Asian Journal of Chemistry; Vol. 23, No. 9 (2011), 4003-4007

ASIAN JOURNAL OF CHEMISTRY

www.asianjournalofchemistry.co.in

Life Cycle Assessment of Acetylene

ZHIMING ZHOU, CHAOJUN YU, MENGQIN WANG*, MANMAN LI and CHANGRONG RAN

Chemistry and Chemical Engineering, Chongqing University, Chongqing, P.R. China

*Corresponding author: E-mail: yutiangudan@163.com

(*Received*: 10 November 2010; *Accepted*: 14 May 2011) AJC-9954

Life cycle assessment is an objective method evaluating the environment pressure of industrial products, process and activities. In this paper, the life cycle assessment method was used to investigate the energy consumption and environmental burden of acetylene production with partial oxidation technology with natural gas. Through analyzed, the result shows the impact of acidification potential was 93 % in the overall impact. The life cycle impact assessment of each pollutant showed that the direct emission of naphthalene is the main sources of environmental burden and the share is 51.02 %. The impact of carbon dioxide and COD were in the second position, which shared 16.75 and 14.79 %, respectively.

Key Words: Acetylene, Life cycle assessment, Energy consumption, Environmental burden.

INTRODUCTION

Acetylene is an important raw material for chemical industry. It can synthesize thousands of compounds. Acetylene and its derivatives are widely used in various industrial fields, *e.g.*, synthetic plastics, synthetic fiber, synthetic rubber, medicine, pesticide, dye, perfume, solvent, adhesive, surfactant, organic conductor, semiconductor, *etc*. Thus, acetylene have the reputation of the mother of organic chemical industry. In the manufacturing process, it will consume a large number of resources and energy and discharge various pollutants, which cause a great influence on environment. Thus, life cycle assessment study on acetylene production is the requirement of sustainable development of the chemical industry.

Life cycle assessment[1] is defined as the “compilation and evaluation of the inputs, outputs and potential environmental impacts of a product system throughout its life cycle”. Thus, life cycle assessment is method for analyzing and assessing the environmental impact of product, process and service throughout the entire life cycle. A whole life cycle includes all processes from the collection and processing of raw materials to production, transportation, sales, use, reuse, maintenance, recycling and waste treatment(in effect, therefore, 'from the cradle to the grave')[2]. The total system of unit processes involved in the life cycle of a product is called the "product system".

Life cycle assessment can enable quantification of environmental burdens and their potential impacts over the whole life cycle of a product, process or activity[3,4]. It has been used in some industrial sectors for about 30 years. life cycle assessment has received wider attention and methodological development since the beginning of the 1990s when its relevance as an environmental management aid in both corporate and public decision making became more evident.

In this study life cycle assessment has been applied in analyzing the production of acetylene. Its objective is analyzing the relationship of various environmental load, identifying the process links and the categories of effect which have a significant impact in the life cycle process and provide quantitative references of rationalizing improvement in the process of the acetylene.

Life cycle assessment

Goal definition and scope[5]: In this study, life cycle assessment is used to analyze the waste emission of acetylene and the raw material is natural gas. The goal is to analyze the cause of process links and categories of effect which have a significant impact on environment in the total life cycle process and provide their reasonable improvement suggestion.

The functional units of life cycle assessment has been defined as 1 t of acetylene. Its range was from extraction of primary resources, the processing of secondary energy and the production process of acetylene. The environmental burden covers all types of impacts upon the environment, including consumption of non-renewable resources (coals, crude oil and natural gas) and emission of hazardous substances (gas, liquid and solid).

Inventory analysis: The inventory analysis is the phase in which the product system (or product system if there is more than one alternative) is defined. In this context, defining includes setting the system boundaries (between economy and environment, with other product systems and in relation to cut-off), designing the flow diagrams with unit processes, collecting the data for each of these processes, performing allocation steps for multifunctional processes and completing the final calculations. Its main result is in an inventory table listing the quantified inputs from and outputs to the environment associated with the functional unit, in terms of kgs of carbon dioxide, mgs of phenol, kgs of iron ore, cubic metres of natural gas, *etc*.

Fundamental data: The main data of operation status and environmental load in the production process of acetylene was displayed in Table-1.

