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# ZERO DISCHARGE TREATMENT TECHNOLOGY OF PALM OIL MILL EFFLUENT

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**ABSTRACT**

*Palm oil processing operation is invariably accompanied by palm oil mill effluent (POME) considered to be an environmental pollutant. While anaerobic digestion and the present tertiary treatment technologies of POME are able to meet the current regulatory effluent discharge requirement of biological oxygen demand (BOD) 100 mg litre*$^{-1}$ *– the current limit set by the Department of Environment (DOE) – the existing technologies are unable to consistently meet the proposed stringent BOD regulatory requirement of 20 mg litre*$^{-1}$ *to be imposed by the DOE. This article investigates the possibility of integrating several bioprocesses for POME treatment at the Malaysian palm oil mills by transforming the POME into several high value-added products; with BOD 20 mg litre*$^{-1}$ *attainable at its final discharge. This integrated approach has the potential of achieving zero-effluent discharge along with the production of biogas, biofertiliser and recycled water, in treating industrial wastewater to reduce pollution.*

**Keywords:** wastewater, biological treatment, biological oxygen demand, biogas, biofertiliser.

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## INTRODUCTION

The Malaysian palm oil industry has been developing over the years and is still progressing, thus assuring the nation of abundant returns. Being the second largest palm oil producer after Indonesia, the palm oil industry contributes greatly to the country's foreign exchange earnings and the increased living life-style of the Malaysians (Wu *et al*., 2009).

Generally, oil palm (*Elaeis guineensis*) is one of the most versatile crops in the tropical region, notably in Malaysia and Indonesia. The extraction of palm oil from the fruit of *E. guineensis* involves a number of processing stages *viz*. sterilisation, stripping, digestion, pressing, clarification, purification and vacuum drying. In the extraction process, a large quantity of water is required. It is estimated that about 1.5 $m^3$ of water is needed to process 1 t of fresh fruit bunch (FFB) - half of this water amount ends up as palm oil mill effluent (POME).

POME, a highly polluting wastewater generated from the palm oil milling process is thick, brownish with a distinct offensive odour, and has a high organic matter content, but is non-toxic as no chemicals are added during oil extraction (Ahmad *et al*., 2009). The thick brownish raw POME in the viscous colloidal form is discharged at a temperature between 80°C and 90°C. If the untreated POME is discharged into watercourses, it certainly will cause considerable environmental problems due to its high biological oxygen demand (BOD) (~25 000 mg litre$^{-1}$), chemical oxygen demand (COD) (~50 000 mg litre$^{-1}$), oil and grease (O&G) (4000-8000 mg litre$^{-1}$), total solids (40 500-63 000 mg litre$^{-1}$) and suspended solids (SS) (18 000-30 000 mg litre$^{-1}$) (Ma,1996; Loh *et al*., 2009).

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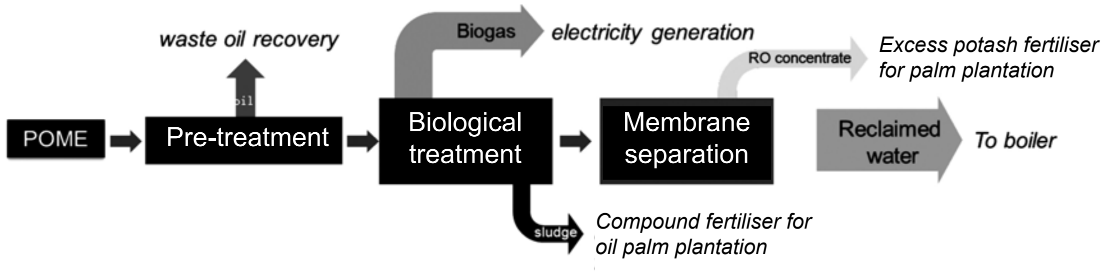


*Figure 1. An integrated biological treatment process for the palm oil mill effluent (POME).*

One of the most conventional and common methods for treating POME is the open pond system which employs the open type lagoons treatment (Ma and Ong, 1985; Khalid and Wan Mustafa, 1992). To date, approximately 85% of POME treatment is based on conventional biological treatment methods of acidification, anaerobic, facultative and aerobic degradation (Zhang *et al*., 2008; Loh *et al*., 2009).

