

Utilizations of Palm Oil Mills Wastes as Source of Energy and Water in the Production Process of Crude Palm Oil

Ridzky Kramanandita[1*], Tajuddin Bantacut[2], Muhammad Romli[3], Mustofa Makmoen[4]
[1,4] School of Industrial Management, Ministry of Industry, Indonesia
[2,3] Department of Agroindustrial Technology, Bogor Agricultural University, Indonesia
* E-mail of the corresponding author: ridzky@kemenperin.go.id

Abstract
Palm oil mills in their production process require a large amount of energy and water. Scarcity and enormous costs of energy and water become factors that may limit the future production of crude palm oil (CPO). On the other hand, demands for palm oil and its derivatives are increasing. Therefore, a number of research on energy and water by utilizing biomass produced by fresh fruit bunches (FFB) are necessary to develop. Analysis on the energy and mass balance of palm oil mills was carried out to obtain accurate information on the needs and the potential of energy and water from the wastes generated. Analysis on the energy and mass balance of palm oil mills was carried out to obtain accurate information on the needs and the potential of energy and water from the wastes generated. The results of the analysis of the energy and mass balance show that the potential of the total solid wastes generated by the palm oil mills with a capacity of 30 tons/hr are equal to 16,090.09 kg/hr or equivalent to 53.63% of the fresh fruit bunches with the composition of empty fruit bunches (26.97%), fibers (17.67%) and shells (6.46%), while the liquid wastes generated are equal to 18,113.15 Kg/hr (%) with the composition of mud (18.38%) and water (42.05%). The palm oil mills required To supply energy for palm oil mills, the solid wastes can be converted into biohydrogen, biogas and bioethanol, while the liquid wastes can be converted into biogas and biohydrogen as well as water sources.
Keywords: oil palm, energy, water, equilibrium

1. Introduction

The conversion processes of fresh fruit bunch (FFB) into crude palm oil (CPO) require sufficiently enormous energy and water supply. To produce CPO, Palm oil mills with the capacity of 30-60 ton/hr require 14-25 kWh of energy (Yusoff, 2006; Chalvaparit *et al*., 2006; Mahlia, 2001; Yoshizaki *et al*., 2013) and 300,000-350,000 tons/year of water (Ahmad *et al*., 2003). In addition, the use of energy and water in a large quantity also generates a sufficiently sizeable waste. Ohimain *et al.* (2013) states that the conversion process of FFB will produce 10-30% CPO with by-product of 30-70% solid waste and 60-70% palm oil mill effluents (POME). According to Nasution *et al.* (2014), the composition of solid wastes generated by the palm oil mills in Indonesia consists of fibers (12-15%), shells (5-7%) and empty fruit bunches (20-23%), depending on the technology process applied.

The potential of wastes from palm oil mills as an energy source for those palm oil mills has also been widely studied. However, these studies remains incomplete, because the wastes converted into energy for palm oil mill is still confined either only to solid wastes (Husain *et al*., 2003; Nasution *et al*., 2014; Ohimain, 2014) or liquid waste (Gobi *et al*., 2013). This issue leads to the analysis of waste potential use which cannot predict the exact amount of energy necessary for those palm oil mills. Therefore, this study will examine the details of mass balance and energy balance in order to determine the potential of by-products in the form of either solid waste or liquid waste and thus palm oil mills will have alternatives to meet its energy requirements.

2. Methodology

2.1 The Analysis of Mass and Energy Balance

The mass and energy balance calculation was made based on the law of conservation of mass and energy which states that mass and energy cannot be created or destroyed, but they can be transformed into another form. The completion stage of mass and energy balance did not involve a chemical reaction because the crude palm oil was generated through the processes of pressing and physical purification.

