An Investigation of Hg Deposition Using MM5/HYSPLIT-Hg: A Case Study on Contribution of Thermal Power Plants in Thailand

Pham Thi Bich Thao and Savitri Garivait

Abstract— *Mercury (Hg) is one of hazardous air pollutants of which the deposition results in both carcinogenic and non carcinogenic adverse effects to human health and ecosystem. In Thailand, Hg anthropogenic emissions are from several sources, as for coal-fired power plants accounted up to 30%. To investigate Hg deposition resulting from coal-fired power plants in Thailand, 7 coal-fired power plants were included in this study. Firstly, Hg emissions of each plant were estimated for year 2010 using bottom up approach. Then, a coupled-model of MM5/HYSPLIT was adopted and adjusted in order to investigate the contribution of each coal-fired power plant's emissions to receptor. Two set of one month simulation were performed for 2 episodes (i.e., April and August, 2010), to investigate the effect of dry and wet seasons to the deposition. Preliminary results indicated that Hg deposition ensemble with source locations, due to high portion of Hg^{2+} in Hg emissions. The EGAT#Lignite and IPP#Coal had high potential contribution to deposition in Thailand for both dry and wet season. The seasonal variation presenting the higher deposition was found in August (i.e, more than twice of those in April) which was mostly caused by Hg^{2+} emissions. Even though no direct evaluation with observation data was performed, output from this study had a reasonable agreement with literature.*

***Keywords*— — Mercury, deposition, coal-fired power plant, modeling.**

1. INTRODUCTION

Mercury (Hg) is one of hazardous air pollutants of which deposition results in both carcinogenic and non carcinogenic adverse effects to human health and ecosystem. Particularly, in early 1900s, the United States had warned people about the risk in consuming fish which contain Hg [1]. In the 20th decade, one of well-known cases was found in the Miamata Bay, Japan where people and other living creatures nearby had neurological to dead syndrome due to severe Hg poisoning [2]. Main sources of Hg contamination originated from anthropogenic including the intentional use of Hg in industrial processes and unintentional use (due to impurity of combusted fuel) [3]. Once emitted from the sources, depending on its speciation (Hg^0, Hg^{2+}, and Hg^P), it has different characteristic and atmospheric lifetime. Hg^0 is insoluble in water and quite inert therefore it has a longest atmospheric life time (from 0.5 – 2 years) among its speciation. Hg^0 is also subject to long range transport. In contrast, Hg^{2+} is water soluble and reactive; therefore, it is subject to quick transform and remove/deposit near the emitted sources. Similarly, Hg^P can be interacted with other particle and deposited near the emitted sources. The concern of Hg is mostly after deposition, where inorganic Hg is converted to organic Hg (i.e., methyl Hg) under the present of bacteria. Such organic Hg are persistence and accumulated in ecosystem and cause adverse effects to living creature and higher level predators [4].

Recent studies on Hg fate in the Northern Hemisphere indicated the relatively high deposition of total Hg in many regions of Asian countries, including some parts (e.g., Northern region) of Thailand [5], which has raised questions about potential emission sources and their contribution to Hg deposition in Thailand. In this country, potential sources of Hg anthropogenic emissions are combustion processes from power plants, incinerators as well as industrial processes such as cement, iron and steel, etc [6]. From the recent estimate for year 2005 [3], emissions from stationary combustion accounted for almost 60% of total Hg emissions in the nation in which coal-fired power plants were major contribution.

In order to reduce effects of Hg, the understanding on its evolution in the atmosphere and other ecosystems is a must. It also includes knowledge of other processes' effects such as emissions, meteorological and chemical driven. In this study, a coupled-model of meteorology and air quality was adopted and adjusted, in order to investigate the contribution of different emissions sources to receptor. In this work, only Hg emissions from major coal-fired power plants (i.e., 1, 1, and 5 coal-fired power plants from the Electric Generating Authority of Thailand-EGAT, Independent Power Producers-IPP and Small Power Producer-SPP, respectively) were included, since they constituted the major contributor to the total amount of anthropogenic emissions in Thailand. Location of emissions sources are shown in Figure 1.

Outcome of this study includes maps of Hg deposition

The authors thank the JGSEE for financial support to this work (through PhD scholarship grant of the first author).

