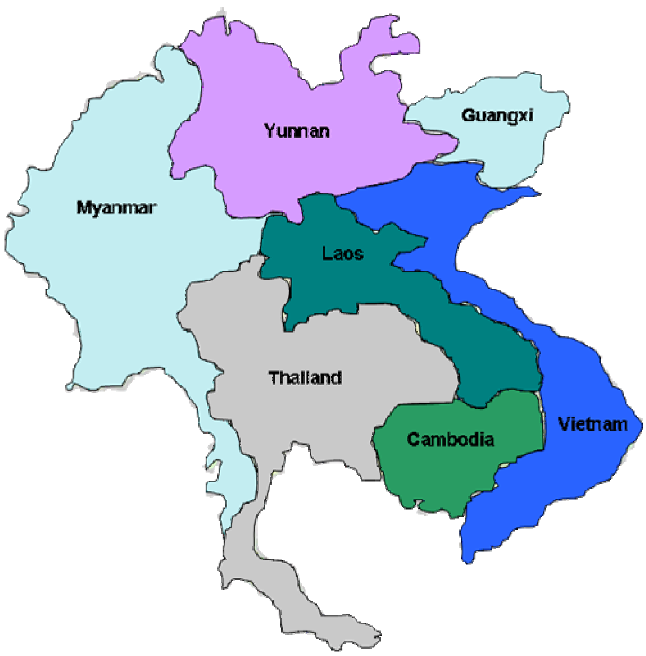
ISSN 1905-9094

GMSARN INTERNATIONAL JOURNAL

Vol. 6 No. 4
December 2012



Published by the

GREATER MEKONG SUBREGION ACADEMIC AND RESEARCH NETWORK
c/o Asian Institute of Technology
P.O. Box 4, Klong Luang, Pathumthani 12120, Thailand

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The Greater Mekong Subregion (GMS) consists of Cambodia, China (Yunnan & Guangxi Provinces), Laos, Myanmar, Thailand and Vietnam.

The Greater Mekong Subregion Academic and Research Network (GMSARN) was founded followed an agreement among the founding GMS country institutions signed on 26 January 2001, based on resolutions reached at the Greater Mekong Subregional Development Workshop held in Bangkok, Thailand, on 10 - 11 November 1999. GMSARN was composed of eleven of the region's top-ranking academic and research institutions. GMSARN carries out activities in the following areas: human resources development, joint research, and dissemination of information and intellectual assets generated in the GMS. GMSARN seeks to ensure that the holistic intellectual knowledge and assets generated, developed and maintained are shared by organizations within the region. Primary emphasis is placed on complementary linkages between technological and socio-economic development issues. Currently, GMSARN is sponsored by Royal Thai Government.

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GMSARN International Journal

Volume 6, Number 4, December 2012

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Barriers to Border Trade along the Southern Economic Corridor: A Case of Thai-Cambodia Trade on the Border of Srakaew Province

Saran Ratanasithi and Pensri Jaroenwanit

Abstract— *This research aims to study barriers hindering trade on the Southern Economic Corridor, specifically border trading activities between Thailand and Cambodia occurring on the border of Srakaew Province. This area was chosen since it has been widely accepted as a major threshold to Cambodia. Appling both qualitative and quantitative research techniques to collect and analyze its data, this research started with compiling qualitative data from various relevant sources prior to operationalizing them via questionnaire survey to clarify and strengthen the former findings. Results show that barriers affecting trade between Thai and Cambodia can be classified into three major groups based on sources of them, i.e. barriers induced by factors internal to Cambodia and related to overseas economic conditions, those influenced by factors internal to the border traders themselves, and barriers caused by factors internal to Thailand. This research concludes that root cause of border trading barriers is failure of both Thai and Cambodia public authorities to facilitate trade flows between the two countries. This situation is unfortunately aggravated by the delicate national relationship together with border traders' preoccupation with factors related to short term financial performance and ignorance of factors related to their long term sustained competitiveness.*

Keywords— **Barriers, Border Trade, Greater Mekong Sub-region (GMS), ASEAN, Southern Economic Corridor (SEC), Srakaew Province.**

1. INTRODUCTION

Studies relating to border trading activities especially in Greater Mekong Sub-region (GMS) are supposed to be of particular interest to academia, practitioners, and general public as a whole (see [1] for GMS history, structure, and plan). This is behaviorally logical since cross border trade and investment is a strategic thrust under ten-year GMS strategic framework [2]. In fact, GMS is an important catalysis of concrete economic cooperation and liberalization among the region through implementation of its economic corridors programs.

Possessing a few eminent characteristics with relatively strong potential to facilitate trade, Southern Economic Corridor (SEC) is of particular interest study context. It is a Flagship Program of GMS [1], having 4 sub-corridors, namely Northern, Central, Southern Coastal, and Inter-Corridor Link, which are the most among GMS corridors [2]. SEC links Thailand, Cambodia, and Vietnam. It probably is the corridor covering the most geographically, stretching from Thailand, crossing over Cambodia, and destining to three important Vietnamese Southern coastal provinces. Furthermore SEC is the only corridor having inter-corridor route which provides both an intra- an inter-corridor links, specifically to East-West Economic Corridor (EWEC).

Strategic position of Srakaew province as a border trading hub of the region is very outstanding owing to a few crucial reasons. Being a threshold of both Northern and Central Cambodia because of its geographical advantage, Srakaew province justifies its location on both SEC Northern and Central sub-corridor. This locale advantage enables Srakaew to become the most important pass point between Thai and Cambodia hereby more than half of border trade transaction occurring [3]; while uprising trend can be expected given the facilitative influence of SEC.

For Thailand, border trading transaction has consistently dominated trade with its neighboring countries. Recent statistics still confirms this trend, showing as huge proportion as around 75% on average of border trade to total trade values over the last 5 years with strong growth potential [3], amidst turbulent situation both on Malaysian border in the South and Cambodian one in the East. By [3]'s statistics, Thai-Cambodia border trading is a very important trading mode between the two nations. It is also a promising bilateral trade link since still comprising of negligible proportion of overall Thai trade with its neighbor.

In fact, recent Thai-Cambodia trade narration still reported some critical impediments, e.g. problematic Cambodian laws and regulations [5]. It is quite obvious that these barriers are similar to what were reported in 2004 by [6] and so far have persisted almost a decade. It seems that sustained prosperity of Thai-Cambodia border trade will be initiated only after barriers hindering it are identified and eliminated as long been posited by [4]. There might be hidden critical obstacles impeding trade exercising their influence over others waiting for

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uncovered.

Apart from its practical interesting, border trading activity, particularly with regarding to barrier issue, also offers ample academic attraction. Taxonomy of export barrier has still been a weakness in the literature when it has not yet been conclusive [7]. Moreover neither the uniform measurement scale of export barrier has yet been established. As such its inclusive measurement items, dimensions, together with priority have left blurred.

Though fair interest in study of border trade occurs, barrier issue has been an overlooked research domain. Moreover, barrier studies have been dominated by macroeconomic perspective, e.g. [8]. In such analysis, identification, classification, and prioritization of particular barriers are at the best not a major focus. This ignorance occurs even scholars still have been challenged by a major open economy puzzle [9] of experiencing inferior inter-border trade to intra-border trade albeit border liberalization. It seems that myriad of study at the macro level has not done enough to uncover the puzzle.

In Thailand, for example, there is probably only one study focusing on barrier to border trade and it was since 2004 [6]; while in most of the study, barrier issues are basically peripheral to other issues as trading strategies and situation. There were hardly any attempt in classifying and prioritizing the barrier. Moreover these studies' results have been isolated and fragmented.

It seems that we cannot afford to overlook the issue of border trade barrier in a micro-level any longer especially when done in a promising area as Srakaew province. This study thus attempts to answer a general research question of "What are barriers to border trade on the Southern Economic Corridor?" Its endeavor sheds some light on our knowledge of export barrier as recently still called in the literature [7] and particularly to border trade one at least in three aspects of barrier identification, classification, and prioritization. This study therefore offers benefits to both practitioners and academics.

2. LITERATURE REVIEW

This section includes discussion of 5 basic groups of literature respectively, i.e. export barriers, border trade, Thai-Cambodia border trade relationship, barriers to border trade as a whole, and specifically to that between Thai and Cambodia. Details of review are presented as follows.

2.1 Barriers to Export:

To be able to have vivid understanding of obstacles to border trade, it is imperative that we first familiarize with extant export barrier literature.

Interested readers are able to refer to [10], and [11] for thorough review of export barrier literature. In addition, succinct review of conceptualization, taxonomy, and contemporary issues of export barrier can be found in [12].

Taxonomy of export barrier is one inconclusive issue of which [10]'s 4-group proposition of domestic external, domestic internal, overseas external, and overseas internal, seems to be exhaustive. However, [11] proposed 2-group typology of domestic and overseas, arguing that it might be too complicated and thus not be applicable to small and medium-sized export enterprises (SMEs). While, [13] has also proposed a 2-group taxonomy, i.e. domestic and internal-firm, claimed to be more suitably accommodate exporters from developing countries.

In fact, [12] empirically found that combining of [11]'s and [13]'s into 3-group one might be the most suitable taxonomy for exporting firms from developing countries basically SMEs engaging in border trading activities with their neighboring countries. [12]'s typology divided barriers into 3 groups of those internal to Lao PDR and related to overseas economic conditions or shortly called overseas barriers, barriers internal to Thailand or also called domestic barriers, and those internal to border trader themselves, or so called internal-firm barriers.

This glaring controversy offers a chance for this study to provide another empirical evidence enabling approaching conclusive consensus in the literature.

2.2 Border Trade:

To gain insights in barrier to border trading activities, we also have to be equipped with knowledge of border trading herewith discussed. Readers can refer to [12] for succinct review of border trade literature for its conceptualization, taxonomy, and recent issues of Thailand.

In the last two decades, there are 2 distinct geographical contexts of study in border trade as appeared in scholarly journal, i.e. North America, and Europe Union (EU); while Asia, Latin America, or Africa are chosen by some. This instance is not surprised given the fact that North America is considered having the "Thinnest" border in the world where minimal trade barriers present; while EU has been known to actively promote intra-regional trade [8].

As such, in the developed trading territories, focus has been somewhat even on two crucial issues of border effects and border liberalization. Those studied border effects are basically economic analysis of time series trade data comparing intra-national with inter-national trading transaction of a specific pair of trading countries, e.g. [14], [15], [16].

Border effect is existed if the intra-national trade significantly differs from inter-national one. [14], for example, found such effect when his results showed that Canadian states trade 22 times more among themselves than with U.S. states once income and distance differences are taken into account. His findings is considered by [9] as an open economy puzzle of which its assumption of equal border barriers was tested and rejected by [8]. Yet having macro-level focus, [8] did not provide a list of particular barrier so that measures can be taken to eliminate them. This instance offers an opportunity for this study to add on the literature by generation of such a list.

These studies might well lead to interest in the issue of border liberalization and its consequences on various macroeconomic variables, for instance [17], and [18].

Still there are some studies interested in conditions of liberalization, e.g. trade policy, and copyright enforcement e.g. [19], and [20].

In developing economies, where preoccupation is on enforcing liberalization, narration of trade pattern, e.g. [21] and [22], and development of bilateral or multilateral trade integration, e.g. [23], seem to be of greater interest. Yet, there is another study interested in border effect analyzing its influence on business cycle utilizing Brazilian-Argentinean trade data and found as such, i.e. [24].

2.3 Thai-Cambodia Border Trade Relationship:

This section discusses the following topics, i.e. Cambodia International Trade and Investment Policy, Cambodia Trade Policy toward Thailand, Thai-Cambodia border trade situation and issues.

Cambodia International Trade and Investment Policy:

After collapsing of socialist economy, Cambodia adopted market economy since1989 [25]; yet during the first decade of this major change, its path to capitalism gradually proceeded owing to difficulties in the country and in the region. Since political stabilization was established in 1999, Cambodia has accelerated its route to open economy development and adopted international free trade and investment policies attractive to the world.

In order to ensure trade and investment counterparts of security to their business, Cambodia also conducts law and regulation reform, especially those related to trade and investment [25]. Classified as one of the poorest nations, Cambodia has received Generalized System of Preference or GSP for its exported products to U.S.A. and E.U. Moreover, it also received Most Favored Nation or MFN status from both U.S.A. and E.U [6].

Cambodia Trade and Investment Policy toward Thailand:

Though regular Thai Cambodia national relationship during Yingluck's administration has resumed, and even Cambodia conveys the same trade and investment policies with Thailand as it applies to the world, sustained national and so as with trade relationship between them have still been believed to be uncertain.

Intermittently National conflicts between the two nations seem to be unavoidable since a few critical issues, i.e. Phraviharn (Preah Vihear) Temple, and overlapping economic territories in the Gulf of Thailand, have not yet been solved or might not be. The conflicts are very complicated owing to alleged conspiracy among leading politicians of Thai and Cambodia and global mighty powers secretly exploiting rich energy deposits of the two countries.

However, fortunately enough, Phraviharn conflict was limited to the areas where trade is sparse, so it has minimal effect to overall border trade volume between Thai and Cambodia.

Thai-Cambodia Trade Situation:

Currently border trade between Thai and Cambodia occurs through 14 official pass points of which 6 are permanent points and 8 are temporarily trade facilitating points [26]. These pass points are located along Thai-Cambodia border in 6 provinces from Ubon Ratchathani, Sisaket, Surin, Srakaew, Chantaburi, to Trat. The 2 most important pass points where 90% of trade existed are Klong Luek custom point and Ban Had Lek custom point [26].

a. Trade Proportion:

These following 5 sections present statistical data adapted from those of [3], and [27].

From Table 1, it is obvious that during the last 4 years period, trade between Thailand and its 4 neighboring countries has been dominated by border trade among them when on average border trade value accounts for around 75% of total international trade. Trade between Thailand and Cambodia repeats the same pattern when border trade also accounts for around 75%. Moreover, there is a high potential of increasing trade between Thai and Cambodia since their trade represents only around 7% of trade between Thailand and its other neighboring countries.

Table 1: Proportion of Total Trade Value, Export, Import, and Trade Balance of International Trade and Border Trade between Thailand and Cambodia, Lao, Mayanmar, and Malaysia (%)

Proportion (%)	2007	2008	2009	2010
	Border Trade between Thailand and its neighboring countries to International Trade between Thailand and its neighboring countries			
Total Trade	70	75	77	77
Export	81	83	87	90
Import	59	66	67	63
Balance	2500	303	685	250
	Border Trade between Thailand and Cambodia to International Trade between Thailand and Cambodia			
Total Trade	78	72	80	68
Export	77	71	80	69
Import	96	98	94	63
Balance	76	70	79	70
	Border Trade between Thailand and Cambodia on the Border of Srakaew Province to Border Trade between Thailand and Cambodia			
Total Trade	51	60	51	56
Export	50	57	50	55
Import	84	92	63	66
Balance	49	55	49	54
	Border Trade between Thailand and Cambodia to Border Trade between Thailand and its neighboring countries			
Total Trade	7	7	7	7
Export	11	12	12	11
Import	1	1	1	2
Balance	40	41	43	24
	International Trade between Thailand and Cambodia to International Trade between Thailand and its neighboring countries			
Total Trade	6	7	7	8
Export	12	14	13	14
Import	1	1	1	2
Balance	1314	180	377	86

Source: Department of Foreign Trade 2011

Table 1 also shows that Srakaew is a very important trading channel between Thai and Cambodia when trading through its border accounts for around 55% on average during the last four years. These facts all prioritize study of the trade relationship between Thai and Cambodia.

b. Trade Value and Trend:

Table 2 below presents overall Thai-Cambodia border trade value and the trade through Srakaew over the last 4 years and their percentage changes. The trade faced difficulties in 2009, drop of around 10%, partly owing to serious national conflicts between Thai and Cambodia leading to military fighting on the border [28].

Table 2: Border Trade Value of trading between Thailand and Cambodia (Million Baht) and Percentage Change

Value		2007	2008	2009	2010	%Δ 08/07	%Δ 09/08	%Δ 10/09
Border Trade between Thailand and Cambodia	Total Trade	37,479	50,307	45,374	55,411	34.23	-9.81	22.12
	Export	35,425	47,372	42,879	51,113	33.72	-9.48	19.20
	Import	1,613	2,936	2,495	4,298	81.97	-15.01	72.26
	Balance	33,812	44,436	40,384	46,815	31.42	-9.12	15.92
Border Trade between Thailand and Cambodia on the border of Srakaew Province	Total Trade	19,224	29,717	22,980	30,904	54.58	-22.67	34.48
	Export	17,870	27,020	21,396	28,090	51.20	-20.81	31.29
	Import	1,354	2,697	1,584	2,814	99.21	-41.27	77.65
	Balance	16,517	24,323	19,812	25,276	47.27	-18.55	27.58

Source: Department of Foreign Trade 2011, and Bank of Thailand 2011

c. Top-Ten Export of Thailand to Cambodia:

Table 3 shows top-ten list of export from Thailand to Cambodia. Having sugar on the top, with a proportion of around 10% of total export, these products account for almost 50% of total border export of Thailand. This list is very dynamics including 6 new products, i.e. sugar, motor tire, non-alcoholic drink, cosmetics perfume and soap, other vehicles and parts, and other livestock. While interestingly other traditional top ten products disappeared from the list, i.e. garments, cement, animal feeds, petroleum gas and gasoline, agricultural machineries, fertilizer, monosodium glutamate, and sarong (traditional long Thai skirt).

Table 3: Top Ten Export of Thailand to Cambodia in 2010 (Million Baht)

Product	2010
1. Sugar	4,826.5
2. Clothes and Yarn	2,314.2
3. Engine	2,199.3
4. Motor Tyre	2,097.8
5. Automobile, its Parts, and Accessories	1,947.4
6. Motocycle and its Parts	1,694.1
7. Non-Alcoholic Drink	1,608.0
8. Cosmetics, Perfume, and Soap	1,602.0
9. Other Vehicles and their parts	1,041.4
10. Other Livestocks	1,014.2
Top 10 Export	20,345.0
Other Export	30,762.7
Total Export	51,112.7

Source: Department of Foreign Trade 2011

d. Top-Ten Import of Thailand from Cambodia:

Concentration of import content of Thailand is very high as statistics in Table 4 states that the top ten imports account for around 75% of total import from Cambodia. Moreover, import contents are stable when 7 products of the top-ten list are the same old import products. Three new top-ten imports are other wooden products, other metal ores and scrapped, and bus and truck. Three traditional imports that disappeared from the list are soybean, used garments, and fish and aqua products.

Table 4: Top Ten Import of Thailand from Cambodia in 2010 (Million Baht)

Product	2010
1. Iron	847.2
2. Corn	704.4
3. Aluminium	552.9
4. Tapioca and its related Products	442.9
5. Copper	235.1
6. Scrapped Paper	190.7
7. Garments	30.6
8. Other Wooden Products	22.5
9. Other Metal Ores or Scrapped	12.2
10. Bus and Truck	3.4
Top 10 Import	3,041.8
Other Import	1,256.6
Total Import	4,298.3

Source: Department of Foreign Trade 2011

Issues relating to Thai-Cambodia border trade:

There are at least two important issues relating to border trade between Thai and Cambodia, i.e. national relationship between the two countries and strategic development projects along the Southern Economic Corridors (SEC). For the former issue, interested readers can refer to [28] for chronological review of Thai-Cambodia Phraviharn conflicts during the last three years.

Surprisingly, unlike East-West Economic Corridor (EWEC), there are hardly any studies focusing directly on development consequences of SEC. Yet there is an interesting comprehensive development project initiated and operated by Burapha University, titled "Research project for Management and Development of Thai-Cambodia border areas" [29]. This main research project consists of various sub-projects concerning joint development of various pairs of Thai and Cambodia provinces, e.g. a project studying development of facilitation to border trade between Srakaew province and Poi Pet.

2.4 Barriers to Border Trade

Comparing with other research topics relating to border trade, barrier issue is a very thin stream of research of which only 3 are identified and reviewed here after. This should due basically to the fact that major borders, e.g. North America and EU, where a large number of trade occurred, are considered liberalized with minimal or no barrier to trade. Moreover, most of the relevant studies, e.g. [14], and [15], usually assume an average level of border barriers when conducting at a macro level focusing on examining border effect on trade between each bilateral trade relationship studied. This ignorance makes it impossible to identify, grouping, and prioritizing those particular barriers affecting border trade so that they can be eliminated. The following paragraphs briefly review these border barrier literatures.

Relaxing an equal barrier assumption, [8] found that barriers to border trade are actually very different among each EU national members. Some EU member, e.g. Netherlands, Finland, and Denmark, have imposed no tariff equivalent barriers to trade on some bilateral relationship; while others, e.g. Austria, Italy, and Spain, still maintain as high level of barrier as 75% tariff equivalent on some of theirs.

Realizing void of study focusing on service border trade, [30] examine effect of border trade liberalization policies of both goods and services of Tunisia and Egypt on two main macro economic variables, e.g. economic growth, and standard of living. Arguing for free flowing of skilled service providers and capital, [30] implicitly propose liberalization of capital and skilled labor across border to promote cross border service trades which are very promising trading sector.

[30] found positive effects of policies liberalizing goods trade on both growth and standard of living in Tunisia where its economy is open to global economy. They also found that liberalizing in service trade furthers the improvement of economic development as initiated by goods trade liberalization. However, in Egypt, where its economy has been relatively closed, liberalization effect almost abortive.

Reviewing Tagliacozzo’s book titled “Secret Trades, Porous Borders: Smuggling and States along the Southeast Asian Frontier 1865-1915”, [31] pointed out that Tagliacozzo did not only well narrate smuggling trade in the region but also investigate the relationship between such illegal activities and growth of state power, imposition of colonial rules, and challenges these processes provoked. It can be inferred that smuggling along the border land of Southeast Asia has long been in exist and exercised its mighty influence ever since even on state administration. Therefore, its present is and will be an important barrier to border trade indefinitely since it has a very long and complicated root.

2.5 Barriers to Thai-Cambodia Border Trade

Surprisingly, there are limited numbers of literature relating to barriers to Thai-Cambodia border trade. Moreover, most of them focus on narration of trading situation describing barriers to trade as addition to their major topics. Actually, there is only one study focusing on the topic in 2004 [6]; yet, barriers issues seem to be subordinate to investment feasibility study. Furthermore, if barriers are studied, they are basically identified and described without classified or prioritized.

The following paragraphs present review of relevant literature by adopting [12]’s taxonomy of border trade barriers in grouping the individual barriers as identified by them except for [6] in which her grouping was done.

In their website describing current border trade situation between Thai and Cambodia in 2011, [5] identifies 13 barriers. There are 7 barriers relating to factors within Cambodia or overseas economic conditions, i.e. uncertainty of trading rules and regulations when they are consistently change or area dependent, complicated and not facilitating import processes as operated by a private company, centralization of authority facilitating trade, unsecured Real currency of Cambodia, high transportation costs owing to poor road condition especially between Aranyaprathet and Banteay Meanchey, Competition from cheaper products from China and Vietnam, and delicate national relationship between Thailand and Cambodia.

There are 4 barriers associating with factors internal to Thailand, i.e. delay in tax refund for export promotion, crowded custom pass point and delay in open new point, no official agency responsible for studying Cambodia market for relevant market information, increase wages deteriorating price competitiveness. While there are 2 barriers linking with factors internal to border traders themselves, i.e. traditional trade practice with no trade document, lack of personnel having knowledge of international trade.

In one of its webpage describing current border trade situation, [32] revealed one barrier considered external to Thailand. It is military fighting between Thai and Cambodia armed forces on the border of Sisaket and Surin provinces early this year leading to close of 2 pass points there. However, fortunately enough this incidence has minimal effect on border trade between the two countries since trade transaction over the border of these two provinces account for negligible value of total border trade between Thai and Cambodia.

In a report narrate border trade situation in 2010, [33] pointed out a similar barrier mentioned above. It is Thai-Cambodia chronic national conflict during the year 2007 to 2010 leading to uncertainty of border trade activities since trader worried about worse conflict causing close of border pass points. This incidence also proves that chronic conflict at least causes anxiety to trader which consequently deterring trading activities.

Studying development approach for border market place, the case of Rong Kluea market, [34] found two important barriers of development relating to Thailand. They are crowded Klong Luek custom pass point, and poor standard of Rong Kluea market.

[35] reported in 2008 that there are 8 barriers impeding border trade between Thailand and Cambodia. Those relating to factors internal to Cambodia comprises of 6 barriers, i.e. poor road condition and other public utilities in Cambodia, uncertainty in rules and regulation of trade owing to their frequent change and area dependence, corruption of Cambodian officers, poor ICT supporting custom operation, competition from cheap products, and Thai and Cambodia national conflict.

There are 2 barriers caused by Thai authorities, which are crowded Klong Luek custom pass point delaying and causing reduce in trade, and the lack of public utilities, electricity, water supply, and telephone connection, at border market of Chong Sa-Ngam, Phusing district of Sisaket province.

In her study of barriers to border trade between Thailand and Cambodia, [6] categorized 5 groups of barriers. These barriers are problematic trading tradition and payment settlement, problems of transportation route and procedure of inbound transportation, problems caused by existence of casino, problems relating to Thai trade rules and regulation and the lack of these rules and regulation of Cambodia, and problems of prevailed cross border criminal transaction.

Yet, it is quite clear that [6] did not apply her conceptual classification criteria in grouping trade barriers since for instance she grouped the problematic rules and regulation of Thailand with those of Cambodia. Moreover, [6] ignored outlining those barriers internal to border traders themselves even though she cited a few of such barriers in her first barrier group. She did not explicitly prioritize these barriers either.

