4
Treatment of Palm Oil Wastewaters

Mohd Ali Hassan and Shahrakbah Yacob  
*University Putra Malaysia, Serdang, Malaysia*

Yoshihito Shirai  
*Kyushu Institute of Technology, Kitakyushu, Japan*

Yung-Tse Hung  
*Cleveland State University, Cleveland, Ohio, U.S.A.*

4.1 INTRODUCTION

This chapter discusses the palm oil extraction process, wastewater treatment systems, and future technologies and applications for the palm oil industry. Crude palm oil (CPO) is extracted from the mesocarp of the fruitlets while palm kernel oil is obtained from the kernel (Fig. 4.1). The oil contents originating from mesocarp and kernel are 20 and 4%, respectively. Palm oil is a semisolid oil, rich in vitamins and several major fatty acids: oleic, palmitic, and linoleic. To produce palm oil, a considerable amount of water is needed, which in turn generates a large volume of wastewater. Palm oil mills and palm oil refineries are two main sources of palm oil wastewater; however, the first is the larger source of pollution and effluent known as palm oil mill effluent (POME). An estimated 30 million tons of palm oil mill effluent (POME) are produced annually from more than 300 palm oil mills in Malaysia. Owing to the high pollution load and environmental significance of POME, this chapter shall place emphasis on its treatment system.

4.1.1 Production of Crude Palm Oil (CPO)

It is important to note that no chemicals are added in the extraction of oil from the oil palm fruits, therefore, making all generated wastes nontoxic to the environment. The extraction of crude palm oil involves mainly mechanical and heating processes, and is illustrated in several steps below (Fig. 4.2).

**Sterilization**

To ensure the quality and the productivity of palm oil mill, the fresh fruit bunches (FFB) must be processed within 24 hours of harvesting. Thus, most of the palm oil mills are located in close
proximity to the oil palm plantation. During sterilization, the FFB is subjected to three cycles of pressures (30, 35, and 40 psi) for a total holding time of 90 minutes. There are four objectives of the FFB sterilization: (a) to remove external impurities, (b) to soften and loosen the fruitlets from the bunches, (c) to detach the kernels from the shells, and, most importantly, (d) to deactivate the enzymes responsible for the buildup of free fatty acids. The sterilization process acts as the first contributor to the accumulation of POME in the form of sterilizer condensate.

**Bunch Stripping**
Upon completion of the sterilization, the “cooked” FFB will be subjected to mechanical threshing to detach the fruitlets from the bunch. At this stage the loose fruitlets are transferred to the next process while the empty fruit bunches (EFB) can be recycled to the plantation for mulching or as organic fertilizer.

**Digestion and Pressing**
The digester consists of a cylindrical vessel equipped with stirrer and expeller arms mainly to digest and press the fruitlets. Steam is introduced to facilitate the oil extraction from the digested mesocarp. At the end of the process, oil and pressed cake comprising nuts and fiber are produced. The extracted oil will then be purified and clarified in the next stage. At the same time the fiber and nuts are separated in the depericarper column. The waste fiber is then burnt for energy generation inside the boiler.

**Oil Clarification and Purification**
As the name of this process implies, the extracted oil is clarified and purified to produce CPO. Dirt and other impurities are removed from the oil by centrifugation. Before the CPO is transferred to the storage tank, it is subjected to high temperatures to reduce the moisture content in the CPO. This is to control the rate of oil deterioration during storage prior to processing at the palm oil refinery. The sludge, which is the byproduct of clarification and purification procedures, is the main source of POME in terms of pollution strength and quantity.
Nut Cracking
At this point, the nuts from the digestion and pressing processes are polished (to remove remnants of fiber) before being sent to the nut-cracking machine or ripple mill. The cracked mixture of kernels and shells is then separated in a winnowing column using upwards suction (hydrocyclone) and a clay bath. The third source of POME is the washing water of the hydrocyclone. The kernel produced is then stored before being transferred to palm kernel mill for oil extraction. Shell wastes will join the fiber at the boiler for steam and power generation.
4.1.2 Production of Refined Bleached Deodorized Palm Oil (RBDPO)

The refining of CPO employs physical/steam refining in which steam distillation is used to separate free fatty acids under high temperature and vacuum (Fig. 4.3). It consists of two main processes as follows.