TABLE-1
FUNDAMENTAL DATA OF THE FUNCTIONAL UNIT

Item	Material	Input and output
Product output	Acetylene	1000 kg
	Syngas	657 kg
Material consumption	Natural gas	7147 m^3
	Oxygen	4355 m^3
Energy consumption	Steam (0.65 MPa)	3.4 kg
	Electricity	3272 kW h
	Industrial water	48.14 m^3
	Circulating water	63975 m^3/h
	Desalted water	3.1 m^3
Exhaust emission	Carbon monoxide	8.32 kg
	Nitrogen oxide	5.32 kg
	Nitrogen	1.83 kg
	Carbon dioxide	1.14 kg
	Dust	4.13 kg
Waste liquid emission	Total amount of wastewater	10333 kg
	COD	62.67 kg
	Benzene	0.13 kg
	Naphthalene	0.21 kg
	Xylene	0.11 kg
Waste sludge discharged	Total amount	73.4 kg
	Nitrogen	0.03 kg

Pretreatment of the list: Table-1 showed the fundamental of survey data. The output of product include acetylene and syngas, so the consumption of raw materials, energy and the pollutant emissions must be distributed between those products. Then, it can obtain the environmental burden which is born by acetylene. Using product quality as the distribution principle, the distribution coefficient of environmental burden of acetylene and syngas were 0.604 and 0.396, respectively. The preliminary list of life cycle of 1 t of acetylene is shown in Table-2.

Upper tracing back of environmental burden: The electricity and oxygen are secondary energy in the preliminary, aren't the primary resources or energy which are required by a complete list. Furthermore, the secondary energy can produce environmental emissions in the production and processing from the perspective of life cycle. So the energy should be brought into environmental burden of the life cycle. It must consider the consumption of resources and energy, environmental emission and trace back the environmental burden of the relevant secondary energy.

TABLE-2
PRELIMINARY LIST OF LIFE CYCLE OF 1 t OF ACETYLENE

Item	Material	Input and output
Material consumption	Natural gas	4316.79 m^3
	Oxygen	2630.42 m^3
Energy consumption	Industrial water	29.08 m^3
	Circulating water	38640.9 m^3
	Steam (0.65 MPa)	2.05 kg
	Electricity	1976.29 kW h
Exhaust emission	Carbon monoxide	5.02 kg
	Nitrogen oxide	3.21 kg
	Nitrogen	1.10 kg
	Carbon dioxide	0.69 kg
Waste liquid emission	Total amount of waste liquid	10333 kg
	COD	37.85 kg
	Benzene	0.08 kg
	Naphthalene	0.13 kg
	Xylene	0.06 kg
Waste sludge discharged	Total amount	44.33 kg
	Nitrogen	0.02 kg

The capacity of thermal power generation plays a leading role in the total generated energy. In this study, the environmental burden index of thermal power represented as relevant index of the whole power generated industry. In the producing process of oxygen, it doesn't produce waste except for some waste nitrogen. As raw material, air don't impact on the environment and don't bring the consumption of resource. In other words, the main pollution was produced by the consumption of electricity in the separation of air. Reference the production of air separation unit, the electricity quantity is consumed by 1 Nm^3 of oxygen is 0.615 kW h.

The primary resources consumption of 1 kW h of electricity and the emission of life cycle of power used the calculations of Yuan Baorong[6].

TABLE-3
LIFE CYCLE INVENTORY OF 1 Nm^3 OF OXYGEN AND 1 kW h OF ELECTRICITY

Item	Material	Input and output of oxygen	Input and output of electricity
Material consumption	Raw coal	0.58 kg	0.36 kg
	Crude oil	1.44×10^{-2} kg	0.89×10^{-2} kg
	Natural gas*	9.69×10^{-4} m^3	5.96×10^{-4} kg
Exhaust emission	CO_2	1.07 kg	0.66 kg
	SO_2	9.93×10^{-3} kg	6.11×10^{-3} kg
	NO_x	6.46×10^{-3} kg	3.97×10^{-3} kg
	CO	1.55×10^{-3} kg	0.95×10^{-3} kg
	Dust	2.02×10^{-2} kg	1.24×10^{-2} kg

*Natural gas and petroleum gas, the unit is m^3.

Calculation and analysis of the life cycle inventory: From the consumption of secondary energy in acetylene production and the life cycle inventory of each secondary energy production, the relevant consumption of primary energy and the indirect emission of gaseous pollutant were calculated. The emissions of life cycle were obtained by combined with direct and indirect emissions in production process (Table-4).