3. METHODOLOGY

Both qualitative and quantitative techniques were applied in this research. Operation commenced by compiling qualitative data from various sources and activities prior to operationalizing the qualitative findings. Its qualitative endeavors included archival data investigation, in-depth interview and focus group discussion. In-depth interview was done with 24 informants comprising of scholar who are border trade researchers and experts of the field who are experienced or successful border traders and government officers in charge of border trading activities. Focus group was conducted with 10 active border traders from various trading sectors. Content analysis was conducted to classify and prioritize barriers to border trade.

Then quantitative field survey research method was conducted by using questionnaire as a data collection tool. Each barrier variable was measured on a six-point Likert scale. The sampling frame for this study is a trader directory of Klong Luek custom office consisting of 110 firms. The targeted respondents are in managerial position either owners or decision makers who directly involve in their company's Thai-Cambodia border trading. Firstly purposive sampling method was used by specifically focusing on those firms trading on a regular basis.

There were 65 firms within the sampling frame approached by telephone soliciting responses from each of them before the questionnaires were faxed or email to target respondents. A total of 32 firms consented to supply the necessary information and returned the questionnaires. Descriptive statistical analysis method was employed for analyzing the surveyed data to validate and confirm qualitative results of this research.

4. RESULTS

This research finds that there are 77 particular barriers to Thai-Cambodia border trade. These barriers were prioritized by their sample mean scores of which the top ten scores are shown in Table 5 below.

By their overall score of 5.11, these barriers are considered very important by border trade. There are 4 barriers thought to be the most important which are repeated taxing or not transparent taxing procedure of Cambodia; higher cost from hiking gasoline cost**;** not international, unclear, and not facilitating trade of law system, trade regulations, and justice process of Cambodia; and problematic law enforcement in Cambodia which is unclear, lack of standard, area dependent, or enforcer dependent.

Table 5: Top Ten Border Trade Barriers

Barrier	Mean	S.D.	Level of Importance
1. Repeated taxing or not transparent taxing procedure of Cambodia	5.47	1.08	Most important
2. Higher cost from hiking gasoline cost	5.22	1.04	Most important
3. Problematic law system, trade regulations, and justice process of Cambodia, i.e. out of date, not international, unclear, and not facilitating trade	5.19	1.04	Most important
4. Problematic law enforcement in Cambodia which is unclear, lack of standard, area dependent, or enforcer dependent	5.19	1.23	Most important
5. Thai products are copied by cheaper China and Vietnamese products	5.10	0.89	Very Important
6. Uncertainty of investment promotion policy and other relating laws and regulations	5.06	1.19	Very Important
7. Delay of Cambodian authorities in communicating with Cambodian consumer for resuming confidence in problematic Thai products and lifting the banning notice	5.00	1.22	Very Important
8. Competition from low quality and very cheap products from China and Vietnam targeting very poor rural Cambodian people	5.00	1.17	Very Important
9. Corruption of Cambodian government officers	4.94	1.48	Very Important
10. Poor transportation route	4.94	1.29	Very Important
Total	**5.11**	**1.16**	**Very Important**

Note: 1.00 – 1.83 *is Not at all important*
1.84 – 2.67 *is Not quite important*
2.68 – 3.50 *is Quite important*
3.51 – 4.33 *is Important*
4.34 – 5.17 *is Very important*
5.18 – 6.00 *is Most important*

The rest on the top ten list are evaluated as very important which are uncertainty of investment promotion policy and other relating laws and regulations; delay of Cambodian authorities in communicating with Cambodian consumer for resuming confidence in problematic Thai products and lifting the banning notice; competition from low quality and very cheap products from China and Vietnam targeting very poor rural Cambodian people; corruption of Cambodian government officers**;** and poor transportation route**.**

Based on [12]'s criteria, these 77 individual barriers were classified into three groups of barrier according to their causes, i.e. barriers relating to factors internal to Cambodia and overseas economic conditions, or overseas barriers, as shown in Table 6, those relating to factors internal to border traders themselves, or internal firm barriers, as shown in Table 7, and barriers relating to factors internal to Thailand, or domestic barriers, as shown in Table 8. Content validation for these barrier components were conducted by 5 experts and support for [12]'s taxonomy was established. The following paragraphs will elaborate on each group of border trade barrier.

Barrier related to Cambodia and overseas economic conditions:

As shown in Table 6 below, the first group of border trade barrier consists of 7 subgroups of barrier related to Cambodia and overseas economic conditions or barriers caused by factors external to Thailand. These barriers all together are considered important by border trader and are the most critical according to majority of respondents.

Table 6: Barriers Internal to Cambodia and relating to Overseas Economic Conditions

Barrier	Mean	S.D.	Level of Importance
1. Out of date law and regulations and uncertainty in their enforcement together with Unclear policy not facilitating trade of Cambodia	5.23	1.21	Most important
2. Competition from international traders especially China and Vietnam and foreign exchange risk	4.52	1.23	Very important
3. Poor public services, corruption of government officers, and political instability of Cambodia	4.26	1.47	Important
4. Misbehavior of Cambodian traders or inappropriate tradition of trade and poor standard Cambodian products	4.15	1.41	Important
5. Poor public infrastructures and trade facilities of Cambodia	4.13	1.68	Important
6. Delicate national relationship with Cambodia	3.99	1.70	Important
7. Low living standard and limited exposure to relevant information of the Cambodian	3.74	1.74	Important
Total	**4.29**	**1.49**	**Important**

There is one subgroup of barrier rated as the most important, i.e. out of date law and regulations and uncertainty in their enforcement together with unclear policy not facilitating trade of Cambodia. This subgroup comprises of 4 particular barriers and they are ranked first, third, fourth, an sixth in the top ten list.

The other subgroup of barrier is evaluated as very important which is competition from international traders especially from China and Vietnam and exposure to foreign exchange risk. It has 3 individual barriers of which two are ranked fifth and eighth in the top ten; while the other one, rated as not quite important, is risk from highly volatile U.S. dollars, a popular payment medium.

The rest 5 subgroups of barrier are considered important and are described as following.

Poor public services, corruption of government officers, and political instability in Cambodia has 4 barrier items of which two are ranked seventh and ninth in the top ten. The rest two barriers are the obscured national unity and hence suspicious national security in Cambodian since there are still independent armed forces left operating on the Thai border, rated as quite important; and complicated and red tape in import processes together with uncertain and short office hours of Cambodian pass points owing to two hours lunch break tradition, rated as not quite important.

Misbehavior of Cambodian traders or inappropriate tradition of trade and poor standard Cambodian products is comprised of 3 barriers, i.e. lack of responsibility in payment of credit trade account of Cambodian trader, rated as very important; poor hygienic standard of Cambodian aqua products; and plant diseases and insects from Cambodian farm crops, both are rated as quite important.

Poor public infrastructures and trade facilities of Cambodia consists of 5 individual barriers of which one is ranked tenth in the top ten list. The others is also rated as very important, i.e. unready of Cambodian trucking transportation, e.g. truck operating without insurance. The other two barriers are quite important which are unready trucking with special equipment, e.g. air conditioner; and unready of communication facilities. The last one is rated as not quite important, i.e. unprepared supporting service industries, e.g. hotel and restaurant.

Delicate national relationship with Cambodia has 2 particular barriers rated as quite important. These are firstly the Cambodian and their government hold negative attitude toward Thailand and hence are suspicious of Thailand in mistreating and taking advantages of them from border trading. Secondly, Phraviharn temple conflict as linked with notorious alleged conspiracy between Cambodian leaders and former Thai political leader in exploitation of controversial energy resource endowment in the gulf of Thailand for their own benefits.

Low living standard and limited exposure to relevant information of the Cambodian consists of 2 barrier variables. The first one is poverty and the lack of information of majority of the Cambodian living in isolated rural area which is rated as quite important. The second one is the lack of identification documents of both individual and business concern in Cambodia, rated as not quite important though.

Barriers caused by factors internal to border traders themselves:

In Table 7 underneath, the second group of border trade barriers caused by factors internal to border traders themselves is presented. This group of barrier is also considered important but is thought of as less critical than the first group by majority of informants. There are three subgroups of border trade barrier in this group. Moreover, each subgroup is also rated as important as narrated hereafter.

Table 7: Barriers Internal to Thai Border Trader

Barrier	Mean	S.D.	Level of Importance
1. Not professional trading practices of Thai border trader	4.06	1.55	Important
2. Disadvantages from trading with trade documents of Thai border trader	3.81	1.66	Important
3. Misbehavior or risky tradition in trading of Thai border trader	3.79	1.59	Important
Total	**3.89**	**1.60**	**Important**

Not professional trading practice of Thai border trader consists of 3 individual barriers. The first one is considered very important, which is the lack of unity and cooperation among traders, focusing principally on personal benefits. The rest two barriers are rated as quite important. The former is lack of vision in business administration, preoccupying with short term ad hoc benefits. The latter is the lack of enthusiastic business action, e.g. procrastinating of market visit, and ignoring product development attempt arguing responsibility of product owners.

Disadvantages from trading with trade documents of Thai border trader is the only single item barrier component rated as quite important.

Misbehavior or risky tradition in trading of Thai border trader has 8 barriers. One barrier is rated as very important, i.e. risk of careless practices in conducting credit trade, e.g. over limit accounts, credit sales without documents, leading to abundant overdue account receivable and bad debt in the end. There are 4 more interesting barriers cited as examples. Firstly the lack of working capital to finance credit sale, and difficulties in managing credit accounts, rated as quite important. Unethical trading practices, e.g. selling of expired foods or beverages to the Cambodian traders, and no prior notice of price changes, rated as quite important. Inefficient and timely processing of small orders, also rated as quite important. Lastly unethical filing for tax refund from Thai government, rated as not quite important.

Barriers related to factor internal to Thailand:

Table 8 below presents the third group of border trade barriers related to factors internal to Thailand or they are generated in Thailand either by governmental or private concerns apart from by border traders themselves. Like the two former groups, this group of barrier is also considered important; yet is the least critical according to most informants' view. There are 9 subgroups of border trade barrier in this group which are describing as follow.

Table 8: Barriers Internal to Thailand

Barrier	Mean	S.D.	Level of Importance
1. Higher cost of trade in Thailand	4.48	1.31	Very important
2. No strategic plan for border trading of Thailand	4.17	1.58	Important
3. Illegal trading and Thai gambler crossing to casinos	4.15	1.59	Important
4. Losing intermediary status and lack of support from relevant private concerns of Thailand	4.12	1.48	Important
5. Out of date laws and regulations relevant to trade of Thailand	3.80	1.63	Important
6. Corruption of Thai government officers	3.68	1.59	Important
7. Inefficient and uncooperative public services of Thailand	3.62	1.71	Important
8. Poor trade infrastructures of Thailand	3.28	1.81	Quite important
9. Low competitiveness of Thai traders caused by national handicaps	2.90	1.66	Quite important
Total	**3.80**	**1.60**	**Important**

There is a subgroup of barrier considered very important, i.e. higher cost of trade in Thailand. This cost rise is caused basically by increases of three costs of trading. The first is oil price hike, rated as the most important and is the second in the top-ten list. Secondly wages surge is considered very important. Lastly interest rise is rated as quite important.

The latter 6 subgroups are rated each as important and narrated as follow.

The first is no strategic plan for border trading of Thailand is comprised of 3 particular barriers. The first of which rated as very important is the lack of national blueprint to deal with exploitation of abound deserted land occupied by various influential entities, from public, private, and military concerns, especially in Srakaew province. The second is a lack of provincial development master plan which specified clear development vision and directions, rated as quite important. The last is the lack of provincial plan for border trade development, also rated as quite important.

Secondly, illegal trading and Thai gamblers crossing to casinos consists of two barriers. The first one is smuggling, especially drugs, labor, and auto vehicles, rated as very important since their trades cause stringent control on the border of Thai armed forces to inhibit such mal-trades. The second is stream of gamblers crossing to Cambodian casino causing jam in immigration toll, rated as quite important.

The third subgroup is losing intermediary status and lack of support from relevant private concerns of Thailand has 4 specific barriers. There is a barrier considered as very important which is direct selling to Cambodian market by products owners or major distributors. Three other barriers are rated as quite important. The first is the lack of monopoly power from being single authorized dealer in Cambodian market. The second is trade obstruction by some trade or industry association or regional influential interest group. The last one is the lack of motivation to work actively for chamber of commerce or industry association since there is a conflict of interest, personally versus collectively.

Fourthly, out of date laws and regulations relevant to trade of Thailand consists of 4 barriers. The first one is rated as very important, i.e. the lack of trade documents and international debt enforcement process. The second barrier is complicated trade rules and regulations increasing transaction costs or limiting trading volume, rated as quite important. The third one is out of date and not facilitating provincial regulations, rated as quite important.. The final one is out of date, conflicting, or inflexible law relevant to trade of Thailand, rated as not quite important.

Fifthly, corruption of Thai government officers has 3 specific barriers. The first one is forced bribery by Thai police officers controlling the routes to border from transported trucks, rated as quite important. The second barrier is no transparency in visa application procedure at the Thai embassy in Phanom Penh deterring traders' application, rated as quite important. The last one is forced bribery by various relevant Thai government agencies investigating products at border passing points, rated as not quite important.

The sixth barrier is inefficient and uncooperative public services of Thailand. It is the largest subgroup comprised of 14 particular barriers of which some interesting one are mentioned hereby. There is one barrier considered very important, i.e. there is no Thai consular office in Poi Pet to facilitate border crossing processes, e.g. visa issuing and extending, especially to the Cambodian residing in the Western provinces wishing to visit Thailand for business or touring, or international tourists wishing to revalidate their visa without voyage a long way to Phanom Penh.

There are four barriers rated as quite important which are no provincial border committee in charge of border issues from security to trade and investment, crowded custom pass points and immigration check points especially Klong Luek, difficulties in opening new pass points caused by security issues, and inefficient or practically failure of one stop service facilities. Yet there are three interesting barriers rated as not quite important which are the lack of cooperation in facilitating border trade transaction both among Thai agencies and between Thai and Cambodia agencies; and delay in and inconsistent of national negotiation on border issues and consequently uncertainty in the border line.

The last two subgroups of barrier are evaluated as quite important.

The first one is poor trade infrastructures of Thailand consisting of 7 specific barriers, surprisingly all rated as not quite important, of which 4 interesting ones are narrated hereby. The first one is delay in construction of Srakaew trade distribution center caused by controversy over location choice. The second barrier is ignorance in improvement and development of rail road transportation especially double rails transportation. The third one is no branch of Thai commercial banks operating in areas adjacent to border such as Poi Pet to facilitate payment. The last barrier is the lack of supporting service industries in Srakaew especially in Aranyaprathet, e.g. good quality hotel and restaurant.

The second barrier is low competitiveness of Thai traders owing to national handicaps comprised of 2 individual barriers, also surprisingly rated as not quite important. The first barrier is poor labor owing to low productivity and short of product development skill leading to inability to compete with cheap products from China and Vietnam. The second one is difficulties in accessing cheap funding from bank or other financial institution owing to short of hard collaterals by operating on public land and getting only temporary renewable rent contract without granting official ownership and certificate.

5. DISCUSSION

The discussion is comprised of three basic parts which are making sense of 3-group typology and comparing it with extant literature, addressing weaknesses in the export barrier and border trade literature as identified and strengthening by this research, justifying the top-ten list of barriers and comparing them with extant literature in Thailand.

Validating three major components of barrier to border trade, this study provides empirical support for 3-group typology of barrier to border trade as found by [12]. This typology is supposedly the most suitable for exporter from developing economies, basically SMEs, conducting cross border trading with its neighboring countries. It is not as complicated as [10]'s 4-group taxonomy applicable to exporters from developed countries conducting international trading activities. At the same time, neither it as rough as [13]'s 2-group one, appropriate with exporters from developing countries conducting international trade.

The 3-group taxonomy of barrier to border trade, i.e. overseas, domestic, and internal-firm barriers, is sufficiently logical. The first two groups are external to the trading firms which mean they do not have control. Overseas barriers are those caused by factors internal to Cambodia or overseas economic conditions which Thailand does not have direct control. Domestic barriers are those caused by factors internal to Thailand which it is supposed to have direct fully control. Internal-firm barriers are those caused by factors internal to the firm which it is supposed to have direct fully control.

This taxonomy is resemblance that of [11] since both studies conducted with SME contexts as a consequence the two taxonomies having domestic and overseas barriers in common. However, idiosyncrasies of border trading, study context of this study, making internal-firm barriers so eminent that they cannot be left blended with the domestic ones and that they are split out.

Such idiosyncrasies for example the inferior competitive position caused by documentary trading which is very unique of border trading activities conducted between developing nations. Yet, further subdivision of internal-firm barriers to those occurring domestically and overseas is not appropriate since borderland though separated by national sovereignty, behaviorally is united in term of business patterns and people's walk of life. This means that the borderland is supposedly an economically sovereignty state where in considering economic activities conducting on it national sovereignty seems to be not applicable.

This taxonomy is also resemblance that of [13] since both are found by studying the developing economy contexts as a consequence the two taxonomies having domestic and internal-firm barriers in common. However, idiosyncrasies of border trading again cause division of those barriers occurring outside of the firm into domestic and overseas ones since the Thai government has been seen evidently that it has at the best limited or temporary ability to take control over any delicate issues related to national relationship, e.g. national boundary issue. This is consistent with what [30] argue that, in developing countries context, these are barriers related to factors far deep and complicated beyond those at the border.

Such idiosyncrasies for example alleged conspiracy between Cambodian leaders and former Thai political leaders in making personal benefits out of both national resource deposits an incidence which widely believed that has dominated every aspect of national relationship between the two nations. Such incidence is even much more complicated when it has been alleged that there are secret intervention from various global mighty powers to exploit one of the world richest energy deposit. The conspiracy issue is an obvious difference between results of this study and [12]'s since Thai-Lao relationship has been very smooth for decades.

This study has done its best to partly move export barrier body of knowledge toward conclusion of the taxonomy issue as recently called by [7]. One of the possible conclusion if it might be put forward is that [10]'s 4-group taxonomy is applicable to exporters from developed countries conducting international trading activities. [13]'s one is appropriate with exporters from developing countries conducting international trade. Whereas [12]'s as empirically supported by this study is suitable for idiosyncrasies of border trading along national border of developing countries.

Moreover, this study has attempted to take part in an endeavor to propose a uniform measure scale done by [7]. By compiling a pool of 77 barriers variables, it endeavored to create exhaustive domain of measurement items which is the first step for development of a better marketing scale as postulated by [36]. Conducting validation and prioritization of barrier components in a preliminary fashion, this study provides a foundation for further operationalization its results; thus also partly helps pushing standard scale construction possible.

Furthermore, it has at its hardest attempt to more or less explicate the open economy puzzle raised by [9]. Chronic stagnant in unfolding the puzzle should due mainly to preoccupation with econometric modeling utilizing macro data analysis explaining overall economic phenomena ignoring undertow of influential decision at the micro level by each business unit. Border effect existence amidst trade liberalization over the border and hardly any psychic distance between the trading nations leading to inferior international trade phenomena is not surprising since those econometric models have not been able to capture exhaustively micro-level factors influencing border trader's decision.

Had such complicated yet not exhaustive model been able to capture such micro-level factors, they would have found that the costs of inter-border trade have still been immense, no matter whether measured in tariff equivalent quantitative term [8] or others. As a consequence, it would not have been puzzled at least for a decade why do inter-border trade is subordinate to intra-border trade in such thinnest border as North America or EU.

This research effort thus more or less helpful in explicate such a myth amidst global integrated economy. A humble answer to [9]'s puzzle is that there are much less inter-border trade than expected along the thinnest borders because what we usually see obstructing trade over there is just a tip of the iceberg of which its huge foundation is undertow ignoring for so long. Therefore what was done by this research is disclosing the underwater part of the iceberg which is identifying possibly exhaustive barrier variables, categorizing, and prioritizing them so that we recognize the genuine hindrance to inter-border trade. And only after this recognition that we are able to figure out how to eliminate them [4].

Taxonomy of Thai-Cambodia border barrier found in this study probably captures every single barrier so far identified by studies conducting in Thailand. Yet, there have been hardly any attempts in classifying these barriers so that comparison can be made. Though not explicitly articulated, one such attempt was done by [6] to which comparison can only be made. [6]'s 5-group typology discussed fairly enough and touched upon almost equally barriers internal to Thailand and Cambodia. She however mentioned just a few of barriers internal to Thai border trader, i.e. non-documentary trading practices of Thai border trader, and their unethical trading practices, more importantly ignoring outlining it.

Barriers identified by this study were also cited in the relevant studies in somewhat corresponding order of importance. In its top-ten list of barriers, 9 of them are those relating to factors internal to Cambodia and overseas economic conditions. In fact, these barriers have also been focused by majority of study conducting in the Thailand [5], [6], [32], [33], [34], and [35]. It is understandable why border traders considerably more worry about uncontrollable factors external to Thailand than those internal to their countries. Coping with these obstacles, border traders have to rely on indirect influence exercising through Thai government on which they take direct control neither.

There are 6 barriers of the top-ten list caused by Cambodian public administration, e.g. poor taxation, problematic laws and their enforcement also emphasized by [5], [6], and [35], poor infrastructure, especial road conditions, also stressed by [5], [6], and [35], and corruption of Cambodian officers also highlighted by [35]. These findings are not surprising since weaknesses of public sector seem to be prevailed in developing countries where governmental agencies usually develop much more slowly than those private concerns.

There are 2 obstacles of the list induced by competition from the world factory, China, and its follower, Vietnam also stressed by [5], and [35]. Their competitive advantages were understandably derived from price sensitiveness of the poor Cambodian. This issue is very worrying since it is apparent that border traders are preoccupied with blaming the factor price hikes, oil and wages, causing their disadvantages. They mistakenly overlook at least two serious national handicaps depreciating their sustained competitiveness as identified by this study, i.e. poor labor productivity, and inconvenient access to sources of fund.

There is a barrier relating to Thai-Cambodia relationship on the top-ten list, i.e. delay in rescuing image of problematic Thai products by Cambodian authorities. Though finding it is important, Phraviharn issue was considered relatively less critical by this study. This is due mainly to the fact that the specific conflicting area, Phraviharn temple in Sisaket province, is reasonably far from Srakaew so the eruption of Thai-Cambodia war on its border had limited effects on trade transaction on Srakaew border as also mentioned in [32], and [33]. Moreover Thai border trader suspicion in its correlation with international conspiracy might confound their judgments and lessen its critical.

In other studies however, Phraviharn conflict seem to be very critical barrier in the sense that it has been frequently cited recently, e.g. [5], [6], [32], [33], and [35], and causing uncertainty and anxiety. However, in term of direct loss on trading value, its effects have still been minimal [32].

The Thai-Cambodia national relationship issue is worrying in the sense that its sustained solution seems to be next to impossible and going toward it seems to take indefinitely time frame. This is due basically to alleged conspiracy theory and intervention from third party mighty power nations. These incidences confer a very crucial policy implication in the sense that foreign ministry of Thailand has to take a very active role in dealing with these serious inconveniences, if we would like to nourish Thai-Cambodia border trade.

There is only one barrier internal to Thailand in the top-ten list which is higher cost of trade owing to oil price hike sharply. The rise occurred not long after privatization of national petroleum company (PTT) alleged to be acquired by nominees of former political leader. Profit incentive inspired PTT to exercising its market leader position in continuously raising oil price by claiming world oil situation as its scapegoat. [5] also mentioned about the issue of higher cost of trade but in their case causing by higher wages.

Those barriers internal to Thailand were mentioned by some relevant studies. Basically focuses were on inefficient services, specifically jam, of custom pass point, especially Klong Luek pass point, causing delay in trade [5], [6], [34], and [35]. This study provides only partial support to the issue since it found that border trader did not consider it that important. It is seemingly because most of border trader trading through Srakaew border are experienced one knowing how to manage routinely to get through the jam. It is quite surprised that smuggling is forgotten at least recently though it was found important by this study and used to be highlighted by [6] and [31] as deep rooted over the border.

There is no barrier caused by border trader themselves at all in the top-ten list of this study. This is not beyond expectation since it is believed that a human being naturally will blame others as causing him difficulties prior to blaming himself. Moreover, people also usually look at others' mistakes as much more serious than theirs. In Thailand there are a few proverbs witnessing such belief, i.e. "A poor performance dancer usually blames the orchestra for turning him down", and "Other people's mistakes are as thick as a mountain but ours are as thin as a hair". [6] discussed the issues of careless and unethical trade practices of Thai border trader fairly enough by putting them modestly under her payment issue also mixing them with the Cambodian's mal-practice.

6. CONCLUSIONS/RECOMMENDATIONS

This study concludes that border traders exhibit their concerns basically over short term factors having direct impacts on their day to day trading activities; e.g. rising costs, competitions by counterfeits and unfavorably practices of Cambodian authorities ranging from repeating tariff charging, poor bad debt suing, multi-standard practices, to corruption. They at the same time somewhat ignore those long term oriented factors affecting their sustained competitiveness, such as labor productivity, logistical infrastructures, their ethical trading practices, and even sustained harmonious national relationship.

Moreover, it also concludes that major sources of border trading barriers are failure of both Thai and Cambodia public administration to facilitate trade flows between the two countries since national relationship and cooperation have been suffered from influential intervention.

Following [13]'s conclusion, this study's rationale for proposing recommendation is more strategically long-term oriented focusing on attacking barriers at their root causes and how controllable the issues are based on border trader perspective not as much on urgency of the issue. It believes that this approach will lead to sustained development in border trading.

