Current Palm Oil Mill Odour Emission Scenario against Proposed Department of Environment (DOE) Requirement

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ABSTRACT

Odorous gases are emitted when palm oil mill effluent is treated via anaerobic digestion. Although odour is a nuisance rather than hazardous most of the times, sensory annoyance complaints provoked local authority to seek feasible mitigation. The Department of Environment (DOE) under the jurisdiction of the Air Division has proposed an odour emission limit of 12 000 OUm^{-3} for Malaysian palm oil mills recently which was found unachievable during previous survey. The objective of this article is to establish the odour concentration (OUm^{-3}) at residential locations close to a palm oil mill and identify ammonia (NH_3) and hydrogen sulphide (H_2S) gas concentration in odour samples collected from anaerobic ponds. The odour sampling and assessment were performed according to MS 1963:2007 Air Quality – determination of odour concentration by dynamic olfactometry with enhanced VDI3940 Grid Method. Experimental results showed that odour concentrations at residential locations are often dominated by local odour sources such as chicken farms. Odour emission levels at all surveyed residential areas identified as palm oil mills origin were well below 10 OUm^{-3} most of the times although high level up to 108.4 OUm^{-3} were observed occasionally due to wind factor. H_2S content ranges from 15.9 ppm to 103.9 ppm and NH_3 content ranges from 4.1 ppm to 16.6 ppm.

Keywords: anaerobic digestion, European reference odour mass, odour nuisance, olfactometry, POME treatment.

INTRODUCTION

Acidic palm oil mill effluent (POME) contains water, oil, protein and trace of minerals (Gurmit Singh *et al.,* 1999). The average biochemical oxygen demand (BOD) of POME is about 25 000 ppm and needs to be treated in order to reduce its BOD to below 20 ppm before being discharged into water course. Conventionally it is treated in a series of anaerobic and aerobic ponds that require long hydro retention time (Nur Azreena *et. al.,* 2018). Open effluent pond digestion treatment is the most common treatment system due to the low capital expenditure (CAPEX) and operation expenditure (OPEX) where the POME is digested by a consortium of micro-organisms commonly found in soil and air (Ma, 2000). Due to the recent biogas capture policy to further address sustainability issues, various treatment systems have been installed in palm oil mills, such as covered lagoon and digester tank systems.

Anaerobic digestion is a complex biochemical process as shown in *Figure 1* in which a consortium of micro-organisms converts organic compounds in the absence of oxygen into methane and carbon dioxide in four stages, which are hydrolysis, acidogenesis, acetogenesis and methanogenesis (Dinopolou *et al.,* 1987).

Anaerobic POME treatment releases odorous gases such as ammonia and hydrogen sulphide (Thauer, 1998) that are known as a particular kind of air pollutants which have become a serious environmental concern for many years. Environmental factors such as wind speed and direction, topography, atmospheric stability and pollutant concentrations need to be considered during odour assessment.

Smell sense is accomplished with two main nerves. Chemicals perception is processed by the olfactometry nerve whereas chemicals irritation or pungency is processed by the trigeminal nerve. All olfactory signals meet in the olfactory bulb where the information is distributed to two different parts of the brain. Limbic system pathway processes emotion and memory response of

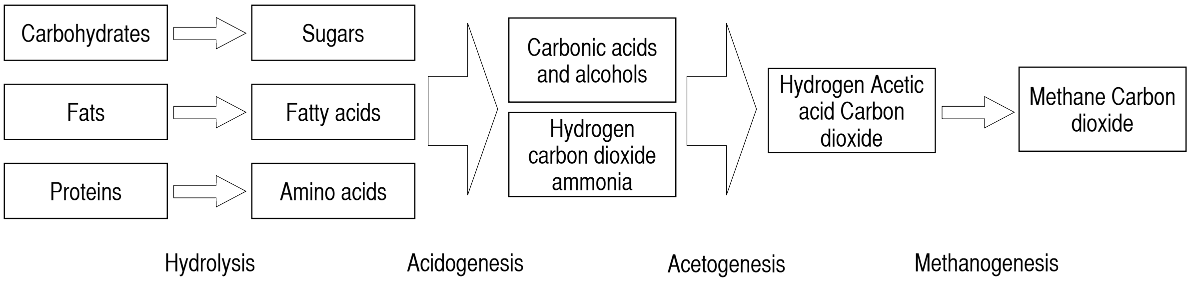

Figure 1. Anaerobic digestion stages.

the body. The other information pathway is to the frontal cortex. From nostril to brain signal, the process takes only about 500 milliseconds (Mauskar, 2008).

