Life Cycle Assessment of Surfactants: A Review

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INTRODUCTION

Nowadays, consumers are becoming more concerned about the environmental problems that are occurring around the world. Global warming, depletion of the ozone layer, emissions of greenhouse gases and increased exploitation of raw materials are examples of such problems. The environmental risks of surfactants have also been assessed regularly in the past decades by various industrial groups, governmental regulatory organizations and multi-stakeholder organizations (Stalmans and Sabaliunas, 2004). There is a need to find solutions to overcome these risks. In order to achieve that, a right tool is needed to assess and optimize the environmental quality of a system over its whole life cycle. At present, life cycle assessment (LCA) is the best tool for such a purpose.

LIFE CYCLE ASSESSMENT (LCA)

Interest in LCA has been growing enormously in recent years. The Society for Environmental Toxicology and Chemistry (SETAC)'s Code of Practice defines LCA (Vijaya, 2007) as follows:

'LCA is a process for the evaluation of the environmental burdens associated with a product, process or activity by identifying and quantifying energy and materials used and wastes released to the environment, to assess the impact of those energy and materials used and released to the environment and to identify and evaluate opportunities to effect environmental improvements. The assessment includes the entire life cycle of the product, process or activity, encompassing extracting and processing raw materials, manufacturing, transportation and distribution, use, reuse, maintenance, recycling and final disposal.'

The four phases in the process of evaluation by LCA according to ISO 14040 are:

- definition of the purpose, goal, functional unit and system boundaries;
- inventory analysis, including data collection for all processes and allocation or system expansion between products and co-products;
- evaluation of the environmental impacts; and
- interpretation of the results and identification of significant issues.

The LCA results become more useful, credible and closer to reality when all these four phases are repeated several times. *Figure 1* shows the four phases in the LCA framework.

In general, the first phase which consists of the goal and scope needs to be clearly defined before LCA can be carried out. It covers the purpose, system boundaries and procedures for each LCA study. The definition of the functional unit is an important step in order to indicate the specific unit that will be used in the LCA study.

Phase 2 is the most time-consuming. It involves measurements and compilation of data on the consumption of raw materials and energy, emissions and discharges to the environment over a certain period of time. The inventory data can be obtained and analysed according to the requirements of various LCA software in the market, such as SimaPro (Netherlands), GaBi (Germany), Team (Ecobilan-UK), Umberto (Germany), Regis (Switzerland) and JEMAI-LCA Pro (Japan).

Phase 3 is important in that it evaluates the impact to the environment that comes from the life cycle study. There are three differ-

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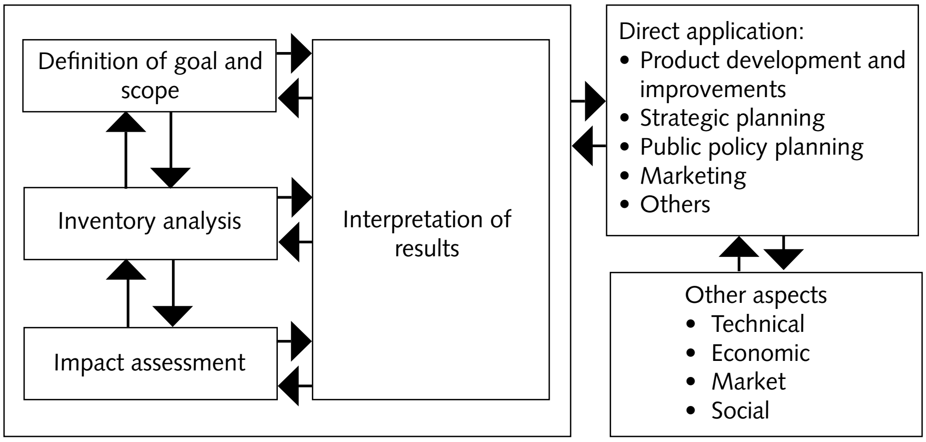

Figure 1. Life cycle assessment (LCA) framework – the four phases of an LCA.

ent well-known life cycle impact assessment (LCIA) methodologies, and they are EDIP 97, CML 2001 and Eco-Indicator 99 (Dreyer *et al.*, 2003). Most LCA studies carried out in Europe have used Eco-Indicator 99 as their preferred methodology. The general impact assessment parameters that are commonly used in Eco-Indicator 99 are listed in *Table 1*.

