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Enhancement of Eco-Efficiency Through Life Cycle Assessment in Crumb Rubber Processing

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Abstract

Indonesia is the second largest country that produce natural rubber in the world after Thailand. The present practice in crumb rubber factories uses large volume of water and energy needs to be more efficient in their materials and energy usage and leads to environmental problems. The rubber industry needs to improve its competitiveness not only to increase profits but to ensure sustainability. Life Cycle Assessment (LCA) and Eco-Efficiency are used as the combined approach in this research to attain that objective. The study was conducted on two selected crumb rubber processing plants, Factory A and Factory B, in North Sumatera, Indonesia. The main objectives of the study are to conduct life cycle inventory for crumb rubber processing, analyze the environment impact from the life cycle processing activities, and implement opportunities towards environmental improvements through LCA and also to suggest improvements of the impacts from the current practices of crumb rubber processing towards eco-efficiency. This study is a gate to gate study where data inventory starts from acceptance of cup lump from plantation and skim latex as a by product of latex concentrate processing. Based on the results obtained, Factory A contributed higher environmental impact than Factory B. Damage to resources is very high, dominantly contributed from fossil fuel. The highest impact in crumb rubber processing for Factory A is caused by formic acid (46.5%) and plastic (40.5%) with a total impact of 5.483 Pt, while for Factory B it is caused by plastic (64.5%), sulphuric acid (27.6%) with a total impact of 3.439 Pt. Factory B is found to be more eco-efficient in water consumption. As for energy intensity, Factory A has greater energy intensity compared to Factory B.

Keywords: crumb rubber processing, life cycle inventory, environmental impact, life cycle assessment, eco-efficiency

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1. Introduction

International forums have been raising much debate regarding the environmental issue such as global warming, ozone layer depletion, destruction of natural habitats and loss of biodiversity. Global warming and its several potential effects on the earth is a consequence of long-term accumulation of the so-called greenhouse gases mainly (CH_4, CO_2, N_2O) in the atmosphere (Khasreen, 2009). Human activities, such as deforestation, burning of fossil fuels and changes in land use, affect the emissions of these gases. They stated that in such a global environmental scenario, activities in all sectors should take sustainability consideration as their prime importance execution in order to secure the future for the next generation (Asif, 2007). Concern for sustainability in the development and manufacture of new products is a strategy that is widely accepted in principle, although not yet widely practiced. The integration of environmental requirements throughout the entire lifetime of a product needs a new way of thinking and new decision tools to be applied (Kaebernick, 2003). Sustainable management of materials and products involve continuous evaluation of ecological, economic, and social factors. A number of methods and tools are now available to support this strategy. One of the most common tool is life-cycle assessment (LCA). Even though LCA is a very influential instrument for assessing the impact of an activity on the environment, it still has some limitations or drawbacks. LCA has limitation related to methodological approach, time boundaries which will affect the quality of the data and availability and further will affect the results significantly (Benedetto, 2009). LCA often lacks a sustainability perspective and bring about difficult trade-offs between depth and details (Henrik, 2006). LCA only correlates between environmental and social factors and has limited inclusion of financial consideration. It is suggested that Eco-Efficiency can complement LCA for establishing a correlation between environmental and economic impacts thus leading the way towards the consideration for sustainability. Concept of eco-efficiency itself was developed by the World Business Council for Sustainable Development (WBCSD) in 1992 and has been widely recognized by the business world (Verfaillie, 2000). Eco-efficiency concept is suitable to the industrial world, because its practical approach makes it possible to balance environmental and economic benefits (Maxime, 2006). It shows how companies get the benefits with minimal impact to the environment. Eco-efficiency basically means *doing more with less* – using environmental resources more efficiently; it improves environmental performance by reducing material, energy and other natural resources while minimizing cost and liabilities (BraungartMcDonough and Bollinger, 2007). Today natural rubber (NR) is one of the natural resources that is used widely to make a variety of end products, such as tyres and medical related products. From the International Rubber Study Group report, global natural rubber production and consumption is still dominated by Asia (IRSG, 2012). According to Indonesian Rubber Producer Association (GAPKINDO), the installed capacity of rubber processing currently in Indonesia is about 4.4 Mt and there are 218 rubber goods industries both small and big in Indonesia (Amir, 2012). Rubber goods industries in Indonesia are generally classified into several groups depending on the type of product, including tyre industries, engineering rubber good industries, latex good industries and general rubber goods industries (Rahman, 2009). Products from natural rubber processing produce many kinds of important rubber goods which provide big benefits to human beings. However, environmental damages created from this processing could become a big issue.

