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Sustainability of natural rubber processing can be improved: A case study with crepe rubber manufacturing in Sri Lanka

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ABSTRACT

Rubber based products are essential commodities in the present day market. Natural rubber, being renewable with its unique qualities, plays a critical role in rubber product manufacture. Most natural rubber are produced in tropical Asian countries and their processing seems to be material- and energy-intensive hence challenged by cost-ineffectiveness and various environmental issues. Based on a case study of a Sri Lankan crepe rubber factory with a novel methodology, this study aimed at improving natural rubber processing sector to be more cost-efficient and eco-friendly. This methodology consisted of three phases: 1. quantification of factory's resource use, economic loss, and greenhouse gas emissions using material flow analysis (MFA), material flow cost accounting (MFCA) and life cycle assessment (LCA), 2. developing proposals of viable improvement options, 3. benefit validation of the suggested improvement options for confident implementations. The results indicated that the economic losses and greenhouse gas emissions generated by processing 1 MT of dry rubber were LKR 18,151 and 254.2 kg CO₂e, respectively. As improvement options, water, chemical, electricity reduction measures were proposed. Application of these options could reduce 45.59 MT of water and 542.8 kWh of electricity per 1 MT of dry rubber, resulting 26% and 79% drops in economic losses and greenhouse gas emissions, respectively. The findings and the research methodology reported here are significantly beneficial in introducing a sustainable manufacturing model not only to natural rubber processing industry but also to other similar manufacturing industries based in developing countries.

1. Introduction

Rubber products are indispensable in present day context; and on average, each person consumes ca. 3.5 kg of rubber per year (Malaysian Rubber Board, 2016; Population Reference Bureau, 2017). Being renewable and having some unique qualities, natural rubber supply plays a decisive role in rubber product manufacture. In rubber product manufacturing, each product has specific needs in raw rubber use; hence, required standards in natural rubber are to be maintained in raw rubber processing assuring acceptable market price. Production of natural rubber is mostly in the tropical Asian region. In Sri Lanka, the rubber sector ranked as the third largest foreign exchange earner with its exports contributing 122,074 million rupees (824 million USD) to the foreign exchange revenue in 2014 (Sri Lanka Export Development Board (EDB), 2015; The Ministry of Plantation Industries, 2015). Furthermore, this sector has been a source of 300,000 direct and indirect job opportunities to Sri Lankans (Sri Lanka Export Development Board (EDB), 2015). Once latex is collected from rubber trees, it is processed

into primary products, referred to as raw rubber, that are then utilized in different manufacturing industries to be reprocessed into rubber products. In Sri Lanka, raw rubber is produced mainly in the form of ribbed smoked sheets (RSS), concentrated latex (CL), and crepe; which have been the principal raw material of many rubber products such as pneumatic and solid tires, some other components in vehicles, condoms, hoses and, pharmaceutical and surgical items (Rubber Research Institute of Sri Lanka, 2003; Sri Lanka Export Development Board, 2016). Being a simple technology, production of RSS is mostly done at cottage level or in small scale. Factories/plants are required for manufacturing of both CL and crepe whilst most rubber plantations in Sri Lanka own crepe rubber processing factories.

Production of raw rubber is a labor-, energy-, and material-intensive process, where a significant amount of electricity and thermal energy, fresh water, firewood, and chemicals are used at different stages of the manufacturing process (Rubber Research Institute of Sri Lanka, 2003). Electricity is mainly used in heavy-duty machinery, pumping water, wastewater treatment, and factory lighting. Meanwhile, thermal energy

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is used for rubber drying and is generated by firewood burning. Fresh water is an important material consumption factor. Water is essential for washing, factory cleaning, dilution of chemicals and field latex, and even for cooling machinery. Furthermore, various chemicals including sodium bisulfite, acids, bleaching agents, diammonium hydrogen phosphate, tetramethylthiuram disulfide and zinc oxide, and ammonia are used in manufacturing different raw rubber types (Jawjit et al., 2010; Jawjit et al., 2015; Cecil and Mitchell, 2005).

Raw rubber processing in natural rubber industry is challenged by low level of material and energy efficiencies, higher degree of wastes and losses, and rising cost of raw materials hence production costs (Peiris, 1997; UNESCAP, 2011). Furthermore, natural rubber processing contributes to numerous environmental problems such as acidic wastewater discharge, malodor caused by rubber particles and chemicals, and greenhouse gas (GHG) emissions (Jawjit et al., 2010; Tekasakul and Tekasakul, 2016; Edirisinghe, 2013). In meeting the global demand and making the industry competitive, adopting sustainable production strategies in natural rubber production has become indispensable.

Several initiatives have been taken to develop and apply some suitable strategies to address the issues concerned. In view of providing an economical solution for wastewater treatment, Kudaligama et al. (2007) proposed and tested a cost-effective wastewater treatment plant. Deploying a water reuse facility at a Thai rubber factory, Leong et al. (2003) studied on the reduction in water and treatment costs. Meanwhile, with the aim of resolving high firewood consumption in crepe rubber processing, Siriwardena (2010) tested four solar powered drying tower systems, and a roof integrated solar air heater-storage system had been the most effective. Also, Rathnayake (2011) proposed a single day smoke dryer for RSS production and tested it applying to a factory in Sri Lanka. New system succeeded in drying RSS within a single day without compromising the standard quality of dried RSS. In addition, shortening of drying period had reduced cost of production as it saved firewood and the labor for handling. Tillekeratne (1999) also investigated how to reduce the cost of production in a crepe rubber processing factory and found that processing unfractionated and unbleached crepe rubber had been the most effective in this regard, as it avoided the cost for the bleaching agent and saved extra labor cost associated with the removal of yellow fraction. Quantifying the material and monetary losses incurred in concentrated latex and block rubber production in Thailand, Department of Industrial Works (Department of Industrial Works (DIW), 2001) provided cleaner technology options that could be effective in reducing the observed losses.

