# Evaluating Environmental Performance of Concentrated Latex Production in Thailand

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## Abstract

*Justification of the paper:* Thailand has been the world's largest natural rubber (NR) producer since 2003. Concentrated latex is one of the three primary rubber products (the other two are block rubber and ribbed smoked sheet rubber), used as raw material for dipped rubber products such as gloves, condoms. Since NR products are being exported to the international market, they need a declaration of information on sustainable production in the near future. The production of concentrated latex is an energy-intensive process, and contributes to several environmental pollutions. Several studies exist on the treatment of this pollution, especially on wastewater treatment for concentrated latex mills. However, studies including a life cycle assessment or cleaner technologies for this industry are still limited.

*Purpose:* The objective of this study is to assess the potential environmental impact of concentrated latex production by Life Cycle Assessment (LCA), and to investigate the effects of cleaner technology (CT) options to reduce the impact.

*Theoretical framework:* The methodology is based on the ISO 14040 series, taking a "Gate-to-Gate" approach (Partial LCA). Our system includes two main subsystems; fresh latex transportation and concentrated latex production. The activities taken into account include electricity use, diesel use (for transportation and heating), chemicals use (ammonia, lauric acid, DAP, zinc oxide), and wastewater treatment. The functional unit is 1 ton of concentrated latex, whereas the environmental impacts considered in this study include global warming, acidification, eutrophication, human toxicity, photochemical oxidation, and the total environmental impact. Data was collected from four concentrated latex mills in the south of Thailand.

*Results:* The results indicate that electricity use for centrifugation has the largest share, compared with other activities, in global warming (53%), acidification (60%), and photochemical oxidation (60%). Ammonia use for latex preservation accounts for 40% of human toxicity, whereas use of DAP accounts for 60% of eutrophication. Diesel use for heating was also found to be an important contributor to several environmental impacts. Based on these results, the following cleaner technology (CT) options are therefore identified: 1) electricity efficiency improvement (by installation of inverters to centrifugal machines); 2) improvement of ammonia preparation and storage (by chilling systems); 3) minimizing the use of DAP (by extending coagulation time); and 4) substitution of diesel by LPG. These four CT options result in reductions of the total environmental impact by 12%, 8%, 3%, and 5%, respectively.

*Conclusion:* Applications of LCA and CT were found to be appropriate tools to identify options to simultaneously increase production efficiency and environmental performance of concentrated latex manufacturers in Thailand. Results from the LCA can be used to identify and prioritize the important activities (electricity use, and ammonia use in this study) associated with the environmental impact. All of the CT options presented in this study were technically and practically feasible for concentrated latex production.

**Keywords:** Rubber; Concentrated latex; Life Cycle Assessment; Cleaner Technology; Thailand

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## 1. Introduction

Thailand has been the world's largest natural rubber (NR) producer since 2003 (RRI, 2008), and has a share of about 35% of the latex produced worldwide. In 2011, Thailand produced about 3.4 million ton of fresh latex with an average yield of 1.6 ton fresh latex per hectare (OAE, 2012). The fresh latex is tapped and collected as a liquid, and then processed to primary rubber products. The primary rubber products are then processed to various final rubber products. Important primary rubber products include concentrated latex, block rubber, and ribbed smoked sheet rubber. Concentrated latex is the primary rubber product used as the raw material for dipped rubber products such as condoms, gloves, balloons, and infant pacifiers. Most of concentrated latex (about 70%) produced in

Thailand is exported, mainly to European countries, China, India and Malaysia (RRI, 2012). In 2011 Thailand exported about 880,000 tons of concentrated latex, with a value of 77,000 million baht (OAE, 2012).

Since natural rubber and concentrated latex are being exported to the international market, the requirement of information on sustainable production has been becoming inevitable. Therefore, it has been challenging for Thai rubber entrepreneurs to seek for appropriate measures to produce environmentally friendly rubber products. The production of concentrated latex is an energy-intensive process, and contributes to several environmental problems such as water pollution (acidic wastewater), malodorous problems (odor of rubber, and chemicals), and toxicity from the use of chemicals (such as sulfuric acid and ammonia). Tekasakul and Tekasakul (2006) described the environmental problems that are caused by concentrated latex production. Wastewater from the concentrated latex processing mill is highly acidic due to sulfuric acid addition, whereas applications of ammonia and de-ammonization process result in malodorous problem and toxicity problems. Diesel combustion in the drying process contributes to air pollution. Several studies on "end-of-pipe treatment", especially on anaerobic wastewater treatment, have been published (e.g. Jawjit and Liengchareonsit, 2010; Leong et al., 2003; Nguyen, 1999; Rakkoed et al., 1999). Applications of "pollution prevention" approaches for concentrated latex production were presented by the Department of Industrial Work (DIW, 2001) and the Pollution Control Department (2005). The Safety Technology Office (STO, 2005) proposed several measures for energy conservation in rubber processing mills. In a recent study on greenhouse gases emissions of rubber industry in Thailand, we also included production of concentrated latex, and found that energy-related emissions are the main causes of greenhouse gases (Jawjit et al., 2010). Nevertheless, life cycle assessments of concentrated latex production have not yet been widely published.

The objectives of this study are 1) to analyse consumption of resources and energy, waste generation, emissions of pollutants, and the potential environmental impact through partial life cycle assessment, and 2) to investigate cleaner technology (CT) options to reduce the environmental impact of concentrated latex production. In the next section an overview of the concentrated latex production process is presented, and the methodology is explained in section 3. Section 4 presents results and a discussion on activity data, emissions inventories, and the potential impact assessment, and section 5 focuses on the effects of cleaner production technology (CT).