Odour intensity is the perceived odour sensation strength which is related to the odourant concentration as shown in the *Equation (1)*, known as Stevens' law or the power law where *I* is the intensity, *k* is a constant *C* is the concentration, *n* is exponent ranges from about 0.2 to 0.8 depending on the odourant.

$$I = k(C)^n \qquad (1)$$

The odour concentrations mentioned as odour units per cubic meter is based on a correlation between a physiological response when the nose detect odour, and exposure concentration of a particular sample. Odour unit is the amount of odourant(s) when evaporated into 1 m^2 of neutral gas at standard conditions, elicits a physiological response equivalent to that elicited by one European Reference Odour Mass (EROM) which is equivalent to 123 µg *n*-butanol evaporated in one cubic meter of neutral gas at standard conditions.

PROBLEM STATEMENT

In the Draft Environmental Quality (Odour) Regulations 201X (unpublished), a limit of 12 000 OUm^{-3} was proposed. However, the findings from previous survey project involved three mills with different treatment systems which were open lagoon, covered anaerobic lagoon and anaerobic tank digester, demonstrated the inability of the mills to comply with the proposed value as shown in *Figure 2*. Thus, an alternative approach to the odour threshold limit is necessary to justify the odour pollution from palm oil mills.

Odour is a nuisance rather than hazard most of the times. Nuisance is defined as cumulative effect on humans caused by repeated annoyance events over an extended period of time that leads to modified or altered behaviour (Van Harreveld, 2001) as shown in *Figure 3*. Thus, odour exposure to surrounding community is also a measurable data to validate odour emission issue from the palm oil mill. It seems probable that despite being noncompliant at source, odour may be minimal below the threshold at the boundary, which is less likely to be a nuisance to the surrounding community. The Nuisance Law approach will be implemented in Malaysia odour legislation.

ODOUR MEASUREMENT METHODS

A defined odour measurement method is described in standard MS 1963:2007 (olfactometry) set out by the Department of Standards Malaysia using n-butanol for equipment calibration and panel member selection. The odour assessment results are expressed in terms of OUm^{-3} EROM where one EROM is equivalent to 123 µg *n*-butanol.

IN FIELD ODOUR MEASUREMENT

Direct real time in-field odour measurement using olfactometer for ambient and boundary investigation will be conducted. Enhanced VDI3940 Grid Method is adopted to execute in field odour survey which include the determination of odour intensity, odour concentration and odour characters for a 10 min observation period at one location.

The Scentroid SM100 in-field olfactometer as shown in *Figure 4* incorporates a dilution device within a portable device, allowing direct odour concentration measurements to be carried out in real time in the field. The odour assessment method will involve the determination of odour intensity, odour concentration and odour characters followed that of Balch *et al.* (2015) and Bakhtari *et al.* (2016). At least three odour concentration (OUm^{-3}) readings will be recorded and further supported by odour intensity of 0 (no odour) to 6 (extremely strong).

