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Ozone Depletion Substances (ODS) Emission Analysis from the Life Cycle of Chemical Substances and Electricity Used in Potable Water Production in Malaysia

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Abstract: Malaysia is a country that is very committed in ensuring a constant development in a sustainable way by creating a balance between economy, social and environment. It can be proven as Malaysia is ranked in a very good position in Environmental Sustainability Index. But this ranking should be a guideline to ensure the pockets of weaknesses in executing sustainable development in this country should be filled especially in effectively managing the environment. Ozone Depletion Substances (ODS) emission needed an environmental management method that is capable to identify the cause of this problem in order to the right action could be taken in place to mitigate the problem of ozone depletion. Event though drastic measures were taken in this country such as the ban of Halon gas use in fire control sector as a signatory to the Montreal Protocol 1989, it does not mean that this measure is enough to stop ODS from being emitted to the air. The use of Life Cycle Assessment (LCA) in a water treatment system proves that this method is capable to identify substances that emit ODS. Chemicals and electricity used in the water treatment is found to emits 8 types of ODS and Methane, bromotrifluoro-, Halon 1301 is contributed the most compared to the other 7 types. Aluminium sulphate (alum) is substance that contributed the most Methane, bromotrifluoro- and Halon 1301 in the atmosphere. Life cycle analysis conducted to identify the cause of ODS emission in Alum found that electricity generation using coal and fossil fuel contributed the highest ODS emission. Electricity generation through hydroelectric is found not to emit any ODS at all. The advantage of LCA in identifying weaknesses and shortcomings of a product should not be taken lightly by Malaysia. Malaysia should use LCA as an effective environmental management method that indirectly secures Malaysia's current ranking to a better position in the future.

Key word: Sustainable development, ozone layer depletion, potable water production, Aluminium sulphate (alum), Polyaluminium chloride (PAC), Electricity generation, Methane, bromotrifluoro-, Halon 1301

INTRODUCTION

Since named as the World Ozone Day by the United Nations Environment Programme, the date of 16 September 1987 meant that it has been more than 20 years since we started putting in various efforts to overcome the problem of ozone layer depletion. Seeing the importance of ozone problem, 2007 has been made as International Year of Ozone Layer. Why ozone layer is very important to us and must be protected? The ozone layer is a thin layer of ozone gas which naturally protected the earth from the negative effects of sun radiation especially the ultraviolet (UV) ray. As the ozone layer gets thinner, more and more of sun's UV ray will reach the earth's surface. Overexposure to UV ray is dangerous to health. Several health problems identified to be caused by UV ray is aging effects, cataract up to permanent damage to the eye and decreased immune system increasing the chance of getting melanoma (dangerous skin cancer). At this moment the ozone layer is rapidly damaging and thinning. Based on the monitoring using the Total Ozone Mapping Spectrometer (TOMS) instrument on the Nimbus 7 and Meteor 3 satellites, the damages had created a hole known as "ozone hole" at both the North Pole and South Pole.

Ozone Layers Depletion issue is not a recent issue to this country or the world. It has been discussed and identified since the 1970s which brought us to the signing of Montreal Protocol Agreement in 1987.

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Among the materials that has ozone depleting substances (ODS) includes Halon that is mostly used in the fire control industry. The emission of Chlorine (Cl), Bromine (Br) and Fluorine (Fl) gases in Halon into the atmosphere can cause the UV ray to penetrate through the ozone layers and affecting life on earth such as effects to the immune system, skin cancer, damage to eye and cataracts. Starting from this realization, Malaysia has stopped the import of Halon in 1996 and Halon system was replaced with various other approved alternatives.

The Halon bank project is actually planned in 1992 as soon as Malaysia becomes a signatory to the Montreal Protocol in 1989. This is an important project to Malaysia, which the Department of Fire and Rescue was appointed to head this project seeing that Halon 1301 and 1211 is mostly used in the fire control sector as fire extinguishers and fire suppression system. Malaysia is the only country in the world selected to conduct the "pilot project" of Halon bank with financial assistance from the World Bank. This project only come to be realised in 1996 where the Department of Fire and Rescue chosed the Sukiada Engineering company to handle the project for a three year period until December 1999. To date, a quantity of 320,000kg of Halon 1301 and 8,000kg Halon 1211 was registered. From this quantity, an amount of 35,000kg Halon 1301 and 4,000kg Halon 1211 was succesfully collected and stored by the Halon Bank of Malaysia.