As such this section starts with what border traders themselves might consider improve. Recognizing their misbehaviors and alleged unethical practices both against their countries in term of taxation and against their Cambodian counterparts, Thai border traders firstly might have to prioritize these issues and determine to adjust their business practices. This is certainly much easier said than done since the obedient and sacrifice ones will be suffer deeply when their price competitiveness is ruining by rising cost incurring by these good deeds.

In fact, inducing a very constructive collective action benefiting a society as a whole is a major responsibility of the government. However, amidst chronic political commotion in Thailand leading to political instability, the solution then seems to be every trader's self initiation to commence such collective change simultaneously. This mission certainly requires unity among trader. Therefore, an ad hoc measure to facilitate gradually build up of unity must be figure out.

One possible way is adopting new perspective in doing business for sustainability based on the King's philosophy of sufficiency economics and moral sentiment concept as referred and explained in [37]. It is creation of a very important innovation but it is mentally not materially and can be started suddenly by every trader provided that they sincerely believe in the King's philosophy. The other is having a visionary and charismatic regional leader who will be able to facilitate their unity.

Thai government might consider focusing its effort on building up and improving of border trader's sustained competitiveness as follow. Firstly, it will have to provide a typical national role model of operating ethically. Ethical practices might have to be a national agenda.

Government might have to generate a blueprint of strategic development of border trade to outlay direction, time frame, and concerned agencies. It will have to make strategic attempt at its best to reduce costs of trader's business operation by focusing on three critical issues which are poor labor productivity, inconvenient access to source of fund, and poor logistics infrastructures.

For productivity barrier, the Three-High approach, i.e. high income, reasonably high price, leading to high productivity, if agreed by the government and actively implemented on a national level might well be very helpful for this specific economic context also.

Improvement and construction of standard logistics system, e.g. improvement of road coverage and conditions, building double-rail transport platform, construction of goods distribution center, seem to require regional unity among influential entities or figures again once personal sacrifice might have to be delivered for collective progress.

Government of Thailand might consider lubricating border trade flow by restructuring of laws and regulation systems affecting trade both on the national and provincial level. Research might be required for investigation of those relevant laws and regulation impeding trade so that targeting and effective correction of them can be done.

Government might also have to consider improve implementation of creative service arrangement, e.g. one-stop export service, and paperless and single-window custom service, so that it is done efficiently and effectively.

Corruption can be effective eliminated, once government officers are reasonably well compensated for their duties and responsibilities as reinforcing by trader's determination on ethical business practice by quitting bribery.

Ministry of Foreign Affair of Thailand has to take a very constructive and active role in dealing with various serious inconveniences caused by the Cambodian sides, if we would like to nourish Thai-Cambodia border trade. It seems that harmonious national relationship between the two nations is the threshold to remedy every barrier internal to Cambodia. One helpful project possibly implemented by Ministry of Foreign Affair. It is an opening of a consular office at Poi Pet to facilitate cross border transaction of those Cambodians residing in the West and international tourists.

Interested scholars might consider conducting these following topics in the future. They might consider investigating laws and regulation system relevant to international trade, especially border trade so that successful amendment can be made.

These academia might extend from this qualitative enquiry by conducting main quantitative empirical study to clarify confirm and generalize the findings of this study is strongly encouraged. They can also study dependent relationship between border barriers and their strategic and performance consequences are also very interested research issues.

ACKNOWLEDGMENT

The authors would like to express most sincere appreciation to Khun Srisawang Toomdee, a custom officer at Aranyaprathet custom office, who consistently assists in providing required information and giving valuable advices relating to border trading activities.

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Are We Walking Hand in Hand? The Case of AEC: Accounting Harmonization in Measurement Practices

N. Likitwongkajon

Abstract*— *This study examines the degree of harmonization of accounting measurement practices. The data is elicited from the financial year 2009 annual reports of 150 sample listed companies in five ASEAN countries, including Indonesia, Malaysia, Philippines, Singapore and Thailand. The degree of harmonization is measured using the I index and between-country comparability index (C_b). The results show that the values of the indices are relatively high in the areas of valuation of inventory, valuation of property, plant and equipment and depreciation method. In contrast, the lower values of the indices indicate a lower level of harmonization in the areas of inventory costing.

***Keywords*— Accounting harmonization, AEC..**

1. INTRODUCTION

Economic integration of countries in the same geographical region has increasing roles in reinforcing their sustainable economic growth. In order to meet the goal, members of the same region economic alliances aim to eliminate extant trade barriers among the member countries. The alliances have emphasized on the harmonization of fiscal, business, and financial policies [1]. As an increasing amount of goods, service and capital flow across domestic border in regional economic community. Such as the Association of Southeast Asian Nations (ASEAN), ASEAN Economic Community (AEC) allows free flows for goods, service, capital, investment, and people among member countries by enacting lenient policies, supporting fund transfers and reducing tariff tax within ASEAN [2]. The total amount of Foreign Direct Investment (FDI) flow among ASEAN countries was 10,461 million dollars in 2008, 21% of the total FDI, increased from 2007 with 9,682 million dollars as 13% of the total FDI [3]. From target as AEC, amount of investments from abroad within ASEAN will proliferation many number of trade transaction and international business in the future.

From decision making perspective, Investors would like to direct their capital to the most efficient and productive companies globally. They need to understand accounting information from other member countries for make well informed financing and investing decision across domestic borders [4, p.2]. Social environment influences accounting, so the variation of country's accounting regulations and practices results the differences in financial statements [4, p.3]. Harmonization of accounting practices among countries improves the comparability of financial statements, as making them more useful to understand and interpret. Regional harmonization of accounting, a step towards greater international harmonization, is less heterogeneous environmental factors within a regional boundary. If regional harmonization is achieved, international harmonization would be much easier to accomplish [5]. Prior accounting harmonization studies mainly concentrates on developed countries or the European Union (EU) countries [6]-[8].

ASEAN accounting harmonization research appears to be little [9]-[11]. ASEAN have different environment in terms of the economic, political, culture and society. ASEAN must promote consistency in accounting practices, in order to facilitate ASEAN financial report users to understand and compare financial reports across countries. The purpose of this study is to examine the degree of harmonization of accounting practices with particular focus on measurement practices of listed companies in AEC context. The samples are retrieved from 150 annual reports of listed companies in five founder countries of ASEAN, namely Indonesia, Malaysia, Philippines, Singapore and Thailand. As the five pioneers has joined in ASEAN[1] for 43 years though the second group has already joined in ASEAN for 11, 13, 15 and 26 years. If the first group is achieved to accomplish regional harmonization, the second group would be easier to adopt the accounting regulations.

This study provides academic and practical contributions. First, the findings add to the current body of accounting harmonization literature by gaining more understanding of corporate accounting practices in South East Asia. Second, the study documents empirical evidence of evolving accounting practices in AEC. Third, the results of the study provide insight for accounting professional and regulators to determine the current status of accounting harmonization in AEC. Therefore, ASEAN commissioners can determine the extent of discrepancies to formulate guidelines for implementing accounting harmonization. In addition, the

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[1] ASEAN has been established by Indonesia, Malaysia, Philippines, Singapore and Thailand since 1967. Brunei joined in 1984, Vietnam joined in 1995, Myanmar and Laos joined in 1997 and Cambodia joined in 1999.

results could be used as a comparative model to develop accounting standards for other economic groups in other world regions, such as, South America, South Asia and Africa.

The remainder of this paper is organized as follows. The second section presents the prior research and review of literature. The third section discusses research methodology, including data selection and statistical analysis and section four provides an analysis of the results by measurement practice. Finally, the fifth section concludes with a summary of the findings, limitations and possibilities for future research.

2. PRIOR RESEARCH AND REVIEW OF LITERATURE

Accounting Diversity and Its Antecedents

The variation of country's accounting regulations and practices results the accounting diversity. Mueller (1976) discussed the impact of the environment on the formulation of accounting practices in a country. Conditions that can shape the accounting practices include culture, economy, society and political system (see also [12]). Research has adopted and supported Muller's conceptualization. Consistently, Reference [13] suggested that environmental factors are related to the accounting system. Reference [14] proposed that environmental factor affecting the development of accounting in each country. Reference [15] proposed the factors affecting the accounting by dividing variable of the culture from Gray whose variables culture divided into four groups plus a variety of six other factors. Research revealed environmental factors affect the development of national accounting, such as culture [15]-[18], the type of legal system [15], the type of political system [19], the type of capital market [20] and colonial [21].

Culture is a factor affecting the accounting within the country. Prior studies have examined the relationship between culture and accounting practices and found that country with different culture has different kind of accounting practices [15]-[18]. Hofstede (1985) defined culture as "the collective programming of mind which distinguishes the members of one human group from another." such as language, race, religion, customs, social roles and attitudes of people in society (see also [16]-[17]). The association between culture and accounting has been discussed widely [16]. Reference [16] extended the Hofstede's cluster of culture to explain the relationship between the characteristics of culture and accounting called the Hofstede-Gray Model. Reference [16] further explicated four characteristics of accounting

Several researchers have studied the relationship between cultures with the accounting in various settings. Reference [22] have identified the impact of Islam nature on accounting in Islam countries. Reference [23] have identified the impact of the languages the accounting disclosure. Reference [17] has identified the influence of culture on the financial reporting of the United States and the Netherlands. Reference [18] have identified the differences in accounting standards by comparing with the countries using International Accounting Standard (IAS) from the difference of culture.

Legal system is another important factor relating to accounting practices. Reference [15] discussed a relationship between the accounting system and the law system. The legal system is divided into two systems as Common law and Codified Roman law. In Common law countries, the accounting law is flexible. That is, the accounting law provides more like framework which allows accountants to exercise their own judgments. The details of how the performance and presentation of financial reporting will be determined by the professional institutions of accounting that are independent of government [24, p.28], [25, p.32]. Examples of developed countries which are using the Common law legal system are Ireland, the United States, Canada, Australia and New Zealand [24, p.28].

In countries using the Codified Roman law, the accounting will be set out in legislation such as the Code of Commerce. In general, the law is defined as a detailed presentation on financial reporting and accounting methods to be used in the preparation of financial reporting and this policy was not changed frequently [24, p.28], [25, p.32]. France, Italy, Germany, Spain, the Netherlands, Portugal and Japan are examples of the countries using the Codified Roman law [24, p.28]. Reference [14] argued that the different political systems would cause the different accounting practices. Political system is defined in terms of power of government and the authority in the country. It is indicative the significant relationship between the political system and accounting system in the country.

Source of capital funding is another factor attributing to the characteristics of accounting systems. Capital market is considered a funding source for domestic companies which want to expand their business by offering shares to public. Reference [26] commented that the accounting practices in countries which have strong domestic capital markets are different from those in countries which mostly depend on funding from financial institutions. Reference [20] commented that growth of capital markets also influences the development of accounting disclosure. In countries with large capital markets, companies would have a higher level of disclosure. On the other hand, in countries with relative small capital markets, companies would have a lower level of disclosure.

From the historical perspective, in the colonial era, the United Kingdom and France had spread their nations of their accounting system to various countries around the world. Now the British accounting still exists in Australia and New Zealand. The French accounting is appeared in its former colonies in East Africa. The Dutch accounting was transferred to countries that used to be a colony of the Netherlands. The accounting system in the United States colony is influenced by the U.S. accounting systems as well. Being the former colonies of foreign countries would contribute to the similarity and dissimilarity of accounting systems of those countries [4], [10, p.8], [25, p.34]. The British accounting was transferred to developing countries in the ASEAN region which were once a British colony [21]. Currently, due to economic integration and the spread of economic power, the isomorphism of accounting system within the EU, NAFTA and ASEAN has been observed and documented. For instance, the U.S. accounting system has been adopted by Canada, Mexico, and Israel [4], [10, p.8], [25, p.34].

Regional Economic Integration

Region Economic integration of countries in the same geographical has increasing roles in reinforcing their sustainable economic growth. One of the strongest trade unions in the world is the European Union (EU) [1]. EU, an international economic group in Europe, has been founded since 1950 with six member countries including Belgium, France, Germany, Luxembourg, Italy, and the Netherlands [27]. Currently, EU has 27 member countries [28]. Total value of Gross Domestic Product (GDP) from EU countries was 16.4 trillion dollars in 2009 (28.3% of the world), which is the top regional economic groups of the world [29]. Canada, the United States and Mexico has established the Free Trade Area since 1994, called North American Free Trade Agreement (NAFTA). The purpose of NAFTA is to reduce barriers for trade and investment among member countries by decreasing the import and export tax, liberating the movement of funds among member countries [30].

In the Southeast Asian Region, the Association of Southeast Asian Nations (ASEAN) has been established since 1967 by five countries namely Indonesia, Malaysia, Philippines, Singapore and Thailand. Currently, ASEAN has ten member countries [31]. The ASEAN countries represent a significant emerging economic group, with a total population of 573 million (8.6% of the world) and a combined GDP almost 1.5 trillion dollars (2.5% of the world) in 2008 [29]. ASEAN has extended negotiations to other countries in Asia. Important negotiations are as follows. ASEAN+3 includes ASEAN countries, China, Japan and Republic of Korea. ASEAN+6 includes ASEAN + 3, Australia, India and New Zealand. ASEAN+6 bundles with a population 3,240 million (48.6% of the world) and a combined GDP almost 13.9 trillion dollars (23.6% of the world) in 2008 represent a big economic group [32]. ASEAN+6 free trade market is viewed as a potential emerging economic group in the world trade.

One important goal of ASEAN is to aggregate economic groups in the region called the ASEAN Economic Community (AEC) in 2015. According to the AEC Blueprint, four characteristics of AEC to be achieved are (1) to be a single market and production base, (2) to be a highly competitive economic region, (3) to be a region of equitable economic development, and (4) to be a region fully integrated into the global economy. These four characteristics are inter-related and mutually reinforcing [2]. From target as AEC, number of trade transaction and international business within ASEAN will be expanding in the future.

Accounting Harmonization

Environment influences accounting, so the variation of country's accounting regulations and practices results the accounting diversity. Harmonization of accounting practices among countries improves the comparability of financial statements. Regional harmonization of accounting is a major means to achieve uniting member countries as a single common market.

Harmonization has been defined in several ways. Reference [8]define it as "the similarity in the frequency of accounting policy choices across countries" and as "the extent of concentration around a particular accounting policy choice". Reference [26] defines as "the process of increasing the consistency and comparability of accounts in order to remove the barriers to the international movement of capital and exchange of information by reducing the differences in accounting and company law". Reference [4, p.36] define as "the process aimed at enhancing the comparability of financial statements produce in different accounting regulations". For the purpose of this study, harmonization is the similarity in the frequency of accounting policy choices across countries [8].

Specifically, accounting harmonization is classified into 2 categories, de jure and de factor harmonization. First, de jure harmonization (or Formal harmonization) is considered the consistency of accounting regulation that has been in force at that time. Second, de facto harmonization (or Material harmonization) is the consistency in accounting practice with focus on financial reporting [33]-[34]. Reference [1] examine the de jure harmonization for adoption of International Financial Reporting Standard (IFRS) in Latin American region. Reference [12] examine the de jure harmonization for adoption of IFRS in South Asia Pacific region: include Papua New Guinea, Fiji, Australia and New Zealand. De jure harmonization is supported by international accounting professional institute via IFRS so accounting harmonization should concentrate on accounting practice. The occurrence of a de jure harmonization among countries does not mean that de facto harmonization will occur among those countries [33]-[34].

Many researchers [6], [8], [33], [35]-[36] measure the degree of accounting harmonization. Reference [33] compares the degree of material measurement harmonization among the United Kingdom, the Netherlands and the United States by statistic method. The researcher takes a measure accounting harmonization within country by H index (Herfindahl index) and between countries by I index. The index value ranges from 0 (no harmony) to 1 (all companies using the same method). Van de Tas index is the widely-accepted for measuring the degree of harmonization. Reference [7] study accounting harmonization practices based on 1991 annual reports from 413 large companies in five countries namely Germany, France, the United Kingdom, Japan and the United States. The degree of harmonization is measured using I index. The findings reveal significant differences in the measurement of accounting for inventory, fixed assets and investment.

Prior harmonization research has concentrated on the EU financial reporting [6], [8], [33], [34], [36]. Reference [6] examined the accounting harmonization of measurement practices in three European Community (EC) countries, namely France, Germany and the UK, based on 1989 annual reports from 26 large industrial companies located in each of the three countries. I and H indexes were used as a measure of the degree of harmonization. They reported relatively low I index indicating significant differences in the measurement practices of inventory valuation, depreciation, research and development costs, goodwill, fixed asset valuation and extraordinary items.

Similarly, Reference [8] examined the degree of harmonization of accounting measurement practices among eight EC Countries, namely Belgium, Denmark, France, Germany, Ireland, the Netherlands, Portugal and the United Kingdom. Their study is based on 1992/93 annual reports from 217 large companies. The degree of harmonization is measured using I index and H index. Their results show a high degree of harmonization in the areas of inventory valuation and foreign currency translation of assets and liabilities, treatment of translation differences, and a low level of harmonization in the areas of fixed asset valuation, depreciation, goodwill, research and development costs, inventory costing and foreign currency translation of revenues and expenses.

Reference [36] examined accounting harmonization of consolidated goodwill and deferred taxation in eight EC countries, namely Belgium, France, Germany, Ireland, the Netherlands, Sweden, Switzerland and the United Kingdom. Their study is based on 1986/87 and 1990/91 annual reports from 89 companies which influenced by international factors. The degree of harmonization was measured using within-country comparability index for measuring harmonization within country and between-country comparability index for between countries. Their results showed a low level of harmonization in two areas of consolidated goodwill and deferred taxation and a little progress of harmonization between 1986/87 and 1990/91.

A few prior studies investigated harmonization in Asia. Reference [5] examine the extent of harmonization of selected accounting measurement practices in three countries of South Asia, namely India, Pakistan and Bangladesh. The study is based on 1997/8 annual report from 566 non-financial companies. The degree of harmonization is measured using I index and modified C index. Their study show a relatively higher degree of harmonization in the areas of property, plant and equipment, foreign currency translation and long-term investment, and a lower level of harmonization in the areas of inventory, amortization of goodwill and leases.

Reference [9] examined corporate annual report disclosure practices both de jure harmonization and de facto harmonization among five ASEAN countries, namely Indonesia, Malaysia, the Philippines, Singapore and Thailand. The sample was based on 1993 annual reports from 145 public companies listed on ASEAN stock exchanges. The degree of harmonization was measured using disclosure index. This result showed a high degree of de jure disclosure harmony in ASEAN since International Accounting Standard Committee (IASC) has sanctioned accounting standard setting processes on national accounting standards. The study found distinction de facto, a significant variation in actual disclosure levels among five countries because of the national environment difference.

3. RESEARCH METHODOLOGY

This study focuses on material harmonization (de facto), which measures corporate accounting practices in each country, namely Indonesia (ID), Malaysia (MY), Philippines (PH), Singapore (SG) and Thailand (TH) as well as among those five countries of AEC. The areas of measurements harmonization of interest are examined two measurement practices includes property, plant and equipment and inventory. The categories of alternative accounting methods are based on the actual wording contained in the company annual reports.

Data selection

The data are collected from annual reports available during fiscal year 2008/09. The sample embodies 150 annual reports from Indonesia, Malaysia, Philippines, Singapore and Thailand. Thirty listed companies were randomly selected from each main national stock exchange.

The annual reports are obtained from the Indonesia Stock Exchange (http://www.idx.co.id) [36], the Bursa Malaysia Berhad (http://www.klse.com.my) [37], the Philippine Stock Exchange (http://www.pse.com.ph)[38], the Singapore Exchange and the Securities (http://www.sgx.com) [39], and Thai Securities and Exchange Commission (http://www.sec.or.th) [40]. The sample represents 14, 4, 12, 4 and 6 percent of the total listed companies in Indonesia, Malaysia, Philippines, Singapore and Thailand, respectively.

Measurement of Variables

To measure degree of national accounting harmonization the Herfindahl (H) index by Van der Tas (1988) and within-country comparability index (C_w) by Archer et al (1995) are used. For the measurement degree of regional accounting harmonization is using the I index by Van der Tas (1988) and between-country comparability index (C_b) by Archer et al (1995).

The general formula of the H index by Van der Tas (1988) is as follows:

$$H = \sum_{i=1}^{n} p_i^2 \qquad (1)$$

where:

H = the Herfindahl index

p_i = the relative frequency of accounting method i

n = the number of alternative accounting methods

The general formula of I index by Van der Tas (1988) is as follows:

$$I = \left(\sum_{i=1}^{n} (f_i^1 \times f_i^2 \times \ldots\ldots \times f_i^m) \right)^{1/(m-1)} \qquad (2)$$

where:

I = the I index

f_i = the relative frequency of accounting method i in country m

m = the number of countries.

n = the number of alternative accounting methods

The general formula of the C_w index by Archer et al. (1995) is as follows:

$$C_w = \frac{\left(\sum_i \sum_j (x_{ij}(x_{ij}-1))\right)}{\left(\sum_i (x_{i+}(x_{i+}-1))\right)} \quad (3)$$

where:

C_w = the within-country comparability index

x_{ij} = the number of companies in country i using accounting method j

x_{i+} = the total number of companies in all countries using method j

The general formula of the C_b index by Archer et al. (1995) is as follows:

$$C_b = \frac{\left(\sum_i \sum_j (x_{ij}(x_{+j}-x_{ij}))\right)}{\left(\sum_i (x_{i+}(x_{++}-x_{i+}))\right)} \quad (4)$$

where:

C_b = the between-country comparability index

x_{+j} = the number of companies in all countries using method j

x_{++} = the total number of companies across countries

The values of the H, the I, the C_b and the C_w indices range from 0 (indicating no harmony, with an infinite number of alternative methods all with the same frequency) to 1 or 100% (all apply the same accounting method). The Chi-square (χ^2) tests are employed to assess whether the pattern of measurement practices is significantly different across the five AEC Countries.

4. RESULTS

Valuation of Property, Plant and Equipment

International Accounting Standard Number 16 (IAS 16) property, plant and equipment, amended effective 2009, prescribes that property, plant and equipment should initially be recorded at cost. Cost would include its original purchase price, costs of site preparation, delivery and handling, installation, related professional fees for architects and engineers and the estimated cost of dismantling and removing the asset and restoring the site [42].

For subsequent measurement, IAS 16 permits two accounting models for after initial recognition including cost model and revaluation model. According to the cost model, property, plant and equipment is presented at cost less accumulated depreciation and impairment. Under the revaluation model, property, plant and equipment is presented at a revalued amount less subsequent accumulated depreciation and impairment [42]. The valuation practices of property, plant and equipment methods are reported in Table 1.

Table 1. Valuation Practices of PPE

Methods	ID	MY	PH	SG	TH	Total
Cost model	30	25	30	27	26	138
Other	0	5	0	3	4	12
Total	30	30	30	30	30	150
H index	1.0000	0.7222	1.0000	0.8200	0.7689	
C_w index	100.00	71.26%	100.00	81.38	76.09	
I index = 0.8979,						
C_b index = 84.04% , χ^2 = 9.6 , p-value = 0.048						

From Table 1, the cost model is the most popular method for the valuation of property, plant and equipment in all five countries (92 %), while a limited number of companies use the revaluation model (4 %). The cost model is the majority method used in Indonesia (100 %), Malaysia (83 %), Philippines (100 %), Singapore (90 %) and Thailand (87 %). The measurement degree of national accounting harmonization is relatively high in Indonesia and Philippines. The I index value of 0.8979 suggests that an 89.79 per cent level of harmony exists among the five countries on the issue of the valuation of property, plant and equipment. The I index produce similar results with the C_b index, which presents a higher level of harmony of the valuation of property, plant and equipment. The χ^2 statistic is significant, which indicates that there is significant difference in the use of valuation methods among the five South East Asia countries. After excluding Indonesia and Philippines, the χ^2 statistic is insignificant (χ^2 = 0.57, p-value = 0.749), which indicates that there is no significant difference in the use of valuation methods among Malaysia, Singapore and Thailand.

Depreciation of Property, Plant and Equipment

IAS 16 prescribes guidance on depreciation for property, plant, and equipment. The standard requires that companies should allocate the depreciable amount of property, plant, and equipment on a systematic basis over its useful life. The companies should apply depreciation method which reflects the pattern of consumption of economic benefits and should review at least annually [42]. The depreciation practices of property, plant and equipment methods are investigated, which are reported in Table 2.

Table 2. Depreciation of PPE

Methods	ID	MY	PH	SG	TH	Total
Straight line	27	30	30	29	30	146
Other	3	0	0	0	0	3
Total	30	30	30	29	30	149
H index	0.82	1.0000	1.0000	1.0000	1.0000	
C_w index	81.38	100.00	100.00	100.00	100.00	
I index = 0.9740, C_b index = 95.98% , χ^2 = 12.14 , p-value = 0.016						

Form Table 2, the straight-line depreciation is the most popular (98 %) method in all five countries, while a less number (2 %) of companies uses other methods. The straight-line depreciation is the majority method in Indonesia (90 %), Malaysia (100 %), Philippines (100 %), Singapore (100 %) and Thailand (100 %). Only 3 companies in Indonesia adopted a combination of the straight line and the reducing balance methods.

