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Life Cycle Assessment of Sodium Hydroxide

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Abstract: Chemicals play an important role in human's life as well as in their daily activities. These are one of the major contributors to the national economy, too (Mokhtar *et al*., 2010). As today's consumers are more environment conscious, the industries need to meet challenges and cope with consumers demand. An analysis was carried out to appraise the environmental affects from the production of an important chemical, sodium hydroxide (NaOH). The results obtained can be used as a benchmark in the production of more environmental-friendly sodium hydroxide. Both the data and the information of the inputs used throughout the production processes were collected from a major manufacturer of sodium hydroxide in Malaysia. On the basis of unit weight (i.e. per Kilogram) of sodium hydroxide, the environmental impacts and the hotspots were determined employing the Endpoint Modelling method equipped in JEMAI LCA Pro software. From this analysis, among the significant environmental impacts for the production of one kilogram sodium hydroxide are fossil energy consumption (3.5 MJ), global warming (0.6329 kg of CO_2 equivalents), aquatic ecotoxicity (1.298 g of 1, 4 dichlorobenzene equivalents), acidification (0.706 of SO_2 equivalents) and human toxicity (carcinogenicity) (0.4927 g of 1, 4 dichlorobenzene equivalents). Most of the environmental impacts are found to be engendered due to the consumption of electrical energy as well as natural gas. The results of the study have successfully represented the Malaysian scenario which could be employed as a resource of investigations in other parts of the world.

Key words: Climate Change; Sodium Hydroxide; Environmental Impacts, Life Cycle Assessment (LCA)

INTRODUCTION

In Malaysia, chemicals and chemical products are regarded as the second highest among manufactured exports, after electrical and electronic products (MITI, 2011). Export for chemical and chemical products increased about 16.0% from RM41.65 billion in the year 2010 to RM47.19 billion in the year 2011. Whereas, import of chemical and chemical products increased about 13.5% from RM 45.04 billion to RM 51.12 billion in that period.

Based on the World Trade Organization's (WTO) Trade Ranking 2010, Malaysia has improved its position to become the 24th leading trading country globally in 2010 compared to 26th place in 2009. Ministry of International Trade and Industry Malaysia (MITI) reported that export has increased in the chemical industry sub sectors, such as fertilizers, soap and cleaning agents, organic, inorganic and other chemical products between 10 and 30% (MITI, 2011).

Nevertheless, Malaysia has already addressed many environmental challenges and the challenge in managing chemicals is one of the issues that require immediate attention. Chemicals are important in our daily life as it enhances the quality of life in term of maintaining and improving our health and comfort level. However, chemicals or chemical products may pose potential adverse effects to human health and the environment during their stages of life cycle (Mokhtar *et al*., 2010).

The utilization of chemicals is important in modern life. These play a significant role mostly in overall human activities as well as contribute effectively to the national economic strengthening. Chemicals were used in many sectors such as in the production of products, such as in producing of life protecting medicines, purifying agents to treat essential drinking water supply, agricultural chemicals which boost to farm productiveness as well as chemicals used in the packaging. There may be an involvement of significant risk to human health as well as environment if good chemical management is not practiced (UNDP, 2009). Hence, if the chemicals are not managed properly it will lead to health and environmental impacts such as increase healthcare costs, damage to fisheries and watersheds and reduced crop output.

It is important to understand and evaluate the environmental impacts of chemicals' production if we are to develop a more sustainable production system. In order to determine the environmental burden associated with laundry detergent production, it is necessary to consider all important encroachments by employing the Life Cycle assessment (LCA). The products' complete life cycle is dealt by the LCA; i.e. starting from the extraction

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processes of resources to the production, utilization, to disposal of the unexpended waste. This study has been confined to the production of sodium hydroxide. [Note:]

Life Cycle Assessment:

Life Cycle Assessment (LCA), a reputed environmental assessment tool, can be used to provide more insight into environmental aspects in a comparative context. More specifically, it can be used to highlight the resulting differences of environmental burdens associated with different product formulations (Procter and Gamble, 2006). It is a tool for assessing environmental burdens and environmental impact quantitatively at all the life cycle stages of the target product, ranging from collection of raw materials to the acquisition of materials, the manufacture, consumption stage, disposal and recycling of the product. The involvement of all the unit processes in a total system a product within the life cycle is known as the “product system” (Guinée, 2002).

Concerns about the environmental issues covers fully the effects of all elements related to it; also includes the extraction methodologies of various types of chemical elements’ resources, hazardous emission compounds as well as misuse of lands by various chemical compounds, etc. The term known as ‘product’ is used in its fullest sense which includes physical goods and services. Another essential point to be noted that, in case of the comparative studies of LCA, the fundamental issues for comparative study are not dependent on products themselves rather functions rendered by those products (Guinée, 2002).

