Specific CO_2 Emission Factors for Ethylene Production in Thailand

Papondhanai Nanthachatchavankul[1,4], Nurak Gridsdanurak[2], and Siriluk Chiarakorn[3,*]

[1]The Joint Graduate School of Energy and Environment, King Mongkut's University of Technology Thonburi, Bangkok, Thailand
[2]Department of Chemical Engineering, Faculty of Engineering, Thammasat University, Pathumthani, Thailand
[3]Division of Environmental Technology, School of Energy, Environment and Materials, King Mongkut's University of Technology, Bangkok, Thailand, [*]Corresponding Author: Siriluk.chi@kmutt.ac.th
[4]Center for Energy Technology and Environment, Ministry of Education, Thailand

Abstract: *There are three main CO_2 emission sources in ethylene production, namely steam production, electricity consumption (from internal supply), and fuel consumption in cracking furnace. Based on most studies of ethylene's emission factors (EF), the CO_2 EFs of ethylene production are normally reported in two values with different raw material, CO_2 EF from naphtha cracker and ethane cracker. The CO_2 EFs of ethylene production in Thailand from this study were 1.28±0.92 tCO_2/t ethylene for ethane cracker and 1.57±0.56 tCO_2/t ethylene for naphtha cracker. Apparently, the CO_2 EF from naphtha cracker was higher than that of ethane cracker which was consistent with other references. As compared to CO_2 EFs from* Intergovernmental Panel on Climate Change *(IPCC) which are the most widely acceptable EFs in international level, CO_2 EF of naphtha cracker from this study was 10.2% lower but that of ethane cracker was 25.8% higher than those of IPCC default values. In summary, total CO_2 emission estimated from these specific CO_2 EFs based on nameplate capacity of ethylene plants in Thailand was 6.43 million tonnes CO_2 which was 3.3% higher than quantity calculating from IPCC default EFs.*

Keywords: Ethylene, naphtha, ethane, Thailand petrochemical industry, specific CO_2 emission factor

1. INTRODUCTION

Ethylene has been widely known as the most important feedstock of intermediate and downstream products in petrochemical chain, namely ethylene glycol, vinyl chloride, styrene, HDPE, LDPE, LLDPE, PS, PVC, etc [1]. Therefore, ethylene production can be considered as the key petrochemical process in petrochemical industry. The operation of ethylene process is the endothermic reaction which requires an enormous amount of energy in the reaction of the process [2]. Practically, there are three main energy sources in ethylene process, namely fuel, electricity and steam. Each of them can be obtained from both internal and external sources [3]. Most of them are normally supplied by the internal system because feedstocks of ethylene production, ethane and naphtha, are the derivative from crude oil distillation which can provide energy as same as other fuels. As a result, the by-products from the ethylene process, methane and hydrogen, are utilized as the internal energy supply. Like other industrial processes, the ethylene production process causes CO_2 emission from its reaction and energy consumption for its production. Among 56 of petrochemical products, ethylene capacity is the highest accounted for 16.7% of all petrochemicals capacity so its production also emits the highest CO_2 emission source in Thailand petrochemical industry [4]. In 2010, capacity of ethylene production in Thailand has substantially increased from 2.5 to 4.4 million tonnes [4]. The sharply increase in its capacity will also dramatically escalate the amount of total CO_2 emission of Thailand industrial sector.

The first attempt to study the specific CO_2 emission factor (EF) from ethylene process in Thailand was included in the Life Cycle Inventory National Database of Thailand which reported the value of CO_2 emission from 1 kg of ethylene production (gate to gate), namely 0.56 $kgCO_2$/kg ethylene [5]. Recently, there was another research which studied the greenhouse gas emission index of olefins products [6] (including ethylene, propylene, and Mixed C4). However, the scope of the later study was beyond ethylene by encompassing the production of propylene and Mixed C4 in the system boundary. Therefore, both values may not match with current ethylene production in Thailand because of two reasons: 1) The base capacity in both studies did not include the additional capacity (in 2010), 2) The scope of selected products in later case (olefins) went beyond the CO_2 EF of ethylene. Moreover, the most important burden to study the CO_2 emission from petrochemical industry in Thailand is the confidentiality of the data source. Those data of petrochemical industry are confidential and not publicly available.