The measurement degree of national accounting harmonization is absolutely high in Malaysia, Philippines, Singapore and Thailand. The I index (0.9740) shows that the harmony level is 97.40 per cent, the results suggest a higher level of harmony with depreciation of property, plant and equipment practices in these countries. The C_b index (95.98 %) produce similar results with the I index. The χ^2 statistic is significant (12.14), which indicates that there is a significant difference in the use of depreciation methods in the five South East Asia countries (p value < 0.05). The use of depreciation methods is not significant difference among Malaysia, Philippines, Singapore and Thailand.

Inventory Valuation

IAS 2 Inventories, revised effective 2005, prescribes that inventories required being valued at the lower of cost and net realizable value (NRV) [43]. The investigated of inventory valuation method are reported in Table 3.

Table 3. Inventory Valuation Practices

Methods	ID	MY	PH	SG	TH	Total
Lower of cost or	21	29	19	22	24	115
Other	0	0	0	0	0	0
Total	21	29	19	22	24	115
H index	1.0000	1.0000	1.0000	1.0000	1.0000	
C_w index	100.00	100.00	100.00	100.00	100.00	
I index = 1.0000, C_b index = 100.00%						

Form Table 3, the lower of cost or net realizable value (NRV) is the only method adopted in all five countries (100 %). All of companies in the five South East Asia countries apply the same accounting method. The I index for the inventory valuation is absolutely high (1.00), which similarly suggests the highest level of harmony. The results for the C_b index (100 %) are consistent with to the index value.

Inventory Costing Methods

IAS 2 prescribes measurement of inventories. The standard permits companies to adopt four inventory costing method includes: the standard cost and retail methods, the specific cost, the first-in first-out (FIFO) and the weighted average costs. The standard cost and retail methods may be used for the measurement of inventories which the results approximate actual cost. The inventory cost should be determined on a specific cost for no interchangeable goods. For inventory items that are interchangeable, IAS 2 allows the FIFO or weighted average cost methods. The last-in first-out (LIFO) methods is not under IAS 2. [43]. The inventory costing methods are investigated, which are reported in Table 4.

Table 4. Inventory Costing Method

Methods	ID	MY	PH	SG	TH	Total
Specific	5	3	0	0	2	10
FIFO	3	10	0	8	3	24
Average	8	10	2	11	10	41
Other	4	7	2	2	3	18
Total	20	30	3	21	18	52
H index	0.2850	0.2985	0.3469	0.4286	0.3765	
C_w index	24.74	27.25	23.81	40.00	33.99	
I index = 0.3382, C_b index = 30.27%, $\chi 2$ = 24.08 , p-value = 0.0200						

Form Table 4, the average method includes weighted average, moving average and average methods. The average method is the most popular method (44 %) in all five countries following by the FIFO method (27 %). The average method is still popular in Indonesia (40 %), Malaysia (36 %), Singapore (52 %) and Thailand (56 %). The measurement degree of national accounting harmonization is low in all five countries. The I index for the inventory valuation is comparatively low (0.3367), which similarly suggests a low level of harmony. The results for the C_b index (30.27 %) are also similar to the I index value. The χ^2 statistic (24.08) supports the position that there are significant differences in the inventory costing methods among companies in the five South East Asia countries.

5. CONCLUSION

The purpose of this study is to examine accounting and reporting practices in five AEC countries, namely Indonesia, Malaysia, Philippines, Singapore and Thailand, with reference to the harmonization of property, plant and equipment and inventory measurement practices. The data were collected from 150 listed companies' annual reports for the year 2009/10 including 30 companies randomly selected from each country. This study used I index and C_b index to examine the differences for measuring the harmony level across countries. The study also used χ^2 statistics to examine whether significant differences exist in the measurement of accounting practices across AEC countries. A summary of the I index, the C_b index and χ^2 statistics with associated significance levels is given in Table 5.

Table 5. Summary

	Measurement Practices	I	C_b index	χ^2
1	PPE	0.8979	85.04%	9.60*
2	Depreciation methods	0.9740	95.98%	12.14*
3	Inventory valuation	1.0000	100.00%	
4	Inventory costing method	0.3382	30.27%	24.08*

*Significant at 0.05 levels.

The results show a high degree of harmonization exists in the treatment of inventory valuation. A relatively high degree of harmonization exists in the treatment of valuation model and depreciation methods for property, plant and equipment respectively. However, a lower level of harmonization is found in the treatment of inventory costing methods. The χ^2 statistics of three measurements are statistically significant, suggesting the existence of significant differences in accounting measurement treatments across five countries. For only the treatment of inventory valuation, there is a not significant difference in accounting measurement treatments across five countries.

The results of this study should be compared to prior research. The high degree of harmonization of valuation model for property, plant and equipment is consistent with [5] and [6]. In contrast, Reference [8] have identified a low level of harmonization in the areas of fixed asset valuation. The high degree of harmonization of depreciation methods for property, plant and equipment is consistent with [8] in case of study excludes Germany. Moreover [5] and [6] have identified a low level of harmonization in the areas of depreciation method. The high degree of harmonization of inventory valuation is consistent with [8]. Moreover [5] and [6] have identified a middle level of harmonization in the areas of inventory valuation. The low degree of harmonization of inventory costing methods is consistent with [8] and [5].

Consistently, Reference [9] has identified a high degree of de jure disclosure harmony in ASEAN since International Accounting Standard Committee (IASC) sanctioned. The study found distinction de facto, a significant variation in actual disclosure levels because of the national environment difference. Until now this study shows a high degree of de facto harmony in AEC countries. Environmental factors knowingly influence adoption of accounting treatments across AEC countries, so the variation of accounting regulations and practices in each AEC countries results in the differences in financial statements. Surprisingly, accounting diversity in AEC countries is low relatively to the evidence of the high degrees of harmonization from prior research.

Regional harmonization in AEC countries is achieved because most of AEC companies use the same accounting measurement method. For investment decision making perspective, a high degree of harmonization of accounting practices among AEC countries improves the comparability of financial statements, as financial statements become more useful to understand and interpret. Investors can understand accounting information from other member countries in order to make well informed financing and investing decision across domestic borders. The results are subject to limitations. First, the results of this study are based on small sample size. The second is the limitations of the indices. This study investigates by two measurement practice across five AEC countries. Further research should extent to investigate the degree of harmonization measurement practices. The future study may consider the degree of harmonization to cover ten member countries in AEC.

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Structure and Carbon Storage in Aboveground Biomass of Mixed Deciduous Forest in Western Region, Thailand

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Abstract— *Thisstudy focuses on the structure and carbon storage in aboveground biomass of mixed deciduous forest (MDF), located in Mae Nam Phachi Wildlife Sanctuary,Ratchaburi Province, Thailand. Experimental plots were set to obtain the structure and aboveground biomass of tree, sapling and bamboo. Allometric equations were used to estimate aboveground biomass of these vegetation types, while seedling, leaf litter, twig and understory were investigated using direct harvesting method. Carbon storage in aboveground biomass was calculated following the IPCC 2006guidelinesfor national greenhouse gas inventory methodology. The obtained resultsindicated that the dominant species of tree stand in MDF are composed of Vitexcanescens, Brideliatomentosa, Xyliaxylocarpa, Largerstroemiacalyxcolata, and Dalbergia cultrate,which have the Important Value Index (IVI)of26.0, 18.85, 11.83, 11.56, and 11.04, respectively. Bamboo has the highestrelative IVIof 43.45, and it was found that the Thyrostachyssimensis is the dominant bamboo species in the area. The number of tree individuals and sapling are 450 ± 218 and 383 ± 225 individuals/ha, respectively, a nd bamboo is 15,342 ± 1,903 culms/ha. The abovegrou nd biomass and associated carbon stock obtained from this study are 77.539± 55.161 tons/ha and 36.44± 25.93 tons C/ha, respectively.*

Keywords— **Mixed deciduous forest, above-ground biomass, carbon stock, Ratchaburi, Thailand.**

1. INTRODUCTION

The western region in Thailand is composed of Tak, Kanchanburi, Ratchaburi, Petchaburi and PrachuapKhiri Khan Provinces, which coversa total area of 53679.018 km^2. The area of mixed deciduous forest (MDF) in this regionrepresents20.01% or 17,501.6 km^2 of natural forest area in Thailand [1]. MDF in Thailand isclassified into three sub-types including upper moist, upper dry and lower dry mixed deciduous forests [2]. In Kanchanaburi province, MDF is composed of these three main sub-typeswith bamboo and bamboo forests. It was stated that the forest type separation of each site depend on the vegetation structure and composition, topography, altitude, and disturbance. These parameters influence the variation of carbon stock in aboveground biomass of each area.Knowledge on the vegetation structure in different types of forest is useful to better understand the carbon storage, carbon sink and source mechanisms or processes.

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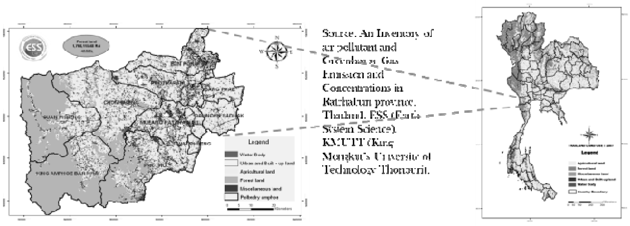
Also, it was found that MDF has high capacity of carbon sink [3, 4]. In this type of forest, capture of carbon dioxide through photosynthesis ranged about 1-2 kg/m^2 [5]. In 2006, FAO reported that the estimation of carbon stock in tropical forest is about 638Gt in the year 2005. The diameter at breast height (DBH) of tree stands around 20-40 cm is considered asrepresenting the stage of the highest capacity to sink carbon via photosynthesis process [3].However, a forest is variable in structure, which constitutes one of the main parameters in determining the amount of aboveground biomass. The rural human activities,such as the gathering of non-timber forest product (i.e. mushrooms, edible plants, fuel wood), to facilitate hunting and agricultural debris elimination are the principal causesof land use change, and so vegetation structure modification. In addition, MDF is the main type of tropical deciduous forest, and frequently subject to wildfires during dry season with sufficiently large amount of biomass fuel loads on the ground cover. In 2000, wildfires in MDF represented about 70% of the total area of forest fire occurrence in Thailand [6]. The high frequency of wildfires can drastically modify the structure and composition of aboveground biomass,and so play an important role in carbon cycle in ecosystem [7, 8]. Generally, this type of forest is located at an altitude from 50-1,000 m above sea level, with precipitation not exceeding 1,200 mm per year, and the period of drought should not be more than 4 months. During dry season (from December to April), the tree stand shed their leaves leading to accumulation of biomass on the ground cover, which served as fuel for forest burning. Wildfiresinfluence the structure and ecosystem because it can burn the seedling with diameter at root collar less than one centimeter completely [9]. Moreover, they affect the soil properties and respiration processes, as well as its nutrient dynamics [10].

However, data on vegetation structure and carbon storage in aboveground biomass of the MDF are still limited, and the existing information does not cover all regions of Thailand. In this study, the MDF in Ratchaburi province was investigated, and the obtained results from field experiments were then presented and discussed.

2. MATERIALS AND METHODS

Studysite

The study site was set up in a natural mixed deciduous forest in Mae Nam Phachi Wildlife Sanctuary Ratchaburi province(13°32′ N – 13°54′N latitude and 99°49′ E – 99°82′E longitude) (Fig. 1.), located in Baan Beung, Suan Pheung District, Ratchaburi province, about 210 km west of Bangkok, the capital of Thailand. It covers atotal area of 489 km^2,and includesdry dipterocarp forest, mixed deciduous forest, tropical rain forest and pure stand bamboo forest. The altitude of the highest mountain peak areas located in the western part of the province, i.e. Suan Pueng district, Khing Amphoe Ban Kha, and Park Tho district, close to the border of the country with Myanmar. The altitude ofthe study area ranges from 200 to 1,400 m asl. It has been considered as "the rain shadow zone" since most of the rain is blocked by the Tanowsri Mountain Chain. The average total rainfall of 959 – 1,285 mm and mean temperature of 28°Care observed during the year, based on data ofRatchaburi's meteorological station during2005 to 2008. The highest temperature during dry season, especially in April, situates between 30.3 – 31.3°C. December corresponds to the coolest month with temperatures interval of 24.5 – 26.9°C. January represents the driest month with only less than 6.5 mm rainfall, and October the wettestmonth, withrainfall level of 117 to 441 mm.



Source:An Inventory of air pollutant and Greenhouse Gas Emission and Concentrations inRatchaburi province, Thailand, ESS (Earth System Science), KMUTT (King Mongkut'sUniversity of Technology Thonburi).

Fig.1. Field experiment study site inRatchaburi province, Thailand

Plot Set Up

The study site was located in a mixed deciduous forest (MDF) of the Mae Nam Phachi Wildlife Sanctuary,Ratchaburi Province, ThailandThree study plots were setup at a terrain with slope <20%. Each plot has a size of 40 m × 40 m. The number of individuals and associate aboveground biomass of tree at DBH>4.5 cmand bamboo were collected in the sub-plot of 20 m × 20 msize located at the left corner of the main 40 m × 40 m plot, while sapling of DBH< 4.5, and height > 1.3 m were from foursub-plotsof 10 m × 10 m size. The data on seedling with total height lesser than 1.3 m, other understory (grass, herb, shrub, climber) and litter (both leaf and small twig) were collected from four 1 m × 1 m subplots (Fig. 2).

Qualitative and Quantitative Analysis of Vegetation

All species of vegetation in the study plot were recorded. For each species, general information of forest vegetation including plantfamily, scientific name, as well as common name, were logged. Theoretically, the evolutioncharacteristics of trees, shrub, ivy, etc., differ by the growth patterns and vegetative individual composition. The differences rely not only in the growth dynamic pattern but also in the variation of environment parameters suitable to each plant species. Information on species and its evolution pattern is useful to better understandthe plant growth and species density influencing the amount of above-ground biomass and biomass fuels during forest fires.

The structure of the MDF was quantitatively characterized by investigating the Important Value Index (IVI) of the plant species. The parameters quantified in relative IVI are relative density, frequency, and dominance, of plant species.

The important value index (IVI) of vegetation structure was obtained based on equation of Curtis, 1959 as

$$IVI = relative\ density + relative\ frequency + relative\ domina \quad (1)$$

where

$$Relative\ Density = \frac{Number\ of\ individual\ of\ the\ species\ i}{Number\ of\ individual\ of\ all\ the\ species} \times 100$$

$$Relatvie\ Frequency = \frac{Number\ of\ occurrence\ of\ the\ species\ i}{Number\ of\ occurrence\ of\ all\ the\ species} \times 100$$

$$Relative\ Dominace = \frac{Total\ basal\ area\ of\ the\ species\ i}{Total\ basal\ area\ of\ all\ the\ species} \times 100$$

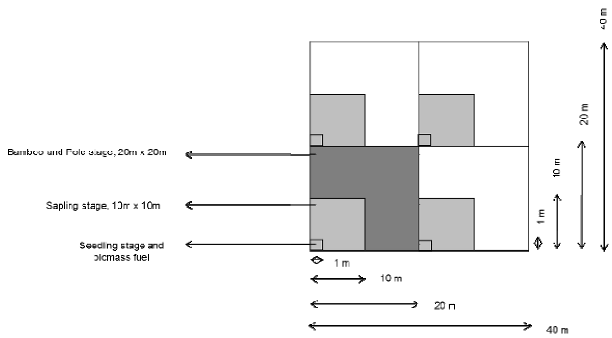


Fig.2. Plot set up for aboveground biomass estimation in MDF at the study site in Ratchaburi province, Thailand

Estimation of Above Ground Biomass and Carbon Stock

DBH and total height were recorded for all tree, sapling and bamboo.Above-ground tree biomass was estimated using the allometric equation from [11], and defined in (2). The estimation of aboveground sapling biomass and above-ground bamboo biomass (*T. siamensis*) were obtained from the allometric equations from [12] and [13], and indicated in (3) and (4), respectively.

$$W_s = 0.0396\, D^2 H^{0.9326}$$
$$W_b = 0.003487\, D^2 H^{1.0270} \quad (2)$$
$$W_l = \left(\frac{28.0}{W_{tc}} + 0.025\right)^{-1}$$

$$W_s = 0.0893059\, D^2 H^{0.66513}$$
$$W_b = 0.0153063\, D^2 H^{0.58255} \quad (3)$$
$$W_l = 0.0000140\, D^2 H^{0.44363}$$

where:
D is the diameter at breast height [cm],
H is the height of tree stand [m],
W_s is the mass of stem [kg],
W_b is the mass of branch [kg],
W_l is the mass of leaf [kg],
W_{tc} is the total mass of stem and branch [kg],

$$W_c = 0.0691512\, D^2 H^{0.7930}$$
$$W_t = 0.0883689\, D^2 H^{0.7703} \quad (4)$$
$$W_{b+l} = W_t - W_c$$

where:
D is the diameter at breast height [cm],
H is the height of culm [m],
W_c is the mass of culm [kg],
W_t is the total mass of culm, branch and leaf [kg],
$W_{b+l}$is the total mass of branch and leaf [kg],

The understory fuel biomass including seedling, grass, shrub, climber, herb and litter (leaf and twig) was determined directly using gravimetric method, consisting in measuring the fresh weight of the biomass just after its cut. Then, samples were oven-dried at 70 °C for at least 48 h, and weighted again to determine the fuel moisture content and the dry weight. The total dry weight of biomass fuel as live and dead parts were converted from fresh weight and dry weight ratios from the sampling area based on (5).

$$Total\ \ DW\ \ (kg\ \ m^2) = \frac{Total\ \ FW\ \ (kg) \times Subsample\ \ DW\ \ (g)}{Subsample\ \ FW\ \ (g) \times Sample\ \ area\ (m^2)} \quad (5)$$

The carbon stock in the aboveground biomass was calculated based on the IPCC 2006 guidelines for national greenhouse gas inventory by multiplying the 0.47 conversion factor to the biomass [14].

Table 1. The Structure (Abundance, Basal Area (BA), Relative Frequency (RF), Relative Density (RDen), Relative Dominance (RDo), and Ecologiacl Important Value Index (IVI) of Vegetation Plant in MDF Plots Located in the Phachi River Wildlife SanctuayRatchaburi Province, Thailand.

Species	Abundance (indiv./ha)	BA (m^2/ha)	RF	Rden	Rdo	IVI
Thyrsostachys siamensis	15,342	6.8966	8.550	97.202	24.592	130.343
Vitex canescens	75	6.4477	2.850	0.158	22.991	25.999
Bridelia tomentosa	25	8.9419	2.850	0.053	15.942	18.845
Xylia xylocarpa	50	4.9757	2.850	0.106	8.871	11.827
Lagerstroemia calyxcolata	50	1.5844	5.700	0.211	5.650	11.561
Dalbergia cultrata	33	0.4251	8.550	0.211	2.274	11.035
Millettia brandisiang	63	0.9729	5.700	0.264	3.469	9.433
Bauhinia saccoclyx	50	0.8505	5.700	0.211	3.033	8.944
Lannea coromandelica	38	0.6889	5.700	0.158	2.456	8.315
Vitex peduncularis	50	0.4077	5.700	0.211	1.454	7.365
Stereospermum neuranthum	25	0.0784	5.700	0.106	0.279	6.085
Terminalia pierrei	50	0.7923	2.850	0.106	1.413	4.368
Bombax anceps	13	0.6832	2.850	0.053	1.218	4.121
Gratoxylum formosum	25	0.6707	2.850	0.053	1.196	4.098
Heterophragma adenophyllum	25	0.5014	2.850	0.053	0.894	3.797
Xanthophyllum lanceatum	75	0.4233	2.850	0.158	0.755	3.763
Atalantia monopylla	25	0.4210	2.850	0.053	0.751	3.653
Bauhinia variegata	25	0.3887	2.850	0.053	0.693	3.596
Pterocarpus macrocarpus	75	0.2349	2.850	0.158	0.419	3.427
Diospyros castanea	25	0.2437	2.850	0.053	0.435	3.337
Bauhinia glauca	50	0.1823	2.850	0.106	0.325	3.281
Croton oblongifolius	25	0.1408	2.850	0.053	0.251	3.154
Terminaria triptera	25	0.1165	2.850	0.053	0.208	3.110
Lagerstroemia loudonii	25	0.1052	2.850	0.053	0.188	3.090
Shorea obtusa	25	0.0733	2.850	0.053	0.131	3.034
Arfeuilea arborescens	25	0.0645	0.251	0.053	0.115	0.419
Total	**16,354**	**37.7747**	**100**	**100**	**100**	**300**

Table 2. The vegetation density,diameter at breast height (DBH)andheight (Ht) in the study site

Vegetation Category	Density	DBH (cm)			Ht (m)		
		mean	range	SD	mean	range	SD
Tree	450 ±218 individuals/ha	11.13	4.77-38.20	5.65	10.53	9.25-24.30	4.23
Sapling	383 ± 225 individuals/ha	3.02	0.57-4.20	0.85	4.23	1.30-7.80	1.37
Bamboo	15,342 ± 1,903 culms/ha	2.44	1.29-5.87	0.48	7.43	2.00-21.70	2.36

3. RESUTLS AND DISCUSSION

Structure of the studied Mixed Deciduous Forest

The vegetation of the studied MDF was composed of 14 families, 21 genus, and 26 species. The family of Fabaceae was the dominant family, and included 7 species which constituted the highest species distribution in the area (Fig.3.). Another dominant family was the family of Gramineae. This result is in good agreement with the other studies related to MDF, which found that the dominant family in MDF in the western region of Thailand consists in Fabaceae and Gramineaespecies [15].

Species with more than 50 individuals per hectare were *Milletiabrandisiang, Pterocarpusmacrocarpus, T. siamensis, Xanthophyllumlanceatum* and *Vitexcanescens* (Table 1.). In addition, *Brideliatomentosa* covered 23.672% of the total basal area, followed by *T. siamensis, V. carnescens, Xyliaxylocarpa,* and *Largerstroemiacalyxcomata*.

Fig.3. Mixed Deciduous Forest at this Study Area

The bamboo (*T. siamensis*) scored the highest IVI (130.343), followed by *V. canescens, Brideliatomentosa, X. xylocarpa, L. calyxcolata, and Dalbergiacultrata*, respectively (Table 1). Based on the IVI results, it was found that these species constitute the dominant species of the MDF in this area. Other species than these six had always an IVI lower than 10 (Table1).

It should be noted from [15, 16] that for the MDF in Kanchanaburi province, the *P.macrocarpus*was observed as the dominant species with an IVI of 34.40, followed by*X. xylocarpa* with 26.82, *Schleicheraoleosa* with 25.18, *Holarrhenapubescens* with 24.30, and *Berryacordifolia* with 19.62, respectively. Moreover, there were two dominant families of bamboo in Kanchanaburiprovince, including species such as *Bambusatulda, Gigantochloaalbaciliata, G. hasskaliana* and *Cephalostachyumpergracile*. Actually, the dominance of tree and bamboo species in MDF in the western region varies with the topography, weather conditions (e.g. amount of precipitation related to the rain shadow area of our study),altitude, and disturbances including forest fires in particular.

Diameter at Breast Height (DBH), Height (Ht), and Basal Area(BA) Distributionof the Studied MDF Vegetation

Table 2 displays the data of DBH and Ht obtained for the studied MDF.

The number of individual trees, sapling and *bamboo*were 450 ± 218individuals/ha, 383 ± 225 and 15,342 ± 1,903 culms/ha, respectively (Table 2). This result showed that this area had a high variation of vegetation composition. The mean DBH of tree, sapling and bamboo stem were 11.3, 3.02 and 2.44 cm, respectively. The mean height (Ht) of tree, sapling and bamboo stemwere10.53, 4.23 and 7.43 m, respectively (Table 2). The DBH distributions showed higher number of individuals of small size classes (4.5-20 cm), resulting in a small basal area as indicated in Table 1.Tree stands with DBH in the range of 20-40 cm are considered as having the highest capacity to sink carbon via photosynthesis process [4].

The DBHand Ht of each vegetation category from Table 2were used to estimate the above-ground biomass using the allometric equation (2) and (3).

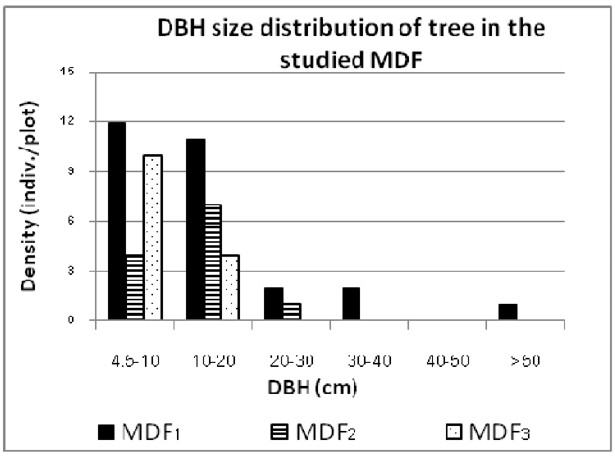


Fig.4. Tree DBH Distribution in MDF Plots

Above-Ground Biomass of Trees

The above-ground biomass of tree and sapling were estimated from 3 parts, i.e. stem, branch and leaf masses, of which the weights were 22.850 ± 18.095, 2.520 ± 2.006, and 0.477 ± 0.550 tons/ha, respectively (Table 3). The total above-ground biomass of tree was therefore25.847 ± 20.651 tons/ha.

In addition, it could be expected that the vegetation in this area should have an important potential of carbon sequestration, since trees were still young, and so should grow up to reach the adult size. In order to evaluate the future capacity of vegetation in carbon capture, the gross and net primary production should be estimated.

