

Application of Cleaner Production in Palm Oil Mill: A Case Study at PT Perkebunan Nusantara IV Adolina Business Unit Perbaungan North Sumatera Indonesia

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Abstract

Palm oil mill (POM) produces CPO (Crude Palm Oil), PKO (Palm Kernel Oil) and wastes (solid, liquid and gas). Environmental pollution has existed together with palm oil processing. Being reactive approach, wastes treatment and disposal conducted by palm oil mill still creates some environmental problems. Cleaner production is a proactive approach concentrates on minimizing wastes through improving effectiveness and efficiency of the process. This research identified and analyzed the alternatives of cleaner production application in palm oil mill with special reference to PT Perkebunan Nusantara IV Adolina in North Sumatera, Indonesia. The analysis focused on technical, financial and environmental aspects of each possible alternative. AHP (Analytical Hierarchy Process) was used to rank alternatives by experts judgment. The results arranged the priority of alternatives: optimization of Standard Operational Procedure application, improvement of efficiency of water use, good operating procedures, utilization of palm oil mill effluent as biogas, optimizing the utilization of empty fruit bunches, free fatty acid control, collection of split oil by making condensate pond, and preventing contamination of fresh fruit bunches. The application of good house-keeping provides financial gain of 1.89 billion rupiah/year, process modification 0.28 billion rupiah/year, and on-site reuse of wastes 1.69 billion rupiah/year (exchange rate was Rp. 10,000/US$). An advance research is needed to make detail quantification and integration of all related benefits both economic and environmental aspects.

Keywords: palm oil industry, cleaner production, analytical hierarchy process, case study, Indonesia

1. Introduction

The production process to produce the desired product is always followed by waste and by-product generation that often create environmental problems. The generation of waste and by-products can be caused by nature of the main raw material properties, and efficiency in the process and production operations. Waste pollution in the environment has endangered humans, flora, fauna and ecosystems that disrupt continuity of the universe. Therefore, wastes and by-product handling should be part of the overall production system (Oltra and Jean 2005a).

Most of the waste management practices still use the End of Pipe (EoP) principles that handling the generated wastes (Frondel et al. 2007) or referred to as a reactive approach (Buysse and Verbeke 2003). This handling often form solid waste (sludge) and air pollutant emissions, so it only changes the shape of waste from one form to another (Bergouignan et al. 2004). Efforts to repair or recover the damage and pollution caused by waste requires a high cost and long time. More advanced approach has evolved namely how to reduce, reuse and recycle, so that the amount of waste generated to be handled becomes relatively little (Foo and Hameed 2010; Qin et al. 2012). One approach in this category is the cleaner production which has potential as a problem solving to improve production efficiency and waste handling. The cleaner production is an environmental management strategy that is integrated prevention applied continuously in the production process and product life cycle with the aim of reducing risks to humans and the environment (Oltra and Jean 2005b).

Cleaner production have attracted the attention of many researchers in various fields of application. The scope of their researches include the integration of process technology (Dunn and Bush 2001), pollution inhibition (Hilson 2003), effective environmental management tool (Gold et al. 2010; Hilson and Nayeeb 2002), relationship with sustainability (Dovi et al. 2007; Kjaerheim 2005), policy (Cooke 2008; Montalvo and Kemp, 2008) and its relation to ecology (Nielsen 2007). The application of the cleaner technologies are very broad (Chavalparit and Ongwandee 2009; Gonzalez 2005; Puah et al. 2007) and is influenced by many factors (Kemp and Volpi 2008) and wisdom (Montalvo 2008).

