

ODOUR EXPOSURE LEVEL MEASUREMENT SURROUNDING PALM OIL MILL

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ABSTRACT

Odorous gases such as ammonia and hydrogen sulphide produced by anaerobic bacteria are emitted when palm oil mill effluent is treated via anaerobic digestion. Although odour is a nuisance rather than a hazardous nature most of the times, sensory annoyance complaints provoke local authority to seek for feasible mitigation. Malaysian Department of Environment (DOE) under the jurisdiction of the Air Division has proposed an odour emission limit of 12 000 OUm⁻³ for palm oil mills recently. The objective of this paper is to establish the anaerobic pond odour concentration at palm oil mill using open ponding system for POME treatment, identify ammonia (NH₃) and hydrogen sulphide (H₂S) gas content in odour sample collected from respective anaerobic pond, and establish the odour concentration (OUm⁻³) at residential locations close to a palm oil mill using open ponding system, covered lagoons and tank digester for POME treatment. 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. Results showed that odour concentration at source of anaerobic pond ranged from 44 135-85 012 OUm⁻³ while hydrogen sulphide content ranged from 15.9-103.9 ppm and ammonia content ranged 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 surveyed residential areas identified as palm oil mills origin were well below 10 OUm⁻³ most of the times although high level of up to 108.4 OUm⁻³ has been observed occasionally. Thus the proposed odour limit value needs to be reviewed and justified based on further study with focus on more data collection, odour control guidelines, community odour impact survey, inclusion limit values for odorous chemical substances, odour regulation framework, odour assessment methods and odour management plan guidelines.

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

Date received: 20 December 2019; **Sent for revision:** 24 December 2019; **Accepted:** 30 July 2020.

INTRODUCTION

For every tonne of fresh fruit bunches (FFB) processed at palm oil mills, 0.6 t of palm oil mill

effluent (POME) is generated to produce crude palm oil (CPO). This acidic effluent contains water, oil, protein and traces of minerals (Fatah *et al.*, 2012).

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 (Loh *et al.*, 2014). Open effluent pond digestion treatment is the most common treatment system practiced by Malaysian mills due to the low capital expenditure (CAPEX) and operation

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expenditure (OPEX) where the POME is digested by a consortium of the microorganisms commonly found in soil and air. 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. Practical data show that 1 m³ of POME could generate 25 m³ of biogas with average calorific value of 22 000 kJm⁻³ containing 62.5% methane, 37.0% carbon dioxide and traces of hydrogen sulphide and ammonia (Loh *et al.*, 2017).

Anaerobic digestion is a complex biochemical process with a consortium of micro-organisms converting organic compounds in the absence of oxygen into methane and carbon dioxide in four stages, which are hydrolysis, acidogenesis, acetogenesis and methanogenesis (Loh *et al.*, 2014). Anaerobic POME treatment releases odorous gases such as ammonia and hydrogen sulphide that are known as air pollutants which have become a serious environmental concern for many years. Malaysian Department of Environmental (DOE) is currently simulating the odour limit and sampling site to be gazetted in the new regulation. Environmental factors such as wind speed and direction, topography, atmospheric stability and pollutant concentration need to be considered during odour assessment.

Smell sensing is accomplished with two main nerves. Chemicals perception is processed by the olfactory 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 the body. The other information pathway is to the frontal cortex. From nostril to the brain signal, the process takes only about 500 milliseconds (Mauskar, 2008). Odour intensity is the perceived odour sensation strength which is related to the odorant concentration as shown in 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 odorant.

$$I = k(C)^n \quad \text{Equation (1)}$$

The odour concentrations mentioned as odour units per cubic meter is based on correlation between a physiological response when the nose detects odour, and exposure concentration of a particular sample. Odour unit is the amount of odorant(s) when evaporated into 1 cubic meter 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.

In the Draft Environmental Quality (Odour) Regulations 201X (unpublished data), a limit of 12 000 OUm⁻³ was proposed, meaning no part or activities in palm oil mills can emit odour beyond the 12 000 OUm⁻³ thresholds. Thus, Malaysian Palm Oil Board (MPOB) and Universiti Sains Malaysia (USM) started an odour investigation project in order to produce reliable odour emission data to validate Department of Environment's proposal. Three mills with different treatment systems: open lagoon, covered anaerobic lagoon and anaerobic tank digester, were studied. However, findings from the previous preliminary survey (Andrew *et al.*, 2019) demonstrated the inability of the mills to comply with the DOE proposed value. 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 a hazardous nature most of the times. Nuisance is defined as cumulative effect on human caused by repeated annoyance events over an extended period of time that leads to modified or altered behaviour (Van Harrevel, 2001). Thus, the odour exposure to the surrounding community is also a measurable data to validate odour emission issue from the palm oil mill. It seems probable that despite being non-compliant 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.