Above-Ground Biomass of Bamboo

The results showed that the *T. siamensis*was the major bamboo speciesin this study area. The density of *T. siamensis*was 15,342 ± 1,903 culms/ha, of which theDBH and Ht ranged from 1.29-5.87 cm and 2.00-21.70 m, respectively. The number of clumps were59 ± 32 clumps per plot, and each clump wascomposed of 12 ± 4 culms. The total aboveground biomass of *T. siamensis*was42.606±30.345 tons/ha, including 34.981 ± 25.148 tons/ha of culm, and 7.625 ± 5.197 tons/ha of branch plus leaf (Table 3).

Above-Ground Biomass of Understory and Litter

The understory vegetation was composed of seedling, herb, climber, and grass. The height of seedling was the highest, followed by that of herb, climber and grass, respectively. Their height varies with the structure and composition of living and dead vegetation types. The litter was consisted in leaf and small twigs, with about 4-6 and 1-4 cm depths, respectively. The ground was almost covered by bamboo leaves.

Carbon Stock of Above-Ground Biomass

The obtained above-ground biomass in this study resulted in a carbon stock of 36.44 ± 25.93 tons C/ha, which is of the same order of magnitude as those found in previous studies [3, 17, 20-22]. The comparison of the obtained above-ground biomass and carbon stock with those from literature is summarized in Table 4. For all, the conversion factor of 0.47, which represents an average value of carbon content in biomass, was used following the IPCC 2006 guidelines [13]. From Table 4, it should be noted that the carbon stock resulted from this study is significantly lower than those found in [11] and [19]. This result confirmed the important role of forest structure and vegetation species composition in influencing the amount of above-ground biomass and the associate carbon stock.

Table 3. The Above-Ground Biomass (AGB) of Different Vegetation Categoriesin MDF

Category	Sub-category	AGB (tons/ha)
Tree	Stem	22.850 ± 18.095
	Branch	2.520 ± 2.006
	Leaf	0.477 ± 0.550
Sapling	Stem	0.491 ± 0.021
	Branch	0.075 ± 0.004
	Leaf	<0.0001
Bamboo	Culm	34.981 ± 25.148
	Branch and leaf	7.625 ± 5.197
Biomass fuel	Understory	0.110 ± 0.060
	Litter	6.150 ± 2.640
	Small Twig	2.160 ± 1.440
Total AGB, ton/ha		77.539 ± 55.161

Another important parameter in varying the amount of above-ground biomass is the age of the forest. From Table 4, it could be indicated that the MDF in this study corresponds likely to a secondary MDF, whose carbon stock never exceeds 50 tons C/ha. This finding is plausible, since the studied MDF was frequently disturbed by rural communities, consisting in setting fires to facilitate their activities (e.g. gathering of non-timber forest product, preparation for hunting, etc.).To this parameter, should be added the influence of the topography, altitude, ecological structure of the vegetation, and the vegetative composition.

4. CONCLUSION

Thestructure of the MDF investigated in this study is composed of 14 families, 21 genus, and 26 species. *T. siamensis*is the most important species in Mae Nam Phachi Wildlife Sanctuary, Ratchaburi Province, Thailand. The results of DBH, Ht and density of vegetation showed that the forest area is mainly constituted of young trees, which is very characteristic of

Table 4.Above Ground Biomass (AGB) and deduced Carbon Storage of Mixed Deciduous Forest in Thailand

Study site	AGB (tons/ha)	C-stock (tons C/ha)	Ref.
Ratchaburi Province	77.54± 55.16	36.44± 25.93	This study
Kanchanaburi Province	68.52 ± 48.36 158.68	34.26 ± 24.18 74.58	[17] [19]
Kanchanaburi Province	96.28 ± 33.44	45.28 ± 15.72	[3]
Chaingmai Province	311 49.63 49.60	146.17 23.33 20.49	[11] [20] [21]
Lampang Province	57.50	27.03	[21]
Phetchabun Province	104.59[a] 50.95[b]	49.16 23.95	[22]

[a, b] primary and secondary mixed deciduous forest

a secondary forest. Additionally, the above-ground biomass includes high density of bamboo and about 50% of tree stands. The total carbon stock of the above-ground biomass in this study (i.e. tree, sapling, bamboo and biomass fuel as leaf litter, twig, seedling and understory as climber, grass, herb) amounts 36.44 ± 25.93 tons C/ha.

ACKNOWLEDGEMENT

This study was financially support by The Joint Graduate School of Energy and Environment, King Mongkut's University of Technology Thonburi, and Center of Excellence on Energy Technology and Environment (CEE-PERDO), Ministry of Education Thailand. This work is part of the National Research University Program on Energy and Environment, King Mongkut's University of Technology Thonburi.

The authors would like to express their gratitude to all staff of the Ratchaburi Forest Fire Control Station, and students of the Department of Silviculture, Faculty of Forestry, Kasetsart University, Thailand, for their field work assistance. Special thanks are extended to every member of the Aerosols from Biomass Burning to the Atmosphere (ABBA) research group at The Joint Graduate School of Energy and Environment, King Mongkut's University of Technology Thonburi.

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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).

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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.

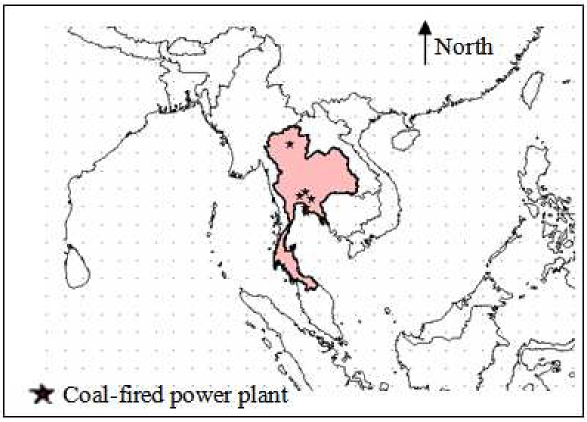


Fig. 1: Location of coal-fired power plants included in this work.

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)

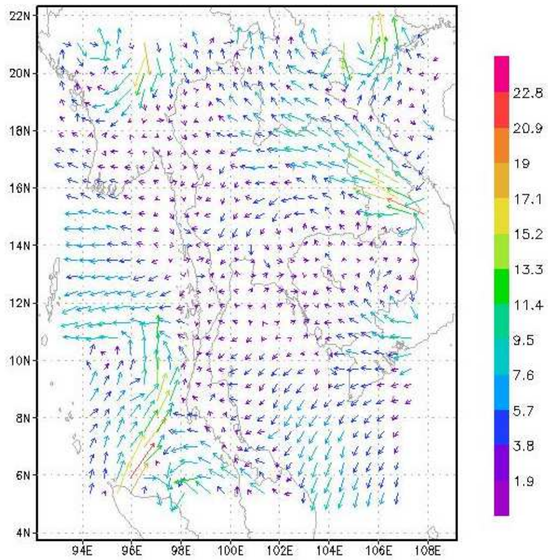


Fig. 2: Wind speed and wind direction in a) April, 2010

b)

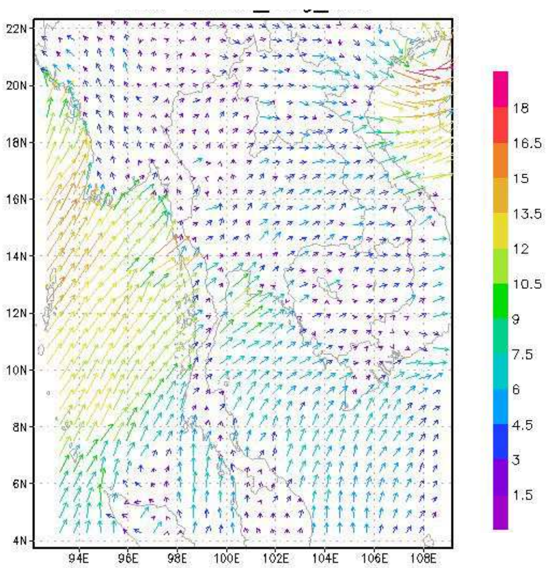


Fig. 2: Wind speed and wind direction in b) August, 2010.

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)

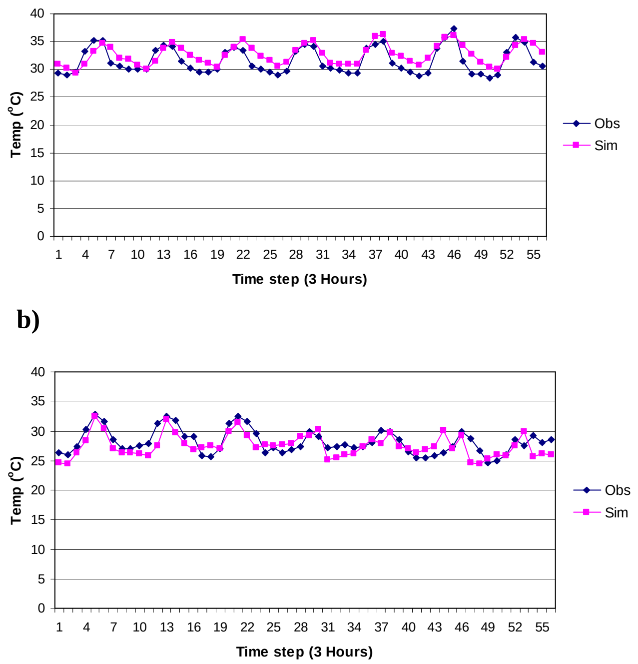


Fig. 3: Comparison of ground temperature between observation and simulation during 2^{nd} week of a) April, 2010 and b) August, 2010.

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)

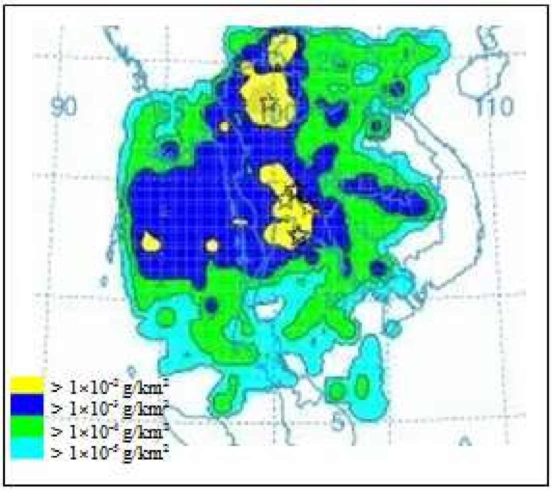
Power plants #Fuel	Dep^T	Dep (Hg^0)	Dep (Hg^{2+})	Dep (Hg^P)
EGAT#Lignite	1,212	138	1,053	21
IPP#Coal	487	35	443	9
SPP1#Lignite	172	24	143	5
SPP2#Coal	128	18	106	3
SPP3#Coal	73	9	62	2
SPP4#Coal	22	2	20	1
SPP5#Coal	8	1	8	-ᵇ
Total	2,102	226	1,836	40

-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)

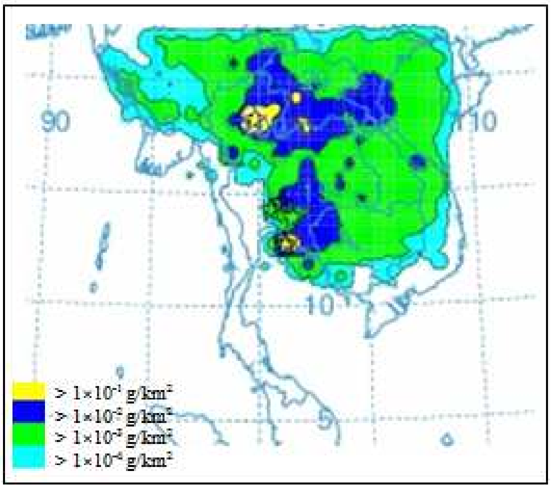


Fig. 4: Monthly accumulated total Hg deposition in Thailand during a) April, 2010 and b) August, 2010.

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.

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Estimation of Emission from Open Burning of Sugarcane Residues before Harvesting

Kanittha Kanokkanjana and Savitri Garivait

Abstract— *This study aims to estimate emission of gases and aerosols from open burning of sugarcane leaves in the field before harvesting. The information of emission factor and amount of biomass is obtained by measurement. Burned area is obtained from combining of national statistic data and sugar factory report. Field experiments were conducted to measure amount of biomass in sugarcane field. Result of biomass load is 1,007±295 g_{dm}/m^2 and residue to product ratio is 0.28±0.05. The measured emission concentrations consisted of $PM_{2.5}$, CO, and CO_2, which were calculated to obtain emission factor. Results of the EF are separated into two categories: flaming and smoldering. During flaming phase, low emission released so the EFs are low. Difference of the EFs in both phases is significant in $EF_{PM2.5}$. Annual open burning of sugarcane leaves released CO 929±341 Gg, CO_2 8,864±1,863 Gg, and $PM_{2.5}$ 152±113 Gg. High standard deviation was presented because the value included flaming and smoldering phase. Flaming phase burning can reduce emission of gases and aerosols, especially $PM_{2.5}$ can be reduced for five times of smoldering phase. Therefore, the control of open burning in sugarcane field represents a significant global warming reduction option.*

Keywords— **Sugarcane residues, open burning, climate change, emission inventory.**

1. INTRODUCTION

Sugarcane is one of major economic crops in Thailand. Thailand is the forth sugarcane exporter of the world with market share 11% [1]. Sugarcane can be planted in nearly all regions of Thailand, except south. Plantation area of sugarcane is increasing because Renewable Energy Development Plan (REDP) of the government promotes renewable energy utilization i.e. gasohol. Gasohol is a renewable energy that can reduce petroleum import and increase agricultural production price. Gasohol (E10, E20, and E85) is made of mixture between benzene and ethanol, which is pure alcohol produced from crops production i.e. sugarcane, cassava, sorghum, rice, and corn [2]. The demand of ethanol has a result in increasing price of the agricultural product so trend of sugarcane cultivation is increasing. Planted area of sugarcane is expanded from 942,468 ha in 2005 to be 1,093,924 ha in 2008 [3]. The sugarcane field was increased so rapidly for 16% in three years. The problem of harvesting sugarcane in a large area was lacking of labor. Consequently, burning of sugarcane before harvesting is more frequent in order to remove sharp foliage and harvest easily. Burning of the agricultural residues in the field is uncontrolled condition so a large amount of gaseous and aerosols is released into the atmosphere. These air pollutants are leading to climate change problem that affect large areas of the world in global level, long-range transport or transboundary problem in region level, and health problem in local level [4]-[5]. Therefore, this study aims to estimate emission of gases and aerosols from open burning of sugarcane leaves in the field before harvesting.

2. METHODOLOGY

Quantification amount of biomass burned

The selected area is main area where sugarcane is planted for input as a raw material to the sugar mill in western and eastern region of Thailand. Field experiments were conducted in sugarcane field planted traditionally by the farmers at Danmakhantia district, Kanchanaburi province in 2008, and Banbueng and Nhongyai district, Chonburi province in 2009-2010 (Fig. 1).

Sampling area was 2 m × 2 m randomly for four replicates in each area. The sampling size covered a part of one row of sugarcane. The above ground biomass of sugarcane was cut at ground level and moved out of the field to separate leaves, stem, and top (Fig. 2). Wet weight of the biomass was measured at the field and brought back to the laboratory to analyze for moisture content.

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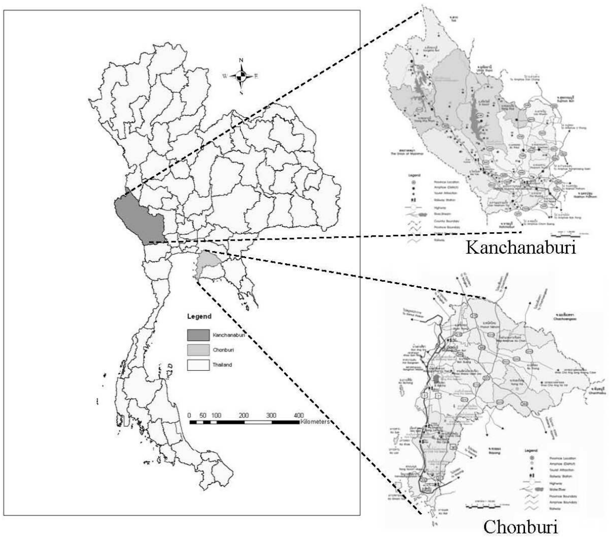

Fig.1. Studied sites in Kanchanaburi and Chonburi province.

Fig. 2. Sugarcane biomass collection at the field

Residue of sugarcane considered in this study is sugarcane leaves because leaves are the most burned part of open burning in the field before harvesting. The biomass load was calculated from dry weight of sugarcane leaves in one square meter (g/m^2). The residue to product ratio (RPR) is the ratio of dry leaves and wet weight of cane production.

Total amount of biomass burned was obtained from information of biomass load in this study, planted area from national statistic data (Office of Agricultural Economics, OAE), and fraction of burned production from sugar mill (Office of the Cane and Sugar Board, OCSB). Calculation of burned sugarcane leaves before harvesting was done by

$$M = A \times BL \times FB \times CE \qquad (1)$$

where M is total amount of sugarcane leaves open burned in the field before harvesting obtained from information of total area burned (A, unit m^2) calculated from planted area by national statistic data (Office of Agricultural Economics, OAE) and fraction of burned production from sugar mill (Office of the Cane and Sugar Board, OCSB), biomass load (BL, unit g/m^2) is the amount of sugarcane leaves per area obtained from field experiment results in this study, fraction burned (FB, unit %) is accounted for burning fraction of the leaves remaining in the field after utilization or moving out of the field, and combustion efficiency (CE) is the percentage of burned leaves after burning.

$$CE = \left[\frac{B_{before} - B_{after}}{B_{before}} \right] \times 100 \qquad (2)$$

where B_{before} is amount of biomass (sugarcane leaves) before open burning and B_{after} is amount of biomass (sugarcane leaves) after open burning. Total amount of sugarcane leaves burned was used for estimating total emission load released from open burning in the sugarcane field before harvesting.

Measurement of emission concentration

In order to estimate the total emission from open burning of sugarcane leaves, burning experiments were conducted in the simulated open burning chamber. The real fire at the sugarcane field is quite harmful and difficult to measure the emission concentration in the plume because top of the flame range is higher than 15 m; therefore, burning in the chamber was conducted in this study.

The chamber was designed to simulate open burning in the field, which was observed in the field experiments that meteorological condition was calm wind. The chamber is located at King Mongkut's University of Technology Thonburi Ratchaburi campus. Figure of the chamber is presented in Fig. 3.

Fig. 3. Simulated open burning chamber.

There are two main parts of the chamber: combustion zone and chimney. Total height of the chamber is 3.50 m. The combustion zone is 1m×1m×1m size made of steel plate that can resist fire and high temperature. Three sides of chamber are closed and one side is opened for let air in or out without any control. The position of emission concentration measurement was set in front of the open side of the chamber.

The samples of sugarcane leaves fuel were collected from the sugarcane field at the studied sites. Sugarcane residues samples were dried naturally to prevent fungi. Preparation of biomass was done by weighing the biomass, placing the biomass on the 1m×1m tray, and placing in the chamber. Amount of samples in each experiment were between 100-200 g_{dry}.

Types of the air pollutant that we measured consists of carbon dioxide (CO_2), carbon monoxide (CO), and particulate with diameter less than 2.5 micrometers ($PM_{2.5}$) measured by real-time with 1 s frequency through air quality monitoring equipments consisting of DustTrak (model 8520 TSI Inc., USA, measure $PM_{2.5}$) and Quest Suite IAQ monitor (model AQ5000Pro Quest Technologies, USA, measure CO and CO_2). The air quality monitoring was conducted before the experiment to obtain ambient air concentration and during the open burning to measure emission from open burning of sugarcane leaves, respectively. The measured emission concentration unit of $PM_{2.5}$ was mg/m^3, but unit of CO_2 and CO was ppm so the unit was converted to mg/m^3 by the temperature was taken into account and then calculated to obtain emission factor. Time of burning was recorded to obtain burned rate. After combustion, ash and unburn were collected to analyze for moisture content to obtain dry mass for determining CE.

Estimation of emission load

The emission load of gases and aerosols released from open burning of sugarcane field before harvesting was estimated by using emission factors (*EF*) that have been developed in this study and total amount of biomass burned (*M*) in Thailand.

$$E_i = M \times EF_i \qquad (3)$$

The emission factors (EF_i) are the emission factor of each pollutant i, consisting of EF_{CO2}, EF_{CO}, and $EF_{PM2.5}$, with unit g of pollutant per kg of dry sugarcane leaves; and amount of biomass burned (*M*) is obtained from Eq. (1). This calculation is the same as IPCC, 2006 [6].

3. RESULTS

Amount of biomass burned in sugarcane field

Results of the field biomass samplings consisted of biomass load (BL) and residue to product ratio (RPR). From four experiments with three replicate in each sampling site, result of sugarcane leaves biomass load is 1,007±295 g_{dm}/m^2. The highest BL was found in the sample that collected from Kanchanaburi province. Although, type of sugarcane planted in Kanchanaburi was the same as in Chonburi but the BL was higher for nearly twice because of soil type. The soil type in Kanchanaburi province is Kamphaengsan brown soil, the most suitable soil for sugarcane plantation, whereas in Chonburi is Banbueng grey soil, the second suitable soil for sugarcane plantation. The result of sugarcane leaves to product ratio (RPR) is 0.28±0.05. This value is in the same magnitude as other research 0.17-0.30 [7]-[9]. However, most studies considered top and trash; whereas, this study focused only on leaves because this part was burned in the field but the top was not burned because of high moisture content.

From the statistic of Office of the Cane and Sugar Board in Thailand, season of operating sugar mill was during November to July. Therefore, sugarcane harvesting was in the same period because the production could not be stored so long before selling. The report of Sugarcane Statistics year 2008/2009 presented total area of sugarcane planted for selling product to the sugar mill 1.03 million ha [3]. Total cane input to the factory was 66.46 million ton, which composed of burned cane 42.25 million ton so percentage of burned product was 63.57% [10]. Therefore, total burned area of sugarcane field was 653,542 ha.

Field survey results showed the farm that burned before harvesting not utilize or move the sugarcane leaves out of the farm. It means all sugarcane leaves were burned in those burned areas. Therefore, fraction of sugarcane leaves burned (FB) was 100%. The main reason of burning before harvesting was to be convenient for harvesting, which was decided by the harvesting labors. Due to lacking of labor, the farmers could not decide the way of harvesting. The farmers did not satisfy with burning before harvesting because they lost some weight of production, and the burned production could not be stored so they needed to sell to the sugar factory as soon as possible. The lower of production weight and unable to store caused lower income to the farmers. However, they still prefer harvesting by labor rather than machine because they believed that harvesting by the machine lost more juice than harvesting by labors.

Emission concentration from open burning of sugarcane leaves

The simulating open burning in the chamber was conducted for seven experiments to measure concentration of CO_2, CO, and $PM_{2.5}$ releasing from open burning of sugarcane leaves. The ambient air concentration of CO and $PM_{2.5}$ were not significant; whereas, the concentration of CO_2 was significantly high in the atmosphere. Therefore, only the ambient air CO_2 concentration was removed from the emission concentration when we considered the emission concentration results and the emission factor. The obstacle of the measurement was occurred when the maximum concentration is over the maximum detection limit so the peak concentration could not be detected. The average maximum concentration of CO_2, CO, and $PM_{2.5}$ was calculated from average of the concentration above ambient air level. Results of the average max concentrations were presented in Table 1.

Table 1. Emission Concentration from Open burning of Sugarcane Leaves

Sampling sites	Value	Emission concentration (mg/m^3)		
		CO_2	CO	$PM_{2.5}$
KB	Max	6,664	325	77
	Avg	1,385±64	111±18	9±2
BB	Max	6,746	494	187
	Avg	1,321± 39	163± 22	25± 3
NY	Max	7,956	951	187
	Avg	1,320±245	184±23	44±16

Note: KB = Kanchanaburi province, BB = Amphoe Banbueng in Chonburi province, and NY = Amphoe Nhongyai in Chonburi province

From Table 1, average values of CO_2 and CO concentrations are the same magnitude among three samples; whereas, $PM_{2.5}$ concentrations are varied by combustion phase. Flaming phase is more dominant in experiment of KB samples burning, noticed from lower CO concentration than BB and NY experiments. The results of $PM_{2.5}$ concentration depends mainly on combustion phase. Lower $PM_{2.5}$ concentration was found in flaming dominant in KB experiment and higher $PM_{2.5}$ was found in smoldering dominant in BB and NY experiments. The maximum value of $PM_{2.5}$ concentration reached maximum detection limit so the results were the same in BB and NY experiments.

Emission factor of sugarcane leaves burning

Results of emission factors are presented in Table 2.

Table 2. Emission Factors from Open Burning of Sugarcane Leaves

Sampling sites	Biomass type	Emission Factors (g/kg)		
		CO_2	CO	$PM_{2.5}$
KB	Sugar leaves	1,449.85 ±198.53	117.25 ±29.79	9.59 ±2.69
BB	Sugar leaves	1,111.84 ±26.22	137.13 ±18.98	20.96 ±2.54
NY	Sugar leaves	1,157.99 ±184.88	161.80 ±16.24	38.77 ±13.36
[4]	Agricultural residues	1,515 ±177	92 ±84	3.9
[11]	Rice straw	1,147 ±169	97 ±8	8.3 ±2.7

From Table 2, the EFs of open burning of sugarcane leaves are in the same magnitude as open burning of other agricultural residues [4] and [11], except higher $EF_{PM2.5}$ result in this study. However, $EF_{PM2.5}$ in flaming dominant phase is similar to the $EF_{PM2.5}$ of other studies.