Waste generation from palm oil mill has been and will continue to increase in line with the growth of the downstream industry, especially biodiesel (Santosa 2008; Sumathi et al. 2008). Numerous researches have been conducted to the use and handling of palm oil mill wastes, such as, the use of waste to energy (Arrieta et al. 2007; Bazmi et al. 2011; Birka et al. 2008; Kelly-Yong et al. 2007; Shuit et al. 2009; Yusoff 2006), production of methane (Hassan et al. 2009), holistic treatment of wastewater (Wu et al. 2009; Zhang et al. 2008), application of membrane technology for liquid waste (Ahmad and Chan 2009; Wu et al. 2007), use of the waste for making bioplastic (Mumtaz et al. 2010), composting (Singh et al. 2010), anaerobic treatment of wastewater (Poh and Chong, 2009; Saleh et al. 2012; Yoshizaki et al. 2012), aerobic treatment of wastewater (Vijayaraghavan et al. 2007), pollution control technology (Wu et al. 2010), and utilization of waste (Chaiyaomporn and Chavalparit 2010; Mekhilef et al. 2011; Ng et al. 2011; Pleanjai et al. 2007). However, the nature of these studies are partial and focusing on the generated wastes. Utilization of these findings in a comprehensive perspective of cleaner technology is still limited. Indrasti and Fauzi (2009) mentioned some of the efforts are minimizing the use of toxic raw materials, reducing the formation of waste at source, application of environmentally friendly technologies, and the application of good management in the industry. These are cleaner production strategies. The palm oil mill is expected to form a benefit along with concern for environmental management. Therefore, this study was aimed to identify opportunity and application of cleaner technology in the palm oil mill so that the findings of the above mentioned researches could be utilized in an integrated manner. For more practical reason, this study took a case study at a Palm Oil Mill of PT Nusantara Plantation IV Adolina-Perbaungan Business Unit at capacity of 30 tones of fresh fruit bunches (FFB)/hour.

2. Methods

This research was conducted with field observations to find the potential and the possibility to apply cleaner production at the palm oil mill. In the preparation phase, an intensive review of literature was conducted to include seminar and working papers, journal articles, books, and company administration reports on the research theme. The next stage was collection of both primary and secondary data. The primary data was obtained through interviewing directly and indirectly the company managers. Secondary data were obtained from previous studies, and data records and reports of the palm oil mill company.

Identification started with observing the production process to assign inputs, production process technology, production output and mass balance calculations at each process station (stage). To each production process was then conducted an analysis of the formation and quantitative characteristics of the wastes to help determination of cleaner production alternatives.

The observation results in the form of quantitative and qualitative data were used as the basis of technical, economic, and environmental feasibility analysis. Then, results of the analysis were used as benchmark to develop recommendation of the cleaner production application. The main consideration to decide an alternative implementation of cleaner production included potential benefit in terms of financial, regulation, improving occupational health and safety, technology procurement, investment cost, maintenance, process flexibility to adapt to the existing condition, the possibility of problems arise in other units, and possibility to fail in the application of cleaner production. These considerations form the basis for experts to make an assessment in filling up AHP (Analytical Hierarchy Process) questionnaire.

The technical aspects mainly concerned with the easiness of alternatives implementation, while the financial aspects included cost estimation, possibility of savings and benefits that can be gained from the application of cleaner production. Environmental aspects were seen from potential of impact reduction. Financial analysis included cash flow, Net Present Value (NPV), Payback Period (PBP), Net Benefit Cost Ratio (Net B/C) and Internal Rate of Return (IRR).

Identified alternatives were tested with AHP which is a simplification of a complex problem that is not structured, strategic, and dynamic into its parts, and arranged hierarchically to help decisions making (Marimin 2008). Decision-making with the AHP assisted by experts in the field of palm oil and the results were analyzed using Expert Choice program 2000.

3. Results and Discussion

3.1. Production Process Technology

The production processes of palm oil mills (POM) include weighing, sorting, boiling, defoliation, compressing, and purifying. The weighing is to determine the amount of fruit to be processed after deduction of rejected fruit during sorting process. The fruit is then inserted into the boiling kettle to inactivate the lipase enzyme in the fruit. A system of three peaks (triple peaks) is used for boiling process, during which follows three peaks attributable to the steam filling and steam releasing, followed by steam filling, steam detention, and steam disposal in one cycle as shown in Figure 1 (Mangunsong and Lamria 2003). Nuts from the compression station is brought to the plant nuts to be further processed into the kernel before it is processed into Kernel Palm Oil (KPO).

