# CHAPTER 5

# INDUSTRIAL ECOSYSTEM : A CASE STUDY OF A CRUDE PALM OIL MILL LOCATED IN COMMUNITY

## 5.1 Introduction

This chapter presents the result of an implant survey of factory A which is as already mentioned in chapter 3 representing the best practice in clean technology of crude palm oil industry in Thailand. The detailed process flowchart, mass balance, raw material and energy consumption and environmental impact are shown. The existing environmental performance of factory A is analyzed based on waste generation, environmental impacts, clean technology option adoptions and waste exchange. Then the possible options for solving the existing environmental problem of the mill will be proposed. The assessment of the available clean technology options and the improvement of the environmental performance are executed on the basis of clean technology and industrial ecology theory. This chapter will also present a physical-technological model of an almost Zero Waste Industrial Ecosystem for factory A created by integrating all options as discussed in this chapter.

## 5.2 Production Process and Environmental Aspects

Factory A has been established in 1978s. It covers an area of 137,600 $m^2$ in Surathani province, about 10 km from the city center. The total staff and workers employed in the company consist of 110 persons. The production capacity is 45-ton fresh fruit bunch/ hour or 173,000 ton FFB/ year. This factory has implemented many clean technologies and also applies an environmental management system (EMS). The reason for clean technology application is to increase oil yield, to minimize waste production and to reduce water consumption. They also got ISO 9000 certify.

### 5.2.1 Production Process

The extraction of palm oil from fresh fruit bunch involves five major operations- fruit separation, sterilisation, digestion, oil extraction and oil purification. In the production process, large amounts of water and energy are needed to convert palm fruits into crude palm oil. Figure 5.1 and 5.2 show schematic flow diagrams of crude palm oil production in factory A, which represent as already mentioned in the introduction, a factory applying advanced technology of crude palm oil production in Thailand. Figure 5.3 shows the mass balances of the production process of factory A which are based on the processing of 1000 kg FFB. Result from study shows that a standard wet processing mill consumes a lot of water in the production process and also generates large amount of wastewater. Besides they are high-energy consuming industries. The most important source of energy use in factories, as is also the case in factory A, is electricity. However most of crude palm oil mills have self-sufficient energy consumption. We will discuss more in detail the most important treatment steps and/ or equipment in the production process in section 5.2.4. The production process of factory A is as following:

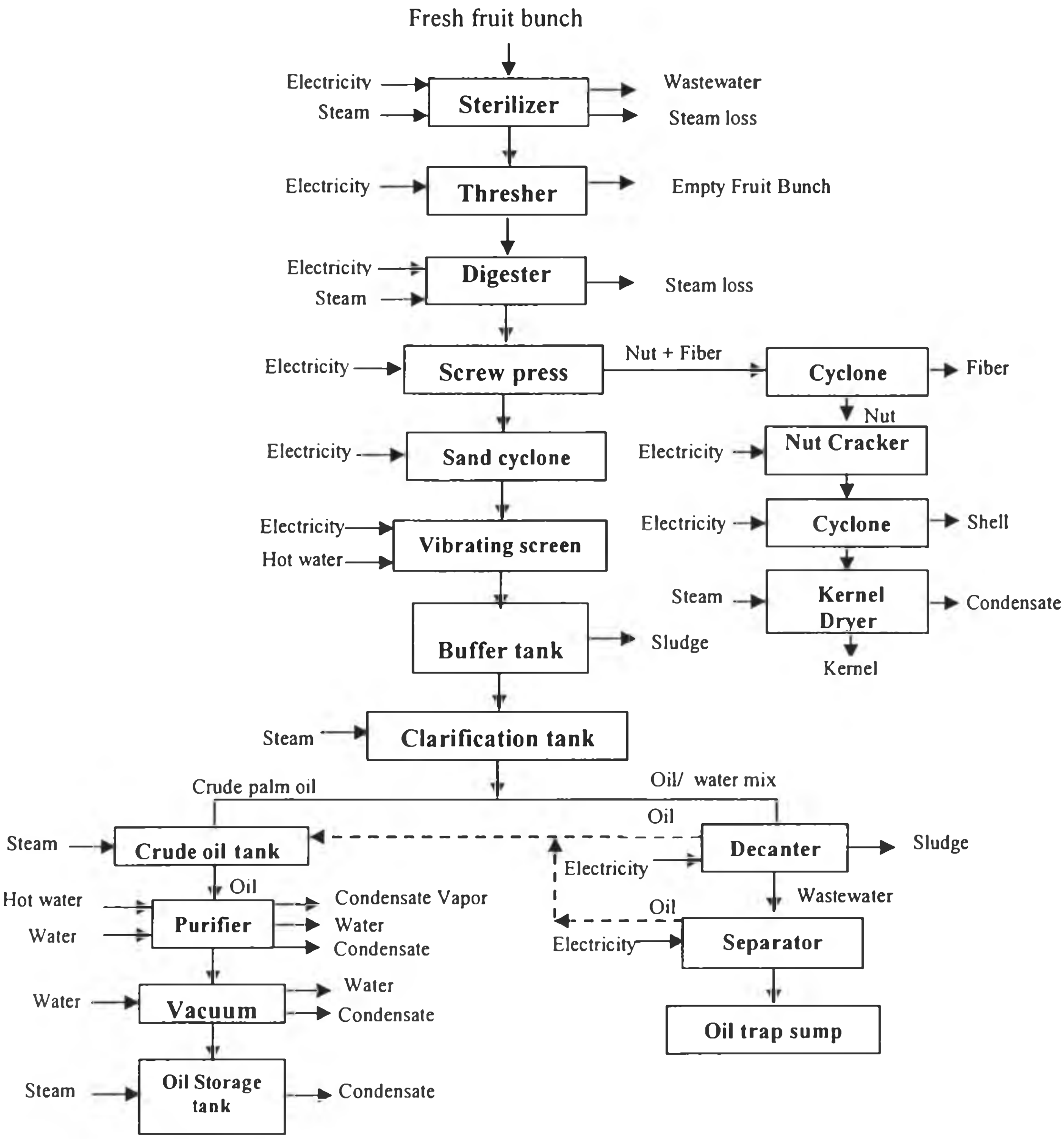



**Figure 5.1** Schematic flow diagram of crude palm oil production in factory A.

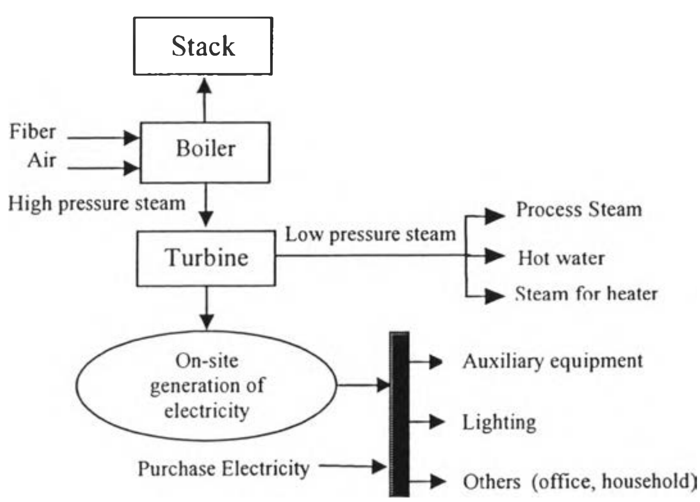



**Figure 5.2** Schematic energy flow diagram of factory A.

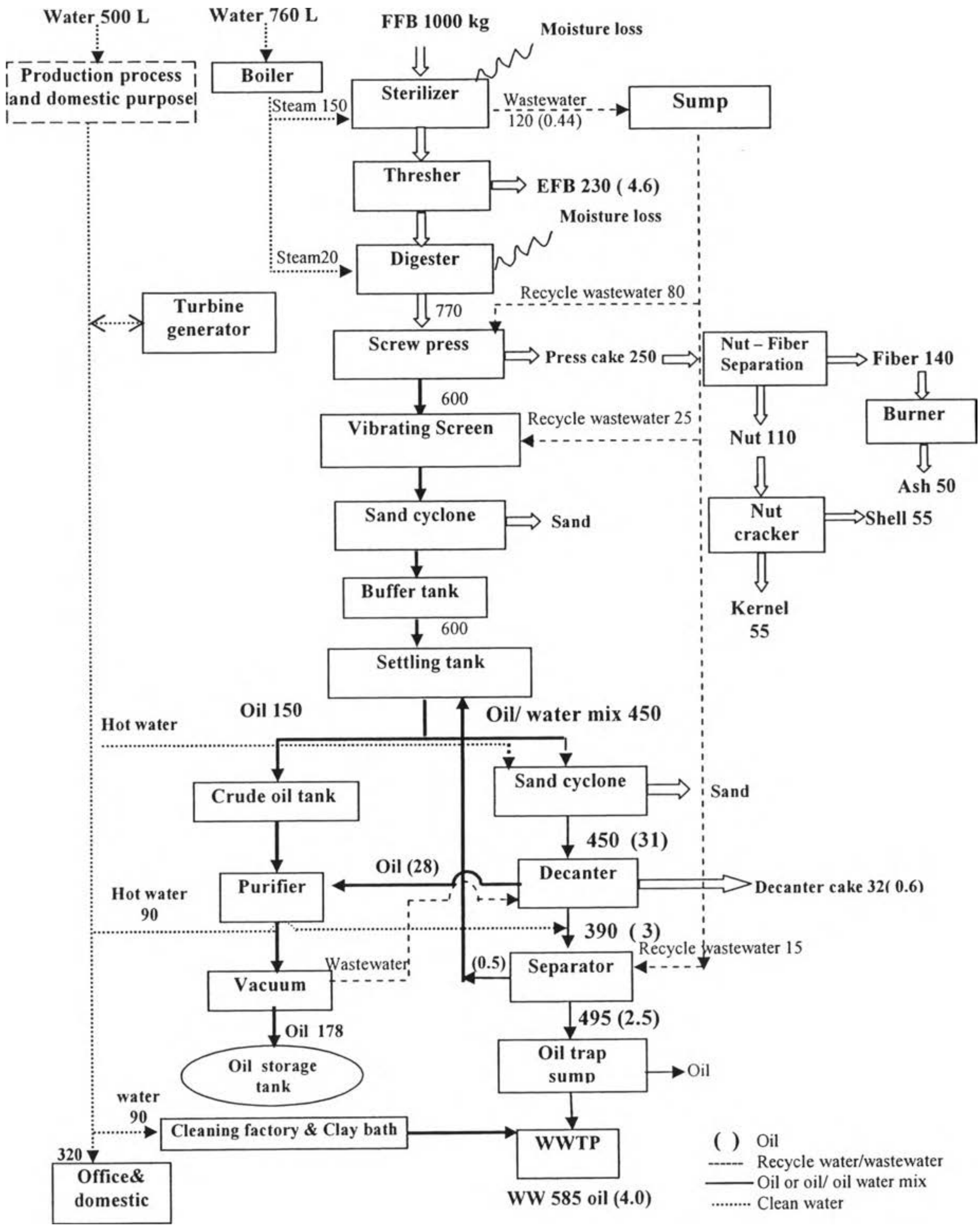
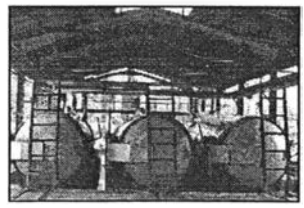



**Figure 5.3** Mass balance of production process of factory A.

***Reception, transfer and storage of fresh fruit bunch.*** The fresh fruit bunches are harvested and transported to the palm oil mills by trucks for immediate processing. At the mill, they are unloaded on a ramp and put in to containers of 2.5 tons each.

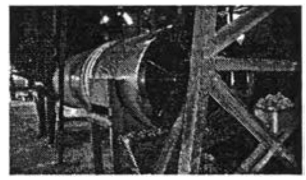
**Loading ramp**

***Sterilization.*** Sterilization of the fresh fruit bunch is done batch wise in an autoclave with the application of steam at 120 –140 °C for1-2 hr. The objectives of the sterilization are to prevent the future formation of fatty acids, to facilitate stripping of fruits, and to prepare the fruit fiber for subsequent processing.



**Autoclave**

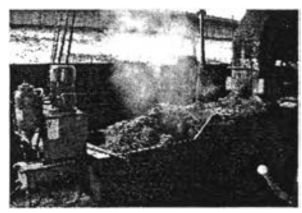
***Bunch stripping.*** The containers with the sterilized bunches are emptied into a rotary drum thresher where the fruits are separated from the bunch stalk. This processing step generates an empty fruit bunch stalk of 230- 250 kg/ton empty fruit bunch.



**Thresher**

***Digestion.*** The separated fruits are carried into digesters and mechanically converted into an extractable mash.

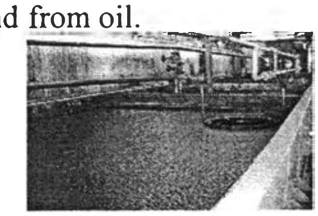
***Extraction.*** The oily mash is fed into a continuous screw press system where the oil is extracted. The extracted crude palm oil is collected and discharged to the purification section. The remaining press cake is transported to a separation system consisting of air classifiers and cyclones for drying and separating of nuts and fibers. Kernels are recovered from nuts in the crackers. Fiber and shells are sent to the boiler and used as fuel.



**Screw press**

***Clarification and purification of the crude palm oil.*** The crude palm oil from the presses is a mixture of palm oil (25% - 35%), water (45% - 55%) and fibrous material varying in proportions.

- ***Screening.*** Small amount of hot water is added to the raw oil and passed through a vibrating screen to separate fibrous particles; the oil after sieving still contains high suspended solids and water.
- ***Sand removal.*** A sand cyclone is use to separate sand from oil.
- ***Suspended solid separating.*** The conventional procedure to separate oil from water is the settling tank method. Steam is used to heat the system and to maintain the temperature at 90°C. Oil is floating on the top of the tank and is collected by a funnel which flows to crude oil tank.

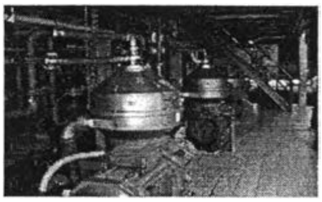


**Settling tank**

- ***Oil purifying.***
    - ***Separating of fine suspended solids.*** The final purification step is also done by centrifugation of the crude oil from the settling tank to remove fine suspended solids.

- o ***Drying and cooling.*** After centrifugation the crude oil still contains water which is removed by a vacuum evaporation system. The dried crude oil is kept in storage tanks before selling an oil refinery.

- ***Treating of sludge (oil/ water mix) from settling tank.*** The sludge from settling tank is collected in the sludge tank and subsequently treated to recover oil. In order to protect the equipment in the subsequent process steps against clogging the sand is separated from sludge by sand cyclone. The sand cyclone is cleaned by discharging the accumulated sang to the drain, followed by the injection of hot water.
- ***Oil recovery.*** The sludge is collected in a sludge tank and then pumped to a decanter (three-phase centrifuge) and a separator (two-phase centrifuge) for oil recovery. To enhance the separator efficiency, it is common practice to add water during centrifugation. The separator will generate more wastewater than the decanter process. The recovered crude oil is pumped to the settling tank.



**Separator**

The cake from the screw press after oil extraction is broken up and the fiber is removed from the kernel nut in the air cyclone. The fiber is then blow through a cyclone to the boilers where it is burnt as fuel. The kernel nut is cracked and the kernel and the shell separated by a clay water bath. The kernel produced is dried to reduce its moisture to prevent molding, and then stored in a silo.