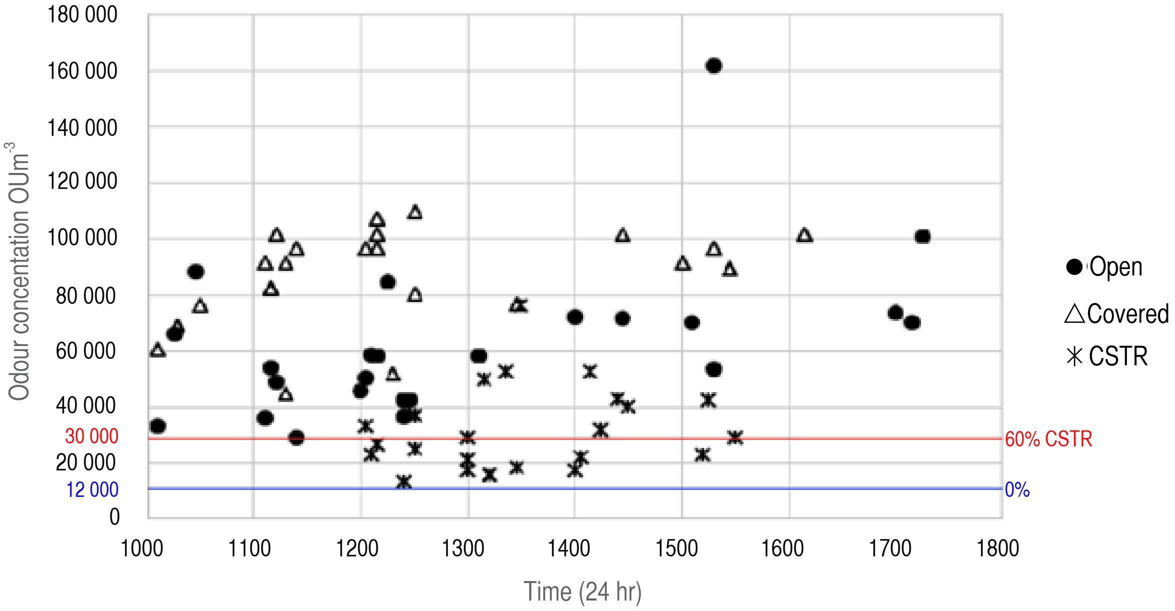

Figure 2. Palm oil mills odour emission level at source.

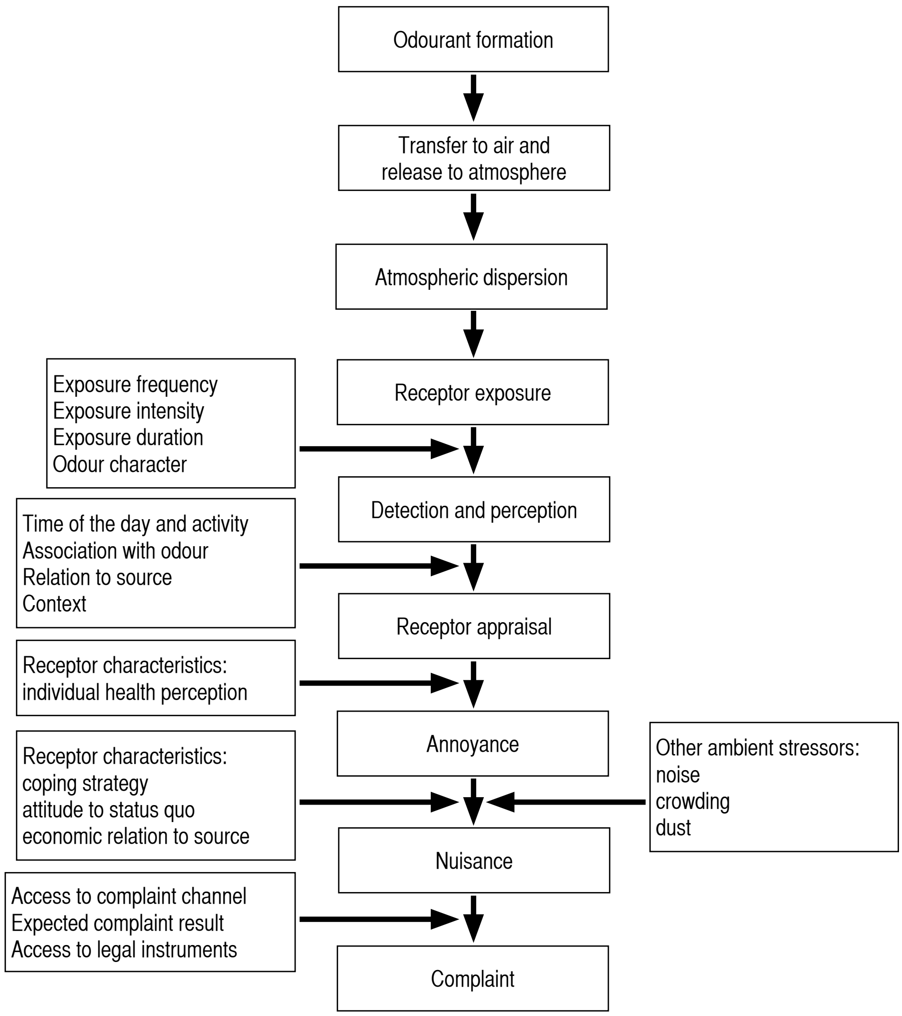

Figure 3. Odour sensory nuisance to psychology effects chronology.