## 2. Concentrated latex production

The lifetime of rubber plantation in Thailand is about 20-25 years. After about seven years of plantation, rubber tree can be tapped for the fresh latex for 13-18 years (Allen, 2004). The usual method applied in Thailand to prevent premature coagulation is to add anti-coagulant to the latex in the tapping cups and collecting buckets in order to increase pH of latex. The anticoagulant must be added as soon as possible after the tree is tapped. Anti-coagulants used in Thailand are ammonia, sodium sulphite, formalin and Tetra methyl thiurum disulphide (TMTD) or Zinc oxide (ZnO). Ammonia is recommended and used commonly in Thailand because it is cheap and can be locally produced. The amount of ammonia to be added to latex for prevention of natural coagulation depends on the season and the distance from collection site to processing factory; longer transportation distances demand for a higher amount of ammonia. It is obvious that a higher added amount of ammonia will need a higher amount of acid for neutralization of the latex in the factory. Thai rubber farmers transport the preserved fresh latex to the concentrated latex processing mills by pick-up car or 6-wheel truck.

A schematic diagram of concentrated latex production is presented in Figure 1. When the preserved fresh latex arrives at the mill, a sample is drawn from the tank for a quick test for DRC (dry rubber content), and for the ammonia concentration**.** The latex is then transferred through a sieve into the reception tank. Ammonia, TMTD/ZnO, and DAP (Diammonium phosphate) are added, and the latex is then transferred into a dilution tank**.** The purpose of dilution is to bring the latex to a standard DRC, for optimum separating efficiency in the centrifuge and to meet the requirements for the concentrate that is to be produced. After thorough mixing, the rubber content and water is separated to produce the concentrated latex. There are four methods for producing the concentrated latex (centrifugation, creaming, evaporation, and electrodecantation). In Thailand centrifugation is the most favorite method (DIW, 2005). After centrifugation, a concentrate fraction and a skim fraction are produce. The DRC in the concentrated latex is about 60-70%, but the water layer (skim latex) still contains up to 8% (by wet weight) dry rubber (Cecil and Mitchell, 2003). This water phase is discharged to a skimming tank for skim rubber production. If high-ammonia concentrated latex is to be produced, it is further ammoniated by adding the appropriate amount of ammonia gas (about 0.7%). For low-ammonia concentrated latex, about 0.25% ammonia and other preservatives (such as TMTD/ZnO) are added. Thereafter the concentrated rubber is put in the stainless steel containers for export (Nguyen, 1999). The skim latex can be further processed for skim block rubber. Rubber content in the skim latex can be coagulated by adding sulfuric acid. Nevertheless, before adding sulfuric acid the skim latex is de-ammonized in order to reduce the amount of sulfuric acid used for coagulation. After a coagulation time of about 24-48 hours, the coagulum is transformed by crushing, milling, and cutting machines to get rubber block. Then the rubber block is sent to a dryer, and is mechanically pressed to form skim block rubber.

## 3. Methodology

### 3.1 Goal definition

The objective of this study is to analyze the potential environmental impact associated with production of concentrated latex by life cycle assessment. In addition, cleaner technology options for reducing the environmental impact are also investigated.

### 3.2 System definition

Figure 1 illustrates the system boundary of this study. We take a "Gate-to-Gate" approach (partial LCA), including fresh latex transportation, production of concentrated latex, and production of skim block rubber. Activities taken into account are diesel use in fresh latex transportation, diesel use for drying, electricity use, and use of chemicals. The important chemicals used in concentrated latex production include ammonia, DAP, zinc oxide, TMTD, lauric acid, and sulfuric acid. There are two types of concentrated latex: high-ammonia (HA) concentrated latex (0.3-0.7%), and low-ammonia (LA) concentrated latex (less than 0.3%). In this study the calculation was based on HA concentrated latex because of its larger share in total production in Thailand. In case of fuel used for drying, either diesel or LPG is used. In this study diesel was selected for emission calculation due to more favorite choice. Based on interviews (see below) on fresh latex transportation, we assume that the farmers use pick-up cars to deliver fresh latex to the mills.

### 3.3 Functional unit

The emission inventory and the potential environmental impact are quantified relative to the functional unit, which is 1 ton of concentrated latex. As mentioned in Section 2, it should be noted that most of concentrated latex processing mills in Thailand also produce the skim block rubber as a by-product, which is produced from the skim latex. On average, the production of 1 ton concentrated latex results in about 65 kg skim block rubber. We therefore allocated energy and resources to concentrated latex and skim block rubber (until centrifugation process) in our analyses. The allocation procedure was based on mass of concentrated latex and skim block rubber. In order to explore the real environmental impact of concentrated latex production in Thailand, energy and resources used in the production of 65 kg skim block rubber were also taken into account in the calculations of emissions and the potential environmental impact associated with 1 ton of concentrated latex.

### 3.4 Activity data collection

Data on concentrated latex production were obtained during high production season of fresh latex from four concentrated latex processing mills located at the south of Thailand (two mills in Suratthani province (Mill A and B), and two mills in Nakhon si thammarat province (Mill C and D). During site visits, interviews were taken, and discussions held with the owners of the mills and technicians. The four mills have similar production capacities, production processes and general practices. the only important exception is the use of LPG instead of diesel for drying skim block rubber at Mill C. Nevertheless for this study diesel use was assumed for the calculations, and LPG was considered alternative option. Information on fresh latex transportation was obtained from interviewing 30 farmers, delivering fresh latex to the mills. There are two means for transporting the preserved fresh latex to the mill; transportation by farmers themselves, or transportation by middlemen. In general, Thai rubber farmers prefer to transport the latex themselves. They may deliver by pick-up car or 6-wheel truck. Farmers consider 60 km as an acceptable maximum distance between plantation sites and mills. For greater distances, the farmers prefer to deliver to the middleman. Additional information of activity data was taken from secondary data such as Jawjit et al. (2010), PCD (2005), STO (2005), and DIW (2001).