Factory A adopted and introduced many clean technology options including good-house-keeping, reuse & recycle and technology change. An overview of apparatus, equipment and other measures is give below:

- Use of decanter and use of separator for recovery oil from wastewater and construction of oil trap sump to remove oil from wastewater before this goes to wastewater treatment plant (WWTP).
- Installation of buffer tank to separate sludge from crude oil before this flows to the clarification tank in order to enhance oil separation in this tank (improvement of clarification tank).
- Installation of $2^0$ bunch stripper to enhance fruit separation from bunch stalk in order to reduce oil loss from EFB.
- Recycling sterilized condense to screw press and vibrating screen in order to reduce water use.
- Recycling hot water from vacuum dryer tank for cleaning decanter and separator.
- Recycling steam condensate (temp 100 $^oC$) from nut drier tank and use as boiler feed water.

### 5.2.2 Inputs

***Raw material demands.*** The raw materials needed for production processes are fresh fruit brunch, clay, alum, anionic polymer, diesel oil, salt, electricity and surface water. Raw material demands of the factory are shown in Table 5.1. Clay is used for preparing solution in order to separate shell from palm kernel. Alum and anionic polymer are used in surface water treatment plant before supply to the production process. The factory consumes water from nearby cannel with free of charge.

***Electricity demand.*** Electricity is the dominant source of energy for the production process. Total energy consumption of all electric machines used in the production process is about 17.11 kWh/ ton FFB. The electricity used in this mill is obtained from 2 sources; turbine generator installed in factory and purchase from government supplier. The electricity generated in the factory is about 85% of total electricity consumption (15 kWh/ ton FFB). The small power plant in the mill incorporates water tube boiler with a steam capacity of up to 20 ton of steam/ hour. Fiber obtained from production process is used as fuel for the power plant. About 3.3% of total electricity consumption in factory is consumed by office buildings.

**Table 5.1** Demand of raw materials for production of the company A.

| Item | Usage purposes | Unit | Consumption |
|---|---|---|---|
| FFB | Basic material for production of crude palm oil | Ton/ year | 173,000.0 |
| Clay | Separate shell from kernel | Ton/ year | 257.1 |
| Alum | Water treatment | Ton/ year | 4.5 |
| Anionic polymer | Water treatment | Ton/ year | 0.6 |
| $O_2$ scavenger 1) | FBW treatment | Ton/ year | 235.0 |
| Sodium chloride 2) | FBW treatment | Ton/ year | 21.4 |
| Diesel fuel oil | Generator | L/ year | 4,200.0 |
| Electricity | Lighting and production | kWh/ year | 2,868,873.0 |
| Surface water | Steam generation, turbine generator and production process | m3/ year | 207,600.0 |

**Note** : 1) use to prevent corrosion of water tube in boiler.
2) use to regenerate resin for feed boiler water treatment.

***Fuel demand.*** Fuel used in the production process consists of 0.024 L diesel oil/ ton FFB. Diesel oil is used for diesel generator for start up boiler and generator.

***Water supply demand.*** Crude palm oil mill uses much water in production process. Cannel water is the source of water supply. This water is treated by coagulation and filtration. Alum and polymer are used as coagulant and flocculent in the clarifier. The average water consumption is equal to 1.20 $m^3$/ton FFB or 720 $m^3$/ day. A detail on overview of water usage in the factory is shown in Table 5.2. The quantity of water consumption per ton FFB is not different among crude palm oil factories due to the fact that most of water is used for feed boiler water and turbine cooling water. Cooling water for turbine is recycled in the production process, cleaning machine and domestic purposes.

Water supply in this factory is required for the following processes :

- During power generation. As cooling water for the turbine used to generate electricity from burning fiber.

- During sterilization and digestion, live steam from boiler is applies to autoclave in order to facilitate the stripping of fruit and to digestion in order to facilitate homogenization.
- During extraction. To remove the oil from fiber.
- During oil recovery from sludge (concentrated wastewater from oil clarification tank). Water is use as a dilution water for sludge to adjust the concentration of sludge before go to separator.
- During removal of large particles from oil in desander step (vibrating screen), hot water is use to clean the surface of vibrating screen.
- Miscellaneous usage such as cleaning machine (decantor and separator) and floor.

**Table 5.2** Water demand for crude palm oil production process of factory A.

| **Process stream** | **consumption** | |
|---|---|---|
| | **$m^3$/ton FFB** | **$m^3$/day** |
| Feed boiler water for steam generation and turbine generator. | 0.76 | 272 |
| Steam leaving the turbine generator is (re)used in | | |
| • Sterilizer | 0.15 | 54 |
| • Digester | 0.02 | 7 |
| • Other machines such as nut dryer, or storage tank such as crude oil storage tank, hot water tank | 0.33 | 211 |
| Water used in production process and domestic purpose | 0.50 | 180 |
| ( reused water from cooling system in turbine) | | |
| • Screw press | (0.08) | (29) |
| • Vibrating screen | (0.025) | (9) |
| • Separator | 0.09 (.015) | 32(5) |
| • Cleaning separator & decanter, Clay bath | 0.09 | 32 |
| • Domestic purpose | 0.32 | 116 |
| Total water consumption | 1.26 | 452 |

**Note:** 1) Number in ( ) indicate quantity of sterilized condense wastewater reuse in screw press, vibrating screen and separator.
2) Production capacity is 360 ton FFB/day

### 5.2.3 Output

***Product.*** The production capacity of the company is 45 tons fresh fruit brunch/hour. For 8 hours operating and processing 360 tons of fresh fruit brunch/ day. A total amount of 63.2 tons of crude palm oil is produced. The maximum production capacity of the company reaches 1200 tons/day (24-hr. operation) in high season production of palm fruit. In 2002, the production capacity of the company is about 60% of the designed capacity. The production capacity of the company depends on the amount of fresh fruit brunch that factory can buy from farmer. The quantity of product consists of crude palm oil and palm kernel which equal to 40,000 and 11,000 tons/year respectively.

This factory operates 300 days/year. The quality of crude palm oil of the company is indicated by the following parameters :

- % Free fatty acid less than 5%
- % Moisture content less than 5%
- % Contaminants less than 0.01%
- Iodine value 50 – 55

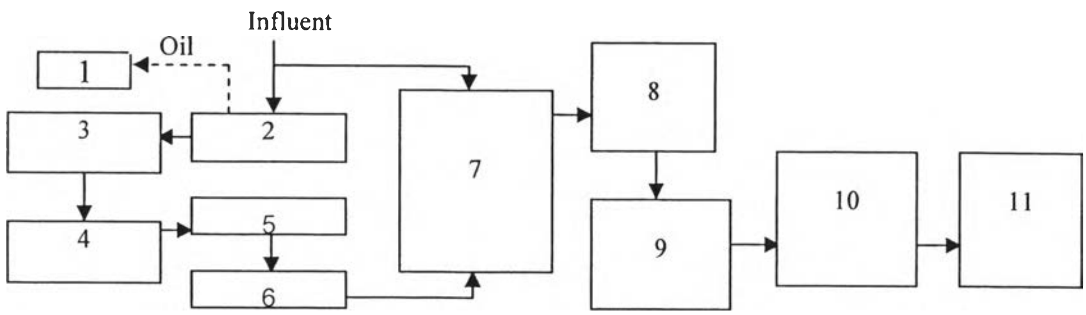
***Wastewater generation***. The main sources of wastewater are from sterilization process and oil separation process. Combined wastewater from production process is more or less brown concentrated slurry with a high organic content. The results from analysis of raw wastewater from production process show that BOD and COD are very high and equal to 52.2 and 68.3 g/L respectively (Tabl 5.3). The ratio of BOD and COD is 0.76. That means that the organic content in wastewater is easily biodegradable. It is found that BOD of the wastewater after anaerobic digestion (pond 3) is reduced to 458 mg/ L (99.1% BOD removal efficiency). Total solids and suspended solids in wastewater is very high too (57.7 and 30.9 g/L respectively). Suspended solids in wastewater are derived from fine particle of fiber that contaminates the oil water slurry while pressing fiber. Wastewater from this industry also contains high nitrogen and phosphorus. Oil contains in wastewater is equal to 4,660 mg/L that is the lowest compared to other 4 factories.

**Table 5.3** Characteristic of wastewater from production process and wastewater treatment plant of factory A (October, 2002).

| Sampling point | pH | $BOD_5$ (mg/l) | COD (mg/l) | SS (mg/l) | TS (mg/l) | TKN (mg/l) | TP (mg/l) | O&G (mg/l) | Color (pt.Co unit) |
|---|---|---|---|---|---|---|---|---|---|
| Sterilizer | 4.93 | 44900 | - | 18000 | - | - | - | 6170 | - |
| Separator | 4.76 | 79200 | - | 72270 | - | - | - | 5220 | - |
| Raw wastewater | 4.83 | 52200 | 68341 | 30933 | 57650 | 1020 | 40 | 7250 | 10000 |
| Pond 3 | 8.20 | 458 | 4307 | 2400 | 15080 | 372 | 20 | 78 | 4833 |
| Pond 6 | 8.63 | 108 | 2036 | 691 | 8420 | 98 | 8 | 19 | 4000 |
| Pond 8 | 8.69 | 255 | 2092 | 500 | 11725 | 104 | 6 | 15 | 4900 |
| Pond 9 | 8.90 | 80 | 1926 | 373 | 11200 | 120 | 5 | 4 | 4600 |
| Pond 11 | 9.37 | 36 | 963 | 100 | 7497 | 38 | 0.4 | 0 | 1750 |
| **Thailand's Eff. Standard** | **5-9** | **20** | **120** | **50** | **3000** | **200** | - | **5** | - |

Wastewater treatment plant is anaerobic pond and oxidation pond in series. The first 2 ponds use for separate oil from wastewater. The $3^{th}$ – $7^{th}$ ponds are anaerobic digestion ponds. Pond 8 and 9 are facultative pond and the last 2 ponds are polishing pond (Fig 5.4). Wastewater in the last pond still contains high total solids, COD and color content. Most parameter can not meet the Thai effluent standard given for BOD, COD, SS and TS. As Most of crude palm oil industry has to store their wastewater in their ponds and prevent overflow in raining season general also factory A. Total volume of treatment ponds in factory A is 335,000 $m^3$ and detention time of wastewater in wastewater treatment plant is about 700 days (wastewater generated is about 450 $m^3$/

day). The wastewater evaporates to the atmosphere during the dry season. So the color intensity and TS of wastewater in final pond is high. The data of wastewater characteristic from this factory at present still indicate of high potential of heavy pollution from this waste source.




Pond 1 Oil collecting pond( 20*38*2 $m^3$) Pond 5 Anaerobic pond (20*75*3.5 $m^3$) Pond 9 Oxidation pond (80*95*4 $m^3$)

Pond 2 Oil trap pond (30*75*3.5 $m^3$) Pond 6 Anaerobic pond ( 20*75*3.5 $m^3$) Pond 10 Oxidation pond ( 82*100*4 $m^3$)

Pond 3 Anaerobic pond (30*25*3.5 $m^3$) Pond 7 Anaerobic pond (110*191*4 $m^3$) Pond 11 Maturation pond (78*106*4 $m^3$)

Pond 4 Anaerobic pond (30*25*3.5 $m^3$) Pond 8 Oxidation pond (110*120*4 $m^3$)

**Figure 5.4** Layout of wastewater pond system of factory A.

***Solid wastes and by-products***. Solid wastes and by – products generated in the palm oil extraction process are: empty fruit bunches; fibers; shell; decanter cake and ash from boiler. The quantities of these materials are summarized in table 5.4. Solid waste can be reused in production process, oil palm plantation or sold to other industries. The problems of solid waste management in this factory are improper storage and handling of solid waste material and disposal techniques on land.

**Table 5.4** Quantity of solid wastes/by-products generated form the factory A (October, 2002)

| Source | Solid waste generated | |
|---|---|---|
| | **kg / ton FFB** | **ton/day** |
| Empty fruit bunch | 230 | 83 |
| Fiber | 140 | 50 |
| Shell | 55 | 20 |
| Decanter cake | 32 | 12 |
| Ash | 50 | 21 |

**Note:** based on production capacity of 360 ton FFB/day.

***Air pollution***. Particulate and smoke are generated from burner/boiler in wet process factories due to incomplete combustion of the solid residuals. Palm oil mills are generally self-sufficient in terms of energy requirement due to the availability of adequate quantities of the fiber and shell materials used as solid fuel in the steam boiler and electrical power generator. In some cases, air emissions have pollutants higher than the limits mentioned in the National Quality Standards.

At present, production activities of the company have not caused serious pollution to the environment and surrounded community even this factory is located very close to them. This is due to a proper management of the wastes, such as:

- Wastewater is stored at the site of the company. All wastewater generated have been stored in the treatment ponds without discharge to the environment. The characteristic of wastewater is shown in table 5.3
- Solid wastes or by products can be sold or stored in the factory before transport to reuse as land filling.
- This factory uses fiber (80% of funel) as fuel in boiler. Fiber causes low particulate matter emission from stack. So there is a low impact of air pollution from the factory.
- A relatively small amount of oil accumulates in anaerobic pond because % oil loss in wastewater is low compared to the other 4 factories.

### 5.2.4 Material and energy balance

The more detailed of the material and energy balance of production process are discussed below:

#### 5.2.4.1 Material balance

***Sterilization*** (Figure 5.5)

Fresh fruit bunches (FFB) are unloaded on a ramp and put into containers of 2.5 ton transport capacity and then put into autoclaves for sterilization. Sterilization of FFB is done batchwise for batches of 20 to 30 ton FFB with the application of steam at a temperature of 120 – 130 °C pressure about 3 bar for 75 min. The purpose of sterilization is :

- Prevention of increase of free fatty acid content in the fruit due to microbial conversion.
- Facilitation of stripping of palm fruit from brunch stalk.
- Precondition of nut and minimize kernel breakage during processing and nut cracking.

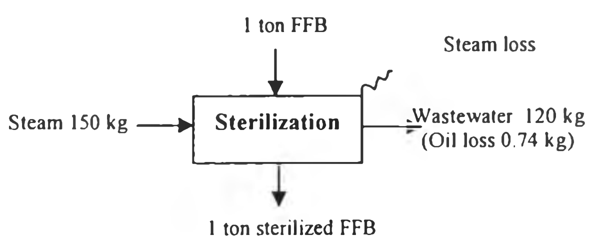



**Figure 5.5** Mass balance of sterilization step.

After sterilization, steam is blown out for 10 minutes for release pressure in autoclave. Then sterilized condensate released and collected in a sump by gravity flow. One ton of FFB generates 0.12 $m^3$ condensate as wastewater that contains 0.74 kg of oil. This condensate is pumped to reuse at screw press, vibrating screen and separator in order to reduce water consumption and oil recovery from wastewater.

***Thresher*** (Figure 5.6)

Two rotary drum strippers are used for separating the sterilized fruit from the sterilized bunch stalks. Empty fruit bunches (EFB) from first stripper are feed to the second stripper to minimize fruit loss in EFB. This method can increase oil yield by 10 %. This process step generates an amount of EFB of 230 kg/ton FFB,

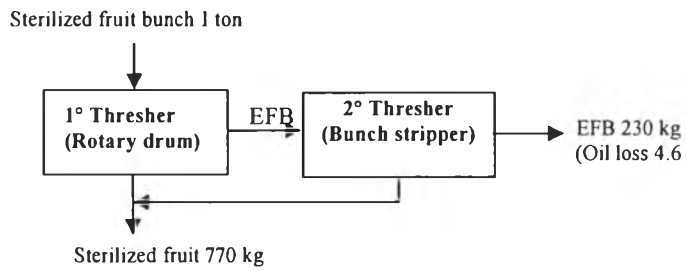



**Figure 5.6** Mass balance of thresher step.

***Digestion*** (Figure 5.7)

The fruit are fed into a vertical steam heated vessel with stirring arms (digesters). Here the fruits are treated mechanically to convert them into a homogeneous oily mash. The temperature in the digester is maintained at 90 °C. Live steam is pumped into the digester to facilitate homogenization. This mash is subsequently fed into the oil extraction press.