Therefore, this paper presents a study of specific CO_2 EF of Thailand by using mass flow diagram which is the publicly available data from Environmental Impact Assessment (EIA) report. Out of 8 ethylene plants in Thailand (as of 2010), 7 of them accounted for 80% of total ethylene capacity were selected as the representatives in this study. Moreover, the CO_2 EFs from other reports or studies will be compared with the results from this paper.

2. METHODOLOGIES

Generally, the default value of CO_2 emission factors are available in IPCC guideline but this paper will calculate specific EF by using mass flow of each ethylene plant in selected plants [7-10] (7 from 8 ethylene plants in Thailand). The mass balance of each plant was investigated to estimate the CO_2 emission from their individual process production. The specific CO_2 emission of ethylene production process can be obtained by calculating of the CO_2 emission from electricity of internal power plant, fuel combustion in the process, and fuel used for generating steam within the system. The CO_2 emission from electricity generation can be calculated by using Thailand electricity emission factor while, other energy sources will be directly calculated using emission factor of each fuel. However, it is important to emphasize that energies supplied from external sources were excluded in this study for preventing the double counting of the CO_2 emission from energy sector. Then, the weight average method was applied to average CO_2 emission of all plants to obtain the specific CO_2 EF. Therefore, the following two steps are applied in this paper: 1) the calculation of CO_2 emission each selected ethylene plant by Eq. (1) by the multiplication between CO_2 emission factor of each fuel (EF_i) with the quantity of each fuel (X_i), 2) the weight average of CO_2 emission from all selected plant can be obtained by Eq (2).

$$CO_2\ emission = X_i \times EF_i \qquad (1)$$

$$Specific\ CO_2\ EF = \frac{\sum_{I=1}^{n} w_I \bullet x_I}{\sum_{I=1}^{n} w_I} \qquad (2)$$

where; X_i is the amount of energy source (i) (tonnes of energy source consumed)
i are types of energy sources consumed in each plant, namely 1 = electricity, 2 = gasoline, 3 = methane, and 4 = fuel oil
EF_i is the emission factor of each fuel in each energy source (i), (tonnes of CO_2/ton of fuel)
w_I is the capacity of each selected plant ,and (tonnes ethylene)
x_I is the CO_2 emission of each plant obtained from the equation (1). (tonnes CO_2/tonnes ethylene)
I are the selected ethylene plants (I are not disclosed in this paper due to the confidentiality of the data source)

In table 1, the emission factors of electricity generation and fuels used for other activities in the process are demonstrated. These values will be used for the calculation in Eq. (1).

Table 1 Emission factor of electricity and other fuels

	CO_2 emission factors	Unit	Sources of data
Electricity	0.5812	tonnes CO_2/MWh	[11]
Gasoline	3.12	tonnes CO_2/ton gasoline	[12]
Methane	2.75	tonnes CO_2/ton methane	[12]
Fuel oil	3.35	tonnes CO_2/ton fuel oil	[12]

Then, the comparison of EFs from other references such as 2006 IPCC guideline[10], life cycle inventory (LCI) database of Thailand [5], and so on were benchmarked against EFs from this study. Finally, the estimation of total CO_2 emission from ethylene production in Thailand was conducted and compared using EFs from this research and other studies. Practically, the CO_2 emission calculation of ethylene production will be separately obtained by type of raw materials, naphtha and ethane. Therefore, this paper will present the specific CO_2 emission factors calculated from Eq. (2) in two values, namely EF_{ethane} and $EF_{naphtha}$ respectively. Moreover, the comparison of CO_2 emission of ethylene production by various sources of CO_2 EFs in Thailand can be quantified by Eq. (3) based on the activity data (AD) of ethylene capacity in year 2010 and multiplying with the specific CO_2 EFs obtained from Eq. (2) and other references.