The conventional anaerobic lagoon or tank digester is characterised by long residence time, often in excess of 20 days. As an example, a pond system, consisting of eight ponds in a series, shows relatively poor efficiency with a discharge end having residual COD and BOD of 1725 and 610 mg litre$^{-1}$, respectively in the POME at a total hydraulic retention time (HRT) of 60 days compared to other recently developed treatment methods (Zhang *et al*., 2008). Another drawback of the conventional anaerobic digester is its difficulty in collecting and utilising the methane generated, which has a detrimental greenhouse effect on the environment, as methane has 21 times the global warming potential of carbon dioxide.

It is common for the POME treatment system that is based mainly on conventional biological treatments of anaerobic and aerobic ponding systems to remain inefficient due to the high BOD loading, low pH and colloidal nature of the SS in the POME (Stanton, 1974; Ahmad *et al*., 2005). A detailed cost calculation has also indicated that this conventional system of POME treatment is not only a less effective system with the lowest utilisation of renewable resources, but also a system with the lowest profit (Schuchardt *et al*., 2005). Thus, proper POME treatment is vital to ensure a sustainable economic growth in palm oil milling, besides protecting the environment (Ahmad *et al*., 2009). With technological advances over the years, other processes with combined aerobic and anaerobic digestions, physico-chemical treatments and membrane filtration may provide the palm oil industry with a possible insight for the improvement of current POME treatment process.

Whilst the present tertiary treatment technologies for POME, under optimum operation coupled with proper maintenance, are able to meet the regulatory effluent discharge limits of BOD 100 mg litre$^{-1}$, most of the technologies employed have uncertainties in the plants' performance, and the confidence if they are to consistently meet 100% compliance on a more stringent BOD 20 mg litre$^{-1}$ requirement recently proposed by the Department of Environment (DOE). As the current POME treatment trend is gearing towards shortening the treatment time needed, lessening the land required, reducing POME BOD to below 20 mg litre$^{-1}$, and at the same time trapping the biogas produced, many high-rate reactors such as tank digesters (Ugoji, 1997), anaerobic filters (Borja and Banks, 1994), anaerobic fluidised reactors (Borja and Banks, 1995), anaerobic baffled reactors (Setiadi *et al*., 1996; Faisal and Unno, 2001), up flow anaerobic sludge beds (UASB) (Borja and Banks, 1996), and other hybrid reactors have been put forward and evaluated in treating POME (Borja and Alba, 1996; Najafpour and Zinatizadeh, 2006; Zinatizadeh and Mohamed, 2006).

The palm oil industry has been identified as a potential threat to the environment due to the discharge of effluent that causes air, water and soil pollution. Hence, a zero discharge route may seem as an appropriate approach to solve this problem. A zero discharge system in the palm oil milling process is one that can treat all the incoming effluent and leave nothing behind. The main aim is to recover usable materials such as oil, sludge and water from the effluent, and to minimise the generation of waste as well as to recover valuable nutrients from treated sludge, so that they can be reused as fertiliser without the need for discharge into the environment. In this study, an integrated biological treatment process (*Figure 1*) was exploited to evaluate its efficiency in treating POME towards zero discharge or effluent-free.

## MATERIALS AND METHODS

### Experimental Set Up

A zero discharge POME treatment pilot plant was installed at Kilang Kelapa Sawit (KKS) Labu, Sime Darby. This plant was equipped with a complex concrete tank functioning as a pre-treatment and aerobic/clarifier system, followed by a biological treatment system and lastly a series of ultra filtration (UF) and reverse osmosis (RO) used for reclamation.

The biological anaerobic and aerobic treatment systems consisted of two units of advanced anaerobic expanded granular sludge bed (AnaEG®) steel tank with diameter and height of 6 m and 16 m respectively, which were designed for running in series or parallel using a set of valve, two buffer tanks and a bio-contact aerobic tank (BioAX®). The two modules of UF used had a nominal molecular weight cut-off (MWCO) of 100 000 g $mol^{-1}$ and the ESPA-2 RO membrane (Hydranautics, USA) has 99.6% NaCl rejection rate. A set of biogas purifier and a biogas gas engine generator set were used to transform biogas (methane) into electrical energy.