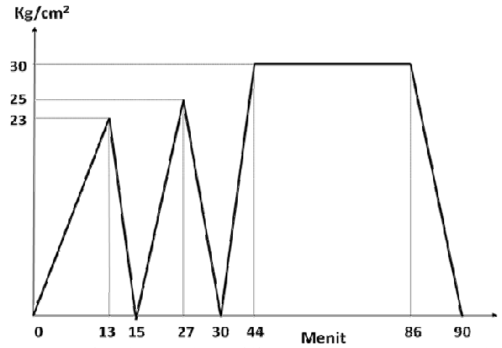

Figure 1. Tripple Peak Boiling System (MCC Adolina 2011)

After boiled the fruits are taken with hoisting crane to defoliation station and put them in an auto feeder, and then threshed. The threshed fruits then are taken to the compression station for stirring and crushed in the digester, and then compressed with a screw press. EFB (Empty Fruit Bunch) is brought into the hopper then transported back to the plantation as material of organic fertilizer. Results of screw press in the form of crude oil is brought to the purification station, while the nuts and fibers to plant nuts to separate the kernel.

Purification station consists of two processes of refining oil and extracting the oil from the mud. Oil refining process starts from the sand trap tank to precipitate sand shipped from the compression station. The results are brought to vibrating screen to separate the carried fibers. Fiber dumped into the exhaust while the crude oil supplied to the tanks for storage of crude oil. Furthermore, the oil is brought to continuous settling tank (CST). In this tank, oil separation continued. This tank has three rooms where the oil is at the top, oil and mud in the middle, and dirt on the bottom. Oil on the top of the tank flow to oil storage tank while the mixed oil sludge goes to sludge oil tank for oil separation. Oil is stored and heated in oil tank and then taken to a vacuum dryer to reduce water content and the results then stored in the storage tank.

The separation process of oil from sludge is in the sludge tanks, the contained oil will be at the top, while the sludge and dirt will be at the bottom which then expelled through the blow down. Oil from sludge tanks is taken to dry brush strainer while the dirt is brought into *fat fit*. Brush strainer serves to separate or eliminate fine fibers that remaining in the liquid sludge. Oil containing impurities poured into sand cyclone to capture the sand contained in the sludge before patched in balancing tanks and then taken to the sludge separator. This equipment is used to receive the sludge from the sludge tank and separate mud and dirt from the oil by centrifugal force. Dirt and mud are filtered directly then sent to the *fat fit* vessel while the oil is returned to the CST to be reprocessed so that the CPO yield is better. In *fat fit* vessel the oil is extracted and taken back to the CST through the pipes while the dirt is brought to anaerobic wastewater treatment.

3.2. Waste Treatment

Solid waste generated from threshing process, compression process and cracking seeds. The threshing process generates solid waste such as empty fruit bunches that is used as an organic fertilizer in the plantation. The compression process produces seed pulp while cracking process produces palm shells. Fiber and shells are used as fuel to generate steam in boiler units (Fauzi, 2007).

Liquid wastes come from the boiling and clarification (purification) processes go through the channel to the sewage treatment pond. This pond consists of cooling (cooling pond), the first anaerobic (primary anaerobic pond), second anaerobic (secondary anaerobic pond), and last pond. The liquid wastes contain high levels of organic matter that can lead to significant pollution load. In general, the palm oil mill utilizes liquid waste for land application as fertilizer.

Gaseous wastes are emitted through boiler stacks and generator sets. The Regional Body of Environmental Impact (a government body responsible for pollution control) where the mill located checks these wastes regularly in every six months. Hazardous solid wastes in the palm oil industry compose used batteries from the forklift, iron, and steel of broken machines. All theses wastes are collected or stored in a safe place before sell to collectors, processors, and users of used goods.

3.3. Potential Application of Cleaner Production

This research was aimed to assess cleaner production approach to prevent the generation of wastes at the source and use them for other applications. Optimization of the implementation of standard operating procedures (SOPs) and implementation of proper operation procedures are the primary steps to cut the generation of waste from the source. In economic terms, the use of waste was assessed from possible advantages such as empty fruit bunches for land application as fertilizer for crops and substituting the use of palm oil mill effluent that was originally for land application into biogas. Water use efficiency was analyzed to see the possibility of savings that indirectly reduces the volume of liquid waste. These are potentials prevention alternatives. The decision-making alternatives were processed using Expert Choice Program 2000 and recommended implementation was arranged based on expert opinion.