$$CO_2\ emission = AD_{2010} \times EF \qquad (3)$$

where; AD_i is the capacity of ethylene production in Thailand in year 2010
EF is CO_2 EFs of ethylene production from various sources and separated by type of raw material

3. RESULTS AND DISCUSSION

3.1 CO_2 emission factors of each selected ethylene plant in Thailand

Based on the mass balance of each ethylene plant from EIA report, the amount of each energy source required for each plant can be obtained but they are not possible to report the individual data due to the confidentiality of the data source. By applying Eqs. (1) and (2), specific CO_2 emissions factor by type of raw material, naphtha and ethane can be obtained and shown in Table 2.

Table 2 Specific CO_2 emission factors of ethylene plants in Thailand by type of raw materials

	Total capacity (tonnes ethylene)	Specific CO_2 emission factor (tonnes CO_2/ton ethylene)	Standard deviation
$EF_{Naphtha}$	1,775,000	1.57	±0.56
EF_{Ethane}	1,778,000	1.26	±0.92
$EF_{Naphtha + Ethane}$	3,553,000	1.43	±0.76

The value of specific CO_2 emission factor of ethane is lower than that of naphtha 25% but its standard deviation is considerably higher than naphtha approximately 40%. The higher variation of ethane cracker emission factor can be explained by the difference of their energy supply sources illustrated in Fig. 1. Some ethane cracker in this study strongly depends on the external energy supply (beyond the boundary of the calculation) which leads to the lower CO_2 emission factor while other consumed energy mainly from the internal supply. Thus, the more the difference of energy supply type, the higher the standard variation. The combined specific ethylene emission factor of Thailand by weight average is 1.43±0.76 tonnes CO_2/ton ethylene.

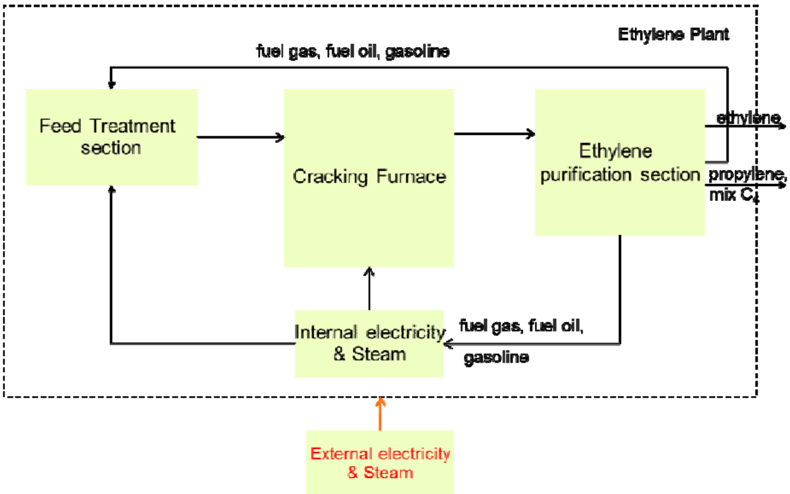

Fig. 1 System boundary of energy source in ethylene plant

3.2 The comparison of specific CO_2 emission factor with other sources

There are many ethylene emission factors proposed by other literatures such as Life Cycle Inventory (LCI) National database of Thailand, 2006 Intergovernmental Panel on Climate Change (IPCC) guideline, EU Emission Trading Scheme (EU-ETS) [12], and Theoretical energy saving potential for chemical industry (NL) [13]. As illustrated in Fig. 2, it was clearly seen that emission factors from naphtha were higher than those of ethane cracker except those from LCI which did not separately report EF by type of raw material. Therefore, EF from LCI will be excluded for following comparison. Interestingly, the emission factor from naphtha from this paper is slightly lower than other sources by 7% while EF from ethane is dramatically higher than those of other sources by 42%. This may be explained by the difference of the system boundary as well as the technological differences of the desired system. As compared to CO_2 EFs from IPCC which are the most widely acceptable EFs in international level, CO_2 EF of naphtha cracker from this study was 10.2% lower but that of ethane cracker was 25.8% higher than those of IPCC default values.