Pretreatment

Before the actual refining process is carried out, the CPO is pretreated with phosphoric acid to eliminate impurities such as gums and trace metals. A bleaching technique is then used to remove phosphoric acid and its content under vacuum, followed by a filtration method. Solid waste in the form of sludge is disposed and buried in a landfill.

Deodorization

At this stage, steam is introduced under a vacuum condition to strip the pretreated oil of volatile free fatty acids, odoriferous compounds, and unstable pigments. The distillate for the deodorization process will form the main source of palm oil refinery effluent (PORE). The distillate has a free fatty acid content of approximately 80–90%. After the refining process, the oil is known as refined, bleached and deodorized palm oil (RBDPO). Further process such as fractionation of RBDPO will separate palm olein and stearin based on the different melting points of each component.

![Flow diagram of physical refining process of crude palm oil and source of PORE.](image-url)
4.2 PALM OIL MILL EFFLUENT (POME)

Palm oil mill effluent originates from two main processes: sterilization and clarification stages, as the condensate and clarification sludge, respectively (Fig. 4.2). The clarification sludge shows higher level of solid residues compared to the sterilizer condensate. Both contain some level of unrecovered oils and fats. The final POME would of course include hydrocyclone washing and cleaning up processes in the mill [1]. Approximately 1–1.5 tons of water are required to process 1 ton of FFB.

4.2.1 Properties of POME

Based on the process of oil extraction and the properties of FFB, POME is made up of about 95–96% water, 0.6–0.7% oil, and 4–5% total solid, including 2–4% suspended solids, which are mainly debris from palm mesocarp [2]. No chemicals are added during the production of palm oil; thus it is a nontoxic waste. Upon discharge from the mill, POME is in the form of a highly concentrated dark brown colloidal slurry of water, oil, and fine cellulosic materials. Due to the introduction of heat (from the sterilization stage) and vigorous mechanical processes, the discharge temperature of POME is approximately 80–90°C. The chemical properties of POME vary widely and depend on the operation and quality control of individual mills [3]. The general properties of POME are indicated in Table 4.1.

Apart from the organic composition, POME is also rich in mineral content, particularly phosphorus (18 mg/L), potassium (2270 mg/L), magnesium (615 mg/L) and calcium (439 mg/L) [2]. Thus most of the dewatered POME dried sludge (the solid endproduct of the POME treatment system) can be recycled or returned to the plantation as fertilizer.

4.2.2 Biological Treatment

Owing to its chemical properties, POME can be easily treated using a biological approach. With high organic and mineral content, POME is a suitable environment in which microorganisms can thrive. Hence, it could harbor a consortium of microorganisms that will consume or break down the wastes or pollutants, turning them into harmless byproducts. In some cases, these byproducts have high economic value and can be used as potential renewable sources or energy. In order to achieve such a goal, a suitable mixed population of microorganisms must be introduced and the

<table>
<thead>
<tr>
<th>Chemical property</th>
<th>Average</th>
<th>Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>pH</td>
<td>4.2</td>
<td>3.4–5.2</td>
</tr>
<tr>
<td>BOD (mg/L)</td>
<td>25,000</td>
<td>10,250–43,750</td>
</tr>
<tr>
<td>COD (mg/L)</td>
<td>50,000</td>
<td>15,000–100,000</td>
</tr>
<tr>
<td>Oil and grease (mg/L)</td>
<td>6000</td>
<td>150–18,000</td>
</tr>
<tr>
<td>Ammoniacal nitrogen (mg/L)</td>
<td>35</td>
<td>4–80</td>
</tr>
<tr>
<td>Total nitrogen (mg/L)</td>
<td>750</td>
<td>180–1400</td>
</tr>
<tr>
<td>Suspended solid (mg/L)</td>
<td>18,000</td>
<td>5000–54000</td>
</tr>
<tr>
<td>Total solid (mg/L)</td>
<td>40,000</td>
<td>11,500–78,000</td>
</tr>
</tbody>
</table>

**Source:** Refs. 3, 4.
process should be optimized. Three biological processes are currently employed by the industry as a series of anaerobic, facultative anaerobic, and aerobic treatments. However, the major reduction of POME polluting strength — up to 95% of its original BOD — occurs in the first stage, that is, during the anaerobic treatment [4].