Average EFs of open burning of sugarcane leaves in the field in this study are 1,181±248 g_{CO2}/kg, 124±45 g_{CO}/kg, and 20±15 $g_{PM2.5}$/kg, respectively. Results of the EF contain high variation because they are separated into 2 categories: flaming and smoldering. During flaming phase dominant, EF_{CO2} is 1,037.92±213.40 g/kg, EF_{CO} is 60.70±26.75 g/kg, and $EF_{PM2.5}$ is 5.21±1.70 g/kg; whereas, during smoldering phase EF_{CO2} is 1,237.61±237.82 g/kg, EF_{CO} is 148.98±19.30 g/kg, and $EF_{PM2.5}$ is 26.35±13.67 g/kg, respectively. When flaming phase dominant, low emission was released; consequently, the EFs are low. Difference of the EFs in both phases is significant in $EF_{PM2.5}$. Lower $PM_{2.5}$ was emitted in flaming phase than smoldering phase for five times.

The results of average EFs in this study are used to estimate emission load from open burning of sugarcane leaves in Thailand.

Emission load of open burning in sugarcane field, Thailand

Annual open burning of sugarcane leaves in the field released CO 929±341 Gg, CO_2 8,864±1,863 Gg, and $PM_{2.5}$ 152±113 Gg. High standard deviation was presented because the value included flaming and smoldering phase. From the literature review, biomass burning released 4,213 Gg CO and 514 Gg PM_{10} [12]. Fraction of emission from open burning of sugarcane compare with biomass burning was 22% CO and 30% PM. Larger fraction of PM should be presented because we considered $PM_{2.5}$, a fraction of PM_{10}. There is no reference for CO_2 released from biomass burning because it is supposed to be nutral by sinking through photosynthesis process of crops in the next cultivation.

4. CONCLUSION

Sugarcane is one of the major economic crops of Thailand. The harvesting of sugarcane is still manual, and hence open burnings of sugarcane fields are generally conducted before harvesting to reduce injury to workers from sharp foliage. Open burning of cropland is an uncontrolled combustion, and leads to a large amount of reduced or incompletely burned gases and aerosols released into the atmosphere. This study aims at estimating the emission of gases and aerosols from open burning of sugarcane fields before harvesting. Total burned area of sugarcane field was 0.75 million ha, which contained 7.5 million ton sugarcane leaves. Emission factors were 1,181±248 g_{CO2}/kg, 124±45 g_{CO}/kg, and 20±15 $g_{PM2.5}$/kg. Therefore, annual open burning of sugarcane leaves in the field released 929±341 Gg of CO, 8,864±1,863 Gg of CO_2, and 152±113 Gg of $PM_{2.5}$. Fraction of the emission from open burning of sugarcane before harvesting covered 22% CO and 30% PM released from biomass burning. High standard deviation was observed because the value included both flaming and smoldering phase emissions. Flaming phase burning produced lower emissions of gases and aerosols compared to smoldering. Flaming phase burning can reduce emission of gases and aerosols, especially $PM_{2.5}$ can be reduced for five times of smoldering phase. Therefore, the control of open burning in sugarcane field represents a significant global warming reduction option.

ACKNOWLEDGMENT

The authors would like to express their gratitude to The Joint Graduate School of Energy and Environment, King Mongkut's University of Technology Thonburi, and Center for Energy Technology and Environment, Ministry of Education Thailand for financial support. The authors gratefully acknowledged the contribution of Dr. Sirintornthep Towprayoon, Dr. Narisara Thongboonchoo, and Dr. Nitin Kumar Tripathi. This work was also supported by Earth Systems Science Research and Development Center (ESS), Petch Phrachomklao, and the Higher Education Research Promotion and National Research University Project of Thailand, Office of the Higher Education Commission (NRU). Aerosol from Biomass Burning to the Atmosphere Research Group (ABBA) and field experiment team are highly appreciated for their support.

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Quality Assessment of Soil and Rice from Good Agricultural Practice Rice Crops

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Abstract— *Good Agricultural Practices (GAP) stands for food safety and quality, and the environmental sustainability of agriculture. Residues testing and certification are some of the main challenges related to GAP implementation.* ***In*** *this study a multiresidue method for the determination of 16 organochlorine pesticides in soil and rice using gas chromatography with electron capture detector (GC-ECD) was achieved and validated. Samples were prepared by QuEChERS (Quick, Easy, Cheap, Effective, Rugged and Safe) method. The linear range used in the calibration curves was from 0.01 to 1.0 mgkg^{-1} and the results showed that the calibration curve linearity was ≥0.99 for all target analytes. Analyses of fortified soil and rice samples were performed at different levels (0.05, 0.25 and 0.5 mgkg^{-1}).Mean recoveries from five replicates ranged from 70% to 120% for most target analytes except endosulfan-sulfate and endrin-ketone in both rice and soil. The RSD values were <20% for all compounds. Thirty samples each of soil and rice from GAP crops of northeast region of Thailand were analyzed by this method application.*

Keywords— **GAP, GC, Pesticides, QuEChERS.**

1. INTRODUCTION

Good Agricultural Practices (GAP) is a collection of principles to apply for on-farm production and post-production process [1]. The benefits of GAP for farmers and consumers are, to meet with specific objectives of food security, food quality, production efficiency, livelihood and environmental protection, economic and social sustainability [2].

The use of fertilizers and pesticides has steadily increased year to year for sustainable high crop yields. Pesticides may contaminate to soil through direct application, accidental emission, and run-off from plant surfaces or from absorption of pesticide contaminated plant materials [3]. Pesticides may cause acute and delayed health effects in those who are exposed. Exposure of pesticides can cause a variety of adverse health effects, ranging from simple irritation of the skin and eyes to more severe effects such as affecting the nervous system, mimicking hormones causing reproductive problems, and also causing cancer. There are strong evidence for other negative outcomes from pesticide exposure including neurological, birth defects, fetal death, and neuro-developmental disorder [4].

Persistent ogranic pollutants (POPs) are organic compounds. They can resist photolytic, biological and chemical degradation. POPs are often halogenated and characterised by low water solubility and high lipid solubility. They are able to enter human food chain, bio-accumulation and mamalian toxicity. POPs are semi-volatile compounds, so their mobility through the atmosphere that is sufficient to allow relatively great amounts to enter the atmosphere and be transported over long distances. OC insecticides such as, aldrin, DDT, dieldrin, endrin, heptachlor are POPs compounds [5].

The Thailand Department of Rice GAP program aims to guide to the proper rice plantation resulting in high quality rice that is safe from chemicals and contamination, with high yield and high head rice. The program includes 3 on-site inspections and the testing of physical (percent head rice, contamination of other rice species and red rice), and chemical (pesticide residues) qualities of soil, water and rice, in the certification process [6]. Therefore pesticides residues testing played an important role to this program.

Residues testing and certification are one of the main challenges related to GAP implementation. Insecticides, rodenticides, herbicides and fungicides are four important types of pesticides used in controlling pests in agricultural areas [7]. The majority pesticides in Thailand rice farming were organophosphates (OP), organochlorines (OC), and carbamates.

There are many methods for determination of pesticides multi-residues in agricultural products and animal derived foods. But the traditional methods are usually multi-stage procedures, requiring large samples and one or more extract cleanup steps. Consequently, they are time-consuming, labour-intensive, complicated,

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expensive and produce considerable amounts of wastes. Furthermore, the traditional methods often give poor quantitation and involve a single analyte or analytes from a single class of compounds. QuEChERS (Quick, Easy, Cheap, Effective, Rugged and Safe) method for the multiclass multiresidue analysis of pesticides in fruit and vegetables was developed in 2003 by Anastassiades *et al*. QuEChERS method have become the main analytical tools in most pesticide monitoring laboratories to meet world standards as a result of the wide analytical scope and high degree of slectivity and sensivity provided by gas and liquid chromatography (GC and LC). Lehotay *et al.* modified QuEChERS method to used relatively strong acetate buffering conditions and Anastassiades *et al*. chose to use weaker citrate buffering conditions and both methods successfully met statistical criteria for accepatibility from independent scientific standards organizations. Acetate-buffering version became AOAC Official Method 2007,01 and the citrate-buffering version was named European Committee for Standardization (CEN) Standard Method EN 15662 [8], [9].

This paper describes a method for the determination of organochlorine pesticide residues in soil and rice from GAP crops from northeast region of Thailand by QuEChERS (EN-15662) method using gas chromatography with electron capture detector (GC-ECD).

2. MATERIALS AND METHODS

2.1. Materials and reagents

Certified pesticide reference standards of high purity were purchased from Dr. Ehrenstorfer (Germany). Acetonitrile (Pesticide residues grade) was purchased from (RCI Labscan Limited). Disodium hydrogencitrate sesquihydrate was purchased from (MERCK 1.122 64.0500). Trisodium citrate dihydrate was purchased from (Sigma, Aldrich 32320). Bondesil-PSA 40 µm (Varian article no.12213024) was purchased from Crawford Scientific Ltd. Magnesium sulphate anhydrous coarsely grained were purchase from (Merck 1.06067). Magnesium sulfate fine powder was purchased from Sigma-Aldrich. Formic acid (85% extrapure) was purchased from (QReC BRIGHTCHEM SDN BHD). Pesticides analyses were done in RADAL (Risk and Decision Analysis Laboratory) Laboratory, Microbiology Department of King Mongkut’s University of Technology Thonburi.

2.2. Samples

Soil and rice samples were obtained from GAP rice crops of northeast region of Thailand.

2.3. Apparatus and conditions

Gas chromatographic analysis was performed using PerkinElmer Auto-System XL GC-ECD with a fused silica capillary column (SPB-1701, 30 m x 0.32 mm x 0.25µm film thickness). Helium gas (99.9999% purity) was used as carrier gas at a constant flow-rate of 1 ml min^{-1}. The oven temperature program was 150 $^{\circ}$C at 4°C min^{-1} and raise to 275 $^{\circ}$C at 4 $^{\circ}$C min^{-1}. The injector temperature was set at 210°C and split ratio (2:1) with injection volume 1µL. The detector temperature was kept at 300°C.

Analytical balance (A&D Company and DENVER Instrument), refrigerated centrifuge (ScanSpeed 1580 MGR), shaker (New Brunswick Scientific), vortex (Scien-tific Industries) and dispersing homogenizer (ULTRA TURRAX IKA T-18 basic) were employed.

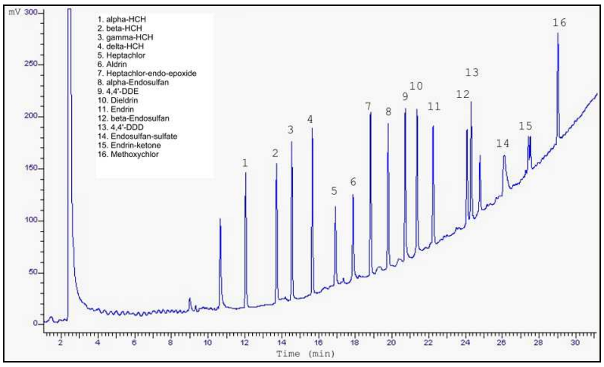


Fig.1. Chromatogram of organochlorine mixed standards at 0.1µg ml^{-1}

2.4. Sample homogenisation, extraction and clean-up

The QuEChERS extraction method was used for samples preparation. Dry samples with water content of lower than 25% like cereals, dried fruits and spices, were used. The sample amount may have to be reduced and water has to be added to make sample pores more accessible to the extraction solvent [8]. For the rice samples, 5 g of previously ground samples were weighed in a 50 ml centrifuge tube and added with 10 ml of cold deionized water (<4°C). Homogenized for 2 minutes and added with 10 ml of acetonitrile and shaken by hand for 1 minute. Four (4) g of $MgSO_4$, 1 g of NaCl, 1 g of trisodium citrate dihydrate and 0.5 g of sodium hydrogen (Na_2H) citrate sesqui-hydrate were added and vigorously vortex for 1 minute and centrifuged at 3000 rpm at 4°C for 5 minutes. After being centrifuged, 6 ml of supernatant (acetonitrile layer) were transferred into 15 ml centrifuge tube containing 200 mg of primary secondary amine (PSA) and 900 mg of $MgSO_4$. Vigorously shaken by vortex for 30 seconds and centrifuged at 3000 rpm for 5 minutes at 4 $^{\circ}$C then 4 ml of the cleaned extract were transferred into a screw cap vial and adjusted to pH between 5 to 5.5 with 5 % formic acid in acetonitrile. The extract was dried under mild stream of nitrogen. The dried extract was reconstituted with 500 µL acetonitrile and analyzed by GC/ECD [8] – [11].

For the soil samples, 20 g of soil samples were weighed in a 50 ml centrifuge tube. They were added with 12 ml of DI water and shaken for 4 hours. Then, 20 ml of acetonitrile were added and shaken by hand for 1 minute. The supernatant was transferred into a second centrifuge tube containing 6 g of $MgSO_4$, 1.5 g of NaCl, 1.5 g of Na_3-Citrate dihydrate and 0.75 g of Na_2H-Citrate-sesqui-hydrate. They were shaken for 1 minute and centrifuged at 3000 rpm for 5 minutes at 4°C [12].

Clean-up step was followed as of the rice samples preparation procedures and analyzed by GC/ECD.

2.5. Method performance and validation

Sixteen components of mixed organochlorine pesticides standard, containing Aldrin, 4,4'-DDD, 4,4'-DDE, Dieldrin, alpha-Endosulfan, beta-Endosulfan, Endosulfan-sulfate, Endrin, Endrin-ketone, alpha- HCH, beta-HCH, gamma-HCH, delta-HCH, Heptachlor, Heptachlor endo-epoxide (trans-, isomer A), Methoxychlor were used for the validation of the QuEChERS method.

For linearity study, the calibration curve was evaluated in the concentrations 0.01, 0.02, 0.03, 0.04, 0.05, 0.1, 0.25, 0.5 and 1.0 µg ml^{-1}.

For recovery study, (accuracy and precision) known pesticide concentration initially added to the soil and rice samples at three levels (0.05,0.25 and 0.5 µg ml^{-1}) and 5 replicates each.

3. RESULTS AND DISCUSSION

3.1. Chromatographic determination by GC-ECD

A good resolution of all pesticides studied was achieved as shown in the chromatogram (Fig.1).

Table.1. Determination of coefficient (r^2)

Sr.	Name of Organochlorines	Coefficient (r^2)
1.	alpha-HCH	0.9999
2.	beta-HCH	0.9998
3.	gamma-HCH	0.9998
4.	delta-HCH	0.9998
5.	Heptachlor	1
6.	Aldrin	0.9999
7.	Heptachlor-endo-epoxide	0.9997
8.	alpha-Endosulfan	0.9990
9.	4,4'-DDE	0.9984
10.	Dieldrin	0.9990
11.	Endrin	0.9999
12.	beta-endosulfan	0.9998
13.	4,4'-DDD	0.9999
14.	Endosulfan-sulfate	0.9988
15.	Endrin-ketone	0.9988
16.	Methoxychlor	0.9999

3.2. Method performance and recoveries

Calibration curves were linear over the range of 0.01 to 1.0 µg ml^{-1} with correlation coefficients of (r^2) ≥0.99 for all analytes (Table 1).

The recoveries of the studied pesticides at three levels (0.05, 0.25 and 0.5 µg ml^{-1}) were checked by spiking to the soil and rice samples. Mean results showed recoveries between 70% and 120% in most target analytes except endosulfan-sulfate and endrin-ketone in both rice and soil. The RSD values were <20% for all compounds**.** (Table 2).

Table 2. (a) Average recovery % and RSD% from rice samples spiked at three levels (n=5)

No.	Pesticide's name	Average recovery % ± RSD% for rice		
		0.05 mg kg^{-1}	0.25mg kg^{-1}	0.5 mg kg^{-1}
1	alpha-HCH	79 ± 5.5	82 ± 0.6	80 ± 6.9
2	beta-HCH	80 ± 15.5	85 ± 1.8	87 ± 5.2
3	gamma-HCH	69 ± 6.6	99 ± 2.7	104 ± 5.2
4	delta-HCH	107 ± 11.2	114 ± 3.6	108 ± 5.2
5	Heptachlor	72 ± 1.7	80 ± 7.8	89 ± 9.8
6	Aldrin	70 ± 3.8	88 ± 2.1	72 ± 5.2
7	Heptachlor-endo-epoxide	61 ± 8.1	78 ± 3.3	84 ± 4.4
8	alpha-Endosulfan	90 ± 11.3	95 ± 3.3	87 ± 6.9
9	4,4'-DDE	82 ± 3.5	85 ± 4.6	79 ± 6.3
10	Dieldrin	114 ± 4.8	92 ± 3.1	83 ± 13.3
11	Endrin	72 ± 18.7	94 ± 1.9	98 ± 5.0
12	beta-Endosulfan	85 ± 14.1	99 ± 3.6	97 ± 6.3
13	4,4'-DDD	79 ± 1.0	98 ± 2.7	101 ± 5.1
14	Endosulfan-sulfate	67 ± 1.8	66 ± 3.6	68 ± 9.2
15	Endrin-ketone	64 ± 5.9	66 ± 1.9	67 ± 1.0
16	Methoxychlor	74 ± 7.4	86 ± 2.0	77 ± 5.9

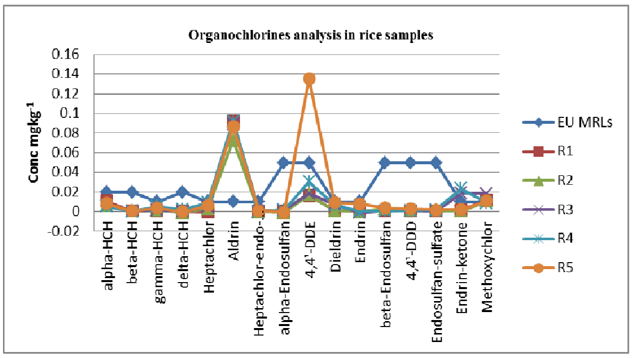
Table.2. (b) Average recovery % and RSD% from soil samples spiked at three levels (n=5)

No	Pesticide's name	Average recovery % ± RSD% for soil		
		0.05 mg kg^{-1}	0.25 mg kg^{-1}	0.5 mg kg^{-1}
1	alpha-HCH	111 ± 11.1	80 ± 18.2	98 ± 9.6
2	beta-HCH	66 ± 4.6	92 ± 10.6	106 ± 11.0
3	gamma-HCH	55 ± 13.7	77 ± 5.2	96 ± 8.1
4	delta-HCH	105 ± 18.0	79 ± 16.0	97 ± 8.9
5	Heptachlor	75 ± 9.6	94 ± 4.1	83 ± 1.7
6	Aldrin	91 ± 10.6	81 ± 2.7	91 ± 3.6
7	Heptachlor-endo-epoxide	118 ± 10.4	111 ± 4.9	114 ± 3.2
8	alpha-Endosulfan	61 ± 15.5	72 ± 4.1	101 ± 4.8
9	4,4'-DDE	119 ± 5.7	118 ± 5.5	84 ± 3.9
10	Dieldrin	110 ± 17.5	79 ± 4.0	110 ± 4.1
11	Endrin	98 ± 8.5	95 ± 3.0	104 ± 3.5
12	beta-Endosulfan	82 ± 18.9	104 ± 1.6	105 ± 1.9
13	4,4'-DDD	82 ± 17.4	99 ± 1.7	102 ± 3.8
14	Endosulfan-sulfate	54 ± 18.0	57 ± 3.9	58 ± 2.3
15	Endrin-ketone	56 ± 4.0	60 ± 5.0	63 ± 2.9
16	Methoxychlor	78 ± 16.7	98 ± 2.2	107 ± 7.4

3.3. Method application

The QuEChERS method was also applied to the determination of pesticides in 30 samples of soil and 30 samples of rice from GAP crops of northeast region of Thailand. The results showed, for the rice samples most of the analytes were ≤ MRLs (maximum residues limits of EU) except aldrin for all samples and 4,4'DDE for some samples (Fig.2). For the soil samples, all of the analytes were not detected for all samples except heptachlor but the concentrations were less than those of the MRLs for all soil samples (Table 3).

(a)



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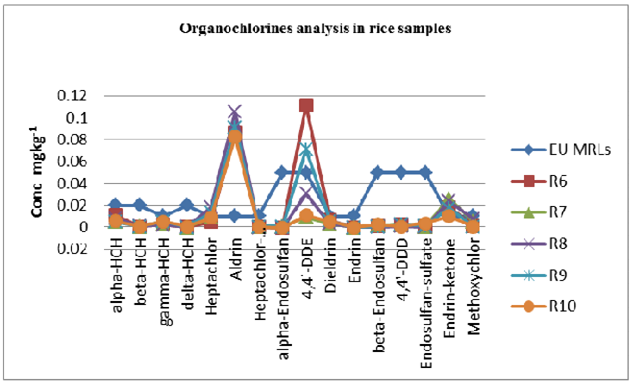

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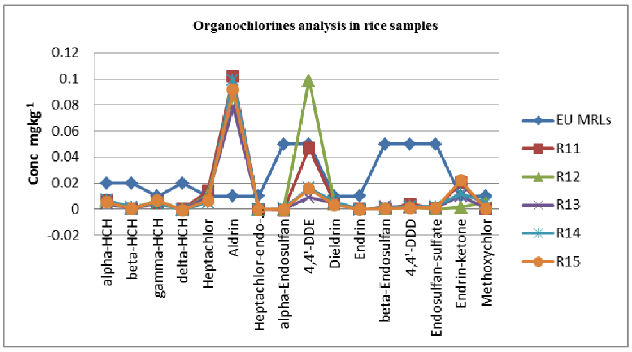

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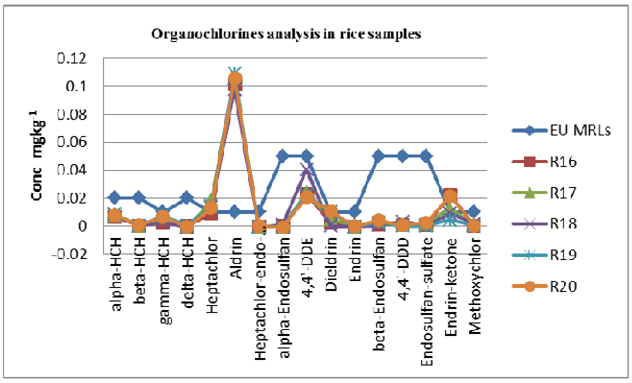

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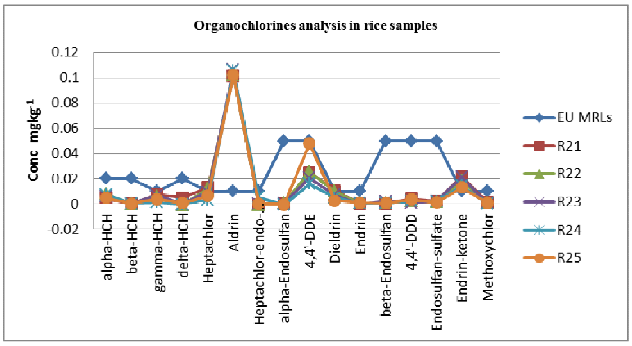

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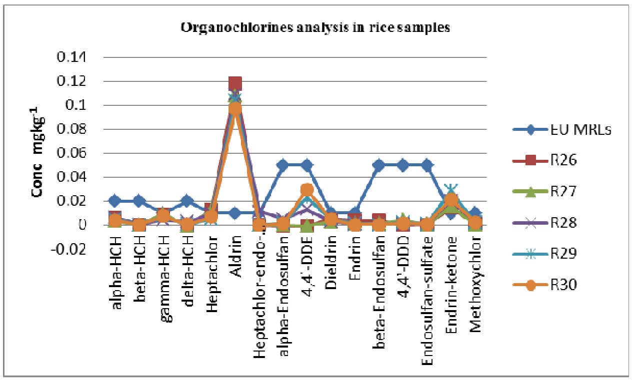

Fig.2. Determination of organochlorine residues in rice samples (a) rice samples R1 to R5 (b) rice samples R6 to R10 (c) rice samples R11 to R15 (d) rice samples R15 to R20 (e) rice samples R21 to R25 (f) rice samples R25 to R30.

4. CONCLUSION

As shown above, the establishment of GAP standard is important to significantly promote and encourage the quality and safety development of the rice production in order to be accepted for both domestic and international trade. GAP concepts in Thailand rice about the efficient production of rice with high yield and safe from toxic chemical residues. Improper use of pesticides can contaminate the environment or leave potentially harmful residues on the crop. High levels of pesticide residues on crops can control by GAP implementation. Appropriately use of pesticide, such as follow the pre-harvest interval (PHI) and the pre-grazing interval (PGI) requirements on the label, keep record of pesticide application are some important points of GAP implementation. High levels of pesticide residues on crops may be a hazard to humans who eat the produce. Thus, pesticide determination is playing an important role in food safety and international trade.

The QuEChERS extraction method used in our study minimized the time, labour consumption and cost of the sample preparation. In the rice samples we detected aldrin residues and also in the soil samples heptachlor residues were be detected. Both of aldrin and heptachlor are POPs compounds. POPs are characterized by their lipophilicity, persistence and semi-volatility. The semi-volatility of these substances facilitates their long range transport to and accumulation, far removed from any source of use. Aldrin residues bind strongly to soil particles and is very resistant to leaching into groundwater. Even though, they can loss from the soil by volatilization. Conversely, the heptachlor has a half-life of approximately 1.3 to 4.2 days in air, 0.03 to 0.11 years in water and 0.11 to 0.34 years in soil. Some study described that heptachlor residues could be found in soil 14 years after its initial application [13]. In our study we detected aldrin and heptachlor hence they are POPs compounds.

