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Waste Recovery and Regeneration (REGEN) System for Palm Oil Industry

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Palm oil mill generates large amount of palm-based biomasses after crude palm oil and crude palm kernel oil extraction from palm fresh fruit bunches. These biomasses are projected to increase up to 110 dry Mt by 2020. With the increasing volume of global palm oil production, palm-based biomass utilisation is gaining significant attention as there are huge opportunities and potentials that the biomass can be converted into bioenergy and value-added products. However, palm biomass is currently underutilised. In addition, most of the palm oil mills are facing challenges in meeting the discharge standards of palm oil mill effluent imposed by local authorities. Despite various treatment systems/ technologies have been developed and implemented in the palm oil mills over the past decades, there is none a single system which eliminates all the solid and liquid wastes in the palm oil mill. In this work, a novel Waste Recovery and Regeneration (REGEN) System is introduced. REGEN System is an integrated system which comprises of various technologies to convert all the solid and liquid biomasses in the palm oil mill into valuable products. The system generates sufficient biogas and power to support the operation of the entire system. It is energy self-sustained and it produces additional power to support the palm oil mill or sold as by-product. The treated liquid waste or palm oil mill effluent (POME) meets the discharge standard steadily and it is further treated for reuse and recycle in the palm oil mill. By adapting such system in the palm oil mill, all the wastes or biomasses from palm oil mill is converted into high value products and bio-energy. The proposed system is projected to attract billion dollar of business opportunity and transform palm oil industry into a sustainable industry.

1. Introduction

Oil palm, scientifically known as Elaeis guineensis Jacg., produces two distinct types of oils: crude palm oil from mesocarp and crude palm kernel oil from kernel. Such oils possess excellent cooking properties and are widely used for edible application (e.g., cooking oil, margarine, shortening, butter, etc.) or non-edible application (e.g., soap, cosmetics, detergents, etc.). Global palm oil production by country in 2012/2013 is showed in Figure 1 (USDA, 2013). As shown, Indonesia and Malaysia are world's largest palm oil producers that account for 52 % and 34 % of world production, respectively. In Malaysia, palm plantation occupies more than 70 % of the commercially cultivated plantations. The primary palm product is palm oil that is extracted from palm fresh fruit bunch (FFB) and palm kernel. As presented previously, Malaysia is one of the largest palm oil producing country worldwide with approximately 19.2 Mt of crude palm oil (CPO) produced in year 2013. Due to the high production of CPO, a large quantity of biomass and palm oil mill effluent (POME) are generated. For every unit of FFB processed in the palm oil mill, approximately 20 % of the weight of FFB is generated as CPO and approximately 70 % of the weight of FFB is generated as by-product/ waste. This "by-product" or "waste" from the palm oil mill has been identified as one of the main biomass sources in the country. The palm oil waste which is generally known as palm-based biomass includes palm empty fruit bunch (EFB), palm mesocarp fibre (PMF), palm kernel shell (PKS), palm kernel cake (PKC) and palm oil mill effluent (POME). In 2012, Malaysia generated approximately 95

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Mt of palm-based biomass. This value indicates the enormous opportunities and green potentials of palm industry in the country (Ng et al., 2012).

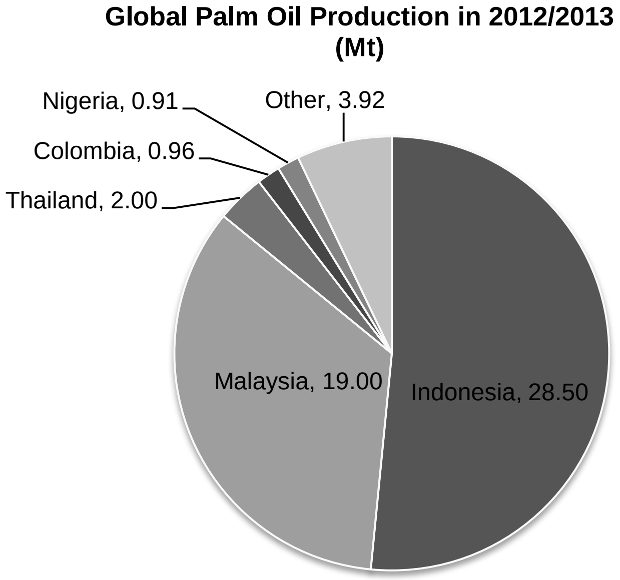

Figure 1: Global palm oil production in 2012/2013 (USDA, 2013)

