting²

¹(Environmental Science Program, Division of Science and Technology, Beijing Normal University-Hong Kong Baptist University United International College)

²(Department of Petroleum Engineering, Faculty of Engineering and Science, Curtin University Malaysia)
Corresponding Author: Kuok Ho Daniel Tang

ABSTRACT: Accidental oil spills and leakage have been a concern of many onshore oil facilities and such spills could lead to contamination of soil surrounding the facilities by noxious petroleum hydrocarbons particularly benzene, toluene, xylene and the polyaromatic hydrocarbons. This study aims to examine the petroleum hydrocarbons in the soil next to an onshore crude oil storage facility qualitatively and quantitatively. Five soil samples were collected outside the facility at 15 m interval towards a residential area about 90 m away. The soil samples were sieved to obtain soil particles less than 2 mm in diameter. Soxhlet extraction with hexane was conducted to extract the petroleum hydrocarbons from the sieved soil samples. The extracts were concentrated and analyzed with GCMS. The results showed that the soil samples contained aromatic, cyclic aliphatic and straight-chain aliphatic hydrocarbons. No PAHs were found. Soil samples in the first 30 m of sampling contained ethylbenzene and xylene which were not detected in subsequent samples. Aliphatic hydrocarbons were prevalent in subsequent samples. Quantitative analysis focused only on aromatic hydrocarbons due to the associated health concerns. It demonstrated that the levels of the aromatic hydrocarbons exceeded the screening levels. This study highlights the need of more extensive spatial and temporal soil investigations around onshore crude oil storage facilities and a buffer zone against commercial and residential development. Remediation should be initiated if the contamination is confirmed.

KEYWORDS: Benzene, Petroleum, Polyaromatic Hydrocarbon, Soil, Xylene

Received 06 Feb, 2021; Revised: 18 Feb, 2021; Accepted 20 Feb, 2021 © The author(s) 2021.

Published with open access at www.questjournals.org

I. INTRODUCTION

Accidental oil spill has been a subject of concern especially in and around offshore drilling facilities, onshore refineries, pipeline system and storage tankers [1][2]. Based on the International Tanker Owners Pollution Federation (ITOPF), approximately 5.73 million tons of oil were estimated to leak into the environment from storage tankers between 1970s and 2016 [3]. In 2011, 10 tons of crude oil leaked into a monsoon drain from a burst pipeline, which transferred crude oil to storage tanks at Port Dickson, Malaysia. The leakage had not been detected in a timely manner, resulting in its subsequent escalation into a massive spillage [4]. Subsequent investigation revealed that technical failure in the crude oil storage facility could be a contributing factor to the leakage [4]. This raises concerns of accidental oil spills in and around onshore and offshore oil and gas facilities which may have gone undetected [5].

Crude oil contains a wide range of hydrocarbon compounds collectively known as the Total Petroleum Hydrocarbons (TPHs) [6]. The hydrocarbon compounds could be aliphatic with straight- and branched-chain structural formula or aromatic containing one or more planar rings of atoms [7]. Polycyclic Aromatic Hydrocarbons (PAHs) are aromatic compounds of relatively high molecular weights with 2 or more aromatic rings in different orientations [8]. There are two types of PAHs, namely pyrogenic PAHs and petrogenic PAHs, based on the number of aromatic-fused rings in their structures. Pyrogenic PAHs have higher molecular weights with 4 to 7 fused aromatic benzene rings in the molecular structures while petrogenic PAHs are of lower molecular weights containing 2 to 3 fused aromatic benzene rings [9]. PAHs are generally classified as persistent organic pollutants and can stay in the environment for a long duration [10].

Pyrogenic PAHs are formed when fossil fuels undergo incomplete combustion or are exposed to high temperature of approximately 350°C to more than 1200°C in low-oxygen environment [11]. Petrogenic PAHs come from the leakage of crude oil and refined petroleum products, and are more widespread in the environment compared to the pyrogenic PAHs [9]. PAHs are also generated from various anthropogenic sources such as cigarette smoke, waste gas emitted from vehicles, and cooking activities particularly grilling using charcoal. Besides, PAHs are produced from natural processes, for example volcanic eruption, forest fires and petroleum seeps [12]. Nonetheless, according to Abdel-Shafy and Mansour, incomplete combustion of organic compounds is the largest contributor of PAHs into environment [11].

Some of PAHs have carcinogenic and mutagenic properties, which can lead to cancer. Due to their toxicity, 16 PAHs have been listed as “priority pollutants” by United State Environmental Protection Agency (EPA) [13]. Among these 16 priority PAHs, 7 of them, i.e. benzo(a)anthracene, chrysene, benzo(a)pyrene, benzo(b)fluoranthene, benzo(k)fluoranthene, dibenz(a,h)anthracene, and indeno(1,2,3-cd)pyrene have been classified as carcinogenic to human health [10]. These carcinogenic PAHs have higher molecular weights and are mostly heavy PAHs. They are listed in Table 1 below. The bolded PAHs are probable human carcinogens [14].