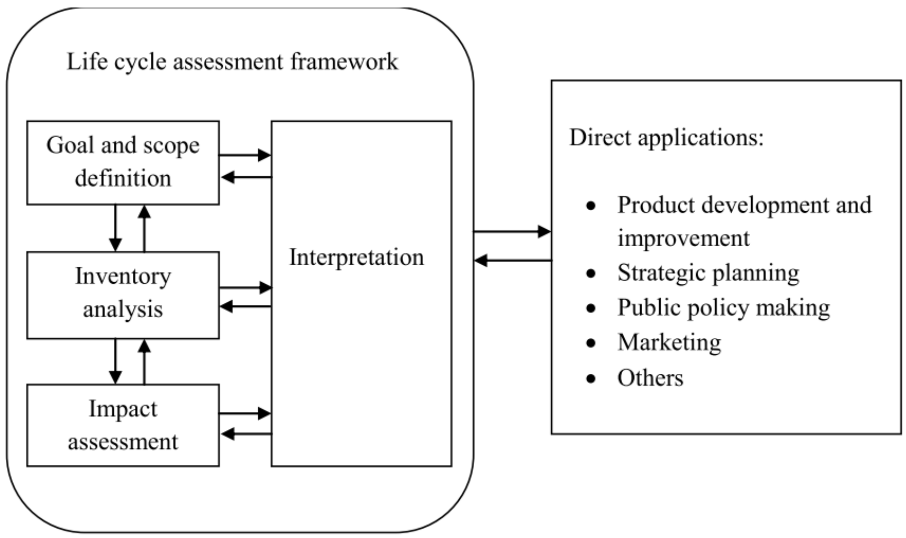

Fig. 1: ISO 14040 Life Cycle Assessment Framework (ISO 14040, 2006a)

On the basis of ISO 14040 (Fig. 1), the LCA study encompasses four phases: Defining the Goal as well as the Scope, Life Cycle Inventory Analysis (LCI), Life Cycle Impact Assessment (LCIA) and Interpretation. The definition of both the goal and the scope include the goals intended to be achieved through execution of the analysis, the intended utilization, and the purported audience (ISO 14040, 2006a, ISO 14044, 2006b). The boundaries in the system of conceived analyses were described; the parameters of the functions were defined, too. The functional parameters are the quantitative measures of those functions which are provided by the goods (or service).

Methodology:

Goal and Scope:

The objective of this analysis is to provide the quantitative information of functional effect on environment of sodium hydroxide over its life cycle. This is due to the increased concern of global warming potential and other related environmental impacts of construction materials/ products among stakeholders. The results can be used as guidance for future improvement for the industries, support tools in achieving sustainable development for the government, and the environmental information for the consumers. The study is not intended to support comparative assertions among different types of sodium hydroxides.

Functional Unit:

Defining the functional unit is regarded as one of the important steps in the LCA study; the definition is concerned about the functions which are provided by their product or the services obtained from the products. The functional unit will be utilized as a fundamental assumption to select one or more alternative product systems which should deliver these functions. It enables various systems to be dealt as equivalent with respect to the functions. Consumptions of all type of energy as well as the raw materials and their related emissions to the environment are computed based on the functional unit. The analysis of average life cycle assessment normally quantifies the impacts for either a unit of the product or mass of the product.

The functional unit considered in conducting the assessment is 1 kg of sodium hydroxide.

Inventory Analysis:

The second phase of LCA, inventory analysis, consists of data collection and analysis (Green, 2002). The definition of the product system is provided in this phase of LCA. In this circumstance, the definition process includes setting up the boundaries of the system, flow diagram designing accompanying with unit processes, accumulating the data from all the processes individually and executing the final computations. Its main output is listed in the inventory table from the quantified inputs as well as the outputs to the environment related to the functional unit, expressing in terms of kegs of carbon dioxide, cubic metres of natural gas etc (Guinée, 2002). This LCA phase, inventory analysis, involved the collecting of relevant data on the unit processes and thereby quantifies all the flows which are linked to those unit processes.

Function Of The Product System:

Sodium hydroxide (NaOH) is an extremely caustic in taste and metallic base compound which are white solid and obtainable in pellets, as flakes & granules and also as a solution that is 50% saturated. It is one of the prime strong base compounds utilized in the chemical industries. These industries are the consumer of 56% of all the sodium hydroxide obtained from their process plants, with 25% of the same total is utilized by the paper industries. Besides, the sodium hydroxide can be utilized in the manufacturing processes of sodium based salts as well as detergents, to regulate the pH, and for the synthesis. It could be also utilized in the Bayer process of aluminium production.

