สารโพลีไซคลิกอะโรมาติกไฮโดรคาร์บอนในฝุ่นละอองแต่ละขนาดในอากาศกรุงเทพมหานคร

นางสาว ปาจรีย์ ทองสนิท

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POLYCYCLIC AROMATIC HYDROCARBONS IN SIZE-SELECTED PARTICULATE MATTER IN THE AIR ENVIRONMENT OF BANGKOK

Miss Pajaree Thongsanit

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ปาจรีย์ ทองสนิท: สารโพลีไซคลิกอะโรมาติกไฮโดรคาร์บอนในฝุ่นละอองแต่ละขนาดในอากาศกรุงเทพมหานคร. (POLYCYCLIC AROMATIC HYDROCARBONS IN SIZE-SELECTED PARTICULATE MATTER IN THE AIR ENVIRONMENT OF BANGKOK) อาจารย์ที่ปรึกษา: รศ. วงศ์พันธ์ ลิมปเสนีย์, รศ. ดร. วนิดา จีนศาสตร์, ASSOC. PROF. Dr. MARTIN HOOPER, 172 หน้า. ISBN 974-17-0834-3

งานวิจัยนี้เก็บฝุ่นที่มีขนาดเล็กกว่า 10 ไมครอน (PM10) โดยใช้เครื่องเก็บตัวอย่างฝุ่น High Volume จาก 6 สถานีในเขตกรุงเทพมหานครได้แก่ จุฬาลงกรณ์มหาวิทยาลัย โรงพยาบาลจุฬาลงกรณ์ ดินแดง สำนักงานนโยบายและแผนสิ่งแวดล้อม โรงเรียนสิงหราช และมหาวิทยาลัยกรุงเทพ ระหว่างเดือนพฤศจิกายน 2542 ถึง เดือนพฤศจิกายน 2543 เฉพาะที่สถานีจุฬาลงกรณ์มหาวิทยาลัย เก็บตัวอย่างฝุ่นทั้งที่มีขนาดเล็กกว่า 10 ไมครอน และแยกขนาด 5 ขนาด อีกทั้งเก็บตัวอย่างฝุ่นจากไอเสียรถยนต์ประเภทต่าง ๆ จากปล่องโรงงานอุตสาหกรรม และฝุ่นบนผิวถนน พบว่าค่าเฉลี่ย 24 ชั่วโมงของฝุ่นขนาดเล็กกว่า 10 ไมครอนในบรรยากาศทั่วไป มีค่า 23 ถึง 160 ไมโครกรัมต่อลูกบาศก์เมตร ที่สถานีมหาวิทยาลัยกรุงเทพ และโรงพยาบาลจุฬาลงกรณ์ตามลำดับ ซึ่งมีผลมาจากการเปลี่ยนแปลงของฤดูกาลและปริมาณรถยนต์ ทุกตัวอย่างกระดาษกรองฝุ่นสกัดโดยสารอะซิโตรไนตราย และวิเคราะห์ปริมาณสารโพลีไซคลิกอะโรมาติกไฮโดรคาร์บอน (PAHs) ด้วยเครื่อง HPLC ที่มีทั้ง UV-Vis และ Fluorescence Detector ค่าเฉลี่ยของปริมาณรวม PAHs 20 ชนิด จากฝุ่นบรรยากาศทั่วไป เท่ากับ 60 นาโนกรัมต่อลูกบาศก์เมตร และพบว่า Benzo[e]pyrene (BeP), Indeno[123cd]pyrene (Ind) และ Benzo[ghi]perylene (BghiP) เป็นองค์ประกอบหลัก PAHs มากกว่าร้อยละ 97 พบในฝุ่นขนาดเล็กกว่า 0.95 ไมครอน PAHs โมเลกุลเล็กพบในตัวอย่างฝุ่นจากรถยนต์ดีเซล ตัวอย่างรถยนต์เบนซินมี BghiP เป็นองค์ประกอบหลัก และ พบว่า BeP และ Pyrene (Pyr) เป็นองค์ประกอบหลักของตัวอย่างจากปล่องโรงงานอุตสาหกรรม ผลการวิเคราะห์ฝุ่นจากบรรยากาศมาเปรียบเทียบกับตัวอย่างของแหล่งกำเนิด พบว่าแหล่งกำเนิดหลักของ PAHs คือ ไอเสียรถยนต์

ภาควิชา วิศวกรรมสิ่งแวดล้อม
สาขาวิชา วิศวกรรมสิ่งแวดล้อม
ปีการศึกษา 2545

ลายมือชื่อนิสิต.....
ลายมือชื่ออาจารย์ที่ปรึกษา.....
ลายมือชื่ออาจารย์ที่ปรึกษาร่วม.....
ลายมือชื่ออาจารย์ที่ปรึกษาร่วม.....

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KEYWORD: POLYCYCLIC AROMATIC HYDROCARBONS / AIR PARTICULATE MATTER / SOURCE EMISSION / PM10 / SIZE FRACTIONATED PARTICULATE MATTER

PAJAREE THONGSANIT: POLYCYCLIC AROMATIC HYDROCARBONS IN SIZE-SELECTED PARTICULATE MATTER IN THE AIR ENVIRONMENT OF BANGKOK THESIS ADVISOR: ASSOC. PROF. WONGPUN LIMPASENI, ASSOC. PROF. Dr. WANIDA JINSART, ASSOC.PROF. Dr. MARTIN HOOPER 172 pp. ISBN 974-17-0834-3

Samples of Particulate Matter less than 10 μm, PM10, were collected from six sites (Chulalongkorn University, Chulalongkorn Hospital, Dindaeng, Office of Environmental Policy and Planning, Singharat School and Bangkok University) in Bangkok, from November 1999 to November 2000, using high volume air-samplers. Both PM10 and Size Fractionating Particulate Matter, SFPM, sampling using a multi-slit Anderson cascade impactor was undertaken at Chulalongkorn University to identify particulate size distribution. Samplings of particulate emission from various types of vehicles, industrial stacks and road dust have also been performed. The 24-hour PM10 concentrations varied from 23 $\mu g/m^3$ to 160 $\mu g/m^3$ at Bangkok University and Chulalongkorn Hospital, respectively. The seasonal variation and traffic densities affected the particulate concentration in ambient air. All filter samples were extracted ultrasonically in acetonitrile and analyzed for PAHs using High Performance Liquid Chromatography with UV-vis and Fluorescence detectors. The total of 20 species of PAHs had an average concentration of 60 ng/m^3. Benzo[e]pyrene (BeP), Indeno[123cd]pyrene (Ind) and Benzo[ghi]perylene (Bghip) were the major PAH in the ambient samples. There were more than 97% of PAHs found in the particulate matter <0.95 μm. The low molecular weight PAHs were found in the heavy diesel emission. BghiP was the dominant PAH of the gasoline vehicles. BeP, Pyrene(Pyr) were dominant PAHs of stack emissions. The PAH profiles from ambient air samples were compared with the patterns obtained from different emission sources. The results indicate that PAHs were primarily from mobile sources.

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Field of study Environmental Engineering	Advisor's signature…….
Academic year 2002	Co-advisor's signature……
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List of Abbreviations

CMB	Chemical Mass Balance
CNG	Compressed Natural Gas
HDDV	Heavy Duty Diesel Vehicle
HPLC	High Performance Liquid Chromatography
LDDV	Light Duty Diesel Vehicle
LDGV	Light Duty Gasoline Vehicle
NAAQS	National Ambient Air Quality Standard
OEPP	Office of the Environmental Policy and Planning
PAHs	Polycyclic Aromatic Hydrocarbons
PCD	Pollution Control Department
PM10	Particulate Matter less than 10 μm
SFH	Size Fractionating Head
SFPM	Size Fractionating Particulate Matter
TSP	Total Suspended Particulate
USEPA	United States Environmental Protection Agency
nm	Nanometer
ng/m^3	Nanogram per Cubicmeter
μm	Micrometer
$\mu g/m^3$	Microgram per Cubicmeter
μg/km	Microgram per Kilometer

CHAPTER 1

INTRODUCTION

The roadside area in Bangkok is known to suffer from severe air pollution. Several air pollution monitoring and control projects have been launched but these have been less concerned with adverse health effects from fine particles. Particulate air pollution includes solid and liquid particles directly emitted in the air, for example, diesel soot, road or agricultural dust or particles resulting from industrial or manufacturing processes. Particles are also produced through photochemical reactions among air pollutant gases, such as sulfur or nitrogen oxides, that are byproducts of fuel combustion. The illnesses associated with airborne particulate matter range from severe acute and chronic illnesses such as asthma attacks and chronic bronchitis to mild acute symptoms such as coughing, wheezing and congestion. Taken as a whole, the available epidemiological evidence shows a strong relationship between particulate matter concentration and public health. Particulate matter health effects are much influent in Thailand. Air quality-monitoring data for Bangkok are now adequate for conducting some epidemiological research to begin to address this important question. Daily measurements of PM10 (Particulate Matter 10 microns in diameter and smaller), which is the size fraction of total airborne particulate matter that is considered inhalable, have been recorded by the Royal Thai Government Pollution Control Department since 1992.