**Sampling of Palm Oil Mill Effluent (POME)**

The plant was assessed based on 10 hr operation over a 12-month period (October 2010 to September 2011). POME samples were taken daily from a series of treatment ponds namely a raw effluent pond, an acidification pond, an anaerobic pond, an aerobic pond and also the final discharge in KKS Labu, Sime Darby, and the identified sampling points of the zero discharge POME treatment plant located less than 1 km from it. The current ponding system in KKS Labu consists of a cooling pond, an acidification pond, two anaerobic ponds, two facultative ponds and a final discharge pond. With the current processing capacity of the mill, the overall HRT of this ponding system is > 100 days.

**Analysis of POME**

Important parameters of POME such as BOD, COD, SS, ammoniacal nitrogen and total nitrogen were analysed based on the methods developed by DOE, Malaysia (1995) while other parameters such as volatile fatty acid (VFA), total alkalinity, pH and temperature were in accordance with the Standard Methods for Examination of Water and Wastewater (APHA, 2005).

## RESULTS AND DISCUSSION

POME, although being typical wastewater generated in the palm oil milling process with its polluting characteristics, is a nutrient-rich organic substance with varying value-added applications (*Table 1*). However, as it has a high BOD and COD values, its disposal is crucial. In POME treatment, it is essential to have a technology that can reduce HRT, occupied area, greenhouse gas (GHG) emissions and provide a final discharge of BOD at 20 mg $litre^{-1}$ or less.

**Integrated Zero Discharge Treatment**

By taking advantage of the abundant POME generated as a waste, an integrated 'zero discharge' treatment process (*Figure 2*) mainly routed in 'Pre-treatment - Biological Processes – Membrane Separation' has been developed based on a sustainable development strategy. As biological treatment so far has been reported as not being efficient enough to treat the high O&G content as well as the SS present in POME, pre-treatment is a necessity in this case.

**Pre-treatment of POME**

The pre-treatment process involved a rotary screen, a grit separator, an equalisation tank (EQ tank), an oil separation tank, an air-flotation, cooling tower and dosing tank (*Figure 2*). The gross solids, unexpected mass, *etc*. in the raw POME were screened by the manual grille before being subjected to oil-water separation in the de-oiling tank. The removal of gross pollutants from POME can protect downstream equipment from damage, avoid interference with plant operations and prevent objectionable floating material from entering the primary settling tanks. Due to the high solid content in POME, a cyclone grit separator was used to separate sand using centrifugal force. On the other hand, an EQ tank was used as a buffer for the raw material. It was used to improve the

**TABLE 1. CHARACTERISTICS OF PALM OIL MILL EFFLUENT (POME)**

| Parameter | POME |
|---|---|
| Temperature (°C) | 80-90 |
| pH | 4.7 |
| Oil and grease (O&G) | 4 000 |
| Biological oxygen demand ($BOD_3$) | 25 000 |
| Chemical oxygen demand (COD) | 50 000 |
| Total solid (TS) | 40 000 |
| Total suspended solid (TSS) | 18 000 |
| Total volatile solid (TVS) | 34 000 |
| Ammoniacal nitrogen ($NH_3$-N) | 35 |
| Total Kjedahl nitrogen (TKN) | 750 |
| Potassium (K) | 2 270 |
| Magnesium (Mg) | 615 |
| Calcium (Ca) | 439 |
| Zinc (Zn) | 2.3 |
| Iron (Fe) | 46.5 |
| Copper (Cu) | 0.89 |

Note: All parameter units in mg $litre^{-1}$, except pH and temperature.

Source: Environmental Quality (Industrial Effluent) Regulations 2009.