The objectives of the survey are: (1) To establish the anaerobic pond odour concentration (OUm⁻³) at palm oil mill using open ponding system for POME treatment, (2) To identify ammonia (NH₃) and hydrogen sulphide (H₂S) gas concentration in odour sample collected from respective anaerobic ponds, and (3) To establish odour concentration (OUm⁻³) at residential locations close to palm oil mill using open ponding system, covered lagoons and tank digester for POME treatment. Wind speed and direction at every location was also recorded.

MATERIALS AND METHODS

Odour measurement method, project site and measuring instruments need to be duly determined prior to the survey execution. Odour measurements consist of in field odour measurement and emission point odour sampling measurement. The project schedule should cover normal and peak crop seasons in order to produce a comprehensive survey. Although weather conditions are uncontrollable, wind blow condition would be recorded.

Odour Measurement Methods

A defined odour measurement method is described in standard MS 1963:2007 (olfactometry) set out by the Department of Standards Malaysia (SIRIM) using *n*-butanol for equipment calibration and panel member selection. The odour assessment results are expressed in terms of OUm⁻³ European Reference Odour Mass (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 was conducted. Enhanced VDI3940 Grid Method was adopted to execute in field odour survey which included the determination of odour intensity, odour concentration and odour characters for a 10 min observation period at each location.

The Scentroid SM100 in-field olfactometer 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 involved the determination of odour intensity, odour concentration and odour characterisation following that of Balch *et al.* (2015) and Bakhtari and Medina (2016). Three odour concentration (OUm⁻³) readings were recorded and further supported by odour intensity of 0 (no odour) to 6 (extremely strong). Odour characters such as 'sour vinegar, rotten egg or others were also noted during the field survey to better understand the odour impact to the surrounding communities. The odour survey form recorded 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 would 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 was conducted for odour emission strength identification and odour control systems design. Samples were collected into 10 litre Nalophan bag and sent to the odour laboratory for olfactometry analysis using the Scentroid SS400 dynamic olfactometer to determine their concentration, expressed as OUm⁻³.

Hydrogen sulfide and ammonia levels in the odour samples were analysed using a portable multi-sensor device, the OdoTracker TR8 (Scentroid, Canada).

Instruments Accuracy

The SM 100 Scentroid Olfactometer with detection range from 3.5-11 355 OUm⁻³ was used for in field measurement whereas the Scentroid SS400 dynamic olfactometer with detection range from 15-18 643 OUm⁻³ was used for source samples measurement within 30 hr of sample collection. 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.

$$\text{Geometric Mean, GM} = \sqrt[n]{a_1 \times a_2 \times \dots \times a_n} \quad \text{Equation (2)}$$

$$\Delta z_i = \frac{a_i}{GM} \text{ if } a_i \geq GM ; \Delta z_i = \frac{GM}{a_i} \text{ if } a_i < GM ;$$

$$1 \leq \Delta z_i \leq 1.5$$

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

Project Sites

Odour exposure measurements in the survey were carried out at three palm oil mills and selected boundaries as described in *Table 1*. The mills differed in terms of effluent treatment system which affected the odour emission from the anaerobic ponds. The survey boundaries for each location was selected within 2 km radius and determined based on the safe assessment into the established residential area. Thus, the boundaries distances were different for each study location.

TABLE 1. SURVEY LOCATIONS

POME treatment	Location	^A Boundary 1	^A Boundary 2
Open pond	Mill A, Kedah	0.8 km NE	2.0 km W
Covered lagoon	Mill B, Penang	0.7 km W	1.0 km E
Digester tank	Mill C, Perak	1.4 km N	1.9 km SW

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

The anaerobic pond odour complete with odorous gases contents assessments and in field boundary odour assessments for the respective three selected palm oil mills were duly carried out according to the schedule as shown in *Table 2*.

During in field odour concentration measurement, odour intensity was also recorded every 10 s for 10 min to a scale of 0-6 following UK Environment Agency guideline as shown in *Table 3*.

TABLE 2. PROJECT SCHEDULE IN YEAR 2019

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

TABLE 3. ODOUR INTENSITY DESCRIPTION

Intensity	Odor 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

RESULTS AND DISCUSSIONS

Malaysia has tropical monsoon climate which is hot with normal ambient temperature ranging from 25°C-35°C, humidity up to 85% and rain throughout the year. The highest ambient temperature is usually recorded from 12:00-15:00 and the sun heating effect is negligible during 19:00-07:00. Thus, the microorganisms' activities within the POME treatment ponds vary from day to night but remained in similar trend throughout the year.

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

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 was 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 as shown in *Figure 4* compared to *Figure 3*. Similar observation was also found on H₂S and NH₃ content in gas samples collected from

anaerobic pond as shown in *Figure 2* compared to previous assessment as shown in *Figure 1*. Thus, biogas capture reduced odour emission from palm oil mill via quarantine approach.