Polycyclic Aromatic Hydrocarbons (PAHs) are a group of organic compounds made up of two or more fused benzene rings in linear, angular or cluster arrangements. Different arrangements of the rings have resulted in the identification of over 200 different compounds. They occur ubiquitously in products of incomplete combustion. PAHs are distributed in the environment via natural combustion e.g. volcanic eruptions, forest burning and by anthropogenic combustion processes (e.g. motor vehicle, industrial boilers). The concentration of vehicle exhaust PAHs is a function of a number of complex factors including engine types, fuel and oil composition and engine operating conditions. Most PAHs come from anthropogenic sources with the majority emitted from

heat and power generation e.g., coal gas, wood oil, industrial processes, refuse burning, automobile emissions and other sources such as cooking, smoking and so on. Human exposure to PAHs may occur via food, water and air including direct inhalation of tobacco smoke or direct contact with materials containing PAHs. The PAHs have long been of concern as a potential human health hazard since some of them can cause carcinogenesis, localized skin effects, pulmonary and respiratory problems, genetic reproductive and developmental effects, behavioral, neurotic, and other organ system effects.

In the atmosphere, PAHs are distributed between the gas phase and particle phase according to their volatility. PAHs are adsorbed predominantly on suspended particulate matter in the respiratory size range less than 5 μm. They can reach human lung when they are inhaled and may contribute to lung cancer. Therefore, it is important to investigate the PAH contaminants in the atmosphere especially in industrial and urban areas in order to assess the PAHs levels and to understand the characteristics of PAHs in those areas.

Until recently there have been few investigations of PAHs in Bangkok. Daily ΣPAHs levels have a mean of 25.4 ng/m^3 of air. Benzo(a)pyrene (BaP) which has been linked with cancer, is commonly used as an indicator for the presence of PAHs. BaP concentrations in Bangkok ranged from 0.18 to 2.44 ng/m^3 between 1993-1997. Benzo(e)pyrene (BeP) has found to be the major PAH present, making up 10.5% of the PAH levels. Levels of Benzo(ghi)perylene (BghiP) and low molecular weight Acenapthene (Ace) and Acenapthylene (Acy) are also significant in Bangkok.

1.1 Thesis Aims

The objectives of this study are

1. To study the present state of the PAHs concentration in ambient air in Bangkok.
2. To study the characteristic of the probable carcinogenic PAHs associated with different particle size.
3. To identify and quantify the sources of PAHs emission.
4. To develop and propose a strategy for an air pollution control model to mitigate these PAHs.

The scope of work

1. The study sites consist of five Pollution Control Department (PCD) sampling sites and one at Chulalongkorn University in Bangkok.
2. PAHs-associated Particulate Matter less than 10 μm (PM10) in particulate air samples was determined at five PCD sampling sites.
3. PAHs-associated Size Fractionating Particulate Matter (SFPM) and PM10 in particulate air samples were determined at Chulalongkorn University.
4. PAHs loading and emission factors of thirteen samples from automotive emission, six samples of industry and five samples of road dust were measured and calculated.
5. The twenty PAHs determined were Naphthalene (Nap), Acenapthene (Ace), Acenapthylene (Acy), Fluorine (Flu), Phenanthrene (Phen), Anthracene (Anth), Fluoranthene (Flt), Pyrene (Pyr), Benzo(a)anthracene (BaA), Chrysene (Chr), Benzo(e)pyrene (BeP), Benzo(b)fluoranthene (BbF), Perylene (Per), Benzo(k) Fluoranthene (BkF), Benzo(a)pyrene (BaP), Dibenzo(ah)anthracene (DBahA), Benzo(ghi)perylene (BghiP), Indeno(123cd)pyrene (Ind), Anthanthrene (Ant) and Coronene (Cor).

1.2 Hypothesis

1. The fine airborne particulate matter will carry high PAHs concentration and this is due primarily to the traffic conditions and types of vehicles in Bangkok.
2. These PAHs loading are of such conditions and amounts as to be a very real concern for the health of the citizens of Bangkok and that this health effect carries an economic penalty.
3. An understanding of the sources of PM and associated PAHs and their influence will allow development of control strategies.

The PAHs profile in Bangkok and seasonal trend in PM10, SFPM and associated PAHs levels were discussed and compared at six sampling sites around Bangkok. PM10 levels were compared with National Ambient Air Quality Standard (NAAQS).

Sources of emission samples, such as types of automotive emission, road dust and industry, were investigated. Both PAHs profile and PAHs ratios on ambient air and source samples were determined for the source apportionment.

Statistical analysis of PM, PAHs data and meteorological data collected during the sampling have been used to determine the effect of meteorological process on PAHs levels in the Bangkok. The effect of rainfall on PAHs concentration was investigated by looking at each SFPM and the ratios of small to large PAHs as the small species are more efficiently scavenged by wet precipitation mechanisms. Statistic analysis of ambient PAHs and sources samples PAHs was used to estimate the contributions of species types of source.

1.3 The Study

The present study was designed to investigate the SFPM, PM10 and their associated PAHs in the air environment of Bangkok.

PM10 high volume air samplers have been operated in PCD sites that were in the North, Central and South of Bangkok. Both PM10 and SFPM high volume samplers were operated only at Chulalongkorn University. The sampling period was between November 1999 and November 2000 (13 months).

The air samplers were run for approximately 24 hours at 70 m^3/hr giving a volume of 1680 m^3 of air passing through the filter paper. The filters were pre-weighed and re-weighed at Center of Environmental Science Laboratory, Monash University.

After determination of PM weight, twenty PAHs were extracted from the filter papers using an ultrasonic technique and separated using High Performance Liquid Chromatography (HPLC) with UV and Fluorescence detectors.

In this part of the study, the types of automotive samples, road dust samples and industry samples have been collected. Some samples were collected from the dynamometer test run at PCD. The stack samples of industry were collected from Air & Waste Technology Co. Ltd. Company. Road dust samples collected by sweeping the four main roads. All source filters were weighed and reweighed again after use and were analyzed for PAHs concentration. Ambient and sources data have been compared to determine the apportionment between two data sets.

1.4 Thesis Outline

This thesis can be divided in six chapters as follows

CHAPTER 1 Introduction

The introduction covers of background methods, aims and hypotheses.

CHAPTER 2 Background

The chemistry and behavior of PM and associated PAHs are described along with a description of the sources of these pollutants. Chemical and meteorological processes associated with the fate of PAHs in the atmosphere are also discussed, including the review of air pollution, PM and PAHs in Bangkok.

CHAPTER 3 Methodology

The sampling programs, fieldwork and sampling sites are described. The standard method of ambient and sources of emission air sampling and analysis techniques used to determine PAH levels in the atmosphere are provided.

CHAPTER 4 Results

The raw data from the quantitative analysis are presented. Some simple descriptive statistics are included.

CHAPTER 5 Discussion

All data are comparatively described across seasons and sampling site variations. Other reference studies and international standards are presented. Statistical analysis of the air quality data and meteorological data are discussed on the basis of seasonal variation. The ambient and source profiles were investigated and used in source apportionment.

CHAPTER 6 Conclusions

Comments on how the objectives have been achieved and suggestions on possibilities for further research are made.