This research reviews the life cycle of rubber in skim latex which is as the by product stage from field latex to produce latex concentrate. Crumb rubber in this study is made from rubber in skim latex and cup lumps from plantation, which known as crumb rubber non-standardized. This process uses large amount of chemicals and consumes large volumes of water and energy. The most common environmental issues are wastewater containing chemicals and odour. Therefore, waste abatement and management in crumb rubber processing sector should be handled effectively and responsibly in order to reduce the damage to the environment. Then the question is how to achieve environmental improvements in parallel with economic benefits from the rubber industry.

2. Literature Review And Hypotheses

2.1 Introduction

The latex of *Hevea brasiliensis* or natural rubber tree consists of 20%-35% rubber and the rest non-rubber material. Each pure rubber particle is surrounded by soapy-like substances which is made up of emulsion in aqueous (watery) phase. Carbohydrates, lipids, microorganisms, minerals, proteins and water are non-rubber matters in the aqueous phase and known as serum (White, 2001). Stability of the fresh latex is controlled by the existence of proteins and lipids (Ho, 1979). Processing in liquid rubber will produce concentrated latex as a main product and skim latex as by product. Skim latex contains non rubber fraction with a large watery fraction known as natural rubber waste serum (NRWS) and contains 5% dry rubber content (DRC) and about 7% total solid content (TSC) (Mahat and MacRae, 1992). Acid is usually added as coagulant to separate rubber from the liquid (skim serum). The effluents resulting from rubber processing have been shown to have high pollution potentials caused by the presence of components such as phosphates and nitrates which will increase the nutrient value of water bodies (Atagana, 1999). Nowadays, increasing demand of chemical products has created a bad perception in the community because it will reduce the quality of life. Based on research, this resulted in high costs due to waste generated and can reach as high as 40% of production costs (Clark, 2005). This is marked by changes in industry behaviour in the 20th century and the 21st century which in some ways focus on reducing the impact to the environment.

There are some common thread that links how to get a process that will produce a product that has full commitment to environmental stability. Also there are several parties that are interconnected to create these conditions, in particular government and industry. Industry has the main aim that a process will produce products with maximum profit, use of minimum and maximum natural resources compliance to government rules. On the other hand, the government is faced with a reality that the industry can employ labour, tax sources to run the government, however the industry can also cause environmental damage. Hence, the government should have rules which support industrial activities without causing environmental damage and could be quantified. Eco-efficiency is a term that connects both economic and environmental parameters.

2.2 Eco-Efficiency

Eco-efficiency is a concept that connects environmental and economic on how industries get the benefits with minimal impact to the environment. Cost will be reduced and increased competitiveness will be achieved through realization of eco-efficiency and finally companies can realize better environmental outcomes (FIFA, 2003). Basically eco-efficiency indicate *doing more with less* – by using resources more efficiently; it can improve environmental performance by reducing materials, energy and other natural resources while minimizing cost and liabilities. Eco-efficiency technologies is selected as environmental technology because of high potentials application (Bleischwitz, 2002).

Concept of eco-efficiency was developed by the World Business Council for Sustainable Development (WBCSD) in 1992 and has been largely accepted by the business world (Verfaillie, 2000). In 2000, WBCSD introduced 3 objectives of eco-efficiency through decreasing resource consumption, decreasing impact to environment and providing high product or service value. Generally, the purpose of these objectives are to offer opportunities for business savings (Canada, 2002).

- *Measuring Eco-Efficiency*

Eco efficiency is calculated as:

(Economic value added)/(Environmental impact added), (Eq.1)

and can be represented by

(Product or Service value)/(Environmental influence). (Eq.2)

Products or service value is adapted to the business that can be operated: quantity of goods or services produced or provided to costumers or net sales (WBSCD, 2000), (Dunning, 2004). Therefore it can be expressed in volume or mass of raw material or product of ongoing process. Besides, it can also be expressed as monetary, to show eco-efficiency is related to money. Meanwhile environmental influences can be divided into two parts: environmental influences during service creation and during service use. Environmental influences during service creation involve the use of materials, energy consumption, water consumption and emissions. Environmental influences during service use concern on packaging usage, energy consumption, and emissions during use. Product value can be shown as functions and performance in Japan (Taeko, 2004).