To comply to the commitment to Montreal Protocol and World Bank in ensuring the Halon disposal program reaches its target according to schedule, the Department of Fire and Rescue has taken over the management of the Halon bank in March 2000 even though they are facing financial, staffing and location constraints. The Department took more than 6 months to restore buildings to be the office and Halon storage depot and also to acquire fulltime staff. Currently the Halon bank office operates in a building at the Centre for Fire and Rescue Training in Kuala Kubu Baharu, Selangor.

With the existing capabilities, cooperation from the Department of Environment and the support of the highest management in the Department, the Halon bank project is now starting to show improvement with the collection and registration work moving again. Under the new Halon bank management, the Department of Fire and Rescue has organised several strategies to comply with Malaysia's commitment to Montreal Protocol such as:

1. Acquiring the data of total Halon in Malaysia latest by the end of 2001 throught registration by Fire and Rescue officers at each states,
2. Recycling Halon and stored in Halon bank for the used of "essential users",
3. Organising awareness programme on ozone depletion caused by Halon gas emission to Halon users and the general public through courses and seminars, and
4. Targeting for "zero halon" in 2005.

The existing powers of the fire and rescue officers under the Fire and Rescue Act has been fortified by the legislation of environmental quality management rules (Halon management) 1999 which was enforced on 1 Januari 2000. Under this law, all Halon owners must register owned Halon to the Department of Fire and Rescue and any accidental release of Halon or during fire extinguishing must immediately reported to the Department of Fire and Rescue. This law also forbids any new installation of Halon 1301 systems and the use of BCF (Halon 1211) fire extinguisher type. The most critical subject under the provision of this law is that Halon cannot be traded (sold or bought), smuggled or recycled accept for "essential users" after getting the approval of the Department of Environment.

Efforts by the Malaysian Government (especially the Department of Fire and Rescue) in the eradication of ODS in this country must be applauded but it should be more comprehensive and stressing the sustainable development principles. It is undeniable that Malaysia is among the developing countries that has moved far ahead in this subject. Even before the introduction of sustainable development concept, Malaysia already has her own efforts in environmental conservation through laws, campaigns, forest management and such. With these continuous efforts, Malaysia achieved a good Environmental Sustainability Index. Looking at this index for the year of 2002, out of the 142 countries studied, Malaysia ranked at the 68^{th} place. This position is far higher than Japan and United Kingdom which was ranked at 78^{th} and 91^{st} place consecutively. In 2005 also, Malaysia has further improved her position to the 38^{th} place from 146 countries. Once again Malaysia has lead far ahead of the developed countries such as United States and (45^{th} place) and United Kingdom (65^{th} place).

This index is produced from the collaboration of World Economic Forum's Global Leaders for Tomorrow Environment Task Force, The Yale Center for Environmental Law and Policy and Columbia University Center for International Earth Science Information Network (CIESIN). This index measures the overall achievement of environmental sustainability of a country. Under this index, 20 main indicators are studied such as water quality, air pollution, nuclear reactor safety and green house gas emission. Malaysia's ranking in this index is rather surprising. Who would have thought that a country as small as Malaysia could surpass other developed countries? Even among the countries in ASEAN, Malaysia ranked at the top of the index. Even though this index is an indicator of the country's position in ensuring sustainable development is implemented in all development aspects, Malaysia must lead in the environmental management. A lot of methods could be used to ensure that the environment is managed efficiently. Among them is the use of Life Cycle Assessment (LCA). Malaysia if compared to two of her neighbor Singapore and Thailand is still far behind in movement and making LCA as an important element in her environmental management program and her sustainable development strategies. The comprehension of LCA is still shallow and there are very few studies on LCA are being conducted. What is LCA and how this method can help in managing the environment effectively?