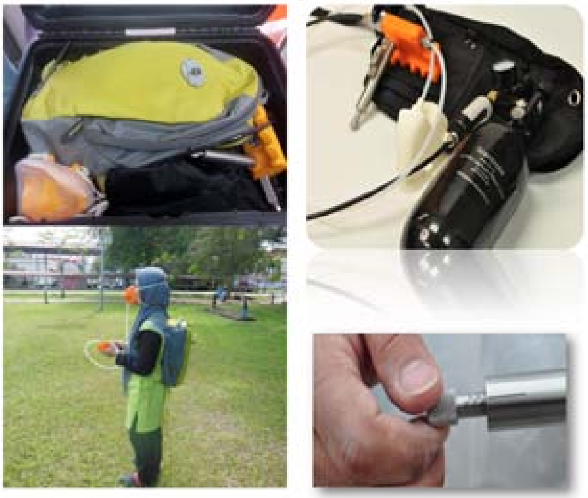

Figure 4. Scentroid SM100 olfactometer.

Odour characters such as *'sour vinegar', 'rotten egg' or 'others'* will also be noted during the field survey to better understand the odour impact on the surrounding communities. The odour survey form records the odour intensity and character, with a short description of the various scales and numbers described in the survey form for easy reference. The potential odour sources from on-site observation will also be recorded to further support the detection of odour and understanding possible nearby contributors.

ODOUR SAMPLING AT EMISSION POINT AND LABORATORY ANALYSIS

Odour sampling at emission point and laboratory analysis in an odour free room will be conducted for odour emission strength identification and odour control systems design. Samples will be collected into 10 litre Nalophan bag and sent to the odour laboratory for olfactometry analysis using the Scentroid SS400 dynamic olfactometer to determine its concentration expressed as OUm^{-3}. *Figure 5* shows the analysis of the odour sample at emission point in the laboratory using Scentroid SS400 dynamic olfactometer.

Hydrogen sulfide (H_2S) and ammonia (NH_3) levels in the odour samples were analysed using a portable multi-sensor device, the OdoTracker TR8 (Scentroid, Canada) as shown in *Figure 6*.

Figure 6. OdoTracker TR8 portable gas sensors for H_2S and NH_3 level determination.

PROJECT SITES

Odour exposure measurements in the survey will be carried out at the palm oil mills as shown in *Figure 7* and boundaries as described in *Table 2*. The mills differed in terms of their effluent treatment system which affected the odour emission from the anaerobic ponds. The study boundaries for each location should be within 2 km radius and are determined based on the safe assessment into the established residential area. Thus, the boundaries distances are different for each study location as shown in *Table 2*.

PROJECT OBJECTIVES

1. To identify ammonia and hydrogen sulphide gas concentration in odour sample collected from respective anaerobic pond.
2. To establish the odour concentration (OUm^{-3}) at the residential locations close to a palm oil mill using open ponding system (*Figure 8a*); covered lagoons (*Figure 8b*) and tank digester (*Figure 8c*) for POME treatment.

Figure 5. Scentroid SS400 dynamic olfactometer for odour source sample analysis.

TABLE 2. SURVEY LOCATIONS

POME treatment	Location	*Boundary 1	*Boundary 2
Open Pond	Mill A, Kedah	0.8 km NE	2.0 km W
Covered Lagoon	Mill B, Pulau Pinang	0.7 km W	1.0 km E
Digester Tank	Mill C, Perak	1.4 km N	1.9 km SW

Note: * Boundary 1:- nearest residence, Boundary 2:- second-nearest residence to palm oil mill.