The anaerobic process involves three main stages; hydrolytic, acidogenic, and methanogenic. In the first stage, hydrolytic microorganisms secrete extracellular enzymes to hydrolyze the complex organic complexes into simpler compounds such as triglycerides, fatty acids, amino acids, and sugars. These compounds are then subjected to fermentative microorganisms that are responsible for their conversion into short-chain volatile fatty acids — mostly acetic, propionic, butyric acids, and alcohols. In the final stage, there are two separate biological transformations: first, the conversion of acetic acid into methane and carbon dioxide by methanogens; secondly, the conversion of propionic and butyric acids into acetic acid and hydrogen gas before being consumed by the methanogens. The endproducts of the anaerobic degradation are methane and carbon dioxide. Traces of hydrogen sulfide are also detected as the result of the activity of sulfate-reducing bacteria in the anaerobic treatment. The biochemical oxygen demand (BOD) at the first two stages remains at the same level as when it entered the anaerobic treatment, because only the breakdown of the complex compounds to a simpler mixture of organic materials has occurred. Only after the methanogenic stage will the BOD be reduced significantly.

4.2.3 Wastewater Treatment Systems for POME

The choice of POME wastewater treatment systems is largely influenced by the cost of operation and maintenance, availability of land, and location of the mill. The first factor plays a bigger role in the selection of the treatment systems. In Malaysia, the final discharge of the treated POME must follow the standards set by the Department of Environment (DOE) of Malaysia, which is 100 mg/L of BOD or less (Table 4.2) regardless of which treatment system is being utilized.

Pretreatment

Prior to the primary treatment, the mixed raw effluent (MRE, a mixture of wastewater from sterilization, clarification, and other sources) will undergo a pretreatment process that includes the removal of oil and grease, followed by a stabilization process. The excess oil and grease is extracted from the oil recovery pit using an oil skimmer. In this process, steam is continuously

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Level</th>
</tr>
</thead>
<tbody>
<tr>
<td>BOD (mg/L)</td>
<td>100</td>
</tr>
<tr>
<td>Suspended solids (mg/L)</td>
<td>400</td>
</tr>
<tr>
<td>Oil and grease (mg/L)</td>
<td>50</td>
</tr>
<tr>
<td>Ammoniacal nitrogen (mg/L)</td>
<td>150</td>
</tr>
<tr>
<td>Total nitrogen (mg/L)</td>
<td>200</td>
</tr>
<tr>
<td>pH</td>
<td>5–9</td>
</tr>
</tbody>
</table>

Source: Ref. 5.
supplied to the MRE to aid the separation between oil and liquid sludge. The recovered oil is then reintroduced to the purification stage. The process will prevent excessive scum formation during the primary treatment and increase oil production. The MRE is then pumped into the cooling and mixing ponds for stabilization before primary treatment. No biological treatment occurs in these ponds. However, sedimentation of abrasive particles such as sand will ensure that all the pumping equipment is protected. The retention time of MRE in the cooling and mixing ponds is between 1 and 2 days.

Ponding System

The ponding system is comprised of a series of anaerobic, facultative, and algae (aerobic) ponds. These systems require less energy due to the absence of mechanical mixing, operation control, or monitoring. Mixing is very limited and achieved through the bubbling of gases; generally this is confined to anaerobic ponds and partly facultative ponds. On the other hand, the ponding system requires a vast area to accommodate a series of ponds in order to achieve the desired characteristics for discharge. For example, in the Serting Hilir Palm Oil Mill, the total length of the wastewater treatment system is about 2 km, with each pond about the size of a soccer field (Fig. 4.4). Only a clay lining of the ponds is needed, and they are constructed by excavating the earth. Hence, the ponding system is widely favored by the palm oil industry due to its marginal cost.