Table 1: US EPA 16 priority PAHs and their physical-chemical properties [15]

Polycyclic Aromatic Hydrocarbon	Structure (number of rings)	Molecular Weight (g/mole)	Solubility (mg/L)	Vapor pressure (mm Hg)
Naphthalene	2	128.17	31.0	8.89E-02
Acenaphthene	3	154.21	3.8	3.75E-03
Acenaphthylene	3	152.2	16.1	2.90E-02
Anthracene	3	178.23	0.045	2.55E-05
Phenanthrene	3	178.23	1.1	6.80E-04
Fluorene	3	166.22	1.9	3.24E-03
Fluoranthene	4	202.26	0.26	8.13E-06
Pyrene	4	202.26	0.132	4.25E-06
Chrysene	4	228.29	0.0015	7.80E-09
Benzo (a) anthracene	4	228.29	0.011	1.54E-07
Benzo(a) pyrene	5	252.32	0.0038	4.89E-09
Benzo(b) fluoranthene	5	252.32	0.0015	8.06E-08
Benzo(k) fluoranthene	5	252.32	0.0008	9.59E-11
Dibenz(a,h) anthracene	6	278.32	0.0005	2.10E-11
Benzo(g,h,i)perylene	6	276.34	0.00026	1.00E-10
Indeno [1,2,3-cd] pyrene	6	276.34	0.062	1.40E-10

PAHs react differently in different media. As PAHs are highly lipophilic, they readily dissolve in organic solvents but not in water [11]. The aqueous solubility of PAHs tends to decrease with increasing rings in their molecular structures. PAHs can undergo photodecomposition upon encountering ultraviolet light from the sun either in water or after adsorbing onto other substances [11]. In the atmosphere, nitro-PAHs, dinitro-PAHs and sulphonic acids can form when PAHs undergo chemical reactions with ozone, nitrogen oxides and sulphur dioxide respectively [16].

Moreover, PAHs in soil might migrate into underground aquifer and cause contamination of ground water. A study showed that PAHs could migrate from pollution sources to topsoil, and subsequently to the bottom layers of the soil, the vadose zone underground and finally underground aquifer, causing groundwater pollution [17]. The contamination of groundwater can severely affect crops especially when the groundwater is used for irrigation and consumption of the contaminated crops leads to human health concerns [18]. While onshore oil and gas facilities are known to be significant sources of TPHs particularly petrogenic PAHs in the environment, very few regional studies have been conducted to investigate the quantity and types of TPHs around major onshore oil and gas facilities particularly a crude oil storage site where crude oil storing, distributing and transporting are likely to cause accidental spillage which can potentially lead to contamination of soil in the surrounding. Most regional studies revolve around detecting and quantifying the TPHs and PAHs in coastal and riverine sediments, and are not directly targeted at soil around a potential source [9]. Such contamination, albeit incidental and minor, could increase the TPHs in soil over time and pose threat to human health when there are human receptors in the vicinity. This study therefore, aims to examine the types and quantity of petroleum hydrocarbons in the soil around a major crude oil storage facility with residential areas established in its proximity. It examines if the levels of petroleum hydrocarbons detected are of concern to these receptors.

II. MATERIALS AND METHODS

2.1. Sampling and Pre-treatment of Samples

Soil samples were collected from the soil surrounding a crude oil terminal in Sarawak, Malaysia using a hand auger. A total of 5 soil samples were collected 15 cm below the top surface of soil, at 15 m interval starting from the perimeter of the crude oil terminal (see Figure 1). The sampling transect was chosen based on the water flow and receptors' distribution of the area. It represents the lower ground of the terminal's proximity where human exposure is possible due to the presence of settlements nearby. Figure 1 shows the soil sampling points denoted as SS1 to SS5.

The soil samples were placed in zip lock plastic bags and transferred to the laboratory within 6 hours after sampling. The samples were stored at 4°C prior to analysis which was conducted within 48 hours after sampling. The samples were air-dried at room temperature for 24 hours and sieved through 2 mm sieve to ensure homogeneity. After that, the sieved samples (<2 mm soil particle size) were stored in containers for subsequent extraction.