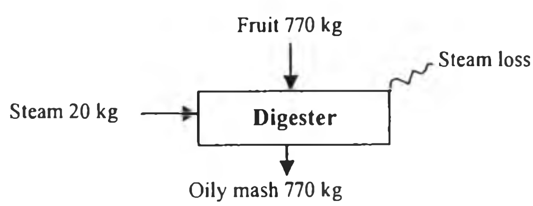



**Figure 5.7** Mass balance of digestion step.

***Oil extraction and solid waste/ by-product separation*** (Figure 5.8)

Extraction of palm oil is done by means of a continuous screw press system. The extracted oil is collected and sent to the purification process in order to separate water and suspended matter from oil. Hot water is fed into the screw press to minimize oil loss in the pressed cake (fiber and nut). The pressed cake is transported to a separation system consisting of air classifiers and cyclones for recovery of the nuts and fibers. The nuts and fibers are dried during this separation process by hot air which is indirectly heated by steam to a temperature of 135 °C. Kernel is recovered from nuts in centrifugal crackers and are sold to a kernel oil mill. Fiber is send to the burner for steam production. Ash from burner is estimated to 50 kg/ton FFB.

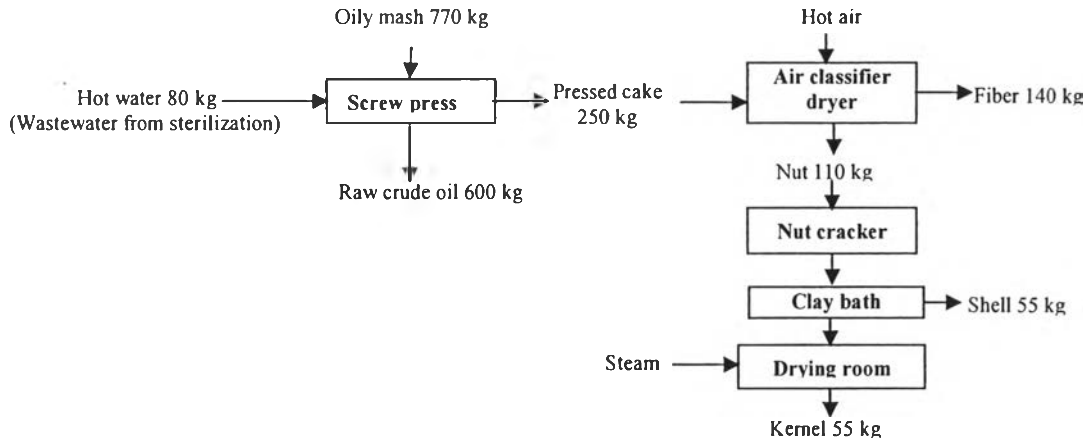



**Figure 5.8** Mass balances of oil extraction and solid waste/ by-product separation step.

*Oil purification* (Figure 5.9 and 5.10)

The raw crude oil is pumped to a vibrating screen, then goes to a sand cyclone in order to separate dirt fibers and sand from the liquid phase before sending to the settling tank.

- *Vibrating screen* Raw crude oil flows to vibrating screen to remove coarse solids. The residual solids recovered from this screen contain a high oil content and are conveyed back to the digester. For improvement of oil clarification, hot water is added to the raw oil before passed through the screen.
- *Sand cyclone.* Raw oil is passed to a sand cyclone to remove fine sand. This stage is used to avoid erosion problems in the equipment in the purification section. The collected sand is drained out every 30 minute.

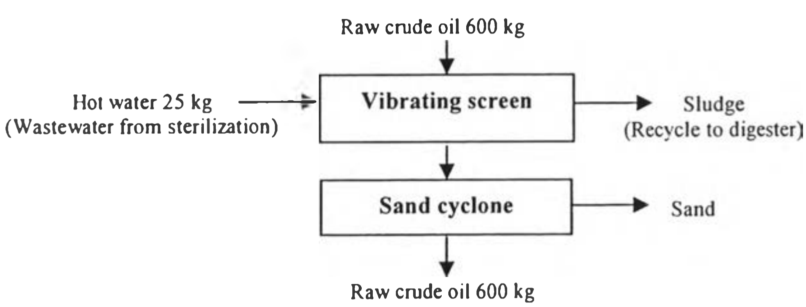



**Figure 5.9** Mass balance of suspended solids removal step.

- ***Clarification tank.*** The continuous settling tank method is the conventional method for separation oil from water and suspended solids. Closed steam heating coils heat the raw crude oil in the tank, in order to facilitate gravity separation. The lighter phase (oil) is collected by a funnel system and sends to a system for further purification system. The settled oily sludge is collected in the sludge tank and oil is collected at the surface of the settling tank is further process in a decanter and separator.

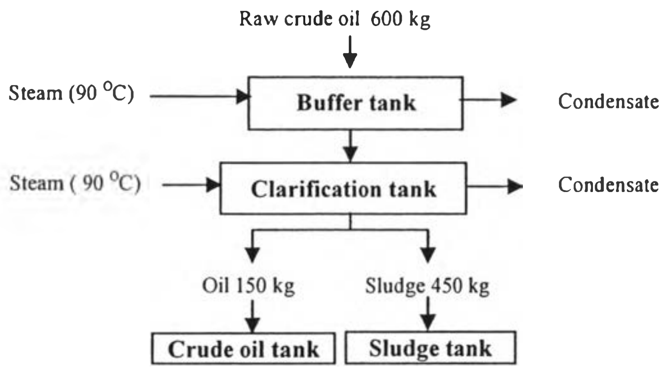



**Figure 5.10** Mass balance of oil clarification step.

- ***Purifier.*** The light phase (oil) from the clarification tank is fed to a crude oil tank and then to a purifier. This purifier consists of a two – phase centrifuges using for solid removal. This process step generates small volumes of wastewater due to the low suspended solids content in the raw crude oil.
- ***Vacuum tank.*** The moisture content in the oil is removed by a vacuum evaporation system. Then the crude oil is kept in storage tanks and transported to a refinery. Temperature of oil (60 °C) in the storage tank is maintained with stein coil heating.

***Treatment of sludge from settling tank.***( Figure 5.11)

The bottom sludge from the settling tank contains a high oil content (7% of sludge) and a high concentration of organic substances. In order to recover oil and decrease the organic load of the wastewater, the settling tank sludge is further treated as following.

- ***Sand cyclone.*** In order to protect the equipment in the subsequently process steps against clogging, sand is removed in a sand cyclone. The bottom sludge is sent to the sand cyclone (hydrocyclone). This cyclone separates sand from wastewater. The accumulated sand are then drained. The wastewater generated is 5L/ton FFB.
- ***Decanter.*** The purpose of the decanter is to remove remaining solids (fine particles) and water from the sludge leaving the sand cyclone to recover oil. Oil is sent to a purifier.
- ***Separator.*** Sludge is pumped to separator for oil recovery. Hot water is added to the sludge to improve oil separation efficiency.

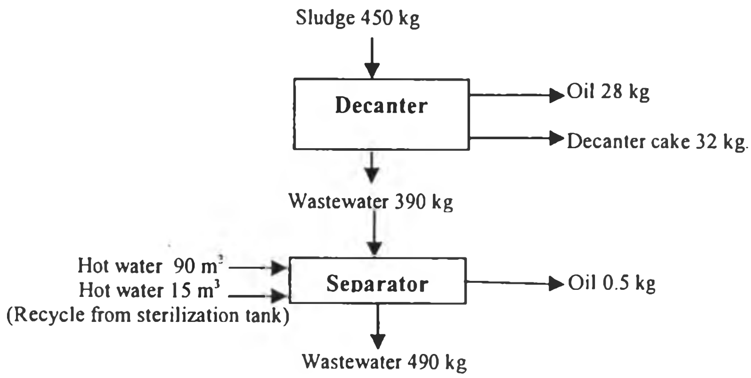



**Figure 5.11** Mass balance of sludge treatment step.

***Material balance***. This balance only considers the (dry weight) flow of all raw materials through the production process including product, by-product and solid waste. These are fresh fruit bunch, crude palm oil, empty fruit bunch, fiber, shell, kernel, decanter cake and ash. Mass balance in term of dry weight for material based on 1 ton of fresh fruit bunch (wet weight) flows can be expressed as follows :

Mass of fresh fruit brunch = mass of crude palm oil + mass of kernel + mass of empty fruit brunch +mass of fiber + mass of shell + mass of decantor cake + total solids in wastewater +mass of solid waste

Or :

1,000 kg (35% moisture content) = 178 + 55(1-0.05) + 230(1-0.3) + 140(1-0.3) + 55(1-0.1) +32(1- 0.8) + 34 + mass of solid waste (soil, soil, etc.)

650 kg = 579.1+ mass of solid waste

Mass of solid waste = 70.9 kg

Thus, the amount of dry solid waste is 70.9 kg/ton of FFB. This amount of solid material (sand, decanter cake, spilled raw material, etc.) is disposed as waste to the environment. The mass balances for material flows in terms of dry weight are described in Figure 5.12.

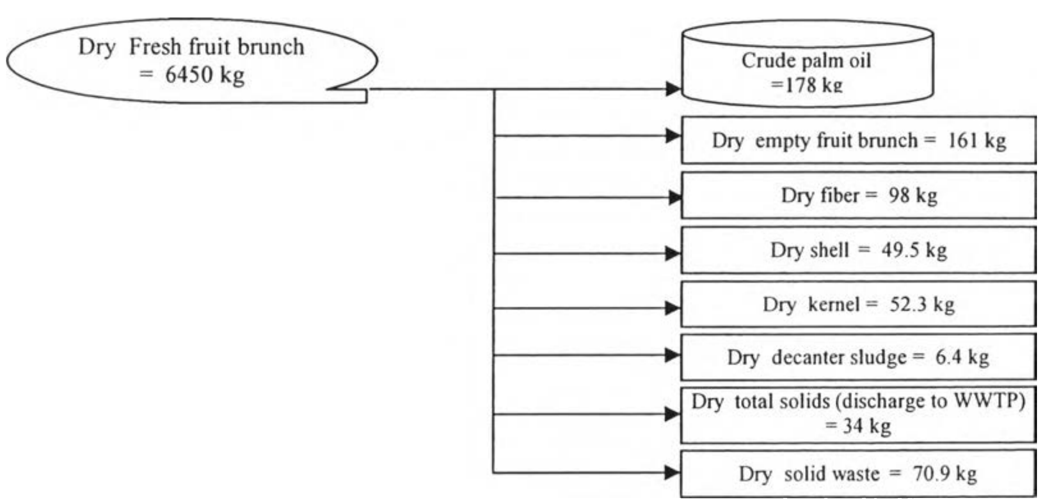



**Figure 5.12** Mass balance in term of dry weight.

***Liquid material balance***. The total availability of water use in the mill was 1.2 $m^3$/ton FFB, but total water consumed in production processes was 0.58 $m^3$/ton FFB while 0.085 $m^3$/ton FFB is recycled in production process. The generated wastewater is 0.56 $m^3$/ton FFB. The volume balance of liquid material flows is described in Figure 5.13.

***Energy Analysis.*** Thermal energy and electricity are two main forms of energy utilized in the palm oil mill. Process steam is supplied by a cogeneration system to produce electricity and live steam together. A back pressure steam turbine for power and heat generation is used by the factory. Waste materials from the production process are mainly composed of fiber and shells or amount of output made steam. These are the fuel used to produce steam. Fiber and shell is fed to the boiler in the ratio of 80:20. The total amount of 165 kg fuel/t FFB The input of boiler are fuel and feed water boiler which are fed in the rate of 59 ton/day and 0.76 $m^3$/t FFB, respectively. Output side steam generates about 200 ton/day (0.56 ton steam/t FFB). Then steam is expanded through a turbine to generate the output power from the operation. The electrical generator provides about 510 kW (5492 kWh/day) during 8 hours of heat to the processes. The factory is cogenerating electricity during all operating days and purchasing electricity only for start up purposes and during non-operating hour.

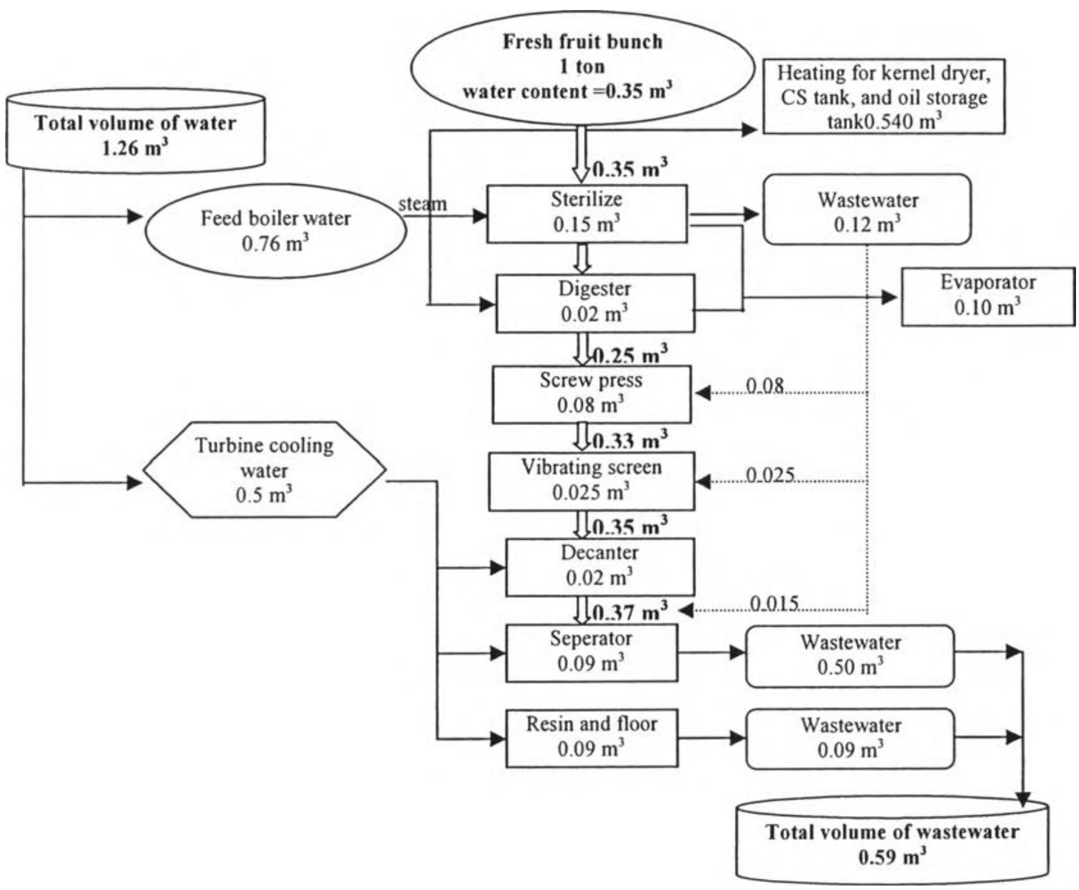



**Figure 5.13** Water balance of factory A.

A cogeneration system using a backpressure steam turbine consists of a combustion chamber, boiler and steam turbine

***Combustion chamber***. The fuel is burnt to process heat requirements. The temperature of flue gas from stack is 360 °C. A dust collector separates fly ash. Bottom ash is removed manual at the gate. These ashes are collected and disposed as waste. For processing 1 ton of FFB the fuel 165 kg is burnt to gain an amount of energy 2,114,000 kJ. This energy is used to heat 760 kg boiler feed water from 70 °C to 240 °C. The main energy losses in the combustion chamber occur in the stack flue gas. A detail energy analysis in factory A is shown in Table 5.5.