2. Palm Oil Milling Process

Figure 2 shows the typical palm oil milling process. Palm fruit arrives at palm oil mill in bunches which is known as fresh fruit bunch (FFB). FFB consists of fruits embedded in spikelet that grow on a main stem. FFB is first sent to steriliser for cooking. They are heated under pressurised steam (approximate 3 bars) to weaken the fruit stem and denature the oil-splitting enzymes in fruit that promote hydrolysis and autoxidation. After cooking, FFB is sent to threshing unit. In this unit, fruitlets are detached from the main stem; leaving behind spikelet on the stem which is generally called empty fruit bunch (EFB) (FAO, 2013).

The loose fruitlets are then sent to the extraction unit. The fruitlets are first mechanically pressed for oil extraction. This oil contains impurities, e.g., water, fibrous material, cell debris, etc., which have to be removed prior to storage. Palm mesocarp fibre (PMF) and nuts or palm kernel nuts are left behind after oil extraction. The impurities in the crude oil are then removed via purification units and form sludge. The crude palm oil is retained and sent to storage tanks. On the other hand, palm kernel nuts are sent to crusher and oil extraction unit for palm kernel oil extraction. Both crude palm oil and crude kernel oil appear to be the main products of palm oil mill.

The by-products and wastes generated at each stage of milling process are indicated in Figure 2, except POME. POME is the collective wastewater generated from palm oil mill. It shall be noted that wastewater is generated at every stage of milling process.

2.1 Solid waste from palm oil mill

Solid palm-based biomass is increasingly being converted into value-added products e.g., dried long fibre (Abdul Khalil et al., 2012), pellet (Ng and Ng, 2013), bio-fertiliser (Sulong et al., 2008), etc. However, there are still a number of palm oil mill owners who retains the biomass for mulching. Over decades, technologies are established to convert such biomass into value-added products. These include pelletising and torrefaction processes to produce pellet from EFB (Ng and Ng, 2013), fiberising process to produce dried long fiber (Eureka Synergy, 2015), briquetting process to produce briquette (GGS, 2015), composting process to convert EFB and sludge into bio-fertiliser (Sulong et al., 2008), etc. Recently, more technologies are developed to convert these semi-finish value-added products into finishing products. For example, dried long fiber is pressed and knitted into fibber mat (Eureka Synergy, 2015), pellet are processed into edible pellet (animal feed) (Fakaruddin and Rahman, 2010), etc. The biodegradable fiber mat has shown potential in combatting soil corrosion, accelerating seed germination and plant growth, suppressing weed and so on. The development of palletising technology from the production of fuel pellet into edible pellet has further explored the potential of palm biomass in agricultural industry. Currently, the edible pellet / animal feed produced is used for fish cultivation.

2.2 Liquid waste from palm oil mill

On the other hand, POME – the liquid waste from palm oil mill – causes significant environmental impacts due to its high contents of biochemical oxygen demand (BOD) (~25,000 mg/L), chemical oxygen demand (COD) (~54,000 mg/L), oil and grease (O&G) (~8,000 mg/L), and total suspended solids (TSS) (~44,000 mg/L). Conventional POME treatment using ponding system incurs high investment cost, no return of capital and large footprint. Recent POME treatment (tank digester and membrane filtration) systems integrate biogas system for power generation to recover capital investment. However, capital pay-back of at least 5 y is needed. Featuring the benefits of capturing biogas that generates surplus energy and reducing carbon footprint, Malaysian government has identified an Entry Point Project in the National Key Economic Area to achieve the installation of biogas facilities in all palm oil mills by 2020 (MPOB, 2014). Hence, there is an urgent need to develop a cost-effective and innovative treatment system for POME.