Impact assessment: Life cycle impact assessment (LCIA)[7] is the phase in which the set of results of the inventory analysis-mainly the inventory table - is further processed and interpreted

TABLE-4
LIFE CYCLE INVENTORY OF 1 t OF ACETYLENE PRODUCTION

Item	Material	Input and output
Material consumption	Raw coal	2093.20 kg
	Crude oil	51.87 kg
	Natural gas	4320.27 kg
Exhaust emission	Carbon monoxide	10.58 kg
	Nitrogen oxide	26.42 kg
	Nitrogen	1.121 kg
	Carbon dioxide	3851.40 kg
	Sulfur dioxide	35.70 kg
	Dust	72.54 kg
Waste liquid emission	Waste liquid emission	10333 m^3
	COD	37.85 kg
	Benzene	0.08 kg
	Naphthalene	0.13 kg
	Xylene	0.063 kg
	Waste sludge	44.33 kg

in terms of environmental impacts and societal preferences. To this end, a list of impact categories is defined and models for relating the environmental interventions to suitable category indicators for these impact categories are selected. The actual modeling results are calculated in the characterization step and an optional normalization serves to indicate the share of the results in a worldwide or regional total. Finally, the category indicator results can be grouped and weighted to include societal preference of the various impact categories.

In the course of this life cycle assessment phase, the supervisory process should be arranged so as to preserve the authoritativeness of the results. The potential input from stakeholders should also be used to improve the quality of the life cycle assessment. In this situation of 'mandated science', this implied that, depending on the specific process context, there should be room for interaction between the parties involved in topics that are relevant to the selection and definition of impact categories, characterization methods, normalization references, weighting principles and so on.

Selection and of impact categories, type parameters and characterization methods: At present, it doesn't have a unified approach for the division of impact categories in the international. EPA in USA, SETAC and EDIP program are generally selected as the division in practice. In this study, this choice is referred to the classification of international popular, the impact categories and type parameters were shown in Table-5.

Classification: To show clearly the environmental issues which are associated with the results of list, the list inventory must allocated to different type of environmental impact, namely, classification. In this step the environmental interventions qualified and quantified in the inventory analysis are assigned on a purely qualitative basis to the various pre-selected impact categories. The result were shown in Table-6.

Characterization: In the characterization step of impact assessment the environmental interventions assigned qualitatively to a particular impact category in classification are quantified in terms of a common unit for that category, allowing aggregation into a single score: the indicator result. In this study, the potential factors were from ICI in British[8] and shown in Table-7.

TABLE-5
RELEVANT IMPACT CATEGORIES AND TYPE PARAMETERS

Impact category	Impact area	Type parameter
Depletion of abiotic resources (ADP)	Global	Antimony equals
Global warming (GWP)	Region	Carbon dioxide equals
Acidification (AP)	Region	Sulfur dioxide equals
Eutrophication (EP)	Region	Nitrogen oxide equals
Photo-oxidant (POCP)	Region	Ethylene equals
Human toxicity (HT)	Local	1,4-Dichlorobenzene equals

TABLE-6
CLASSIFICATION OF ENVIRONMENTAL IMPACT

Impact category	Item of load
ADP	Raw coal, Crude oil, Natural gas
GWP	Carbon dioxide
AP	Carbon dioxide, Sulfur dioxide, Nitrogen oxide
EP	Benzene, Nitrogen oxides, COD, Nitrogen, Naphthalene
POCP	Benzene, Carbon monoxide, Naphthalene, Xylene
HT	Benzene, Sulfur dioxide, Nitrogen oxides, Dust, Naphthalene

TABLE-7
POTENTIAL FACTORS OF ENVIRONMENTAL BURDEN

Impact category	Item	Potential factors (kg kg^{-1})
ADP	Raw coal	0.0134
	Crude oil	0.0201
	Natural gas	0.0187 kg m^3
GWP	CO_2	1
AP	SO_2	1
	CO_2	1.9
	NO_x	0.7
EP	NO_x	0.131.35
	Benzene	1.091
	Nitrogen	0.42
	Naphthalene	0.91
	COD	0.022
POCP	CO	0.03
	Benzene	0.218
	Xylene	0.4
	Naphthalene	12
HT	SO_2	0.096
	NO_x	1.2
	Dust	0.82
	Naphthalene	5.6
	Benzene	1800

According to the data in the inventory analysis, which combined with the classification of environmental impact and sum up different potential factors of same impact category, to get the comprehensive environmental burdens of each type of impact category. The impact loads are shown in Table-8.