Product System:

The “cradle-to-gate” approach has been used as the system boundary in the production process of sodium hydroxide. In this approach, the entering and exiting of both the raw materials and the energy flows in the manufacturing facilities were considered together with their raw materials’ extraction, production and transportation of the raw materials to the plant. Packaging process together with the materials is not included in this system boundary. The product system boundary and unit processes are summarized in fig. 2.

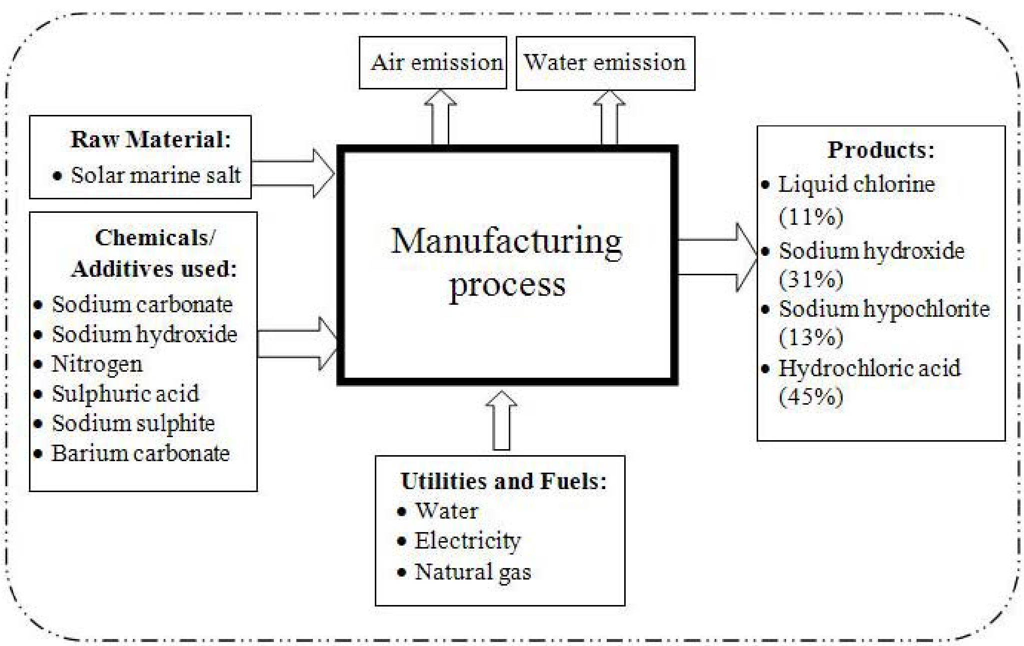

Fig. 2: System Boundary for “Cradle-to-gate” of Sodium Hydroxide Production

Cut-off Criteria (Mass And Environmental Cut-Off Criteria):

The cut-off criteria was adopted only for the primary case of the analysis, i.e. the Barium Carbonate used as chemical compound in the production of sodium hydroxide has been omitted in this analysis due to insufficient information and data. For the other sections, all available data collected from the related industry has been used in the computational works without applying any cut-off rules.

Allocation Procedure:

As per the ISO 14040 (ISO, 2006a), allocation could be defined as a procedure where the input flows or the output flows are partitioned in a process's product system under analysis. And it is one of the critically considered issues in the LCA analyses in case of the involvement of more than one products in production processes. Since the manufacturing process has four products: Liquid chlorine (11%), sodium hydroxide (31%), sodium hypochlorite (13%) and hydrochloric acid (45%); it behooved the allocation in the analysis to apportion the total electricity, water and other raw materials. The mass allocation process was considered on average yearly production basis.

Data Requirements:

Site data were used as foreground data for raw materials, transportation of raw materials and utilities consumption. Emissions and conversion factor were based on the literature, Jemai LCA database and SIRIM National LCA database. The data source is shown in Table 1.

Table 1: Data sources and component involve.

Component	Data description	Data source
Foreground data		
Transportation of raw materials to manufacturing plant	Transport mode, quantity and distance.	Sodium hydroxide manufacturer
	Fuel consumption.	MYLCID
Manufacturing of sodium hydroxide	Energy and raw materials needed for manufacturing of sodium hydroxide.	Sodium hydroxide manufacturer
Emission to air	Total volume of flue gas	Sodium hydroxide manufacturer
	Concentration of CO_2, CH_4, HFC, N_2O, NO, NO_2, NH_3, HCl, etc.	
Emission to water	Total volume of waste water discharged.	Sodium hydroxide manufacturer
	Concentration of COD, BOD, total PO_4, total P, NH_4, etc.	
Background data- Utilities		
Public treated water	Treatment of water supply.	SIRIM National LCA database
Electricity	Electricity generation at power plant.	SIRIM National LCA database
Fuel	Fuel production and combustion.	SIRIM National LCA database
Background data- Raw Materials		
Solar marine salt	Sodium hydroxide manufacturer.	Literature and JemaiPro LCA database
Chemicals	Chemicals manufacturing.	Literature and JemaiPro LCA database

Data Management:

The collection of Life Cycle Inventory (LCI) was based on questionnaire form provided by SIRIM Berhad.