In constructing the ponds, the depth is crucial for determining the type of biological process. The length and width differ based on the availability of land. For anaerobic ponds, the optimum depth ranges from 5–7 m, while facultative anaerobic ponds are 1–1.5 m deep. The effective hydraulic retention time (HRT) of anaerobic and facultative anaerobic systems is 45 and 20 days, respectively. A shallower depth of approximately 0.5–1 m is required for aerobic ponds, with an HRT of 14 days. The POME is pumped at a very low rate of 0.2 to 0.35 kg BOD/m³/day of organic loading. In between the different stages of the ponding system, no pumping is required, as the treated POME will flow using gravity or a sideways tee-type subsurface draw-off system. Under these optimum conditions, the system is able to meet the requirement of DOE. The number of ponds will depend on the production capacity of each palm oil mill.

One problem faced by pond operators is the formation of scum, which occurs as the presence of oil and grease in the POME, which are not effectively removed during the pretreatment stage. Another disadvantage of the ponding system is the accumulation of solid sludge at the bottom of the ponds (Fig. 4.6). Eventually the sludge and scum will clump together inside the pond, lowering the effectiveness of the pond by reducing the volumetric capacity and HRT. When this happens, the sludge may be removed by either using submersible pumps or excavators. The removed sludge is dewatered and dried before being used as fertilizer. The cleanup is normally carried out every 5 years or when the capacity of the pond is significantly reduced.

Open Digester and Ponding Systems

This system is a combination of an open digester tank and a series of ponding systems (Fig. 4.7). The anaerobic digestion is carried out in the digester, then in the facultative anaerobic and algae ponds. It has been shown that by using an open digester, a better reduction of BOD can be achieved in a shorter time. Digesters are constructed of mild steel at various volumetric capacities ranging from 600 up to 3600 m³. The treatment of treated POME from the digester
A description of the ponding systems is outlined in the previous section “Pretreatment.”

The HRT of the digester is only 20–25 days and has a higher organic loading of 0.8–1.0 BOD kg/m³ · day compared to anaerobic ponds. With minimal financial input from the operators, no mechanical mixing equipment is installed in the digesters. Using the same principle as anaerobic ponds, mixing of POME is achieved via bubbling of biogas. Occasionally, the mixing is also achieved when the digester is being recharged with fresh POME. The treated POME is then overflowed into the ponding system for further treatment.

Although the digester system has been proven to be superior to anaerobic ponds, it also has similar problems of scum formation and solid sludge accumulation. Another serious problem is
the corrosion of the steel structures due to long exposure to hydrogen sulfide. Incidents such as burst and collapsed digesters have been recorded. Accumulated solids could be easily removed using the sludge pipe located at the bottom of the digester. The dewatered and dried sludge can then be disposed for land application.

Extended Aeration
To complement the previous systems, mechanical surface aerators can be introduced at the aerators are normally installed at the end of the ponding system before discharge. However, this happens only where land area is a constraint and does not permit extensive wastewater treatment. Otherwise, aerators must be provided to meet DOE regulations.

4.3 PALM OIL REFINERY EFFLUENT (PORE)

Following the production of CPO from the palm oil mill, the CPO is then subjected to further refining before it can be categorized as edible oil. Even after the clarification and purification processes, there are still large amounts of impurities such as gums, pigments, trace of metals, and soluble fats that cause unpleasant taste, odor, and color. There are three common types of operation in the palm oil refineries: (a) physical refining and dry fractionation, (b) physical refining and detergent fractionation, and (c) physical and chemical refining with dry/detergent fractionation [6].
4.3.1 Chemical Properties of PORE

The main sources of PORE are water from the deodorization process and cleaning operations within the mill (Fig. 4.3). The characteristics of PORE are very much dependent on the type of process employed. The main chemical properties of PORE are as described in Table 4.3.

Figure 4.6  Formation of islets of sludge in the middle of the pond. (Courtesy of Felda Palm Industries.)

Figure 4.7  A series of 3600 m³ open digesters for POME treatment. (Courtesy of Felda Palm Industries.)
In comparison with POME, PORE is less polluting. This is largely due to the absence of oil and grease, and its low organic load. From Table 4.3, it is obvious why most of the palm oil refineries in Malaysia have adopted physical refining and dry fractionation to produce edible oil. Not only does the system reduce the effluent problem, but higher yield and oil purity with lower operating costs are obtained.