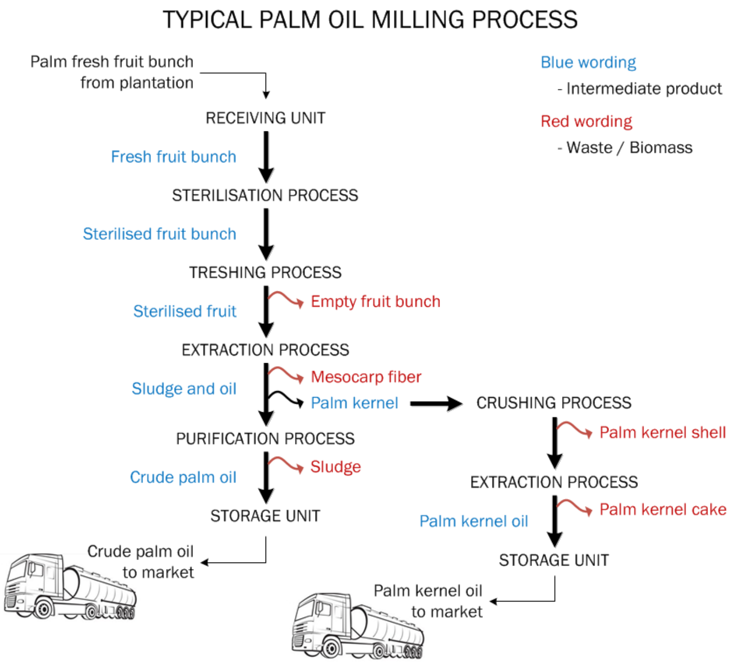

Figure 2: Typical palm oil milling process

3. Waste Recovery and Regeneration (REGEN) System

As indicated above, various treatment systems/ technologies have been developed and implemented in the palm oil industry. However, there is no single technology that tackles all the solid and liquid wastes in the palm oil mill. Most palm oil mills implement one or more biomass conversion technologies; yet, none has successfully implemented zero waste management which eliminates all wastes while securing attractive net earnings. Recognizing this gap of technology, a novel Waste Recovery and Regeneration (REGEN) system for palm oil mill is presented in this work. Figures 3 and 4 show the concept and process block diagram of REGEN system respectively.

As shown in Figures 3 and 4, REGEN system integrates all possible technologies to convert both the solid and liquid biomasses generated from the palm oil milling process into value-added products. Solid waste is processed via technologies such as pelletizing system, fiberizing system, composting system and other conversion processes based on the owner’s interest. The system is flexible to mix-and-match different technologies to produce a variety of products and, therefore, it is able to produce multiple products based on real-time market demand. The allocation of biomass in the system based on different market demand and biomass availability allows for full utilisation of biomass.