CHAPTER 2

BACKGROUND

2.1 Particulate Matter

2.1.1 Particulate Matter in the Atmosphere

The atmosphere is comprises of a mixture of gases and particulate matter suspended within it. Particulate matter in the atmosphere is a complex mixture of liquid and solid particles of varying size distribution and chemical composition. Once particles have been emitted from their sources into the atmosphere, their dilution or concentration is dependent on the prevailing meteorological conditions. These conditions determine how dispersion of pollutants will occur, whether they are removed from the atmosphere via deposition processes and whether they undergo degradation in the atmosphere.

Particles present in the atmosphere come from sources, both natural and anthropogenic origins (Figure 2.1). Particles are defined as aggregations of matter larger than the surrounding molecules of gas and ranged from 1 nm to 100 μm in diameter. Particles larger than 100 μm can settle rapidly.

Particles less than 20 μm in diameter remain suspended in the atmosphere and are known as suspended particles. Inhaleable particles are all those less than 15 μm in diameter. Particles with a mean aerodynamic diameter less than 10 μm are capable of penetrating to the tracea-bronchial region of the lung. Hence, they may be ingested via the alimentary tract and if toxic, may have adverse health effects. These particles are known as PM10. Particles less than 2 μm can penetrate deep into the alveoli of the lungs and cause damage there. Some of the larger particles may settle in the nasal passages.

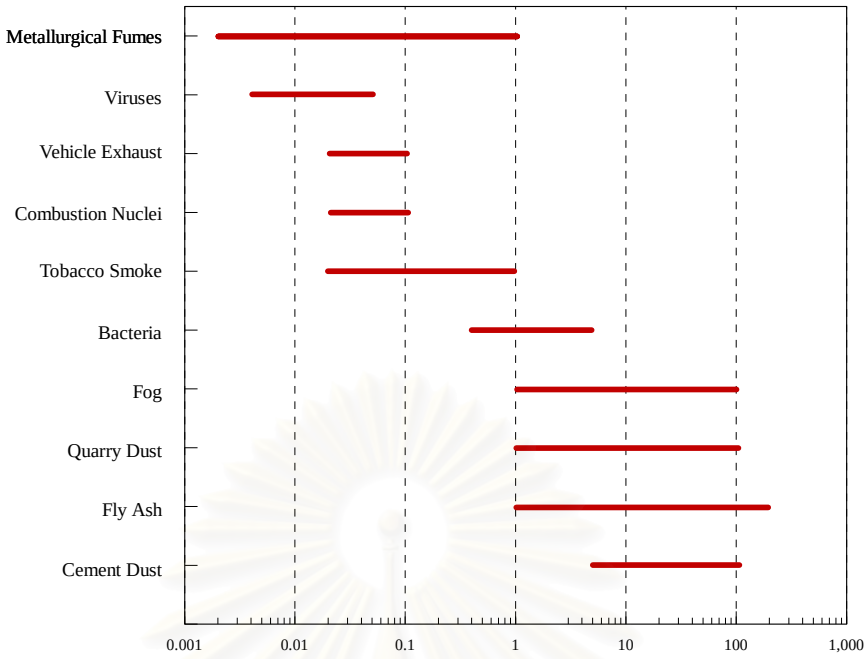


Figure 2.1 Size range of particles (EPA, 1991)

Particles in the air may be placed into several categories such as dust, fumes, smoke, mists/fog and secondary particles. Dust particles are defined as particles of mechanical or biological origin and include soil, sea spray, spores and pollen. Any particles of biological origin, such as bacteria, are also included in this category. Smoke describes carbonaceous residues from incomplete combustion processes. Secondary particles are formed in the atmosphere due to reaction of gases. Particulate material present in fog is an example. Mists or fogs are liquid droplets in the atmosphere and fumes result from gaseous materials which nucleate in the atmosphere to form larger aggregates.

2.1.2 Behavior of Particulate Matter in the Atmosphere

Figure 2.2 shows the finest particles with diameters of 0.005 to 0.1 μm, formed in the atmosphere mostly by condensation of hot vapors from combustion sources. Overtime, these smallest particles grow, mostly by agglomeration onto each other. Some of this agglomeration occurs in the gas phase, caused by Brownian motion bringing them into contact, some occurs inside cloud fog droplets. Mid size particles (0.1 to 1 μm) are formed partly by the agglomeration of finer particles and partly by chemical conversion

of gases and vapors on to particles in the atmosphere. These particles are large enough to be removed by rainout (capture by drops in clouds) or washout (capture by falling raindrops). Although they do grow by agglomeration to from larger particles, this process is slow compared to rainout and washout. The larger particles (2 to 100 μm) are mechanically generated, some are derived from industrial particle sources. The third peak represents for the most part, primary particles, emitted to the atmosphere in particulate form. There is some deposition of smaller particles onto these primary particles but it is not the major method of removal of these smaller particles.

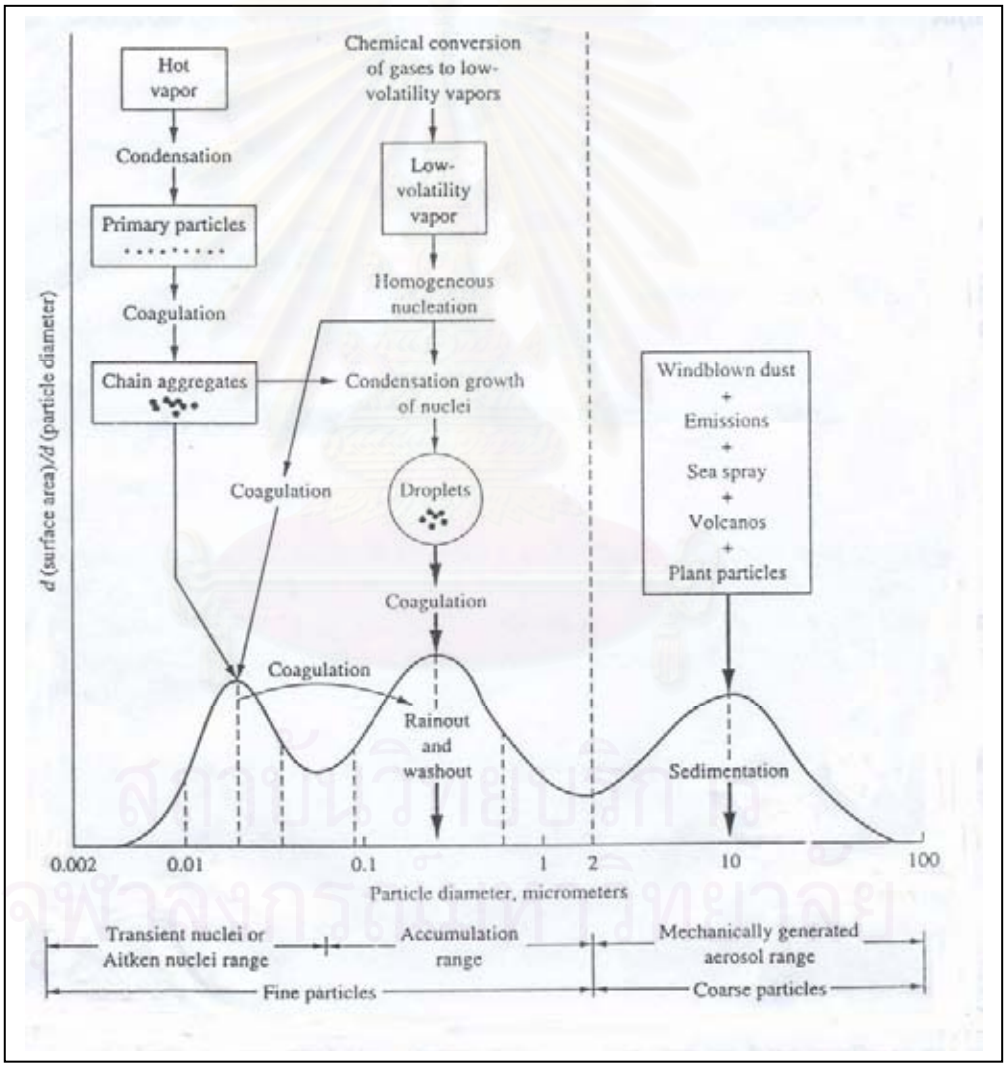


Figure 2.2 An estimate of the distribution of particles, by surface area, in an industrial atmosphere (Noel de Nevers, 2000)

2.1.3 Particulate Matter in Bangkok

Bangkok, a large city with a population of more than 6 millions, has faced serious problems from air pollution for long time. In many areas, the levels of PM10 were higher than these of National Ambient Air Quality Standard (PM10 24-hour = 120 μg/m^3).
PM levels reported by PCD are shown in Table 2.1.