Figure 1. Soil sampling points from outside the crude oil terminal towards a residential area

2.2. Soxhlet Extraction

5 g of the respective sieved soil samples were mixed with 5 g of solid anhydrous sodium sulfate at a ratio of 1:1. Next, the mixture was transferred to a cellulose thimble which was lowered into in Soxhlet extractor vessel [19]. 200 ml of hexane (extraction solvent) was poured into a 250 ml round bottomed flask in the fume cupboard. The Soxhlet extraction unit was set up as shown in Figure 2. The bottom arm of the Liebig condenser was connected to the cold water tap via a rubber tube and the upper arm connected to a rubber tube draining into a sink. The Soxhlet extraction vessel was connected to the round bottomed flask with a suitable glass adaptor. The solvent was heated at 60°C. The extraction was conducted for 24 hours at 4-6 cycles/hour [20]. Figure 2 shows the schematic diagram for Soxhlet extraction apparatus setup. The solvent/extract was subsequently concentrated with the Kuderna-Danish concentrator until all the solvent had been distilled off. Duplicates of the extract were produced from each soil sample for analysis.

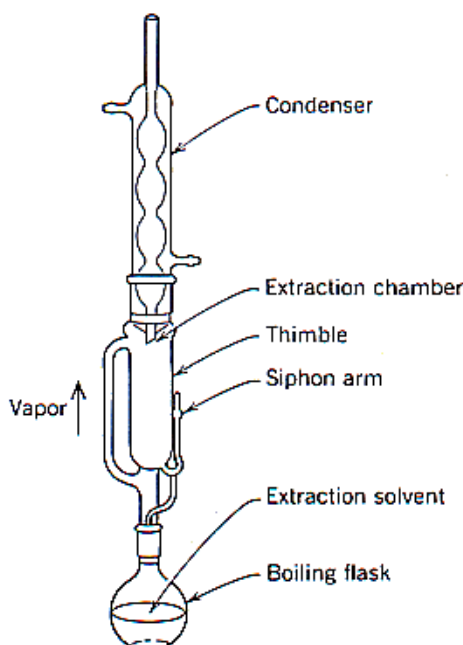


Figure 2: Soxhlet extraction for TPHs in soil samples

2.3. Gas Chromatography-Mass Spectrometry (GCMS)

After the extraction was complete, the extracts were analyzed using GCMS. The presence and concentrations of the 16 priority PAHs namely naphthalene, acenaphthylene, fluorene, phenanthrene, chrysene, benzo(b)fluoranthene, benzo(k)fluoranthene, benzo(a)pyrene, indeno(1,2,3,-cd)pyrene, dibenzo(a,h)anthracene, benzo(g,h,i)perylene, acenaphthene, fluoranthene, pyrene and benzo(a)anthracene, were analyzed together with other petroleum hydrocarbons.

HP 6890 Gas chromatographer (Agilent Technologies) coupled to a 5973 Mass Selective Detector (Agilent Technologies) with 30 m x 0.25 mm ID, RtxVolatiles (Restek Corp.) capillary column with 3.0- μ m film thickness was used to identify and quantify the petroleum hydrocarbons. Purging was done before running the GC. Analyte was prepared by diluting the extracts with hexane, constituting a 1.0 ml mixture. An aliquot of 2 μ l diluted solution was injected with splitless mode and purged for 6 minutes. High purity helium gas was used as carrier gas and the flow rate was set at 1.0 ml/min. The temperature was programmed at 40°C for the initial 4 minutes and subsequently increased to 165°C at a rate of 9°C per minute and held for 2 minutes. After that, the temperature was increased to 220°C at a rate of 12°C per minute and held for 7 minutes. The temperatures of injection port and ion source were set to be 150°C and 230°C respectively. The interface of GC to MS temperature was set to be 250°C. Mass spectrometry was switched to the electron ionization (EI) mode and ion monitoring (SIM) mode was selected to examine the quantities of petroleum hydrocarbons of interest in the sample.

2.4. Analysis and Interpretation of Results

Qualitative and quantitative analyses were conducted to determine the abundance and concentration of a specific petroleum hydrocarbon. For qualitative analysis, the presence of each petroleum hydrocarbon of interest in the extracts was determined by comparing the retention time against the reference retention time provided by the GCMS database from previous calibrations to evaluate the similarity. Similarity above 80% indicates high chances of the compound existing in the extracts.

Quantitative analysis was conducted to determine the concentration of a target chemical compound in the extracts. Based on the results of qualitative analysis, petroleum hydrocarbons of interest detected were then quantitatively analyzed to measure their concentrations against an internal standard under same analytical conditions. The internal standards of the particular chemical compounds were injected into GCMS at a concentration of 100mg/ml after diluting with hexane to a final volume of 1.0 ml in order to obtain the peak area for concentration calculation of the target compounds [21]. The concentration of the target chemical compounds can be calculated by following equation below.

$$C_X = \frac{C_S}{A_S} \times A_X \quad \rightarrow (1)$$

where C stands for concentration and A the peak area, and the subscripts refer to the target compound (X) and internal standard (S).