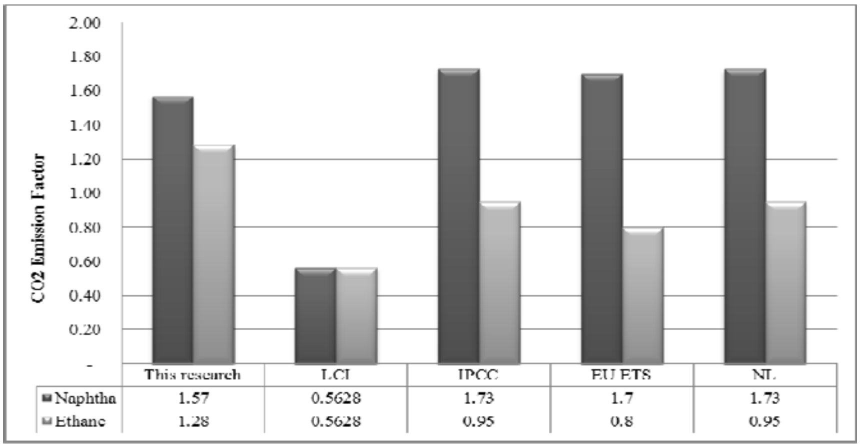

Fig. 2 Comparison of CO_2 emission factors from ethylene production in Thailand with other sources

3.3 CO_2 emission from ethylene production in Thailand

The latest capacity of ethylene production in Thailand (as of 2010) was multiplied with various values of CO_2 EFs to investigate whether CO_2 EFs from this research provide any difference of CO_2 emission against other sources. As shown in Fig. 3, the accumulation of CO_2 emissions from each ethylene CO_2 EF was also separated by type of raw materials, ethane and naphtha. It was clearly seen that the total emission by applying the EFs from this research were in line with other sources. Moreover, total CO_2 emission estimated from these specific CO_2 EFs based on nameplate capacity of ethylene plants in Thailand was 6.43 million tonnes CO_2 which was 3.3% higher than quantity calculating from IPCC default EFs.