To make the calculation, the basic mass balance employed was 30 ton of FFB/hr, based on the results of the proximate analysis of FFB processed in palm oil mills, FFB composition was dominated by empty fruit bunches (23%), oil (21%) and silt (22%), while the rest was water (12%), endoscarp (6%), kernel (5%) and fibers (11%). The mass balance was calculated based on the law of mass balance by Perry *et al.* (1997) with the formula as follows:

$$m_{input} = m_{output}$$

Where:
m_{input} = mass input (kg)
m_{output} = mass output (kg)

In some production processes, production costs can be estimated based on the amount of energy required for the production process. The basic concept of energy balance is defined as follows:

$$E_i - E_0 \pm Q = 0$$

Where:
E_i = Energy input (kJ)
E_0 = Energy output (kJ)
Q = Heat (kJ)

The assumptions used in the calculation of the energy balance are:

- stationary and material flows are in a state of a thermodynamic equilibrium level at both the entrance station and the exit station
- one-dimensional flows at both the entrance station and the exit station
- kinetic energy and potential energy are ignored

1.1.1 The determination of the steam requirement

The calculation of the steam requirement of palm oil mills with a capacity of 30 ton of FFB/hr was performed using the following formula:

$$Q_s = M \times C_p \times D_t$$

Where:
M = flow mass of FFB (kg)
Dt = temperature difference (^oC)
Cp = the average specific heat of EFB (kcal/kg ℃)

1.1.2 The determination of the average Cp of FFB

The approach taken to determine the Cp average of FFB is:

$$C\_(p\ avg) = (m \times Cp\ FFB\ component)/M$$

Where:
M = mass of FFB components (kg)
Cp of FFB components = water; shell; kernel; EFB; fiber (kg)
M = Mass of FFB (kg)

The mass and energy balance analysis was performed in all stations (sterilization, Stripper, Digester, Pressing, Continous Settling Tank, Sludge Tanks, Sludge Separator, Oil Purifier, Vacuum Dryer, CPO Storage, Depericarper, Silo Dryer, Nut Crackers, Hidrocyclone, Kernel Dryer and Kernel Storage).

2. Data

The primary data consisting of CPO production process were retrieved from a palm oil mill in Southern Borneo, which had a production capacity of 30 ton of FFB/hr. The secondary data including the waste-to-energy conversion process were based on the results of the literature study related to the research topic.