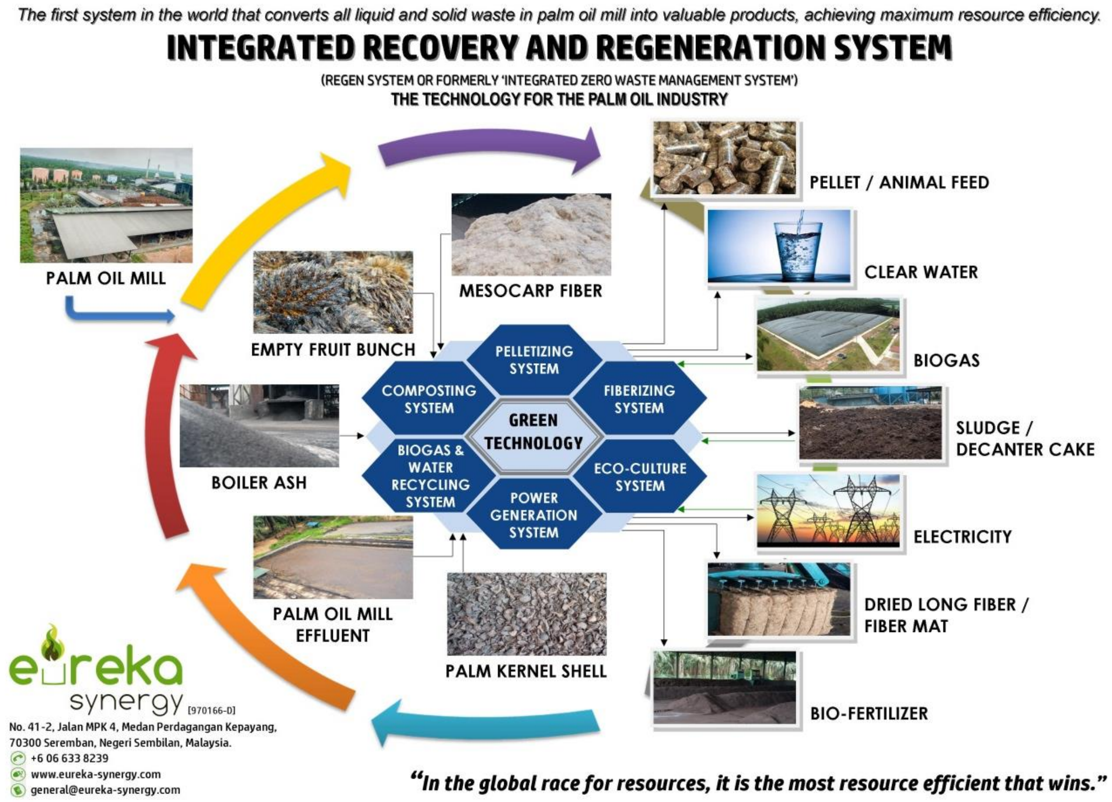

Figure 3: Concept of REGEN system

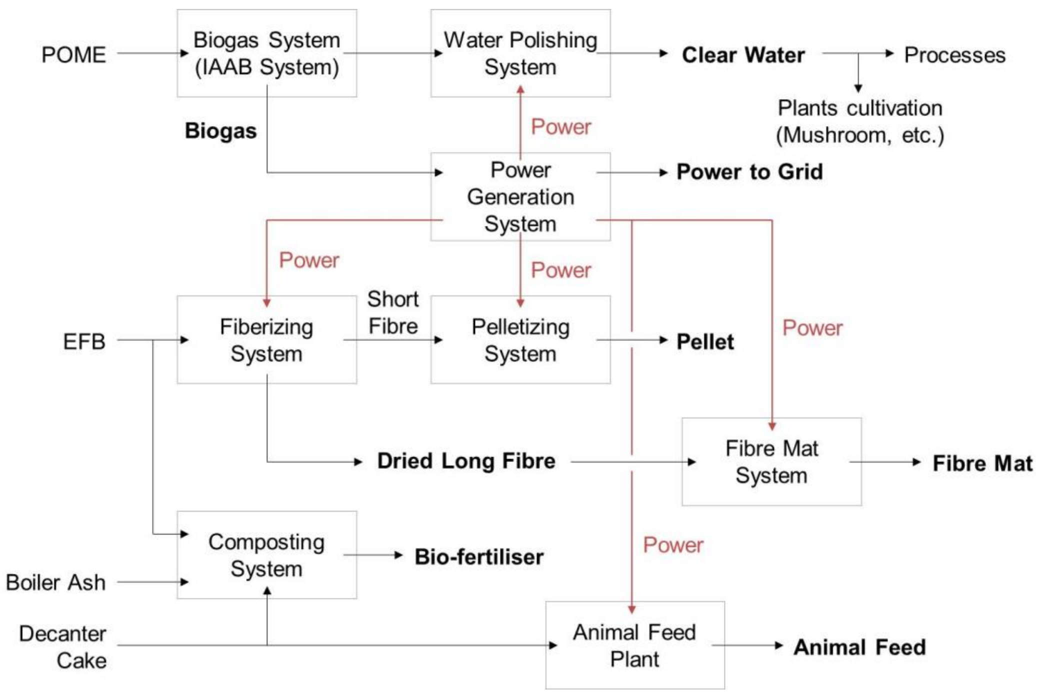

Figure 4: Process block diagram of REGEN system

On the other hand, the liquid waste - POME is treated in a newly designed biogas system which is known as Integrated Anaerobic and Aerobic Bioreactor (IAAB) system (Chan, 2011). The IAAB system consists of three compartments: anaerobic, aerobic and settling compartments with an optional polishing system. The IAAB system is able to treat POME to meet the country's environment standard consistently. The treated water after settling compartment has BOD < 30 mg/L, COD < 500 mg/L, TSS < 45 mg/L and pH ~ 7.4. In IAAB system, sufficient power can be generated from biogas for the entire REGEN system. Biogas is generated from POME in the anaerobic compartment. The collected biogas is then treated and used to generate power via gas engine to support the energy requirement of the REGEN system. The IAAB system developed is a high-rate reactor and it is able to control and stabilise the quality of treated POME. Once the POME is treated through the anaerobic, aerobic and settling compartments, it can be further polished to reduce the COD and TSS content in POME. After the polishing system, high quality water is generated and can be reused and recycled to the palm oil mill. Note that the IAAB system produces sufficient power for the entire system, thus, no external power is required. In addition, IAAB system implicates small footprint and requires shorter retention time as compared to the conventional biogas technologies (covered lagoon and tank system) that produce the same amount of energy. Note that in this system, POME is fully treated and recovered. The treated POME not only meets the environmental discharge limit steadily; the water is further polished for reuse and recycle in the palm oil mill. It is noteworthy to mention that clear water quality is achieved. Besides, this system is energy self-sustained and able to generate excess power for energy export.

4. Potential of a 60 t/h Palm Oil Mill

For a typical 60 t/h palm oil mill, it is expected to produce 36 t/h of POME, 14 t/h of EFB, etc. By adapting REGEN system (integration of all individual biomass processing systems) in a palm oil mill, the palm oil mill is able to achieve zero liquid and solid waste discharge. Table 1 shows the potential application of REGEN system and their respective economic performances.

Table 1: Common technologies for palm biomass processing and their economic performances

	Annual Capacity	Capital Cost (MYR)	Return on Investment (ROI - 20 y)	Payback