III. RESULTS AND DISCUSSIONS

The GC result presented as abundance against retention time plot showed no significant peaks caused by detection of PAHs. It indicates that the 16 priority PAHs were absent from the soil samples. However, other petroleum hydrocarbons were found in the samples and some of them belong to the benzene, toluene, ethylbenzene and xylene (BTEX) category. The Regional Screening Levels (RSLs) of the US EPA were used to evaluate the contamination levels of the soil samples [22]. The RSLs are widely adopted for the screening and management of contaminated sites. The concentrations of any petroleum hydrocarbons in the soil sample that exceed the threshold or screening levels were considered as contamination. MS results show the concentrations of the petroleum hydrocarbons of interest detected in the soil samples.

3.1. Qualitative Analysis

Qualitative analysis revealed the presence of aromatic as well as cyclic and straight-chain aliphatic compounds in the soil samples. PAHs were not detected. Table 2 shows the chemical species in SS1. 5 aromatic compounds, 7 cyclic aliphatic and 9 straight-chain aliphatic compounds were detected in SS1, including EX of the BTEX, except toluene and benzene.

Table 2: Petroleum hydrocarbons detected in SS1

Aromatic	Cyclic Aliphatic	Straight-chain Aliphatic
1,3-dimethylbenzene (m-xylene)	1,3-dimethyl-trans-cyclohexane	2-methyloctane
Ethylbenzene	Methyl-cyclohexane,	Nonane
o-Xylene	1,2-dimethyl-trans-cyclohexane	Octane
1,2,3-trimethylbenzene	Ethyl-cyclohexane	2,5-hexanedione
1-ethyl-2-methylbenzene	1,2,4-trimethyl-cyclohexane	2,3-dimethylhexane
	1-Ethyl-4-methyl-cyclohexane	3-methylheptane
	Propyl-cyclohexane	2-methyloctane
		Nonane
		Decane

Note: BTEX compounds bolded

Table 3 shows the soil sample contained 3 aromatic hydrocarbons, 4 cyclic aliphatic and 9 straight-chain aliphatic hydrocarbons. The aromatic hydrocarbons are benzene derivatives but are not classified as BTEX. Tables 4, 5 and 6 show the absence of BTEX compounds. The numbers of cyclic and straight-chain hydrocarbons decreased with increasing distance from the oil terminal and cyclic aliphatic compounds were not detected in SS5 furthest from the perimeter of the terminal. The decreasing number of hydrocarbon species is also demonstrated in Figure 3 as the distance from the perimeter of the crude oil terminal increases. Detection of EX in SS1 raises potential concern of accidental and occupational exposure though there were no settlements along the 75 m sampling transect extending in the direction of the nearest settlement about 90 m from the perimeter of the terminal. This is in line with the findings of Soukup et al. that BTEX had been detected in the soil near the pipeline system of a decommissioned crude oil and natural gas production facility [23]. No PAHs, however, had been detected in the soil samples.

Table 3: Petroleum hydrocarbons detected in SS2

Aromatic	Cyclic Aliphatic	Straight-chain Aliphatic
1,2,4-trimethylbenzene	Methyl-cyclohexane	2,4-dimethylhexane
1-ethyl-2-methylbenzene	1,3-dimethyl-trans-cyclohexane,	2-methylheptane
1,2,3-trimethylbenzene	1-ethyl-3-methyl-cis-cyclopentane	3-methylheptane
	Ethyl-cyclohexane	Octane
		Nonane
		Decane
		10-Methylnonadecane
		Tetracosane
		Nonadecane

Note: BTEX compounds bolded

Table 4: Petroleum hydrocarbons detected in SS3

Aromatic	Cyclic Aliphatic	Straight-chain Aliphatic
	Methyl-cyclohexane	Nonadecane

Decane
Tetracosane
3-Hexanone
2-Hexanone
3-Hexanol

Table 5: Petroleum hydrocarbons detected in SS4

Aromatic	Cyclic Aliphatic	Straight-chain Aliphatic
	Methyl-cyclohexane	3-Hexanone 2-Hexanone 3-Hexanol

Table 6: Petroleum hydrocarbons detected in SS5

Aromatic	Cyclic Aliphatic	Straight-chain Aliphatic
		3-Hexanone Tetracosane 5-butylidocosane