This paper showed QuEChERS method was suitable for organo-chlorines pesticide residues analysis for rice and soil in routine work.

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APPENDIX

Table.3. Determination of organochlorine residues in soil samples (a) soil samples S1 to S10 (b) soil samples S11 to S20 (c) soil samples S21 to S30

(a)

No.	OC	MRLs	S1	S2	S3	S4	S5	S6	S7	S8	S9	S10
1	alpha-HCH		0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2	beta-HCH		0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
3	gamma-HCH		0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
4	delta-HCH		0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
5	Heptachlor	0.03	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
6	Aldrin	0.04	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
7	Heptachlor-endo-epoxide	0.08	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
8	alpha-Endosulfan	0.05	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
9	4,4'-DDE		0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
10	Dieldrin	0.02	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
11	Endrin	0.04	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
12	beta-Endosulfan	0.04	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
13	4,4'-DDD		0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
14	Endosulfan-sulfate	0.04	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
15	Endrin-ketone		0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
16	Methoxychlor	0.05	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

(b)

No.	OC	MRLs	S11	S12	S13	S14	S15	S16	S17	S18	S19	S20
1	alpha-HCH		0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2	beta-HCH		0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
3	gamma-HCH		0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
4	delta-HCH		0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
5	Heptachlor	0.03	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
6	Aldrin	0.04	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
7	Heptachlor-endo-epoxide	0.08	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
8	alpha-Endosulfan	0.05	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
9	4,4'-DDE		0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
10	Dieldrin	0.02	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
11	Endrin	0.04	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
12	beta-Endosulfan	0.04	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
13	4,4'-DDD		0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
14	Endosulfan-sulfate	0.04	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
15	Endrin-ketone		0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
16	Methoxychlor	0.05	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

(c)

No.	OC	MRLs	S21	S22	S23	S24	S25	S26	S27	S28	S29	S30
1	alpha-HCH		0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2	beta-HCH		0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
3	gamma-HCH		0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
4	delta-HCH		0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
5	Heptachlor	0.03	0.01	0.01	0.00	0.01	0.01	0.01	0.01	0.00	0.01	0.01
6	Aldrin	0.04	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
7	Heptachlor-endo-epoxide	0.08	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
8	alpha-Endosulfan	0.05	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
9	4,4'-DDE		0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
10	Dieldrin	0.02	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
11	Endrin	0.04	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
12	beta-Endosulfan	0.04	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
13	4,4'-DDD		0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
14	Endosulfan-sulfate	0.04	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
15	Endrin-ketone		0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
16	Methoxychlor	0.05	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Litter Production and Decomposition in Dry Dipterocarp Forest and Their Responses to Climatic Factors

Phongthep Hanpattanakit and Amnat Chidthaisong

Abstract— *Understanding carbon processes in tropical forests is crucial for evaluating their sources or sink capacity, climate feedbacks, and hence the overall global carbon cycle. One of the important porcess of tropical carbon cycle is litter production and decomposition. The objectives of the present study are to quantify litterfall production and litter decomposition rate constant in a dry diptercarp forest and its responses to environmental factors. The study was carried out to determine the annual litterfall production by using litter traps method and the decomposition constant (k) of 4 dominant tree species of dry dipterocarp forest; Afzelia xylocarpa,* Barringtonia acutangula, *Dipterocarpus obtusifolius, and Dipterocarpus tuberculatns. Litter decomposition was carried out by using litter bag method during June 2009 – May 2010. The average annual litterfall was 7.26 ton ha^{-1} $year^{-1}$, of which 87% was leaf litter. Litter production occurred throughout the year but the high rate was found during dry period (November – April). The maximum litter fall was in January, 2010, which was 3.6 ton m^{-2} $year^{-1}$ or 34% of total litter fall during a year. The high soil temperature and low soil moisture have resulted in high total litterfall production in this forest. It was found that the litterfall production was positively correlated to soil temperature ($y = 52.46 x – 953.53$, $R^2 = 0.37$) but negatively correlated to soil moisture ($y = 1363.7 e^{-0.07}$, $R^2 = 0.32$). Based on the number of data points used in these regression analysis, these correlations are statistically significant at $p \leq 0.01$. Investigating the litter decomposition reveals that decomposition rate of leaf was higher than branch in all species. The average decomposition rate constant (k) of leaf and branch of 4-main species was 0.26 and 0.l4, respectively. The leaf of Afzelia xylocarpa showed the highest and leaf of Dipterocarpus tuberculatns the lowest decomposition rate constant. In contrast, the branch of Dipterocarpus Obtusifolius and Barringtonia acutangula shows the highest decomposition. Both compositions of all species were positively correlated to soil moisture and soil temperature. From these data, it was estimated that 7.26±0.94 ton dry matter $ha^{-1}year^{-1}$ of litter was decomposed annually and subsequently released 13.32 tonCO_2 ha^{-1} to the atmosphere..*

Keywords— **Litterfall Production, Litter decomposition, Dry Dipterocarp Forest.**

1. INTRODUCTION

Litter production and decomposition are the important components of carbon cycling pathway in the forest ecosystem. They are directly related to photosynthesis and microbial respiration which play an important role in the global carbon cycle. The tropical forests also contain higher carbon storage than other regions, approximately 60 percent of total carbon in biomass stock on the Earth [9]. It has annual net primary production about 32% of global terrestrial photosynthesis [11]. Dlioksumpun *et al.* (2009) studied the net primary production (NPP) in the Sakaeral Dry Evergreen (DEF) and the Maeklong Mixed Deciduous Forests (MDF) in Thailand. They found that NPP in DEF (15.3 tC ha^{-1} yr^{-1}) was higher than MDF (6.2 tC ha^{-1} yr^{-1}). However, the litter biomass product in MDF was higher than DEF about 7% because the plant in MDF shed leaves while in DEF did not.

The Litter on the forest floor acts as input-output system of nutrient and rates at which forest litter falls and subsequently, decomposes contribute to the regulation of nutrient cycling and primary productivity, and to the maintenance of soil fertility in forest ecosystems [12, 21, 23, 24, 28]. Plants and microbes in forest get benefits from nutrients released from litter decomposition. Therefore, it is critical to understand the amount and pattern of litterfall in tropical forest ecosystems [3, 15, 17, 18, 22, 32].

During litter decomposition, chemical compositions in litter are converted from fresh litter to humus. Microorganisms start degrading plant litter as soon as it has fallen to the ground and been invaded by decomposers, that is fungal mycelium and bacteria. In tropical forest ecosystem, decomposition processes of litter are rapid [30]. Glumphabutr (2004) studied the annual CO_2 release of litterfall in Moist Evergreen Forest (MEF), Dry Evergreen Forest (DEF), and Hill Evergreen Forest (HEF), Chanthaburi Province, Thailand. Their results showed that the decomposition rate of DEF, MEF and HEF were 7.44, 5.86, and 2.80 ton dry matter ha^{-1} yr^{-1}, respectively. These indicate that decomposition are different in each forest type depending on community of plants and climatic condition. The important issues related microorganism activity to biomass decomposition is physical and chemical properties of biomass such as

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the value of C/N ratio. Furthermore, climatic condition affects to the activity and amount of microorganisms. The important components of climatic condition are temperature and moisture [33]. These factors will affect the development of vegetation and microbial activity which decomposes organic matter on surface [27].

In the tropics, our understanding of carbon cycle responses to both short-term as climate variability and long-term changes as climate change is still very poor. Therefore, improving our knowledge on carbon processes in tropical forests is crucial for evaluating their sources or sink capacity, their climate feedbacks, and hence the overall global carbon cycle. The objectives of the present study are to quantify litterfall production and litter decomposition rate constant in a dry diptercarp forest and its responses to environmental factors.

2. MATERIALS AND METHIDS

a. Site Description

This study was carried out within dry dipterocarp forest of King Mongkut's University of Technology Thonburi, Ratchaburi Campus in Ban Ranbua, Tambon Rangbua, Chombung District, Ratchaburi province (13^o 35' 13.3'' N, 99^o 30' 3.9" E, elevation of 110 m above mean sea level). The total area of dipterocarp forest used in this study covers 187.2 ha. This area has been kept as the dipterocarp forest for approximately (more than) 50 years. Communities around this forest have utilized it for energy (wood and charcoal), timber, and other products such as mushrooms and local hunting. As a result, most of the trees are those from the re-generated ones after being cleared occasionally by villagers. In 2009, aboveground trees were 6-7 years old with the average height and perimeter of 5 m and 16 cm, respectively. This forest ecosystem has been preserved and protected, and cutting of trees is no longer permitted, allowing forest to grow and recover towards becoming an undisturbed ecosystem. According to Phiancharoen *et al.*, (2008) there are about 77 tree species found in this study area. The main species are *Dipterocarpus intricatus*, *D. obtusifolius*, *D. tuberculatus*, *Shorea obtuse and S. siamensis*. This forest ecosystem is unique that while the aboveground biomass is periodically cut by villagers, the belowground biomass stays intact. Therefore, the aboveground to belowground biomass ratio for most of dominant species is <1.

The annual average of precipitation, air temperatures, and soil moisture at the study site during May, 2009 to April, 2010 were 102.47 mm/month, 7.33% (%WPFS) and 28.50 ^{o}C, respectively. The annual average of precipitation, air temperatures, and soil moisture at the study site on wet season (during May – October, 2009), and dry season (during November, 2009 – April, 2010) were 194.62 mm/month, 10.47 %WPFS, 27.38 ^{o}C, and 11.32 mm/month, 4.14 %WPFS, 29.62 ^{o}C, (Fig. 1).

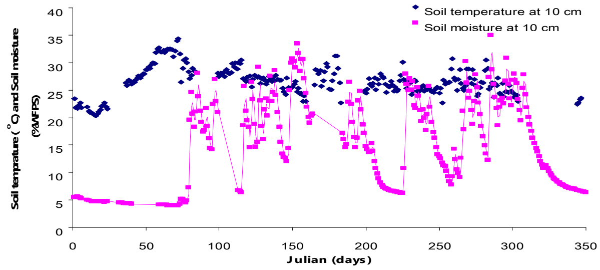

Fig. 1 Seasonal variation in soil temperature (^{o}C) (10 cm depth) and soil moisture (%WFPS) (10 cm depth) at dry dipterocarp forest, Ratchaburi site in the year 2009.

b. Litter Collection

Litterfall was measured from June 2009 to May 2011 by using permanent litter traps. Thirteen litter traps, each of 1 m^2 area, were randomly placed in 2500 m^2. Each trap consisted of 1-mm mesh nylon netting (on a PVC frame) suspended from a wire hoop and was raised 1 meter above the ground. The litterfall was collected at 30-day intervals. The collected litter at each time was oven-dried at 80 ^{o}C to constant weight. The dried litter was combined by month and plot at the end of each month.

c. Litter Decomposition

Branch and leaf litter decomposition was studied using the standard litter-bag technique [10]. Freshly fallen leaf litter was collected and air dried for decomposition study in April 2009. Leaf and branch decomposition of 4 dominant species in dry dipterocarp forest; *Afzelia xylocarpa* Kurz , *Barringtonia acutangula* Lin, *Dipterocarpus Obtusifolius* Teijsm., and *Dipterocarpus tuberculatns* Roxb were measured at the soil surface with three replications (36 bags per sample type of leaf and branch). The biggest size of leaf and branch of 4 dominant species were *Dipterocarpus tuberculatns* (26 wide x 40 lenght cm) and smallest of leaf and branch were *Afzelia xylocarpa* (4.5 wide x 6.5 lenght cm). One-hundred gram of air dried leaf and branch litters were placed inside 30cm x 30cm nylon bags with 1.0 mm mesh. Litterbags of each treatment (three plots) were randomly placed on the surface of forest soil in June 2009. The bags were attached to the forest floor by metal pins to prevent movement and to ensure contact between the bags and the litter layer. Tweenty-four litter bags per month were brought back to laboratory. The collected litters were oven-dried at 70 ^{o}C for 48 hours and brushed for cleaning out the soil contamination. The residual litter in each litter bag was weighed to find out the weight of biomass left or loss.

The study of leaf decomposition measures the lost weight of leaf through the period of time. The simplest model possible used to describe the decomposition rate is the exponential model or often called Olson's model [21] and the decomposition rate constant value (k) also can be calculated from this equation (Eq. 2.1).

$$Y_t = Y_o . e^{-kt} \qquad (2.1)$$

where; Y_o = initial weight of litter,

Y_t = weight of litter at time t

k = decomposition rate constant

e = natural logarithm

t = time of decomposition

Nevertheless, decomposition rate value may be shown in the form of percentage of annual decomposition by calculating the initial amount of litter and the amount of residual litter in the period of study time to show the value in the form of percentage of decomposition.

3. RESULTS AND DISCUSSION

a. Litter Production

Annual litterfall during June 2009 to May 2011at dry dipterocarp forest varied from 137 to 3583 g m^{-2} year^{-1} (Fig. 2). The mean annual litterfall at this forest was 726 g m^{-2} year^{-1}or 7.26±0.94 ton dry matter ha^{-1} year^{-1}. The contribution of litterfall portion in total litterfall was 87 % or 9.06 ton dry matter ha^{-1} year^{-1} of leaf, 11% or 1.17 ton dry matter ha^{-1} year^{-1} of branch, and 0.29 ton dry matter ha^{-1} year^{-1} of others including flowers and fruits.

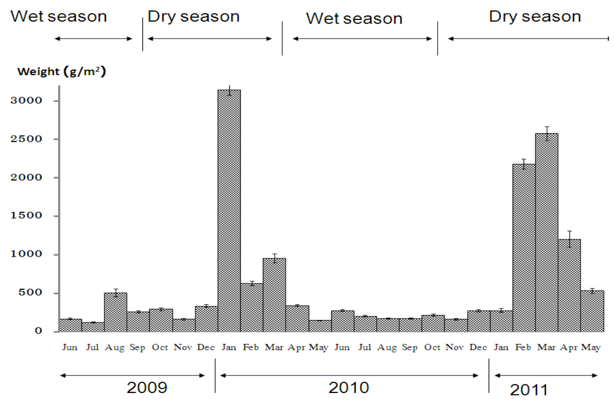

Fig. 2 Monthly litterfall in the dry dipterocarp forest during June 2009 to May 2011.

Seasonal variation in litterfall at the dry dipterocarp forest was showed in Fig. 2. Litterfall occurred throughout the year but the maximum rate of leaf shed occurred in cool and dry period (November - April). The maximum litter fall occurred on January, 2010 around 3.6 ton dry matter m^{-2} year^{-1} or 45% of total litter fall during a year.

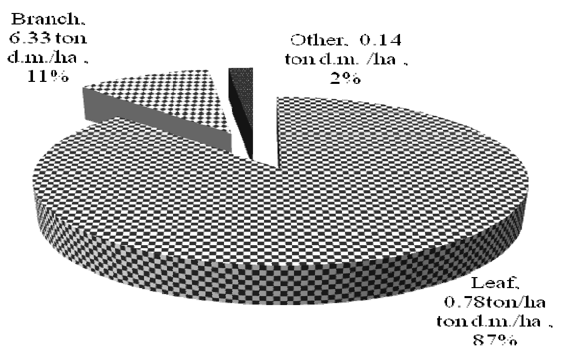

Fig. 3 Fraction of litterfall in the dry dipterocarp forest from June, 2009 to May 2011.

The forests in equatorial zone or tropical zone produce more litter product than temperate zone and polar zone [4, 14]. The comparisons of litter production in all regions of the world are done by O' Neill & De Angelis (1980) used woodlands data set from International Biological Programme (IBP). They reported that the averages litter production in arctic zone, cooling zone, and warm zone were 3.30, 4.60 and 4.70 ton.ha^{-1}.yr^{-1}, respectively, and the highest in tropical zone was 9.30 ton.ha^{-1}.yr^{-1}. The results are different depending on the temperature and precipitation in each zone. Normally, in tropical zone is higher temperature (approximately, 20-25 ^{o}C) and precipitation (more than 2000 mm.) than other zone.

The litterfall in the present study was concentrated during the cool and dry period (November-April) of the year and about 85% of total litterfall occurred during this period. Pattern of litterfall in this study was comparable with other results in other tropical forest in Thaniland [5, 17, 18, 29, 32]. The tendency of litterfall to be concentrated in cool and dry season is related to a combination of decline in temperature and lowered soil moisture during this period. Pascal (1988) had also reported that heavy litterfall of leaf occured during the dry season in evergreen forests of Attappadi, Western Ghats, India. This pattern can be explained by annual cycles of moisture and temperature. Leaf fall would occur to avoid seasonal moisture and temperature stress during dry period [15]. As mentioned above the annual litterfall in the dry dipterocarp forest was occurrence in dry period because the trees must adapt themselves to conform in dry-air condition by shedding their leaves to reduce evaporation so the amount of litterfall in this period is high. In the wet period which has high moisture content in the air, the trees do not need to reduce evaporation so the amount of litterfall is low. In addition, water stress could cause to synthesize abscissic acid in the foliage of plants which could stimulate senescence of leaves and other parts [19].

There are strong (99% confidence level) relationships between soil moisture (r^2 =0.32) and soil temperature (r^2 =0.37) with litterfall, as shown in Fig. 4-5.

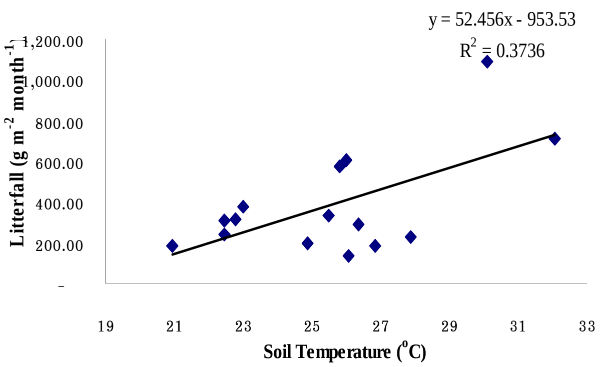

Fig. 4 The relationship between litterfall and soil temperature (n = 14; *p-value* = 0.01).

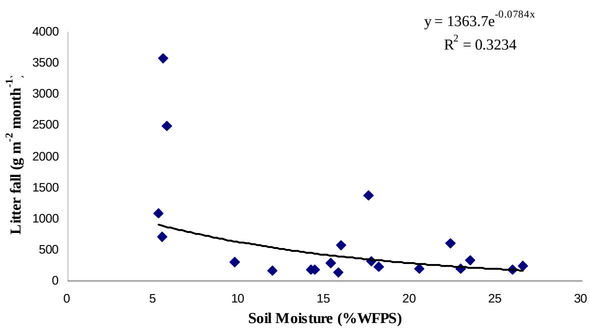

Fig. 5 The relationship between litterfall and soil temperature (n = 19; *p-value* = 0.008).

b. Litter decomposition

Mass loss of leaf and branch was significantly positively correlated ($r^2 > 0.93$, *p*-value < 0.05) with the time elapsed in months (Fig. 6-7). The decomposition rate of leaf litter in the dry dipterocarp forest was increased in the order: *Dipterocarpus tuberculatns* (DT) < *Dipterocarpus obtusifolius* (DO) < *Barringtonia acutangula* (BA) < *Afzelia xylocarpa* (AX). However, the branch litter decomposition rate was increaed in the order: *A. xylocarpa* < *D. tuberculatns* < *B. acutangula* and *D. Obtusifolius*. The leaf and branch litter disappearance was 13-16% during the first month. Rapid decline in leaf residual weights were noticed during the rainy months of July-October, nearly 55% in *B. acutangula* and *A. Xylocarpa*, 40% of *D. Obtusifolius* and 25% of *D. Tuberculatns*. In addition branch residual weights were noticed during the rainy season, nrarly 50% of *D. Obtusifolius*, 30% of *B. acutangula* and *D. Tuberculatns*, and 20% of *A. Xylocarpa*. The leaf litter were faster decomposed than branch litter of all plant species (Table 1). The relative mass loss trends amongst species observed during the 1st year but some of species were decomposed completely before a year.

Table 1. Decomposition rate constant (k) of four species leaf and branch litter in dry dipterocarp forest

Scientific name	***k*** **value of leaf (per month)**	
	Leaf	**Branch**
Afzelia xylocarpa	0.36	0.10
Dipterocarpus Obtusifolius	0.29	0.17
Barringtonia acutangula	0.21	0.17
Dipterocarpus tuberculatns	0.17	0.13
Average	**0.26**	**0.14**

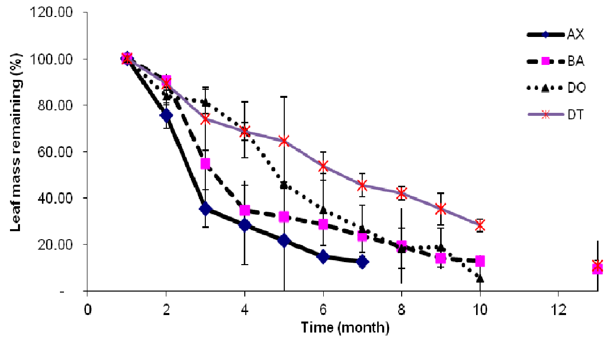

Fig. 6 Decomposition pattern of four species leaf litter in dry dipterocarp forest.

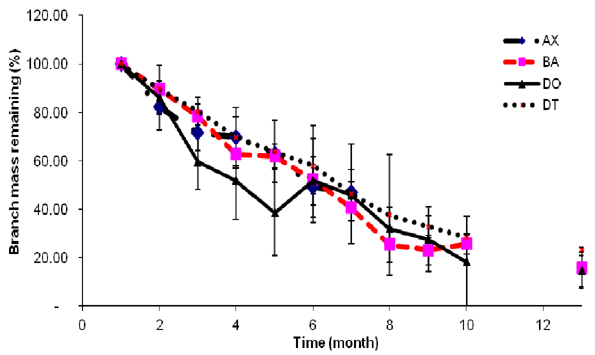

Fig. 7 Decomposition pattern of four species branch litter in dry dipterocarp forest.

In tropical forest ecosystem, decomposition processes of litter are rapid [30]. For example, the annual mass lose of hill evergreen forest, Doi-pui, Chiang Mai it was 56% per year [31]. In the dry evergreen forest, Sakaerat Environment Research Station, Nakhon Ratchasima was 48.77% per year [6]. Mangrove forest, Chanthaburi was 54.90% per year [1]. Tropicacal rain forest, Trinidad was 100% [7]. Our results show that the annual mass lose of the dry dipterocarp forest was 83% per year. Generally, the average value of *k*-value was calculated in each region of the world such as; in boreal region the *k*-value was in the rage of 0.223-0.446, cold temperate region was in the range of 0.140-0.693, warm temperate region was in the range of 0.162-0.751 and tropical region was in the range of 0.162-2.813 [19]. The average *k-value* of four species in leaf and branch litter at dry dipterocarp forest were 0.26 and 0.14, respectively (Table 1). The variability of decomposition rates is also high in tropical forest ecosystems but variability was not strongly related to site conditions and litter quality [3]. The high temperature and moisture ranges are probably the main driver for leaf and branch litter decomposition in the dry dipterocarp forest. There are strong (95% confidence level) relationships between soil moisture (r^2 = 0.22-0.96), soil temperature (r^2 =0.23-0.58) and litter mass loss as shown in Fig. 8-9.

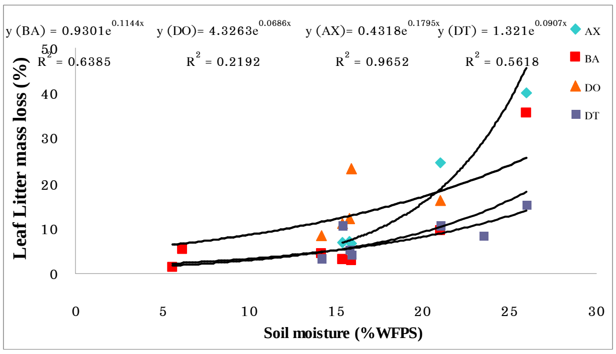

Fig. 8 The relationship between leaf litter mass loss and soil temperature (n = 7; *p-value* < 0.05).

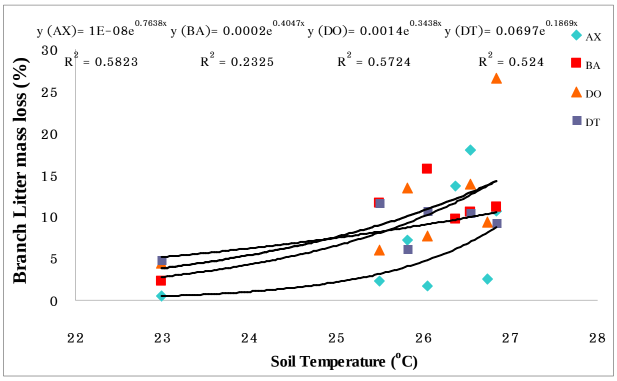

Fig. 9 The relationship between branch litter mass loss and soil temperature (n = 7; *p-value* < 0.05).