During the field observation following the process stages, it was identified aspects of the application of clean technologies include the procurement of raw materials and processing: (1) fruit contamination control, (2) the increase of free fatty acids control, (3) best operating procedures application, (4) wasted oil collection, (5) standard operating procedures assertion, (6) empty fruit bunches utilization, (7) water use efficiency improvement, and (8) liquid waste utilization for producing biogas. These aspects of implementation of the cleaner production was then analyzed and verified by experts using AHP.

3.4. Hierarchy of Alternatives Implementation

The cleaner production application analysis included technical, economical, and environmental aspects. Recommended alternatives were tested with AHP. Figure 2 and 3 show the results of the AHP assessment of the recommended alternatives. All recommended alternatives benefiting the oil companies. The experts filled questionnaire that especially designed to consider economic benefits, environmental benefits and technical aspects of the application.

The order of application of the recommended alternative were: (1) optimization of standard operating procedures affirmation, (2) the efficiency of water use improvement, (3) proper operation procedures assertion, (4) the use of palm oil mill effluent as a source of alternative biogas energy, (5) optimizing the use of empty fruit bunches as organic fertilizer, (6) free fatty acid control with crop scheduling and efficient use of the truck, (7) collecting the wasted oil by constructing condensate water reservoir, and (8) and prevention of fruit contamination.

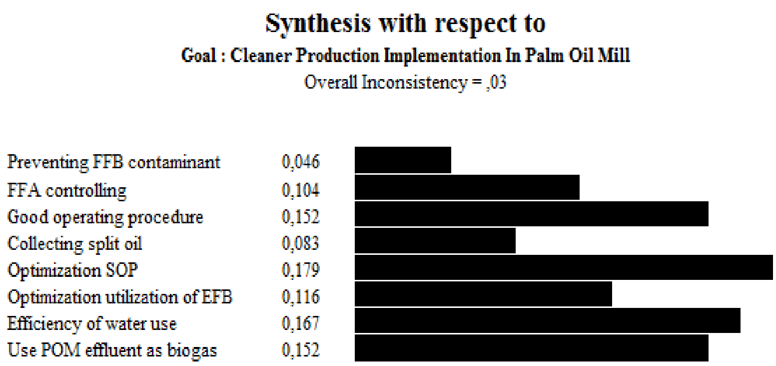

Figure 2. AHP values and consistency using Expert Choice 2000

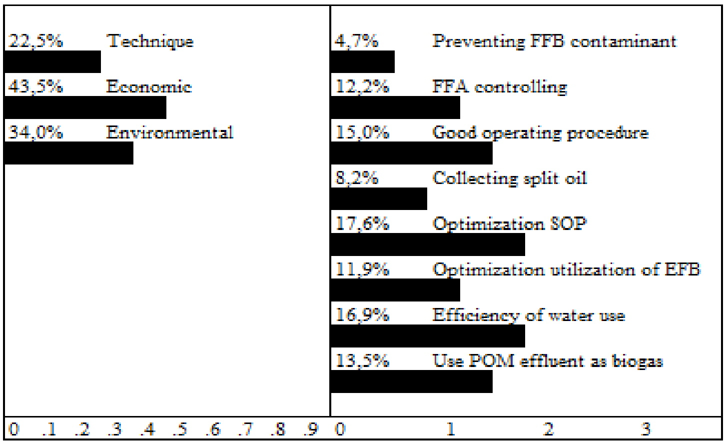

Figure 3. Komposisi sensitif dinamis AHP dengan Expert Choice 2000

Affirmation of SOP Optimization

Boiling pressure does not reach 2.8 kg/cm^2 at the third peak due to the distance between the kettle with Back Pressure Valve (BPV) is too far, there may be a leak in the steam of stew or on the pipe leading BPV to stew, and too much steam consumption for installation outside the stew (Hariyanto, 2007). If the implementation by the SOP, the situation is the same then the prevention is necessary as not to affect other processes. Prevention efforts through the operational control by the operator, foreman, and assistant needs to be improved. Operational control is taken by evaluating the decoction graph (boiling recordings on the operator machine) to decide the boiling pressure, steam leaks, holding time, boiling time, and boiled time. Daily inspection of pressure and temperature gauges must be done before starting the process.