- *Eco-Efficiency Indicator*

The National Round Table on the Environment and the Economy, (NRTEE, 2001) identified three indicators for eco-efficiency i.e., waste intensity indicator, energy intensity indicator and water intensity indicator. These indicators can be calculated as:

$$\text{Waste intensity} = \frac{\text{total waste leaving the project boundary}}{\text{unit of production or service delivery}} \qquad \text{(Eq 3)}$$

$$\text{Energy intensity} = \frac{\text{energy consumed within the project boundary from all sources}}{\text{unit of production or service delivery}} \qquad \text{(Eq.4)}$$

$$\text{Water intensity} = \frac{\text{water taken into boundary}}{\text{unit of production or service delivery}} \qquad \text{(Eq.5)}$$

There are environmental indicators to show eco-efficiency, such as material consumption, energy consumption, water consumption, waste water consumption, solid waste consumption and greenhouse gas emission (Rattanapan, 2012). Energy, waste, and water have been used by many companies to identify efficiency or the performance of the process.

2.3 Life Cycle Assessment (LCA)

Life cycle thinking is one of the main ways to reduce emission to environment by reducing resource use and also to enhance performance of socio-economic through life cycle (UNEP, 2004). Life cycle perspective helps ensure that the activities are environmentally sound, have competitive advantage, reduce costs, and designing a result in better product. determined Life Cycle Assessment (LCA) is a concept as well as a tool to determine the amount of burden to the environment as a result of human activity (Das, 2005). The European Commission (EC) concluded that LCA provides the best framework for assessing the potential environmental impacts. It provides a framework for analyzing and evaluating the environmental impacts of the life cycle products system (EC, 2008). The assessments of activities are reviewed from extraction until disposal, known as from cradle to grave or gate to gate, such as during processing. Material use, energy use and waste released to the environment are reviewed quantitatively and qualitatively. The advantage of using LCA principles helping decision makers to choose a series of activities that will give the smallest effect to the environment. Life Cycle Assessment is used as a tool to support the eco-efficiency concept and will give a quantitative value of the impact caused by the processes through the Life Cycle Impact Assessment (LCIA). This potential of LCA as a tool can support the eco-efficiency approach (van Berkel, 2002). LCA is currently regulated in ISO 14040 (2006), and ISO 14044 (2006). ISO 14040 is about the technical requirements which describe the principles and framework and ISO 14044 is about requirements and guidelines. Life cycle impact assessment (LCIA) is used as a tool by identifying quantitatively the energy and materials used, and wastes released to the environment.

3. Methodology

The study is conducted on the selected premises of two crumb rubber processing factory, Factory A and Factory B in North Sumatera.

There are stages to apply LCA: Goal and Scope, life cycle inventory, life cycle impact assessment, life cycle interpretation. Goal and scope of the study is to assess the impact of water, energy and material uses and releases to the environment in crumb rubber processing

Functional unit of the study is to process 1,000 kg crumb rubber non-standardized.

System boundary will limit activities that will be reviewed. Crumb rubber processing in this research is chosen start from skim latex produce in centrifuge until production of crumb rubber. This system boundary is shown in Figure 1.

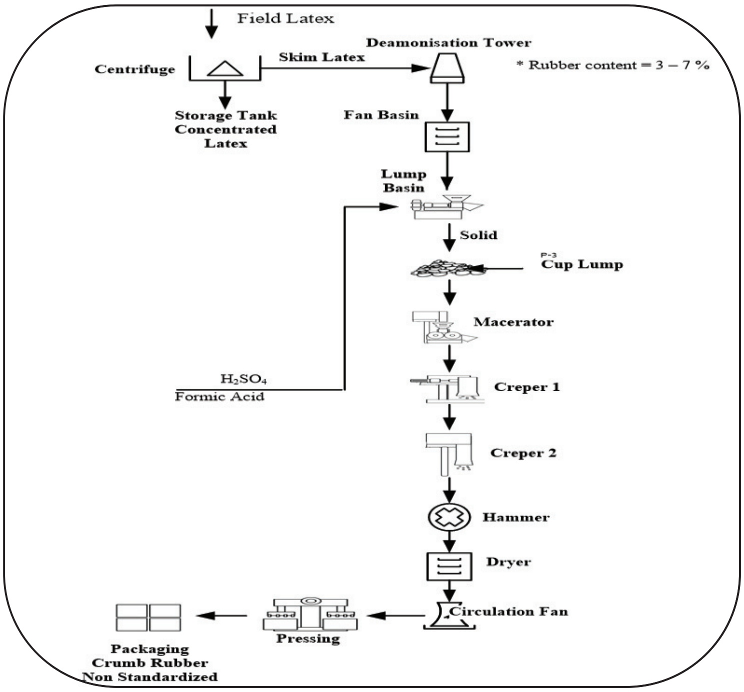

Fig 1. System boundary crumb rubber processing

Life cycle inventory is done to collect data such as rubber composition, chemical consumption, energy consumption and water consumption. Life cycle impact assessment (LCIA) is a step to evaluate the impact of crumb rubber processing, such as impact categories. Simapro is used as a software to calculate the impact categories by using Eco-Indicator 99 methodology.