2.0Methodology of LCA:

This study is using the procedure suggested by the International Organization of Standardization (ISO) under environmental management namely ISO 14040 series. There are four main phases in the suggested ISO 14040 series:

2.1 Goal and scope definition (ISO 14040)
2.2 Life cycle inventory (LCI) (ISO 14041)
2.3 Life cycle impact assessment (LCIA) (ISO 14042)
2.4 Life cycle assessment and interpretation (LCAI) (ISO 14043)

2.1Goal and Scope Definition:

In goal definition and scoping, the use of the results is identified, the scope of the study is stated, the functional unit is defined, and a strategy and procedures for data collection and data quality assurance are established.

2.1.1Objectives:

This objective of this study is to get the overall depiction of ozone depletion substances (ODS) gas emission released from the process of producing chemicals and electricity used during the water treatment process. To achieve this general objective, several specific objectives were underlined as follows:

- Collecting inventory for input (foreground data) needed to produce treated water in a day that fits the set standard
- Identifying substances which has the inclination to emit more Ozone Depletion Substances (ODS) gases

2.1.2Functional unit:

Functional unit is quantified performance of a product system for use as a reference unit in a life cycle assessment study (ISO14000, 2000). A constant value must be created to make the comparison (Miettinen & Hamalainen, 1997). Functional unit for this study is the production of $1000cm^3$ of treated water a day that fits the standard quality set by Ministry of Health, Malaysia.

2.1.3Description of the system under study:

To define the system boundaries for a product, it is essential to understand how a product is manufactured. In producing treated water, raw water goes through several phases before drinking water that fits the set standard is produced. Raw water extracted from rivers will go through the following process in the water treatment plant:

- **Screening**, to remove floating big sized rubbish on the surface of the water.
- **Coagulation and flocculation**, coagulation process is a process of forming particles called floc. Coagulant need to be added to form floc. The coagulants that are normally use includes Aluminium sulphate, Ferric sulphate and Ferric chloride. Tiny flocs will in turn attract each other while at the same time pulling the dissolved organic material and particulate to combine, forming a big flocculant particle. This process is called flocculation.
- **Sedimentation**, Floc produced will settle on the base of the sedimentation basin. The accumulation of floc settlement is called sludge.
- **Filtration**, part of the floc which does not settle in the sedimentation basin will go through filtration. Water passing through filtration consisting of sand layers and activated carbon or anthracite coal.
- **Disinfection** process is needed to eliminate pathogen passing through the filters. Among the chemicals used for the disinfection are chlorine, chloramines, chlorine dioxide, ozone, and UV radiation.

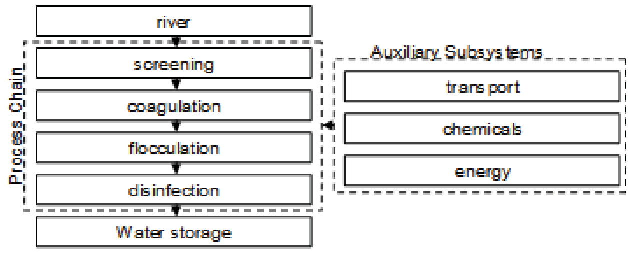

Fig. 1: shows the system boundary of the study.

2.2Life Cycle Inventory (LCI):

After scoping the product system, the inventory in the system under study is gathered. It includes information on the input and output (environmental exchanges) for all the process within the boundaries of the product system. The result of an inventory is a long list of material and energy requirements, products and co-products as well as wastes. This list is referred to as the material and energy balance, the inventory table, or the eco-balance of the product (Guinée, 2002). This LCA study is a streamlined LCA where background data for electricity, chemicals and transport using database contained in the Jemaipro and Simapro 7 software. Foreground data collected from the treatment plant are:

- Electricity usage, and
- Chemicals such as Aluminium sulphate (alum), Polyaluminium chloride (PAC), Chlorine, and Calcium hydroxide (lime)
- Foreground data mentioned above was compiled from selected treatment plant. Data inventory for background data was acquired from two main sources namely SimaPro and JemaiPro. Inventory schedule is shown in

Table 1: Foreground data for chemical substances and electrical consumption to produce 1m^3 treated water

Electrical consumption (Kw/H)	397.28
Aluminium sulphate (kg)	22.55
Polyaluminium chloride (PAC) (kg)	16.85
Chlorine (kg)	3.65
Calcium hydroxide (kg)	11.12

2.3Life Cycle Impact Assessment (LCIA):

The purpose of the life cycle impact assessment is to interpret the inventory results into their potential impacts on the areas of protection of the LCA (Michael Hauschild, 2007). i.e in Eco-indicator 99 (see table 2), the entities that the use of the LCA shall help protect. Areas of protection for LCIA are human health quality, ecosystem quality and natural resources. However in this study, ODS was categorized as damage to human health (refer **Table 2**).