Assumptions:

Since there is only one data provider in this study, assumption has been made that there is no deviation in process technology and materials used in manufacturing of sodium hydroxide in this country in order to make the data represent national average.

Life Cycle Interpretation (LCI):

The goals as well as the scopes of the analysis were kept in attention while interpreting the obtained results from LCI of sodium hydroxide. Interpretation is one of the phases of LCA in which the outpurs of the inventory analysis as well as the impact apraisals are mixed together. But, in case of analysis of LCI, only the outputs of inventory analysis covering the defined goals and scopes with the objective of reaching to conclusion and further recommendations (ISO 14040, 2006a). The outcomes of the LCI analysis was fairly, wholly and accurately accounted to the aimed audience as reported by the pertinent parts of the clause 6 of ISO 14040 (ISO 14040, 2006a).

RESULTS AND DISCUSSION

Life Cycle Inventory Analysis:

Data related to sodium hydroxide production has been collected primarily from a sodium hydroxide manufacturer in Malaysia. The input and output data was collected based on three years production of sodium hydroxide. The data related to raw materials consumption, utilities utilization, transportation of raw materials to the manufacturing plant and quantity of emissions were determined by measurement, referring to the inventory records and results of laboratory analysis. The inventory analysis of one kg of sodium hydroxide is presented in Table 2.

Table 2: Inventory analysis of one kg of Sodium Hydroxide

	Parameters	Total (kg)
Resources	Al reserves	3.95E-05
	Cu reserves	6.65E-06
	Pb reserves	2.41E-07
	U reserves	9.37E-09
	Zn reserves	1.35E-06
	coal (coke)	5.37E-06
	coal (combustion)	1.09E-01
	crude oil	6.62E-03
	limestone	2.14E-03
	natural gas	7.09E-05
	oil reserves	5.51E-03
	silica sand	1.95E-06
Air	CO2	6.25E-01
	As	9.09E-09
	CH4	4.15E-06
	Cd	7.51E-10
	Cr	1.65E-08
	Hg	1.10E-08
	N2O	2.75E-05
	NMHC	6.64E-06
	NOx	1.15E-03
	NOx (mobile source)	8.09E-05
	Ni	1.86E-08
	PM10 (mobile source)	4.93E-06
	Pb	4.35E-08
	SO2	8.49E-06
	SOx	6.56E-05
	dust	3.06E-06
	hydrocarbons	3.78E-05
Water	As	3.92E-10
	BOD	6.06E-05
	Cd	5.89E-11
	Cr	1.18E-09
	Hg	3.92E-11
Industrial	industrial waste landfill (unspecified)	3.31E-03
	low-level radioactive waste	6.55E-09
	plastic wastes (landfill)	4.93E-09
	rubbles (landfill)	9.80E-09
	slag (landfill)	1.27E-05
	sludge (landfill)	4.72E-08

Sources of Published Literature:

Background data for utilities production and raw materials extraction and production has been collected through published literature as follows;

- Conversion factor from IPCC 2006 and other published literature and website
- SIRIM National LCA database
- Datasets available in Jemai LCA Pro

Calculation Procedures:

The calculation procedure was based on input/output data provided by sodium hydroxide manufacturer. The data of raw material consumption, utilities and transportation were unitised to every one kg of sodium hydroxide produced according to the functional unit used in this study. The calculation of LCI assessment for selected impact category has been carried out using relevant conversion factors from databases or literatures.

Life Cycle Impact Assessment (LCIA):

Figure 3 (fig. 3) represents total life cycle impacts of one kg sodium hydroxide as per the following classification upon their impact: global warming, human toxicity, aquatic ecotoxicity, terrestrial ecotoxicity, acidification, eutrophication, photochemical oxidant, solid waste, resource consumption and fossil energy resource consumption. Endpoint Modelling (LIME) method equipped in the JEMAI LCA Pro software was used as an impact assessment model. Malaysia background data has been incorporated in the JEMAI LCA Pro to conduct this study and ultimately representing Malaysian scenario. Due to the lack of LCIA software in Malaysia, LIME from Japan has been adopted and used.