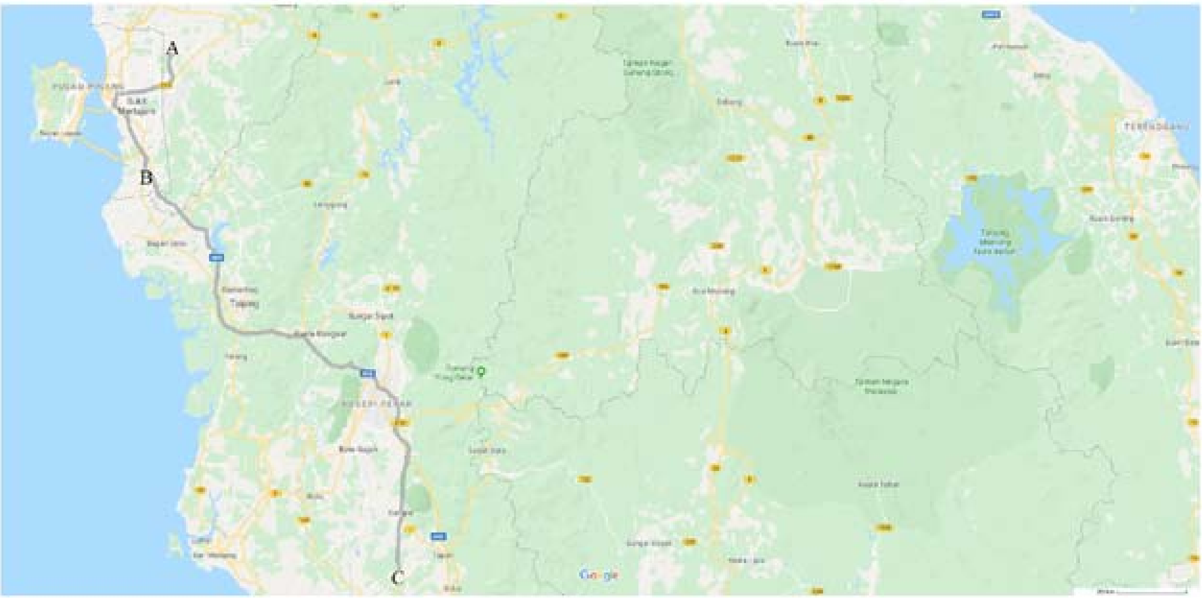

Figure 7. Palm oil mills locations involved in odour exposure measurements survey.

Figure (a) Open pondling. *Figure (b) Covered.* *Figure (c) Digester tank.*

Figure 8. Establish the odour concentration (OUm^{-3}) at the residential locations close to a palm oil mill.

RESULTS

The anaerobic pond odour complete with odorous gases contents assessments and in field boundary odour assessments for respective three selected palm oil mills were duly carried out according to the schedule as shown in *Table 3*.

For each palm oil mill, one odour assessment at the mill gate as shown in *Figure 9a* was recorded as B0 and two community locations within 2 km radius from the respective mill as mentioned in *Table 2* over three consecutive days as shown in *Table 3*. Three assessments have been carried out in a day for every location, started around 8.00am and ended around 8.00pm as shown in *Figure 9b*-d.

TABLE 3. PROJECT SCHEDULE

Project assessment	Normal crop		Peak crop	
	Start	End	Start	End
Anaerobic Pond	28 Jan 2019	30 Jan 2019	19 Aug 2019	21 Aug 2019
Boundaries Mill A	19 Feb 2019	21 Feb 2019	13 Aug 2019	15 Aug 2019
Boundaries Mill B	25 Feb 2019	27 Feb 2019	29 Jul 2019	31 Jul 2019
Boundaries Mill C	25 Mar 2019	27 Mar 2019	08 Jul 2019	10 Jul 2019

Figure (a.) Odour measurement at respective mill gate.

Figure (b.) Morning odour measurement at the boundary.

Figure (c.) Afternoon odour measurement at the boundary.

Figure (d.) Evening odour measurement at the boundary.

Figure 9. Odour assesment

TABLE 4. ODOUR INTENSITY DESCRIPTION

Intensity	Odour strength	Description
0	No odour	Odour detection threshold (ODT)
1	Very weak	Some doubt whether odour is actually present
2	Weak	Odour is present but cannot be described precisely
3	Distinct	The odour character is barely recognisable
4	Strong	The odour character is easily recognisable
5	Very strong	Odour is offensive and the exposure level is undesirable
6	Extremely strong	Odour is offensive and instinctive reaction would mitigate against further exposure

During in field odour concentration measurement, odour intensity was also recorded every 10 for 10 min to a scale of 0 to 6 following UK Environment Agency Guideline as shown in *Table 4*.

Odour intensity level 0 to 2 was recorded most of the times and intensity level 3 was occasionally recorded during in field assessments.

Figure 10 shows the correlation between the odorous gas content and odour concentration of the gas samples collected from anaerobic pond. Boundary odour concentration survey results are shown in *Tables 5-7*. *Figure 11* shows the POME properties for in-flow and out-flow of anaerobic pond during survey period.