Pelletizing System Product: Palm pellet	24,000 t	8,000,000	194 %	4 y
Fiberizing System Product: Dried long fiber	4,800 t	6,000,000	214 %	3.75 y
Composting System Product: Bio-fertilizer	24,000 t	15,000,000	371 %	2.5 y
IAAB System Product: Electricity, clear water	21,600 MWh 103,000 m^3	21,000,000	146 %	5.5 y
REGEN System (integration of all individual systems)		50,000,000	229 %	4 y

* ROI calculation is based on a 60 t/h palm oil mill and interest rate at 8 %.

It is noted that based on the estimated 50 MMYR of capital investment, the preliminary economic study shows that it is expected to have a payback period of 4 y and ROI (20 y) of 229 %. In addition, it is noteworthy to indicate that the above potential of a palm oil mill includes only four common technologies. There are more physical technologies, such as animal feed technology, fibre mat technology, etc., that can be included which may further improve the performance of ROI and payback.

5. Conclusions

In this work, a novel REGEN system is presented. The proposed system integrates multiple technologies as a whole to maximise the material recovery from palm oil mill to achieve zero waste discharge. The proposed system generates sufficient power to support the entire operation. Surplus power generated can be sold to the national grid to generate additional income. This inventive system converts previously unutilized resources into end products with viable commercial value; thus creating additional value chains to the industry. In the global race for resources, it undoubtedly the most resource efficient that wins. REGEN system drives for resource efficiency and recovery with commercial applications that are sustainable with viable returns. For a 60 t/h palm oil mill, it is expected to have payback period of 4 y and ROI (20 y) of 229 % with the capital investment of 50×10^6 MYR. By employing REGEN system, the palm oil mill will convert both solid and liquid biomass feedstock into value-added products.

Future works can be developed to study the environmental performance (Prasara-A, 2012) of REGEN system. It is expected that the adaptation of REGEN system will bring significant impact on reducing the carbon, nitrogen and water footprints. Besides, research works can be extended to further explore palm biomass's potential and uses, e.g. Silgado et al. (2014) have studied the potential of activated carbon made of palm biomass for heavy metal adsorption. Besides, palm biomass's uses can be explored in the direction of high value products generation, e.g. biochemical such as bioethanol, lactic acid and so on.

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