**Table 5.5** Energy balance of production process of factory A.

| **Unit operation** | **Inlet** | | | | **Outlet** | | | |
|---|---|---|---|---|---|---|---|---|
| | Flow | Temp °C | Mass kg | Energy MJ | Flow | Temp °C | Mass kg | Energy MJ |
| Boiler | Make up wate<br>Fiber & shell<br>Electricity<br>Condensate recycle | 70<br>30<br>-<br>100 | 760<br>165<br>3.71 kWh<br>24 | 127<br>2,110<br>23<br>10 | Steam<br>Exhaust steam<br>Stack loss | 240<br>240<br>360 | 400<br>200 | 1,120<br>630<br>400 |
| | **Total** | | | **2,270** | **Total** | | | **2,270** |
| Electric generation | Cool water in<br>Steam<br>Diesel | 30<br>230 | 390<br>400<br>0.025 L / tonFFB | 0<br>1,120<br>0.9 | Cool water out<br>Steam<br>Electricity<br>Exhaust | 35<br>140<br>- | 390<br>350<br>15.3 | 10<br>950<br>55<br>105 |
| | **Total** | | | **1,120** | **Total** | | | **1,120** |
| CPO production | FFB<br>Steam<br>Electricity | 30<br>140<br>- | 1,000<br>350<br>15.3 | 0<br>950<br>55 | Crude oil<br>Wastewater<br>Exhaust steam<br>Energy loss | 55<br>90<br>130 | 178<br>588<br>130 | 0.5<br>221<br>355<br>428.5 |
| | **Total** | | | **1,005** | **Total** | | | **1,005** |

***Boiler.*** The boiler generates high-pressure steam by transferring heat from the fuel burnt to the incoming high-pressure boiler feed water. The boiler is a water-tube with a capacity of 20 ton/hr. The boiler provides steam to generate enough electrical to supply the whole demand in the factory. For processing 1 ton of FFB, 400 kg steam (1,121,664 kJ) is needed to generate enough electricity for production process. The mainly energy losses in the boiler occur are due to exhaust steam and blow down water.

***Turbine.*** In the steam turbine, the incoming high pressure steam is expanded to a lower pressure level, converting the thermal energy of high pressure steam to kinetic energy through rotating blades and finally into electrical energy. The on-peak load of this factory is 658 kWh. From a survey it is clear that the electrical generator provides about 510 kWh or 15.3 kWh/ton FFB (55,080 kJ/ton FFB). The extracted steam from a back steam turbine meets the heat demand at pressure levels higher than the exhaust pressure of steam turbine. Total energy loss in production process of factory A is 2,110 MJ per ton FFB processed. 50% of energy loss is occurred in boiler. The rest 38% is loss in production process.

Power and steam from turbine are supply to the production process. The detail of electricity supply in the production process is shown in Fig. 5.14 Steam after use for generating electrical power (400 kg/ton FFB or 1,092 kJ) is sent to the sterilizer, digester and other step of production to control temperature of production process. The excess steam in the sterilizer has to be blow out from the sterilizer once 3.2 bar is reached. Steam is exhausted until the pressure in the sterilizer become 1 bar atmosphere. For temperature control system, the steam is also sent to steam coil in hot water tank, settling tank, nut dryer tank and oil storage tank and finally blow out. From Table 5.6, it can be seem that energy input in production process is about 1,147,000 kJ/ton FFB and energy output is in form of enthalpy in crude palm oil and high temperature wastewater that is about 678,000 kJ/ton FFB. Finally the energy is loss from product and wastewater by temperature decreaseing. Most of energy loss is in steam exhaust (355,000 kJ). Figure 5.15 shows the energy balance in crude palm oil production of factory A.

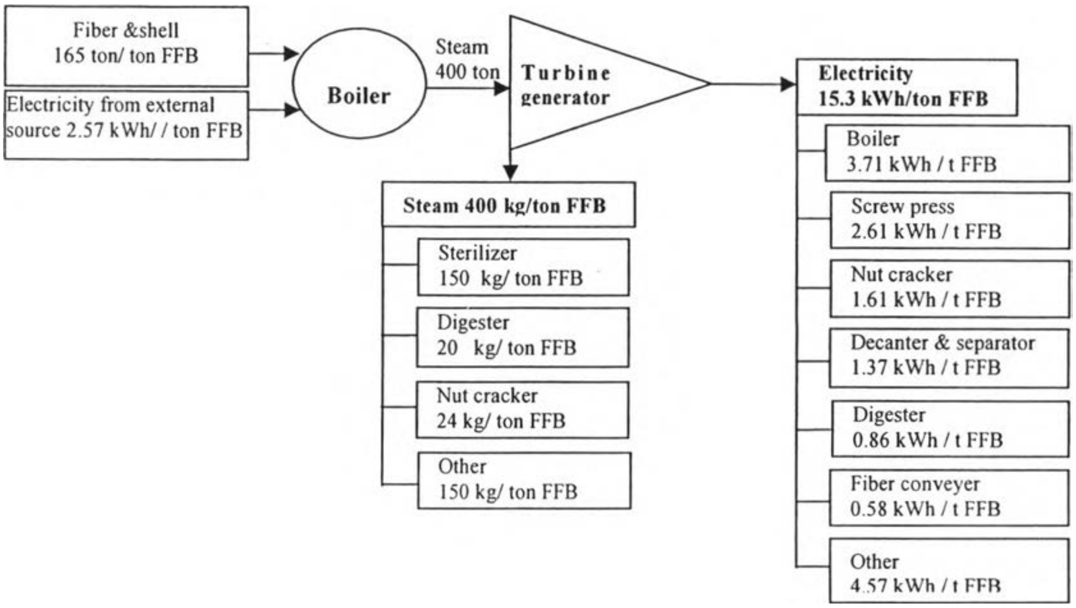



**Figure 5.14** Energy balance in production process of factory A.

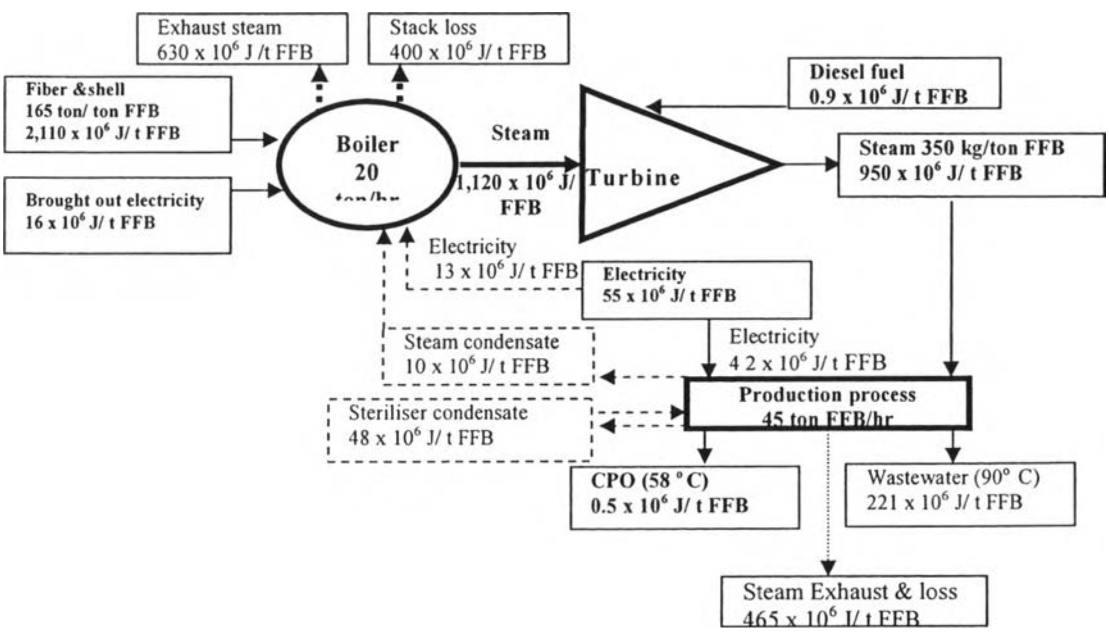



**Figure 5.15** Energy balance in production process of factory A.

### 5.2.5 Cost Benefit Analysis

The cost benefit analysis of the crude palm oil factory is established to find out their economic performances. From the data obtained from the factory, the profit/loss from crude palm oil production can be estimated. The FFB price is depended on the CPO costs. Generally the price of fresh fruit bunch varies depending on the season of the year. During wet season, fresh fruit bunch costs 1.5 - 2 Baht per kg. During dry season, the fresh fruit bunch costs 3-4 Baht per kg (year 2002). This is due to the fresh fruit bunch is more available in wet season.

Production costs consist of the expenditure for purchasing fresh fruit bunches, electricity, diesel fuel, chemical cost, labor and machine maintenance. The company earns money from selling crude palm oil, palm kernel, shell and empty fruit brunch. The total production costs and incomes are described in Table 5.6. For depreciation, the calculation is based on 20 years or equivalent to 5% /year of total investment capital (including machine and building). This investment capital amounts is 180 million Baht.

**Table 5.6** Production cost per ton crude palm oil of factory A (2002).

| Items | Unit | Amount | Unit cost | Total cost (Baht/ day) | Cost ( Baht/ ton FFB) | Cost (Bath/ton CPO) |
|---|---|---|---|---|---|---|
| **Variable cost** | | | | | | |
| FFB* | Ton/ day | 359 | 1,500 Bath/ ton FFB | 538,500 | 1,500 | 8571.4 |
| Electricity | KWh/ day | 922.3 | 3.01 Bath/ kW | 2,883.7 | 8.03 | 45.9 |
| Diesel fuel | L/ day | 68 | 15 Bath/ L | 1,020 | 2.84 | 16.2 |
| Raw water production** | kg/ day | 308.8 | 8.7 Bath/ kg | 2,685.3 | 7.48 | 42.7 |
| Chemical cost** | kg/ day | 8.41 | 2.34 Bath/ kg | 7,075.9 | 19.71 | 112.6 |
| **Fixed cost** | | | | | | |
| Labor | person/ day | 120 | 165 Bath/ person | 19,800 | 55.15 | 315.1 |
| Maintenance cost | Bath/ year | 12,000,000 | - | 33,000 | 91.92 | 525.3 |
| Depreciation | %/ year | 5 | 9,000,000 Bath/year | 30,000 | 83.57 | 477.5 |
| Total (2) | | | | | 1,768.70 | 10,106.86 |

Note * Price of empty fruit bunch is vary between 1,500-4,000 Baht/ ton.

** Cost of water supply and chemical are estimated in figure 5.18

(1) the extraction efficiency = 17.5%

(2) not including office expresses and cost of distribution. (~10% of total cost)

Figure 5.16 illustrates income from selling product and by-products of factory A. It is clear that income from selling by-product is very low compared to those from product. And Figure 5.17 summarizes cost of chemicals which are used in processing fresh fruit bunch.

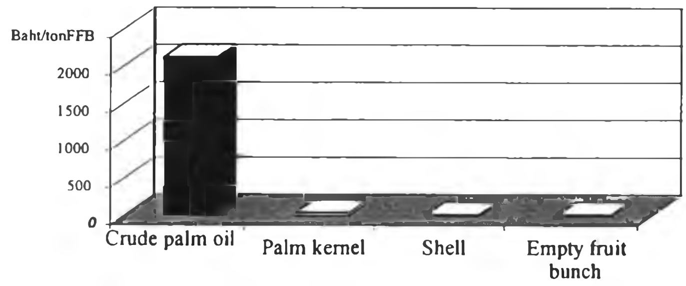
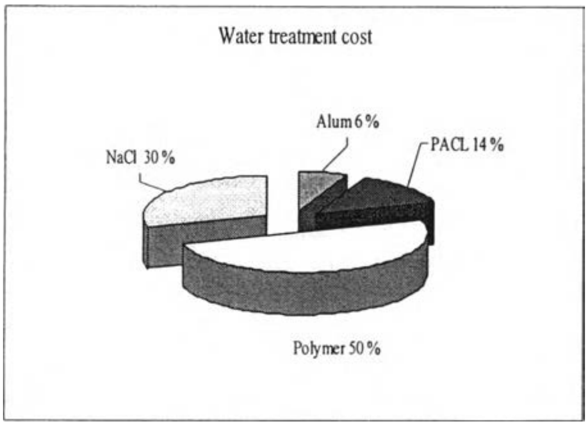



**Figure 5.16** Income per ton of fresh frit bunch processing (Baht/ ton FFB) of factory A (October,2002).



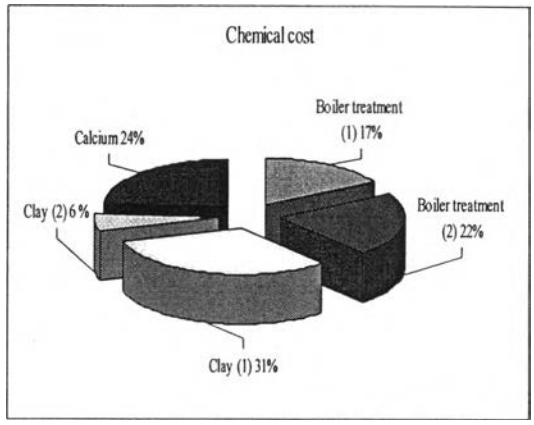




**Figure 5.17** Water treatment costs and other chemical costs (Baht/ ton FFB processing) of factory A.

## 5.3 Existing Environmental Performance of Factory A.

### 5.3.1 Waste generation

The substances found in the products, by – products and residues are originated from the fresh fruit bunch because the entire production process does not need any chemical as a processing aid. However, there are a number of pollution problems at the facility, such as a high water consumption, generation of a high organic content of wastewater, generation of a large quantity of solid waste and emissions of greenhouse gas. The pollution problems which have environmental impact to people surrounded the factories are in-efficiency of wastewater treatment plants and smell from anaerobic ponds. Figure 5.18 shows the waste generation from Factory A.