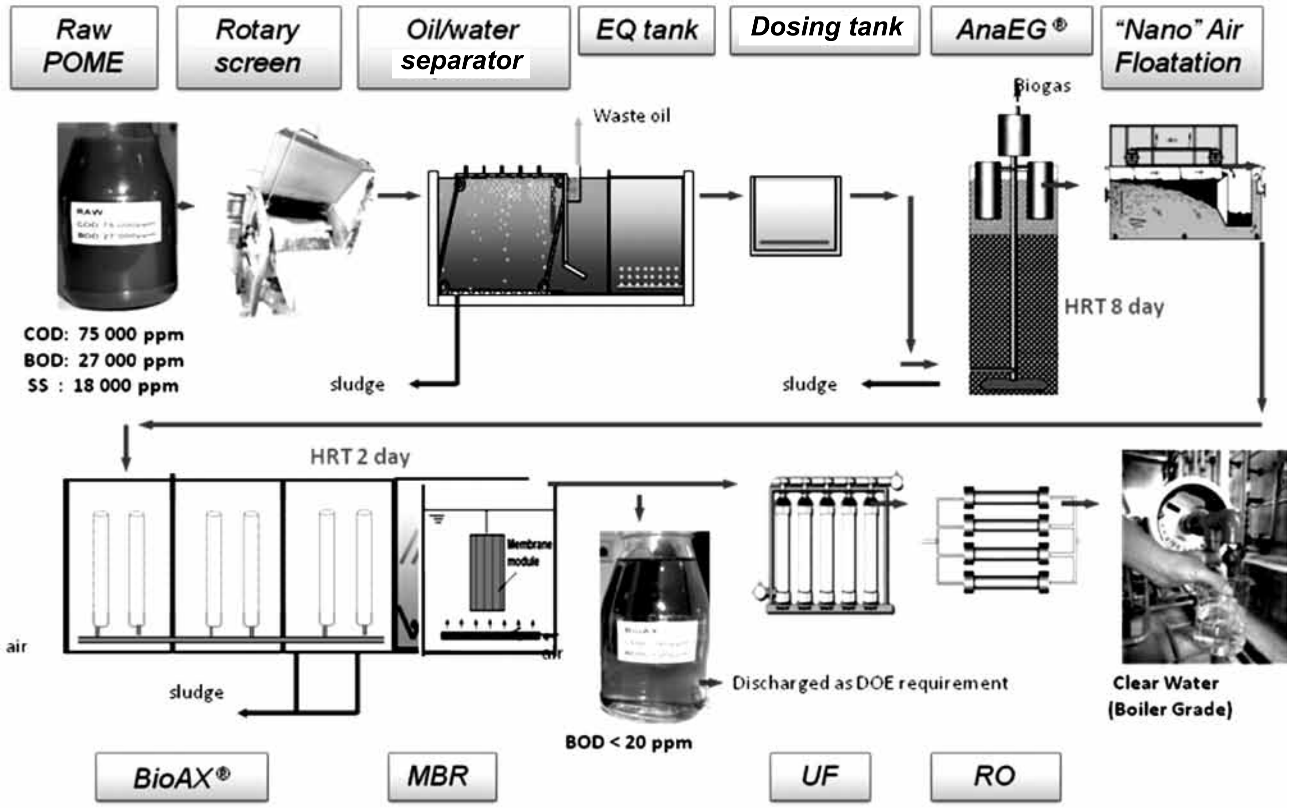


*Figure 2. Zero discharge treatment technology of palm oil mill effluent (POME).*

effectiveness of POME treatment by leveling out the operation parameters such as flow, pollutant levels and temperature over a period of time. The characteristics of POME (BOD, COD and SS) after undergoing treatment in EQ tank were relatively lower as compared to the raw POME as shown in *Table 2*. After equalising in EQ tank, the POME was coagulated and flocculated by dosing selected chemicals to remove the SS and residue oil in the air-flotation unit. The oil separation tank was used to collect sludge oil. In order to reduce the temperature of the feed of the anaerobic process to the optimum mesophilic condition (35 ± 3°C), the cooling tower was used before the dosing tank. The dosing tank was a holding tank that discharged POME at a rate required by the treatment plant. It also adjusted the pH of POME to 7 (neutral).

