

Zero Discharge using Flash Evaporation of POME at Atmospheric Conditions

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INTRODUCTION

One of the major unresolved issues faced by the palm oil mills is their inability to address concerns of the global community in finding a permanent solution to handle the large volumes palm oil mill effluent (POME) that the mills generate during the oil extraction process. Unlike most other oil processing industries, the biological oxygen demand (BOD) of the POME usually ranges from 25 000 to 28 000 mg litre⁻¹. The relatively high volume of the POME which can vary from 65% of the fresh fruit bunch (FFB) processed in a well operated palm oil mill to even 100% of the FFB processed in some mills where its control is not given the priority it deserves. The conventional method of POME treatment practiced by most mills is based on natural degradation of the protein-rich

wastewater using both anaerobic as well as aerobic bacteria in a number of large ponds. The bacteria are very active in the anaerobic digestion ponds as it generally brings down the BOD to about 5000 mg litre⁻¹.

At this point, some of the digested POME used to be tapped off for field application as the POME still possessed significant nutrition for the palms. But as the land application of partially digested POME at a BOD level of 5000 mg litre⁻¹ could cause ground water pollution by seepage the permitted limit for land application was brought down to be on par with the water course discharge limit of 100 mg litre⁻¹. As this value is much higher than the international limit of 20 mg litre⁻¹, the palm oil industry is reeling under the pressure to conform to the regulation on one end and the absence of an affordable system that can guarantee to achieve the set limits by the Department of Environment (DOE). As even the 20 mg litre⁻¹ may not necessary be the final end as the limit may again change even 5 mg litre⁻¹. So it is prudent for the millers to aim for zero discharge.

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There are two options when selecting a zero POME discharge system. One is to retain the conventional anaerobic digestion system and tap all methane gas that is released for either power generation or heating and drying the POME ex-anaerobic ponds to achieve zero discharge. The second one is to use biomass like empty fruit bunch (EFB) to evaporate the raw effluent resulting in neither effluent discharges nor methane released to atmosphere. Some of the MPOB researchers and innovative mill engineers have tried out other systems like filtration and reverse osmosis on experimental scale but the prohibitive cost and uncertainty about its performance have discouraged them to try them out at commercial scale. The current low crude palm oil (CPO) price also does not give much incentive for investing high capital for any untested system. The evaporation systems also have been tried out but so far an acceptable system has not emerged to attract the industry for immediate acceptance the obvious obstacles being the high cost and the non-confidence in its performance.

In this article, the POME fracturing technology coupled with its flash evaporation is presented. As this technology is already well established for the treatment of waste water related to other industries, it can be adapted to POME with some changes in the system design as some parameters like dissolved solids and BOD in POME may differ significantly from other waste water.

POME production rate can generally range from 70% to 80% of the FFB processed, the cause for the variation being due to the frequency of mill floor cleaning operation followed by its discharge into the effluent stream. The sludge water amount to approximately 50%, the steriliser condensate about 15% to 20% and hydrocyclone about 5% as a ratio to the FFB processed. The mill wash water which contains spilled oil from the tanks or from steriliser cages are also considered to be part of the effluent of the FFB processed. The turbine cooling water, boiler blowdown

water, overflows from the vacuum dryer are discharged into the monsoon drains as they are not contaminated with oil.

POME ANALYSIS

In order to study the full characteristics of the digested POME with retention time in ponds exceeding 100 days, a sample of the POME taken from a mill in Tawau prior to its discharge for land irrigation was analysed by the University Sabah Malaysia. The chemical and ionic analysis of the sample are shown in *Table 1*.

The analysis shows the main constituents of the mature POME at the final discharge stage. It contained suspended solids (SS), nitrogen, chloride, potassium, magnesium and calcium. The current practice of POME treatment systems installed in mills is based on reducing BOD to 20 mg litre⁻¹ by eliminating SS. The SS can also be reduced by using coagulants, flocculants and filtration but the results may not obtain consistent values.