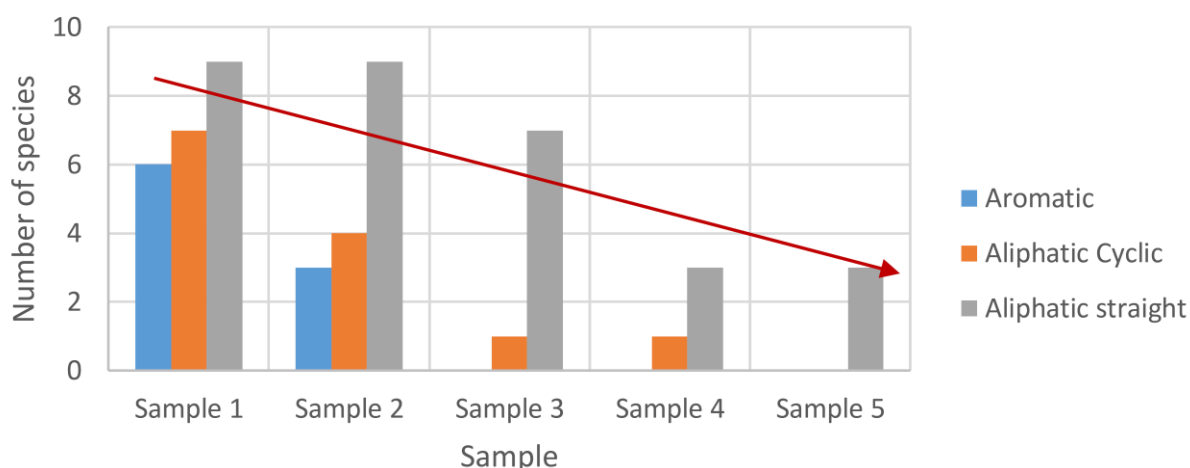


Figure 3: Number of aromatic, cyclic aliphatic and straight-chain aliphatic hydrocarbon species in the soil samples

The qualitative analysis is in agreement with the findings of Udoinyang et al. that the number of petroleum hydrocarbon species decreased with increasing distance from the contamination point and the common contaminants comprise aromatic and aliphatic hydrocarbons [20]. Both aromatic and aliphatic hydrocarbons had been detected in this study with aliphatic hydrocarbons dominating in terms of number. In fact, only aliphatic hydrocarbons were detected from SS3 onwards. Aliphatic hydrocarbons generally have higher screening levels than the aromatic hydrocarbons, thus having lower risks to health [22]. Besides, none of the petroleum hydrocarbons detected in SS5 were listed in the US EPA’s RSLs Summary Table [22]. 2-hexanone detected in SS4 has an RSL of 1300 mg/kg for industrial soil but it was not detected in SS5. Except for 1,3-dimethylbenzene which is also named m-xylene, certain benzene derivatives namely 1,2,3-trimethylbenzene, 1,2,4-trimethylbenzene and 1-ethyl-2-methylbenzene detected in SS1 and SS2 are not members of the BTEX.

3.2. Quantitative Analysis

Since PAHs were absent in all the soil samples, the quantitative analysis focused on the aromatic BTEX compounds to determine if the levels of the BTEX were compliant with the RSLs. The internal standards of the detected BTEX, namely 1,2,4-trimethyl-benzene, 1-ethyl-2-methyl-benzene, 1,3-dimethyl-benzene, ethylbenzene and o-xylene, were prepared at the concentrations of 100 mg/ml, 200 mg/ml, 300 mg/ml, 400 mg/ml and 500 mg/ml. Calibration curves of peak versus concentration (mg/ml) were obtained to extrapolate the concentrations of the targeted compounds in the soil samples. The percent peak area of the compounds and the corresponding concentrations are shown in Table 7. As EX were detected only in SS1 and SS2, quantitative analysis was conducted only for these two samples. O-xylene recorded the highest concentration (19.04 mg/ml)

among aromatic hydrocarbons detected in SS1 while 1,2,3-trimethylbenzene was the most abundant (15.16 mg/ml) of all aromatic hydrocarbons detected in SS2.

Concentrations of the aromatic hydrocarbons in mg/ml of hexane were converted to mg/kg of soil for comparison with the RSLs. With 5g of soil samples yielding 1 ml of extracts for analysis, a conversion factor of 200 was applied to obtain the concentrations in mg per kg of soil. Table 8 reveals that the concentrations of all the target chemical compounds exceeded the RSLs for industrial soil. The sampling sites would be more appropriately categorized as industrial soil where no settlements have been established even though residential areas are only approximately 90 m away from the boundary of the terminal. Industrial soil has generally higher screening levels of the aromatic hydrocarbons than residential soil. Exceedances of the BTEX members, particularly xylene, were significant. Although these chemicals were not detected in subsequent soil samples, they could present risk to the workers or the public who pass by the area.