Table 2.1 24-hour PM10 concentration at PCD sites (μg/m^3)

PCD Station	1997	1998	1999	2000
Huamark	71	60	53	54
Klong Jun	62	59	50	58
Huai Khwang	98	80	78	69
Yannawa	83	65	62	65
Bang Khunthien	89	69	59	54
Thonburi	96	90	83	81
Lad Prao	118	80	69	71
Dindaeng	139	100	71	72
Paumwan	42	86	84	89
Phayathai	63	49	101	115
Phahoyothin	69	51	80	107
Yowwarah	45	62	62	77

Source: Pollution Control Department Annual Report (1997-2000)

2.2 Polycyclic Aromatic Hydrocarbons

PAHs are a group of organic compounds made up of two or more fused benzene rings in linear, angular or cluster arrangements. Different arrangements of the rings have resulted in the identification of over 200 different compounds. The characteristics of PAHs used in this study are shown in Table 2.2.

Table 2.2 Characteristics of PAHs used in this study

Carcinogenic rankings (-) No evidence for animal carcinogenic

(±) Uncertain or weakly carcinogenic

(+) Weakly carcinogenic

(++) Moderately carcinogenic

(+++) Strongly carcinogenic

(++++) Very Strongly carcinogenic (IARC, 1983)

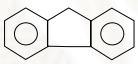
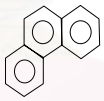
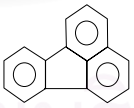
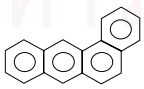
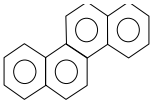
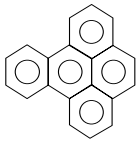
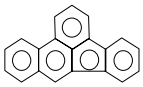
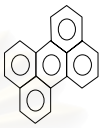
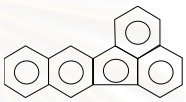
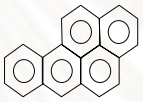
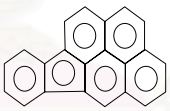
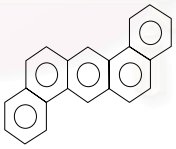
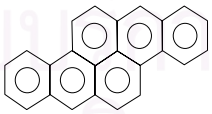
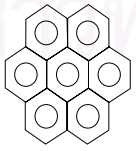
Name	Abbreviation	Formula	Structure	Molecular Weight	Carcinogenic Ranking
Naphthalene	Nap	$C_{10}H_8$		128	(-)
Acenapthylene	Acy	$C_{12}H_8$		152	(-)
Acenapthene	Ace	$C_{12}H_{10}$		154	(-)
Fluorene	Flu	$C_{13}H_{10}$		166	(-)
Phenanthrene	Phen	$C_{14}H_{10}$		178	(-)
Anthracene	Anth	$C_{14}H_{10}$		178	(-)
Fluoranthene	Flt	$C_{16}H_{10}$		202	(-)
Pyrene	Pyr	$C_{16}H_{10}$		202	(-)
Benzo[a]anthracene	BaA	$C_{18}H_{12}$		228	(+)
Chrysene	Chr	$C_{18}H_{12}$		228	(+/-)
Benzo[e]pyrene	BeP	$C_{20}H_{12}$		252	(-)

Table 2.2 Characteristics of PAHs used in this study (continued)

Name	Abbreviation	Formula	Structure	Molecular Weight	Carcinogenic Ranking
Benzo[b]fluoranthene	BbF	$C_{20}H_{12}$		252	(++/+++)
Perylene	Per	$C_{20}H_{12}$		252	(-)
Benzo[k]fluoranthene	BkF	$C_{20}H_{12}$		252	(+)
Benzo[a]pyrene	BaP	$C_{20}H_{12}$		252	(++++)
Benzo[ghi]perylene	BghiP	$C_{22}H_{12}$		276	(±)
Indeno[123cd]pyrene	Ind	$C_{22}H_{12}$		276	(++)
Dibenzo[ah]anthracene	DBahA	$C_{22}H_{14}$		278	(+++/++++)
Anthanthrene	Ant	$C_{22}H_{12}$		278	(+/++)
Coronene	Cor	$C_{24}H_{12}$		300	(-)

NaP enters the atmosphere primarily from fugitive emissions and exhaust connected with its presence in fuel oil and gasoline. Naphthalene reacts with photochemical produced hydroxyl radicals and degrades with a half-life of 3-8 hr. In polluted urban air, reaction with NO_3 radicals may be an additional sink for night time loss.(EPA, 2002)

Ace is a component of crude oil, coal tar and a product of combustion which may be produced and released to the environment during natural fires. Emissions from petroleum refining and coal tar distillation are major contributors of Ace to the environment. Ace is expected to exist entirely in the vapor phase in ambient air. An atmospheric half-life of is about 7.2 hours (EPA, 2002).

Flu occurs in fossil fuels. Its release to the environment is wide spread since it is a ubiquitous product of incomplete combustion. It is released to the atmosphere in emissions from the combustion of oil, gasoline, coal, wood and refuse. Flu is expected to exist primarily in the vapor phase in the ambient atmosphere; vapor phase Flu will degrade readily in the ambient atmosphere by reaction with photochemical produced hydroxyl radicals (estimated half-life of about 29 hr). Flu has been detected in rain, snow and fog samples, therefore, physical removal from air can occur through wet and dry deposition. Ambient air monitoring has shown that relatively small percentages of atmospheric Flu are associated with particulate-phase (EPA, 2002).

Phen most likely results from the incomplete combustion of a variety of organic compounds including wood and fossil fuels. Phen released to the atmosphere is expected to rapidly adsorb to particulate matter. Phen adsorbed on fly ash has been shown to photolyze rapidly and Phen adsorbed on particulate matter will be subject to wet and dry deposition. Vapor phase Phen will react with photochemical generated, atmospheric hydroxyl radicals with an estimated half-life of 1.67 days. Phen is a contaminant in air, water, sediment, soil, fish and other aquatic organisms and food. Human exposure results primarily from ingestion of food contaminated with Phen (EPA, 2002).

Anth's release to the environment is quite general since it is a ubiquitous product of incomplete combustion and has extensive natural and Anth sources. It is largely associated with particulate matter, soils, and sediments. Anth is expected to be present both in the vapor and the particle-sorbed state. Over 78% of atmospheric Anth may be present in the vapor state. Both chemical processes including ozone and hydroxide radical and photochemical reaction will degrade atmospheric Anth. The degradation of vapor phase atmospheric Anth is expected to be faster than particle sorbed Anth. The atmospheric half-life of Anth may vary from hours to days. The long range transport of Anth indicates that particle sorbed Anth may have a half-life of the order of days (EPA, 2002).

Flt released into the atmosphere exists as the free vapor as well as adsorbed to particulate matter. The unabsorbed chemical will photolyze as well as react with such molecules as ozone, nitrogen oxides and sulfur oxides. The half-life is approximately 4-5 days. The sorbed molecule is considerably more stable, traveling long distances under appropriate wind conditions. It will be subject to gravitational settling and rainout. The sorbed chemical, however, appears to degrade at about the same rate as the free chemical under photochemical smog conditions (EPA, 2002).

Pyr released to the atmosphere will likely be associated with particulate matter and may be subject to long distance transport, depending mainly on the particle size distribution and climatic conditions which will determine the rates of wet and dry deposition. Its presence in areas remote from primary sources demonstrates the potential for this long range transport as well as Pyr's considerable stability in the air. It may be subject to direct photo oxidation but evidence suggests that this process is retarded by the material being in the adsorbed state. In the vapor phase Pyr will be subject to reaction with various atmospheric pollutants with reported half-lives of 0.67 days for O_3 and 14 days for NO_2 . The estimated half-life for reaction with photochemical produced hydroxyl radicals is 1.12 days (EPA, 2002).