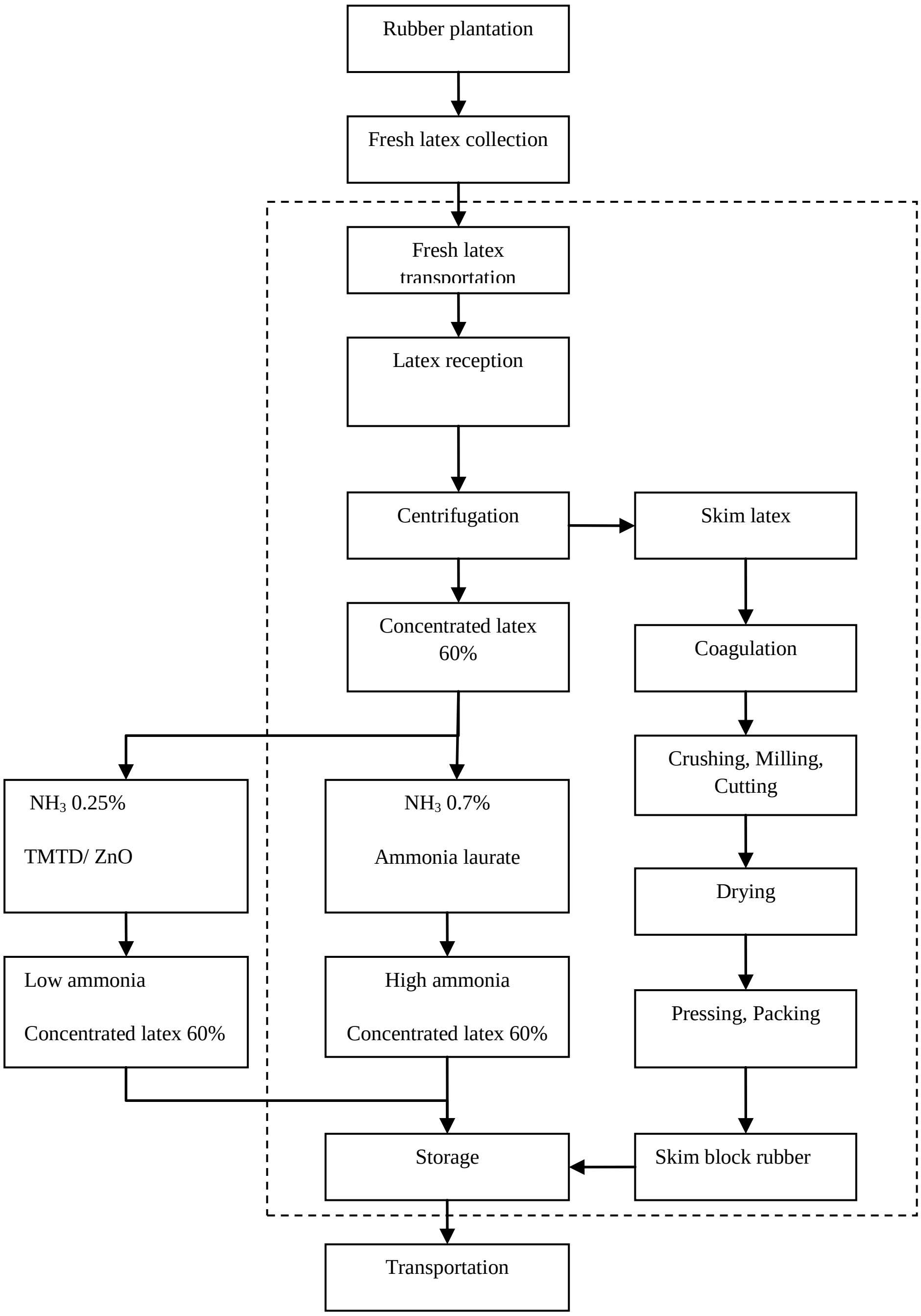


**Figure 1** Schematic diagram of concentrated latex production. The dotted lines indicate the system boundary of this study. See text for explanation.

### 3.5 Inventory analysis

Emissions of pollutants emitted from concentrated latex production were quantified as a function of activities (section 3.4) and emission factors. Activity data used in the analysis were mainly from local sources as mentioned above. Values of energy and resources used for producing 1 ton of concentrated latex and 65 kg of the by-product skim block rubber were summed for calculating emissions and potential environmental impact. Emission factors were taken from both Thai and international sources. If available, Thailand-specific emission factors were used. However, Thailand-specific emission factors are not widely available, and they were developed mainly for greenhouse gases emissions. Thailand-specific emission factors used in this study include emission factors for greenhouse gas emissions from electricity production (EGAT, 2011), and diesel use in transportation (TGO, 2011). In case no Thailand-specific emission factors are available, emission factors were taken from Eco-invent 2.0. The emission factors of the chemicals are included both for the production of the chemicals and during use. Nevertheless, emission factor and charectisation factor for TMTD or related substances are not available from any sources. Therefore, emissions and impact assessment from TMTD are therefore not calculated.

### 3.6 Impact assessment

Five environmental impacts were selected in this study based on geographical scale of the impact. These environmental impacts include global warming (global scale impact), acidification and eutrophication (regional scale impact), human toxicity and photochemical oxidation (local scale impact). The potential impact assessment was quantified by using characterisation factors developed by the Center of Environmental Science of Leiden University (CML) (Guinee et al., 2002). The CML method is based on “problem-oriented” or “mid-ponit” approach. The method “Eco-indicator 99” was also used for quantifying an aggregated single environmental impact number. It also served for reason of a sensitivity analysis in order to estimate the influence of the choice of life cycle impact assessment method on the result. The Eco-indicator 99 method is based on “damage-oriented” approach. The various environmental impacts are summed up and categorized to three damage categories including: human health, ecosystem quality, and resource consumption (Geodkoop and Spriensma, 2001).

### 3.7 Cleaner Technology (CT) options

Results from the emissions inventory and potential impact assessment were used for identifying the activities that are the largest causes of the environmental impacts. Cleaner technology (CT) options for these activities were reviewed and selected. Information on the CT options was obtained from site visits, interviews, and the literature. The potential effect of CT options on the environmental impact was quantified relative to the reference (no option) case.