Table 7: Percent peak area and concentrations of the BTEX of concern

BTEX	Percent Peak Area (%)		Concentration (mg/ml)	
	SS1	SS2	SS1	SS2
1,2,3-trimethylbenzene	3.416	2.193	16.385	15.163
1,2,4-trimethylbenzene	-	2.232	-	12.430
1-ethyl-2-methylbenzene	3.454	2.685	13.592	12.061
1,3-dimethylbenzene	3.416	-	16.698	-
Ethylbenzene	1.513	-	0.148	-
o-xylene	4.400	-	19.040	-

Table 8: Comparison of the Concentrations of BTEX in mg/kg against the Regional Screening Levels (RSLs)

Chemical Compound	Concentration (mg/kg of soil)		Screening Level (Industrial Soil) (mg/kg)
	SS1	SS2	
1,2,3-trimethylbenzene	3277	3032	2000
1,2,4-trimethylbenzene	-	2486	1800
1-ethyl-2-methylbenzene	2718	2412	Not specified
1,3-dimethylbenzene	3340	-	2400
ethylbenzene	29.6	-	25
o-xylene	3808	-	2800

Note: Bolded numbers indicate exceedance of the screening levels

The BTEX members from the soil samples at the study site were substantially higher than the range of 1.1 – 689.4 µg/kg reported for the soil samples of contaminated sites near underground storage tanks in Korea. As BTEX is generally volatile and degrades rapidly, the concentration of BTEX could be lower than other hydrocarbons [24]. This could therefore infer potential leakage or spillage from an operational facility compared to a decommissioned facility where the BTEX could have degraded with time [25]. The EX levels detected in this study are also higher than those reported for the subsurface soil sampled near wellhead and group gathering facility of a contaminated site in Nigeria with the highest BTEX level of approximately 2.5 mg/kg and the highest TPHs of about 4 mg/kg detected [20]. The retention of BTEX is partly affected by soil texture where loam and clay loam soils tend to adsorb TPHs more strongly than sand [26]. The high levels of BTEX members at the study site might be attributed to soil profile of the site but they were not detected in SS3 onwards further away from the crude oil terminal due probably their volatility.

However, it is not uncommon to have high levels of BTEX in contaminated soil and the concentrations often differ with the types of contaminant. Pinedo et al. detected an average of 13.22 mg/kg benzene in 10 soil samples contaminated with heavy oil in the Netherland [21]. Seven soil samples contaminated with gasoline recorded average concentrations of 121 mg/kg, 82.08 mg/kg and 549 mg/kg for toluene, ethylbenzene and xylene respectively. Soil contaminated with heavy oil contained relatively high concentrations of PAHs at an average of 2844 mg/kg among 10 soil samples analyzed. PAH levels in soil samples contaminated with weathered heavy oil were also high, averaging at 2252 mg/kg [21]. Exceedingly high TPHs had been reported for soil contaminated by subsoil pipelines while the levels of PAHs were considerably low [27]. This partially aligns with the non-detection of PAHs in this study. Crude oil contains a mix of the light and heavy components of various molecular weights and it is likely that soil contaminated by crude oil has significantly lower PAHs than that contaminated by heavy oil alone [7].

3.3. Implications and Limitations

This study reveals the absence of PAHs in the soil samples collected between the crude oil terminal and the nearest residential area, hence the absence of exposure risk to PAHs due to soil contact. This study shows the presence of EX in the soil samples near the terminal which were not detected in soil samples near the residential area, thus, negating the risk of exposure to EX as a result of soil contact. Nonetheless, this study found the presence of aliphatic hydrocarbons in the soil near the residential area albeit not having their RSLs provided by the US EPA. It can be safely said that the risk of exposure of the residents in the vicinity of the crude oil terminal to petroleum hydrocarbons, especially the BTEX, due to contact with soil is low. There is higher risk of occupational and incidental exposure to the hydrocarbons including the EX. Air exposure to BTEX is deemed to be likely since BTEX are volatile [21]. This is beyond the scope and forms an obvious limitation of this study.

Despite that the number of hydrocarbon species decreased with increasing distance and there were only three species of hydrocarbons detected in the soil sample nearest to human settlements, the presence of 3-hexanone might raise concern. 2-hexanone, an isomer of 3-hexanone, has been conferred an RSL of 1300 mg/kg for industrial soil [22]. The US EPA did not provide the RSLs for tetracosane and 5-butyldocosane. It could be essential to continue tracking the level of hexanone in the soil nearer to the residential area and this forms a limitation of this study as the soil sampling stopped about 15 m from the residential area whose surrounding has been cemented. With the presence of high levels of BTEX members in the soil immediately outside the crude oil terminal, it is also worthwhile to monitor the levels of these compounds in the air near human receptors in future studies.

There are also limitations with sampling. More samples could be collected to track the levels of petroleum hydrocarbons in different directions from the crude oil terminal to understand the spatial variation of petroleum hydrocarbons around the terminal. Besides, sampling can be done over a certain duration to shed light into the temporal variation of the petroleum hydrocarbons [28]. Variations of petroleum hydrocarbon along the vertical soil columns can also be tracked.