In Phase 3, normalization and weighting are also carried out. Normalization has two purposes in an LCA study. Firstly, it provides an impression of the relative magnitudes of the potential impacts and resource consumptions. In normalization, the impact potentials and resource consumptions which have been determined are compared with an impact which is common for all impact categories and of which the consequences on the environment, resources and working environment are known. Secondly, it presents the results in a form suitable for the final weighting and decision-making (Wenzel *et al.*, 2000). When the impact potentials are normalized, they are expressed in person-equivalent (PE), *i.e.* fractions of the contribution to the impact derived from the average person.

Weighting is obtained by multiplying the normalized impact potential or resource consumption by the weighting factor. The weighting factor for an environmental impact must reflect the seriousness of the effect potentially being caused by the impact and the possible consequences of this effect relative to the other environmental effects (Wenzel *et al.*, 2000).

Lastly, Phase 4, the final one, completes the assessment by deriving possible improvements or enhancement to products or processes in order to reduce their impact on the environment.

There are many amongst the population who are still unaware of the importance of LCA of a substance or service. In practical terms, LCA can help minimize the magnitude of pollution, and maximize the recycling of materials and wastes in the production processes. By conducting LCA, stakeholders can also save the non-renewable resources like energy and ecological systems. In recent years, LCAs have been actively adopted by the public and private sectors as practical steps to help conserve the environment. Nowadays, it is widely accepted that products and services need to be environmentally, socially and economically sustainable (Saouter *et al.*, 2004). Environmental sustainability requires that the products improve lives, with minimum environmental impact in terms of consumption of both energy and materials, and the production of emissions and solid wastes.

However, the problems associated with LCA should not be underestimated. They included data discrepancies and reliability, defining the system and the system boundary, access to information and possibility, misuse of the assessment for commercial advantages (Charlton and Howell, 1992).

LCA OF SURFACTANTS

Surfactants are organic compounds that are amphiphilic, meaning they contain both the water-attracting hydrophilic groups (their 'heads') and the water-repelling hydrophobic groups (their 'tails'), with the latter made up of long-

TABLE 1. ASSESSMENT PARAMETERS (Eco-Indicator 99)

Impact Category	Characterization	Damage Category
Emissions		
Carcinogens	DALY kg^{-1}	Human health
Respiratory organics	DALY kg^{-1}	Human health
Respiratory inorganics	DALY kg^{-1}	Human health
Climate change	DALY kg^{-1}	Human health
Radiation	DALY kg^{-1}	Human health
Ozone layer	DALY kg^{-1}	Human health
Ecotoxicology	PAF.m^2. yr kg^{-1}	Ecosystem quality
Acidification	PDF.m^2. yr kg^{-1}	Ecosystem quality
Eutrophication	PDF.m^2. yr kg^{-1}	Ecosystem quality
Land use		
Decrease diversity	PDF.m^2. yr kg^{-1}	Ecosystem quality
Resource depletion		
Metals/minerals	SE kg^{-1}	Resources
Fossil fuels	SE kg^{-1}	Resources

Source: Sumiani (2007).

Note:
DALY : disability adjusted life years (years of disabled living or years of life lost due to the impacts).
PAF : potentially affected fraction (animals affected by the impacts).
PDF : potentially disappeared fraction (plant species disappeared as result of the impacts).
SE : surplus energy (MJ) (extra energy that future generations must use to excavate scarce resources).