In addition, litterfall production and decomposition rate in each forest are related to CO_2 production and emission from soil surface. If litterfall production in forest is quite high and decomposition rate is rapid, the CO_2 emission to atmosphere is rapid, too. From the amount of litterfall and its decomposition rate, it was estimated that 7.26±0.94 ton dry matter ha^{-1} $year^{-1}$ of litter was decomposed annually and subsequently released 13.32 tonCO_2 ha^{-1} to the atmosphere.

4. CONCLUSION

This studies as dresses the litterfall pattern and decomposition rate constant in the dry dipterocarp forest. The average annual litterfall was 7.26 ton ha^{-1} $year^{-1}$, of which 87% was leaf litter. Litter production occurred throughout the year but the high rate was found during dry period (November – April). The litterfall production was positively correlated to soil temperature (y = 52.46 x – 953.53, R² = 0.37) but negatively correlated to soil moisture (y = 1363.7 $e^{-0.07}$, R² = 0.32). For litter decomposition, the average decomposition rate constant (*k*) of leaf and branch of 4-main species was 0.26 and 0.l4, respectively. Both compositions of all species were positively correlated to soil moisture and soil temperature.

ACKNOWLEDGMENT

The authors would like to thank King Mongkut's University of Technology Thonburi, Ratchaburi campus in ban Ranbua, tambon Ranbua, Chombung district, Ratchaburi province for providing access to the study plots. This research was supported by funding from Joint Graduate School of Energy and Environment, King Mongkut's University of Technology Thonburi, The Royal Golden Jubilee (RGJ) – Ph.D. Program

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Removal of Methyl Orange from Synthetic Wastewater onto Chitosan-Coated-Montmorillonite Clay in Fixed-Beds

C. Umpuch and S. Sakaew

Abstract— *The removal of methyl oragne from aqeous solution onto chitosan-coated-montmorillonite (CTS/MMT) was studied in this work by using fixed bed adsorption column. Experiments were carried out as a function of inlet methyl orange concentration (C_0: 50-200 mg/L), liquid flow rate (Q: 3.60 - 9.25 mL/min) and mixed sand-clay bed height (H: 15-25cm). The breakthrough characteristics of the adsorption were investigated. The breakthrough point appears faster with increasing liquid flow rate and inlet methyl orange concentration, but more slowly with increasing the bed height. It was found that the highest bed capacity of 7.34 mg/g was obtained at the condition: 200 mg/L inlet methyl orange concentration, 15 cm bed height and 3.60 mL/min flow rate. The adsorption data were fitted to three well-established fixed-bed adsorption models namely, Adam's-Bohart, Thomas and Yoon-Nelson models. The results fitted well to the Thomas and Yoon-Nelson models with coefficients of correlation $R^2 \geq 0.9415$. The adsorption test shows that CTS/MMT can be used as effective adsorbent for adsorption of the mtheyl orange using fixed-bed adsorption column.*

Keywords— **Methyl orange, chitosan-coated-montmorillonite, adsorption, fixed-beds.**

1. INTRODUCTION

Presently, textile industries are much larger scale-up to increase the amount of products. An azo dye such as methyl organe, which contains at least one azo bond (-N=N-) bearing aromatic rings, is the most common dye used due to their advantages such as bright colors, excellent color fastness and ease of applications [1]. Many azo dyes are toxic to some organisms and may cause direct destruction of creatures in water. They are hardly biodegradable in the natural stream codition. Azo dyes are highly soluble in water, their removal from effluent is difficult by conventional physicochemical and bilological treatment methods [2]. The removal of methyl orange from wastewater by adsorption technique using low-cost meterial could be an alternative method to handle this problem.

Montmorillonite clay (MMT) is a natural matter, low-cost and high spport in Thailand. It is a larmina structure with 2:1 silica. The clay inner layer composes of an alumina (Al_2O_3) complex octahedral sheet, which is sanwhiched by two silica (SiO_4) tetrahedral sheets. The substitution of Al^{3+} for Si^{4+} in the tetrahedral layer and Mg^{2+} or Fe^{2+} for Al^{3+} in the octahedral layer results in a net negtive charge. In nature, the permanant negative charge on clay surface and lamella interlayer is compensated naturally by accomulation of cation Na^{+}, or Ca^{2+} on the layer surfaces. The MMT is water swellable which is due to the proton can be loaded in the interlayer resulting in larger basal spacing. The adsorption capacity of cations dye onto the clay is high due to electrostatic interaction between the negative layer charge and cationic dye molecules, for example, natural MMT can adsorb high amount of cationic dye such as methylene blue with the monolayer adsorption capacity of 322.6 mg dye/g clay [3]. Although high amount of cationic dye loaded on MMT was observed, anionic dye uptake on the MMT is very small because of electrostatic replusion. The use of modified MMT for anionic dyes has been widely considered in recent years by a number of researches [4], [5]. The coated catioic surfacant on the clay surface colud affect the clay structure which echances adsorption capacity to methyl organe [5]. The MMT activated by hydrochloric acid promotes the uptake of methyl orange on the modified clay as compared to the untreated MMT [6]. It can be mentioned that the modified clays display higher dye adsorption capacity than that of the original clay.

Chitosan (CTS) is the N-deacetylated derivative of chitin and the second most plentiful natural biopolymer. As a well-known sorbent, CTS is widely used for the removal of heavy, transition metals and dyes because the biopolymer chain of CTS contains amine group ($-NH_2$) and hydroxyl group (-OH) which can bind with cationic and anionic molecules [7]. Therefore, the CTS is a good adsorbent for methyl orange adsorption. On the other hand, CTS has some limitation that is the weak mechanical property and low specific gravity so it swells and floats when it is dissolved in water. To improve this limitation, it can be immobilized on the MMT surface to form a composite such as CTS/MMT. Therefore, the objective of this research is to study adsorption of methyl oragne onto CTS/MMT in fixed-bed column. The important design parameters such as inlet concentration of methyl orange solution, flow rate of fluid and column bed height were investigated. The breakthrough curves for the adsorption of methyl orange were analyzed using Adam's-Bohart, Thomas and Yoon-Nelson models. Further, modeling on the adsorption dynamics of the fixed bed was presented. Finally, the correlation between

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the model and the experimental data were compared.

2. RESEARCH METHODOLOGY

2.1 Materials

The methyl orange ($C_{14}H_{14}N_3NaO_3S$) obtained from Asia Pacific Specialty Chemicals Co. Ltd., is a monovalent anionic dye with molecular weight of 327.33 g/mol. The dye stock solution was prepared by dissolving accurately weight methyl orange in distilled water to meet 1 g/L of the dye concentration. The experimental solutions were obtained by dilution of the dye stock solution in accurate proportions to needed inlet concentrations. The chemical structure of methyl orange is shown in Fig.1. CTS ($C_{12}H_{24}N_2O_9$) obtained from Aldrih Chemistry has molecular weight of 340.33 g/mol.

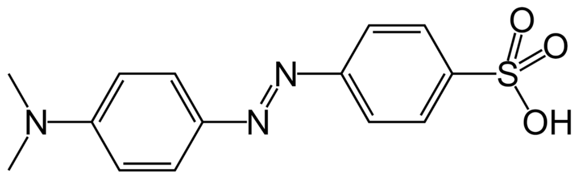

Fig.1. Molecular Structure of the Methyl Orange [5]

The MMT used was supplied by Thai Nippon Chemical Industrial Co. Ltd., Thialand. The chemical composition of MMT in weight percent is 56-60% of SiO_2, 16-18% of Al_2O_3, 5-7% of Fe_2O_3, 2.4-3% of Na_2O, 1.5-2% of MgO, 1.9-2.1% of CaO, 0.3-0.5% of K_2O and 1.2-1.5% TiO_2. The cation exchange capacity (CEC), data from the supplier, is 80 meq per 100 grams of MMT. The chemicals and clay were used without furthur purification.

2.2 Preparation of chitosan-coated-montmorillonite

An amount of 1 g of MMT dissolved in 100 mL distilled water and 100 mL of 2 g/L CTS solution were added into a batch reactor. The mixing was done by stirring at constant speed 200 rpm for 1 h at room temperature (25ºC). The pH of the suspension was adjusted to 7.0-7.5 by adding 0.1M NaOH and/or 0.1M HCl solutions and left it 30 min for gel formation. The formed composite was filtrated and washed with distilled water and then dried at 40ºC for 12 h. The dried clay was ground and sieved to 200 mesh sieve to obtain particle size in range of 300-600 µm. The CTS adsorbed onto MMT was confirmed by using CHNS-analyzer**.**

2.3 Column investigation

The CTS/MMT clay was mixed with quart sand at 2% by weight of adsorbent and then it was loaded into the glass column (1.2 cm inner diameter and 40 cm in height). Glass wool was inserted in the column as support. The column was loaded with different initial methyl orange concentrations, different flow rates and different mixed clay-sand bed heights as listed in Table 1. The effluent samples were continuously collected at the bottom of the column every 5 min in order to obtain breakthrough curve and the collected time was noted to determine the mean liquid flow rate. The dye concentration was analyzed by using UV-Vis-spectrophotometer at maximum absorbance wave length of 536 nm. The experiments were carried out at temperature of 25±1°C without pH adjustment.

2.4 Analysis of fixed-bed column data

The time for breakthrough appearance and the shape of the breakthrough curve are very important characteristic for determining the operation and the dynamic response of an adsorption fixed-bed column. The breakthrough curve shows the behavior of dye removed from the aqueous solution in a fixed-bed column and is usually in term of adsorbed methyl orange concentration (C_{ad}), the initial methyl orange concentration (C_0), outlet methyl orange concentration (C_t) or normalized concentration defined as the ratio of outlet methyl orange concentration to inlet methyl orange concentration (C_t/C_0) as a function of time or volume of effluent for a given bed height. Effluent volume can be calculated by multiplying total flow rate (Q: mL/min) and total flow time (t_{total}: min).

The total adsorbed methyl orange quantity (maximum column capacity) or q_{total} was determined by integrating area under curve of the plot between C_{ad} (mg/L) versus t (min) multiplied by mean flow rate velocity (mL/min). The area under the breakthrough curve (A) obtained by integrating the adsorbed concentration (C_{ad}: mg/L) versus t (min) plot can be used to find the total adsorbed methyl orange quantity (maximum column capacity). Total adsorbed methyl orange quantity q_{total} (mg) in the column for a given feed concentration and flow rate is calculated as:

$$q_{total} = \frac{Q}{1000} \int_{t=0}^{t=t_{total}} C_{ad} dt \qquad (1)$$

Equilibrium uptake q_e (mg/g) or maximum capacity of the column is determined by division of the total amount of adsorbed (q_{total}) per gram of adsorbent (w) at the end of total flow time.

3. RESULTS AND DISCUSSION

3.1 Breakthrough characteristics and adsorption capacities

A plot between the effluent volumes against the time was constructed. It was found that the plot was linear line with correlation coefficients of $R^2 \geq 0.9999$ showing that no blocking of mixed clay-sand in the column. The liquid mean flow rate velocities (Q) are shown in Table 1.

Fig. 2 shows the effect of a variation of the inlet methyl orange concentration of 50 to 200 mg/L on the adsorption characteristic was carried out using a fixed bed height and a solution flow rate. The normalized concentration (C_t/C_o) initially increases with time t and then remains constant. Moreover, it was observed that the slope of breakthrough curve obtained at 50 mg/L initial dye concentration was steeper than those 100 mg/L and 200 mg/L, respectively. At lower inlet dye concentrations, breakthrough curves were dispersed and the breakthrough points were reached slower. This can be described that a lower concentration gradient causes a slower methyl orange transport with a small diffusion coefficient or mass transfer coefficient. The larger inlet concentration provides steeper breakthrough curve and faster breakthrough point which is a result from the greater concentration gradient promoting the saturation rate. As the inlet methyl orange concentration increases, the methyl orange loading rate increases, so does driving force or mass transfer increase, which in a decrease in the adsorption zone length [8].

Table 1. Column Data Parameters obtained at Different Inlet Methyl Orange Concentrations, Bed heights and Flow Rates

C_0 (mg/L)	H (cm)	Q (mL/min)	t_b (min)	V_b (mL)	q_{total} (mg)	q_e (mg/g)
50	15	3.60	1.78	3.79	2.24	3.73
100	15	3.60	2.72	9.29	3.26	5.44
200	15	3.60	2.10	7.59	4.41	7.34
100	20	3.60	2.28	8.21	3.78	4.72
100	25	3.60	2.97	8.21	4.21	4.21
100	15	7.20	1.93	10.7	2.67	4.45
100	15	9.20	1.43	13.19	1.87	3.12

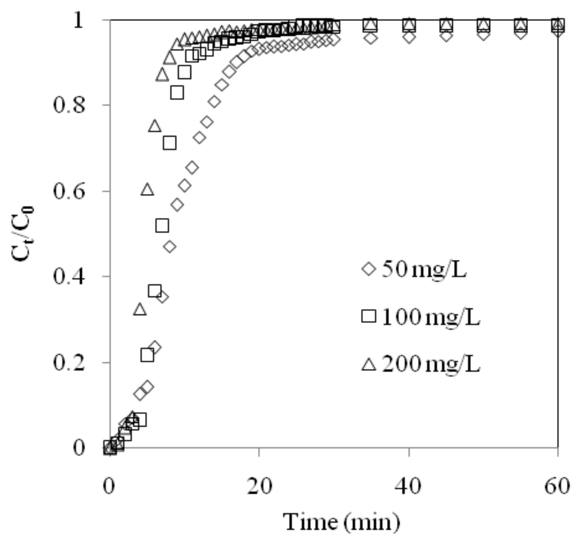

Fig.2. Breakthrough Curves for Methyl Orange Adsorption at Different Initial Concentration (15cm Bed Height and 3.6 mL/min).

Fig. 3 shows the breakthrough curve of methyl orange adsorption on the mixed clay-sand bed with variation of three flow rates such as 3.60, 7.20 and 9.20 mL/min. It was observed that breakthrough generally occurred faster with higher flow rate. Breakthrough time reaching saturation was increased significantly with a decreased in the flow rate. At low flow rate, the inlet methyl orange has more time to contact with bed resulting in higher capacity adsorption of methyl orange in column. It can be described that at higher flow rate the rate of mass transfer gets increase with flow rate leading to faster saturation. At a higher flow rate, the adsorption capacity was lower due to insufficient residence time of the solute in the column and diffusion of solute into the pores of the adsorbent, and therefore, the solute left the column before equilibrium reached.

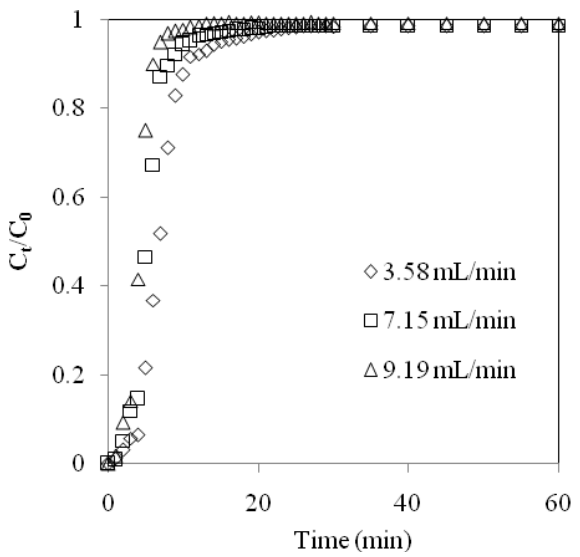

Fig.3. Breakthrough Curves for Methyl Orange Adsorption at Different Flow Rates (100 mg/L Initial Methyl Orange Concentration and 15cm Bed Height).

Fig. 4 shows the breakthrough curve of methyl orange adsorption on the mixed clay-sand bed with different bed heights of 15, 20 and 25 cm (0.6g, 0.8g and 1.0g). The breakthrough increases with increasing the bed height. As the bed height increases, methyl orange had more time to contact with the bed resulting in higher adsorption capacity of methyl orange in the column. The slope of breakthrough curve decreased with increasing bed height, which results in a broadened mass transfer zone. High adsorption capacity was observed at the highest bed height due to an increase in the surface area of adsorbent, which provided more binding sites for the adsorption.

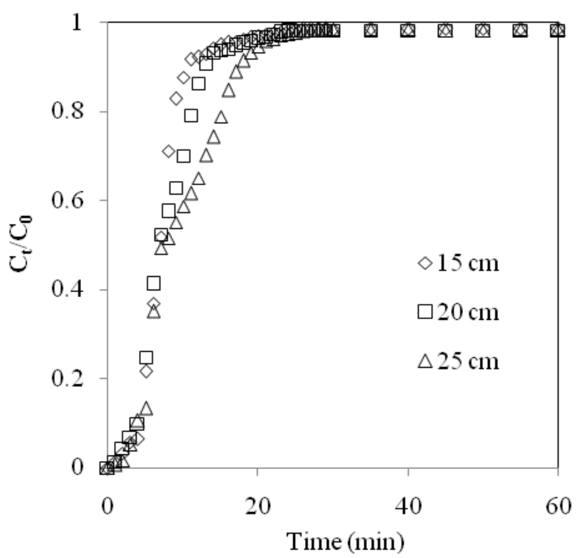

Fig.4. Breakthrough Curves for Methyl Orange Adsorption at Different Bed Height (100 mg/L Initial Methyl Orange Concentration and 3.6 mL/min).

Table 1 shows not only the liquid mean flow rate velocities but also the breakthrough characteristics, adsorption capacity and exhausted time, of methyl orange in the mixed CTS/MMT-sand clay beds at different inlet methyl orange concentration, different flow rate and different bed length. The breakthrough point (the position at C_t/C_0 = 0.05) appears faster with increasing liquid flow rate and initial methyl orange concentration, but more slowly with increasing the bed height. The highest of breakthrough time (t_b) was 2.97 min which obtained at condition: 100 mg/L inlet methyl orange concentration, 25 cm bed height and 3.60 mL/min flow rate. The highest breakthrough volume (V_b) was 13.19 mL which obtained at condition: 100 mg/L inlet methyl orange concentration, 15 cm bed height and flow rate of 9.20 mL/min. The highest bed capacity (q_e) was 7.34 mg/g obtained at the condition: 200 mg/L methyl orange concentration, 15 cm bed height and flow rate of 3.60 mL/min.

3.2 Modelling of Brakthrough curves

It is necessary to fit the adsorption data using established models and subsequently determine noticeable parameters associated with these models to determine their influence for optimization of the fixed-bed adsorption process.

3.2.1The Adam's-Bohart model

Adam's-Bohart model [9] established the fundamental equations describing the relationship between C_t/C_0 and t in a continuous system. The Adam's-Bohart model was applied to experimental data for the description of the initial part of the breakthrough curve. The expression is following:

$$\ln\left(\frac{C_0}{C_t}\right) = k_{AB}C_0t - k_{AB}N_0\left(\frac{Z}{F}\right) \qquad (2)$$

where C_0 and C_t (mg/L) are the inlet and effluent methyl orange concentration, k_{AB} (L/mg.min) is the kinetic constant, F(cm/min) is the linear velocity calculated by dividing the flow rate by the column cross section area, Z(cm) is the bed depth of column and N_0 (mg/L) is the saturation concentration. A linear plot of $\ln(C_t/C_0)$ against time (t) was determined values of k_{AB} and N_0 from the intercept and slope of the plot (Figure not shown).

Table 2. Adam's – Bohart Parameters at Different Conditions Using Linear Regression Analysis

C_0 (mg/L)	H (cm)	Q (mL/min)	k_{AB}x10^3 (L/mg min)	N_0 (mg/L)	R^2
50	15	3.60	9.048	94.410	0.9128
100	15	3.60	5.462	182.907	0.9049
200	15	3.60	5.377	220.652	0.9033
100	20	3.60	6.289	118.848	0.9261
100	25	3.60	8.170	90.162	0.9530
100	15	7.20	9.036	121.962	0.8727
100	15	9.20	10.440	99.738	0.8939

After applying Adam's-Bohart model to experimental data, a linear relationship between $\ln(C_t/C_0)$ and time (t) according to Eq.(2) was constructed for the relative concentration (C_t/C_0) up to 0.5, i.e, 50% breakthrough. For all breakthrough curves, respective values of N_0, and k_{AB} were calculated and presented in Table 2 together with correlation coefficients (R^2>0.8727). The values of k_{AB} decrease with inlet methyl orange concentration and solution flow rate, but it increases with bed height. This shows that the overall system kinetics was dominated by external mass transfer in the initial part of adsorption in the column [10]. Although the Adams-Bohart model provides a simple and comprehensive approach to running and evaluating sorption-column tests, its validity is limited to the range of conditions used.

3.2.2Thomas mode

Thomas model [10] assumes plug flow behaviour in the bed, and uses Langmuir isotherm for equilibrium, and second-order reversible reaction kinetics. This model is suitable for adsorption processes where the external and internal diffusion limitations are absent. The linearized form of Thomas model can be expressed as follows:

$$\ln\left(\frac{C_0}{C_t} - 1\right) = \frac{k_{Th}q_0w}{Q} - k_{Th}C_0t \qquad (3)$$

where k_{Th} (mL/min.mg) is the Thomas rate constant; q_0 (mg/g) is the equilibrium methyl orange uptake per g of the adsorbent; w (g) is the mass of adsorbent, Q (mL/min) is the flow rate and total time (min) stands for flow time. The value of C_t/C_0 is the ratio of outlet and inlet methyl orange concentrations. A linear plot of $\ln[(C_0/C_t)-1]$ against time (t) was employed (figure not shown) to determine values of k_{Th} and q_0 from the intercept and slope of the plot.

Table 3. Thomas Model Parameters at Different Conditions Using Linear Regression Analysis

C_0 (mg/L)	H (cm)	Q (mL/min)	k_{Th}x10^3 (L/mg min)	q_0 (mg/g)	R^2
50	15	3.60	9.750	2.489	0.9797
100	15	3.60	7.343	4.137	0.9629
200	15	3.60	6.270	5.600	0.9608
100	20	3.60	7.349	2.984	0.9794
100	25	3.60	8.359	2.489	0.9822
100	15	7.20	10.117	3.173	0.9415
100	15	9.20	11.462	2.624	0.9601

The column data were fitted to the Thomas model to determine the Thomas rate constant (k_{Th}) and maximum solid-phase concentration (q_0). The determined coefficients and relative constants were obtained using linear regression analysis according to Eq.(3) and the results are listed in Table 3. It is found that the determined coefficients (R^2) are among 0.9415 to 0.9822. The values of k_{Th} and q_0 are presented in Table 3. As flow rate increases, the value of q_0 decreases but the value of k_{Th} increases. As the inlet concentration increases, the value of q_0 decreases while the value of k_{Th} increases. The reason is that the driving force for adsorption is the concentration difference between the methyl orange on the adsorbent and the methyl orange in solution [8]. As the bed heights increase, the value of q_0 increases significantly while the value of k_{Th} decreases significantly. Thus, lower flow rate, lower initial methyl orange concentration and higher bed heights would increase the adsorption of methyl orange on the bed column. The Thomas model is suitable for adsorption processes where the external and internal diffusions will not be the limiting step [10].

3.2.3The Yoon-Nelson model

Yoon and Nelson [11] developed a model based on the assumption that the rate of decrease in the probability of adsorption of adsorbate molecule is proportional to the probability of the adsorbate breakthrough on the adsorbent. The Yoon-Nelson is a linearized model for a single component system i expressed as:

$$\ln\left(\frac{C_t}{C_0 - C_t}\right) = k_{YN}t - k_{Th}\tau \quad (4)$$

where k_{YN} (1/min) is the rate velocity constant, τ (min) is the time required for the relative concentration region up to 0.5. A linear plot of $\ln[C_t/(C_0\text{-}C_t)]$ against sampling time (t) according to Eq.(4) gives the values of k_{YN} and τ from the intercept and slope of the plot (figure not shown). The values of K_{YN} and τ are listed in Table 4. The rate constant K_{YN} increases and 50% breakthrough time τ decreases with flow rate and inlet methyl orange concentration. An increase of bed height, the values of τ increases while the values of K_{YN} decrease. Table 4 indicates that τ values from the calculation are significantly different from the experimental results.

Table 4. Thomas Model Parameters at Different Conditions Using Linear Regression Analysis

C_0 (mg/L)	H (cm)	Q (mL/min)	K_{YN} (L/mg min)	τ (min)	R^2
50	15	3.60	0.488	8.283	0.9797
100	15	3.60	0.729	6.943	0.9629
200	15	3.60	1.245	4.700	0.9608
100	20	3.60	0.741	6.578	0.9794
100	25	3.60	0.841	6.874	0.9822
100	15	7.20	1.020	5.245	0.9415
100	15	9.20	1.160	4.322	0.9601

4. CONCLUSIONS

The fixed-bed adsorption system was found to perform better with lower inlet methyl orange concentration, lower feed flow rate and higher mixed clay-sand bed height. The breakthrough point appears faster with increase of liquid flow rate and initial methyl orange concentration. The highest bed capacity of 7.34 mg/g was obtained at the condition: 200 mg/L inlet methyl orange concentration, 15 cm bed height and 3.60 mL/min flow rate. The fixed-bed column adsorption system containing mixed CTS/MMT-sand is effective to removal methyl orange from aqueous solution. The column experimental data were analyzed by the Adam's-Bohart, Thomas and Yoon-Nelson models. For methyl orange adsorption, the column data were fitted well to the Thomas and Yoon-Nelson models.

The use of MMT modified with other chemicals, for example, cationic surfactant and strong acid might be further studied for the pollution control.

ACKNOWLEDGMENT

The authors acknowledge the research grant provided by the Ubon Ratchathani University.

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GMSARN International Journal **Vol. 6 No. 4 December 2012**