IV. CONCLUSION

This study shows that EX of the BTEX had been detected in soil samples 15 to 30 m from the crude oil terminal together with other benzene derivatives but were not detected in soil samples further from the terminal and nearer to the residential area. The number of petroleum hydrocarbon species decreased with increasing distance from the terminal. The concentrations of the EX and two other benzene derivatives exceeded the RSLs of the US EPA which could pose health risk due to occupational and incidental exposure to the soil. Though not detected in soil samples near the residential area, EX are volatile and exposure through air was possible depending on the wind direction. The findings provide insight into the severity of soil contamination by petroleum hydrocarbons in the proximity of a crude oil storage facility and the risks of occupational and non-occupational exposure. Unchecked occupational exposure could pose health and safety concerns to the workers of the terminal and non-occupational exposure may trigger public health concerns [29][30]. This study recommends a more extensive investigation to track the spatial and temporal variations of petroleum hydrocarbons in the soil surrounding the facility and an observation of the operations of the facility to draw the correlations between its operations and the levels of petroleum hydrocarbons in its vicinity. It advocates the monitoring of petroleum hydrocarbons in the air at the residential area only about 90 m from the facility. Upon confirmation of the soil contamination, remediation is required.

REFERENCES

- [1]. Tang DKH, Md Dawal SZ, Olugu EU. Actual safety performance of the Malaysian offshore oil platforms: Correlations between the leading and lagging indicators. *J Safety Res* [Internet]. 2018;66:9–19. Available from: <http://www.sciencedirect.com/science/article/pii/S0022437518300045>
- [2]. Tang KHD, Md. Dawal SZ, Olugu EU. Generating Safety Performance Scores of Offshore Oil and Gas Platforms in Malaysia. *Proc One Curtin Int Postgrad Conf*. 2018;(November):325–31.
- [3]. Roser M. Oil spills [Internet]. 2017. Available from: <https://ourworldindata.org/oil-spills/>
- [4]. Dahalan Z. Uproar over massive oil spillage [Internet]. 2011. Available from: <http://www.freemalaysiatoday.com/category/nation/2011/09/23/uproar-over-massive-oil-spillage/>
- [5]. Tang KHD. Safety performance measurement framework for offshore oil and gas platforms in Malaysia. University of Malaya; 2018.
- [6]. Tang KHD, Angela J. Phytoremediation of crude oil-contaminated soil with local plant species. *IOP Conf Ser Mater Sci Eng* [Internet]. 2019;495:12054. Available from: <http://dx.doi.org/10.1088/1757-899X/495/1/012054>
- [7]. Tang KHD, Chai HTJ. The Effect of Fertilizer on *Epipremnum Aureum* in Phytoremediating Soil Contaminated with Crude Oil. *IOP Conf Ser Mater Sci Eng* [Internet]. 2020;943:12032. Available from: <http://dx.doi.org/10.1088/1757-899X/943/1/012032>
- [8]. Harvey RG. Polycyclic aromatic hydrocarbons: chemistry and carcinogenicity. CUP Archive; 1991.
- [9]. Chiu TR, Nanyan NFM, Ali MM. Distribution of Polycyclic Aromatic Hydrocarbons (PAHs) in Surface Sediments of Kapas Island, Terengganu, Malaysia. *Procedia Environ Sci* [Internet]. 2015;30:162–7. Available from: <http://www.sciencedirect.com/science/article/pii/S1878029615006234>