## 4. Results and Discussions

### 4.1 Activities data

Table 1 presents the activities data for the production of 1 ton of concentrated latex (and 65 kg of the by-product skim block rubber). The four mills do not differ a lot with respect to these activities (except for electricity use in Mill D which may be overestimated). This similarity can be explained by the fact that the four mills are using similar technologies, production processes and practices. Technologies for concentrated latex production have not much changed during the last 6-7 years. Nevertheless, new machines, for example centrifuges, are likely to have higher separation efficiencies and lower energy consumption than that of the old machines. To produce 1 ton (dry rubber content) of concentrated latex, about 2.5 ton of fresh latex is used. Amount of chemical use for preservation directly depends on the composition of fresh latex. Ammonia, TMTD and ZnO are applied to the fresh latex for preserving latex quality. On average about 16-18 kg ammonia is used per ton concentrated latex, whereas TMTD and ZnO are equally applied by about 0.5-0.7 kg/1 ton concentrated latex each. DAP is used for removing magnesium from fresh latex, and is used by about 2-2.5 kg/1 ton concentrated latex.

Water is mainly used for cleaning reception tanks, centrifugation machines, and crushing and cutting machines. Some mills also use water for diluting concentrated latex. The average water use is about 6-7 $m^3$/ 1 ton concentrated latex. From site visits, it can be observed that Mill A and D apply some good practices for water conservation. Such practices include, for example, pressurized water guns for cleaning centrifuges, reception tanks, and floors. From sites visits, it became clear there are not many incentives for the mills to apply good practices for water conservation. This is because several mills use free-of-charged ground water and/or spring water. In contrast, mills have been applying several practices for reducing electricity use. Average electricity use is about 105-107 kWh/ 1 ton concentrated latex. Centrifugal machine is an important source that contributes to electricity use. Crushing, milling, cutting machines in skim block rubber production are also additional sources of electricity use.

To produce skim block rubber from the skim latex, sulfuric acid is applied to the serum after centrifugation for neutralization. As mentioned before, amount of applied sulfuric acid directly depends on ammonia content in the serum. In Mill A larger amounts of sulfuric acid are used because of more ammonia applied after tapping. The coagulated rubbers (Coagulum) are then sent to crushing, milling, and cutting machines to form the block rubber. After that it is dried. About 5-6 kg litre of diesel is used to dry 1 ton of concentrated latex. It is noteworthy that diesel may become less favorable as a fuel in the near future because of increasing prices. Mill C already switched from diesel to LPG, and the other three mills may follow in the near future.

Interviewing 30 farmers indicated that the distance between the rubber plantation fields and the rubber mill, to which the farmers deliver the fresh latex by themselves, is in the range of 5-60 km. An average value of 30 km (60 km round trip) was used for the emission calculations. The favorite vehicle of Thai farmers for transportation is a modified pick-up car. In case of further distance (more than 60 km), the farmers would instead deliver to the middleman, who collects the fresh latex to about 25-30 tons, and delivers by a trailer truck.

**Table 1** Activity data collected from four concentrated latex processing mills in Thailand. See text for details on mills and data collection methods. (Units: amounts per 1 ton of concentrated latex produced)

| Resource/ Energy use | Unit | Mill A | | Mill B | | Mill C | | Mill D | | Average value use for emission calculation |
|---|---|---|---|---|---|---|---|---|---|---|
| | | conc. latex[a)] | SBR[b)] | conc. latex | SBR | conc. latex | SBR | conc. latex | SBR | |
| Fresh latex | Ton | 2.35 | | 2.8 | | 2.2 | | 2.52 | | 2.5 |
| Water | $m^3$ | 5 | 1 | 10 | 2 | 8 | 1.5 | 6 | 1 | 7 |
| Electricity | $m^3$ | 102 | 5 | 100 | 5 | 100 | 5 | 150 [c)] | n.a.[d)] | 105 |
| Ammonia | kg | 18.3 | 0.55 | 16.7 | 0.50 | 16.9 | 0.51 | 17 | 0.51 | 17 |
| TMTD [e)] | kg | 0.65 | 0.03 | 0.5 | 0.02 | 0.6 | 0.03 | 0.65 | 0.03 | 0.6 |
| ZnO | kg | 0.65 | 0.03 | 0.5 | 0.02 | 0.6 | 0.03 | 0.65 | 0.03 | 0.6 |
| DAP [f)] | kg | 2.3 | 0.12 | 2.3 | 0.12 | 2.6 | 0.13 | 2 | 0.1 | 2.3 |
| Lauric acid | kg | 0.55 | 0 | 0.5 | 0 | 0.6 | 0 | 0.5 | 0 | 0.5 |
| Sulfuric acid | kg | 0 | 16 | 0 | 13.2 | 0 | 12.8 | 0 | 15.5 | 13.4 |
| Diesel | litre | 0 | 5 | 0 | 8 | - | - | 0 | 6 | 6.5 |
| LPG | kg | - | | - | | 3.4 | | - | | 3.4 |

[a)] conc. latex = concentrated latex; [b)] SBR = Skim Block Rubber; [c)] This value was not used because we consider it an over-estimation by the mill; [d)] n.a. = not available; [e)] Emissions of TMTD (Tetra Methyl Thiurum Disulphide) are not calculated because of lack of emission factors; [f)] DAP = Diammonium Phosphate