A test was carried out to evaluate the BOD performance of the POME after it had undergone filtration using a Novoflow ceramic filter from Germany having pore sizes 0.2 µm and 30 nm. The POME was passed through a spinning ceramic membrane filter rotating at 200 rpm to allow the solids to adhere to the side walls thus permitting the passage of the POME without clogging. The issuing clear filtrate was analysed and the results are shown in *Table 2*.

The ceramic membrane selected for this analysis had the smallest pores available in the market measuring only 30 nm in order to ensure that the filtrate contained very minimal SS amounting to only 14 mg litre⁻¹, or 0.0014%. Despite the very low SS in the filtrate, the BOD still remained at 60mg litre⁻¹. The results of this analysis could clearly establish that the SS in the effluent did not have any influence on the BOD but raise the question of what other

TABLE 1. CHEMICAL ANALYSIS OF POME

Elements	(mg litre ⁻¹)	Parameter	Result
Potassium	3 713.99	Suspended	353.87
Magnesium	467.58	Total nitrogen	88.83
Calcium	275.16	Ammoniacal chloride	31.13
Sodium	50.21	Sulphate	758.57
Bismuth	7.61	Bromide	39.80
Aluminium	3.31		10.03
Arsenic	3.06		
Rubidium	3.87		
Strontium	3.14		
Barium	1.63		
Cobalt	1.80		
Copper	1.82		
Iron	1.42		
Gallium	1.37		
Manganese	1.92		
Titanium	1.07		
Vanadium	1.05		
Zinc	1.60		

Source: University Malaysia Sabah Test Results (2013).

TABLE 2. ANALYSIS OF FILTERED POME

Test parameters (mg litre ⁻¹)	Pre-filtration	0.2 µm filter	30 nm filter
BOD	106	92	62
COD	1 064	947	642
Total solids	6 138	5 636	3 876
Suspended solids	379	76	14
Oil and grease	13	7	11

Note: BOD – biological oxygen demand. COD – chemical oxygen demand.
Source: KDC Laboratory Tawau Test Results (2012).

factors are involved in the BOD make-up of the effluent or preventing its decline to the acceptable value of 20 mg litre⁻¹.

BIOLOGICAL OXYGEN DEMAND (BOD)

The biological organisms present in any mass of water will by nature break down into its simple forms without any external aid other than certain amount of oxygen

generally referred to as biochemical demand or BOD expressed as mg litre⁻¹. The measurement is taken after an incubation period of five days at a temperature of 20°C, time for the organic matter will be assumed to flow in a river before it reaches the sea. In order to identify the source of the organic matter that was responsible for the high BOD levels, the SS were filtered out and BOD tests were carried out but the BOD value could not be reduced to any

significant levels indicating that something else could be contributing towards the BOD other than suspended organic solids.

Attention was now diverted to carbonaceous oxygen demand and nitrogenous oxygen demand the two components of BOD. Carbonaceous oxygen demand refers to carbon based compounds like sugar and the nitrogenous based compounds refers to protein based compounds both of which are abundantly present in POME as detailed in *Table 3*.

Agamuthu and Tan (1985) reported that the organic matter in POME comprised the major pollutants five and six carbon chain monosaccharides such as arabinose, xylose, glucose, galactose and manose having concentrations of 6.43%, 0.44%, 0.22%, 0.15% and 0.10% dry weight respectively. The compositions and concentrations of proteins, nitrogenous compounds and lipids are summarised in *Table 4*.

POME subjected to anaerobic digestion taking place in open ponds can be considered to be a very rudimentary way of handling the POME when there is a specific target to meet especially when that target happens to be a very stringent one. The mill engineers will have to undergo a paradigm shift and consider the POME treatment as an important component of the process

operation. They have to think of a perfect system where the chemical conversion to methane and carbon dioxide take place in a conducive environment favouring maximum conversion and for this the ponds will have to give way to steel tanks with automatic monitoring of all associated parameters. In fact, a chemist or a chemical engineer will have to be engaged on full time to ensure maximum conversion rates and minimum BOD values.