Pham Thi Bich Thao is a graduate student in the Joint Graduate School of Energy and Environment (JGSEE), King Mongkut's University Technology of Thonburi (KMUTT). E-mail: ptbthao@gmail.com or choose_star@yahoo.ca)

Assoc. Prof. Dr. Savitri Garivait (corresponding author) is a full time lecturer in Environmental Division of the JGSEE, KMUTT. Address: 126 Prachauthit Rd, Bangmod, Tungkru, Bangkok, Thailand 10140; Tel.: 66-2-470-8309 (ext.4134); Fax. 66-2-872-9805. E-mail : savitri_g@jgsee.kmutt.ac.th

Both authors are members of Center on Energy Technology and Environment (CEE), S&T Post Graduate Education and Research Development Office (PERDO), Commission on Higher Education, Ministry of Education, Bangkok, Thailand.

that document the hotspots of Hg environmental contamination. The seasonal variations of deposition are also presented. The involvement of each thermal power plant and the contribution per capita to the total deposition due to electricity consumption will be discussed.

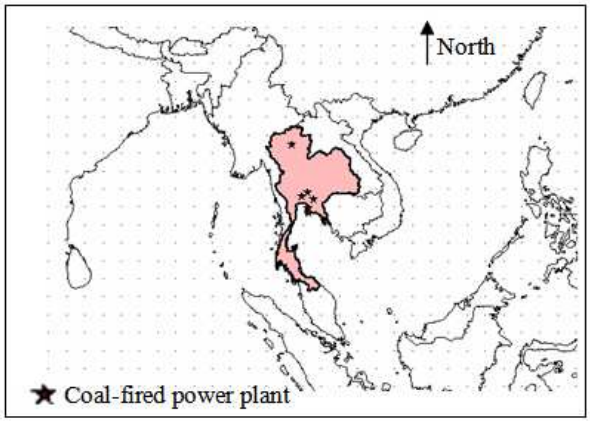


Fig. 1: Location of coal-fired power plants included in this work.

2. METHODOLOGY

2.1 Background

Thailand locates in the Southeast Asia region (Figure 1), under climate condition which is influenced and characterized by monsoon [7]. According to the analysis of key meteorological parameters, 2 episodes are chosen, which are one month in April (1 April 00UTC – 30 April 00UTC) and one month in August (1 August 00UTC – 31 August 00UTC) for the purpose of seasonal variation investigation.

To assess Hg deposition in a receptor location, information on Hg emissions, transportation of air mass and Hg chemical evolution are required. Each of them is presented in the following section

2.2 Emissions

Emissions from coal-fried power plants in Thailand were developed by using bottom-up approach, which was described in a previous work [8]. Annual emissions were first processed by distributing sources spatially using geographical coordinate systems, and allocating them temporally using fuel consumption rate [9] for use as an input into the model. Hg was speciated into 3 species; elemental Hg-Hg^0, reactive gaseous Hg-Hg^{2+}, and particulate Hg-Hg^P; based on the general Hg speciation profiles was obtained from literature [3]. In order to input into HYSPLIT model, hourly Hg emissions of each source were prepared. The hourly emissions of an interested hour of a source were calculated as a product of hourly ratio with annual emissions of that particular source. According to the estimation from literature review which provided non-specific-species temporal allocation profiles for emissions from power generation [9], hourly Hg emissions from coal-fired power plants in Thailand were ranging from 0.0416 % to 0.0675% of annual Hg emissions.

2.3 Meteorological model-MM5

To simulate the transport of air mass, the fifth generation of Mesoscale Model developed by PSU/NCAR, namely MM5 was used to perform the atmospheric transportation in order to obtain the profiles of keys meteorological parameters, i.e., wind speed, wind direction, pressure, temperature, precipitation. Domains of this work were set to capture effects of wind field to Thailand. The coarse domain covered the Southeat Asia and some parts of Southern China and Eastern India, consisting of 17,424 cells with a grid size 36 x 36 km^2. The finer domain covered Thailand, consisting 20,736 cells with a grid size 12 x 12 km^2. The study domains were in Lambert conformal projection centered at Bangkok (i.e., 13.5^o N and 100.5^o E). Input of MM5 was from 1 x 1 degree global re-analysis data and for each episode; simulation was performed for one month period with spinning up 10 days.

2.4. Transport model - HYSPLIT

Finally, Hybrid Single Particle Lagrangian Integrated Trajectory Model with Hg extensions (HYSPLIT-Hg) developed by NOAA/ARL was used to understand the fate of Hg species from sources to deposition. HYSPLIT had been developed to have a capacity to simulate Hg transport and deposition [10, 11]. Theories and assumption of the work which can be found in literature [10] is briefly described here. Hypothesis emissions of each Hg species were released as a hybrid puff, to transport and transform under the chemical and deposition mechanisms and to receptor. The actual deposition of each source at receptor was estimated using actual emissions and its speciation profile based on chemical interpolation.