TABLE-8
LIST OF ENVIRONMENTAL BURDEN

Impact category	Result of characterization
ADP	109.88
GWP	3851.40
AP	7371.85
EP	4.86
POCP	1.88
HT	232.13

Normalization and weighting: ISO 14042 defines normalization as "calculation of the magnitude of indicator result relative to reference information". The reference information may relate to a given community, person or other system, over a given period of time. Other reference information may also be adopted, of course, such as a future target situation. The main aim of normalizing the category indicator results in each product system under study. Normalization can also be used to check for inconsistencies, to provide communicating information on the relative significance of the category indicator results and to prepare for additional procedures such an weighting.

The reference value[9] was chosen the various environmental burden of the world in 1995. The normalized basis data were: ADP is 1.57×10^{11} kg of antimony equals, GWP is 3.86×10^{13} kg of carbon dioxide equals, AP is 2.99×10^{11} kg of sulfur dioxide equals, EP is 1.29×10^{11} kg of PO_4^{3-} equals, POCP is 4.55×10^{10} kg of ethylene equals, HT is 4.98×10^{13} kg of 1,4-dichlorobenzene equals.

Weighting is an optional step of impact assessment, in which the indicator results for each impact category assessed are assigned numerical factors according to their relative importance, multiplied by these factors and possibly aggregated. Weighting is based on value choices. A convenient name for the result of the weighting step is 'weighting result', of which there is generally one for each alternative product system analyzed. The term 'weighting profile' is used in this Guide for the overall result of the weighting step: a table showing all the weighting results, supplemented by any other relevant information.

By endowing scale values with non-renewable resources, global warming, acidification, eutrophication, photo-oxidant formation and human toxicity, the single indicator was obtained. Using analytic hierarchy process (AHP)[10] to conduct multi-objective planning, the matrix is given in Table-9.

TABLE-9
JUDGMENT MATRIX

Impact category	ADP	GWP	AP	EP	POCP	HT
ADP	1	2	3	4	5	6
GWP	1/2	1	2	3	4	5
AP	1/3	1/2	1	2	3	4
EP	1/4	1/3	1/2	1	2	3
POCP	1/5	1/4	1/3	1/2	1	2
HT	1/6	1/5	1/4	1/3	1/2	1

The maximum eigen value λ_{max} is 6.109 by using AHP and the corresponding eigenvector W is $[0.379, 0.249, 0.160, 0.102, 0.065, 0.044]^T$. These six values are the weights of non-renewable resources, global warming, acidification, eutrophication, photo-oxidant and human toxicity, respectively. In the consistent formula of the judgment matrix, $CI = (\lambda_{max}-n)/(n-1) = 0.022$ and when the value of N is 6, RI = 1.24, then CR = CI/RI = 0.018 < 0.1. It shows the consistency of this matrix was satisfactory and the weight can be applied. The single index value of LCIA is 4.24×10^{-9}/a. The results of value are given in Table-10.

Life cycle interpretation: Fig. 1 showed the percentage of normalized results. In the six impact category, the acidification potential account for the major position and the share is 93 %; the depletion of non-renewable resource account for 6.26 %; the share of global warming is 0.59 %; the relative importance of eutrophication and photo-oxidant account for 0.09 and 0.06 %, resperctivley; the effect of human toxicity could be neglected and the share is 0.005 %. Therefore, the acidic gas, such as carbon dioxide, sulfur dioxide, nitrogen oxide must be strictly managed and control there emission.

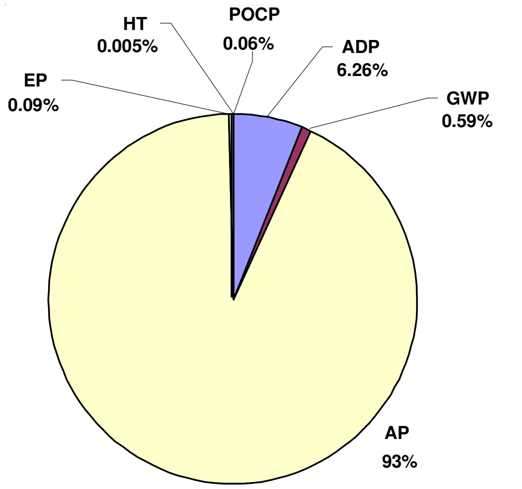

Fig. 1. Comparison of importance of impact category in environmental burden

As seen in Fig. 1, in the environmental burden of life cycle in which product acetylene, the load of acidification potential occupied the largest share, the other were shared by various pollutant emission and the environmental burden was 4.24×10^{-9} in every year.