Table 2: Damage Assessment and Impact According to Eco-Indicator 99 Evaluation Method (Goedkoop & Spriensma, 2001)

Damage Assessment	Unit	Impact
Human Health	DALY	Carcinogen, radiation, respiratory organic and inorganic, climate change and ozone layer
Ecosystem Quality	PDF*m^{2}yr	
PAF*m^{2}yr	Land use and acidification/eutrophication,	
Ecotoxicity		
Resources	MJ surplus	Minerals and fossil fuels
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)	

Generally there are 3 steps in LCIA:

- Classification and Characterization
- Normalization, and
- Weighting

2.3.1Classification and Characterization:

Classification is the step in which the data from the inventory analysis (the substance emissions) are grouped together into a number of impact categories (Bovea & Gallardo, 2006). Grouping to impact categories is according to their ability to contribute to different environmental problems. While characterization are the effect of each item on each impact category is quantified. A typical way is to use equivalency factors, in some instances also called potentials. For example, global warming potential for a substance indicates its relative potential to increase the global warming effect compared to CO_2, whose GWP is set to one. In ISO 14040 series classification and characterization are two basic mandatory elements. Analysis for normalization and weighting is not conducted as it is not a mandatory step in the procedures of conducting LCA analysis. **Fig. 2** shows that ODS is the main contributor to the ozone layer depletion from the processes of producing chemicals and electricity used in treating drinking water. From the figure we can see that the chemicals Methane, bromotrifluoro-, Halon 1301 contribute the most to ozone layer depletion. Other than that chemicals Ethane, 1,2-dichloro-1,1,2,2-tetrafluoro-, CFC-114 is the second highest contributor after Methane, bromotrifluoro-, Halon 1301.

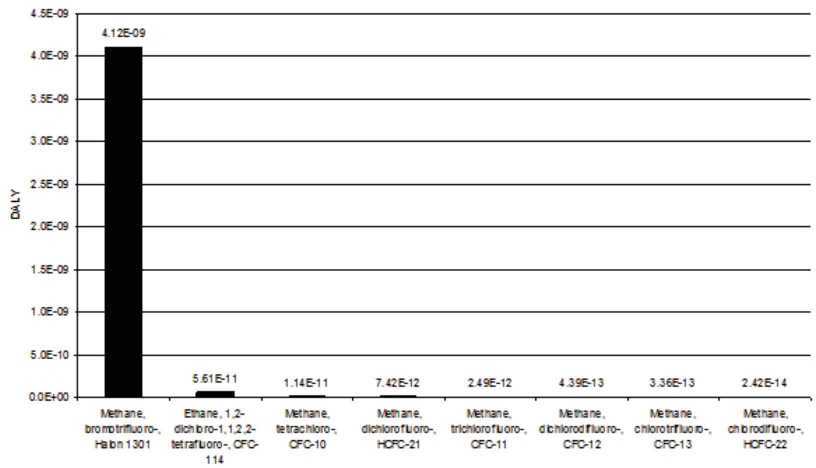

Fig. 2: Overall total Ozone Depletion Subtances (ODS) contributed by chemicals and electricity used in water treatment process