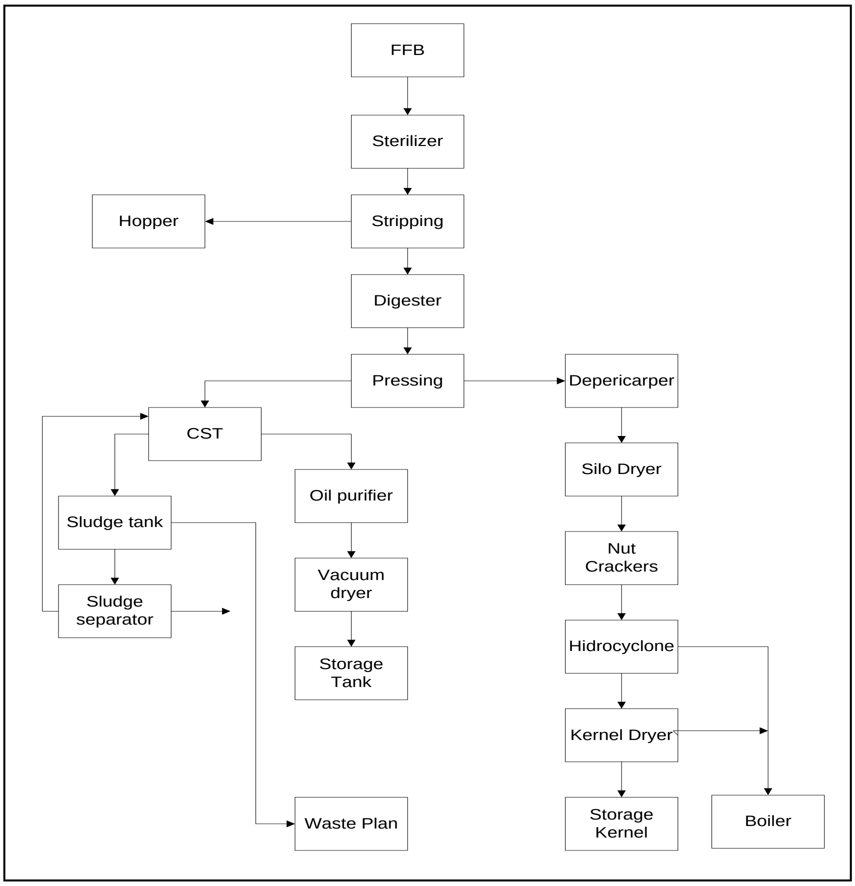

Figure 1. The stages of CPO production processes at palm oil mills

3. Result and Discussion

3.1 CPO Production Process

Fresh fruit bunch (FFB) processing into crude palm oil (CPO) has several stages including raw materials input, boiling, digesting, fruit compression, waste and nut disseverance, palm oil clarification, sludge processing and nut cracking (Pardamean, 2008). While according to Pahan (2006), palm oil mills basically can be divided into two stations – the main station and the supporting station. The main station, which covers the entire series of the primary process to convert palm oil into crude palm oil, comprises units of fruit acceptance, sterilizer, stripper, digester, press, purification as well as nut and kernel separation (Figure 1).

3.1.1 Sterilizer Station

The sterilization process was performed by inserting fresh fruit bunches (FFB) at a temperature of 125^{o}C–135^{o}C for 82-90 minutes. The amount of the steam required was 3,345 kg/hr (11%), whereas the steam loss that occurred was 3.65% (1,095 kg/hr). This process generated 85% of cooked FFB (25.041 kg/hr) and a condensate by 6,905 kg/ hr (22.5%). Based on the results of the calculation, it is suggested that the efficiency of the sterilization process was 85%. The energy need in this process was 19,954.05 MJ/ hr.

3.1.2 Stripper Station

In this station, the cooked fresh fruit bunches produced in the sterilizer station were fed into a 33.95 rpm stripper drum to dislodge fruits from their stems. The total number of cooked FFB generated in this station reached 25,041 kg/hr with a by-product in the form of empty fruit bunches (EFB) that reached 8,093.27 kg/hr. In this process, the estimated heat loss reached 85,645.02 MJ /hr, with a total energy contained in this station by 308,921.4 MJ/hr.

3.1.3 Digester Station

Palm oil fruits generated in the stripping station by 17,079.9 kg/hr were fed into the digester. In this stage, the digester separated flesh fruit and nut using agitator blades at a temperature of 90 – 95^{o}C. Furthermore, the estimated steam demand was 6.67% of the amount of the feed and therefore the amount of the heat required was 7,494.01 MJ/ hr.

3.1.4 Pressing Station

Palm oil fruits generated from the digester station were then circulated into the pressing machine with addition of hot water as much as 3,710.76 kg/hr of the amount of the mass of the material to be pressed. This stage produced crude oil by 12,245.50 kg/hr (consisting of oil by 5,632.93 kg/ hr; dirt by 857.19 kg/ hr, and free fatty acids by 514.31 kg/ hr) and silt by 41, 9%.

3.1.5 Continous Settling Tank (CST) Station

The crude oil generated by the pressing station was flowed into the continous settling tank (CST), where sewage sludge was separated from the oil by gravity. This stage is divided into two, namely crude oil flowing to the sludge tanks station and crude oil flowing to the oil purifier station. On the other hand, the sludge flowing to the sludge tank amounted to 8,449.40 kg/ hr (4.90% of oil, 7.5% of water and 87.6% of impurities), whereas the amount of crude oil leading to the oil purifier station was as much as 6,245.21 kg/ hr. In this process, the estimated heat loss was at 857.24 MJ/ hr.

3.1.6 Sludge Tank Station

Sludge which still contains oil from CST was flowed into the sludge tank to separate the oil from the impurities. The sedimentation process generated crude oil by 8,381.80 kg/ hr, which will be streamed to the sludge separator station. This stage will generate sludge as a by-product by 67.59 kg/ hr. The heat required in the tank sludge station was 11,587.21 MJ/ hr.