Interpretation is made after calculation the impact.

Eco-efficiency is calculated after doing life cycle inventory and having the impacts from LCIA

3.1. Research Goal

The main objectives of the study are to conduct life cycle inventory for crumb rubber processing, analyze the environment impact from the life cycle processing activities, implement opportunities towards environmental improvements through LCA and also to suggest improvements of the impacts from the current practices of crumb rubber processing towards eco-efficiency.

3.2. Sample and Data Collection

Centrifugation is a simple way to concentrate suspensions in liquids and separate rubber to form latex concentrate and a by-product skim latex. Some rubber also makes its way to the coagulation pond and there are losses in rubber along the process lines (Cecil, 2003). Based on observations, composition of rubber in skim latex is 5.4%-14% (DIW, 2001).

Table 1. Life cycle inventory in crumb rubber processing of Factory A and Factory B

No	Component	Unit	Factory A	Factory B
1	Rubber in Skim Latex	%	6.85	6.75
2	Chemical: Formic Acid	kg	7.33	
	Sulphuric Acid	kg		18.38
3	Energy consumption	kwh	199.93	128.03
4	Water consumption	M^3	34.93	10.99
5	Plastic for packaging	kg	3.99	3.99

3.3. Analyses and Results

To produce crumb rubber, acids are added to skim latex to coagulate the rubber. Different compounds are used by the two factories. Factory A adds 7.33 kg of formic acid per ton of concentrated latex while Factory B uses sulphuric acid as much as 18.38 kg per ton of crumb rubber.

The use of energy for crumb rubber processing in Indonesia is still within the limits (Anas, 2007) (DIW, 2001). Based on energy audit in Malaysia's rubber and rubber industries showed electric motor as the equipment that consumes the highest energy followed by pumps and heater (Saidur, 2009).

.Factory A uses 36% energy more than Factory B. The amount of additional energy can be caused to use cup lumps. Cup lumps in Factory A which come from requirements independent sources, thereby cleanliness does not meet Indonesia National Standard, SNI 06-2047-2002. Lump in Factory B come from its own plantation therefore the quality and cleanliness can be regulated. Cup lump that come from other plantations still contain many pieces of wood and sand and must be washed repeatedly resulting in high energy and water usage (Utomo, 2010).

The amount of energy used in block skim rubber of Factory A and Factory B is still within the range of similar industry, although Factory A uses more energy than Factory B. Dryer, circulation fan and pressing are the equipments in crumb rubber processes that use the highest amount of energy. Energy consumption during drying involves sensible heat and latent heat for the phase change of water content to be evaporated. It means that water content before drying must be in a minimum amount to lower energy consumption.

Water used at Factory A in crumb rubber processing is more widely used for washing coagulum, and washing the cup lump from independent source and washing the thin layer of rubber at every stage before drying. Hence, cup lumps from independent sources need to obtain as clean cup lumps before it is sold to the factory. Water usage for crumb rubber in Factory A is 3.18 times more compared to Factory B. It shows that Factory B has already used the water efficiently. Water consumption is closely related to the wastewater generated. The more water used, the more the amount of wastewater discharge (effluent) to a system (Leong S.T.; Muttamara S.; Laortanakul, 2003), (Rungruang, 2008). So water usage must be used efficiently.

3.3.1 Life Cycle Impact Assessment

Life cycle impact assessment is calculated using Eco-Indicator 99, with Hierarchical (HI) version as a damage model. According to Eco-Indicator 99, characterization consists of 11 impact categories that give impact to air, water and soil: namely, carcinogen, respiratory organics, respiratory inorganics, climate change, radiation, ozone layer, ecotoxicity, acidification/eutrophication, land use, minerals, and fossil fuels (M. Goedkoop, & Spriensma, R, 2001; M. Goedkoop, Schryver, A., & Oele, M, 2008). Generally, processing of natural rubber causes many environmental impacts to air, water and odor pollution (Tekasakul, 2006). Addition of acid to coagulate the rubber in skim latex causes the effluent to become acidic and there are many other impacts caused by natural rubber processing as describe below.