**Biological Treatment – Anaerobic and Aerobic Process**

Anaerobic digestion is a bacterial process that is carried out in the absence of oxygen. The process can either be thermophilic digestion in which sludge is fermented in tanks at a temperature of 55°C or mesophilic, at a temperature of around 36°C. As thermophilic digestion requires only a shorter retention time for which a smaller tank would suffice, it is more expensive in terms of energy consumption in heating the sludge. Therefore, the mesophilic process was chosen in this study. The installed AnaEG® in the anaerobic biological process at the zero discharge POME treatment plant played a very important role in digesting and degrading the high organic content of POME effectively. POME was pumped and treated in series or parallel in the AnaEG® tanks depending on the mode used. In the tanks, the POME was digested before the degradation process occurred. Then the treated water was discharged to the BioAX® system where the clarified effluent was treated via aerobic digestion, followed by further degradation of organic compounds. An attached growth system was used in this system - allowing the biomass to grow and domesticate on the media and the effluent to pass over its surface.

The results of the analysis of POME showed that the removal rate of COD and BOD in the anaerobic treatment using the integrated anaerobic and aerobic system was 94% and 96.5% (*Table 2*), thus showing evidence of a highly efficient treatment system. Other POME parameters analysed such as the SS, Kjedahl nitrogen, ammoniacal nitrogen and volatile fatty acid were also reduced significantly.

**Biogas Purification and Utilisation**

Anaerobic digestion in this pilot plant was able to generate biogas with a high proportion of methane that may be used to generate electricity. *Table 3* shows the performance of the plant in

**TABLE 2. CHARACTERISTICS OF PALM OIL MILL EFFLUENT (POME) SAMPLES TAKEN AT EACH STAGE OF THE TREATMENT IN THE ZERO DISCHARGE TREATMENT PLANT**

| [a]Parameter | Raw POME | Equalisation tank (EQ) | Anaerobic | | Aerobic | Membrane bioreactor (MBR) |
|---|---|---|---|---|---|---|
| | | | Inlet | Outlet | | |
| pH | 4.50 ± 1.19 (26.4) | 4.01 ± 1.02 (25.4) | 5.50 ± 1.34 (24.4) | 7.35 ± 1.55 (21.1) | 8.23 ± 2.04 (24.8) | 8.65 ± 2.09 (24.2) |
| Biological oxygen demand ($BOD_3$) @ 30ºC | 27 500 ± 100 (0.4) | 24 000 ± 97 (0.4) | 20 000 ± 113 (0.6) | 800 ± 16 (2.0) | 25 ± 9 (36.0) | 18 ± 5 (27.8 ) |
| Chemical oxygen demand (COD) | 76 896 ± 119 (0.2) | 69 552 ± 98 (0.1) | 66 528 ± 116 (0.2) | 2 523 ± 19 (0.8) | 681 ± 11 (1.6) | 486 ± 5 (1.0) |
| Suspended solids | 27 000 ± 82 (0.3) | 25 700 ± 75 (0.3) | 24 700 ± 88 (0.4) | 2 200 ± 68 (3.1) | 140 ± 6 (4.3) | ND |
| Kjedahl nitrogen | 60 ± 6 (10.0) | 56 ± 4 (7.1) | 900 ± 11 (1.2) | 327 ± 11 (3.4) | 14 ± 1 (7.1) | 28 ± 1 (3.6) |
| Ammoniacal nitrogen | 36 ± 1 (2.8) | 22 ± 1 (4.5) | 33 ± 1 (3.0) | 220 ± 8 (3.6) | ND | ND |
| Volatile fatty acid | 1 060 ± 13 (1.2) | 4 940 ± 25 (0.5) | 4 996 ± 27 (0.5) | 578 ± 6 (1.0) | 48 ± 8 (16.7) | 48 ± 5 (10.4) |
| Total alkalinity | ND | ND | ND | 4 688 ± 260 (5.5) | 2 427 ±164 (6.8) | 1 875 ± 143 (7.6) |
| Calcium as Ca | 286.00 ± 4.39 (1.5) | 387.88 ± 4.09 (1.1) | 426.63 ± 5.13 (1.2) | 220.38 ± 8.67 (3.9) | 70.88 ± 3.29 (4.6) | 76.38 ± 2.01 (2.6) |
| Magnesium as Mg | 287.80 ± 8.41 (2.9) | 364.65 ± 3.94 (1.1) | 384.65 ± 5.59 (1.5) | 327.15 ± 7.15 (2.2) | 159.03 ± 2.99 (1.9) | 177.78 ± 2.19 (1.2) |
| Potassium as K | 1 154.80 ± 3.14 (0.3) | 1 459.75 ± 4.29 (0.3) | 1 459.75 ± 1.98 (0.1) | 1 379.75 ± 2.47 (0.2) | 847.25 ± 2.78 (0.3) | 972.25 ± 3.29 (0.3) |
| Zinc as Zn | 1.98 ± 0.74 (37.4) | 3.28 ± 0.28 (8.5) | 3.23 ± 0.17 (5.3) | 0.50 ± 0.03 (6.0) | 0.20 ± 0.07 (35.0) | 0.18 ± 0.01 (5.6) |
| Iron as Fe | 65.70 ± 1.09 (1.7) | 118.20 ± 2.18 (1.8) | 138.08 ± 3.62 (2.6) | 11.88 ± 2.75 (23.1) | 0.90 ± 0.04 (4.4) | 0.90 ± 0.06 (6.7) |
| Copper as Cu | 0.85 ± 0.05 (5.9) | 1.33 ± 0.03 (2.3) | 1.25 ± 0.03 (2.4) | 0.23 ± 0.01 (4.3) | 0.03 | 0.03 |
| Manganese as Mn | 2.80 ± 0.13 (4.6) | 3.85 ± 0.01 (0.3) | 3.95 ± 0.21 (5.3) | 0.90 | 0.08 | 0.05 |