**Table 2** Emissions of selected pollutants generated from production of 1 ton concentrated latex

| Environmental impact/ Pollutants | Unit | Total | Activities | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | DAP use | ZnO use | Lauric acid use | Ammonia use | Diesel use for transport | $H_2SO_4$ use | Electricity use | Diesel use for drying |
| Global warming | | | | | | | | | | |
| $CO_2$ | kg | 148 | 3.6 | 1.8 | 0.4 | 34.1 | 17.3 | 1.8 | 74.5 | 14.5 |
| $CH_4$ | g | 533 | 5.4 | 4.3 | 1.7 | 67.7 | 0.6 | 2.4 | 433.2 | 17.7 |
| $N_2O$ | g | 3 | 0.1 | 0.0 | 0.9 | 0.5 | 0 | 0.03 | 1.5 | 0.4 |
| Acidification | | | | | | | | | | |
| $SO_2$ | g | 1105 | 80.3 | 1.2 | 1.4 | 75.2 | 14.4 | 173.2 | 736.9 | 21.9 |
| $NO_x$ | g | 583 | 10.9 | 1.6 | 2.9 | 42.0 | 70.1 | 10.8 | 183.1 | 261.4 |
| $NH_3$ | g | 2 | 0.1 | 0.0 | 1.2 | 0.3 | 0 | 0.1 | 0.1 | 0.0 |
| Eutrophication | | | | | | | | | | |
| Phosphate | g | 122 | 121.4 | 0.0 | 0.2 | 0.4 | 0 | 0.1 | 0.1 | 0.0 |
| Nitrate | g | 23 | 4.8 | 0.6 | 0.7 | 16.2 | 0 | 5.0 | 5.7 | 0 |
| COD | g | 141 | 7.0 | 0.5 | 3.0 | 85.9 | 0 | 7.9 | 36.2 | 0.7 |
| N | g | 2 | 0.0 | 0.0 | 0.6 | 1.7 | 0 | 0.0 | 0.0 | 0 |
| Human Toxicity | | | | | | | | | | |
| $SO_2$ | g | 1105 | 80.3 | 1.2 | 1.4 | 75.2 | 14.4 | 173.2 | 736.9 | 21.9 |
| $NO_x$ | g | 583 | 10.9 | 1.6 | 2.9 | 42.0 | 70.1 | 10.8 | 183.1 | 261.4 |
| $NH_3$ | g | 2 | 0.1 | 0.0 | 1.2 | 0.3 | 0.0 | 0.1 | 0.1 | 0.0 |
| Particulate matter | g | 23 | 2.3 | 0.1 | 1.6 | 9.6 | 1.8 | 0.7 | 1.2 | 6.0 |
| Smog | | | | | | | | | | |
| CO | g | 190 | 6.5 | 0.9 | 14.3 | 20.0 | 48.4 | 5.1 | 14.8 | 79.7 |
| NOx | g | 583 | 10.9 | 1.6 | 2.9 | 42.0 | 70.1 | 10.8 | 183.1 | 261.4 |
| NMVOC | g | 143 | 1.3 | 0.5 | 0.3 | 12.5 | 13.8 | 0.8 | 23.4 | 90.6 |

Table 2 presents emissions of selected pollutants causing the various environmental impacts. The pollutants considered are responsible for 80% or more of these environmental impacts. The results of the emission inventory are discussed in the next section (4.2) with the results of impact assessment. It should be noted that solid waste from concentrated latex production is mainly sludge from precipitation of magnesium from fresh latex by using DAP. The amount of this waste sludge is about 4.8-5.2 kg/ one ton of concentrated latex. Most of sludge is disposed by incineration or landfill. Since the sludge contains magnesium and phosphate, it can also be used as fertilizer. The solid waste in term of rubber residues can be omitted, because most of rubber particles in wastewater or other liquid are retrieved as much as possible. Besides skim block rubber, there also is rubber trap installed before the wastewater treatment to recover the rubber residues.

4.2 Impact Assessment

The results of the impact assessment are presented in Table 3, and the contributions of the activities to the different environmental impacts are shown in Figure 2 and 3. From Tables 2 and 3 and Figure 2, it is clear that electricity use in concentrated latex production is an important source of pollutants and their environmental impacts. It is the main source of $CO_2$, $CH_4$, $N_2O$ and $SO_2$ emissions, and also has the largest share in global warming (53%), acidification (60%), and photochemical oxidation (60%). For the production of 1 ton concentrated latex, about 105 kWh electricity is used for centrifugation machines (100 kWh), and for crushing, milling, and cutting machines (5 kWh). Our estimated greenhouse gas emissions (161 kg $CO_2$-eq) are higher than in our previous study (144 kg $CO_2$-eq) (Jawjit et al., 2010), because in the previous study the production of skim block rubber was excluded. The use of ammonia was found to be another important contributor to the environmental impact. Ammonia use contributes to emissions of N, nitrate, COD (all leading to eutrophication), and particulate matter, and it is the main contributor (38%) to human toxicity. In addition, technicians at the mills indicated that odorous ammonia is a sensitive issue that often leads to nuisance and complaints from nearby communities.

