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OEE MEASURES FOR SUSTAINABLE ENVIRONMENT IN PALM OIL MILL: A REVIEW

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ABSTRACT : *The purpose of this paper is to review the potential of overall equipment efficiency (OEE) measures for a sustainable environment in palm oil mills. Several numbers of journals were reviewed, and semi-structured interview with relevant persons with the business natures were performed. A conceptual model is presented to illustrate the linkage between the three primary OEE measure, namely availability, performance and quality; and six big losses that can create the inefficiency of production, and contribute to adverse impact to environmental. The finding highlights that the potential of OEE measures contribute to manufacturing sustainability in the organisation, especially to reduce greenhouse gas emissions, utilisation of raw material, pollution control of soil, air, and water, as well as utilisation of natural resources. This model is useful for the manufacturing organisation, primarily to achieve an improvement in operational and cost saving efforts without neglecting the environmental impact.*

KEYWORDS: OEE Measure, Sustainable Environment, Palm Oil Mill, Conceptual Model

1.0 INTRODUCTION

Production of palm oil is expanding rapidly to fulfil worldwide needs, not only cooking oil or as food ingredient, but also used for biofuels, soap and other chemicals. There is growing awareness that the greater production of palm oil can increase the risk of destruction to the environment, causing adverse impacts on biodiversity and climate change. For this reason, pressure for sustainable environment of Palm Oil Mill (POM) are getting serious primarily driven from stakeholder engagement, market competition, changing needs of sustainable palm oil [1]. Sustainable environment in the manufacturing are focused on managing the production processes with sustainable input such as energy, people, equipment and machines, coupled with the objective of reducing waste, rework, inventory and delays as well as reducing the environmental footprint [2].

Overall Equipment Effectiveness (OEE) as a key performance indicator is widely used in manufacturing because it helps to monitor the actual performance of an equipment relative to its performance capabilities under optimal manufacturing conditions [3]. Analytically, OEE can be determined by the ratio between actual manufacturing performance and the ideal manufacturing or, alternatively, as the fraction of time in which an equipment works at its full operating capacity [4]. OEE can be measured in terms of the six big losses (breakdown, set-up and adjusted, minor stoppage, reduced speed, start up rejecting, and production rejects), provides a systematic method for establishing production targets and incorporates practical management tools and techniques to achieve a balanced view of process availability, performance efficiency and rate of quality [5]. As stated by Dal et al. [6], in production operation, availability measures are calculated as the ratio of actual operating time to planned operating time, and constitutes the theoretical production time against unplanned downtime. Performance efficiency can be measured as the ratio of the actual speed of the equipment to the ideal speed. The quality rate is computed as the ratio of defective production to the total production output. The product of availability, performance and quality rate is how OEE is formulated.

The application of OEE is increasingly gain interest, and considerable relevance to the manufacturing sustainability and the environmental issues [7]. The changing needs of environmental sustainability in manufacturing recently have been putting great pressures on the organisation to adopt proactive strategies for meeting the global requirements. One of the substantial alternatives to achieve the sustainability goal is by maintaining excellent performance and effectiveness of equipment. This is important for production to have the top performance equipment to perform ordered task efficiently, i.e. with optimum use of resources (materials, energy, etc.) as well as safety, and retained the equipment's life cycle [8]. Accordingly, implementing OEE to a system for analysing production data to identify potential areas of improvement and contribute to the reduction of environmental aspects identified and provides specific and measurable performance in the organisation. Thus, characteristically, OEE advances from a base measure of efficiency as the initial purpose, to being a tool to improve effectiveness to support environmental sustainability via the identification and elimination of losses and wastes.

The objective of this study is to explore the usability of OEE, not only as an operational measure, but also as a tool to support environmental sustainability within the Malaysia's POM operation. It evaluates literatures and semi-structured interview with relevant persons by focusing on the contribution of OEE towards environmental sustainability in the POM. Environmental issues and concern in the palm oil mill is presented at first. Next, the potential effects of OEE within the palm oil mill against environmental sustainability are explored and the conceptual model is discussed. Finally, the conclusions and areas for further research are disclosed.

2.0 ADVERSE ENVIRONMENTAL IMPACTS AND CONCERNS IN PALM OIL MILL

The principle of the palm oil milling process is to extract the oil from palm fruit using steam and a pressing machine. It

produces two types of oil, crude palm oil from the flesh of the fruit (mesocarp), and crude palm kernel oil from the seed or kernel. The extraction of palm oil from the fresh fruit bunches 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 was claimed to be one of the causes of environmental problems. Pollution of water, air, and soils, palm oil effluents, residues and wastes, and Greenhouse Gasses (GHG) emissions are among the environmental impacts from palm oil mill. Thus, this environmental footprint this has a critical need, to be addressed and reduced.