3. RESULTS AND DISCUSSION

3.1. Hg emissions

As seen in Table 1, total Hg emissions from 7 coal-fired power plants were 662.51 kg. It is in conformance with value found in literature review (i.e., 700.0 - 800.0 kg of total Hg from coal-fire power plants in Thailand) [12]. The possible reason for small discrepancy is due to emission control efficiencies applied for large coal fired power plants, e.g., 40% was used in [12] and 67% was used in our study- resulting from onsite stack samplings [13]. For sectoral contribution, Hg emissions were mostly from the EGAT, followed by the IPP, and the SPP. For speciation, Hg^0, Hg^{2+}, and Hg^P accounted for 20%, 78%, and 2% [14].

Spatial distribution of Hg emissions from coal-fired power plants indicated that most of the sources located in the Central region. However, highest contribution was from the Northern region, followed by the Eastern region.

Table 1: Hg emissions from coal-fired power plants in Thailand (unit: kg/year)

Power plant # Fuel	Hg^T	Hg^0	Hg^{2+}	Hg^P
EGAT#Lignite	385.54	77.11	300.72	7.71
IPP#Coal	145.72	29.14	113.66	2.91
SPP1#Lignite	57.13	11.43	44.56	1.14
SPP2#Coal	42.43	8.49	33.09	0.85
SPP3#Coal	21.74	4.35	16.96	0.43
SPP4#Coal	7.29	1.46	5.69	0.15
SPP5#Coal	2.65	0.53	2.07	0.05
Total	662.51	132.50	516.76	13.25

a)

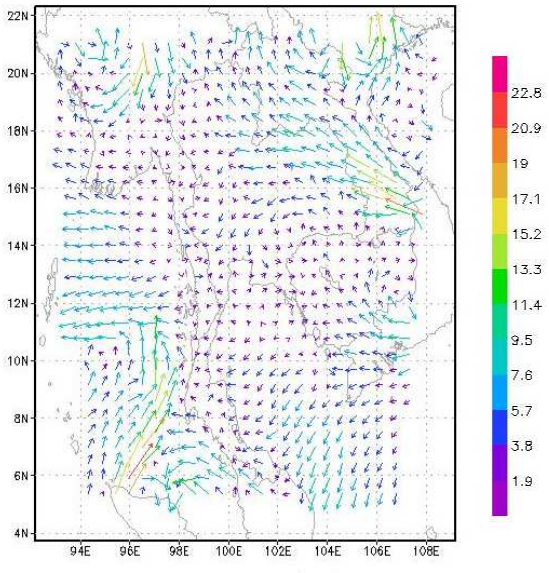


Fig. 2: Wind speed and wind direction in a) April, 2010

b)

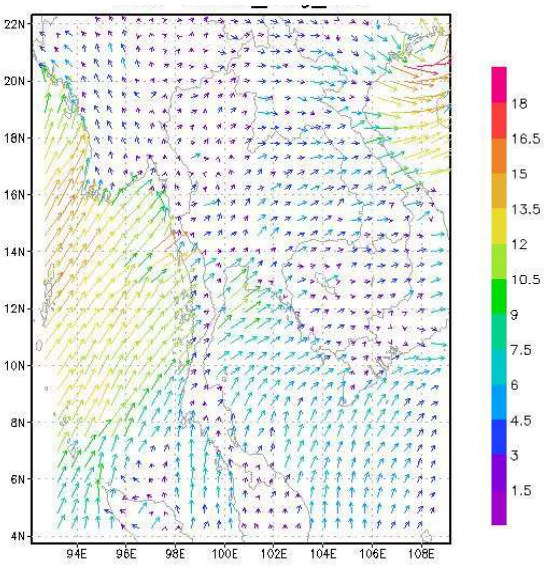


Fig. 2: Wind speed and wind direction in b) August, 2010.