Figures 5 and *6* show the boundary odour assessments for covered lagoon system during normal crop and peak crop season, respectively. *Figures 7* and *8* show the boundary odour assessments for digester tank system during normal crop and peak crop season, respectively. Results showed that the odour concentration at source was very much higher than in-field odour concentration. The odorous gases content varies with in-field odour concentration profile and is affected by environmental factors which influence microorganisms' activities such as temperature, humidity and air pressure due to wind blow.

Samples analysis showed that hydrogen sulphide (H₂S) content was always higher than ammonia (NH₃) content. Both odorous gases content is in ppm. Thus, the disappearance of the odour effect is mainly due to gases dilution with atmospheric air. Ammonia threshold is 500-1000 µgm⁻³ whereas hydrogen sulphide threshold is 1.5-150 µgm⁻³ (Ding *et al.*, 2012). However, small portion of the odorous gases are decomposed via bacterial activities. Sulphur bacteria oxidise hydrogen sulphide via pathway as shown in Equation (3) (Startsev, 2017).



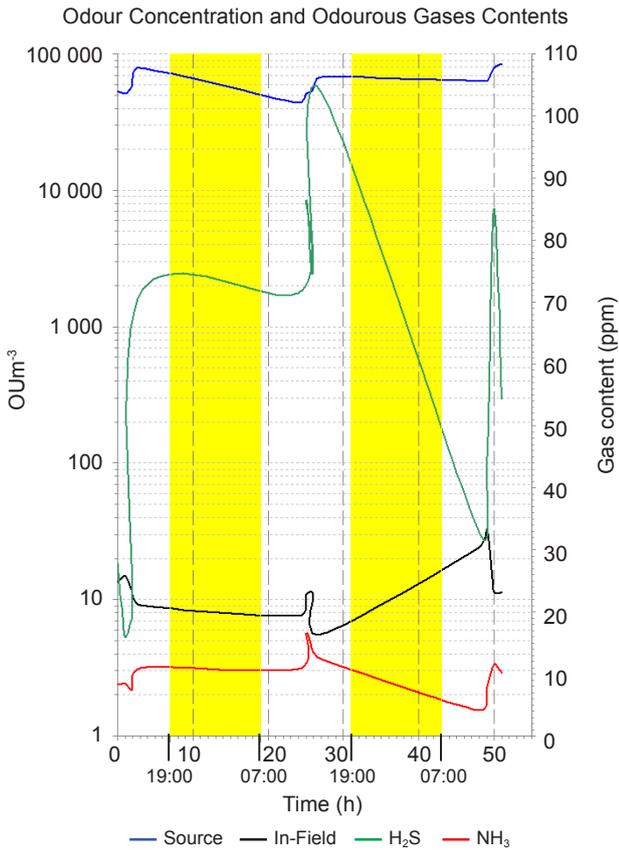


Figure 1. Normal crop anaerobic pond odour concentration and odourous gas content.

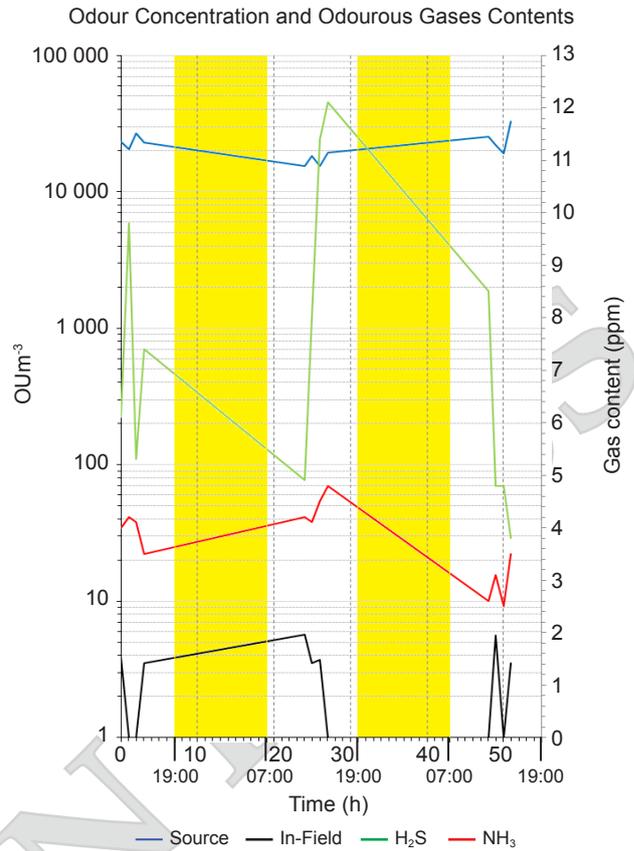


Figure 2. Peak crop anaerobic pond odour concentration and odourous gas content.