3.1.7 Sludge Separator Station

In sludge separator station, oil and impurities that the crude oil produced in the sludge tank station were separated using a precleaner and a stainer. The amount of the crude oil separated, while the results obtained from this process were 2,449.10 and a by-product in the form of sludge by 5,867.26 kg/ hr. The amount of the energy required in this station was 258.83 MJ/ hr.

3.1.8 Oil Purifier Station

The total amount of crude oil generated in CST station amounted to 6,245.21 kg/hr. Crude palm oil was then purified to be separated from its impurities. This process generated a total of 6,231.46 kg/hr of crude palm oil which consisted of 96% of oil, 0.45% of water, 0.13% of impurities and 2.92% of free fatty acids. The by-product generated from this process was 13.74 kg/hr of sludge. In this process the heat lost reached 658.67 MJ/ h with a total energy involved in the system as much as 23,606.3 MJ/hr.

3.1.9 Vacuum Dryer Station

Crude oil generated in the oil purifier station was then dried to remove the water, to make the FFA value do not increase. The crude oil produced in this process was equal to 6,170.40 kg/hr with a water content that reached 0.002% (0.123 kg/hr) and was then stored in the storage tank, while the by-product was in the form of 61.07 kg/hr of water. On the other hand, this process also produced heat steam as a by-product by 163,419.04 MJ/hr and the heat needs reached 778.51 MJ /hr.

3.1.10 Depericarper Station

The by-product generated in the pressing station was nuts 4,408.38 kg/hr, fibers 5,460.38 kg/hr and water 150.29 kg/hr. This process was intended to separate the nut from the fiber. The solids produced in the depericarper station was 4,608.76 kg/ hr, while the by-product that consisted of fibers reached 5,410.29 kg/hr. The heat energy involved in this process was 38,606.16 MJ/hr while the estimated heat loss was 1,347.87 MJ/hr.

3.1.11 Silo Dryer Station

This station serves to remove water contained in the nuts, therefore the heat required in this process was 139.81 MJ/hr. This process produced nuts by 4,332.24 kg/hr and a byproduct in the form of water vapor as much as 276.53 kg/hr (6% of the input).

3.1.12 Nut Cracker Station

Palm nuts that had been dried in the silo dryer station were fed to this station to encounter a breakdown process. Palm nuts that had encountered the breakdown process would generate 3,444.13 kg/hr of kernels and 888.11 kg/hr of shells. The heat missing in this process reached 14,198.3 MJ/hr.

3.1.13 Hidrocyclone Station

A mixture of fractions generated in the nut crackers station was put into a hidrocyclone. In the hidrocyclone, separation of kernels from their shells occurred based on the specific gravity. The core of the kernels would move upwards the hidrocyclone, while the shells would fall under the hidrocyclone. The by-product generated in this stage consisted of 1,949.50 kg/hr of shells, while the heat loss was equal to 13,016.18 MJ /hr.

3.1.14 Kernel Dryer Station

Kernels from the hydrocyclone were fed into a kernel dryer. In this process, the water content as much as 357.41 kg/hr contained in the kernels was evaporated. Furthermore, the kernels (2,025.32 kg/hr) was stored in a kernel shelter. The by-product generated was in the form of steam by 956.42 MJ/hr, while the heat required was equal to 233.50 MJ/hr.

3.2 The Mass and Energy Balance of CPO Production Processes

Based on these data, the calculation of the mass balance is described in Figure 2, and the energy balance for each station is described in Figure 3.