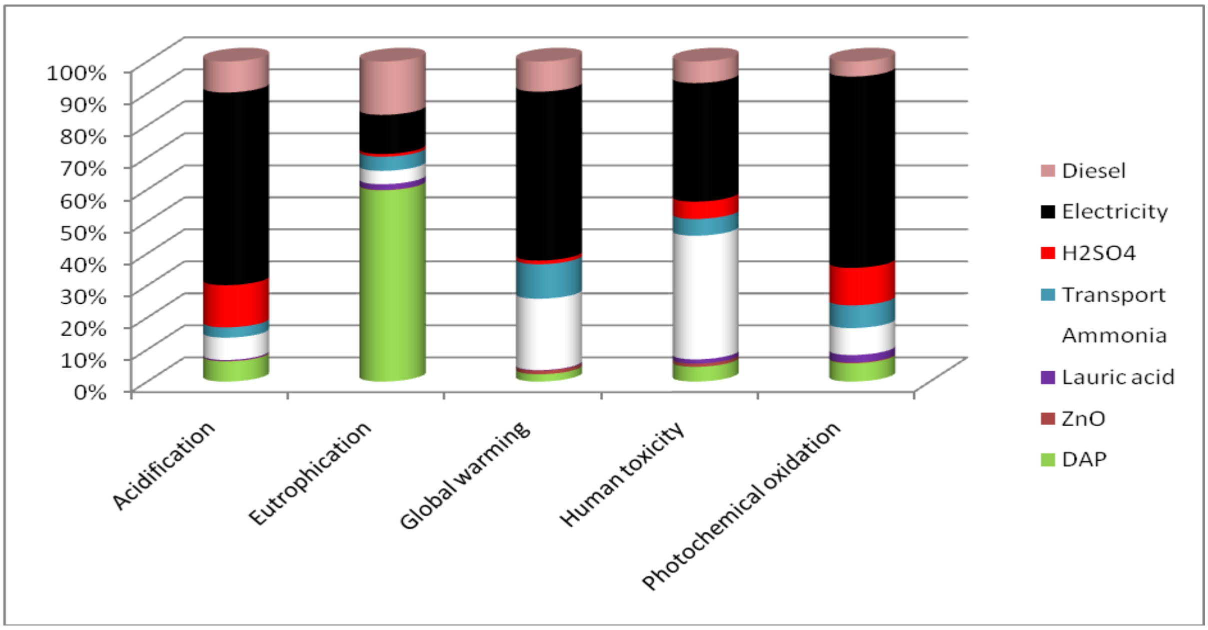


**Figure 2** Relative share of activities in the environmental impacts of concentrated latex production (based on CML method).

**Table 3** Potential environmental impact of the production of 1 ton concentrated latex

| Impact category | Unit | Total | Activities | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | DAP | ZnO | Lauric acid | Ammonia | Diesel use for transport | $H_2SO_4$ | Electricity | Diesel use for drying |
| Acidification | kg $SO_2$ eq | 2 | 0.10 | 0.00 | 0.01 | 0.11 | 0.05 | 0.21 | 0.98 | 0.16 |
| Eutrophication | kg $PO_4^{3-}$ eq | 0.2 | 0.12 | 0.00 | 0.00 | 0.01 | 0.01 | 0.00 | 0.03 | 0.03 |
| Global warming | kg $CO_2$ eq | 161 | 3.70 | 1.89 | 0.22 | 35.90 | 17.38 | 1.84 | 84.97 | 15.17 |
| Human toxicity | kg 1,4-DB eq | 36 | 1.69 | 0.37 | 0.48 | 14.09 | 1.91 | 1.97 | 13.51 | 2.45 |
| Photochemical oxidation | kg $C_2H_4$ eq | 0.1 | 0.00 | 0.00 | 0.00 | 0.01 | 0.01 | 0.01 | 0.04 | 0.00 |

Diammonium Phosphate (DAP) was found to be an important source of phosphate ($PO_4^{3-}$) emission, and therefore accounts for 60% of eutrophication. DAP is added to the fresh latex in order to precipitate magnesium (Mg). Although diesel use was not found to be the largest contributor to one of the environmental impacts, it should not be overlooked. In this study diesel is used for transportation and heating. It was found to be the main source of $NO_x$, CO, and NMVOC emissions, and contributed by about 10% to global warming, and acidification. Since the price of diesel has been continuously increasing, several mills tend to look for alternative sources of energy (such as biomass, natural gas, and LPG). Sulfuric acid accounted for 13% and 12% of the acidification, and photochemical oxidation. As mentioned above, the amount of sulfuric acid applied for neutralization directly depends on the ammonia content in the skim latex. Technologies to reduce ammonia use would, therefore, reduce sulfuric acid use as well. Zinc oxide, lauric acid and other chemicals are only used in small amounts, which explains their small share (< 3%) in the environmental impact. These can, therefore, be omitted from our inventory of options to reduce the environmental impact.

Using the Eco-indicators 99 method for impact assessment (Figure 3) leads to similar results as the CML method (Figure 2). Again, electricity was found to be the main contributor to the environmental problems. It causes human health problems (42%), and is the most important resource consumed (54%). Likewise, ammonia was again found to be an important contributor to resource consumption (25%), and human health (14%), whereas diesel and DAP account for 15% and 14% for human health problems, respectively. Nevertheless, we also found some differences. Lauric acid was found to be the main cause of ecosystem quality problems (28%) (Figure 3), whereas it has relative small share (less than 2.5%) in the environmental impact categories considered by the CML method (Figure 2). When all three environmental impacts considered in the Eco-indicators method were aggregated to single score of overall environmental impact, it was found that electricity has largest share (49%), followed by ammonia (22%), and diesel use for heating and transportation (10% each) (Figure 4).