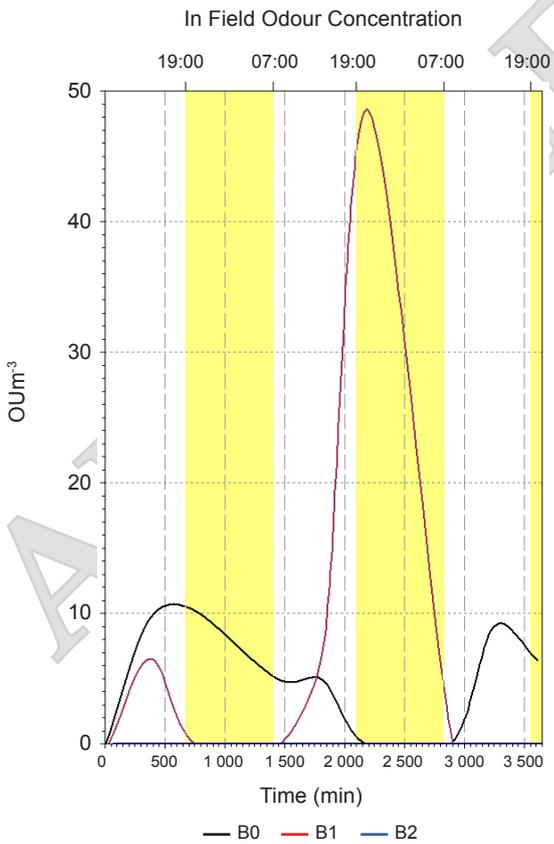


Figure 3. Boundary odour assessments for open pond system during normal crop.

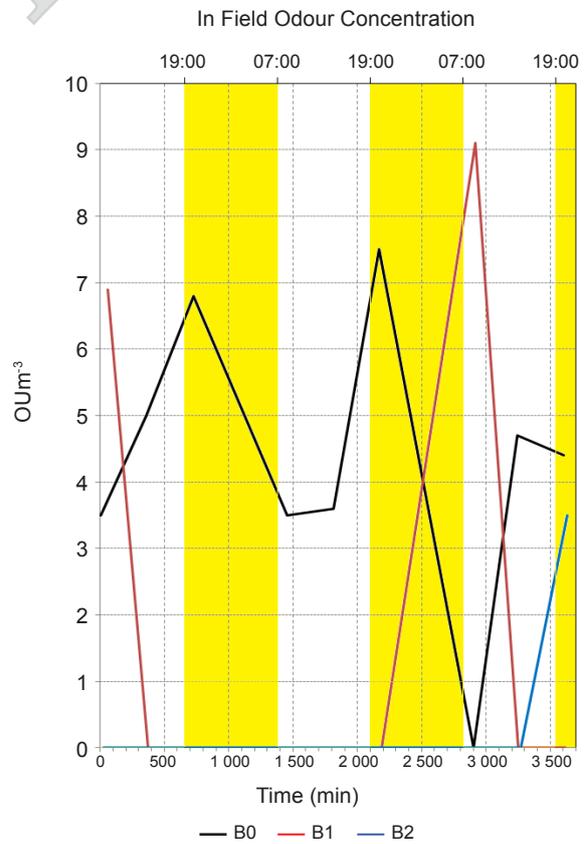


Figure 4. Boundary odour assessments for open pond system during peak crop.

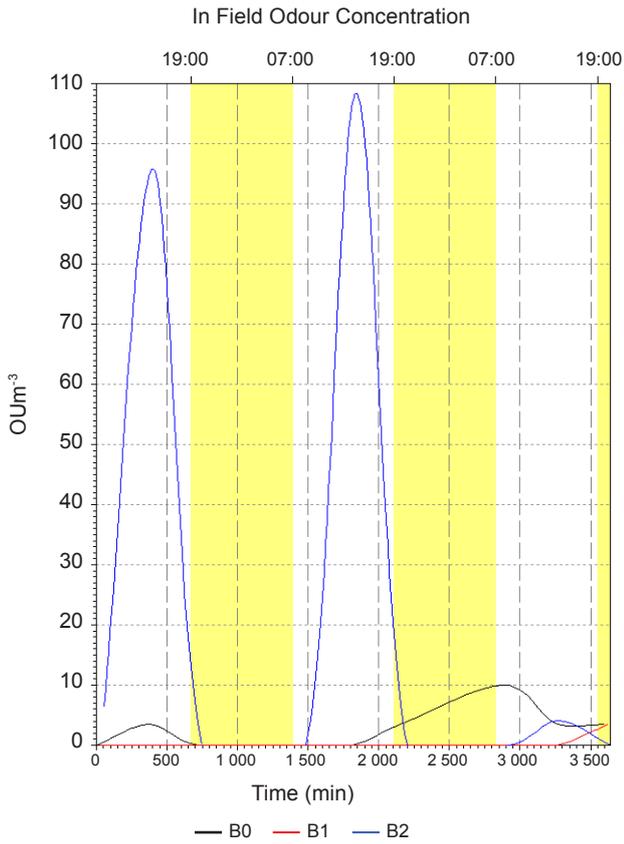


Figure 5. Boundary odour assessments for covered lagoon system during normal crop.