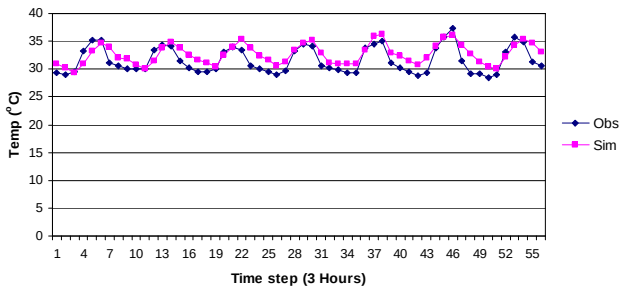
3.2. MM5 results

MM5 results were analyzed and presented for 2 seasonal episodes during April and August for the year 2010. In the following, discussions of key parameters are presented.

Wind: Figure 2 shows typical wind speed and wind direction in Aril and August. As seen, in April, winds were calm and prevailing winds are originated mostly from the northeast and east while in August, wind were stronger and originated from the south, southwest and west over the country

Ground temperature: Simulations shows that in April, monthly average ground temperature was 26.1 ^oC which maximum daily was 32.5 ^oC and minimum daily was 17.7 ^oC. While in August, monthly average ground temperature is 27.0 ^oC which maximum daily was 32.4 ^oC and minimum daily was 22.3 ^oC. Figure 3 below shows an extraction of comparison between simulation and observation during second week (i.e., 8^{th} - 14^{th} August, 2010) of each episode for the Suwanabhumi airport station. The comparison of ground temperature shows encouraging agreement, in which correlation between simulation and observation for each episode was in acceptable level, (i.e., larger than 0.5)

a)



b)

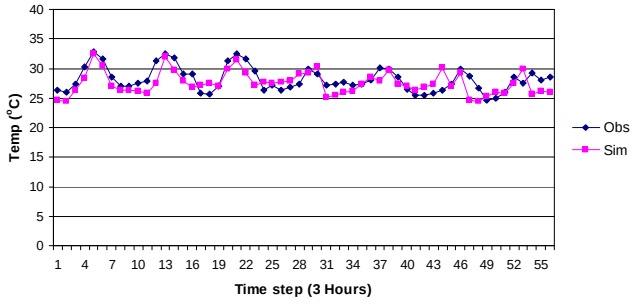


Fig. 3: Comparison of ground temperature between observation and simulation during 2nd week of a) April, 2010 and b) August, 2010.

3.3. HYSPLIT results

Table 2 presents transfer co-efficient (deposition / emissions) for each Hg species from each source location to the receptor. For example, that transfers co-efficient of Hg^0 emitted in source location of EGAT#Lignite was 0.01 indicated that 1 g of Hg^0 emitted from that source would lead to 0.01 g of Hg deposited in the receptor. It is noted that there was no real emissions information (including magnitude and speciation profile) had been incoporated. As seen, among three species, Hg^0 had less contribution to the deposition at receptor compared to

Hg^{2+} and Hg^{P}. In general, in April, it was Hg^{P} that had highest contribution to deposition while in August, it was Hg^{2+}. This was expected and could be generally explained by the driven of dry deposition in April and wet deposition in August.

Table 2: Overall transfer co-efficient for Hg (g of total Hg deposited /month)/ (g of Hg emitted/month) during a) April, 2010 and b) August, 2010

a)

Source Location	Hg^0	Hg^{2+}	Hg^P
EGAT#Lignite	0.01	0.01	0.02
IPP#Coal	-[a]	0.02	0.06
SPP1#Lignite	0.01	0.02	0.04
SPP2#Coal	0.01	0.02	0.04
SPP3#Coal	0.01	0.03	0.04
SPP4#Coal	0.01	0.03	0.04
SPP5#Coal	0.01	0.02	0.04

-[a]: Less than 0.005

b)

Source Location	Hg^0	Hg^{2+}	Hg^P
EGAT#Lignite	0.02	0.04	0.03
IPP#Coal	0.01	0.05	0.04
SPP1#Lignite	0.03	0.04	0.05
SPP2#Coal	0.03	0.04	0.05
SPP3#Coal	0.02	0.04	0.04
SPP4#Coal	0.01	0.04	0.04
SPP5#Coal	0.02	0.04	0.04

Table 3 presents contribution of each power plant to Hg deposition in Thailand. It was calculated from the transfer co-efficient and source characteristic (i.e., emissions magnitude of each plant and speciation profiles particular for coal-fired power plants). As seen in Table 3, EGAT#Lignite and IPP#Coal had high potential contribution to deposition in Thailand for both dry and wet season. The seasonal variation shows that higher deposition was found in August (i.e, up to 3 times as much as those in April) which was mostly caused by Hg^{2+} emissions.