- *Weighting*

Weighting is done following the procedures from Eco-Indicator 99, to know the important categories after characterization and normalization, and makes it possible to directly compare the categories. The unit of weighting is point in which one point indicate the weighted impact from one mille-person equivalent (the impact per year from 1/1,000 persons).

In crumb rubber processing, fossil fuel is the highest impact, followed by respiratory inorganics, carcinogens and climate change. Impacts to fossil fuel comes from formic acid at 1.9527 pt (49%) and wrapping plastic at 1.7473 pt (43.81%). Overall impact to crumb rubber processing in Factory A comes from formic acid at 2.5504 pt (46.52%) and plastic packaging at 2.2218 pt (40.45%). Plastic packaging gives the most impact during manufacturing (5.1 mPt), while in usage 0.31 mPt and disposal 0.025 mPt (VaržinskasStaniškis and Lebedys, 2009). It appears that impact during manufacturing is bigger than usage and disposal, so the use of plastic packaging should be as efficient as possible. Excessive size and thickness will have a large impact on the environment.

Crumb rubber processing in Factory B, contributed the most impact to fossil fuels, followed by respiratory in-organics, carcinogens and climate change. Plastic packaging contributes the highest impact (64%), and sulphuric acid (28%) from the total impacts of 3.4393 pt. Plastic packaging gives impact most in fossil fuels and sulphuric acid gives impact most to respiratory in-organics.

Figure 2, shown that Factory A contribute more impact to environment almost in all impact categories than Factory B and fossil fuel is the highest

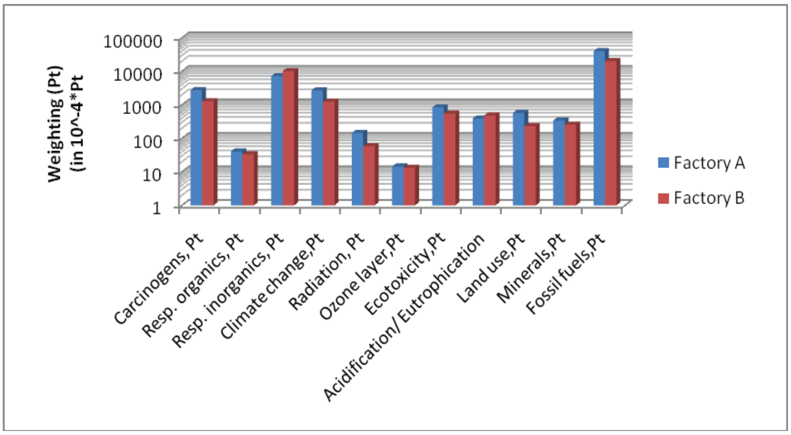

Fig 2. Weighting in crumb rubber processing of Factory a and Factory B

- *Eco-Efficiency*

The Eco-Efficiency concept is suitable for the industrial world because its practical approach makes it possible to balance environmental and economic benefits (Maxime, 2006). Eco efficiency is calculated as Eq. (2):

Eco-Efficiency = (Product or Service Value/ Environmental Impact)

In this research product or service value is functional unit or mass of crumb rubber, and environmental impact as impact categories or damages in Eco-Indicator 99. Based on the Life Cycle Impact Assessment for crumb rubber processing for Factory A and Factory B, there were some impact categories that are significant and some are very small and can be neglected. In crumb rubber processing the value of organic respiratory, radiation, ozone layer are very small. Therefore the impacts can be neglected compared to the other categories. depicted in Table 2.

Table 2. Eco-Efficiency of crumb rubber processing in Factory A and Factory B based on Impact Categories

Impact Categories	**Eco-Efficiency (kg/Pt) Crumb Rubber**	
	Factory A	**Factory B**
Carcinogens	3,620,E+03	7,872,E+03
Resp. inorganics	1,399,E+03	9,871,E+02
Climate change	3,711,E+03	8,110,E+03
Ecotoxicity	1,198,E+04	1,825,E+04
Acidification/ Eutrophication	2,562,E+04	2,075,E+04
Land use	1,752,E+04	4,291,E+04
Minerals	2,948,E+04	3,893,E+04
Fossil fuels	2,507,E+02	4,966,E+02

Eco-efficiency of crumb rubber processing of Factory B is greater than Factory A. Formic acid contributes impact of 35.6% and plastic 31.9% to fossil fuels which will give small eco-efficiency value in Factory A. Respiratory inorganic also affect small eco-efficiency because of impact by formic acid 4.6% and plastic 5.5%. Plastic (50.8%) was found to be the main cause for impact to fossil fuels and sulphuric acid 19.1 % to respiratory in-organics that influence the eco-efficiency in Factory B.