Chr released to the atmosphere will likely be associated with particulate matter and may be subject to long distance transport, depending on the particle size distribution and climactic conditions, which will determine the rates of wet and dry deposition. It may be subject to direct photo degradation, but evidence suggests that adsorption to various substrates may affect the rate of this process (EPA, 2002).

BbF, an atmospheric half-life of 1.00 day was estimated for the reaction of vapor phase BbF with photo chemically generated hydroxyl radicals. Adsorbed BbF will not react with hydroxyl radicals at this rate. Vapor phase BbF is expected to directly photolyze at a rapid rate in the atmosphere, but the adsorbed compound may not do so (EPA, 2002).

BaP released to the atmosphere will likely be associated with particulate matter and may be subject to moderately long transport, depending mainly on the particle size distribution and climactic conditions which will determine the rates of wet and dry deposition. Its presence in areas remote from primary sources demonstrates the potential for this long range transport as well as BaP's considerable stability in the air. A half-life of 1.4 years has been reported for removal of BaP from the gas phase by rainout and has a lifetime of 7.9 days for removal by aerosol particles . It may be subject to direct photo degradation but evidence suggests that this process is retarded by the material being in the adsorbed state. Half-life for reaction of a thin film of BaP with 0.19 ppm O_3 is 37 min and for reaction of adsorbed BaP with NO_2 is 7 days. The estimated half-life for reaction with photo chemically produced hydroxyl radicals is 21.49 hr (EPA, 2002).

Benzo[a]pyrene (BaP) has traditionally been given the most attention due to its high carcinogenic and it is ubiquitous nature. BaP has been generated from many sources in the atmosphere such as the manufacture of aluminum, asphalt, coke, petroleum, steel moulds, the combustion of automobile fuel, coal, and diesel fuel. BaP is one of the most potent carcinogens known and the most extensive data are available for this compound. Although BaP is one of the principal carcinogenic PAHs, it represents only a small fraction of the total PAHs present in most circumstances (Baek, 1991a).

BkF and other PAHs in distant places far removed from sources, demonstrates not only their potential for long-ranged transport but also their stability to degradation in their predominant atmospheric state which is associated with submicron particles and aerosols. These particulate will be transported but are subject to gravitational settling and scavenging by rain and snow (EPA, 2002).

DBahA released to the atmosphere will likely be associated with particulate matter and may be subject to moderately long range transport, depending mainly on the particle size distribution and climactic conditions which will determine the rates of wet and dry deposition. Its presence in areas remote from primary sources demonstrates the potential for this long range transport as well as DbahA 's considerable stability in the air. The estimated vapor phase half-life in the atmosphere is 1.00 day as a result of reaction with photochemical produced hydroxyl radicals (EPA, 2002).

If released to the atmosphere, BghiP will exist almost entirely in the particulate (adsorbed) phase. The rate of photolyze has been found to vary with the adsorbing substrate; photolyze of BghiP adsorbed to fly ash may have some importance, but adsorption to carbon black stabilizes the compound toward potential photo transformation (EPA, 2002).

Most Ind in the atmosphere will be sorbed to particulate matter . Therefore, in the absence of major photo decomposition or other chemical transformations, the atmospheric fate of Ind will depend primarily on physical processes such as dry and wet deposition. A computer estimated half-life for Ind in the vapor phase of the atmosphere is 20 hours due to reaction with photo chemically produced hydroxyl radicals (EPA, 2002).

2.2.1 Sources and Production of PAHs

Sources of PAHs are both natural and anthropogenic. Natural sources of PAHs include biosynthesis by algae, plants, or bacteria, volcanic eruptions, and forest fires. The major anthropogenic sources of PAHs may be split into stationary and mobile combustion sources. Stationary sources include residential heating, power-generated industry, and incineration. Mobile sources include motor vehicles and aircraft (Figure 2.3).

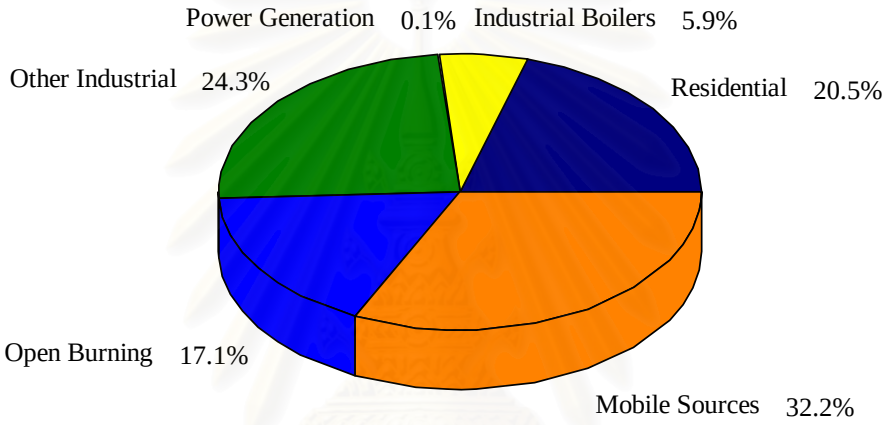


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Figure 2.3 Estimated total PAHs emissions for USA in 1981 (Ramdahl et al., 1983)

Mobile Sources

Absolute PAHs levels have been decreasing in urban environments due to the replacement of coal burning for energy with other cleaner processes. Therefore the contribution of motor vehicles to total urban PAHs levels has increased. In London, around a one fourth of the BaP measured in the air was attributed to mobile sources (Commins and Hampton, 1976). A review of sources of PAHs in the USA in 1983 found that motor vehicles accounted for aproximately 30% of the PAHs emissions (Smith, 1984). Emissions from motor vehicles have been estimated at 136.6 kg of PAHs emitted to the urban aerosol of Los Angeles per day in 1982 (Rogge et al., 1993).

With the introduction of unleaded petrol, emissions from mobile sources have decreased significantly. However, mobile sources are still a major contributor to urban particulate matter and PAHs concentrations. Emissions from leaded petrol cars with no catalytic converter may increase the PAHs concentration up to 25 times higher than for unleaded petrol engines (Rogge et al., 1993).

Many studies have been carried out to determine the levels of PAHs present in vehicular exhausts (Nelson, 1989; Rogge et al., 1993). Several factors have been found to influence the production of PAHs in mobile sources including fuel aromatic, temperature, fuel consumption, air/fuel ratio, condition of engine, engine load and the presence of other substances that modify the combustion process. Generally, less PAHs are produced when the car is at high speed with few stops and starts. PAHs improving combustion efficiency of car engines may reduce emissions. Figures 2.4 and 2.5 showed the PAHs presented in the exhaust of catalyst and non-catalyst equipped motor vehicles. Although the emission concentrations are much lower for catalyst-equipped engines, for both emissions, BghiP is still the major product. BghiP has been used as a tracer for the emissions of motor vehicles for many years (Janssen, 1980). In unleaded/catalyst equipped engines, Cor levels are much lower than for leaded petrol engines. This is dued to the fact that Cor is more effectively removed from the exhaust by the catalytic converter than other PAHs.

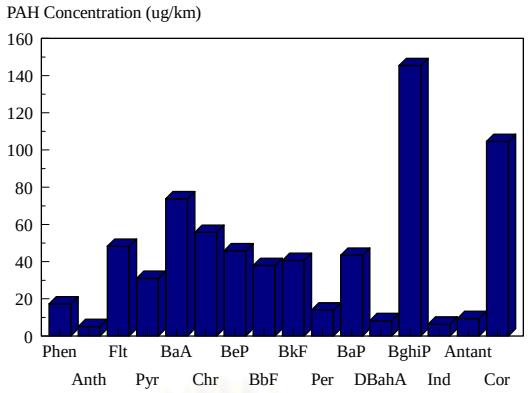


Figure 2.4 PAHs emission for non-catalyst equipped (leaded petrol) motor vehicles (Rogge et al., 1993).