Given that population in Thailand was approximately 70 million, country average capital contribution to Hg deposition due to electricity generation from coal combustion was estimated as 0.12 - 0.36 µg/year/capita. Acording to [13], electricity generation from coal combustion were about 29,020 Gwh for the year 2010, therefore, it can be estimated that Hg deposition caused by electricity generation from coal combustion were 0.30/GWh - 0.90 g/GWh.

Table 3: Contribution of each power plant to Hg deposition in Thailand (unit: g/month) during a) April, 2010 and b) August, 2010

a)

Power plants #Fuel	Dep^T	Dep (Hg^0)	Dep (Hg^{2+})	Dep (Hg^P)
EGAT#Lignite	249	73	161	15
IPP#Coal	228	11	203	14
SPP1#Lignite	100	14	82	4
SPP2#Coal	73	10	60	3
SPP3#Coal	42	5	36	1
SPP4#Coal	14	1	13	1
SPP5#Coal	5	-[b]	4	-[b]
Total	711	114	559	38

b)

Power plants #Fuel	Dep^T	Dep (Hg^0)	Dep (Hg^{2+})	Dep (Hg^P)
EGAT#Lignite	1,212	138	1,053	21
IPP#Coal	487	35	443	9
SPP1#Lignite	172	24	143	5
SPP2#Coal	128	18	106	3
SPP3#Coal	73	9	62	2
SPP4#Coal	22	2	20	1
SPP5#Coal	8	1	8	-[b]
Total	2,102	226	1,836	40

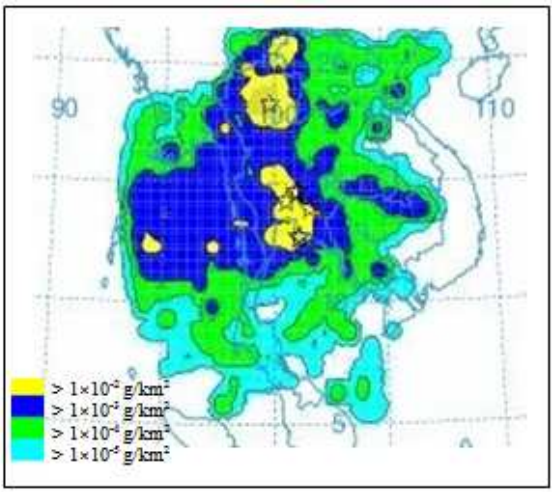
-[a]: Less than 0.5

The spatial distribution of accumulated Hg deposition in April and August are shown in Figure 4a) and b) respectively. In general, deposition was resemble emission sources well, which could be explained by the high portion of Hg^{2+} in emission sources profile, resulting quick removal process. In April, deposition was well distributed around the sources due to calm wind in this episode while in August, deposition was laid on the upper east of the sources due to relatively strong wind from the west, south and southwest has been observed in this eposide. Maximum monthly accumulated deposition was found in Northern region, particularly surrounding of EGAT#Lignite plant with 0.59 g/km^2 in April and 1.1 g/km^2 in August.

Evaluation between observation and simulation is crucial to assure quality of model's output. However, output of this work was not directly performed by in pair comparing with observations because firstly, there was no records of Hg concentration or deposition in study domain; secondly, this work focused on the contribution of coal-fired power plants to the deposition in receptor and we did not include all the sources therefore the deposition presented here was expected less compared to the ambient situation. In addition, to the best of authors' knowledge, our work was the first modeling attempt to assessment of Hg deposition in Thailand. In an effort to roughly evaluate the output of this work, we estimated annual accumulated Hg deposition and compared our value with literature, i.e, global scale modeling

application [5]. Annual accumulated Hg depositions from our work and literature were 7.1 – 13.2 g/km^2/year and 50 g/km^2/year, respectively, for a same hotspot location in the Northern of Thailand. It is same order of magnitude with a less value in our work as expected. Given that coal-fired power plants accounted for 30% of anthropogenic emissions in the country, and we also did not include Hg emissions inflow from outside Thailand (i.e., India and China) into the domain which possibly leads to higher deposition flux in the Northern of Thailand, our work shows a reasonable agreement.

a)



b)