Oil loss also occurs in the process of compression. The oil spill in the digester contaminates the factory due to the improper implementation of the process SOP. Kautsar (2006) states that it is too full so that the water of digestion process overflowing from a manhole which is a hole to decide the state of the inside digester. Similarly, it can also be caused by incomplete mixing due to blunt of digester knife. The proposed alternative to overcome such a problem is to periodically replace the knife every 140 days. If the SOP were executed properly, but there is still oil that melts from the digester, the operator should clean the floor manually. Technically, it is easy to optimize SOP affirmation in all elements of the plant to encourage workers to do their duties by the standard provisions. Good performance will improve the effectiveness, efficiency, and productivity of the process and potentially improve the financial gain. The financial benefits requires further study to accurately calculate its quantitative values. Environmentally, this improvement provides benefits in reducing by-product and wastes generation.

Water Use Efficiency

Water is an important production factor for and is used in almost all stages of the process. Boiling process, purification, collecting palm kernel, cleaning the process equipment, and cleaning the plant area are of the most widely used water. The proposed alternative was to close the water leakage, especially in the purification process area and kernel plant by welding on leaking pipes and replacement of leaking hose. Inspection of hoses and pipes entire station should be done every day before starting the process. Cooperation of operators in the form of awareness of water use for washing machines and factory area around the compression station, purification, and kernel plant are also needed. This leakage control offers benefit and technically easy to carry out. Water efficiency would save about 15 billion rupiah per year. Finally, reducing of water use will also cut the amount of wastewater generation so it helps protect the environment.

Good Operating Procedures

Good operating procedures can be defined as a proper operation in doing the job to achieve optimum effectiveness and efficiency in the work by applicable standards. The purpose of good operation is to improve productivity and product produced in conjunction with minimizing completion time, saving resources and costs, and maximizing safety and health.

The good operating procedures have not been fully implemented due to lack of awareness of workers in implementing applicable SOPs (including the use of Personal Protective Equipment) causes decreased production. Low workers' awareness is likely due to personal commitments. Therefore, a company needs to give extension, especially in terms of occupational health and safety and understanding the risks at the plant, and what it should be and what should not be done according to SOP. Providing incentives (overtime, holiday allowance, bonuses) can be a motivating factor to work better. The palm oil mill, in general, has been implementing SOPs and procedures for proper operation, but not all employees perform their duties in accordance with the provisions. Implementing proper operation procedures could improve the productivity and minimizing pollution that indirectly improve financial gain.

Utilization of Palm Oil Mill Effluent as Material for Biogas production

The palm oil mill generates liquid waste, or commonly known as Palm Oil Mill Effluent (POME) in large quantity and contain high organic matter so that it cannot be discharged directly into the environment. Most of the palm oil mills treat POME in an anaerobic pond and the sludge produced is applied to the soil as organic fertilizer. The advantages of anaerobic pond are simple construction and operation, and does not need skilled labor. However, this pond requires a large area, low efficiency and low rate of elimination of organic matter, produce unpleasant odors, and biogas produced are not used. Utilization of POME for producing biogas could offer better returns than just used for land application. Methane in the biogas has greater energy and more cleaner than coal. In addition to its energy, biogas production will also reduce waste volume and discharge (Foo and Hameed 2010; Hassan et al. 2009; Suprihatin 2012). Biogas can replace oil and can be converted into electricity for processing activities in the factory, offices and employee housing. To optimize the existing facilities, organic materials in POME can be processed to biogas by adding cover to stabilization ponds (cover lagoon pond system) or constructing anaerobic bioreactor. Every ton of FFB is able to produce 14.30 m^3 biogas equal to 7.20 L diesel oil.