Palm oil mill has generated million tonnes of empty fruit bunches, fibre and palm shell every year as wastes. The two main wastes that results from palm oil production in mill are the solid and liquid wastes. Solid wastes consist of palm kernel shells (Figure 1(a)), mesocarp fruit fibres (Figure 1(b)), and empty fruit bunches (Figure 1(c)). The liquid waste is generated from the extraction of palm oil by wet process, mainly from the oil room after separator or decanter. The liquid waste that combined with the wastes from steriliser condensate and cooling water is called Palm Oil Mill Effluent (POME) (Figure 1(d)). It is wastewater with high organic content, discharged from the processing operations includes sterilization of FFB, clarification of the extracted crude palm oil, and hydrocyclone separation of a cracker mixture of kernel and shell. The high methane production potential of POME is problematic for the environment if released to the atmosphere, but can be considered as a major possibility for biogas production if collected. POME has been recognized as a main contributor of GHG emission which consists of methane from open pond or tank treatment system [9].

Emissions of GHG are one key sustainability issue related to palm oil mill. POME treatment in open anaerobic ponds is the main source of direct GHG emissions. Minor indirect GHG emissions are derived from raw materials, product and co-product's transport. The impacts of palm oil processing activities on the environment, including biogas generated from the anaerobic digestion escapes into the atmosphere and such biogas contains about 65% methane, which is one of the most potent GHG; the incineration of Empty Fruit Bunches (EFB) discharges particulates into the surrounding atmosphere; and haphazard dumping of EFB causes the additional methane emission into the atmosphere [10]. The extraction efficiency of crude palm oil is the one of the most important factors, and EFB end-use as energy and high energy efficiency also have an effect on the GHG balance of the mill.

Smoke and dust emissions are the main concerns due to incomplete combustion of the solid waste materials. These air emissions from the oil palm mills are from the boilers and furnaces mainly gases with particulates such as tar and soot droplets and a dust load. Oil palm ash production is striving towards huge criticisms and complaints, mainly attributed to its persistence, carcinogenic and bio-accumulative effects [11]. This environmentally polluting ash, which is disposed as waste is produced from burning the extracted palm oil husk and palm oil shell is as fuel in the boiler of palm oil mill. Incomplete combustion of the boiler and incinerator produce dark smoke resulting from burning a mixture of solid waste fuels such as shells, fibres and sometimes EFB. These boiler fly ashes are also wastes and pose problems of disposal. In terms of water pollution, illegal disposal of POME into waterways creates some problems related to destroying aquatic life. EFB is the residue after the milling process of fresh fruit bunches. It is a common practice to dispose the EFB into a plantation for nutrient recycling, however, it leads to pollution problems such as eutrophication and an increase of toxicity in the soil [12].

3.0 OEE POTENTIALS FOR SUSTAINABLE ENVIRONMENT IN PALM OIL MILL

OEE is a foundation to track progress over time in eliminating waste from the manufacturing which is integral in manufacturing commitment to environmental sustainability. Figure 2 illustrates the conceptual model of the potential of OEE measures for a sustainable environment in the POM. This conceptual model was constructed based on the gathered data from literature reviews. As the literature review did not reveal a large number of empirical data on how OEE influences environmental sustainability in POM, a qualitative case study approach, i.e., interview, was included. In cooperation with the

(a) Palm Kernel Shells (b) Mesocarp Fruit Fibres (c) Empty Fruit Bunches (d) Palm Oil Mill Effluent

Figure 1: Examples of Palm oil mill wastes

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Malaysian Ministry of Plantation Industries and Commodities for palm oil sector, Malaysian palm oil mill were contacted. For this study, four operations managers of eight to ten years' experience from different POM in Malaysia were involved in semi-structured interview as suggested by Yin [13]. The interviewee was keen to understand the major environmental impacts faced by the organisations and the contribution of equipment effectiveness in minimising and preventing these issues.

As can be seen in Figure 2, the main OEE measures; availability, performance and quality are recognised to have positive influence the environmental sustainability of POM in terms of increase utilisation of natural resources, control pollution of soil, air, water, increase utilisation of raw materials and reduce GHG emissions. The direct impact of availability measure in OEE are the elimination of breakdown losses and set-up adjustment time losses [14]. Breakdown losses happen when a sudden and unexpected equipment breakdown or failure results in loss of production time. While set-up adjustment time losses result of downtime and defective products that occur when production of one item ends and the equipment is adjusted to meet the requirements of another process or product. Non-productive downtime losses in POM result in a reduction of the time that the equipment can perform its intended function, usually caused by the equipment itself. Therefore, elimination both break down and set-up adjustment losses could increase the available time (uptime).