Carbonaceous biochemical oxygen demand (CBOD), a component of BOD, is the result of the breakdown of carbon based organic matter such as sugars into carbon dioxide and water. Nitrogenous biochemical oxygen demand (NBOD), a component of BOD, is the result of the breakdown of organic based nitrogen, such as proteins, into nitrates. Proteins are one of the more chained amino acids that are linked to nitrogen. The breakdown of these amino acids requires more than four times the amount of oxygen as the conversion of an equal amount of sugar to carbon dioxide and water. *Table 4* summarises the various amino acids and lipids found in POME.

The important finding here is the breakdown of protein that requires a large portion of oxygen compared to the breakdown of organic compounds as well as the SS. The POME still containing the residual carbohy-

TABLE 3. CONSTITUENTS OF RAW PALM OIL MILL EFFLUENT

Constituents	Quantity (g g ⁻¹ dry sample)
Crude protein	9.07
Crude lipids	13.21
Carbohydrates	20.55
Nitrogen-free extracts	19.47
Total carotene	20.07
Ash	32.12
Moisture	6.75

Source: Habib *et al.* (1997).

drates, proteins and lipids will not be able to achieve 20 mg litre⁻¹ unless biological treatments are focused on specific components for their complete breakdown.

A NEW APPROACH – EVAPORATION

Evaporation of water from the rivers, lakes, sea and oceans is a natural phenomenon that creates the clouds throughout the day using the heat from the sun. When the surface water temperature reaches a certain value the water molecules undergoes a phase change from liquid phase to vapour phase and if the vapour flow rate is increased by wind, the evaporation process will likewise increase. The evaporation process will continue until the relative humidity of the atmosphere above the evaporation surface becomes saturated at 100%.

The evaporation rate is influenced by many factors like ground temperature, relative humidity, rainfall, solar radiation and wind. Maximum evaporation takes place on a hot, dry day with no rain. The pan evaporation rate considers rainfall, solar radiation, humidity, temperatures and wind to provide an average daily drop in water levels within a pan over a 24 hr period. When rainwater exceeds evaporation, the daily evaporation rate is considered as 0 mm.

In Malaysia, the pan evaporation rates average between 3 mm to 5 mm or even more per day across the country. Sabah (Kota Kinabalu region to Sandakan) has the highest pan evaporation rates in the country consistently averaging above 4 mm daily. That is any open water source in an outdoor environment will naturally deplete by 4 mm daily, on average. The daily average evaporation rates and annual average rainfall for Malaysia are summarised in *Tables 5 and 6*.

Based on a number of weather stations selected across Malaysia the data were collected. The results indicate that the minimum daily evaporation rates were

above 3 mm, the average rainfall over three years being 2668 mm annually.

The average annual pan evaporation rate for Australia is shown in *Figure 1*. Australia has winter and summer seasons.

It can be seen that the evaporation rate in Australia takes place consistently at an average annual rate of 1000 mm to 1500 mm or 2.74 mm to 4.10 mm per day around coastal areas. These figures are largely similar to that of Malaysia.

POME DRYING

POME can be treated in many ways and the systems used may vary from one mill to another as it is very much dependant on the preference of the head of the engineering division or the operation division. The common goal in all cases is meeting the target set by the DOE. Most of the mills could meet the BOD target of 100 mg litre⁻¹ the exception being some private mills who become over aggressive and try to maximise the mill utilisation rate resulting in not being able to meet the DOE standards. The most often repeated excuse cannot meet the target of the DOE because the target is beyond reach is not well substantiated as any effluent treatment system can comply with the statutory requirement if either the mill throughput is reduced or the effluent treatment system capacity is expanded or the treatment efficiency is improved. Some of the methods that could help the mills to comply with the regulations are given below:

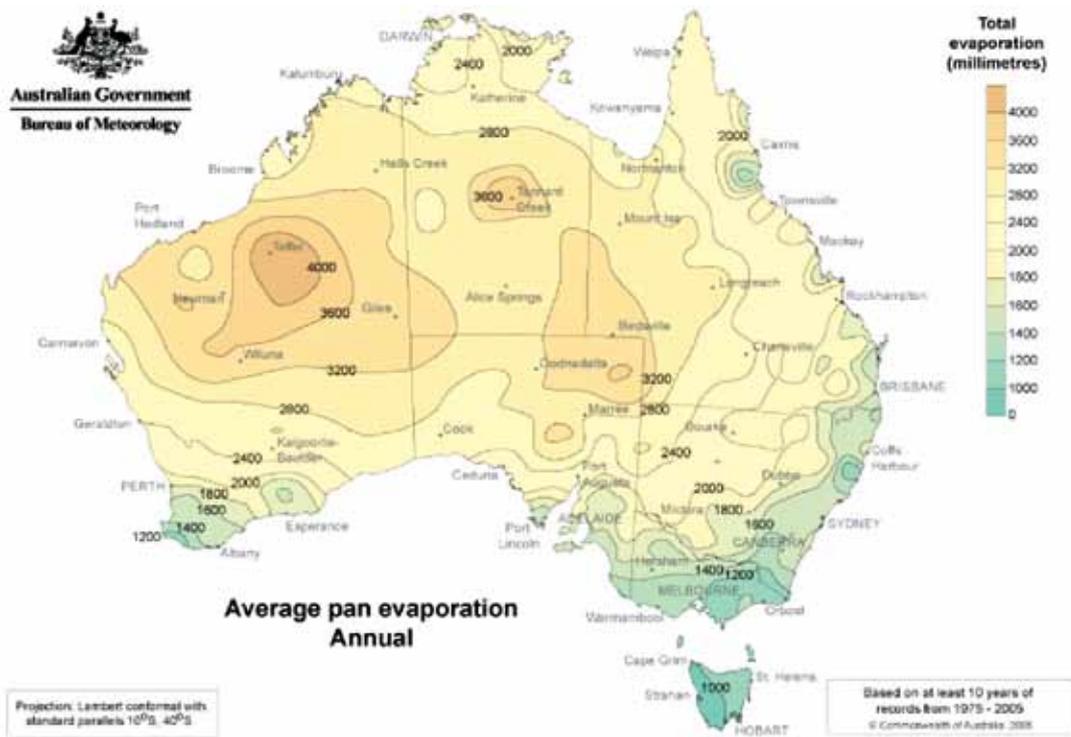
- increase the capacity of the treatment ponds that will offer extra retention time and ensure that the effluent degradation is effective. Dilution of the effluent by rainwater also would help to reduce the BOD.
- offer favourable environment for the bacteria to completely break down all the residual components that need degradation to reduce the BOD to acceptable limits.