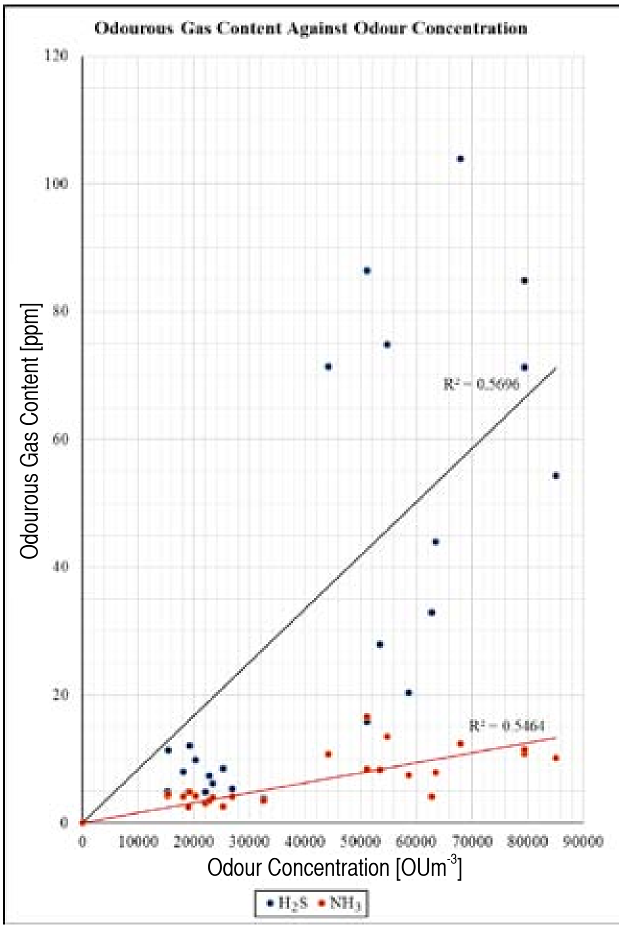

Figure 10. Correlation between odourous gas content and odour concentration.

TABLE 5. BOUNDARY ODOUR CONCENTRATION FOR MILL A (open pond)

Season: Normal					
Time (m)	B0	Time (m)	B1	Time (m)	B2
5	0	30	0	60	0
365	9.5	383	6.5	400	0
727	10.3	744	0	764	0
1 443	5	1 461	0	1 480	0
1 812	4.9	1 828	7.8	1 847	0
2 172	0	2 193	48.5	2 209	0
2 890	0	2 907	0	2 924	0
3 246	9	3 262	0	3 280	0
3 616	6.4	3 630	0	3 646	0

Season: Peak crop					
Time (m)	B0	Time (m)	B1	Time m)	B2
5	3.5	60	6.9	23	0
360	5	374	0	388	0
726	6.8	739	0	756	0
1 454	3.5	1 469	0	1 485	0
1 814	3.6	1 828	0	1 843	0
2 170	7.5	2 186	0	2 201	0
2 904	0	2 918	9.1	2 933	0
3 240	4.7	3 253	0	3 269	0
3 603	4.4	3 618	0	3 634	3.5

Note: Numbers in red indicate odour interference from local odour sources.
B0: at the mill gate, B1: nearest residence, B2: second-nearest residence to palm oil mill.

TABLE 6. BOUNDARY ODOUR CONCENTRATION FOR MILL B (covered lagoon)

Season: Normal					
Time (m)	B0	Time (m)	B1	Time (m)	B2
5	0	20	0	58	6.5
370	3.5	386	0	404	95.8
725	0	738	0	755	0
1 450	0	1 465	0	1 482	0
1 810	0	1 825	0	1 840	108.4
2 170	3.7	2 185	0	2 202	0
2 890	10	2 908	0	2 922	0
3 250	3.7	3 265	0	3 273	4.1
3 600	3.5	3 623	3.5	3 638	0

Season: Peak crop					
Time (m)	B0	Time (m)	B1	Time (m)	B2
5	3.5	20	0	33	3.9
355	0	370	0	386	0
720	0	734	0	750	0
1 427	0	1 440	3.5	1 457	0
1 782	3.5	1 800	0	1 817	6.5
2 163	0	2 179	0	2 194	3.5
2 876	0	2 887	3.5	2 903	0
3 229	3.5	3 242	0	3 257	4.6
3 600	3.5	3 612	0	3 628	0

Note: Numbers in red indicate odour interference from local odour sources.
B0: at the mill gate, B1: nearest residence, B2: second-nearest residence to palm oil mill.