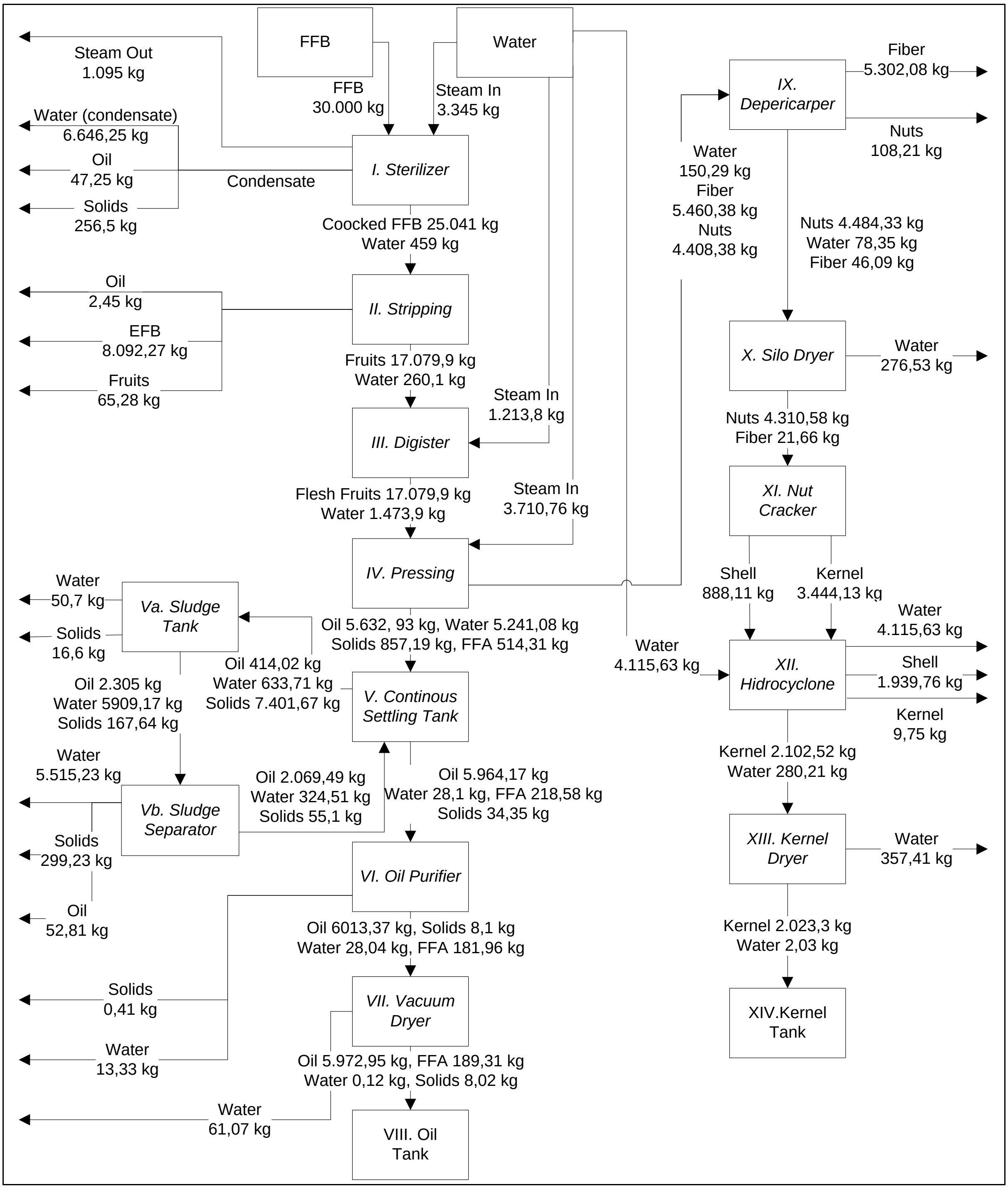

Figure 2. Detail Mass Balance of Palm Oil Mill

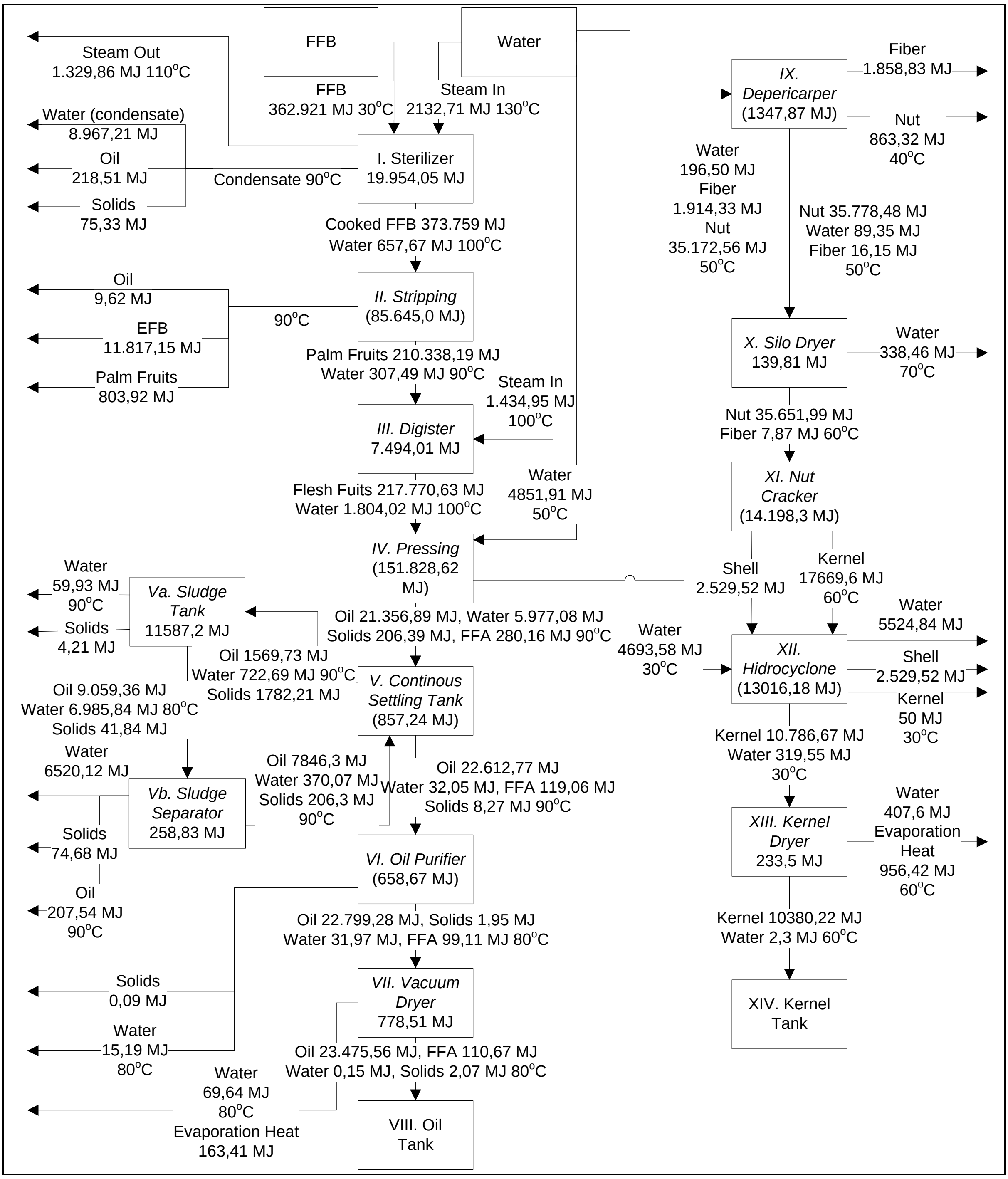

Figure 3. Detail Energy Balance of Palm Oil Mill

4. The Potency Of By Product Generated Palm Oil Industry

Based on the analysis of the mass balance and the energy balance that had been performed, it is revealed that the by-product of the palm oil mills with a capacity of 30 ton/hr can be categorized into three: solid waste, liquid wastes and gases. Table 2 shows that the most dominating solid waste is empty fruit bunch with a total number of 8,092.27 kg/hr, followed by fiber wastes (5,348.17 kg/hr) and shell wastes (1,939.76 kg/hr). Compared to the obtained fresh fruit bunches, the total solid wastes generated reached 51.27% with a composition that consisted of empty fruit bunches (26.27%), fibers (17.83%) and shells (6.47%). This is in line with the study conducted by Ohimain et al. (2013) suggesting that the solid wastes generated by palm oil mills reach 30 to 70%, depending on the technology and the type of the plant used. The empty bunches were converted into biohydrogen (Abdul et al., 2013; Kalinci et al., 2011; Chiew *et al.*, 2013; Chong et al. 2013), biogas (O-Thong et al. 2012) and bioethanol (Sudiyani et al. 2013).