**Figure 4.8** An aerator system installed to accelerate BOD reduction at the aerobic pond. (Courtesy of Malaysian Palm Oil Board.)

**Table 4.3** Chemical Properties of Palm Oil Refinery Effluent (PORE) Based on Different Operations

<table>
<thead>
<tr>
<th>Chemical properties</th>
<th>Type of refinery processes</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Physical refining and dry fractionation</td>
</tr>
<tr>
<td>Temperature (°C)</td>
<td>35</td>
</tr>
<tr>
<td>pH</td>
<td>5.3</td>
</tr>
<tr>
<td>BOD (mg/L)</td>
<td>530</td>
</tr>
<tr>
<td>COD (mg/L)</td>
<td>890</td>
</tr>
<tr>
<td>Total solids (mg/L)</td>
<td>330</td>
</tr>
<tr>
<td>Suspended solids (mg/L)</td>
<td>50</td>
</tr>
<tr>
<td>Phosphorus (mg/L)</td>
<td>4</td>
</tr>
<tr>
<td>Total fatty matter (mg/L)</td>
<td>220</td>
</tr>
</tbody>
</table>

*Source: Ref. 3.*
4.3.2 Wastewater Treatment Systems for PORE

Unlike POME wastewater treatment systems, the PORE system is more systematic and predictable. Most PORE systems involve biological processes, with some using physical and chemical methods such as sedimentation, dissolved air flotation after coagulation and flocculation using lime, alum and polyelectrolytes [8].

Pretreatment of PORE

The first step in ensuring satisfactory performance of a PORE treatment plant is to remove oil and fat from the MRE. The separation is carried out using several methods such as fat traps, tilted-plate separators, and dissolved flotation units. Beside physical separations, the addition of chemical flocculants and coagulants also helps in reducing the total fatty matter and other suspended solids. Before the commencement of the biological treatment, the pH of the PORE is adjusted to the desired level as pH plays an important role in the optimum biodegradation of PORE.

Activated Sludge System

Many palm oil refineries use activated sludge systems to treat PORE. This is because of land constraints (for ponding systems) and effective removal of BOD in a short HRT [6]. This system can be very effective if the level of total fatty matter is kept low after the pretreatment stage. The presence of fatty matter in the activated sludge systems will contribute not only higher BOD but the formation of scum. This leads to poor performance of the system.

The treatment is carried out by bringing PORE into contact with a mixed population of aerobic microorganisms in the controlled environment of the activated sludge system. In this process, oxygen is supplied via aeration or vigorous agitation for the oxidation of organic wastes to carbon dioxide. After the treatment, the suspended biomass is separated in the clarifier. The biomass is reintroduced back into the activated sludge systems as “return activated sludge.” This is to ensure the density of microorganisms is maintained at an optimum level for maximum removal of BOD. The supernatant from the clarifier can then be safely discharged into the watercourse. The HRT of PORE and cell residence time are 1–2 days and 3–10 days, respectively. Using this system, a final BOD and suspended solids of 20 and 30 mg/L, respectively, can be obtained with 1500–2000 mg/L of mixed liquor suspended solids. Apart from the energy requirement to operate the treatment facilities, additional nutrients are normally added to the effluent. This is because the effluent from the palm oil refinery is low in nitrogen content, which is essential for the growth of aerobic micro-organisms. A ratio of BOD:N of 100:5 is kept constant throughout the process.

4.4 POTENTIAL TECHNOLOGIES AND COMMERCIAL APPLICATIONS OF PALM OIL WASTES

4.4.1 POME Treatment

Evaporation Technology

In one study, a 200 L single-effect evaporator was constructed to test the evaporation technique in POME treatment [8]. It used the principle of rapid heating to vaporize water at 600 mmHg and 80°C using a plate heat exchanger. Staggered feeding of fresh POME was introduced into the evaporator when the liquor dropped by half of the initial volume. The feeding was carried out until the accumulated solid sludge reached the pre-set level of 30%. The solid was then
discharged before the new cycle began. The single-effect evaporator was able to recover 85% of water from POME with a good quality distillate of 20 mg/L BOD. The distillate could be recycled as process water or feedwater for the boiler in the mill. Even though the system promises a significant reduction of liquid waste (and thus less dependence on vast land area for ponding systems), the energy required for heating may impose financial constraints for the mill operator. Moreover, the mill may have to make a big investment in equipment, skilled operators, and maintenance. Further studies are being carried out to produce cost-effective systems such as utilizing excess organic biomass from the mill as an energy source.