Table 3 shows the list of ODS emitted from each chemicals and electricity generation. There are 7 ODS emitted and it is found that Methane, bromotrifluoro-, Halon 1301 is emitted by all chemicals and electricity used in water treatment process and these substances are the only ODS emitted from the production of chemicals such as Chlorine and Alum including electricity generation. Meanwhile PAC and Lime emits all listed ODS. Even though PAC and Lime emits all listed ODS but the overall total quantity of ODS is still lowercomparing to Alum and Chlorine which only emits the main ODS namely Methane, bromotrifluoro-, Halon 1301 (refer fig. 2). **Fig 2** also shows that PAC contributes the least ODS compared to other substances. Meanwhile Alum contributes the highest value of ODS among all substances. Previous study which compares these two substances (Amir Hamzah, Noor Zalina, & Abdul Halim, 2008a, 2008b, 2008c, 2008d), PAC and Alum shows that PAC contributes to damage to environmental quality (especially acidification and eutrophication impact) and human health quality (especially respiratory inorganic impact). This situation is caused by the PAC production process emitting sulphur oxides and nitrogen oxides. This analysis shows the contradicting result if look at from the area of protection perspective stressed in the eco-indicator 99 evaluation method analysis. This ODS analysis even shows that Alum is the main contributor in emitting Methane, bromotrifluoro-, Halon 1301 compared to PAC which clearly contributes the least ODS.

2.4Life Cycle Assessment Interpretation (LCAI):

Interpretation is the phase of the LCA where the results of the other phase are interpreted according to the goal of the study using sensitivity and uncertainty analysis. The outcome of the interpretation may be a conclusion serving as a recommendation to the decision makers, who will normally consider the environmental and resource impacts together with other decision criteria (such as economic and social aspects) (M. Hauschild, Jeswiet, & Alting, 2005).

Table 3: List of Ozone Depletion Subtances (ODS) contributed from chemicals and electricity used in water treatment process.

Substance	Unit	Chlorine	Alum	PAC	Lime	Electricity
Methane, bromotrifluoro-, Halon 1301	DALY	7.36E-10	2E-09	3.19E-13	6.45E-10	7.41E-10
Ethane, 1,2-dichloro-1,1,2,2-tetrafluoro-, CFC-114	DALY	x	x	1.57E-17	5.61E-11	x
Methane, tetrachloro-, CFC-10	DALY	x	x	5.62E-18	1.14E-11	x
Methane, dichlorofluoro-, HCFC-21	DALY	x	x	8.46E-18	7.42E-12	x
Methane, trichlorofluoro-, CFC-11	DALY	x	x	6.99E-19	2.49E-12	x
Methane, dichlorodifluoro-, CFC-12	DALY	x	x	1.24E-19	4.39E-13	x
Methane, chlorotrifluoro-, CFC-13	DALY	x	x	9.44E-20	3.36E-13	x
Methane, chlorodifluoro-, HCFC-22	DALY	x	x	6.97E-21	2.42E-14	x

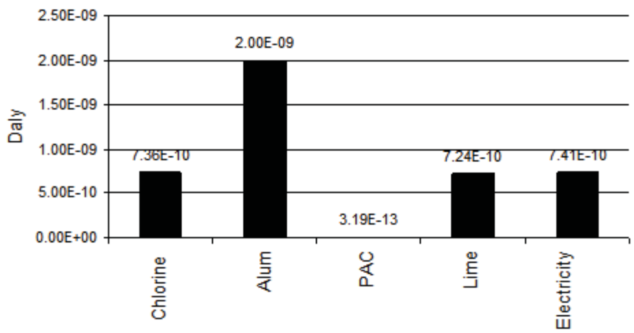

Fig. 3: Comparison of ODS emitted from chemicals and electricity used in water treatment process.

2.4.1Improvement Assessment:

Analysis shows that Alum is the main substance that contributes to the emission of Methane, bromotrifluoro-, Halon 130. An analysis is conducted to gain the information on life cycle for aluminium sulphate and identifying the substances that has the potential to emit Methane, bromotrifluoro-, Halon 130. The result of the analysis shows that three main component that contributes to ODS emission are production of sulphuric acid, electricity and transportation (train). Electricity is found to be the highest contributor for Methane, bromotrifluoro-, Halon 130 with the value of 4.70E-11 DALY.