TABLE 7. BOUNDARY ODOUR CONCENTRATION FOR MILL C (digester tank)

Season: Normal					
Time (m)	B0	Time (m)	B1	Time (m)	B2
7	0	25	0	44	0
370	3.5	383	0	408	0
735	3.5	752	0	772	0
1 445	3.5	1 461	0	1 479	0
1 815	3.5	1 831	0	1 848	0
2 175	3.5	2 189	0	2 207	0
2 890	14	2 904	0	2 919	0
3 245	8.1	3 259	0	3 277	0
3 592	3.5	3 605	0	3 623	3.5

Season: Peak crop					
Time (m)	B0	Time (m)	B1	Time (m)	B2
8	4.1	27	0	42	0
370	6.6	387	0	408	0
730	3.5	746	0	763	7
1 450	3.5	1 467	0	1 485	0
1 802	10.6	1 816	0	1 835	0
2 165	6.9	2 181	0	2 198	0
2 892	3.5	2 909	0	2 926	0
3 250	3.5	3 268	0	3 286	0
3 607	0	3 621	34.2	3 638	0

Note: Numbers in red indicate odour interference from local odour sources.
B0: at the mill gate, B1: nearest residence, B2: second-nearest residence to palm oil mill.

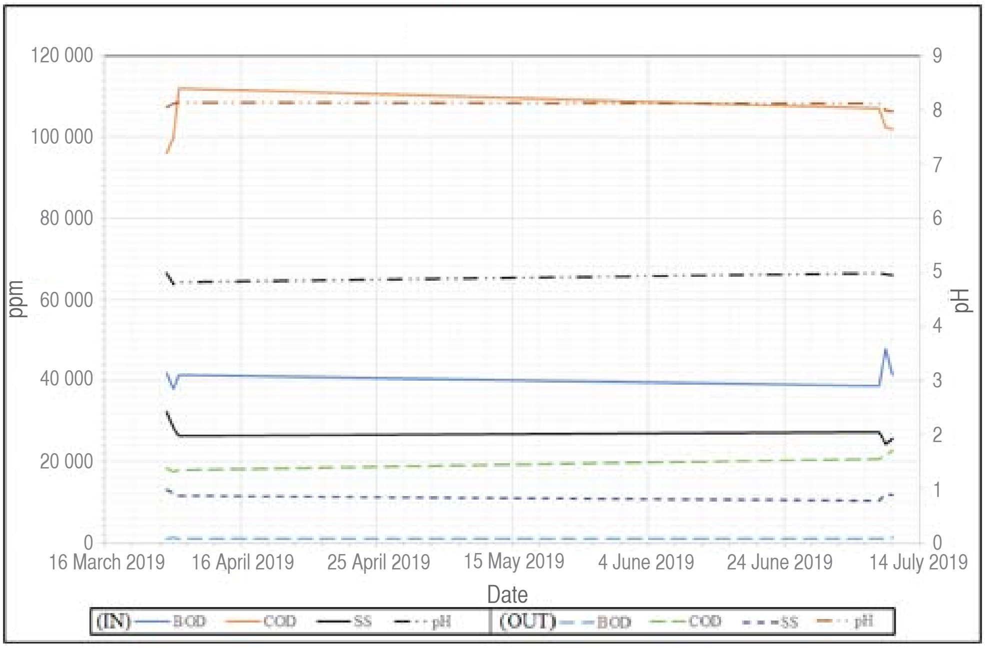

Figure 11. POME properties for in-flow and out-flow anaerobic pond during survey period.

DISCUSSION

The SM 100 Scentroid Olfactometer detection range is from 3.5 - 11355 OUm^{-3} was used for in field measurement whereas the Scentroid SS400 dynamic olfactometer detection range from 15 OUm^{-3} - 18643 OUm^{-3} was used for source samples measurement within 30 hr of sample collection. Thus, due to the predicted odour samples strength, pre-dilution was necessary prior to analysis. The Geometric Mean as shown in *Equation (2)* is used to compare and analyse the data properties.

$$\text{Geometric Mean, } GM = \sqrt[n]{a_1 \times a_2 \times \ldots \times a_n}\,;$$
$$\Delta z_i = \frac{a_i}{GM} \text{ if } a_i \geq GM\,;\ \Delta z_i = \frac{GM}{a_i} \text{ if } a_i < GM\,;\ 1 \leq \Delta z_i \leq 1.5 \quad (2)$$

OdoTracker TR8 (Scentroid, Canada) is equipped with electrochemical sensors for hydrogen sulfide H_2S detection range from 1 ppm to 2000 ppm with resolution 1 ppm and ammonia detection range from 0 - 100 ppm with resolution 0.3 ppm.