High-Technology Bioreactor Design

There have been numerous studies to optimize the anaerobic treatment of POME using various designs of bioreactor. Laboratory-scale studies have been carried out to evaluate the effectiveness of anaerobic filters (AF) and a fluidized-bed reactor (FBR) in treating POME [9]. About 90% of the fed COD was effectively removed by both reactor systems. However, when the COD loading was increased, a significant reduction in terms of COD removal was recorded in the FBR system, while clogging of the filter was evident in the AF reactor. A higher COD removal efficiency was reported [10] when using a modified anaerobic baffled reactor (MABR). The system also demonstrated a short retention time of 3 days. Despite the good potential of the bioreactor systems for POME treatment, none has been implemented at a larger scale.

Power Generation: Closed Digester

The composition of biogas emitted from an open digester tank and the lagoon was lower than that reported for laboratory studies [2]. The biogas composition was 40% methane and 60% carbon dioxide for the open digester tank, and 55% methane and 45% carbon dioxide in anaerobic lagoons. In terms of energy value, it is comparable to commercially available gas fuels as shown in Table 4.4. The potential energy that could be generated from 1 m³ of biogas is 1.8 kWh [11].

A closed digesting system was tested to improve the anaerobic digestion of POME, leading to the production of biogas. Using the same design of open digester, a fixed or floating cover is included, equipped with the other facilities such as gas collector, safety valves, and monitoring facilities.

Compost

Based on our research, dewatered POME sludge can be composted with domestic wastes and bulking agents such as shredded wood and sawdust. A modified composter from a cement mixer with insulated drum was used as a reactor to run the composting process. Experimental

Table 4.4 Comparisons Between Methane Derived from Anaerobic Digestion of POME and Other Gas Fuels

<table>
<thead>
<tr>
<th>Chemical properties</th>
<th>Methane</th>
<th>Natural gas</th>
<th>Propane</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gross calorific value (kcal/kg)</td>
<td>4740–6150</td>
<td>907</td>
<td>24,000</td>
</tr>
<tr>
<td>Specific gravity</td>
<td>0.847–1.002</td>
<td>0.584</td>
<td>1.5</td>
</tr>
<tr>
<td>Ignition temperature (°C)</td>
<td>650–750</td>
<td>650–750</td>
<td>450–500</td>
</tr>
<tr>
<td>Inflammable limits (%)</td>
<td>7.5–21.0</td>
<td>5–15</td>
<td>2–10</td>
</tr>
<tr>
<td>Combustion air required (m³/m³)</td>
<td>9.6</td>
<td>9.6</td>
<td>13.8</td>
</tr>
</tbody>
</table>

Source: Ref. 11.
parameters such as aeration, pH, temperature, C/N ratio, and moisture content were controlled and monitored during the fermentation phase of the composting process. It took about 40 days to completely convert the POME sludge into compost via the solid substrate fermentation process with mixed microbial inoculum. The carbon content decreased towards the end of the composting process, which resulted in a decrease of the C/N ratio from 30 to 20. The low C/N ratio of the final compost product was very important as an indicator of maturity. The characteristics of the final compost products for POME sludge were similar to commercial composts and complied with US Environmental Protection Agency (EPA) standards, especially in heavy metal content and total coliforms. Planting out tests with leafy vegetables showed satisfactory performance [12].

Organic Acids

Two-stage fermentation was carried out in a study where POME was used as substrate for volatile fatty acids (VFA) production by continuous anaerobic treatment using a locally fabricated 50 L continuous stirred tank reactor (CSTR). The highest VFA obtained was at 15 g/L at pH 6.5, 30°C, 100 rpm, sludge to POME ratio 1 : 1, HRT 4 days, without sludge recycle. The highest BOD removal corresponded with the high production of organic acids. The organic acids produced from POME were then recovered and purified using acidification and evaporation techniques. A clarified concentrated VFA comprised of 45 g/L acetic, 20 g/L propionic and 22 g/L butyric acids were obtained with a recovery yield of 76% [13].