An investment of 20 billion rupiah and operating costs of 728.9 million rupiah are required to set up closed (covered) stabilization lagoon for palm oil mill capacity of 30 tones of FFB/h. This investment returns at NPV 17 billion rupiah for the 10 year cash flow, net B/C of 1.69, IRR of 16%, and PBP in the fifth year. This analysis suggested that the construction of a closed lagoon system is feasible. This system would also reduce pollution load, especially greenhouse gases emission.

Optimization of Empty Fruit Bunches (EFB) Utilization

EFB is a by-product of palm oil mill in a very abundant amount that is more than hundreds of tons per day. It can be processed into various products, however the existing utilization is mostly used for the land application to substitute fertilizer. EFB is carried using an empty bunch conveyor to hopper where some bunches are ejected from the conveyor barrier and fell on the floor between the compression station and the hopper. Loekito (2002) found that the EFB nutrient content equal to fertilizer sold in the market, i.e. each ton equal to 6.10 kg urea, 1.60 kg TSP (Triple Superphosphate), 15.90 kg MOP (Potassium Chloride), and 3.30 Kieserit.

EFB which fall under the threshing floor and along of empty bunch conveyor areas must be prevented. Manual collection of the felt bunches is the most proper method to cut the losses. In addition to addressing the fruit fall prevention, covering conveyor with an iron lid should be better. Optimal effort can recollect lost bunches equivalent to 0.39% of the total FFB with economic benefits of about 5.43 million rupiah/year if used as fertilizer application. Technically, it can easily be implemented and from environmental perspective, it is very good effort. Another benefit is the more cleaner process working area.

FFA Control by setting Harvest Schedule and Truck Use Efficiency

Increased Free Fatty Acid (FFA) may be caused by mechanical damage and the presence of the enzyme activity in the fruit. FFA formation begins from the plantation after harvesting before being transported up to the reservoir at the loading ramp. Inappropriate harvesting time and too long waiting time before boiling cause the formation of FFA. High FFA levels mean low oil quality. Fruit cell wall rupture (cuts/bruises) causes the enzyme contacts with oil and cause hydrolysis reaction will soon take place quickly formed FFA. The palm oil mill controls FFA by disabling the enzyme by boiling. A proper FFB handling before boiling is precondition of having low level of FFA. Harvest scheduling and efficient use of trucks can significantly cut the formation of FFA.

Harvesting the fruit at the right time and volume according to the number and capacity of available truck that ready to transport to the factory is a good practical effort. Loading, transporting and unloading should meet SOP requisite to avoid fruit bruised or damaged. Harvested fruit transported to the factory immediately with careful supervision of fruit at reception station (loading ramp) by operator. Since, there is no a tool or an automated technology to determine the fruit maturity level, then the control operator of fruit station reception must work optimally with a high commitment. FFB transport scheduling system from farm to factory could improve cost-efficiency that savings from truck rental. A time planning of harvest and transport is one of important way to avoid FFB quality deterioration and to gain cost saving.

Technically, implementation of harvest scheduling system and the efficient use of the truck is undertaken through coordination of the company management. The financial benefit of this scheduling to control FFA level needs a more detailed analysis. Truck rental savings in the case of the oil palm mill at capacity of 30 tones FFB/hour is about 576 million rupiah per year. From the environment aspects, this scheduling contribute to reducing gasoline of the truck, and keeping the rejected unripe and overripe fruits in the plantation for soil application.

Oil Recolection by Making Water Condensate Reservoirs

Hariyanto (2007) mentions that high oil content in condensate water probably caused by the leftover fruit mixed with fresh fruit in a boiling, too long holding time, many injured or bruised fruit, crushed fruit by vehicles, and incomplete disposal of condensate water. This is a natural occurrence and is always there at the boiling station of oil palm mill. Some part of oil is evaporated and tied with condensate water at high temperature and high pressure. Maintaining the pressure of one cycle of boiling at 80-90^{0}C for each pick I, II and III is 2.3, 2.5, and 3.0 kg/cm^2 respectively would cut the oil containing level of condensate water not exceeding the standard. Examination of the boiling measurement instrument, panel lights, alarms, pipe leaks, chart work of boiling machines should always be monitored by the operator, and assistant in charge to conduct daily checks before starting the process.