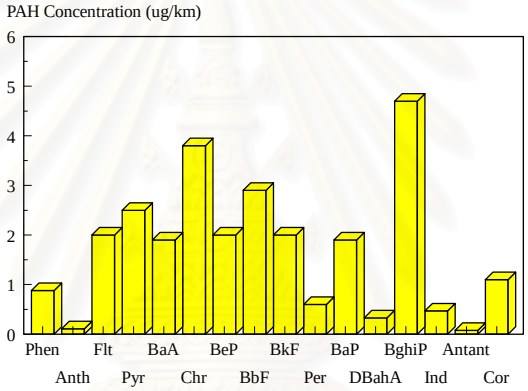


Figure 2.5 PAHs emission for catalyst equipped (unleaded petrol) motor vehicles (Rogge et al., 1993).

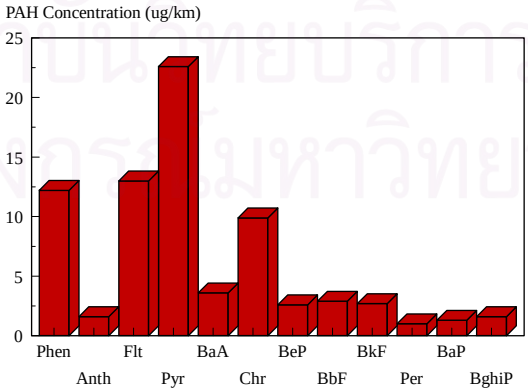


Figure 2.6 PAHs emission for heavy duty diesel trucks (Rogge et al., 1993).

Diesel fuelled vehicles produce more different concentrations and profiles of PAHs than petrol fuelled vehicles. Particulate emissions from diesels are generally higher than those from gasoline fuelled vehicles however; less PAHs are emitted from well-maintained diesel fuel engines. BaP emission rates of around 1.3 μg/km have been measured for heavy-duty diesel trucks. Total PAHs emissions are around 200 μg/km, one-seventh as large as non-catalyst petrol motor vehicles, however 4 times higher than those from unleaded catalyst engines are (Rogge et al., 1993). Figure 2.6 shows the emission concentrations of PAHs from diesel fuelled engines. Major PAHs components of diesel exhaust are Nap and Ace. Phen, Pyr and Flu are also present in significant proportions. (Nelson, 1989)

PAHs concentrations of individual species may not give an appropriate indication of the sources of PAHs in the atmosphere. In the past, ratios of various PAHs have been used to indicate the emission sources. These ratios have generally been calculated from leaded automobile sources. Overall, cars using unleaded fuel emit much lower levels of PAHs, however, the ratios of various PAHs in the exhaust are generally similar, except for those involving Cor. Cor levels emitted from unleaded vehicles are much lower in respect to other PAHs emitted, so BaP/Cor ratios are higher than those that would be present in leaded petrol exhaust and Cor/BeP ratios are lower.

Table 2.3 shows the ratios calculated from emissions from leaded and unleaded vehicles. BaP/BghiP, BghiP/Ind and BghiP/BeP ratios are fairly similar between the two sources, however the two ratios involving Cor are markedly different.

Both diesel and petrol engines have been found to both emit similar ratios of BghiP, Cor and BaP although diesel engines also emit large amounts of lower molecular weight PAHs (Stenberg et al., 1979). Diesel exhausts are generally enriched in Flu, Chr and Pyr. So ratios, such as Flt/BeP; Chr/BeP; Pyr/BeP and Pyr/BaP, will be higher in areas where more diesel engines are present. Once again, ratios involving Pyr may be unreliable due to analytical problems. Another ratio used to indicate the presence of diesel fuel exhausts is BkF/Cor (Venkataraman et al., 1994).

Table 2.3 Ratios calculated from emissions from non-catalyst and catalyst equipped automobiles (Rogge et al., 1993).

Ratio	Non-catalyst (Leaded) Engines	Catalyst (Un-leaded) Engines
BaP/Cor	0.42	1.0
BaP/BghiP	0.30	0.40
BghiP/Ind	2.70	1.80
BghiP/BeP	3.17	2.35
Cor/BeP	2.28	0.55

Bangkok has a severe motor vehicle problem. Around 30% of the total motor vehicle registrations in Bangkok during 1999 were trucks and buses using diesel fuel. The number of vehicles in Bangkok estimated at over 4.0 million in 1999. It has been reported (WHO, 1992) that emission from traffic is often so bad that reductions in visibility are a safety hazard. In the city, taxis and tricycles mostly use Liquid Petroleum Gas (LPG). Diesel sale rates are also significant in Bangkok because it is a lot cheaper than petrol. Because a large number of trucks and buses in the city use diesel fuel, PAHs associated PM produced by these vehicles increased dramatically (WHO, 1992).

Domestic and Industrial Emissions

Bangkok has two thermal power stations in the metropolitan area; both fired with natural gas, supplying 11% of the nations electricity. 89.2% of Thailand's electricity is generated from fossil fuels, the remaining being hydroelectric generators. Small and medium industries such as textile and building materials, food processing and electronic equipment assembly plants are situated in the city. Energy consumption has increased in Thailand by more than 50% in the ten years up to 1989.

Since 1976, the Thai Government of Thailand has a policy to build new industrial parks on the outskirts of the city (WHO, 1992). Areas, such as Samut Prakan (South East of Bangkok), are heavily industry-based towns. Emissions from this town usually bypass Bangkok because most winds are from the NorthEast or SouthWest and the city is buffered from the heavy industrial zone in Samut Prakan by the Bangkrajao forest belt.

Other major sources of particles in Thailand are fugitive dust from open field burning and agricultural sources. Furthermore, it has been documented that households and agriculture activities combined emit 42% of particles in the atmosphere.

2.2.2 Particulate-bound Versus Vapor Phase Fractions

High molecular weights PAHs are predominantly adsorbed on soot and particulate matter (due to the low vapor pressure). The ratio of the amount of PAHs present in the particulate-bound phase to the amount present in the vapor phase is dependent upon the specific PAHs and the system properties (particulate loading and temperature). Particulate bound versus vapor phase fractions is shown in Figure 2.7

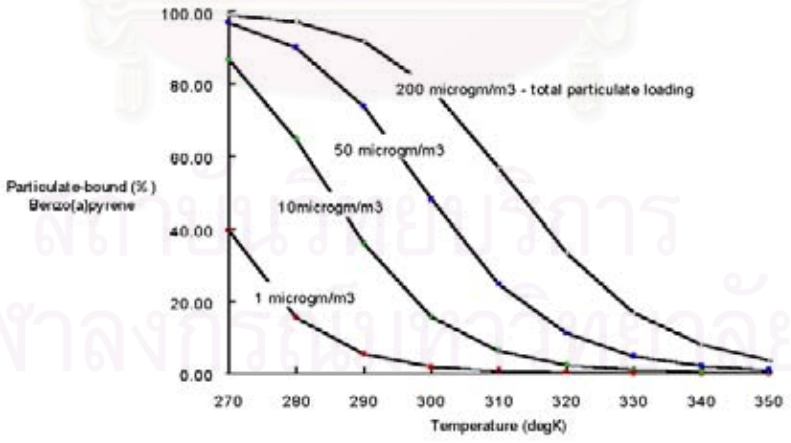


Figure 2.7 Particulate bound versus vapor phase fractions (Baek, 1991b)

2.2.3 Particulate Fraction for Health Concerns

Ultrafine particles (< 2.5 micron) are not removed by the upper respiratory tract and are carried into the lungs. These ultrafine particles act as carriers of chemicals in to the human body. Particulate fraction for health concerns is shown in Figure 2.8.