Table 2. The potential of solid wastes generated by palm oil mills with a capacity 30 ton/hr

Station	Types of Solid Waste	Composition	Quantity (kg/hr)
Stripper	Empty Fruit Bunches	99,17% EFB, 0,8% Fruits and 0,03% oil, at 90^{o}C	8.092,27
Depericarper	Fiber	98% Fiber and 2% kernel at 40^{o}C	5.348,17
Hidrocyclone	Shell	99,5% Shell dan 0,5% kernel at 28.5^{o}C	1.939,76
The total amount of solid wastes			15.380,20

The liquid wastes produced by palm oil mills originate from several processing stations, among others are sterilization, sludge tank, sludge separator, oil purifier and hidrocyclone stations. Each station has different characteristics of wastes. The characteristics depend on the processes conducted, but in palm oil mills, liquid wastes generally can be categorized into two: water (10,865.63 kg/hr) and sludge (5,948.60 kg/hr). The amount of the liquid waste that reached 58% (16,814.23) is one of the potential to be developed into other forms of energy sources such as (Choi et al., 2013; Poh *et al.*, 2010; Gobi *et al.*, 2013), biohidrogen (Singh *et al.*, 2013a; Singh *et al.*, 2013b; Singh *et al.*, 2013c; Badiei *et al.*, 2011; Badiei *et al.*, 2012; Ismail *et al*., 2010) and water (Ahmad *et al*., 2003).

Table 3. Palm Oil Mill Effluents with a capacity of 30 ton/hr

Station	Types of liquid waste	Composition	Quantity (kg/hr)
Sterilisasi	Water	0.70% oil, 3.8% Impurities and 95.5% water at 90^{o}C	6.750
Sludge Tank	Sludge	75% water and 25% water at 90^{o}C	67,60
Sludge Separator	Sludge	0.95 oil, 94% water and 5.10%impurities, at 90^{o}C	5.867,26
Oil Purifier	Sludge	97% water and 3% impurities	13,74
Hidrocyclone	Water	Pure water (100%) at 30^{o}C	4.115,63
The total amount of liquid wastes			16.814,23

5. Conclusion

Based on the analysis of the mass balance and the energy balance, palm oil mills with a capacity of 30 ton of FFB/hr require 12.38 ton of water sources (41% of TBS). The amount of water input by 12.38 ton eventually generated 18.11 ton of water, where the water surplus originated from FFB containing 5.73 ton of water (19.1% FFB).

The amount of the output produced by CPO was 6.07 ton, while the yield generated by palm oil mills was 5.97 ton (19.9% of FFB). In the processing of oil palm into CPO, there was unprocessed oil which amounted to 0.102 ton (1.68% of CPO output).

Furthermore, the potential of solid waste generated by palm oil mills with a capacity of 30 ton/hr is equal to 15,380.20 kg/hr or 51.27% of fresh fruit bunches (FFB) consisting of empthy fruit bunches (26.27%), fibers (17.83%) and shells (6.47%). On the other hand, the amount of the liquid wastes generated are equal to 16,814.23 kg/hr or 58% with the composition of the wastes that consisted of sludge (64.62%) and water (35.38%). To meet the energy requirements of the palm oil mills, the solid wastes can be converted into biohydrogen, biogas and bioethanol, while the the liquid wastes can be converted into biogas and biohydrogen and water sources.

The station with the highest value of energy input/ output is the Sterilizer Station by 385,008 MJ/hr. The total energy produced by the by-product of palm oil mills was equal to 42,865 MJ/hr consisting of the three largest components, namely condensate water (16,063 MJ/hr), fibers (2,722 MJ/hr) and shells (8,104 MJ/hr). The potential of untapped energy produced by palm oil mills using the appropriate technology can be used as a source of energy.

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