In view of reducing the pollution associated with natural rubber processing, in-plant pollution control guidelines and wastewater discharge standards have already been established by central environmental authority of Sri Lanka (Central Environmental Authority (CEA), 1992; Central Environmental Authority (CEA), 2013). Also, several studies have used life cycle assessment (LCA) based approaches to quantify and mitigate the environmental impacts (i.e., emissions) associated with overall natural rubber production process. For instance, Jawjit et al. (2010) quantified the GHG emissions associated with the production of RSS, block rubber, and CL in Thailand. This study highlighted that fertilizer and energy use were the leading sources of GHG emissions in Thai natural rubber industry and such emissions could be reduced switching from synthetic fertilizer to animal manure, shifting from fossil fuels to renewable energy, and by energy and fertilizer efficiency improvement. Meanwhile, Jawjit et al. (2015), investigated the environmental performance of CL production in Thailand with use of LCA and proposed technically and practically viable cleaner technology options for improving the efficiency in consuming energy (i.e., electricity and fossil fuel), ammonia, and diammonium phosphate. GHG emissions in crepe rubber processing have also been appraised stressing the importance of using renewable energy (Kumara et al., 2016). Taking a different approach, Musikavong (2016) quantified the consumptive water use and water scarcity footprint of RSS production in

different provinces of Thailand with an ultimate goal of preserving water resources. No records were found on process analyses of crepe rubber manufacture.

All previous studies have taken only a partial approach by investigating either the economic or the environmental aspect of the natural rubber manufacturing process. There have been no studies on the efficiency of the entire manufacturing process. Therefore, this study aims to develop a sustainable manufacturing process in natural rubber processing industry using a novel methodical hierarchy that could be adopted by any other industry. This methodology was based on the process analysis tools of material flow analysis (MFA), material flow cost accounting (MFCA), and life cycle assessment (LCA). Unlike previous studies (i.e., Ulhasanah and Goto (2012), Nakano and Hirao (2011), and Schaltegger et al. (2012) that combined MFA, MFCA, and LCA, the present study took another step further by integrating Pareto, What-if, and cost benefit analyses into the methodology. Further, it proposes a concrete framework for conducting and continuing an improvement process at a facility for efficient management (please refer to Materials and Methods for more details).

With no any previous studies, processing of one of the principal raw rubber type, crepe rubber, was considered in the present study by investigating a Sri Lankan crepe rubber factory. Crepe rubber manufacturing is severely threatened by various economic and environmental issues and any improvements made in the process could be directly applied in medium/large scale RSS manufacturing. Crepe rubber is considered to be the purest form of natural raw rubber available in the market and Sri Lanka is known as the world's leading producer of crepe rubber (Rubber Research Institute of Sri Lanka, 2003). Due to the high degree of purity, crepe rubber is used to produce pharmaceutical and surgical items that are in contact with human body. However, in our previous research (Dunuwila et al., 2018), we analyzed the average material flow of the overall crepe rubber manufacturing process. To us, focusing on one factory would give a more specific idea toward developing a financially viable and eco-friendly manufacturing process in any natural rubber factory and an opportunity to test the preceding methodical hierarchy on a more practical level.

2. Crepe rubber manufacturing process

Fig. 1 illustrates the crepe rubber manufacturing process and the activities that we consider in this study. First, fresh rubber latex (field latex) collected from rubber fields is transported to the factory and unloaded into bulking tanks for the standardization process. Initially in this process, percentage dry rubber content of the field latex (i.e., 30–40% by weight of latex (Rubber Research Institute of Sri Lanka, 2003)) is measured using Metrolac instrument (i.e., a type of hydrometer). Thereafter, proportional to the dry rubber content, sodium bisulfite and water are added into the tanks as a dilutant and a preservative, respectively. After these additions, fractionation tends to occur. Fractionation is a partial coagulation where the yellow fraction is coagulated right after the addition of both the preservative and water. This yellow fraction is usually 10% of the dry rubber mass (Rubber Research Institute of Sri Lanka, 2003). After the extraction of the yellow portion, the fractioned latex (white fraction) is passed into coagulation tanks. In the coagulation process, formic acid (coagulant) and bleaching agent are added into the system. Water is also added to dilute the chemicals and make them consistently dispersed across the white fraction. After the coagulation process, coagulum is removed as cubical pieces and sent through a series of roller mills (macerator, diamond roller, smooth roller) to get thin laces of rubber. For the whole milling process, a large amount of fresh water is used for cleaning the laces and bulks, and for machinery cooling. After the milling process, laces are sent to the drying tower for the drying process. The laces are left for three to four days for drying and then sent to the folding section. In this section, crepe laces are placed in a stack form to make 25-kg bulks, and the dirt is removed. Then, the folded mats are passed through two

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