TABLE 2. TYPE OF SURFACTANTS

Surfactant Group	Surfactant
Anionic	Linear alkylbenzene sulphonates Alkyl sulphates Alkyl ether sulphates
Non-ionic	Alcohol ethoxylates Alkyl polyglucosides
Cationic	Monoalkyl quaternary ammonia compounds (quats) Dialkyl quats Esterquats
Amphoteric/zwitterionic	Amine oxides Alkyl betaines

chain hydrocarbons. Therefore, they are soluble in both organic solvents and in water. Generally, surfactants are classified into four primary groups, namely, anionic, cationic, non-ionic and amphoteric/zwitterionic (dual charge) (*Table 2*).

Surfactants play an important role as active ingredients in products such as detergents, fabric softeners, emulsifiers, paints and adhesives. The environmental properties of the surfactant in detergents have been studied in detail over the last 40 to 50 years. These studies were initially triggered by the occurrence of foaming in sewage treatment plants and in the rivers in the mid-1960s (Stalmans and Sabaliunas, 2004). Since the early 1970s, the detergent industry has initiated wide-ranging programmes to assess and ascertain environmental safety of major surfactants.

In Europe, the detergent industry players have been conducting LCA studies since a long time ago. Saouter (2003) reported that Procter & Gamble (P&G) participated in a life cycle inventory (LCI) study group comprising more than

13 surfactant producers and detergent formulators. The objective of this study was to assess quantitatively the resource requirements and environmental releases associated with the production of surfactants from oleochemical *vs.* petrochemical feedstocks.

In Japan, LCA was used for evaluating whether or not their products are environmental-friendly. Lion Corporation evaluated the impact of the production of methyl ester sulphonates (MES) detergent on the environment by conducting LCA. The LCA study covered the comparison of carbon dioxide (CO_2) emissions between MES from palm oil and linear alkylbenzene sulphonates (LAS) from petroleum. It was established that in the production process, LAS showed a higher amount of CO_2 emissions compared to MES. This better performance of the plant-based surfactant, MES, was attributed mainly to the utilization of carbon-neutral material (Lion Corporation, 2007).

In Germany, Henkel has been well-known as a major detergent producer and specialist. They are also using LCA for evaluating their detergent products (Kluppel *et al.*, 1995). The LCA study conducted by the company showed that the production of palm alcohol sulphates generated sulphur dioxide (SO_2) and nitrogen oxide (NO_x) and particulate emissions. The SO_2 emissions occurred at the energy-intensive transesterification, hydrogenation and sulphating steps. This study also observed that palm oil mills generated high particulate emissions due to burning of fibre and shells for energy generation.

Stalmans *et al.* (1995) studied the LCI of the production in Europe of surfactants which included the petroleum-based LAS, alcohol ethoxylates (AE), alcohol ethoxylate sulphates (AES), alcohol sulphates (AS) and secondary alkane sulphonates (SAS), and the oleochemical-based alcohol ethoxylates (AE), alcohol ethoxylate sulphates (AES), alcohol sulphates (AS), alkyl polyglucosides (APG) and soap. Inventory data for oleochemical surfactants evaluated were related to the procurement and processing of Malaysian palm oil and palm kernel oil and also coconut oil from the Philippines. The boundaries in the study covered plantations, extraction mills, kernel-crushing plants, oil refineries and transportation. In the case of the production of fatty alcohols, the boundary also covered the production of methyl esters for which methanol from natural gas was used as one of the raw materials. The study showed that the production of petrochemical surfactants had different boundaries from that of oleochemical surfactants. The boundaries included several operations which comprised drilling, pumping and separation of crude oil from brine water, tank storage, transportation by tankers and pipelines. Additional operations such as desalting, distillation, cracking, hydro-treatment, fractionation or extraction of crude oil into paraffin, olefins, benzene and ethylene were also included.

It was also reported that production of petrochemical surfactants required more energy than oleochemical surfactants. The petroleum-based AE required the highest total energy demand compared to any other surfactant. However, soap manufacture from oleochemicals had the lowest process energy requirement. Interestingly, soap produced from palm and coconut oils required lower process energy compared to those from tallow.

The study also reported that among the many surfactants, AS from petrochemicals gave the highest emission of sulphur oxides. Meanwhile, soap derived from tallow showed high methane and carbon dioxide emissions. This is because the production of tallow is considerably more complex and it is generally associated with a large number of co-products and wastes. It was also highlighted that environmental emissions do occur during the production and transport of all surfactants.