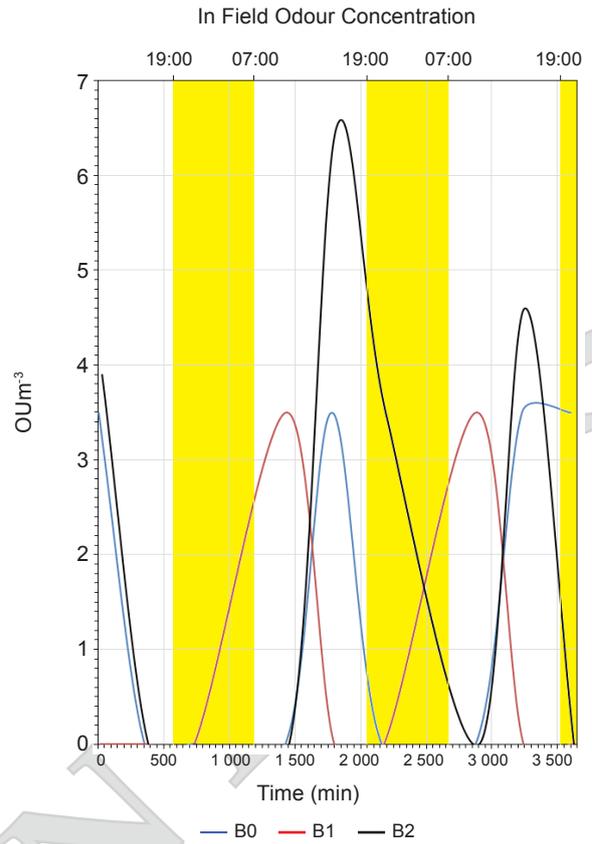


Figure 6. Boundary odour assessments for covered lagoon system during peak crop.

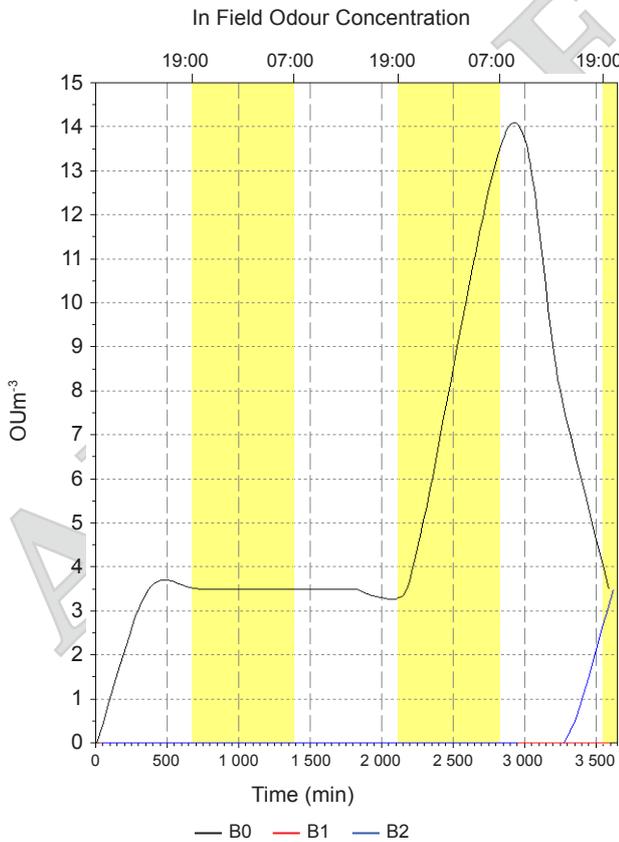


Figure 7. Boundary odour assessments for digester tank system during normal crop.