Availability measure in OEE targets on reduction of these non-productive breakdown so as the maintenance performance needs to be monitored and measured as an important role in managing safety, energy saving, plant and machinery failure and productivity amongst others [15]. With the effective maintenance management aimed for greater equipment availability and performance, the POM is not only could retain the equipment / facility in proper condition but also extends its life cycle [16]. The life cycle of equipment, often referred to as the cradle to the grave approach, could identify the negative environmental impacts produced by the use of materials and energy throughout their life. At the early stage of equipment life, maintenance role is to maintain equipment to the specific functional characteristics. When machines are functioning at the top condition and the system availability is increased, the energy consumption also could be reduced because non-value added activities on the machine (i.e. failures) are reduced. Maintenance also concentrated around retaining technical worthiness and assurance of reusability until then subjected to the material recycling process at the end of equipment's life. Indirectly, availability measure through effective maintenance activities could indirectly increase energy efficiency and at the same time could reduce the environmental impact such as GHG emissions from palm oil mill.

The increasing availability measure of OEE could be beneficial for POM organisations to improve their energy efficiency and consequently their carbon footprint can improve their position to face challenges and costs resulting from current and future environmental regulations. Crude palm oil extraction is energy intensive. Energy and materials consumed and produced in oil palm plantation and palm oil milling obtained from the field survey by Patthanaissaranukool et al. [17]. The energy consumption for palm oil production is related to the energy needed both directly (petroleum products, electricity) and indirectly (used for producing materials and for equipment) in the fuel life cycle. The electricity consumption of all the machines

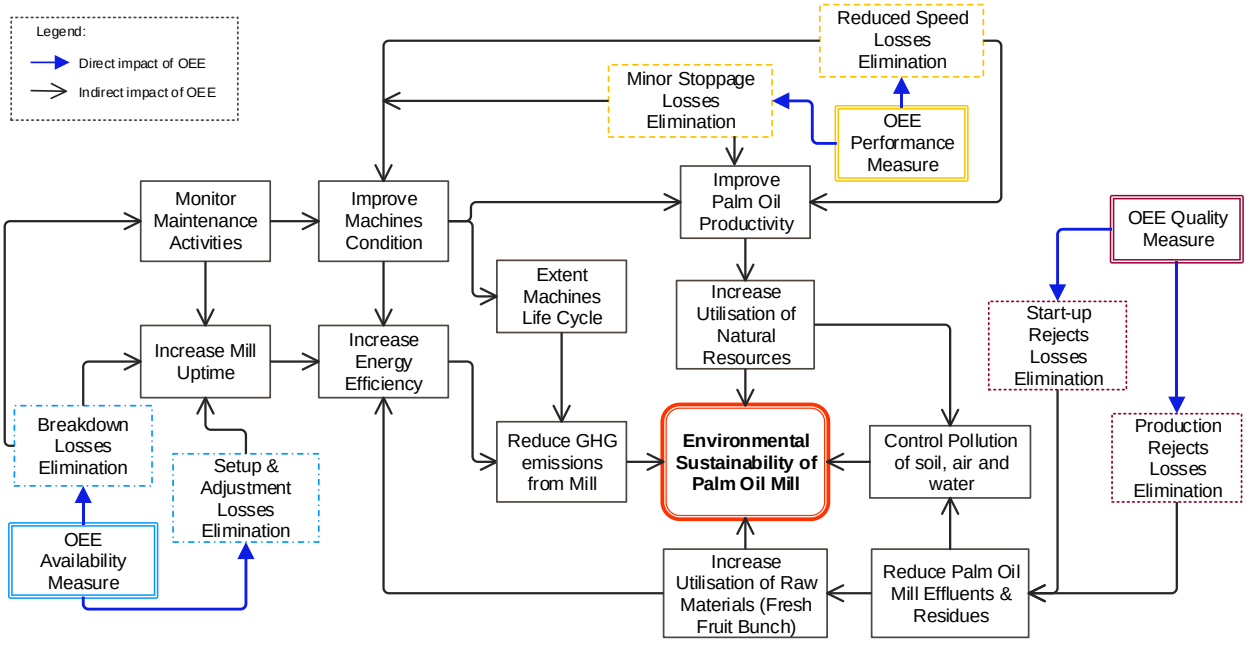

Figure 2: The conceptual model of OEE potentials for environmental sustainability in palm oil mill