Malaysia has tropical monsoon climate which is hot with normal ambient temperature ranging from 25°C to 35°C, humidity up to 85% and rain throughout the year. The highest ambient temperature is usually recorded from 12.00 noon to 3.00 pm and the sun heating effect is negligible during 7.00 am to 7.00 pm. Thus, the micro organisms' activities within the POME treatment ponds vary from day to night but remain in similar trend throughout the year.

A bio-digester has been installed at Mill A since the first run during normal crop season as part of the palm oil mill effluent treatment system, which includes a covered anaerobic lagoon and a gas collection system. The bio-digester precedes five open anaerobic lagoons, a facultative pond, aeration pond, and two settling ponds before final discharge. At the time of the odour assessment in the second run during peak crop season, the same effluent treatment plant configuration was present and although the bio-digester is completed, it was in the commissioning stage and yet to be fully operational. However, the odour concentration at source and in-field reduced significantly during the second assessment. Similar observation is also found on H_2S and NH_3 contents in gas samples collected from anaerobic pond compared to previous assessment. Thus, biogas capture reduces odour emission from palm oil mill via quarantine approach.

Survey results show that the odour concentration at source is very much higher than in-field odour concentration. The odorous gases contents vary with in-field odour concentration profile and are affected by environmental factors which influence microorganisms' activities such as temperature, humidity and air pressure due to wind blow. Samples analysis shows that H_2S contents are always higher than NH_3 contents. Both odourous gases contents are in ppm. Thus, the disappearance of the odour effect is mainly due to gas dilution with atmospheric air. The ammonia threshold is 500-1000 μgm^{-3} whereas the hydrogen sulphide threshold is 1.5-150 μgm^{-3} (Ding Ying *et* *al.,* 2012). However, small portion of the odourous gases are decomposed via bacteria activities. Sulphur bacteria oxidises hydrogen sulphide via pathway (Startsev, 2017).

$$2H_2S + O_2 \rightarrow 2S + 2H_2O \quad (3)$$

Ammonia is oxidised by nitrifying bacteria via complex autotrophic nitrification process that requires several enzymes, proteins and oxygen as shown in Equation (4).

$$NH_3 + O_2 + 2H^+ + 2e^- \rightarrow NH_2OH + H_2O \rightarrow NO_2^- + 5H^+ + 4e^- \quad (4)$$

Based on the empiric data and the threshold limits, the odour emission from palm oil mill is dominated by hydrogen sulphide.

Low correlation between the respective odourous gas and odour concentration as shown in *Figure 10* indicates that the odour of the gas samples collected from the anaerobic pond are not single odourant effect but rather combination of various odourous gases generated from POME anaerobic fermentation. Although the amount of such odourous gases is regulated by the microbial activity, the odour concentration theoretically is proportional to the amount of odourant present in the gas sample. Thus, linear multivariate regression has been performed yield empiric odour model as shown in Equation (5) where x_1 is H_2S content in ppm; x_2 is, NH_3 content in ppm and y is odour concentration in OUm^{-3}.

$$y = 372.9286x_1 + 1718.5450x_2 + 17419.7682 \quad (5)$$

The R^2 value increases to 0.7854 with estimation error 14573.7023 shows that besides H_2S and NH_3, other unidentified odorous gases exist and influent the odour concentration.

CONCLUSION

Experimental results showed that odour concentration at source ranges from 44 135 OUm^{-3} - 85 012 OUm^{-3} while H_2S content ranges from 15.9 - 103.9 ppm and NH3 content ranges from 4.1 - 16.6 ppm. Odour concentrations at residential locations are often dominated by local odour sources such as chicken farms. Odour emission levels at all residential surveyed areas identified as palm oil mills origin were well below 10 OUm^{-3} most of the times although high level up to 108.4 OUm^{-3} has been observed occasionally.

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Appendix 1

Source	Degree of freedom	Sum of square	Mean square	F value
Regression	2	8551324254	4275662127	17.71520843
Residual	22	5309819930	241355451.4	
Total	24	13861144184		

Appendix 2

Nomenclature

Symbol	Particular	SI Unit
C	Concentration	kgm^{-3}
I	Intensity	-
k	Odourant constant	-
n	Odourant exponent	-
x_1	Hydrogen sulphide (H_2S) content in gas sample	ppm
x_2	Ammonia (NH_3) content in gas sample	ppm
y	Odour concentration	OUm^{-3}

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