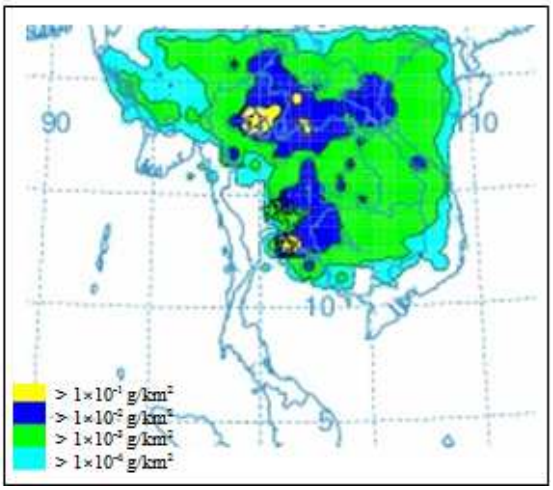


Fig. 4: Monthly accumulated total Hg deposition in Thailand during a) April, 2010 and b) August, 2010.

4. CONCLUSIONS

This paper investigated Hg deposition in Thailand resulting from emissions from 7 coal-fired power plants. Couple modeling MM5/HYSPLIT was used for 2 episodes (i.e., April and August), representative for dry and wet period to investigate the seasonal concentration and deposition variation. The results showed that Hg deposition ensemble with source locations, due to high portion of Hg^{2+} in Hg emissions. The EGAT#Lignite and IPP#Coal had high potential contribution to deposition in Thailand for both dry and wet season. The seasonal variation showed that higher deposition in August which was mostly caused by Hg^{2+} emissions. The output from this study had a reasonable agreement with literature. For future work, more other major sources such as incinerators, large industrial facilities should be also included in up coming modeling performance so that the deposition is more realistic.

ACKNOWLEDGMENT

The authors would like to thank all organization mentioned in the manuscript for their kind assistance in data collection. General technical assistance of Dr. Chatchawan Vongmahadlek (EGAT) is also grateful. The information presented and discussed in this study reflect view of authors only, and not necessary reflect the view of the organizations mentioned here in.

REFERENCES

[1] US-EPA (1997) Mercury study report to Congress - Executive Summary.
[2] Ui, J. 1992 Minamata disease, in Industrial pollution in Japan, J. Ui, Editor., The United Nations University Press: Tokyo, Japan.
[3] AMAP/UNEP (2008) Technical background report to the global atmospheric mercury assessment.
[4] US.EPA (1997) Fate and Transport of Mercury in the Environment.
[5] Travnikov, O., Lin, C.-J., and Dastoor, A., eds. (2010) Part B: Mercury-Chapter 4: Global and Regional Modeling. HTAP Assessment Report 2010.
[6] UNEP (2001) Mercury Assessment in Thailand.
[7] TMD. Climate in Thailand. 2011. Available at http://www.tmd.go.th/en/archive/thailand_climate.php [Assessed on Feb 2012]
[8] Pham, T.B.T. and Garivait, S. Mercury Emissions from Thermal Power Plants in Thailand. in 4th International Conference on Sustainable Energy and Environment (SEE 2011): A Paradigm Shift to Low Carbon Society 2010. Bangkok, Thailand.
[9] Pham, T.B.T., Manomaiphiboon, K., and Vongmahadlek, C. (2008) Development of an inventory and temporal allocation profiles of emissions from power plants and industrial facilities in Thailand. Science of the Total Environment, 397: p. 103-118.
[10] Cohen, M., Artz, R., Draxler, R., Miller, P., Poissant, L., Niemi, D., Ratte, D., Deslauriers, M., Duval, R., Laurin, R., Slotnick, J., Nettesheim, T., and McDonald, J. (2004) Modeling the atmospheric transport and deposition of mercury to the Great Lakes. Environmental Research, 95: p. 247–265.
[11] Ryaboshapko, A., Bullock, R., Ebinghaus, R., Ilyin, I., Lohman, K., Munthe, J., Petersen, G., Seigneur, C., and Wangberg, I. (2002) Comparison of mercury chemistry models. Atmospheric Environment, 36: p. 3881-3898.
[12] Khongpaitoon, N., Quantification of mercury containing wastes and management practices in Thailand, in School of Environment, Resources and

Development. 2010, Asian Institute of Technology: Bangkok, Thailand.

[13] PCD (2010). The study of mercury and metals emission from industrial combustion process - Final report, SECOT Ltd.

[14] [Streets, D. G., J. Hao, J., Wu, Y., Jiang, J., Chan, M., Tian, H., and Feng, X. (2005). Anthropogenic mercury emissions in China. Atmospheric Environment 39: 7789-7806.