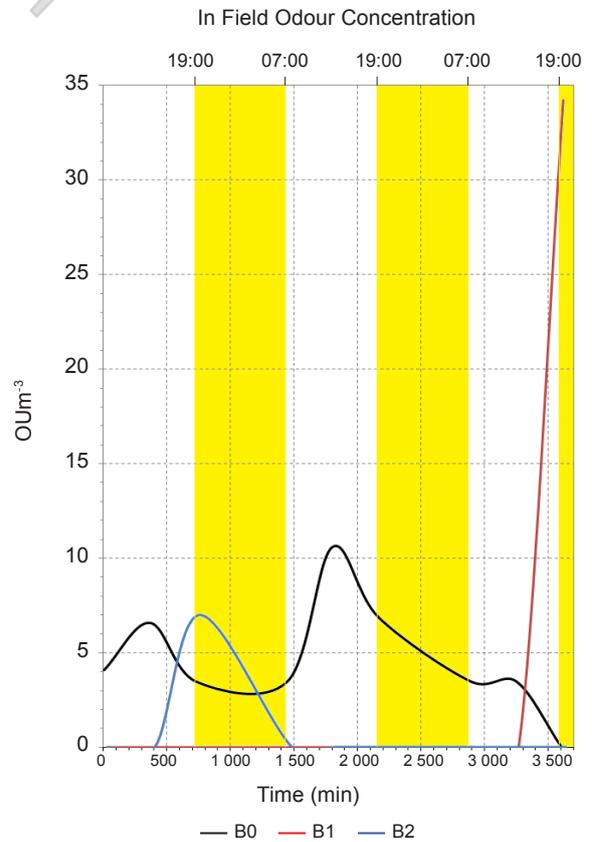
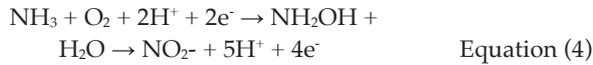


Figure 8. Boundary odour assessments for digester tank system during peak crop.

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



Based on the empiric data and the threshold limits, the odour emission from palm oil mill is dominated by hydrogen sulphide. Figure 9 shows the correlation between the odorous gas content and odour concentration of the gas samples collected from anaerobic pond. Low correlation between the respective odorous gas and odour concentration indicated that the odour of the gas samples collected from the anaerobic pond were not single odorant effect but rather a combination of various odorous gases generated from POME anaerobic fermentation. Although the amount of such odorous gases was regulated by the microbial activity, the odour concentration theoretically was proportional to the amount of odorant present in the gas sample. Thus, linear multivariate regression has been performed yielding empiric odour model as shown in Equation (5) where x_1 is hydrogen sulphide, H_2S content in ppm; x_2 is ammonia, NH_3

content in ppm and y is odour concentration in OUm^{-3} .

$$y = 372.9286x_1 + 1718.5450x_2 + 17419.7682 \quad \text{Equation (5)}$$

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		

The R^2 value increases to 0.7854 with estimation error 14573.7023 showed that besides H_2S and NH_3 , other unidentified odorous gases also existed and influenced the odour concentration.

Wind rose diagram for survey locations of Mill A, Mill B and Mill C is shown in Figures 10, 11 and 12, respectively. Diagrams analysis show that only Mill A Boundary 1 and Mill B Boundary 2 have potential of odour complaints due to wind blow. However, the wind speed at all survey sites was well below 5 mph most of the time even strong wind was recorded at Mill A; once 21.15 mph South and once 5.3 mph South to Southeast (SSE).

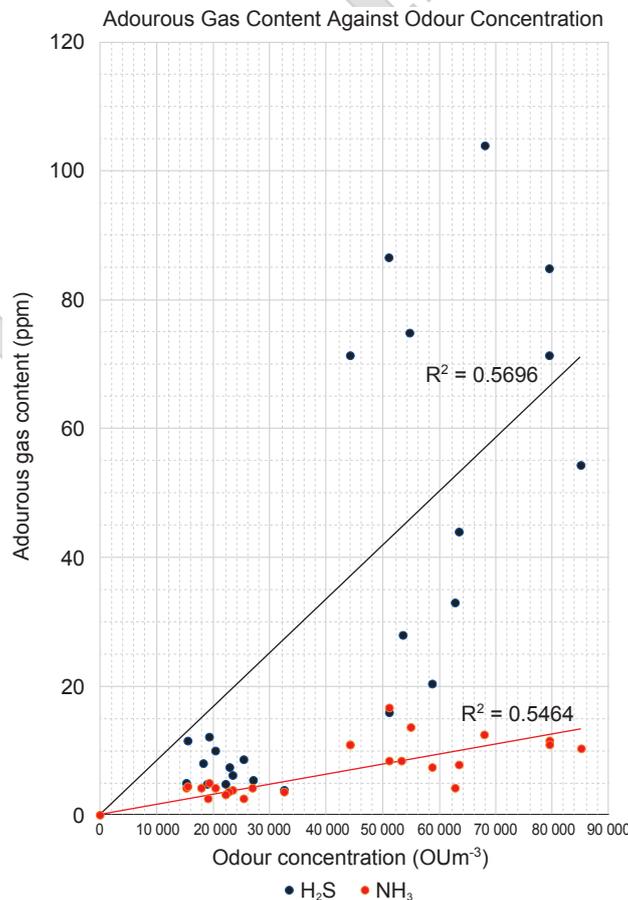


Figure 9. Correlation between odourous gas content and odour concentration.