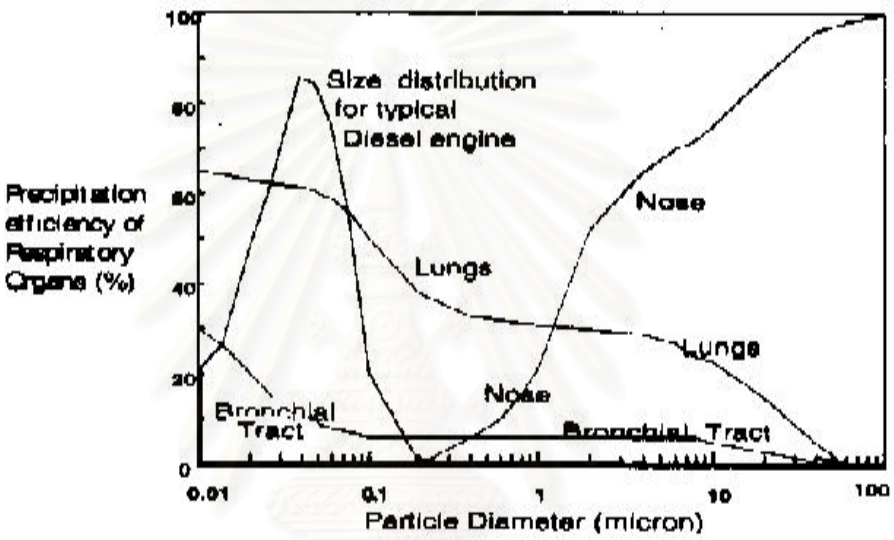


Figure 2.8 Particulate fraction for health concerns (Ledbetter, 1972)

Benzo(a)pyrene (BaP), which has been linked with cancer, is commonly used as an indicator for the presence of PAHs (Freeman and Cattell, 1990). It is generally considered that there are no safe limits for PAHs in the ambient air. The only national guideline for PAHs is that set by the Netherlands for BaP. This includes an annual average limit value for BaP of 0.5 ng/m^3. However they also have an annual average guide value considerably lower at 0.5 ng/m^3. In Bangkok the average BaP levels was 1.0 ng/m^3(Panther, 1996).

Ratios of individual PAHs are commonly used with varying degrees of success to give an indication of the type of activity responsible for the generation of PAHs.

Transportation sources are classified as mobile while stationary sources include industry, heating and refuse burning. Mobile sources include diesel and petroleum while stationary sources can include various fuels such as coal, oil and wood. The ratios traditionally used for distinguishing between mobile and stationary sources are Bap/Cor and Bap/BghiP (Brasser, 1980)

Table 2.4 Polycyclic Aromatic Hydrocarbons ratios for source determination (Brasser, 1980)

	BaP/Cor	BaP/BghiP
Mobile source	<0.4 – 1.0	0.2 – 0.6
Stationary souse	> 1.7	> 0.8

The major justification for the more recent measurements has been in the studies of emissions of toxic organic species, such as benzene; 1,3 – butadiene; formaldehyde; acetaldehyde and PAHs, from motor vehicles emissions (Nelson, 1989)

2.2.4. Benzo(a)pyrene (BaP)

BaP is released to the atmosphere and associated with particulate matter and moderately long transport, depending mainly on the particle size distribution and climatic conditions. A half-life of 1.4 years is reported for removal of BaP from the gas phase by rain and has a lifetime of 7.9 days for removal by aerosol particles .

BaP is the most carcinogenic of the PAHs and is commonly used as an indicator for the presence of PAHs. The annual average guide value for BaP in Netherlands is 0.5 ng/m^3(Freeman and Cattell, 1990). BaP levels were measured in different cities and towns. In three group of different population, Big city > 5 million, city 1-5 million and city or town <1 million. It was found that the range of BaP concentration was effected from both population and seasonal variation (Table 2.5).

Table 2.5 BaP levels measured in different cities.

City	Year of Study	BaP Range (ng/m^3)	Sources
Bangkok, Thailand*	1993-1994	0.18-2.44	Panther et al.,1996
Bangkok, Thailand*	1996-1997	0.50-1.70	Oanh et al., 2000
Bangkok, Thailand*	1996	0.67	Garivait et al.,1999
Birmingham, UK**	1997	0.08	Lim et al.,1999
Bombay, India*	1973	0.80-36.00	Mohan et al.,1975
Darwin, Australia***	1994-1996	0.09	Vanderzalm et al.,1998
Delhi, India**	1984	0.04-0.81	Banerjee et al.,1986
Dili, East Timor***	1995-1997	0.80	Vanderzalm et al.,1998
Hong Kong, China*	1993	0.00-0.78	Panther et al.,1996
Jakarta, Indonesia*	1993	0.83-10.22	Panther et al.,1996
Mumbai, India*	1996	1.80-1.90	Kulkarni et al., 2000
Naples, Italy**	1996	0.03-12.00	Caricchia et al.,1999
Seoul, South Korea*	1993	1.20	Panther et al.,1996
Singapore**	1983	1.65-3.55	Ang et al.,1986
Sydney, Australia**	1986	1.30	Pradhan et al.,1986
Taipei, Taiwan**	1987-1991	0.04-0.81	Chang et al., 2000
Tokyo, Japan*	1997	0.13-0.90	Sugita et al., 1999

* City > 5 million population.

** City 1- 5 million population

*** City /Town < 1 million population

2.2.5 PAHs in Bangkok

The level of daily PAHs concentration in Bangkok has been measured. The results showed that the minimum and maximum PAHs level were in May-beginning of rainy season (4.97 ng/m^3), and March-beginning of summer (74.03 ng/m^3), respectively.

Table 2.5 shows BaP concentration in Bangkok ranged from 0.18 to 2.44 ng/m^3. BaP is the most carcinogenic of the PAHs. The daily average exposure in Bangkok to BaP is 9.9 ng /day. (Panther et al. 1996)

BeP is one of the PAHs present, making up to10.5% of the total PAHs levels. Levels of BghiP and low molecular weight Ace and Acy are also significant. BeP mainly produced from stationary sources, whereas Ace, Acy and Flt were from diesel fuel burning (Panther et al. 1996).

Pyr, BaA, BeP, BkF, BaP and BghiP were found prevailing in Bangkok urban air. The lower molecular weight PAHs, such as Pyr; BeP and BaA, were present mainly in the gaseous phase (80%, 40% and 24%, respectively), while the higher molecular weight compounds were present almost totally in the particulate fraction (Garivait H. 1999).

About 30%-60% of each PAHs content were found on particles smaller than 0.43 μm fraction and more than 70% on particles smaller than 2.1 μm. The incorporation of PAHs into particulate matter was consistent with the adsorption and condensation processes with a marked preference for the sub-micron size particles (Garivait H. 1999).
The concentration of total PAHs in the samples obtained from traffic policemen on duty outside (68.64$\pm$28.59 ng/m^3) and those from the policemen working in offices (8.43$\pm$3.54 ng/m^3) (Pui-ock et al. 1999)

2.2.6 ∑PAHs in Different Cities

The ∑PAHs levels measured in different cities are shown in Table 2.6. In large city ∑PAHs was higher than that for Small City or town. The range effected from both population and seasonal variation. BghiP is dominant PAH in many countries.

Table 2.6 ∑PAHs levels measured in different cities

City	∑ PAHs (ng/m^3)	Numbers of PAHs	Dominant PAHs	Year	
1.Bangkok, Thailand*	14.7-43.0	9	Pyr,BaA,BeP BkF,Bap,BghiP	1993	R1
2.Bangkok, Thailand*	6.5-58.0	18	BghiP,Pyr,Cor	1996-7	R2
3.Bangkok, Thailand*	5.0-74.0	20	BeP,BghiP,Ace Acy	1993-4	R3
4.Jarkarta, Indonesia*	13.3-177.2	20	NaP,Ace,Acy BeP,BghiP	1993	R5
5.Darwin, Australia***	0.8-13.1	20	NaP,Ace,BeP BaP,BbF	1994-7	R4
6.Dili, East Timor***	0.0-36.8	20	NaP,Ace,BeP BaP,BbF	1995-6	R4
7.Mumbai, India*	24.5-138.8	17	Pyr,BaA,BbF BkF	1996	R6
8.Naples, Italy**	2.0-130.0	17	BghiP,BaP,Cor	1996-7	R7

R1 = Garivait H.,1999 R4 = Venkataraman et al., 2000 R7= Caricchia et al.,1999

R2 = Oanh et al., 2000 R5 = Panther et al., 1999

R3 = Panther et al.,1996 R6 = Kulkarni et al., 2000

* City >5 million population

** City 1- 5 million population

*** City /Town <1 million population

2.3 Meteorological Features

Bangkok's climate is classified as tropical savanna. Temperature is warm all year round and very hot in April. Bangkok has three seasons: winter (November- mid February), summer (mid February to mid May) and rainy season (mid May to October). Southwest wind predominates during the rainy season and wind is generally Northeast during the winter. During the summer, average temperature is around 30°C and reduces to 25°C during the winter. Annual rainfall is aproximately 1400 mm and 80-90% of this occurs during the rainy season. The flat plains around Bangkok allow free air movement, so pollutants are generally efficiently dispersed, except when the air is calm.