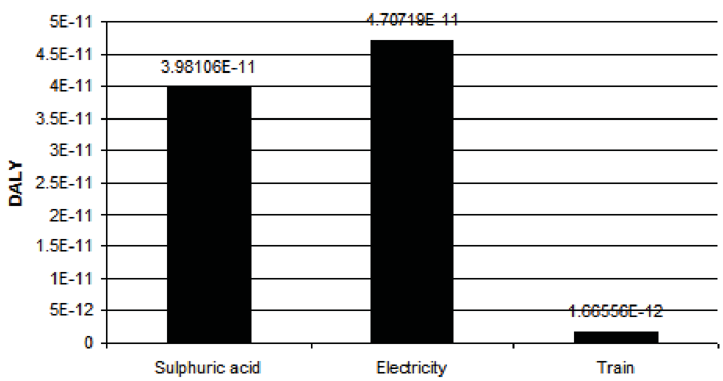

Fig. 4: ODS contribution (Methane, bromotrifluoro-, Halon 130) from the process of producing Aluminium Sulphate which involves three main component namely sulphuric acid, electricity and transportation (train).

Electricity is the main factor contributing to the emission of ODS (Methane, bromotrifluoro-, Halon 130). It contributes as much as 53.2% compared to the production of sulphuric acid and train. If transportation using train is analyzed, almost 50% contribution of ODS also comes from electricity (0.017MJ) compared to heat from diesel (refer fig. 5). Several method is used in generating electricity and it is found that 50% of ODS contribution is from electricity generation using oil while 2.5% is contributed by coal. The same with electricity used to move the train; analysis found that the two types of electricity generation is also the main contributor to ODS. However analysis also shows that electricity generation using hydropower does not emits any ODS at all if compared to other electricity generation methods (gas, lignite, and uranium) which contributes a very small percentage.

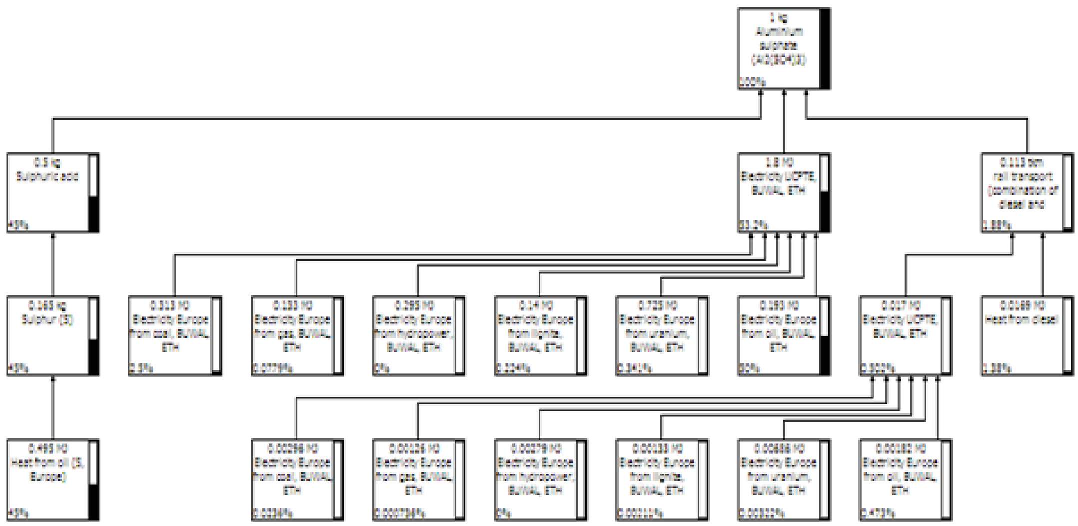

Fig. 5: Flowchart of ODS contribution process from the production of 1kg aluminium sulphate (in percentage)

Conclusion:

There are 8 types of ODS emitted during the process of producing chemicals and generating electricity used in water treatment process. The following are the 8 substances:

1. Methane, bromotrifluoro-, Halon 1301
2. Ethane, 1,2-dichloro-1,1,2,2-tetrafluoro-, CFC-114
3. Methane, tetrachloro-, CFC-10
4. Methane, dichlorofluoro-, HCFC-21
5. Methane, trichlorofluoro-, CFC-11
6. Methane, dichlorodifluoro-, CFC-12
7. Methane, chlorotrifluoro-, CFC-13
8. Methane, chlorodifluoro-, HCFC-22