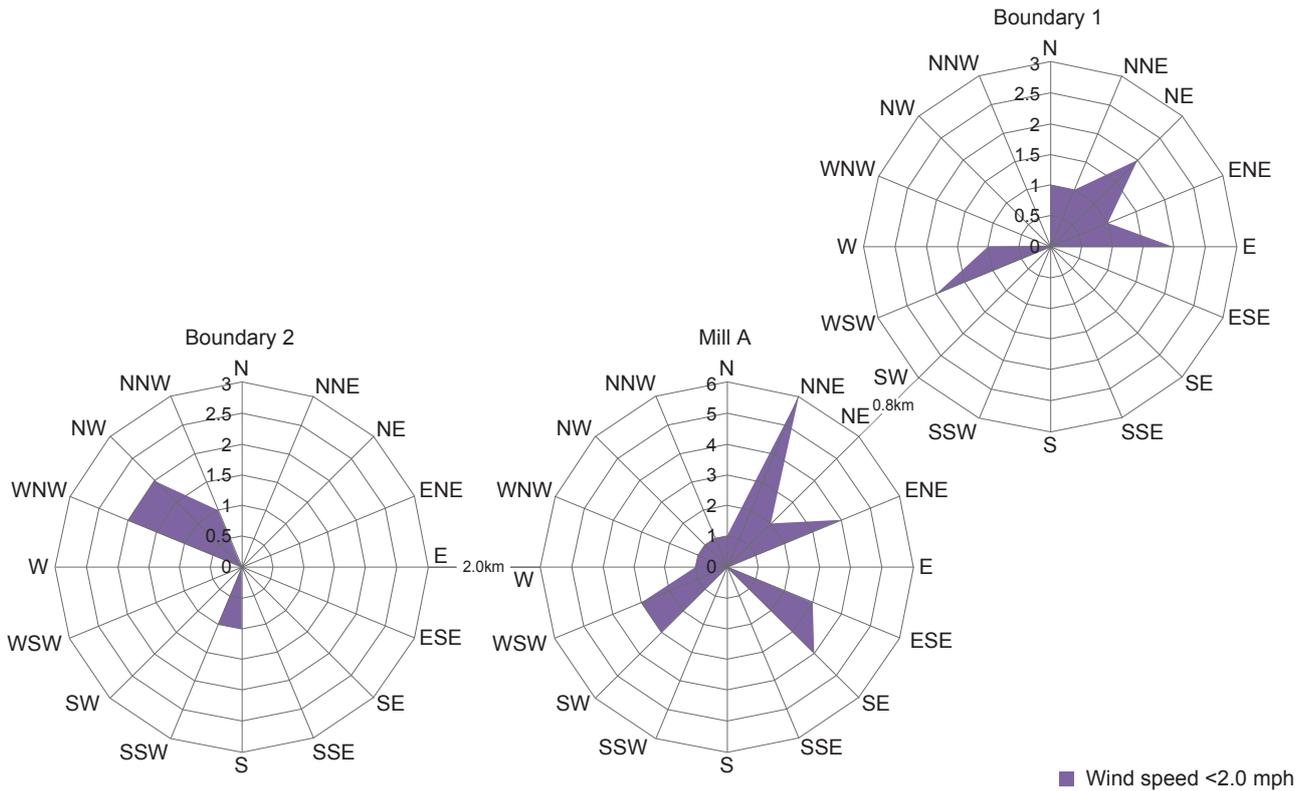


Figure 10. Wind Rose Diagram Analysis for Mill A and the survey boundary areas.

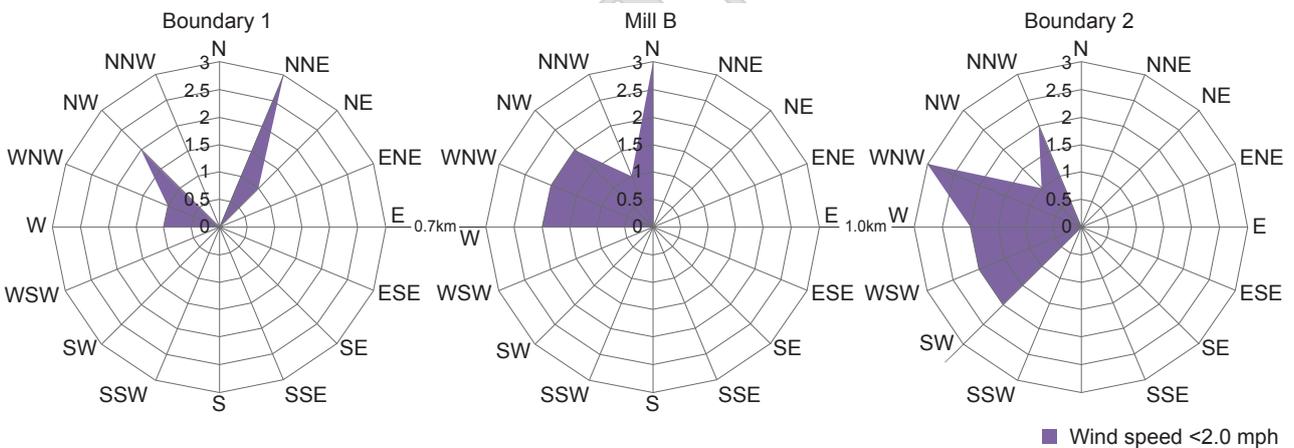


Figure 11. Wind Rose Diagram Analysis for Mill B and the survey boundary areas.