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used in the mill was found to be equal to 18.7 ± 5.4 kWh/ton FFB (or 67.3 ± 19.5 MJ/ton FFB). Although palm oil mills typically burn some of the wastes to fulfil most of their electricity from the steam turbine generator installed in the CPO mill (90%), and process steam demands, but the energy for start-up the burning process being provided by back-up diesel and the mixed electricity grid (10%). Diesel oil used in the production process is 0.068 litre per ton FFB, which is used for the diesel generator and other diesel generated equipment in the mill [18]. Energy efficiency improvements are attainable with the implementation of OEE that offers the greatest potential for reducing GHG emissions within the mill.

The direct impact of performance rate of the OEE measure reduced speed losses and minor stoppage losses elimination. Most common speed losses happen when equipment speed decrease but it is not zero. It can depend on a malfunctioning, a small technical imperfections, such as the start-up of the equipment related to a maintenance task, a setup or a stop for organizational reasons [19]. Elimination of these losses, the performance measure could indirectly improve the machine condition and efficiency. Inefficient of machines including leaking, setup and adjustment stoppage, and malfunctioning equipment may often be the reason for extra crude palm oil losses. Oil losses due to process instabilities and leakage result in increased oil concentration in the mill effluents and thus, rise the environmental pollution. Efficient mill process control and equipment effectiveness measures could minimise waste generation and wastage of resources indirectly, as well as reduce the pollutant load to be removed in the effluent treatment process and its treatment costs.

Productivity is highly influenced by the effectiveness of equipment. During a production cycle, inputs are transformed into output. Ideally, equipment should perform at speed of theoretical production output. However, this is not possible in a real operation situation as many interruptions on the equipment from performing ideally. But, focusing on the performance rate, OEE could improve the utilisation of production equipment and yields more productive capacity of the mill. Higher performance equipment produces more output per hour work compared to the equipment that are not operating as per the design specification. The productivity of palm oil could be increased and advanced the organisation to maintain natural resources, particularly the consumption of water, energy, and minerals in the production process. Besides, by improving equipment performance also could indirectly extend the life cycles of the machineries for less waste or scrap of machine equipment with longer lifetimes. This will further reduce the environmental impacts of GHG emissions from the mill.

OEE improves conformance to the palm oil production through more reliable and consistent operation. Quality measure is the percent of good sellable product out of total product produced per time frame. It has a direct impact on the start-up rejects and production rejects losses elimination. When the produced output does not conform to quality specifications, it is consider as quality loss. It reflects the equipment's effective work situations, refers to productivity loss caused by the quality question, such as product loss before equipment operation, product loss when equipment operates normally [8]. The quality measure elimination these reject losses in palm oil mill and therefore indirectly reduce the production waste, including POME, fibres, and other residues. Minimising these wastes, quality measure indirectly helps the company control the environmental impacts such as pollution of soil, air, and water. Indirectly, higher utilisation of raw materials, i.e. fresh fruit bunch, in POM could achieve with quality measure in OEE for greater production performance. Hence, with more output with the same input and processing time, energy efficiency of the mill could be increased as well.

4.0 CONCLUSION

This study evaluated the contribution of OEE towards sustainable manufacturing in Malaysian POM based on literature reviews and semi-structured interview with relevant persons on the business nature. The conceptual model illustrates the linkage between the three primary OEE measure, availability, performance and quality; and six big losses that significantly causes of efficiency loss, and thus contribute to adverse environmental impact. The model discloses that OEE measures are able to give impact on the manufacturing sustainability, especially in the reduction of greenhouse gas emissions, utilisation of raw material, pollution control of soil, air, and water, and utilisation of natural resources. This signifies the great potential of OEE measure in realising environmental sustainability within POM in Malaysia. Although OEE was initially a performance indicator of efficiency it have justified that the use of OEE can be extended as a tool to improve effectiveness to support environmental sustainability via the identification and elimination of losses and wastes. For the study, in implementing OEE to tackle the environmental impact from the production standpoint, it could also result in organisation achieving improvement in operational and cost saving efforts. Future works will focus on evaluation of the barriers and challenges faced by Malaysian POM for adopting OEE measures. This will done by critically examine through literature studies and surveys on the factors influencing the successful implementation of OEE in the Malaysian POM and working out success factors towards improving mill performance and sustainability.

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