Note: All parameters measured are in mg $litre^{-1}$ except pH. ND - not detectable. [a] Values are means ± standard deviations (SD) (n = >99); wherever applicable. CV: coefficient of variation.

biogas production. During the course of the plant performance assessment, the results showed that the AnaEG® was capable of producing biogas amounting to 52.7 $m^3$ $hr^{-1}$ with a biogas production rate of 15-21 $m^3$ biogas per $m^3$ POME; and the biogas produced had an average compositions of 65%-70% $CH_4$, 25%-30% of $CO_2$ and 200-1500 ppm of $H_2S$. A desulphurisation system installed so far using chemical treatment showed a removal rate of $H_2S$ of ~ 70%.

### Treated POME/ Sludge Recovery as Biofertiliser

The treated sludge can be recovered from the pre-treatment and AnaEG® system, and then piped and condensed in a sludge tank for thickening purposes. The treated sludge once recovered showed good fertiliser values compared to the raw POME (*Table 4*). The pot trial conducted showed that the application of organic fertilisers derived from the treated sludge could enhance the fertility of the soil much better and was more significant compared to the fertiliser derived from raw POME and organic fertiliser derived from chicken manure (unpublished data). This is supported by the fact that organic fertiliser derived from treated effluent contains a higher percentage of nitrogen, phosphorus and potassium (NPK) compared to the untreated ones. This finding is consistent with the finding from Ugoji (1997).

### Reclamation System

In recent years, membrane filtration-based technologies have started making their debut in POME treatment systems (Ahmad and Chong, 2006). However, the major drawback for the

**TABLE 3. EVALUATION OF AN ANAEROBIC SYSTEM (AnaEG®) IN BIOGAS PRODUCTION**

| Parameter | Unit | Average value [a] (CV%) |
|---|---|---|
| Plant capacity | $m^3$ $day^{-1}$ | 5 |
| Biogas generation | $m^3$ $day^{-1}$ | 474.6 ± 97.4 (20.5) |
| Efficiency of biogas production | $m^3$ biogas $hr^{-1}$ | 52.7 ± 10.8 (20.5) |
| Influent | $m^3$ $day^{-1}$ | 31.4 ± 5.1 (16.2) |
| Upflow velocity | m $hr^{-1}$ | 0.062 ± 0.010 (16.1) |
| Influent COD | mg $litre^{-1}$ | 47 914.4 ± 13 584.3 (28.4) |
| Effluent COD of AnaEG1 | mg $litre^{-1}$ | 2 764.4 ± 371.4 (13.4) |
| Effluent COD of AnaEG2 | mg $litre^{-1}$ | 2 780.0 ± 399.7 (14.4) |
| Volumetric loading rate | kg COD/$m^3$.day | 1.642 ± 0.467 (28.4) |
| COD removal rate | % | 93.7 ± 2.0 (2.1) |
| COD reduction | kg $day^{-1}$ | 1 399.0 ± 419.8 (30.0) |
| Efficiency (in POME injection) | $m^3$ biogas $m^{-3}$ POME | 15.31 ± 3.05 (19.9) |
| Efficiency (in COD reduction) | $m^3$ biogas $kg^{-1}$ COD | 0.34 ± 0.14 (41.2) |

Note: [a] Values are means ± standard deviations (SD) (n = >99); wherever applicable. CV - coefficient of variation; wherever applicable. COD - chemical oxygen demand. POME - palm oil mill effluent.