Major ODS contributor are Methane, bromotrifluoro-, Halon 1301. This substances are emitted from the process of producing chemicals (alum, chlorine, lime, and PAC) and electricity generation for used during water treatment process. Alum production is found to contribute the highest quantity of Methane, bromotrifluoro-, Halon 1301 if compared to other substances. Alum production process is analyzed to identify the cause of high ODS emission and it was found that electricity generation contributes the highest ODS compared to sulphuric acid production and transportation (train). Electricity generation from oil and coal are two methods that contribute the highest ODS compared to other methods. Generation method of hydropower is found to emit no ODS at all. Even though Alum is found to contribute higher ODS compared to another coagulant, PAC used in water treatment, it does not mean that Alum is more environmental friendly than PAC. This is due to the fact that previous studies has found that PAC also contribute to damage to environmental quality (acidification and eutrophication impact) and damage to human health (especially respiratory inorganic)(Amir Hamzah *et al*., 2008a, 2008b, 2008c, 2008d)

The use of LCA in analysing a substance and product is found to be proven method in identifying weaknesses and shortcomings from the production process of a product. This is important for searching alternatives or improving system weaknesses that was identified. Malaysia as a country that focused on environmental issues should make LCA a tool to assist in achieving sustainable development. Even though ozone layer depletion is a global issue, Malaysia has to proactively act in concert at global level to overcome this issue seriously. Execution of LCA is very potential in detecting not only ODS but substances that contribute to global warming and acid rain that are also environmental issues that gets global attention.

REFERENCES

Amir Hamzah, S., M. Noor Zalina, & S. Abdul Halim, 2008a. *Life Cycle Impact Assessment (LCIA) of Potable Water Production.* Paper presented at the The National Conference in Enviroment and Health, Kota Bharu, Kelantan.

Amir Hamzah, S., M. Noor Zalina, & S. Abdul Halim, 2008b. *Life Cycle Impact Assessment (LCIA) of Potable Water Production in Malaysia: A Comparison between Different River Class.* Paper presented at the The Eight Conference on Ecobalance 08, Tokyo Big Sight, Japan.

Amir Hamzah, S., M. Noor Zalina, & S. Abdul Halim, 2008c. *Life Cycle Impact Assessment (LCIA) of Potable Water Production in Malaysia: A Comparison among Different Technology used in Water Treatment Plant.* Paper presented at the International Symposium on Environmental Management 2008: Hazardous-Environmental Management Toward Sustainability, Nakorn Nayok, Thailand.

Amir Hamzah, S., M. Noor Zalina, & S. Abdul Halim, 2008d. *Life Cycle Impact Assessment (LCIA) of Potable Water Production in Malaysia: A Comparison of Water Level Supply.* Paper presented at the 10th Symposium of the Malaysian Society of Applied Biology: Realization of Biodiversity Potentials Through Applied Biology, Kuching, Sarawak.

Bovea, M.D., & A. Gallardo, 2006. The influence of impact assessment methods on materials selection for eco-design. Materials and Design, 27: 209-215.

Goedkoop, M., & R. Spriensma, 2001. *The Eco-indicator 99 - A damage oriented method for Life Cycle Assessment Methodology Report* (3rd ed.). BB Amersfoort: Pre Consultants.

Guinée, J.B., 2002. *Handbook on Life Cycle Assessment: Operational Guide to the ISO Standards*: Springer.

Hauschild, M., 2007. Why LCA? [Powerpoint presentation]. Technical University of Denmark: Department of Manufacturing Engineering and Management, Denmark

Hauschild, M., J. Jeswiet, & L. Alting, 2005. From Life Cycle Assessment to Sustainable Production: Status and Perspective. Annals of the CIRP, 54/2/2005: 535-555.

ISO14000., 2000. *Malaysian standards handbook on environmental management: MS ISO 14000 Series - 2nd Ed*. Shah Alam, Malaysia: SIRIM.

Miettinen, P., & R.P. Hamalainen, 1997. How to benefit from decision analysis in environmental life cycle assessment (LCA). European Journal of Operational Research, 102: 279-294.