TABLE 4. AMINO ACIDS / LIPIDS IN RAW PALM OIL MILL EFFLUENT

Amino Acids (g/100 g protein)	Chemical formula	g
Aspartic acid	$\text{HOOC-CH}_2\text{-CH(NH}_2\text{)-COOH}$	9.66
Glutamic acid	$\text{HOOC-(CH}_2\text{)}_2\text{-CH(NH}_2\text{)-COOH}$	10.88
Serine	$\text{HO-CH}_2\text{-CH(NH}_2\text{)-COOH}$	6.86
Glycine	$\text{NH}_2\text{-CH}_2\text{-COOH}$	9.43
Histidine	$\text{NH-CH=N-CH=C-CH}_2\text{-CH(NH}_2\text{)-COOH}$	1.43
Arginine	$\text{HN=C(NH}_2\text{)-NH-(CH}_2\text{)}_3\text{-CH(NH}_2\text{)-COOH}$	4.15
Threonine	$\text{CH}_3\text{(OH)CH(NH}_2\text{)-CHCOOH}$	2.58
Alanine	$\text{CH}_3\text{-CH(NH}_2\text{)-COOH}$	7.7
Proline	$\text{NH-(CH}_2\text{)}_3\text{-CH-COOH}$	4.57
Tyrosine	$\text{HO-Ph-CH}_2\text{-CH(NH}_2\text{)-COOH}$	3.26
Phenylalanine	$\text{Ph-CH}_2\text{-CH(NH}_2\text{)-COOH}$	3.2
Valine	$\text{(CH}_3\text{)}_2\text{-CH-CH(NH}_2\text{)-COOH}$	3.56
Methionine	$\text{CH}_3\text{-S-(CH}_2\text{)}_2\text{-CH(NH}_2\text{)-COOH}$	6.88
Cystine	$\text{HS-CH}_2\text{-CH(NH}_2\text{)-COOH}$	3.37
Isoleucine	$\text{CH}_3\text{-CH}_2\text{-CH(CH}_3\text{)-CH(NH}_2\text{)-COOH}$	4.53
Leucine	$\text{(CH}_3\text{)}_2\text{-CH-CH}_2\text{-CH(NH}_2\text{)-COOH}$	6.86
Lysine	$\text{H}_2\text{N-(CH}_2\text{)}_4\text{-CH(NH}_2\text{)-COOH}$	5.66
Tryptophan	$\text{Ph-NH-CH=C-CH}_2\text{-CH(NH}_2\text{)-COOH}$	1.26
Fatty acids (g/100 g lipid)	Chemical formula	g
Capric acid (10:0)	$\text{CH}_3\text{(CH}_2\text{)}_8\text{COOH}$	4.29
Lauric acid (12:0)	$\text{CH}_3\text{(CH}_2\text{)}_{10}\text{COOH}$	9.22
Myristic acid (14:0)	$\text{CH}_3\text{(CH}_2\text{)}_{12}\text{COOH}$	12.66
Palmitic acid (16:0)	$\text{CH}_3\text{(CH}_2\text{)}_{14}\text{COOH}$	14.45
Heptadecanoic acid (17:0)	$\text{CH}_3\text{(CH}_2\text{)}_{15}\text{COOH}$	1.39
10-heptadecanoic acid (17:01)	$\text{CH}_3\text{(CH}_2\text{)}_8\text{CH=CH(CH}_2\text{)}_5\text{COOH}$	1.12
Stearic acid (18:0)	$\text{CH}_3\text{(CH}_2\text{)}_{16}\text{COOH}$	11.41
Oleic acid (18:1n-9)	$\text{CH}_3\text{(CH}_2\text{)}_7\text{CH=CH(CH}_2\text{)}_7\text{COOH}$	8.54
Lenoleic acid (18:2n-6)	$\text{CH}_3\text{CH}_2\text{(CH=CH.CH}_2\text{)}_3\text{(CH}_2\text{)}_6\text{COOH}$	4.72
Linolenic acid (18:3n-3)	$\text{CH}_3\text{CH}_2\text{(CH=CH.CH}_2\text{)}_3\text{(CH}_2\text{)}_6\text{COOH}$	4.72
Arachidic acid (20:0)	$\text{CH}_3\text{(CH}_2\text{)}_{18}\text{COOH}$	7.56
Eicosatrienoic acid (20:3n-6)	$\text{CH}_3\text{CH}_2\text{(CH=CHCH}_2\text{)}_3\text{(CH}_2\text{)}_8\text{COOH}$	1.49
Arachidonic acid (20:4n-6)	$\text{CH}_3\text{(CH}_2\text{)}_4\text{(CH=CHCH}_2\text{)}_4\text{(CH}_2\text{)}_2\text{COOH}$	1.12
Eicosapentaenoic acid (20:5n-3)	$\text{CH}_3\text{CH}_2\text{(CH=CHCH}_2\text{)}_5\text{(CH}_2\text{)}_2\text{COOH}$	0.36
Behenic acid (22:0)	$\text{CH}_3\text{(CH}_2\text{)}_{20}\text{COOH}$	2.62

Source: Habib *et al.* (1997).



Source: Australian Bureau of Meteorology (2009).

Figure 1. Australian average evaporation rates.