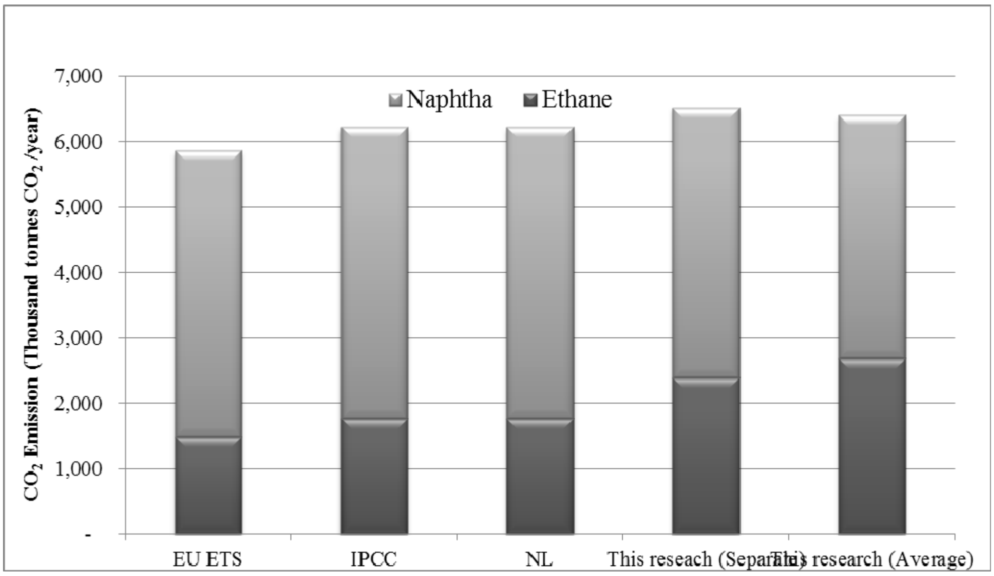

Fig. 3 Simulation of CO_2 Emission by various sources of CO_2 EFs

However, the calculation of the CO_2 emission from using combined EFs (calculated by weight average values of EF_{ethane} and $EF_{naphtha}$) denoted as This research (Average) was added in Fig. 3. to compare with the value obtained from separated EFs denoted as This research (separate). It was found that the CO_2 emission from the accumulation of combined EFs was slightly lower than that obtained from the separated CO_2 EFs by 1.6%. However, this result may change depend on which type of feedstock, ethane and naphtha, will be consumed in the ethylene production. For example, if the quantity of ethane as feedstock is higher than naphtha, the CO_2 emission of ethylene production calculated by separated EFs will be lower than the average EF.

4. CONCLUSION

The results from this research provide the specific emission factors of Thailand ethylene production separated by type of raw materials, ethane and naphtha. The specific EFs of ethane and naphtha were 1.28 ± 0.92 tCO_2/t ethylene cracker and 1.57±0.56 tCO_2/t ethylene respectively. The combined specific EF of ethylene calculated by weight average method was 1.43±0.76 tCO_2/t ethylene. Interestingly, the very high standard deviation of EFs resulted from the difference of energy sources supplied in each selected plant. The comparison of the ethylene EF from this research with other sources was made in order to benchmark the results with other studies. According to the finding in this research, the $EF_{naphtha}$ was higher than EF_{ethane} which is consistent with other references. On the contrary, EF_{ethane} of this research was slightly higher than those from other references. To quantify the CO_2 emission calculated by EFs obtained in this research, the base year 2010 of ethylene capacity was applied to compare with CO_2 emission calculated by EFs from other references. It was shown that CO_2 emission estimated this research was in line with others; however, its value was slightly higher than those ranging from 3% to 8%.

5. ACKNOWLEDGMENTS

The authors would like to express their gratitude to The Joint Graduate School of Energy and Environment, King Mongkut's University of Technology Thonburi, Center for Energy Technology and Environment, Ministry of Education Thailand, and National Research Council of Thailand (NRCT) for financial support.

7. REFERENCES

[1] Asua, J.M. (2007) *Polymer reaction engineering*, Blackwell Pub, Oxford, United Kingdom.
[2] Sami, M.L.F.H. (2001) *Chemistry of Petrochemical Processes*, Gulf Professional, Massachusetts, United States of America.
[3] Department of Alternative Energy Development and Efficiency (2007) *Study of energy consumption in Petrochemical industry project*, pp. 10-15.
[4] National Metal and Material Technology Center (2010) *Thai GHG Software,* Pathumthani, Thailand.
[5] Petroleum Institute of Thailand Foundation (2010) *PTIT Focus Special Annual Issue 2010,* Priweish, Bangkok, Thailand.
[6] Naraporn, J., Premrudee, K., Chanathip, P. and Orathai, C. (2011) Greenhouse Gas Emission Index of Olefins Products from Upstream Petrochemical Industry in Thailand, *Proceeding of the 2nd Climate Thailand Conference 2011*, pp. 393-400.
[7] Macro Consultant (2005) *Environmental Impact Assessment Report of Improvement and Expansion of Olefins Plant*, pp. 60-80.
[8] Consultants of Technology (2005) *Environmental Impact Assessment Report of Olefins Plant Project*, pp. 75-96.
[9] Consultants of Technology (2005) *Environmental Impact Assessment Report of Olefins Plant Branch I-1Road*, pp. 85-124.
[10] Intergovernmental Panel on Climate Change (2006) *2006 IPCC Guidelines for National Greenhouse Gas Inventories*, (3), pp. 3.57-3.86.
[11] Thailand Greenhouse Gas Organization (2009) *Summary Report The Study of emission factor for an electricity system in Thailand 2009*, Bangkok, Thailand.
[12] Joosten, L.A.J. (1998) *Process Data Description for the production of synthetic organic materials*, Utrecht, The Netherlands.
[13] Enviros (2006) *EU-ETS Phase II new entrant benchmarks*, London, United Kingdom.