Production of Polyhydroxyalkanoates

The organic acids from treated POME can be used to biologically synthesize polyhydroxyalkanoates (PHA), a bacterial bioplastic. The concentrated organic acids obtained were used in a fed-batch culture of Alcaligenes eutrophus for the production of PHA. About 45% PHA content in the dry cells could be obtained, corresponding to a yield of 0.32 from acetic acid. The overall volumetric productivity of PHA is estimated at 0.09 g PHA/L hour. This indicates that the application of a high-density cell culture to produce bioplastic from POME can be achieved [14].

Biological Hydrogen

Another potential application of POME as a renewable resource of energy is the production of biological hydrogen via a fermentation process. The main purpose of producing biological hydrogen is to offer an alternative source of energy to fossil fuels. The major advantage of biological hydrogen is the lack of polluting emission since the utilization of hydrogen, either via combustion or fuel cells, results in pure water [15]. Currently, two proposed systems produce biological hydrogen using photoheterotrophic and heterotrophic bacteria. However, the latter is most suitable for POME due to limited light penetration caused by the sludge particles as experienced during the production of PHA by phototrophic Rhodobacter sphaeroides [16]. Moreover, it would be costly to construct and maintain a photobioreactor at a commercial-scale operation.

In the anaerobic degradation of POME, complex organic matter is converted into a mixture of methane and carbon dioxide in a network of syntrophic bacteria. Prior to this, fermentative and acetogenic bacteria first convert organic matter into a mixture of VFA and hydrogen before being consumed by methanogenic bacteria. Based on the metabolic activities of these microorganisms in POME degradation, a system combining the organic acids and biological hydrogen production is suggested. However, the utilization of biological hydrogen from POME is still at the planning stage. Major development in terms of selection of suitable microorganisms and optimization of process conditions is required for cost-effective production.
of hydrogen. Nevertheless, this technology promises a means to conserve the environment by generating clean energy.

### 4.4.2 PORE Treatment

**Sequential Batch Reactor System**

A new technology using the sequential batch reactor (SBR) technique has been shown to provide an effective treatment of PORE [7] as shown in Figure 4.9. Among the advantages of SBR over the conventional activated sludge are an automated control system, more versatility, stability, and the ability to handle high fluctuations in organic loading. A consistent output of BOD below 50 mg/L was observed. With this system, the hydraulic retention time and solid sludge content could be controlled, thus eliminating the need for clarifier and sludge recycling facilities.

### 4.5 FUTURE TRENDS

From the preceding section, several potential and emerging technologies for POME wastewater treatment system can be integrated into the palm oil mill operation (Fig. 4.10). The strategy is to combine the existing wastewater treatment system with the production of appropriate bioproducts, towards zero discharge for the palm oil industry [17]. In anaerobic treatment, methanogenic activity will be suppressed or inhibited in order to extract the organic acids produced. This, in turn, shall lower the greenhouse gases (methane and carbon dioxide) emissions from the anaerobic digestion, thus reducing the effects of global warming. Further separation and purification processes are needed before organic acids can be utilized as a

---

![Figure 4.9](image.png)  
**Figure 4.9** A pilot plant sequential bioreactor system tested for POME treatment. (Courtesy of Malaysian Palm Oil Board.)
substrate for PHA-producing microorganisms. The solid wastes (sludges) generated from the wastewater treatment system will be used as a mixture with EFB to form biocompost.

Wastes generated from the palm oil mill contain a high percentage of degradable organic material and can be converted into value-added products and chemicals. It is expected that changes in the technologies in POME treatment could lead to a substantial reduction in terms of waste discharged. On the other hand, the palm oil industry will experience a sustainable growth by addressing the excessive pollution issue through development of biowastes as alternative sources of renewable energy and valued chemicals. This in turn shall generate additional revenue for the industry. Finally, better-integrated waste management is associated with other environmental benefits such as reduction of surface waterbody and groundwater contamination, less waste of land and resources, lower air pollution, and a reduction of accelerating climate changes.

REFERENCES