TABLE 5. MALAYSIA EVAPORATION RATES (all rates in mm per day)

Year	KLIA	Senai	Kuantan	Melaka	Tawau	Kota Kinabalu	Kuching	Alor Setar
2010	4.3	3.5	4.0	4.3	3.8	4.5	3.5	4.4
2011	4.4	3.3	3.6	4.2	3.5	4.4	3.6	4.0
2012	4.5	3.3	3.8	4.2	3.7	4.5	3.6	4.6

Source: Malaysian Meteorological Department (2013).

TABLE 6. 2010 TO 2012 AVERAGE ANNUAL RAINFALL

	KLIA	Senai	Kuantan	Melaka	Tawau	Kota Kinabalu	Kuching	Alor Setar
Rainfall	2 056.2	2 696.7	2 948.5	1 907.1	2 111.6	2 906.7	4 338.8	2 379.7

Source: Malaysian Meteorological Department (2013).

- systems that either mixes shredded biomass and effluent water to make compost after partial drying using waste heat from the boiler flue gases or other heating systems or by simple evaporation of the effluent to produce effluent cake. Thermophilic bacteria also are capable of generating sufficient heat to assist in the evaporation of effluent water.

In this article, the focus is achieving zero discharge by complete evaporation of POME by offering a conducive environment comprising both high temperature and pressure. Current BOD limit of 100 mg litre⁻¹ may not be environmentally friendly if the POME discharged into water course is to remain at a safe value for marine life if the POME mixed with the natural river water may not have sufficient time to degrade naturally to values that will not adversely affect marine life thriving at a location downstream. If on the other hand the BOD of POME at discharge for the mill is already at 20 mg litre⁻¹ in all likelihood, the water source would be safe for marine life. So whatever the system, it must be able to ensure a BOD level that is always below 20 mg litre⁻¹ and no allowance would be made for non-compliance during peak crop season when the mill is forced to process more than what it is designed for based on strict BOD considerations.

Most of the mills have a number of digestion ponds to cater for anaerobic and aerobic digestion of effluent generated by the mill. In the absence of a system to ensure that the operation is under controlled conditions, the efficiency of POME degradation can be considered to be far from satisfactory. The Tawau mill that was selected to collect data had two aerobic ponds each having a dimension 150 x 50 x 5 m and two aerobic ponds each having a dimension of 90 x 30 x 3 m. The total volume exceeded 100 000 m³ and the total surface area of all the four ponds were 20 400 m². If the pan evaporation rate is taken as 3 mm, the daily natural evaporation rate will

amount to 61 m³ of water. Rainwater may amount to 168 m³ per day and together with POME at 328 m³ will be 496 m³ of diluted POME flowing through the ponds per day. In tank digestion system, the rainwater comprising 33% by volume is reduced but the natural evaporation is also likewise reduced.

FRACTURING TO ACHIEVE 100% EVAPORATION

In order to promote evaporation without a corresponding increase in rainwater, the proposed method is to convert the POME into a fine mist without the need for increasing the pan area. This is accomplished by pressurising the POME and allowing the pressurised jet to hit a high speed turbine to create a fine mist with vastly increased surface area that can instantaneously evaporate. This is called fracturing the POME. This is purely a mechanical technology in which two processes are involved in the splitting up of the liquid into millions of fine droplets that considerably increase the total surface area exposed for easy evaporation coupled with the kinetic energy the droplets acquired by the high speed rotation of the turbine thus achieving the required properties of wind and temperature. *Figure 3* shows how the mist is projected upwards by the high speed rotating turbine.



Figure 2. SMI 420F Evaporator.

Water molecules completely vaporise at its boiling point of 100°C at sea level atmospheric pressure. The remainder of the major components found in POME are potassium, magnesium and calcium which would be present as salts, sugars, proteins and lipids. The boiling points of these other major components are summarised in *Table 7*.

With the major components of POME having boiling points more than three times above that of water, it is not possible that these components would flash evaporate like water at normal outdoor temperatures.



Figure 3. Mist Creation.

Moreover, the unevaporated component of the mist would eventually coagulate, saturate with ambient humidity, gain weight and slowly drift back to the pond surface.