### 5.3.2 Existing Industrial ecosystem in factory A

The crude palm oil industry is applying a number of ecosystems for its waste recycling and abatement of emission. The nature of these ecosystems can be divided as in-plant measures, cross industrial and cross-border measures. The details of these three types of measures of factory A is as followings:

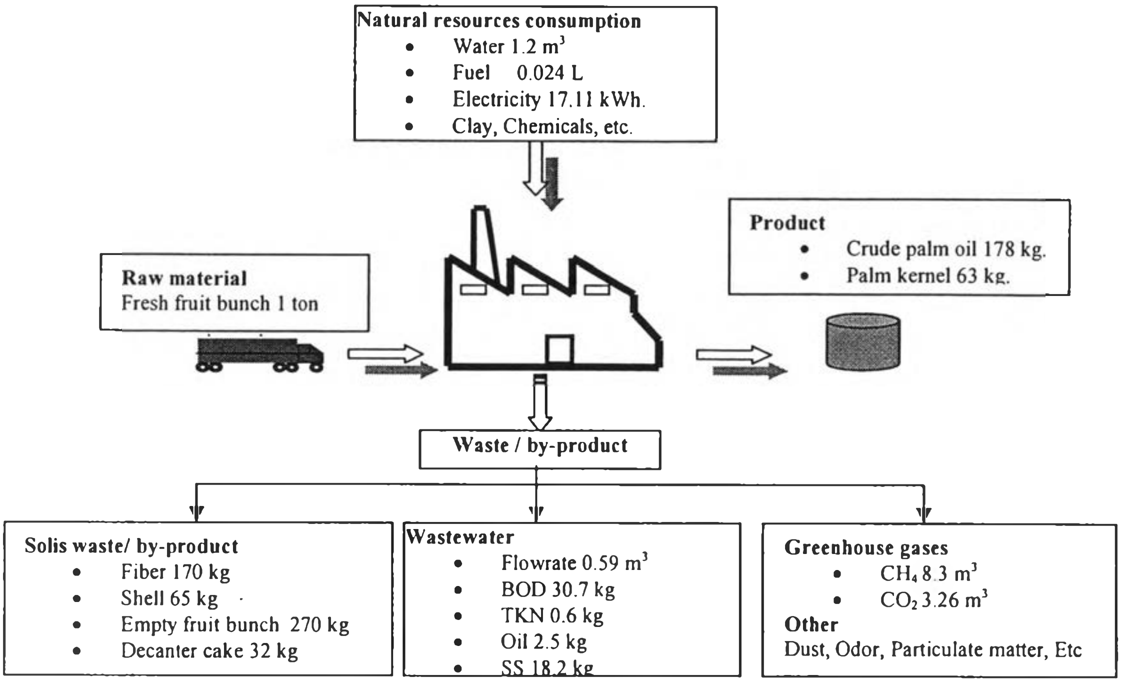



**Figure 5.18** Waste generation rate from Factory A.

**1) In-Plant Ecosystem (clean technology option)**

- ***Beneficial use of fiber and shell in boiler***

Factory A operate a cogeneration system using fiber and shell as fuel in boiler to produce high pressure steam which is that expanded through a steam turbine to produce electricity. Table 5.7 shows chemical composition and calorific value of fiber and shell. The low pressure steam is used in the manufacturing process for sterilization, digestion, purification and also for control temperature in production process. The electricity generated is used to supply the mill's electricity requirement which is estimated as much as about 15.3 kW per ton of fresh fruit brunch processed. Based on 1 ton FFB processed 135 kg of fibers and 30 kg of shell are burned to supplement the steam required in production.

**Table 5.7** Chemical composition on dry basis of fiber and shell.

| Element | Fiber | Shell |
|---|---|---|
| H (%) | 6.0 | 6.3 |
| C (%) | 47.2 | 52.4 |
| S (%) | 0.3 | 0.2 |
| N (%) | 1.4 | 0.6 |
| O (%) | 36.7 | 37.3 |
| Ash (%) | 8.4 | 3.2 |
| Gross calorific value (kJ/kg) | 17,422 | 19,462 |
| Net calorific value (kJ/kg) | 11,324<br>(35% moiture ) | 17,516<br>(10% moiture ) |

- ***Recycle of sterilizer condensate.***

After use for production of electrical power from the turbine operating, the steam is sent to sterilizer. Sterilization of FFB is done batchwise in an autoclave of 20-30 ton FFB capacity. The amount of sterilization condensate is about 0.12 $m^3$ /ton FFB. This wastewater can be recycled to the screw press and vibrating screen in order to reduce the amount of hot water in those processes. This is shown in Figure 5.3 and 5.13. Moreover the sterilizer condensate contains about 0.6 % oil which can be recovered as crude oil in clarification tank.

For a factory with an operation capacity at a 1,000 ton FFB, this correspond requires at an investment cost of approximately 135,000 Bath for pumping, tank etc. This option can save cost of water production of about 108,000 Bath per year. The water production cost is expected 3.0 Bath/ $m^3$ based on 300 operating days / year). The recovery of oil from recycled wastewater is about 1.4 liter/ ton FFB. Benefits from these increase oil yield are 1.26 million Bath per year. Total profit for this option is about 1.36 million Bath per year.

- ***Recycle of excess steam condensate.***

Certain amount of steam from the turbine is sent for drying kernels in kernel dryer silo and also a certain amount of steam is sent to vacuum dryer to eliminate water from crude palm oil. Last stage condensate is generally discharge as wastewater. However this condensate can be recycled in the mill. Condensate from kernel dryer is reused as feed boiler water and condensate from vacuum dryer is also reused for cleaning decanter and separator. These options will reduce the amount of water consumption and wastewater generation. An additional benefit from this approach is the energy for heating water to 90 degree Celsius (Fig 5.19). It is estimated that approximately 0.03 $m^3$ /ton FFB of hot water could be saved by recycling the excess condensate.

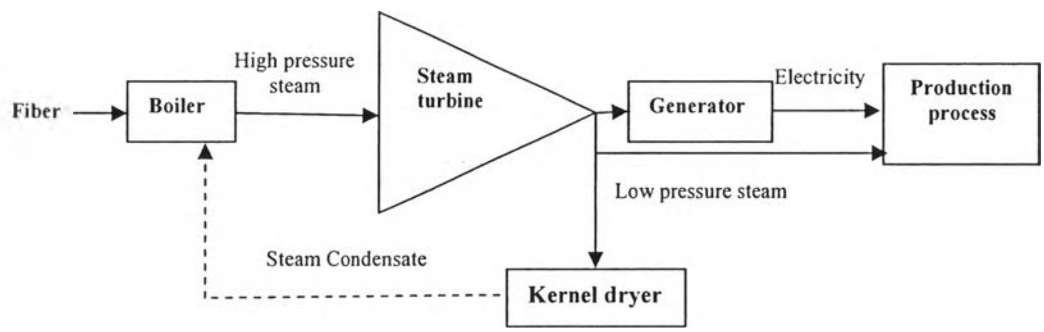



**Figure 5.19** Recycling of condensate to boiler.

### 2) Cross-industry Ecosystem

- ***Shell as fuel in cement factory***

Fiber and shell are used as boiler fuel in the factory. However, fibers are more than enough to be used as fuel for boiler. At present a part of shell can be sold to use as solid fuel in cement factory and brick factory. One ton of shell can be sold for 170 Bath. Another possible use of shells is the production of activated carbon, which should need further investigation.

**3) Cross-Border Ecosystems**

- ***EFB as a substrate for straw mushroom cultivation***

At present, EFB is returned back to the field as media for growing straw mushroom (a special type of mushroom). EFB could be used directly as a substrate for mushroom cultivation. About 30 kg mushroom can be harvested from 1 ton of EFB and sold for 45 Baht/ kg. mushroom. The factory can sell EFB for 15 Bath/ ton. After harvest the mushroom, EFB is available as substrate to the palm fertilizer. Analysis of the composition indicates that it contains high amount of plant nutrients as shown in Table 5.12. Figure 5.20 shows the flow diagram of mushroom cultivation from EFB.

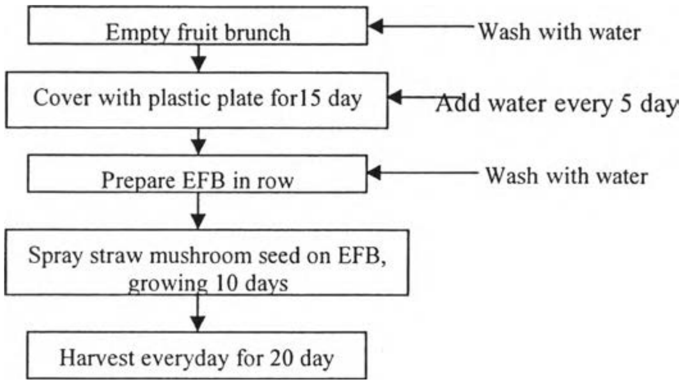



**Figure 5.20** Flowchart of straw mushroom cultivation using empty fruit brunch as media.

**5.3.3 Model of existing Industrial Ecosystem of Factory A**

Figure 5.21 presents a schematic diagram of a crude palm oil mill A. For purpose of an environmental evaluation, the estimated mass balances are based on the processing of 1000 tons of fresh fruit brunch per day, harvesting from 18,000 hectares oil palm plantation area and producing 178 ton of crude palm oil and palm kernel 55 ton for selling to oil refinery industry. The production process is results in the generation of about 585 $m^3$ of wastewater, 230 tons of empty fruit brunch, 140 tons of fiber, 55 tons of shell and 32 tons of sludge from decanter.

In conclusion, only 23.2 % of raw material is product (oil and kernel), the rest is by-product and waste. Even most of these by-products can be sold or reused in the production process such as: shell (5.5%) and EFB (23%) sell to use in other industry. Fibers (14%) are reused as fuel in boiler. However there is a lot of waste that has to treat properly before disposal. These wastes include 585 $m^3$ of wastewater, ash 5% and decanter sludge 3.2%. Since factory A is located far from plantation area, they can not recycle their wastewater for irrigation because the transportation is very expensive. Meanwhile, coconut plantation areas nearby the factory do not want the wastewater for irrigation. So they have to keep their wastewater in ponds without discharge. For decanter sludge and ash, they pay for truck to disposal these solids waste everyday because these waste cause bad smell and dust which nuisance to people surround the factory.

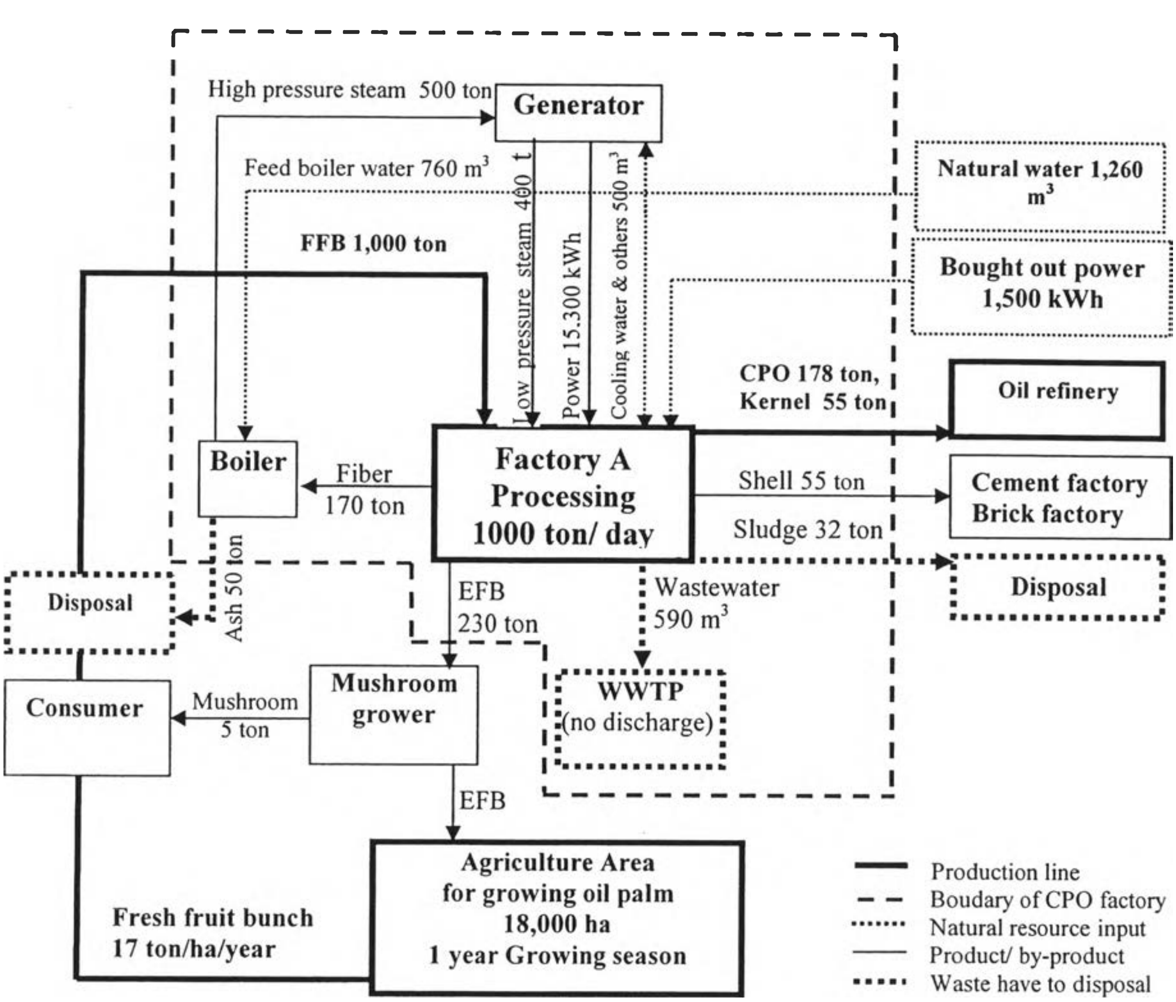



**Figure 5.21** The existing industrial ecosystem model of factory A.

## 5.4 Improving Environmental Performance of Factory A.

This paragraph deals with possible solutions for the existing environmental problems of factory A. The options proposed here will aim to improve the environmental performance of this factory and also to make the palm oil production in this factory environmentally more sustainable. Based on the results from many researches both in Thailand and Malaysia we discussed only the solutions that can be implemented.

Residue from crude palm oil processing of factory A consists of empty fruit bunches, shells, fiber, decanter cake, ashes and wastewater. Some of them are already beneficial used. Residues such as EFB and shells are already reused/ recycled as solid fuel however the other alternative options that may have potential as a more value added product will be presented. For wastes which have to be disposed such as decanter sludge and ash, the possible solutions for these wastes will be proposed based on recent research. Possibility for offsite reuse and recycling of each kind of solids non-product will be also describes.

### 5.4.1 Alternative Reuse/ Recycle of Empty Fruit Bunch

- ***Organic composting***

At present EFB are sold at the price of 170 Baht/ ton EFB or corresponding with a total amount about 283,000 Baht/ year. EFB can be used as media for mushroom cultivation in plantation area. EFB can also be used as soil cover material in the oil palm plantation in order to preserve moisture and reduce soil erosion. EFB contains a high fertilizer value. The N, $P_2O_5$ and $K_2O$ content in EFB is equal to 0.8%, 0.006% and 2.79% respectively (Unapumnuk, 1999). On the basis of nutrient content alone, these materials can be directly applied to the plantation area as fertilizer. However the conventional use of EFB for soil cover material takes almost year because it is hard to decompose. Besides the transportation is costly.

Composting is a tool to be used to produce organic fertilizer from this by-product. Composting results in 50% reduction of both the volume of bulky by-product and the transportation cost. Unapumnuk (1999) conducted the application of compost technology for complete mixtures of studied EFB, decanter sludge and urea (as N source). It is a batch process carried out in heaps which were piled up to with a size of 2m x 2m x 1m and covered with plastic. The pile requires turning and water spraying to control moisture content on level 50%-60%. The compost piles were set up at an initial C: N ratio of 39:1showed rapid degradation rate and maturated at 80 days. The maturated compost contained N, $P_2O_5$ and $K_2O$ equal to 2.26%, 3.3% and 2.25%, respectively based on the total amount of compost. The value of the nutrients in the compost, based on cost of fertilizer chemically, amount to cost of nutrient in compost product 1000 tons to chemical fertilizer was equal to 135,529 Baht (prize at whole sale market in Bangkok, 1991). Table 5.8 shows the composition of EFB, decanter sludge and compost (dry basis) which indicates that compost contains a higher plant nutrient content than EFB and Decanter sludge.