**TABLE 4. CHARACTERISTICS OF BIOFERTILISER DERIVATIVES DERIVED FROM UNTREATED EFFLUENT, TREATED EFFLUENT (sludge) AND CHICKEN MANURE**

| Parameter | Untreated effluent[a] | Treated effluent[b] | Chicken manure[b] |
|---|---|---|---|
| Nitrogen, N (%) | 0.61[a] | 1.78[b] | 0.01[b] |
| Phosphate as $P_2O_5$ (%) | 0.30[a] | 0.97[b] | 1.97[b] |
| Potasisum as $K_2O$ (%) | 6.68[a] | 20.63[b] | 1.66[b] |
| Calcium as CaO (%) | 2.19[a] | 6.13[b] | 12.43[b] |
| Magnesium as $Mg_2O$ (%) | 1.46[a] | 6.54[b] | 3.53[b] |
| Cation Exchange Capacity, CEC (miliequivalent/100 g) | 10.95[a] | 16.91[b] | 25.96[b] |

Note: [a,b] Values were compared using F-test. Values with the same letter are not significantly different.

membrane application technology is flux decline due to membrane fouling.

In the pilot scale reclamation system installed, the treated water went through a string of filtering system via safety filter, UF, fine filter and RO. It provided a final treatment stage in order to enhance the effluent quality. After clarification in the second clarifier, any macromolecules in the treated water were removed through UF before removal of salt ions using RO. RO removed many types of large molecules and ions from the treated water by applying pressure to it. RO concentrate amounting to 40% recovery of rejected water was collected as a liquid fertiliser with high content of potassium. Around 60% of RO permeate (boiler grade) was recovered and may be recycled back for use in the boiler and cooling tower in the palm oil mill.

The quality of water after biological treatment, *i.e.* aerated water, UF permeate and RO permeate were analysed (*Table 5*) to investigate the ability of the pilot plant to reclaim water with boiler grade quality. The results showed COD and BOD at values almost not detectable. The visual observation showed the quality of water from each stage having an improvement in terms of colour, odour and turbidity. At the final stage of RO, the RO permeate collected was odour-free and clear. Based on the findings, the treatment of POME in this proposed 'zero discharge' integration system gave >99% removal of COD, BOD, SS, Kjedahl nitrogen and

**TABLE 5. CHARACTERISTICS OF TREATED AND REJECTED REVERSE OSMOSIS (RO) WATER AFTER RECLAMATION PROCESS**

| [a]Parameter | After biological treatment | UF permeate | RO permeate |
|---|---|---|---|
| Chemical oxygen demand, COD | 774.9 ± 10.9 | 701.1 ± 3.7 | ND |
| Biological oxygen demand, $BOD_3$ | 20.0 ± 9.4 | < 20.0 | ND |
| Turbidity (NTU) | 111.0 ± 7.9 | 0.8 ± 0.05 | 0.4 ± 0.01 |
| Suspended solid, SS | 289.6 ± 15.0 | ND | ND |
| Kjedahl nitrogen | 2.9 ± 0.67 | ND | ND |
| Ammoniacal nitrogen | 23 ± 3.89 | ND | ND |

Note: All parameters measured in mg litre$^{-1}$ except turbidity. UF - ultra filtration. RO - reverse osmosis. ND - not detectable (< 0.5 ppm). [a] Values are means ± standard deviations (SD) (n = >99); wherever applicable.

almost 99% ammoniacal nitrogen. In addition, the system can also completely remove the colour, odour, turbidity and O&G with a final pH of 8.33 for the POME treated.