There are three types of impact assessment results found using LIME. Characterization results (Indicator results), LIME damage assessment results and single index aggregated LIME results. According to ISO 14040 standards, characterization is a mandatory element of an impact assessment. LIME characterization results for the selected impact categories, using the selected characterization models is shown in Figure 3 and Figure 4.

Impact category		Characterization model	Indicator result
Global warming	GW	IPCC-100 years (2001)	6.329E-01
Ozone depletion	OD	WMO 1998	
Human toxicity (carcinogenicity)	HTCA	HTP_cancer	4.927E-04
Human toxicity (chronic disease)	HTCH	HTP_chronic disease	6.944E-07
Aquatic ecotoxicity	AET	AETP	1.298E-03
Terrestrial ecotoxicity	TET	TETP	2.580E-02
Acidification	AC	AP (Huijbregts,1999)	7.065E-04
Eutrophication	EU	EP (Huijungs,2000)	3.505E-05
Photochemical oxidant	PO	POCP (UNECE,1990)	5.321E-05
Solid waste	SW	m3	3.318E-06
Land use (occupation)	LUM	m2yr	
Land use (transformation)	LUC	m2	
Resource consumption	RC	1/R(Sb base)	4.707E-07
Fossil energy resource consumption	EC	MJ	3.505E+00

Fig. 3: Result of environmental impact assessment (characterisation results) for one kg of sodium hydroxide using LIME

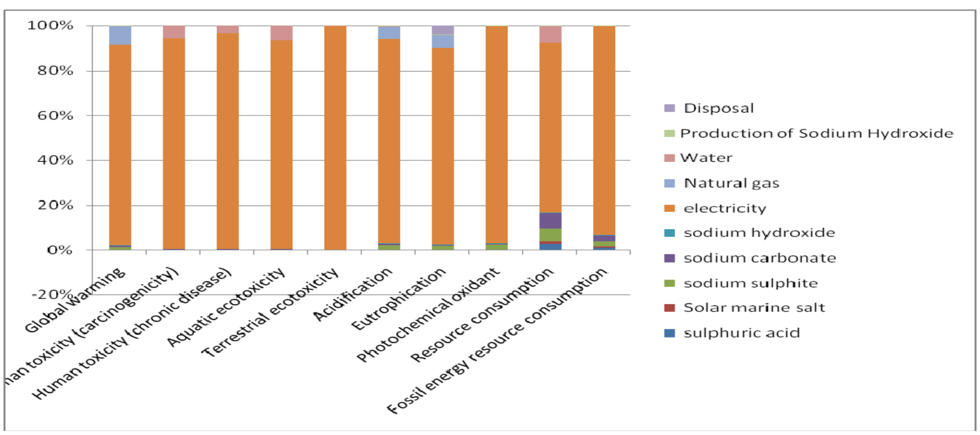

Fig. 4: Environmental impacts of one kg sodium hydroxide

Global Warming Potential (GWP):

The Global warming potential (GWP) has been characterized with the application of usually more distinguished factors following the International Panel on Climate Change for a time frame of 100 years. The GWP allows the prospective consequences on climate changing due to various activities which might be assessed on a usual basis (Anna *et al.*, 2012). Calculation of full life cycle of GWP is performed with respect to equivalent substance CO_2 (hereinafter adverted as CO_2 equivalent). Figure 5 (Fig. 5) shows the major sources of GHG emission per kg of sodium hydroxide in which electricity contributes 89% followed by natural gas (9%). The chemicals used in the production contribute less than 1% of the total GHG emission. Concerning the contributing substances, airborne CO_2 emission contributed the most about 0.625 kg CO_2/kg sodium hydroxide followed by CH_4 contributed 9.55e-05kg CO_2equivalent and N_2O contributed about 8.13e-03 kgCO_2 equivalent.

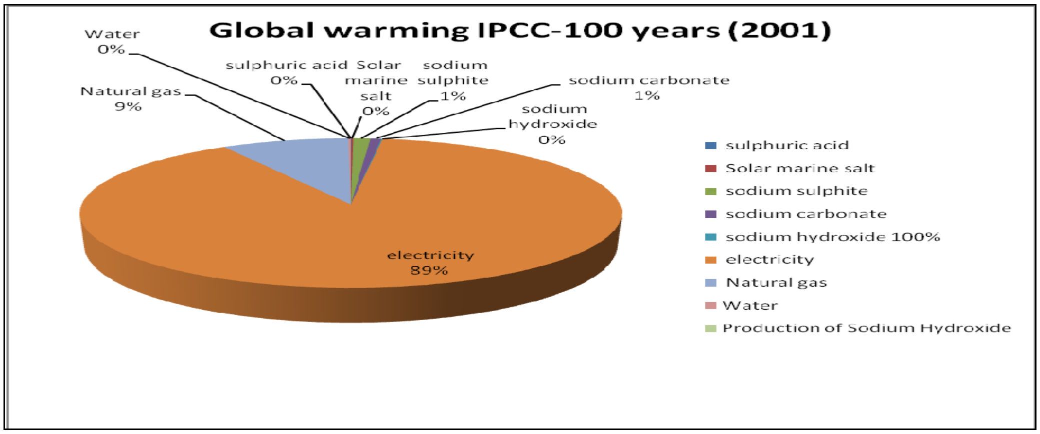

Fig. 5: Hotspots identification with respect to GHG emission for production of one kg sodium hydroxide