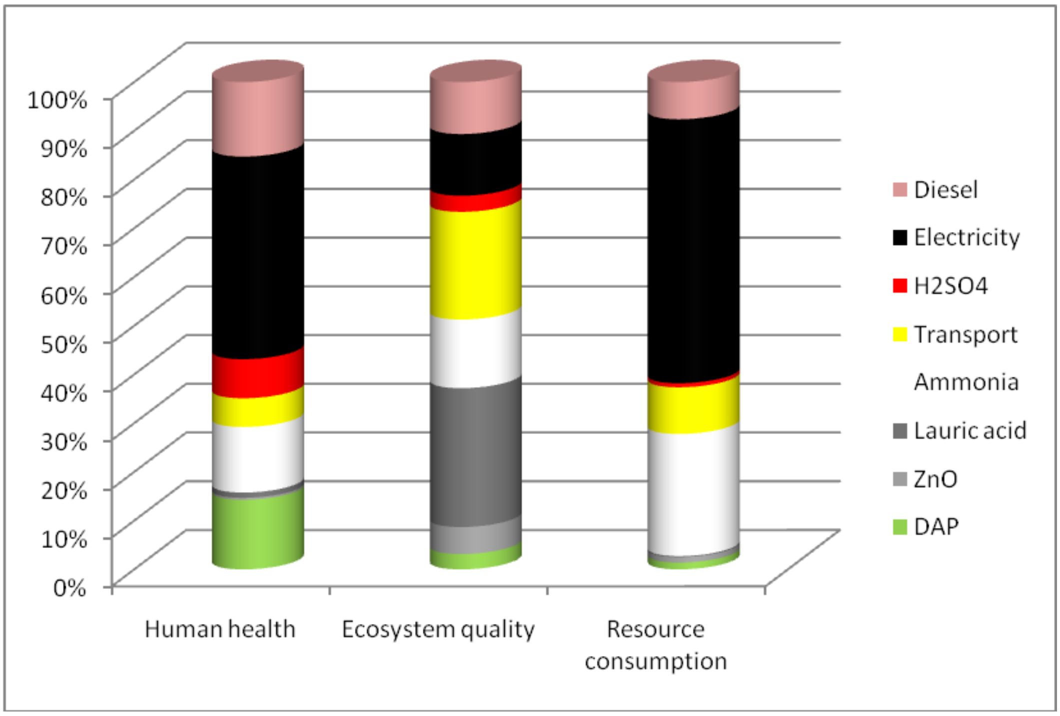


**Figure 3** Contributions of activities in concentrated latex production on human health, ecosystem quality, and resource consumption (Eco Indicator method).

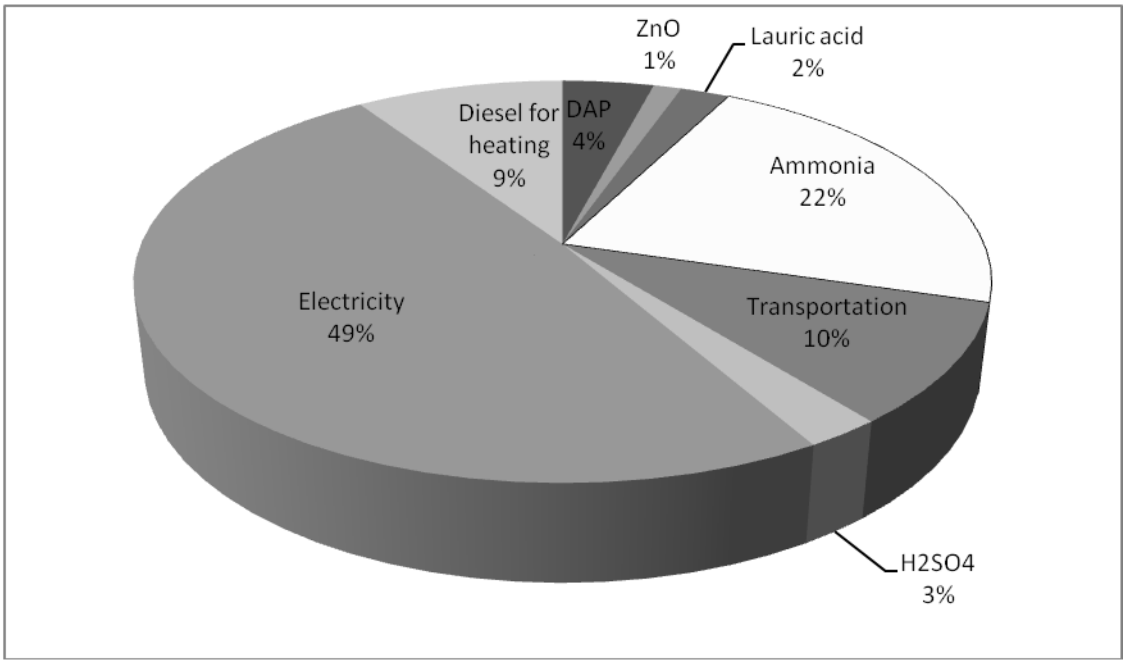


**Figure** 4 Contributions of activities in concentrated latex production on overall environmental impact (Eco Indicator method).

### 4.3 Cleaner Technology (CT) options

From results of the emission inventory and potential environmental impact assessment, we conclude that there are four important activities cause the majority of the environmental problems: 1) electricity use, 2) ammonia use, 3) diesel use, and 4) DAP use. These activities should be taken into account when identifying cleaner technology (CT) options to reduce the environmental impact. Cleaner Technology includes various techniques and practices based on principle of pollution prevention. It can be categorized to three main groups of options, including 1) Source reduction, 2) Reuse and Recycle, and 3) Resource and Energy saving. Based on the results presented in section 4.2, CT options were identified to reduce environmental impact for selected activities. The selected CT options are assumed to be mutually exclusive in order to investigate their effectiveness in reducing the various environmental impacts (Table 4).

#### I. Electricity efficiency improvement

Electricity use for centrifugation was found to be a major cause of the environmental impact of the mills. During the sites visits it became clear that some mills still use *clutch and gear systems* in centrifugation machines. This system consumes more electricity than other systems, because of friction on the clutch surfaces during the starting up period. At Mill C inverters were installed on some centrifuges, which reduced electricity use by about 10-12 %. The inverters gradually distribute electrical currents to the machines until required rotation speed is achieved. This option prevents energy loss during starting up. Mill A has begun to replace the old centrifuges by new machines with variable pulleys, which is used for adjusting RPM (revolution per minute) of the centrifuge. Technicians at Mill A explained that application of this new system reduced electricity use by about 10-15%. A 10% reduction in electricity use was used in the calculations of the effect of these two options. As a result, the “electricity efficiency improvement” option results in a 7-9% reduction in the potential global warming, acidification, and photochemical oxidation relative to reference (no CT option) case (Table 4). The calculated overall environmental impact is about 13% reduced by this option.

Besides above-mentioned measures, PCD (2003) also recommended installation of “motor load controllers” for saving electricity. This equipment controls the starting sequence for a plurality of electrical loads. It includes a start demanding unit that generates a demand to start at least one of the plurality of electrical loads. This leads to minimization of energy loss during starting up as well.