For analysis and identify the links and direction of process improvement, the single environmental burden of life cycle were calculated from evaluating the emission of various pollutants, Then, the most important control objectives can be obtained besides the consumption of resources. The direct emissions of pollutant that include carbon monoxide, nitrogen oxide, nitrogen, carbon dioxide, COD, naphthalene, xylene in production of acetylene was carried out single life cycle assessment and calculated the proportion of the total environmental burden. The results are shown in Table-11.

As seen in Table-11, in the pollutants of direct emission during the production of acetylene, the impact of naphthalene is the largest and the value is 51.02 % that half of total value in the pollutant emissions; the carbon dioxide and COD was relevant and the share were 16.75 and 14.79 %, respectively.

Conclusion

The life cycle of production of acetylene was assessed and the single index was 4.24×10^{-9} in every year. In the effects of life cycle, the impact of acidification potential occupied

TABLE-10
SINGLE INDEX VALUE OF LCIA (the unit is a^{-1})

ADP	GWP	AP	EP	POCP	HT	Total
2.65×10^{-10}	2.48×10^{-11}	3.94×10^{-9}	3.84×10^{-12}	2.69×10^{-12}	2.05×10^{-13}	4.24×10^{-9}

TABLE-11
IMPACT ASSESSMENT OF INDIVIDUAL POLLUTANTS

Impact item	Carbon monoxide	Nitrogen oxide	Nitrogen	Carbon dioxide	COD	Naphthalene	Xylene
GWP	–	–	–	4.44×10^{-14}	–	–	–
AP	–	1.20×10^{-12}	–	7.01×10^{-13}	–	–	–
EP	–	3.30×10^{-13}	3.72×10^{-13}	–	6.58×10^{-13}	9.14×10^{-14}	–
POCP	2.15×10^{-13}	–	–	–	–	2.18×10^{-12}	3.60×10^{-14}
HT	–	3.41×10^{-15}	–	–	–	6.28×10^{-16}	–
Total	2.15×10^{-13}	1.53×10^{-13}	3.72×10^{-13}	7.45×10^{-13}	6.58×10^{-13}	2.27×10^{-12}	3.60×10^{-14}
Ratio	4.83 %	3.44 %	8.36 %	16.75 %	14.79 %	51.02 %	0.81 %

the main position and the share of total load up to 93 %. For pollutant emission, the discharge of naphthalene were the main issues, the environmental burden was account for 51.02 % in the total of environmental category.

REFERENCES

1. International Organisation for Standardisation. ISO 14040: Environmental Management-Life Cycle Assessment-Principles and Framework[S] (1997).
2. I. Boustead, Guidelines for Life Cycle Assessments: A Code of Practice, Brussels: SETAC, Europe (1993).
3. A. Tukker, *Environ. Impact Assess. Rev.*, **20**, 435 (2000).
4. F.I. Khan, V. Raveender and T. Husain, *J. Loss Preven. Process Ind.*, **15**, 455 (2002).
5. International Organisation for Standardisation (ISO). ISO 14041: Environmental Management-Life Cycle Assessment-Goal and Scope Definition and Inventory Analysis[S] (2000).
6. B.R. Yuan, Z.R. Nie, X.H. Di and T.Y. Zuo. *Chem. Ind. Eng. Prog.*, **25**, 334 (2006).
7. International Organisation for Standardisation. ISO 14042: Environmental Management-Life Cycle Assessment-Life Cycle Impact Assessment[S] (2000).
8. Y.L. Hun, *Environ. Herald*, **2**, 29 (1999).
9. J.B. Guinee, M. Gorree, R. Heijungs, G. Huppes, R. Kleijn, A. de Koning, L. van Oers, A.W. Sleeswijk, S. Suh, H.A.U. de Haes, H. de Bruijn, R. van Duin and M.A.J. Huijbregts, Handbook on Life Cycle Assessment: Operational Guide to the ISO Standards, Kluwer Academic Publisher, Dordecht (2002).
10. A. Hart, R. Clift and S. Riddlestone, EngD in Environmental Technology Conference (1998).