Human Toxicity Potential (Carcinogenicity):

The classification of impact characterization of toxic chemicals is conceived on the basis of human exposure. This is evinced in terms of the chemical substance 1, 4 dichlorobenzene (1, 4-DB). The results presented in the figure 6 (Fig. 6) demonstrates that the production of one Kilogram of sodium hydroxide contributes to the generation of 0.493g 1,4-DB eq. In this case, electricity again leads the key hot spot through contributing 94% of entire emission sources leading to the human toxicity potential. Airborne and water emission such as chromium and arsenic from the combustion of fossil fuels prevail among the substances which are responsible for contributing on these categories.

Human toxicity (carcinogenicity) : HTP_cancer

	Item	LCI result	Unit	Characterization factor	Converted result
air	As	9.09E-09	kg	1.95E+04	1.78E-04
air	Cd	7.51E-10	kg	3.76E+03	2.83E-06
air	Cr	1.65E-08	kg	1.54E+04	2.54E-04
air	Ni	1.86E-08	kg	8.40E+01	1.56E-06
air	Pb	4.35E-08	kg	5.26E+01	2.29E-06
water	As	3.92E-10	kg	3.14E+04	1.23E-05
water	Cd	5.89E-11	kg	7.50E+03	4.41E-07
water	Cr	1.18E-09	kg	3.50E+04	4.13E-05
				Indicator result	4.93E-04

Fig. 6: The contributors to the human toxicity potential

Aquatic Ecotoxicity Potentials:

Over again the electricity has been recognized as the responsible for the major contribution on this impact category (93% of total). Referring to the contributing substances, mercury (Hg) is found to be the main responsible substances followed by lead (Pb) for aquatic ecotoxicity potentials as shown in figure 7 (Fig. 7). Total kg of 1, 4-DB eq is 1.298e-03kg.

Aquatic ecotoxicity : AETP					
	Item	LCI result	Unit	Characterization factor	Converted result
air	As	9.09E-09	kg	5.31E+03	4.83E-05
air	Cd	7.51E-10	kg	2.69E+05	2.02E-04
air	Cr	1.65E-08	kg	9.04E+03	1.50E-04
air	Hg	1.10E-08	kg	4.33E+04	4.75E-04
air	Ni	1.86E-08	kg	6.71E-04	1.25E-11
air	Pb	4.35E-08	kg	6.02E+03	2.62E-04
water	As	3.92E-10	kg	1.55E+04	6.10E-06
water	Cd	5.89E-11	kg	7.89E+05	4.64E-05
water	Cr	1.18E-09	kg	2.65E+04	3.11E-05
water	Hg	3.92E-11	kg	1.94E+06	7.62E-05
				Indicator result	1.30E-03

Fig. 7: Contributors of the aquatic ecotoxicity potential

Eutrophication Potential:

Excess of phosphates released into the lake and river stimulates the growth of algae faster than the normal rate (Uri Zoller, 2004). This blooming of algae interrupts water ecosystem and engenders many troubles to the acquatic organisms (Smayda, 2008, Heisler *et al*., 2008). The high level of algae may cause serious oxygen depletion bringing on death of many aquatic organisms, especially fish. The algal bloom can hinder the sunlight to perform the photosynthesis of the marine plants underneath the water; moreover, few species of algae even give rise to toxins which are harmful to the more prominent forms of life (Struijs *et al*., 2010). This can generate problems on the food chain and also affect any of the animals that feed upon them. Therefore, it causes deterioration of overall water quality and affects the potential drinking water. This environmental phenomenon is called eutrophication (Saarinen *et al*., 2012).

Eutrophication is assessed in terms of PO_4 equivalent (Saarinen *et al*., 2012). All the impacts towing to excessive degrees of macronutrients in the environment are included which are caused due to emanations of nutrients to air, water and soil (Saarinen *et al*., 2012). Electricity has been recognized as lead responsible for the eutrophication emissions (about 88%) obtained from the yield of the sodium hydroxide. Natural gas contributes about 6% and the disposal stage contributes about 4% (Fig. 8). NOx is the principal contributor pertaining to the contributive substances and leads about 3.15e-05 kg PO_4equivalent and BOD from the water emission contributes about 1.33e-06 kg PO_4 equivalent.