- [10]. Bojes HK, Pope PG. Characterization of EPA's 16 priority pollutant polycyclic aromatic hydrocarbons (PAHs) in tank bottom solids and associated contaminated soils at oil exploration and production sites in Texas. *Regul Toxicol Pharmacol* [Internet]. 2007;47(3):288–95. Available from: <http://www.sciencedirect.com/science/article/pii/S027323000600211X>
- [11]. Abdel-Shafy HI, Mansour MSM. A review on polycyclic aromatic hydrocarbons: Source, environmental impact, effect on human health and remediation. *Egypt J Pet* [Internet]. 2016;25(1):107–23. Available from: <http://www.sciencedirect.com/science/article/pii/S1110062114200237>
- [12]. Tang KHD. Hydroelectric dams and power demand in Malaysia: A planning perspective. *J Clean Prod* [Internet]. 2020;252:119795. Available from: <http://www.sciencedirect.com/science/article/pii/S0959652619346657>
- [13]. WANG C, WU S, ZHOU S, SHI Y, SONG J. Characteristics and Source Identification of Polycyclic Aromatic Hydrocarbons (PAHs) in Urban Soils: A Review. *Pedosphere* [Internet]. 2017;27(1):17–26. Available from: <http://www.sciencedirect.com/science/article/pii/S1002016017602935>
- [14]. National Toxicology Program. Report on Carcinogens, Fourteenth Edition [Internet]. Research Triangle Park, North Carolina; 2016. Available from: <https://ntp.niehs.nih.gov/go/roc14>
- [15]. ATSDR. Toxicological profile: Polycyclic Aromatic Hydrocarbons (PAHs) [Internet]. 2020. Available from: <https://www.atsdr.cdc.gov/toxprofiles/tp.asp?id=115&tid=25>
- [16]. Obini U, Okafor C, Afiukwa J. Determination of levels of polycyclic aromatic hydrocarbons in soil contaminated with spent motor Engine oil in Abakaliki Auto-Mechanic Village. *J Appl Sci Environ Manag*. 2013;17(2).
- [17]. Tao S, Cui YH, Xu FL, Li BG, Cao J, Liu WX, et al. Polycyclic aromatic hydrocarbons (PAHs) in agricultural soil and vegetables from Tianjin. *Sci Total Environ* [Internet]. 2004;320(1):11–24. Available from: <http://www.sciencedirect.com/science/article/pii/S0048969703004534>
- [18]. Tang KHD. Phytoremediation of Soil Contaminated with Petroleum Hydrocarbons: A Review of Recent Literature. *Glob J Civ Environ Eng*. 2019;1(December):33–42.
- [19]. Shin HS. Determination of MTBE, TBA and BTEX in soil by headspace gas chromatography-mass spectrometry. *Bull Korean Chem Soc*. 2012;33(5):1693–8.
- [20]. Udoinyang U, Dennis E, JHU A. Petroleum Hydrocarbon Contents in Tropical Soils near Crude Oil Exploration and Processing Site in Niger Delta, Nigeria. *J Environ Sci Curr Res*. 2019 Apr 25;2:1–8.
- [21]. Pinedo J, Ibáñez R, Lijzen JPA, Irabien Á. Assessment of soil pollution based on total petroleum hydrocarbons and individual oil substances. *J Environ Manage* [Internet]. 2013;130(October 2017):72–9. Available from: <http://dx.doi.org/10.1016/j.jenvman.2013.08.048>
- [22]. US EPA. Regional Screening Levels (RSLs) - Generic Tables [Internet]. 2020. Available from: <https://www.epa.gov/risk/regional-screening-levels-rsls-generic-tables>
- [23]. Soukup DA, Utery AL, Jones S. Distribution of Petroleum and Aromatic Hydrocarbons at a Former Crude Oil and Natural Gas Production Facility. *Soil Sediment Contam An Int J* [Internet]. 2007 May 1;16(2):143–58. Available from: <https://doi.org/10.1080/15320380601166439>
- [24]. Shin H, Yang H. South Koreans return to work, crowd parks, malls as social distancing rules ease. *Reuters* [Internet]. 2020 Apr 20; Available from: <https://www.reuters.com/article/us-health-coronavirus-southkorea/south-koreans-return-to-work-crowd-parks-malls-as-social-distancing-rules-ease-idUSKBN2220EO>
- [25]. Tang KHD. A Case Study of Asset Integrity and Process Safety Management of Major Oil and Gas Companies in Malaysia. *J Eng Res Reports*. 2021;20(2):6–19.
- [26]. Zytner RG. Sorption of benzene, toluene, ethylbenzene and xylenes to various media. *J Hazard Mater* [Internet]. 1994;38(1):113–26. Available from: <http://www.sciencedirect.com/science/article/pii/0304389494000271>
- [27]. Iturbe R, Castro A, Perez G, Flores C, Torres LG. TPH and PAH concentrations in the subsoil of polyduct segments, oil pipeline pumping stations, and right-of-way pipelines from Central Mexico. *Environ Geol* [Internet]. 2008;55(8):1785–95. Available from: <https://doi.org/10.1007/s00254-007-1129-4>
- [28]. Tang KHD, Awa SH, Hadibarata T. Phytoremediation of Copper-Contaminated Water with *Pistia stratiotes* in Surface and Distilled Water. *Water, Air, Soil Pollut* [Internet]. 2020;231(12):573. Available from: <https://doi.org/10.1007/s11270-020-04937-9>
- [29]. Tang KHD. A comparative overview of the primary Southeast Asian safety and health laws [Internet]. Vol. ahead-of-p, *International Journal of Workplace Health Management*. 2020. Available from: <https://doi.org/10.1108/IJWHM-10-2019-0132>
- [30]. Lee KK, Tang KHD. Agaricales (Gilled Mushrooms) as Biosorbents of Synthetic Dye. *Malaysian J Med Heal Sci*. 2020;16(SUPP11):10–7.