**Table 5.8** Composition of EFB, decanter sludge and composting (dry basis) (Unapumnuk,1999).

| | **EFB** | **Decanter sludge** | **Compost** |
|---|---|---|---|
| Moisture content (%) | 68.7 | 77.3 | 55 |
| C, % | 51.1 | 50.2 | - |
| N, % | 0.81 | 1.39 | 2.26 |
| $P_2O_5$, % | 0.006 | 0.96 | 3.3 |
| $K_2O$,% | 2.79 | 6.5 | 2.25 |
| Boron, ppm | 10 | - | - |

- ***Extraction of oil from EFB***

Another alternative reuse of EFB is extraction of oil from EFB. EFB has mention and explain importance an oil content of 2% and contains small amounts of oil palm fruit. Kittikhun (2002) studied the process of oil extraction from EFB by using a screw press in a crude palm oil mill with capacity of 30 ton FFB/hr. He reported equipment in which first the EFB is chopped and followed by pressing to extract oil. The pressed EFB can be used as fuel in the boiler. Gross calorific value of EFB is about 18,000 kJ/ kg which is more or less the same value as for fiber. The benefits are increase of kernel with1% and increase of oil yield with 0.5%. For factory A when processing 173,000 ton FFB/year, they can get a profit from this processing step as following:

- Profit from 1% kernel increase:

| | | |
|---|---|---|
| Kernel increase | = | 173,000 ton FFB production/year *1% |
| | = | 1,730 ton/ year |
| Price of kernel | = | 500 Baht/ton kernel |
| Profit from selling kernel | = | 1,730*500 = 865,000 Baht/ year |

- Profit from 0.5% extra oil yield increase:

| | | |
|---|---|---|
| CPO increase | = | 173,000 ton FFB production/year * 0.5% |
| | = | 865 ton/year |
| Price of CPO | = | 10,000 Baht/ ton CPO |
| Profit from selling extra CPO | = | 865* 1,000 = 8,650,000 Baht/year. |

- Total profit from selling CPO and kernel = 9,515,000 Baht/ year.

Profit from this alternative option is higher compared to directly selling EFB. However the possible pollution effects in this case are a higher BOD and SS loading in the wastewater. Since the extracted oil from EFB also contains a high suspended solids, which have to remove from crude oil in oil clarification step.

- ***Pulp and paper***

The EFBs can also be used as sources of the material for producing pulp. The Palm Oil Research Institute of Malaysia developed use of fibers from EFB to produce pulp and paper of high quality. Of three types of oil palm fibers namely EFB, frond and trunk, the fiber from EFB is shortest. Table 5.9 shows morphological properties of fibers from oil palm compared to hardwood and soft wood.

**Table 5.9** Morphological properties of fibers from oil palm, hardwood and soft wood (Kamaruddin et al., 1997).

| Property | EFB | Frond | Trunk | Hardwood | Softwood |
|---|---|---|---|---|---|
| Average fiber length, mm | 0.67 | 1.03 | 1.37 | 0.83 | 2.39 |
| Width of fiber, mm | 0.012 | 0.015 | 0.02 | 0.015 | 0.27 |

Processing of EFB into pulp and paper can be achieved by two methods

- Kraft Pulp Method. Digestion of biomass with white liquor at 165°C for 3 hour.
- Kraft Anthraquinone (Soda AQ) method. Conventional pulping with Anthraquinone as additive to improve strength of fiber.

The paper made from empty fruit bunch has properties of good tear strength and excellent opacity. The brightness is good (40%) compared to hardwood pulp (25%-30%). Sheet properties of Bleach Kraft Pulp are illustrated in the table 5.10

**Table 5.10** Properties of Bleach Kraft Pulp (Kamaruddin et al., 1997).

| Raw material | Opacity (% | Density ($g/m^3$) | Tear ($mNm^2/g$) | Burst Kpa $m^2/g$ | Air Permeability (sec) |
|---|---|---|---|---|---|
| EFB | 80.6 | 0.63 | 11.7 | 4.5 | 10 |
| Hardwood | 74.1 | 0.63 | 9.5 | 4.5 | 15 |
| Softwood | 62,7 | 0.64 | 13.1 | 7.6 | 22 |

- ***Medium density fiber broad***

Another alternative use is medium density fiberboard (MDF) produced from EFB. The manufacture of MDF using EFB was studied in 1986. Husin et. al. (2003) stated that EFB can be used for manufacture of MDF. The strength properties measured from its compression strength exceed the 200 kg $cm^{-2}$ stipulated in JIS A 1408 for fiberboard. Ramli (2002) concluded that pretreatment of the fiber by using water or NaOH to remove its residual oil significantly improved the MDF performance and eliminated delaminating during consolidation of the panels (Table 5.11). The result also showed that NaOH was more effective than water for removing oil. But a poorer fiber was obtained with a higher bulk density which also reduced the mechanical and physical properties. The dimensional stability of rest of the part was meeting the commercial standard.

**Table 5.11** Comparison of mechanical and physical properties of EFB, MDF after pre-treatment with water and NaOH with the National Particle Board Association (NPA) Standard ( Ramli, 2002)

| Pretreatment | Machanical property | | | | Physical property | | | | | Density Darg $Kg/m^3$ |
|---|---|---|---|---|---|---|---|---|---|---|
| | Resin % | MOR MPa | MOE GPa | VIB KPa | WA2 % | WA24 % | TS2 % | TS24 % | LE 50/90 | |
| Hot water | 4 | 34.3 | 2.4 | 785 | 52 | 61 | 25 | 27 | 0.58 | 1041 |
| | 6 | 7.9 | 3.0 | 827 | 44 | 51 | 15 | 17 | 0.31 | 1057 |
| 2% NaOH | 4 | 19.3 | 1.7 | 655 | 78 | 82 | 41 | 44 | 0.60 | 1089 |
| | 6 | 27 | 2.2 | 689 | 64 | 74 | 33 | 36 | 0.56 | 1025 |
| MDF property of NPA Standard | | 24.1[a] | 2.1[a] | 689[a] | - | 14.6 | - | 11.9[b] | 0.35[a] | - |

- ***Production of Chemicals***

Moreover EFBs can also be used as sources of raw material for producing chemicals or half-products. Aziz (2002) reports about research to the preparation of cellulose from EFBs via ethanol digestion, an alcohol pulping process. The highest yield was 57% of pulp, containing hemi cellulose, lignin and cellulose

### 5.4.2 Value-add of Product from Shell

In the crude palm oil extraction process, shells are the by-product. About 65 kg of shells are generated from 1 ton of FFB processing. Only 20% of shell is burnt together with fiber, the rest is sold as fuel in cement and charcoal production. The price of shell is approximate 170 Baht/ ton. Conversions of the shell to a product with a higher added value such as activated carbon will directly turning the by-product to a resource for another industry. Commercial processes to produce activated carbon use a variety of raw material including peat, coal, wood and coconut shell. Any cheap substance with a high carbon content and low ash content can be used as raw material for the production of activated carbon. Suravatt and Sakol (1998) reported that shell have properties similar to coconut shell but the BET surface area showed that shells have higher specific surface than coconut shells, so shell are likely to be a precursor for the production of activated carbon. The study of activated carbon production from shell using different activation procedures in Thailand is shown in table 5.12. The yield of activated carbon prepared by zinc chloride activation shows 14% higher yield than those activated by steam. However the chemical cost of the zinc chloride activation method is very high compared to steam activation method or commercial coconut or palm shell activated carbon. For commercial palm shell activated carbon made in Nigeria, (trade name MIDAC) the price range between 1,000 and 1,526 USD/ton. In general the application is for color adsorption, particulate coagulation and dechlorination in distillers, bottling companies, plant and animal refineries, chemical industries and used in water purification equipment and water filter cartridges.

**Table 5.12** Properties of activated carbon from palm kernel shell compared to coconut shell.

| Description | Minsirinun (1999) | Terachai (1998) | Patra (1997) | Commercial Coconut shell |
|---|---|---|---|---|
| Carbonization | 400°C for 1 hr | 750°C for 3 hr | 400°C for 1 hr | No information |
| Activation | 800°C for 3 hr with zinc chloride | steam | steam | No information |
| Yield (%) | 33.83 | 12.18 | 19.31 | 18.8 |
| Iodine number(mg/g) | 1069 | 767 | 779 | 976 |
| Methylene blue number(mg/g) | 600 | 189 | 137 | 500 |
| B.E.T.($m^2/g$) | 1099 | 670 | 697 | 900 |

The preparation of raw materials involves sorting out of dirt and crushing of material to a suitable size. The crushed material is dried to remove moisture. The first step in the production of activated carbon is the carbonization or pyrolysis of the shell to the char. Then the char is further crushed to a smaller size followed by activation. The activation system consists of a boiler unit to generate steam and a furnace containing the activating chamber. The carbonized product is ground into powder according to the required mesh size. Figure 5.22 shows the production process of activated carbon prepared by zinc chloride activation.

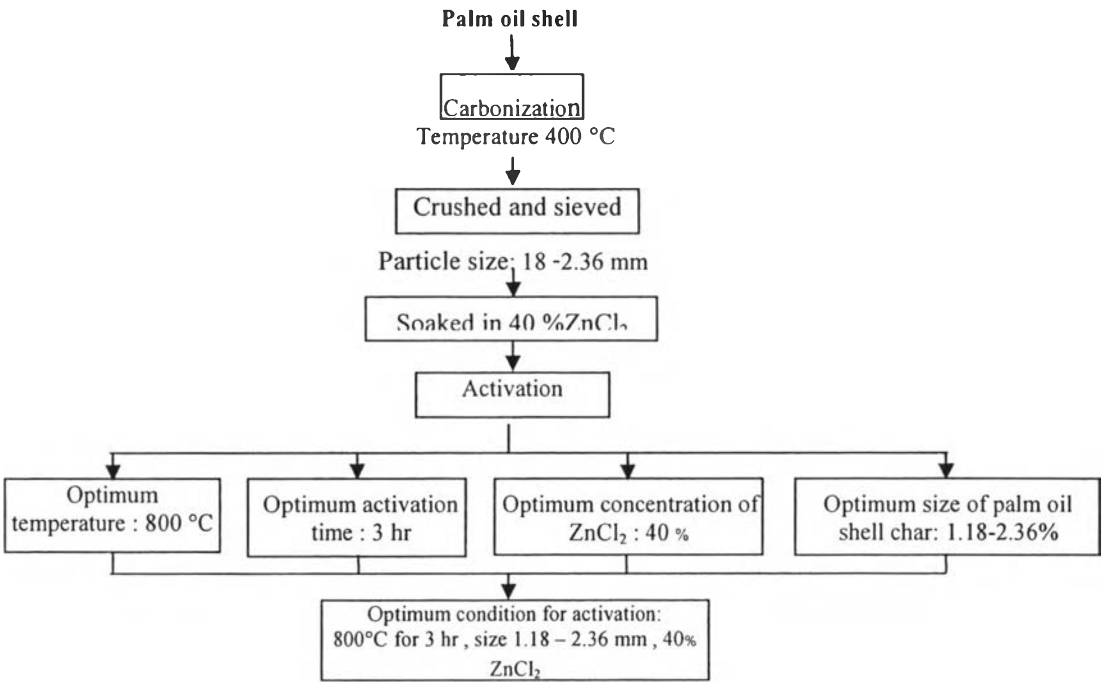



**Figure 5.22** Flowchart of activated carbon preparation by zinc chloride activation (Minsirinun, 1999).

Factory A generates 5.5% of shell from 1 ton of FFB processing. In the year 2003, they processed 173,000 ton of FFB, so the total amount of shell generated is about 11,245 ton. The preparation of activated carbon by activation with steam gives a yield of 19% of shell. The factory has excess steam from boiler of an activated carbon plant capacity of 10 ton activated carbon per day. The product can be sold activated carbon for about 40,000 Baht /ton. So they can gain 85 million Baht/ year. Based on the above figures, Factory A has a great potential in turning its abundant supply of these by-product into products with a high added value.

Besides combustion of the shells, also pyrolysis is possible. From the research of Kawser (2000) it follows that pyrolysis yields liquid oil, solid char and gas. The liquid was found to contain a very high concentration (43.3%) of phenol and its derivatives (cresol, catechol, guaiacols, syringol and syringol). These components are considered to be chemicals with a high added value, if they can be produced in a sufficiently high quality. However costs of these processes are also very high.

### 5.4.3 Reuse of Decanter Sludge

The mill employ decanter machine for recovery oil from wastewater. The generated decanter cake can be utilized as fertilizer like EFB. However decanter sludge has high potential to use as animal feed. The chemical composition of sludge is shown in Table 5.13.

**Table 5.13** Chemical composition of decanter sludge.

| | **Fresh decanter sludge** | **Palm oil sludge (Hutagaluncy, 1977)** |
|---|---|---|
| Moisture content, % | 70-80 | 93.1 |
| Crude protein, % | 12.5 | 12.4 |
| Ash, % | - | 11.2 |
| Phosphorus, % | 0.8 | 0.18 |
| Magnesium, % | 0.4 | 0.25 |
| Potassium, % | 0.2 | - |
| Zinc,mg/L | - | 1,075 |
| Iron, mg/L | - | 1,757 |
| Gross energy, MJ/kg | - | 19.6 |

Decanter sludge contains about 75% moisture content. It composes of high protein content which can be used as animal feed. However if keep for longer than 24 hour, it is fermented and produces a bad smell. In order to sell this by-product to feed mill, the factory has to dry it. The mill could use low pressure steam from boiler to dry the decanter sludge. An indirect, horizontal dryer could be used to dry the decanter solids to low moisture content (90% total solids) (Fig. 5.23). Low pressure steam from the boiler with a temperature of 210°C could be used as a heating media to dry the decanter sludge to moisture content of below 10%. The temperature in the dryer exhaust gases is about 100°C. Dry decanter product can be made into commercial grade pellet animal feed.

For factory A with production of 173,000 ton/ year can be characterize as following :

- Amount of decanter sludge 32 kg/ton FFB. The moisture content of the decanter sludge is 75%.
- Dry decanter cake production is 0.032* ( 100-(75-10))/100 * 173,000 = 1,938 ton/ year.
- Dry decanter cake can be sold for 500 Baht/ ton.
- Value of decanter cake = 1,938 * 500 = 969,000 Baht.

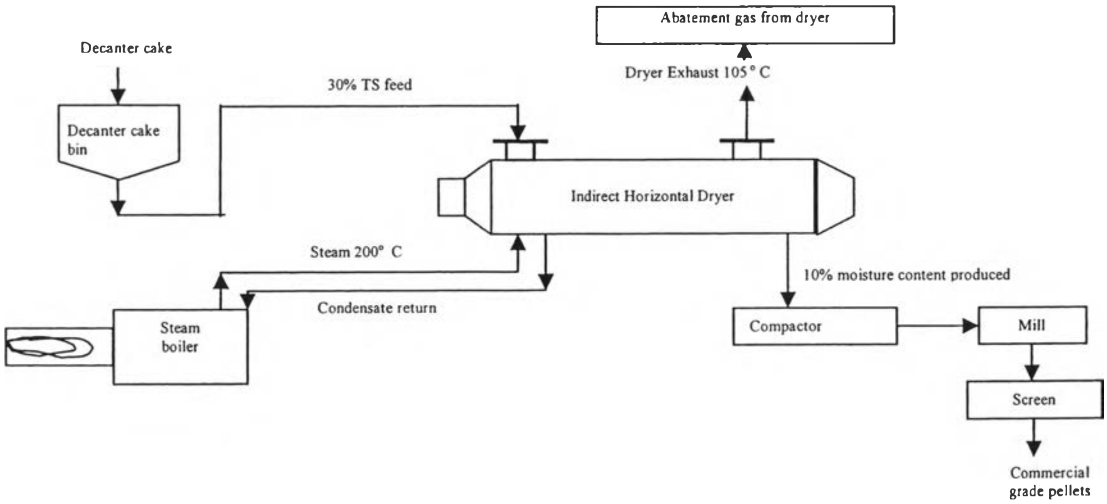



**Figure 5. 23** Indirect, horizontal dryer used in decanter cake drying.

Perhaps, one idea would be to promote the use of the fresh decanter sludge (15-20% dry matter) for finishing pigs which, compared to younger animals, have a greater capacity to effectively use larger amounts of more liquid feeds. This approach might require supplementation to increase the crude protein content to that of cereal, as well as some molasses to improve palatability. It would have to feed immediately, preferable near the mill in order to avoid transportation of a product. Several authors ( Devendra et al, 1981; Hertrampf,1988 and Abu et al.,1984) reported the use of these sludge in place of maize at a level of from 15-30% in order to reduce feed costs.