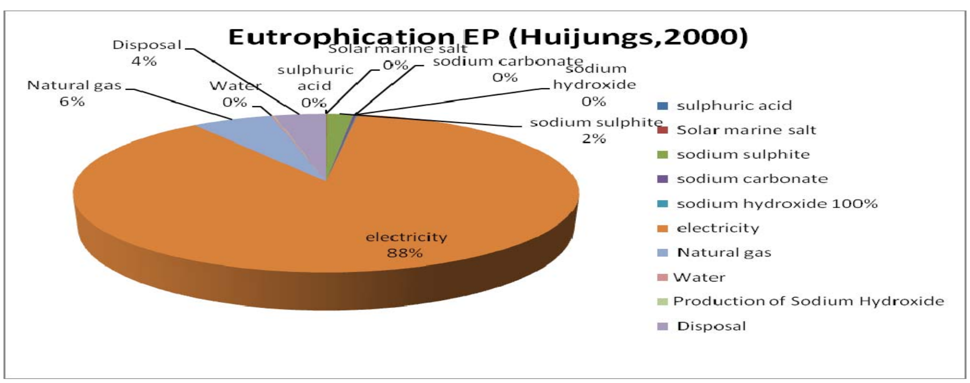

Fig. 8: Hotspots identification with respect to eutrophication potential for production of one kg sodium hydroxide

Acidification Potential:

The acidification process refers to the emanation of acidifying compounds that causes an impact on the soil, groundwater, ecosystems, and materials (Peters *et al*., 2011). In this analysis, acidification is evinced in equivalent amount of SO2 emissions for each functional unit. Mostly the deposition of acid compounds derives from SO_2 and NOx which are generated through agricultural as well as industrial processes' actions. The emanation of these compounds combines with other atmospheric substances to yield acids as well as other compounds, especially acid rain which can attenuate the pH of both soil and water, ensuing in adverse affects on the ground water, fishes and forests. In this case, electricity was found responsible for contribution of about 91% of the total acidification potential succeeded by natural gas (6%). Main contributors for the acidification are NO_X , SO_2 and SO_X. In this analysis, total SO_2 is equivalent to 7.06e-04kg SO_2 (Fig. 9).

Acidification : AP (Huijbregts,1999)					
	Item	LCI result	Unit	Characterization factor	Converted result
air	NOx	1.15E-03	kg	5.00E-01	5.77E-04
air	NOx (mobile	8.09E-05	kg	5.00E-01	4.05E-05
air	SO2	8.49E-06	kg	1.20E+00	1.02E-05
air	SOx	6.56E-05	kg	1.20E+00	7.87E-05
				Indicator result	7.06E-04

Fig. 9: Contributors of the acidification potential for one kg sodium hydroxide

Resource Consumption:

Electricity contributes about 76% to the resource consumption category followed by water, 7% as shown in figure 10 (Fig. 10). As shown in the figure 11 (Fig. 11), the main contributors for resource consumption are coal, crude oil and oil reserves. Most of these contributors are from electricity usage in production of one kg sodium hydroxide.

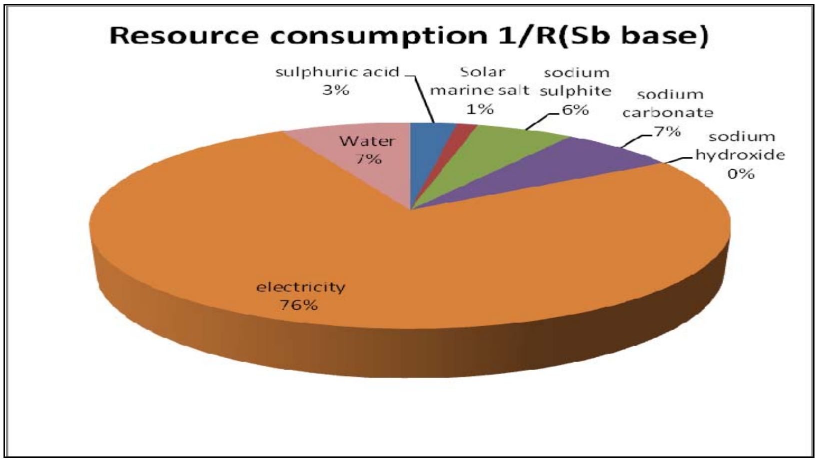

Fig. 10: Hotspots identification with respect to resource consumption potential for production of one kg sodium Hydroxide