**Table 4** Potential environmental impact and overall environmental impact when applying clean technology (CT) options (Unit: amount per 1 ton of concentrated latex produced)

| Impact category | Unit | Reference (no option) case | CT Options | | | |
|---|---|---|---|---|---|---|
| | | | Electricity[a)] | Ammonia[b)] | DAP[c)] | LPG[d)] |
| Acidification | kg $SO_2$ eq | 1.6 | 1.48 | 1.60 | 1.55 | 1.49 |
| Eutrophication | kg $PO_4^{3-}$ eq | 0.21 | 0.20 | 0.20 | 0.18 | 0.17 |
| Global warming | kg $CO_2$ eq | 161 | 148.94 | 153.90 | 156.22 | 156.84 |
| Human toxicity | kg 1,4-DB eq | 36 | 34.55 | 33.66 | 35.47 | 34.10 |
| Photochemical oxidation | kg $C_2H_4$-eq | 0.07 | 0.067 | 0.072 | 0.070 | 0.070 |
| Overall environmental impact | Pt | 18.00 | 15.74 | 16.21 | 16.42 | 16.25 |

a) = Electricity efficiency improvement

b) = Improvement of ammonia storage and preparation

c) = Reduction in DAP use

d) = Substitution of diesel with LPG

II. Improvement of ammonia preparation and storage

Ammonia use is the most important cause of human toxicity problems caused by concentrated latex production (Table 3). Ammonia is the main chemical used for preserving latex quality. the amount of ammonia use directly relates with the amount of sulfuric acid applying later for neutralization. A reduction in ammonia use can be achieved by improvement of preparation and storage of ammonia. Ammonia is stored in liquid form in pressurized tanks. Mixing of ammonia with water results in increasing water temperatures, which increase the evaporation of ammonia. Installation of chillers can reduce ammonia losses, since then the preparation takes place at lower condition. At Mill C, a chiller was installed to reduce the ammonia temperature, reducing ammonia losses by about 5%. Results from Table 4 indicated that application of chillers result in 8% and 5% reductions in human toxicity problems and global warming, respectively, to reference (no CT option) case (Table 4). The overall environmental impact is about 10% lower. Besides this option, PCD (2003) also recommends an optimal concentration of ammonia at 0.4% (with TMTD/ZnO 0.025%). Nevertheless, in practice, the quality of fresh latex delivered from the farmers fluctuates considerably. It is, therefore, practically difficult to set a specific concentration of ammonia.

III. Reduction in DAP use

DAP use is an important cause of eutrophication (Table 3, Figure 3). DAP is added to remove magnesium from fresh latex. Magnesium adversely affects the mechanical stability time (MST), and addition of excessive DAP has been found to reduce the quality of concentrated latex produced. Reducing DAP use can be realized by an extension of the sedimentation time.

Sedimentation times in the four mills are 10-12 hours (during high season of fresh latex production). DAP use can be reduced by about 10%, if sedimentation time is extended to 20-24 hours. Results from Table 4 indicated that extending sedimentation time results in a 14% and 9% reduction in eutrophication and the overall environmental impact, respectively.

IV. Substitution of diesel with LPG

Diesel has been used as fuel for drying the skim block rubber. Due to increasing price of diesel, concentrated latex mills may switch to LPG, which is cheaper. For this option, we assume that LPG 3.4 kg (used for producing 1 ton of concentrated latex and equivalent to diesel 5 litre) was used as fuel instead of diesel. It was found that the potential impact of acidification and human toxicity are reduced by about 8% and 7%, respectively.

It should be noted that there are more CT options than included in the analysis, and that we limited ourselves to options currently applied. The CT options described above are effective in reducing the environmental impact of concentrated latex production. We argue that they are also technically, practically and economically feasible. Some mills (Mill A and C) in this study already have begun to adopt CT options by introducing new machines and fuels. Nevertheless, we also observed that the rubber mills seem to neglect the basics of good CT practices, which could be easily realized. This may be because of miscommunication among employers with different nationalities (e.g. from Thailand and Myanmar). Although the last two Thai governments clearly promoted CT and pollution prevention for industries, there still are barriers when applying CT in the rubber industries. From the interviews and discussions with owners and technicians at the rubber mills, it became clear that these barriers include, for example, 1) lack of communication on, and awareness of the basics of good practices ; 2) lack of systematic databases; 3) limited in-plant expertise; 4) higher priorities to production expansion and market share (especially current high demand of the international market); 5) attitudes and resistance of entrepreneurs due to lax enforcement of environmental regulations; and 6) worries about the high initial capital costs and the requirement of additional infrastructure. It was also found that some rubber mills that have applied CT options are not willing to share their information on successful CT options with others, for commercial and competition reasons.

## 5. Conclusion

Concentrated latex is increasingly exported to the international market. It has therefore been challenging for the Thai rubber entrepreneurs to seek for appropriate measures to produce environmentally friendly rubber products. The objective of this study is to analyze the potential environmental impact associated with production of concentrated latex by life cycle assessment

(LCA), and to investigate cleaner technology (CT) options to reduce the environmental impact. The results indicate that electricity use for centrifugation has the largest share, compared with other activities, in global warming (53%), acidification (60%), and photochemical oxidation (60%). Ammonia use for latex preservation accounts for 40% of human toxicity problems, whereas use of DAP accounts for 60% of eutrophication. The environmental impact assessment is similar when applying different assessment methods (CML and Eco-indicator 99).

The overall environment impact of concentrated latex production in Thailand is mainly caused by electricity (49%), followed by ammonia (22%), and diesel use for heating and transportation (10% each). We identified potentially effective CT options for the most polluting activities. The four selected CT options include 1) electricity efficiency improvement (by installation of inverters to centrifugal machines); 2) improvement of ammonia preparation and storage (by chilling systems); 3) minimizing the use of DAP (by extending coagulation time); and 4) substitution of diesel by LPG. GThese four CT options could reduce the environmental impact by 12%, 8%, 3%, and 5%, respectively. In spite of some barriers in applying CT options for Thai rubber processing mills, application of LCA and CT has proven to be very useful tools to identify options to improve the environmental performance of the Thai concentrated latex industry. Making this industry more sustainable undoubtedly enhances its competitiveness in the world rubber market.

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