Hutagolung et al (1977) investigated the use of sludge as feed for growing pig. Two type of different mixing meal used in this study such as: type I, 35% palm oil sludge, 32.5% cassava root meal and palm kernel cake and type II, 32% palm oil sludge, 17% palm kernel cake, 17% grass meal and 34% cassava root meal. He conclude that it is economical to replace 50% maize (the regular diet constituent) with mixing meal, which gave a saving of RM 0.02 per pig per day and a higher extra dollar benefit of RM 0.08and 0.01 per kg gain, respectively.

The later option could be applied in factory A too. The sludge could be recycling as animal feed for small farm households in the Surat Thani Province because there are many small milk cow farms in the southern region of Thailand. For this meal, decanter cake will be mixed with palm kernel cake ( extracted kernel) at a ratio of 1:1 before selling it to the farmer.

### 5.4.4 Reuse of Fly- Ash

The boiler of crude palm oil factory uses fiber and shell (ratio 4:1) as the energy source. The fly ash of this biomass fuel is a mixture of $SiO_2$, $CaO$, $K_2O$, $P_2O_5$, $MgO$ and $Al_2O_3$ ( 59.16, 8.0, 7.6, 4.74, 4.13 and 1.9, respectively). This fly ash can be used to directly to replace Portland cement up to 10% by weigh. This is a high value-added application; provided its carbon content is less than 8.5% and its physical and chemical properties are reasonably stable.

### 5.4.5 Alternative Use as Fertilizer or Sustainable Treatment of Wastewater

Results of wastewater analysis from factory A indicate high quantities of oil and organic substances as the main contaminants. BOD, COD, SS, TKN and O&G are about 52.2, 68.3, 30.9, 1.0 and 7.3 g/L, respectively. The organic components in the wastewater are biodegradable and could be reused as fertilizer or recovery of biogas for electricity regeneration.

#### 5.4.5.1 Fertilizer

POME contains about 94.2% water and 5.8% total solids. By evaporation technology of POME the water can be recovered and the residual solid concentration utilized. Ma (1999) presented a commercial scale evaporation plant using a multi-stage evaporation system. Efficient evaporation of the water is achieved by taking advantage of the available heat in fresh POME at its average temperature of 80°C and applying a vacuum of 600 mg Hg to lower its boiling point to about 60°C. A high solids concentration in the effluent is achieved due to introduction of a forced- circulation system to pump the concentrate liquid. The concentrated sludge is an appropriate raw material for making fertilizer while the presence of small quantities of oil does not affect product quality. Table 5.14 shows the amount of nutrient composition in concentrated sludge. And Table 5.15 illustrated the quality of distillate from evaporation. The concentrate also contains about 13.5% of essential amino acids. Thus, it can potentially be used for making other products like animal feed, or as a feedstock for fermentation products. The distillate is contained low solids content as 150 mg/l and can be reuse in production process. However there have been numerous attempts to convert palm oil mill effluent into viable animal feed resources; however, most methods have been discontinued due to the large initial capital investment required, and particularly to the cost of fuel for dehydration

**Table 5.14** Nutrient analysis of POME concentrate from evaporation ( Ma,1999).

| Parameter | Concentrated POME |
|---|---|
| Moisture content (%) | 80.0 |
| N, % | 2.07 |
| $P_2O_5$, % | 0.96 |
| $K_2O$,% | 6.5 |
| Calcium (CaO), % | 0.023 |
| Magnesium (MgO), % | 0.396 |
| Manganese (MnO), % | 0.003 |
| Iron, % | 0.007 |
| Sodium, % | 0.04 |

**Table 5.15** Quality of distillate from evaporation ( Ma, 1999).

| Parameter | Concentration |
|---|---|
| Appearance | Clear to slightly turbid |
| pH | 5-6 |
| COD, mg/L | 100-600 |
| BOD, mg/L | 20-150 |
| Total solids, mg/L | 150 |
| Oil & grease, mg/L | 10 |
| Total nitrogen, mg/L | 20 |

### 5.4.5.2 Wastewater Treatment

#### 1) Biogas Recovery and Anaerobic Treatment

The major source of wastewater generation in factory A is clarification process. The general characteristics of wastewater are highly organic. The water contains a high oil content, acidic high solids and high temperature. It is made up of 94.2 % water, 0.7 % oil and 5.8 % total solids including 3.1% suspended solids, which are mainly debris from fiber (cellulose). Since wastewater contains biodegradable organic content, the treatment system consists of anaerobic/ oxidation ponds. At present, wastewater from the production process is treated by ponding system including anaerobic ponds and facultative ponds as described in section 5.2.3. A disadvantage of this system is the effluent does not meet effluent standard.

From review literature, show that it is feasible to recover biogas from POME by using anaerobic digester tank. For 60 ton FFB/hr palm oil mill operations for 20 hr/day, approximately 20,000 m3 of biogas can be obtained per day. The gas has a calorific value of 53,000 kcal/ $m^3$). The gas contains about 65% methane 35% $CO_2$ and less than 20,000 mg/L of $H_2S$ (Ma, 1999). From the result of biogas production from POME in Thailand both pilot plant scale and full scale plant ( Kochapansunthorn, 1998 and Lavanprasert, 2003) show that the using of completely mixed anaerobic digestion tank capacity of 2,300 $m^3$ for treating wastewater from palm oil mill at the flow rate of 300 $m^3$ / day can generate 6,000 $m^3$ / day of biogas ( 60% methane). The biogas can reuse as fuel in boiler for generate steam and electricity using in production process or reuse for electricity generation directly. The use of methane for power generation could be considered, but most palm oil mill self-sufficient in power. So the mill could sell electricity to electricity generation authority of Thailand. Another advantage of anaerobic digestion tank is 95.5% BOD reduction. The construction cost of the closed anaerobic tank system including gas engines for electricity production on the produced biogas is 18.4 million Baht (~ 10,000 Baht/ $m^3$ of wastewater per day). The simple pay back time for this system, when calculating saved electricity as an income, will be about 4.3 years

Another alternative to reduce costs as well as operation cost for treatment of wastewater and production of gas system is the cover lagoon system. The investment costs ~ 5,000 Baht/ $m^3$ of wastewater per day. For factory A with daily capacity at 300 $m^3$/ day will cost around 15 million Baht. The simple pay back period, when calculating saved electricity as an income, will be about 2.5 years. The efficiency as BOD reduction will be 60 %. The BOD reduction will generate 0.8 $m^3$ of biogas each kg of BOD removal. Table 5.16 shows efficiency of POME treatment using completely mixed anaerobic digestion tank and Cover lagoon system.

**Table 5.16** Comparison of Completely mixed anaerobic digestion tank and Cover lagoon system.

| | **Completely mixed anaerobic digestion tank** [1] | **Cover lagoon system** [2] |
|---|---|---|
| Investment cost, million Baht | 18.4 | 15 |
| Construction cost, Baht/ $m^3$of wastewater per day | 10,000 | 5,000 |
| Pay back period, years | 4.3 | 2.5 |
| BOD removal efficiency | 95.5 | 60 |
| Biogas production, $m^3$/day | 6,000 | 4,000 |
| Wastewater after treatment: | | |
| • BOD, mg/L | 2,300 | 20,000 |
| • COD, mg/L | 3,000 | 26,000 |

Note: 1) Kochapansunthorn, 1998 and Lavanprasert, 2003
2) Ministry of Science tehnology and Energy, 2004

Result from the measurement of factory A showed that about 71 % of methane and 29 % $CO_2$ are generated in the first anaerobic pond. It is estimated that biogas generation = 0.3 $m^3$ / kg BOD of POME digested or 13 $m^3$ / $m^3$ of POME ( 9.3 $m^3$ methane / $m^3$ ). This figure is more or less the same quantity of biogas generation of the above literature. This wastewater treatment situation of factory A can be significantly improved by introducing completely mixed anaerobic digestion tank which reduce the COD and BOD of the effluent and produce capture methane. The methane could use for fuel in boiler or for power generation and sell electricity to electricity generation authority of Thailand.

**2) Complete Treatment System**

- **Wastewater characteristic**

The quantity of wastewater generated from Factory A is 0.6 $m^3$/ ton FFB. This means that about 101,000 $m^3$ of wastewater need to be handled every year. Fresh POME is acidic and contains a high concentration of organic and suspended matter, and is discharged to a treatment pond at a temperature of 80-90°C. BOD, COD and oil & grease concentration of such wastewater are 52.2, 68.3 and 7.2 g/ l, respectively. The BOD: N: P ratio is equal to 100: 1.9: 0.07. The nutrient content in wastewater is too low for a completely aerobic biological treatment system. However POME can be effectively treated by reactor or pond anaerobic treatment followed by an aerobic post treatment (oxidation pond or facultative pond or another aerobic treatment system such as activated sludge) system. The characteristics of wastewater from factory A is given in table 5.17. This composition characteristic more or less the same properties as other crude palm oil mills in Thailand. Comparing to Malaysia, the oil content and suspended solids in wastewater from Thai crude palm oil mill is higher than in Malaysian wastewater.

**Table 5.17** Characteristic of raw wastewater from crude palm oil mills in Thailand and Malaysia.

| parameter | Factory A | Thailand(1) | Malaysia(2) | Emission standard in Thailand |
|---|---|---|---|---|
| Temperature, °C | 80-90 | 80-90 | 80-90 | 45 |
| pH | 4.83 | 4.81 | 4.7 | 5-9 |
| BOD, mg/L | 52,200 | 46,500 | 25,000(3) | 20 |
| COD, mg/L | 68,300 | 51.000 | 50,000 | 200 |
| SS, mg/L | 30,900 | 34,600 | 18,000 | 50 |
| Oil& grease, mg/L | 7,250 | 6,200 | 4,000 | 5 |
| TKN, mg/L | 1,020 | 1,100 | 750 | 200 |
| TP, mg/L | 40 | 47 | - | - |
| Amount of wastewater, $m^3$/ tonFFB | 0.6 | 0.64 | 0.5 | - |

Note: (1) Average value of the five studied factory in Thailand, 2003
(2) Yeoh, 2004
(3) $BOD_3$, 3 day at 30°C

Factory A employs a lagoon system in wastewater treatment system. Anaerobic first stage followed by facultative treatment. As discussed already wastewater in the final pond still contains high amounts of COD and BOD (960 and 34 mg/L) and does not meet Thai effluent standards. Such wastewater is kept into the pond without discharge. This system is used by about 90 % of Thai palm oil mills. The reason that Thai palm oil mills have adopted the lagoon systems for treating their POME because of their low capital and operating costs. In fact looking to the composition of the wastewater BOD/COD ratio and the temperature it can be expected that anaerobic treatment is a very serious option. It is observed that not all crude palm oil factories can treat their wastewater up to the level that meets the effluent standard at all time. However, a serious drawback of the lagoon system is the emission of the greenhouse gas methane. Only two mills in Thailand use and operate of an anaerobic treatment by mean of completely stirred tank reactors equipped with a biogas recovery system. The required effluent COD and BOD limits are achievable if the treatment systems are well designed and operated.

- **Crude Palm Oil Wastewater Treatment System**

Many researches (Yeoh, 2004; Faisal and Unno, 2001; Borja et al., 1996) indicated that an anaerobic biological system offer a lot of benefits potential for the treatment of POME. It has been recognized that a first-stage treatment of the wastewater using anaerobic technology in which the methane is recovered for reuse is the best option because of the high organic concentration in POME and do not have the high energy demand of aeration as aerobic biological system. Chin et al. (1996) stated that experience in South-East Asia has shown that POME can be effectively treated by facultative and anaerobic biological treatment process. He evaluated the treatment efficiency of a pond system consisting of 8 ponds in series treating 600 $m^3$/ day of POME at an overall HRT of more than 60 days in a Malaysia crude palm oil mill and reported that the effluent was not able to meet the discharge standard of 50 mg/L. However, he recommended that the final effluent contained COD: N: P ratio at 159:18:1 that sufficient nutrient for further treatment by the aerobic treatment system to meet with the effluent standard. Comparable treatment study of POME from a mill of similar capacity using an anaerobic-aerobic treatment system showed that the treated effluent met with the discharge standard of 50 mg/L. The use of conventional anaerobic lagoons to treat POME is characterized by long residence times, often in excess of 20 day, necessitating large areas of land or large digesters (Borja et al., 1996). Moreover, the lagoon is quite difficult to control and monitor due to the size and configuration of the lagoon. The greatest environmental problem is the emission of methane to the atmosphere. Another problem of lagoon system is the accumulated sludge at these ponds and then reduces the pond treatment capacity and consequently shortens the HRT. So bottom sludge have be removed to improve the treatment efficiency (Chin et al., 1996). However desludge from lagoons is a difficult task. In practise, they remove the bottom sludge and dump near the pond. Mills have to face the pollution problem with large amount of sludge and bad smell generated during drying these sledges. However, the most common and efficient treatment systems adopted by the crude palm oil mills both in Thailand and Malaysia are lagoon system. In Malaysia, only a few mills have reported the use and operation of closed-tank anaerobic bioreactors equipped with biogas recovery system.

The application of modern high rate anaerobic digester technologies for POME treatment have been investigated in lab scale tests, As modern high rate anaerobic digesters have been investigated as continuously stirred tank reactor (Kochapansunthorn, 1998); anaerobic baffled reactor (Faisal and Unno, 2001); thermophilic upflow anaerobic filter (Mustapha, 2003); high rate anaerobic fixed film (RDCUKM, 2004); thermophilic digestion ( Yeoh, 2004). Table 5.18 shows research on various type of wastewater treatment of palm oil wastewater Not all these systems are applied in crude palm oil mill yet. Kochapansunthorn (1998) reported bench-scale experiments with full mixed continuously stirred tank reactor (CSTR) digesters. It was found that the system removed 90%COD at a hydraulic retention time of 20 day. The full scale CSTR system is now adopted by a Thai crude palm oil mill BOSCH (2004). Yeoh (2004) studied the effect of temperature on the anaerobic digestion process by comparison of systems operated at digestion temperatures of 45 $^oC$, 50$^oC$ and 55 $^oC$. He revealed that methane production was significantly enhanced a thermophilic condition compared with mesophilic condition of POME. It was also found that methane yield from the thermophilic digestion increase with increasing the temperature of the system. The temperature at 55°C, the COD removal efficiency was 96% which was higher efficiency than the mesohpilic digestion. Table 5.19 shows the process parameters used for the comparative economic analysis.