CONCLUSION

Experimental results showed that odour concentration at source of anaerobic pond ranged from 44 135-85 012 OUm⁻³ while hydrogen sulphide content ranged from 15.9-103.9 ppm and ammonia content ranged 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 surveyed residential areas identified as palm oil mills origin were well below 10 OUm⁻³ most of the times although high level of up to 108.4 OUm⁻³ has been observed occasionally.

ACKNOWLEDGEMENT

Authors would like to express the sincerest gratitude to the Director-General of MPOB for the support in project execution.

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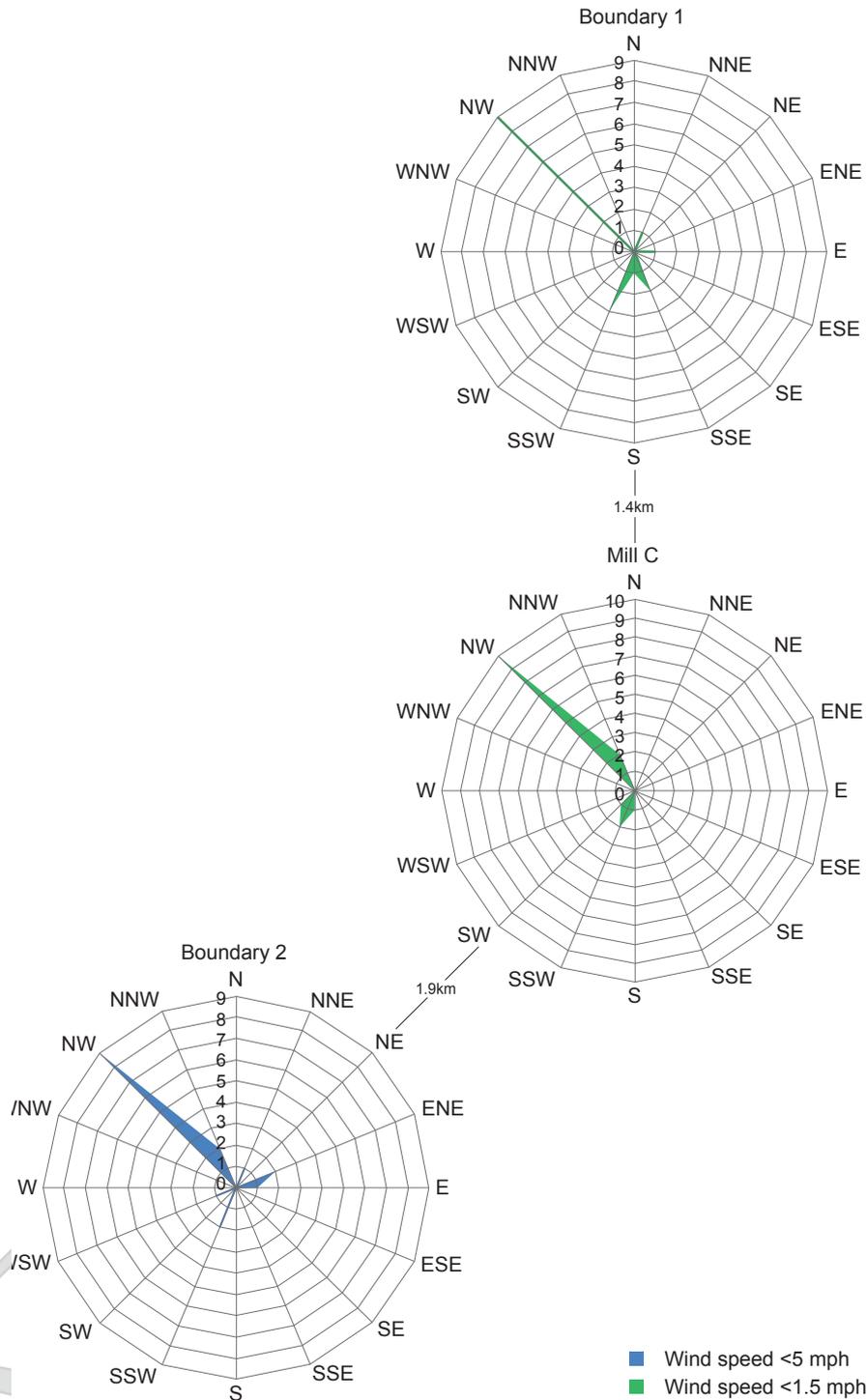


Figure 12. Wind Rose Diagram Analysis for Mill C and the survey boundary areas.

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