A more intensive oil recollection from condensate water of boiling vessel can be done by making the condensate water ponds and oil reservoirs. In this way, the collection is easier than *fit fat* because the oil is not mixed with the mud from the other stations. Water condensate out of the stew poured into blow down silencers through the pipes, while water vapor leaks in pipes and boiler stew flowed through the trenches leading to the condensate water storage ponds. Condensate water reservoir should be built in between the boiling kettle and *fat fit* tub. This pool will accommodate water containing oil where oil will be at the top because of differences in specific gravity and carried to an oil reservoir. Collected crude oil is pumped back to the purification station (sand trap tanks) and water is flowed to *fit fat* tub.

The case study was carried out when the mill processed 188,000 tons of FFB/year and resulted condensate water by 12% or equal to 22,500 ton/year. Making the condensate water storage ponds requires a land area of 4 m^2 to build pond size of 2.0 x 2.0 x 1.6 m^3 and land for oil reservoir of water condensate 0.25 m^2 to provide space for 0.5 x 0.5 x 0.5 m^3. The cost of the investment required to build condensate water storage ponds and reservoirs of oil is about Rp. 18.689 million. This effort would generate return at NPV Rp. 2,483,550,913 in 10 years cash flows, Net B/C of 8.26 and a payback period of 0.04 years. Technically the pool could be made with the company management coordination for improvement of the productivity (yield). A possible environmental benefit is less liquid waste for further processing.

Contaminants such as soil, sand, stone, and plastic from the plantation entrained together with the fruit transportation to the palm oil mill. These contaminants must be prevented or at least reduced because they will damage the product quality and processing equipment as well as pollute the factory environment. Without intensive efforts for prevention, the contaminants is in large quantities will certainly disrupting plant operations. The palm oil mill overcomes the problems by making the grating on the loading ramp. Sand, soil, and rocks will fall through the grid. Then, the lorry rail operator would manually collect falling dirt and then dispose them away.

Efforts to optimize the control of fruit quality is at the reception station fruit loading ramp. Fruit must be cleaned (with a broom) before loading into the truck so that sand, soil, rocks, and other impurities are not carried on to the factory. It is important to clean up the loading ramp floor area before starting the process and at specific time intervals during the process. Increasing awareness and understanding towards fruit quality and cleanness of workers in the plantation and in the factory is important. Technically, no charge for applying the prevention of contamination of fruit. Environmental aspects of this effort is better maintaining the cleaness of the plant area. The contamination free fruit will improve the quality of CPO. In addition, the contamination control will cut the risk of the machine damage, especially the boiling kettle due to too frequent rubbing with fruit containing sand or other hard materials. This will indirectly provide financial benefits to the industry through maintenance costs deduction. The financial benefit of this effort need to be studied further.

4. Conclusion and Recommendation

4.1. Conclusion

The application sequence of recommended alternatives based on AHP assessment were affirmation of standard operating procedure (0.179), water use efficiency (0.167), good operating procedures (0.152), palm oil mill effluent utilization as a material for biogas production for alternative energy (0.152), optimizing the use of empty fruit bunches as organic fertilizer (0.116), free fatty acid control with crop scheduling and efficient use of the truck (0.104), collection of oil by constructing condensate water storage ponds and water condensate oil reservoir (0.083), and prevention efforts of fruit contamination (0.046). All offered alternatives could be applied by the priority because it will benefit the palm oil mill or the palm oil industry. Recommended actions for implementation includes good house-keeping, process modification, and on-site reuse. The implementation of good house-keeping potentially improves the revenue of the palm oil mills by Rp. 1,894,118,036 per year, process modification would generate revenues about Rp. 248,355,091 per year, and on-site reuse would generate revenues about Rp. 1,693,941,992 per year.

4.2. Recommendation

Implementation of recommended selected alternatives in the palm oil mill give technical advantages (productivity), economic (financial), and the environment by the given priority. Further studies for detailing quantification of the economic benefits would give a more exact figure of the advantages. A study on detailed engineering would be useful for basis of integrated design of process improvement adopting the cleaner production strategies.

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