**Table 5.18** Lab scale of various wastewater treatment processes for treating POME.

| Parameters | Pond system (Chin, 1996) | Complely stirred tank reactor (Kochapansunthorn,1998) | Termophilic digestion (Yeoh, 2004) | High rate anaerobic fixed film (RDCUKM,2004) | Anaerobic baffled reactor (Faisal and Unno, 2001) | Termophilic upflow anaerobic filter (Mustapha, 2003) | Constructed wetland (Nusuk, 2004) |
|---|---|---|---|---|---|---|---|
| Operating temp, °C | 35-40 | 42-52 | 55 | - | - | 55 | - |
| Organic Loading Rate, kgBOD/m$^3$.d | 0.2-0.35 | 0.8-1.0 | 1.88-3.52 | - | 1.6-5.33 | 2.6-4.9 | - |
| Influence COD, mg/L | - | - | - | - | 1,600 | 55,000 | - |
| Minimum retention time, day | 30 | 20 | 7 | - | 3 | - | - |
| HRT, day | 30-135 | 20-30 | 7-13 | 3-4 | 3-10 | 5-10 | 15 |
| Treatment Efficiency, % | >90 | >90 | >96 | >90 | 87-95 | 94% | 74% |
| Effluent COD,mg/L | <150 | 1,250 | 2,320- 4,910 | - | 754-3,630 | - | - |
| Biogas production rate, m$^3$ / m$^3$.d | - | 0.4-0.6 | 2.64-4.96 | 0.4-0.5 | 0.82 l/g COD | 0.6 | - |

**Table 5.19** Process parameters for CSTR and thermophilic anaerobic digestion system of palm oil mill.

| Parameter | CSTR[1] | Thermophilic anaerobic digestion[2] | | |
|---|---|---|---|---|
| | | Temp.45 °C | Temp.50 °C | Temp.55 °C |
| **Operating parameter** | | | | |
| Digestion temperature, °C | 42-52 | 45 | 50 | 55 |
| Minimum retention time, day | 8 | 10.9 | 9.2 | 7.0 |
| Minimum effective reactor volume, m$^3$ | 4,000 | 4,950 | 4,150 | 3,200 |
| HRT, day | 13-8 | 20.6-11.0 | 17.3-9.2 | 13.3-7.1 |
| BOD loading rate, kg/day | 0.8-1.0 | 1.21-2.27 | 1.45-2.71 | 1.88-3.52 |
| Biogas production rate, m$^3$ / m$^3$ POME/ day | 1.5-2.0 | 1.11-2.09 | 1.44-2.68 | 2.65-4.96 |
| Effluent BOD, mg/L | 1,250 | 1,230-4,890 | 2,500-5,000 | 2,320-4,910 |
| **Cost-benefit analysis** | | | | |
| Capital cost, million Euro | 0.38 | 0.97 | 0.98 | 1.2 |
| Payback period, year | 3 | 9.6 | 8.6 | 6.7 |
| Electricity generation, million Euro | 0.13 | 0.22 | 0.24 | 0.34 |

Note: Mill capacity of 45 ton FFB/hour, wastewater load at 240-450 m$^3$ / day

(1) Kochapansunthorn,1998; Capital cost including reactor, biogas and generator

(2) Yeoh, 2004; Capital cost including reactor, biogas, generator and land application

BOSCH (2004) reported that CSTR system is suitable for treating POME. The treatment plant capacity of 4,000 m$^3$ treating wastewater at the flow rate of 300 m$^3$ / day (6,000kg BOD loading/day) can generate 4,500- 6,000 m$^3$ boigas/ day. These biogas can be used for generate electricity 2.4-3.5 million unit/ year by using gas-engine generators 300-400 kW. The investment costs are 19 million baht and pay back period is approximately 3 year.

In Malaysia, The anaerobic digesters are operated as a conventional high rate system with organic loading of 4.8 kg VS/ $m^3$ / day. The HRT is about 10 days operating at temperature range of 42-50°C. The biogas produced is harnessed for heat and electricity generation. The digester liquor is applied to the plantation nearby as fertilizer. Quah and Gilles (1981) reported field data on the operation of two 3,700 $m^3$ CSTR digesters and indicated that the digestion temperature was maintained at 44-52 °C by the inherent heat of the influent alone. The temperature variation was 2-4 °C and no operation difficulty had been experienced with these temperature fluctuations.

- **Purposed Wastewater Treatment Plant for Factory A**

Based on literature research several sustainable options for treatment of wastewater can be set up. At present, wastewater from the production process is treated and stored in ponds as described above. The new more sustainable wastewater treatment system is schematically showed and described. The plant will treat POME and recovers methane for power generation and makes effluent able to discharge to the river near by the factory. In this case, it is possible to apply a closed ideally mixed anaerobic tank system (CSTR) followed by anaerobic pond and aerobic treatment system (aerated lagoon) and post wetland treatment system. The design parameters of each unit in the system are summarized in Table 5.20 and flowchart of wastewater treatment technology is presented in Figure 5.24.

**Table 5.20** Designs parameter of the purposed WWTP for crude palm oil factory.

| Parameters | Unit | Oil Skim Tank | Anaerobic Digestion Tank | Anaerobic Pond | Aerated Lagoon | Maturatio n Pond | Wetland |
|---|---|---|---|---|---|---|---|
| HRT | day | 5-12 | 10-20 | 20-50 | 4-10 | 5-20 | 15-20 |
| Organic Loading Rate | kgCOD/ $m^3$.-d | - | 5-10 | 0.1-0.5 | - | <0.014 | - |
| Arial Loding Rate | kgCOD/ $m^3$.-d | - | - | 0.02-0.05 | - | - | - |
| Solids Loading Rate | kgSS/ $m^3$.-d | - | 1-5 | - | - | - | - |
| Volume | $m^3$ | 200 | 5000 | 15000 | 2000 | 2500 | 7500 |
| Surface Area | $m^2$ | 140 | 380 | 4000 | 400 | 1800 | 10,000 |
| Treatment efficiency | %(by COD) | - | 90 | 90 | 50 | 50 | 60 |
| Effluent COD | mg/l | - | 7000 | 700 | 350 | 180 | 80 |

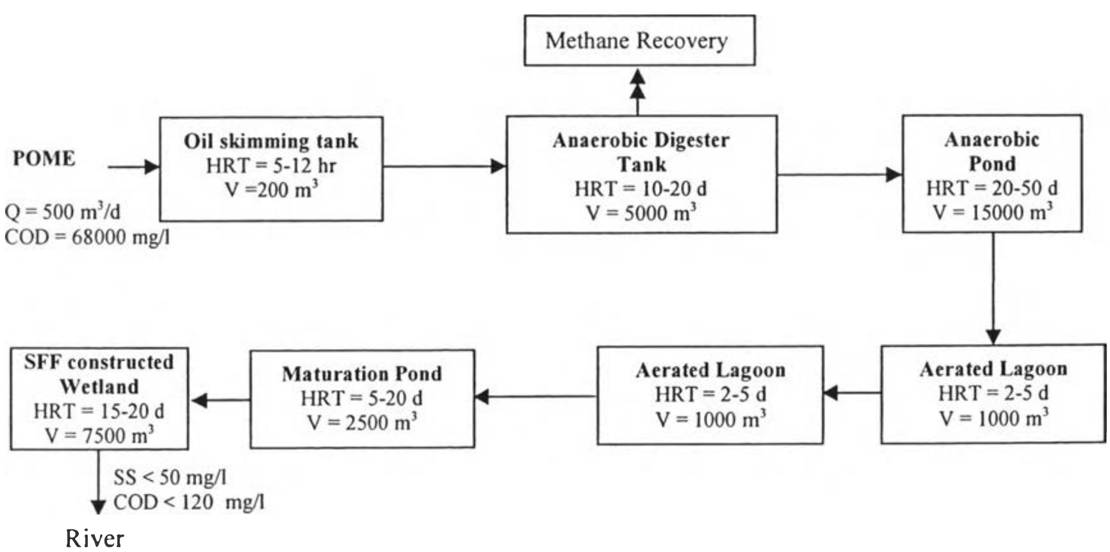



**Figure 5.24** Proposed WWTP for crude palm oil mill wastewater located far from plantation area.

Result from wastewater characteristic of crude palm oil production in Thailand which contain high organic and high suspended solids concentration as shown in table 2.22, I proposes a wastewater treatment plant as shown in table 5.22 and Figure 5.24. The criteria and objective of each unit process is :

- ***Oil skimming tank*** Since POME contains high oil content (~ 1%), the objective of the oil skimming tank is to reduce oil contaminated in wastewater. Oil removal in wastewater results in reducing BOD/COD in wastewater prior feeding to biological treatment. For anaerobic digestion tank, oil removal from wastewater can efficiently increase mass transfer between microorganism and dissolved organic contaminating in wastewater because oil film can cover the mass of microorganism and effect on mass transfer reduction.

- ***Anaerobic digester tank*** Since POME contains very high solids content (31 g/l), anaerobic digestion tank system (completely stirred tank reactor, CSTR) is recommended in this study. Since the temperature of the digester is in the range of 42-52°C that is closed to thermophilic digestion, the organic removal efficiency is high. The objective of this unit process is to remove BOD, COD, SS by using anaerobic bacteria. The COD removal efficiency is higher than 90% (see Table 5.22). However the wastewater after treatment still contains high organic content which have to be further treated by other biological treatment system. The by-product from anaerobic digester tank is biogas which can be reuse as fuel in boiler or electricity generation as previous mentioned in section 5.4.5. The advantage of anaerobic are:
    - Receive highly organic pollutant loading wastewater
    - Generates low sludge in digestion tank
    - Requires low COD : N: P ratio for anaerobic bacteria
    - Generates biogas as byproduct
    - No oxygen required

Biogas production rate from CSTR is 0.4-0.6 $m^3$ / $m^3$-d. Biogas produced from POME contains 60-70% of methane. This biogas can be reused as fuel.

- ***Anaerobic pond*** Since large portion of biodegradable organic content in wastewater is removed in anaerobic digestion tank, effluent from this unit process contains hard biodegradable organic content (low BOD/COD ratio). The objective of anaerobic pond is to remove suspended solids and BOD/COD form wastewater. The anaerobic digestion tank is used for pretreatment of organic contaminated in wastewater and recovery biogas. The other benefits of anaerobic digestion tank are to reduce organic loading in wastewater before feeding to anaerobic pond and at the same time to reduce GHGs emission to the atmosphere. The result is reduction in volume of anaerobic pond. Moreover increase the HRT of anaerobic pond will increase in organic and suspended solids removal efficiency.

- ***Aerated lagoon*** The objective of aerated lagoon is to remove residual organic contents and color in wastewater. Since anaerobic treatment system cannot treat wastewater to meet the Thailand effluent standards, aerated lagoon is used for removal BOD, COD and color in wastewater which cannot treated by anaerobic bacteria. Then final effluent from this proposed wastewater treatment systems can meet the effluent standard.

- ***Maturation pond*** Since effluent from aerated lagoon contains high sludge content, maturation ponds is used to remove suspended solids in wastewater by gravity sedimentation. Long retention time results in a further biodegradation by microorganism and results in reduction of organic and SS contents in wastewater.

- ***Constructed wetland*** The objective of constructed wetland is to remove suspended solids, COD and color. Effluent from maturation pond still contains high SS (algae and microorganism), color and nutrient (N). Subsurface-flow constructed wetland can be removed SS, nitrogen and color efficiently. Effluent characteristic meet the effluent standard and can be discharge to near by cannel.

### 5.4.6 Physical – Technological Model of an almost Zero Waste Industrial Ecosystem

A physical – technological model of an almost zero waste industrial ecosystem at factory A is created by integrating all options as discussed in this chapter. This model representation of crude palm oil factory that located in community and far from oil palm plantation area, so they can not reuse their solids waste (ash, decanter cake) and and wastewater in oil palm plantation area. The material flow network of the model is simulated in Figure 5.25.

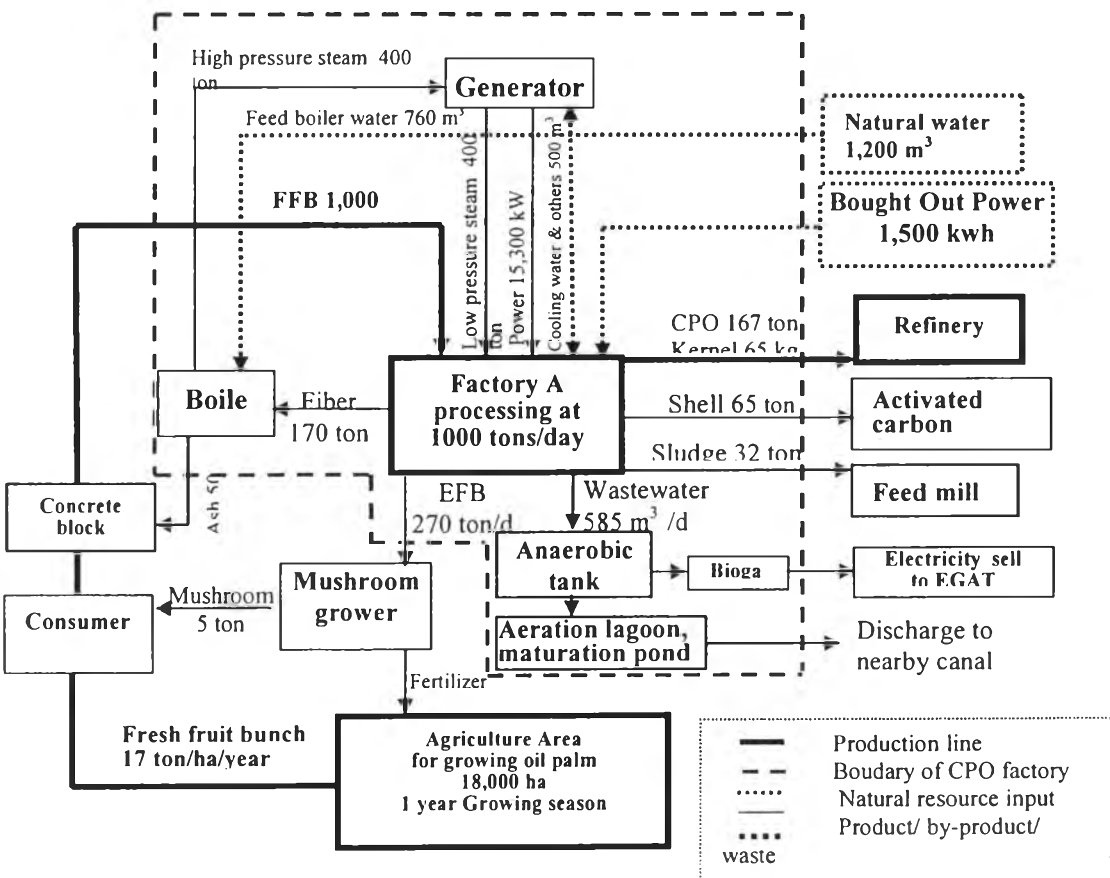



**Figure 5.25** Material balance of the proposed physical-technological model an almost zero waste industrial ecosystem at factory A.

In this model, crude palm oil production of factory A is uses as a starting point for the model of the development. Existing oil palm plantation area, new designation of brike enterprise, modification of the existing wastewater ponds to recover biogas, construct of activated carbon plant are all designed to reach a model of a zero waste industrial ecosystem.

This situation can be significantly improved by introducing enclosed anaerobic digestion system which reduce the COD, BOD and SS of the effluent and capture methane. Anaerobic system converts the dissolved organic substrate into biogas. Result from measurement showed that about 70 % of methane and 22 % CO2 are generated in anaerobic pond no.1. It is estimated that biogas generation =0.5 $m^3$ / kg COD of POME digested or 32 $m^3$ / $m^3$ of POME

## 5.5 Conclusion

During the last decade, there is development in the crude palm oil industry. Factory A is aware of the environmental pollution and adopt in clean technology approach. However there are still a number of pollution problems in production process of factory A, such as generation of high organic content of wastewater, generation of large quantity of solid waste and greenhouse gas. These pollution problems which have environmental impact to community surrounded the factories are in-efficiency of wastewater treatment plants and solids waste management. Industrial ecology theory is applied to improve the environmental performance of the factory and also to make the palm oil production more sustainable. The proposed possible solutions for these problems based on recent research are as following:

1. Some by-product such as empty fruit brunch, fiber and shells are already reused/ recycled, however the other alternative options that may have potential as a more value added product such as using shell as raw material for activated carbon, fiber for medium density fiber broad.
2. Waste such as decanter sludge can be sold to animal feed mill after drying by reuse excess steam as a heat source.
3. Recovered biogas from palm oil mill effluent and burning the gas in boiler to generate steam used in production process or feed to gas turbines to generate electricity which can be sold to the grid.