The pilot plant performance assessment showed that an integrated anaerobic and aerobic biological treatment system of POME was possible to achieve a COD and SS removal rate of 93.7% and 93.4%, respectively (*Table 6*). For every tonne of COD removed in the AnaEG®, about 340 m$^3$ biogas was produced (*Table 3*). The integrated membrane treatment further removed the COD to reach 98% removal rate. *Table 6* summarises the overall performance of the integrated zero discharge POME treatment pilot plant. Based on this performance, the plant has potential to be scaled up. *Table 7* provides an indication on the economic feasibility of the biogas plant and the potential energy production from a typical 60 t hr$^{-1}$ palm oil mill (based on basic financial model).

## CONCLUSION

The preliminary data of the proposed integrated approach in this article showed possible attainment of zero discharge of POME for the oil palm industry. Undoubtedly, POME has its own potential for sustainable reuse through biotechnological advances. This is because it generates valuable end products that can be potentially harnessed for revenue, such as the utilisation of biogas for heat or electricity, the treated POME as biofertilisers and the reclaimed water for boiler feed use. It is evident that this zero discharge concept can be explored by many sectors which have set priority in their endeavour to ensure sustainable development in protecting the environment. However, the economics of this approach needs to be further addressed for commercial uptake.

**TABLE 6. PERFORMANCE OF THE ZERO DISCHARGE PALM OIL MILL EFFLUENT (POME) TREATMENT PILOT PLANT AT EACH STAGE OF THE PROCESS**

| Treatment process/stage | | Average COD removal rate (%) | Average TSS removal rate (%) | Average O&G removal rate (%) |
|---|---|---|---|---|
| Pre-treatment | Oil separation tank | - | - | 36.9 |
| | Equalisation tank | 41.4 | 37.1 | - |
| | Dosing tank | - | - | - |
| Biological treatment | AnaEG1 | 93.7 | 37.9 | - |
| | AnaEG2 | - | - | - |
| | Nano air flotation | 20.9 | 92.7 | - |
| | BioAX | 71.1 | - | - |
| | MBR | 53.4 | 93.4 | - |
| Membrane filtration | Ultra filtration | - | - | - |
| | Reverse osmosis | 98.0 | - | - |

Note: Based on 10 hr operation over a 12 months period (October 2010 to September 2011). COD - chemical oxygen demand. TSS - total suspended solids. O&G - oil and grease.

**TABLE 7. ECONOMIC ANALYSIS OF THE BIOGAS SYSTEM (for a typical 60 t FFB $hr^{-1}$ palm oil mill)**

| Material | Production rate/Conversion factor | Quantity |
|---|---|---|
| Fresh fruit bunch (FFB) | - | 60 t $hr^{-1}$ or 432 000 t $yr^{-1}$ |
| Palm oil mill effluent (POME) | @ 65% of FFB processed | 39 t $hr^{-1}$ or 39 $m^3$ $hr^{-1}$ |
| Biogas (based on COD reduction*) | @ 21 $m^3$ $m^{-3}$ POME | 819 $m^3$ $hr^{-1}$ |
| Potential energy from biogas | @ 20 000 kJ $m^{-3}$ | 16 380 000 kJ $hr^{-1}$ or 4 550 kJ $s^{-1}$ or 4 550 kW |
| Power output/size of power plant | @ 30% thermal efficiency | 1.4 MW |
| Potential electricity to the grid | @ 80% utilisation factor x 7200 hr $yr^{-1}$ (300 days x 24 hr) | 8 064 000 kWhr $yr^{-1}$ |
| Potential of electricity sales | @ RM 0.31 $kWhr^{-1}$ | RM 2.5 million $yr^{-1}$ or RM 52.5 million/21 yr |
| Total CAPEX | @ RM 7 million $MW^{-1}$ | RM 9.8 million |
| Total OPEX per year | @ 2.25%/yr of CAPEX | RM 220 500 $yr^{-1}$ |
| Net profit per year | Annual electricity sales – OPEX | RM 2.3 million $yr^{-1}$ |
| Payback period | RM 9.8/2.3 | 4.3 yr |

Note: * IPCC default value = 0.25 kg $CH_4$ $kg^{-1}$. COD - chemical oxygen demand.

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