The sequence of impact for Factory A is caused by: Formic acid 46.5%, Plastic 40.5%, Water 10.4% and Electricity 2.6% with total impact of 3.439 pt. The same result is obtained for Factory B where the sequence of components that provide the impacts in crumb rubber processing are: plastic 64.5%, sulphuric acid 27.6%, water 5.2% and electricity 2.7% with total impact of 5.483 pt.

Contributors of impact in crumb rubber processing at Factory A are formic acid, plastic, water and electricity. Meanwhile contributors impact on Factory B are: plastic, sulphuric acid, water and electricity. The plastic used for packaging crumb rubber should be used with the precise size so that the volume and weight meet minimum desirable dimensions. This will lead to minimum impact to the environment (Mahat and MacRae, 1992).

3.3.2 Eco-Efficiency Indicator

Eco-Efficiency Indicator is determined by three factors: waste intensity, energy intensity and water intensity as shown in Table 2 for Factory A and Factory B.

Table 3. Eco-Efficiency Indicator Factory A and Factory B in crumb rubber processing

Eco-Efficiency Indicator	Crumb Rubber	
	Factory A	Factory B
Waste Intensity (kg/kg)	Nil	Nil
Energy Intensity (kWh/kg)	0.20	0.1280
Water Intensity(m^3/kg)	0.0349	0.0110

The definition of waste here is rubber which did not participate as a product in block skim rubber, which is also known as rubber losses. For the production of block skim rubber, there was no waste, because all the rubber entered to the first stage, Macerator in Factory A and Pre-breaker in Factory B, become crumb rubber as a product. It should be understood that waste entails double payment, namely, cost of raw material and management or disposal of the waste (Das, 2005).

Energy in crumb rubber processing is used to operate equipments such as, macerator, creper, hammer mill and drying machine. As for energy intensity, Factory A has greater energy intensity compared to Factory B. Dryer is the equipment that uses the most energy followed by hammer mill, and presses. Therefore more attention is required to use energy more efficiently. This indicates that factory B is more eco-efficient in term of energy use.

A great quantity of the water consumed in crumb rubber processing is used for washing solid rubber from skim latex and cup lumps from plantation which has poor quality, cleaning equipment and surrounding area. Thereby Factory B is found to be more eco-efficient in water consumption.

4. Conclusion

Factory A uses more chemical than Factory B in crumb rubber processing. Energy is needed to drive the motors and pumps as well as for the drying process. Factory A is less efficient than Factory B since it uses 36% more energy. Factory A uses water 2.18 times more compare to Factory B. Therefore, chemical, energy, water and plastic packaging are the components required in crumb rubber processing, but furthermore will give negative impact on the environment.

Impact on environment of crumb rubber processing is calculated using the Eco-Indicator 99 method. A similar trend of impact to the environment was shown by both factories. Fossil fuel is very dominant in impact categories and has the highest percentage value followed by respiratory in-organics, climate change. Based on research conducted, Factory A contribute higher environmental impact than Factory B for crumb rubber processing.

The highest impact in crumb rubber processing for Factory A is caused by formic acid at 46.5% and plastic at 40.5% with total impact of 5.483 Pt, while for Factory B is caused by plastic at 64.5%, sulphuric acid at 27.6% with total impact of 3.439 Pt.

For eco-efficiency measurement, 8 impact categories were chosen from 11 impact categories as the most influential impacts which cause environmental damage from block skim rubber processing. It appears that damage to resource cause of impact on fossil fuels provides the smallest eco-efficiency. Therefore there is a need to manage the resource in order to improve the eco-efficiency.

- *Eco-Efficiency Indicator is determined by three factors: waste intensity, energy intensity and water intensity. Waste intensity is almost zero for both factories. Based on eco-efficiency indicator, water intensity for Factory A for crumb rubber processing is greater than Factory B. Therefore factory B is found to be more eco-efficient in water consumption. As for energy intensity, Factory A has greater energy intensity compared to Factory B for crumb processing. Factory A give greater emissions compared to Factory B. This indicates that factory B is more eco-efficient in energy consumption.*

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