Resource consumption : 1/R(Sb base)					
	Item	LCI result	Unit	Characterization factor	Converted result
resource	Al reserves	3.95E-05	kg	8.40E-05	3.32E-09
resource	coal (coke)	5.37E-06	kg	2.13E-06	1.15E-11
resource	coal (combustion)	1.09E-01	kg	2.13E-06	2.32E-07
resource	crude oil	6.62E-03	kg	1.36E-05	9.00E-08
resource	Cu reserves	6.65E-06	kg	6.18E-03	4.11E-08
resource	natural gas	7.09E-05	kg	1.61E-05	1.14E-09
resource	oil reserves	5.51E-03	kg	1.36E-05	7.50E-08
resource	Pb reserves	2.41E-07	kg	3.28E-02	7.92E-09
resource	U reserves	9.37E-09	kg	5.34E-01	5.00E-09
resource	Zn reserves	1.35E-06	kg	1.11E-02	1.49E-08
				Indicator result	4.71E-07

Fig. 11: Contributors of the resource consumption potential

Fossil Energy Resource Consumption:

Figure 12 illustrates the major source of fossil energy resource consumption for one kg of sodium hydroxide is electricity, contributing about 93 %. Total fossil energy resource consumption is 3.5 MJ for one kg of sodium hydroxide.

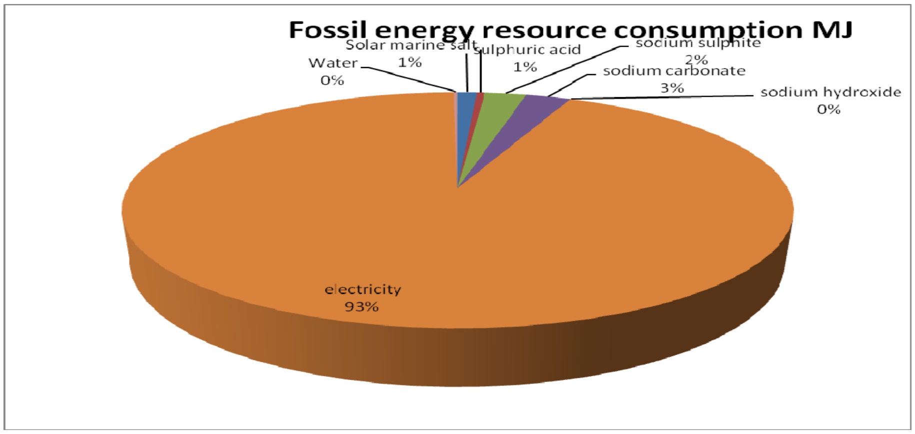

Fig. 12: Hotspots identification with respect to fossil energy resource consumption (MJ) for one kg of sodium hydroxide

Conclusion:

In general fossil fuel, respiratory inorganic and global warming potential are the main sources in life cycle analysis of sodium hydroxide from cradle-to-gate. These sources of environmental impact come from consumption of electricity and natural gas.

Impact category has been calculated using Malaysia's primary scopes' data for one kg of sodium hydroxide and the results are briefly noticed as follows:

- 0.6329 kg of CO_2 eq that represents Global Warming Potential
- 0.4927 g of 1, 4 dichlorobenzene eq. that represents Human Toxicity Potential (Carcinogenicity)
- 1.298 g of 1,4 dichlorobenzene eq. that represents Aquatic Ecotoxicity Potential
- 0.035 g of PO_4 eq.that represents Eutrophication Potential
- 0.706 g of SO2 eq. that represents Acidification Potential
- 3.5 MJ that represents Fossil Energy Resource Consumption

However there are several limitations associated with the interpretation of the obtained results in this study and those are:

Although only one company participated in this project but the company is one of the major producers of sodium hydroxide in Malaysia. The inventory data for the foreground system consisted of average annual data obtained by on-site measurements in the company.

Novelty of this study is that the life cycle assessment (LCA) was conducted using Malaysia's background data which was established under National LCA project in Malaysia. Background data or primary data such as natural gas and crude oil, electricity, water, transport and landfill were established and used in this study.

Before this all the LCA conducted in Malaysia used European data (Vijaya, 2009, Yusoff, 2006, Sumiani Yusoff and Hansen, 2007). Most of the European data is not applicable for Malaysian scenario. For example source of electricity, crude oil and natural gas production are different from country to country based on the actual practice in the country. So it is critical to develop primary data for these areas. Primary data or foreground data were also collected for transportation of raw materials to Malaysia, raw materials manufactured in Malaysia, transportation of finished goods. Our SIRIM LCA database do not have enough information on raw materials and chemicals used in the production, therefore JEMAI LCA Pro database was used to fill up the data gap. The advantage of using the Jemai LCA Pro software is Malaysian data on electricity, water and natural gas were used and represents Malaysian senario.

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