Pittinger (1991) compared the life cycle analysis between AES from oleochemicals and that from petrochemicals, focusing on the characterization of the raw materials, energy requirements and environmental emissions. However, the LCA did not differentiate between co-products and by-products. Three environmental factors – atmospheric emissions, water-borne wastes and industrial solids – were examined. All these wastes were considered as being discarded or disposed of into the environment.

The study confirmed that different feedstocks for the surfactants have different energy requirements and environmental emissions. Furthermore, it identified that the five major constituents of the atmospheric emissions were particulates, NO_x, hydrocarbons, SO_2 and CO_2. Of these, only NO_x and CO_2 released during the production process exhibited high impact to global warming due to their greenhouse gas effect. In addition, the report also highlighted the seven components related to water-borne wastes, *i.e.* dissolved solids, biochemical oxygen demand (BOD), chemical oxygen demand (COD), suspended solids, acids, phosphorus and nitrogen. All these components can cause eutrophication and acidification in the rivers and lakes.

In another study, Pittinger *et al.* (1993) conducted a further LCA on the production of petrochemical surfactants, including LAS, AS, AE and AES, and also oleochemical surfactants AS, AE, AES and MES derived from palm oil, palm kernel oil and inedible tallow. This study indicates that the requirements of natural resources were primarily related to the source of the feedstock and then only to the type of surfactant produced. It also showed that energy requirement of each feedstock and surfactant type was different from one another.

The study revealed that the production of petroleum-based AS, AE and AES resulted in the emission of high levels of NO_x, hydrocarbons and carbon monoxide. In the case of surfactants from palm and palm kernel oils, the atmospheric emissions in the whole chain process were mainly released during the combustion of plant materials in the oil palm plantations and mills. In the process chain for the production of tallow-based surfactants, the emission can be traced to the manufacture of fertilizers, cultivation of corn, the operation of the livestock feedlots and the abattoir for the cattle that produced the tallow.

A review by Stalmans and Sabaliunas (2004) showed that environmental risk assessment was an important issue in the production of detergents and surfactants. Their evaluation concluded that environmental risks associated with the use of modern surfactants such as LAS, AS, AES, AE, esterquats, alkyl polyglucosides, dialkyl quats, amine oxides and alkyl betaines were considered acceptable. They also compiled a comprehensive database on the effects and the environmental fate from the use of high volume detergent surfactants.

Gert *et al.* (2003) carried out a comparative study on the production of laundry detergents in the United Kingdom. There were eight airborne emissions and four waterborne emissions reported in this study. Under the conditions of the study, it was found that both powder and liquid compact detergents were environmentally the preferred detergents because of the presence of a lower dosage of chemicals in their formulations. As a result, both powder and liquid compact detergents have the advantages of exhibiting lower acidification, aquatic toxicity, climate change, human toxicity and ozone depletion than regular powder formulations. The results are shown in *Table 3*.

From all the above studies, one can realize that production of surfactants can bring about negative effects to the environment. Global warming, climate change, ozone layer depletion and greenhouse gases are some of the most critical impacts from this industrial activity. However, with due prudence and the proper implementation of a sound environmental policy, all these impacts can be minimized if not totally avoided.

CONCLUSION

LCA is an acceptable and a suitable technique for evaluating the environmental impacts from the production of a product. Combining LCA with additional safety assessment can help manufacturers to reduce waste and emissions that could be generated during the production process. At the same time, it provides avenues for making further improvements in transportation, the manufacturing processes, the products, as well as the packaging in order to minimize negative environmental impacts in the whole life cycle of that product.

Currently, manufacturers in Malaysia are in the process of evaluating the environmental impacts of their local products using the LCA approach. However, it may take time before the whole LCA of these products can be completed. Commitment and co-operation from all government agencies, industrial players and manufacturers are important and needed in order to make the LCA approach successful.