Volatile organic compounds (VOC) are organic chemicals that have a high vapour pressure at ordinary, room temperature conditions. Their high vapour pressure results from a low boiling point, which causes a large number of molecules to evaporate or sublime from the liquid or solid form of the compound and enter the surrounding air. As summarised in *Table 7*, none of the major components of POME, apart from water, demonstrate a boiling point below water. The closest one is lauric acid, with a boiling point three times higher than water.

IMPACT ON AIR POLLUTION

As burning is not involved, there are no emissions of gases such as sulfur oxides, nitrogen oxides and carbon monoxide gases that are relevant as a result of POME fractured into a mist and projected into the

TABLE 7. BOILING POINTS OF SELECTED ORGANIC COMPOUNDS FOUND IN POME

Compound	Boiling point (°C)
Water	100
Potassium chloride	1 420
Magnesium chloride	1 412
Calcium carbonate	Only decomposes. Melting point: 825
Arabinose	Only decomposes. Melting point:164/165
Xylose	Only decomposes. Melting point: 144/145
Glucose	Only decomposes. Melting point: 146 -150
Aspartic acid	Only decomposes. Melting point: 324
Glutamic acid	Only decomposes. Melting point: 199
Glycine	Only decomposes. Melting point: 233
Lauric acid	298.8
Myristic acid	250.5°C at 100 mmHg
Palmitic acid	351

Source: Various references through Wikipedia.



air are VOC and hydrogen sulphide (H₂S). Whilst not a gas, particulates may also be a concern. SS are tiny particulates and this may cause an issue if airborne. The Malaysian Ambient Air Quality Guidelines (MAAQG) sets a standard of 260 µg m⁻³ (24 hr) for total suspended particulate (TSP).

Environment air quality testing was conducted to test for VOC, H₂S and TSP. The testing was carried out by Kiwiheng Wood and Environmental Consultants Sdn Bhd (DOE Reg No. C0924). The evaporator was set-up in the centre of a pond testing of VOC, H₂S and TSP was carried out directly at the bank of the pond, 50 m away from the pond, and lastly 100 m away from the pond. Samples were taken with the evaporator off at the pond bank, and then switch on and again taken at the pond bank, 50 m away, and lastly 100 m away. This would show if any gases moved outwards, if detected, or remained constrained within the vicinity of the evaporation pond.

The results clearly demonstrate two observations; firstly that VOC and H₂S do not increase as a result of fracturing of POME. This is mainly because a chemical or thermal reaction does not take place in the process. Furthermore, the organic compounds in POME are not highly volatile to cause VOC gases, as in comparison to paints, thinners and fuels that are highly volatile. Secondly, all gases reduced to virtually undetectable beyond 100 m from the pond. At all times, total SS were below that of MAAQG guidelines.

COMMERCIAL DEPLOYMENT

The evaporation system has now been deployed in two Sabah palm oil mills; one at a privately held Tawau based mill, and the other at Sime Darby at a Keningau based mill. Both mills obtained Sabah DOE approval to operate the evaporators with a

reduced quota for any discharge of POME via land irrigation to 50% the normal expected discharge at 1:1 POME/FFB ratio. The evaporation system in Tawau has been in operation for more than 18 months and it only discharge 20% of the POME compared to expected levels. It is in the process of procuring additional evaporators to reduce the discharge to zero. Sime Darby has been operating their evaporators for more than nine months and has achieved zero discharge of any POME since operating the machines. A factor benefiting the Keningau area in Sabah is higher than average pan evaporation rates when compared to other parts of Malaysia.

CONCLUSION

POME is a highly organic wastewater by-product that emerges from palm oil mills. Its organic loading is derived from a combination of components including SS, plant sugars, proteins, lipids, metallic salts, and calcium hardness. Evaporation efficiency depends on the moisture content of the wastewater stream and humidity level of the ambient to vaporise water into air. Evaporation of wastewater is being successfully utilised in many countries across a diverse range of industries and its effective use could result in complete control of preventing any wastewater streams from entering our sensitive ecosystems.

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