REFERENCES

CHARLTON, C and HOWELL, B (1992). Life cycle assessment: a tool for solving environmental problems? *European Environment*, 2 *(2)*: 4.

DREYER, L C; NIEMANN, A L and HAUSCHILD, M Z (2003). Comparison of three different LCIA methods: EDIP 97, CML 2001 and Eco-Indicator 99. Does it matter which one you choose participant(s)? *International Journal of LCA*, *8*: 191-200.

GERT, V H; DIEDERIK, S; TOM, C J F GEERT, B and PATRICK, H M (2003). Comparative life-cycle assessment of laundry detergent formulations in the UK. Part I: Environmental fingerprint of five detergent

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TABLE 3. LIFE CYCLE IMPACT CATEGORIES PER WASH CYCLE FOR YEAR 2001 BASED ON FORMULATIONS IN THE UNITED KINGDOM

Impact Category	Unit	Powder			Liquid	
		Regular	Compact	Tablet	Compact	Tablet
Acidification	gSO_2eq	0.19	0.16	0.16	0.14	0.15
Aquatic toxicity	m^3PW	33	24	29	26	36
Eutrophication	gPO_4eq	0.66	0.67	0.85	0.92	1.08
Human toxicity	g BW	7.6	6.5	6.6	5.8	6.4
Climate change	gCO_2eq	1 053	978	1 018	933	994
Ozone depletion	μgCFC^{-11}eq	53	36	43	24	29
Photochemical smog	gC_2H_4eq	0.75	0.83	1.18	0.41	0.50

Source: Gert *et al.* (2003).

formulations in 2001. *Tenside Surfactant Detergent, 40*: 266-275.

KLUPPEL, H J; HIRSINGER, F; KNAUT, J and SCHICK, K P (1995). Life cycle assessment of palm alcohol sulphate. *INFORM*, 6 *(6)*: 647-657.

LION CORPORATION (2007). Estimation of environmental impact on detergents. Slide presentation. MPOB, Bangi.

PITTINGER, C A (1991). *Case Study: Life Cycle Analysis of a Detergent Ingredient.* Franklin Associates Ltd. Kansas. p. 7-35.

PITTINGER, C A; SELLERS, J S; JANZEN, D O; KOCH, D G; ROTHGEB, T M and HUNNICUTT M L (1993). Environmental life-cycle inventory of detergent-grade surfactant sourcing and production. *J. Amer. Oil Chem. Soc.*, *70 (1):* 1-15.

SAOUTER, E (2003). Natural and synthetic surfactants; which one is better?. url: www.scienceinthebox.com. Accessed on 5 September 2007.

SAOUTER, E; VAN HOOF, G and WHITE, P (2004). Life cycle assessment: a novel approach to the environmental profile to detergent consumer products. *Handbook of Detergents. Part B: Environmental Impact.* CRC Press. New York. p. 195-209.

STALMANS, M and SABALIUNAS, D (2004). Retrospective review of surfactant environmental assessment. *J. Detergents and Surfactants*, *130*: 42.

STALMANS, M; BERENBOLD, H; BERNA, J L; CAVALLI, L; DILLARSTONE, A; FRANKE, M; HIRSINGER, F; JANZEN, D; KOSSWIG, K; POSTLETHWAITE, D; RAPPERT, T H; RENTA, C; SCHARER, D; SCHICK, K P; SCHUL, W; THOMAS, H and SLOTEN, R V (1995). European life-cycle inventory for detergent surfactants production. *J. for Theory, Technology and Application of Surfactants*, *32*: 84-109.

SUMIANI, Y and SUNE, B H (2007). Feasibility study of performing a life cycle assessment on crude palm oil production in Malaysia. *International Journal of LCA*, *12 (1)*: 50-58.

VIJAYA, S (2007). Life cycle analysis of the production of crude palm oil. Viva Report. MPOB, Bangi. p. 2.

WENZEL, H; HAUSCHILD, M and ALTING, L (2000). *Environmental Assessment of Products. Vol. 1: Methodology, Tools and Case Studies in Product Development.* Kluwer Academic Publishers. USA. p. 105-115.