CHAPTER 3

METHODOLOGY

3.1 Sampling

3.1.1 Sampling Sites

In this study, six sampling were chosen. Five were in Bangkok i.e. Chulalongkorn University, Chulalongkorn Hospital, Dindaeng, Office of Environmental Policy and Planning (OEPP), Singharat School. One sampling site is outside Bangkok i.e. Bangkok University, Rangsit, Patumthani province, 30 kilometers North of Bangkok.

Five sites, namely Chulalongkorn Hospital, Dindaeng, OEPP, Singharat School and Bangkok University, were PCD monitoring station sites. Only at Chulalongkorn University, sampling conducted by the author. Wind dominant direction up wind site and down wind site during the rainy season and winter. In winter, Bangkok University is upwind and Singharat School is downwind and vice versa in summer and rainy season.

The PM samples were collected from six sites. Four sampling sites were in the inner area of Bangkok represented heavily polluted area, namely Chulalongkorn University and OEPP, Chulalongkorn Hospital and Dindaeng. Singharat School is located at the cleaner site at South West and is expected to be moderately polluted site. Bangkok University, which is at the outer edge of Bangkok, represented the low polluted monitoring site. The map of the six sampling sites is shown in Figure 3.1.

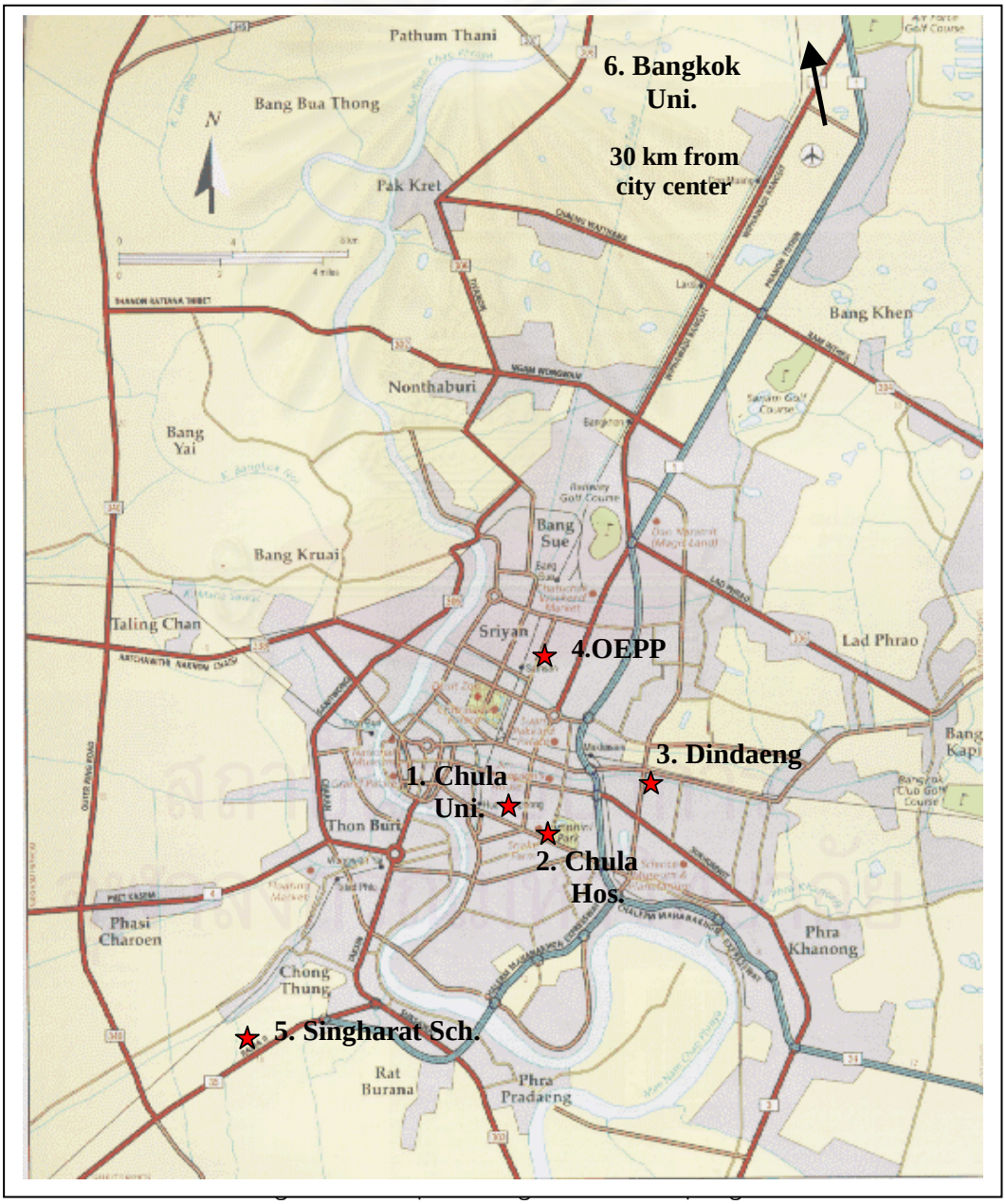


Figure 3.1 Map of Bangkok and sampling sites

The sampling locations for each site are described as follows:

1. Chulalongkorn University (Figure 3.2) This location is classified as mixed area, commercial environ with office block, shopping area and educational building. The PM10 and SFPM samplings were set up at the roof of the fourth level of General Science Building, Faculty of Science, Chulalongkorn University, Patumwan. This site was about 15 meters above the ground and 300 meters from Phayathai roadside.

Figure 3.2 Chulalongkorn University sampling site

2. Chulalongkorn Hospital (Figure 3.3) This location is classified as roadside area, located at the Saladaeng intersection, Lumpinee. This sampling site was at the ground of Chulalongkorn Hospital and opposite Lumpinee Public Park. This site was considered as business and supermarket zone. There are a sky train running on the Rachadumri Road and also the construction of the underground train. It has been recorded that there were approximately 109,400-cars/ 12 hour-day in June 2000 (Office of the Commission for the Management of Road Traffic, 2000) (Appendix D).

Figure 3.3 Chulalongkorn Hospital sampling site

3. Dindaeng (Figure 3.4) This location is classified as a roadside area, on the Asoke-Dindaeng Road. This site was closed to Dindaeng flat and opposite of a secondary school. The sampling equipment was placed on the top of container, 3 meters above the ground. There was approximately 72,200 cars/ 12 hour-day in February 2000 (Appendix D).

Figure 3.4 Dindaeng sampling site

4. OEPP (Figure 3.5) This location is classified as a mixed area since it is located in the urban center and surrounded by commercial buildings, government offices and houses. This site has minor surrounding roads and an express way at approximately half a kilometer. The sampling apparatus was placed on top of a container, which was about 3 meters above the ground.

Figure 3.5 Office of Environmental Policy and Planning sampling site

5. Singharat School (Figure 3.6) This location was considered as a mixed area, near the Singharat secondary school. There are a few factories in this area. The sampling apparatus was placed on the top container, 3 meters above the ground. It is located at Soi Akachai 36, 300 meters from Akachai road.

Figure 3.6 Singharat School sampling site

6 Bangkok University (Figure 3.7) This location was classified as an outer suburban area. It is located at Klong-Luang, Patumthani province, which was the suburban of Bangkok. The sampling apparatus was located at the ground of Bangkok University, 600 meters from main road (Phahonyothin Road). There were a few factories surrounded this area, such as the animal food products.

Figure 3.7 Bangkok University sampling site

3.1.2 Sampling Duration

Sampling was conducted during November 1999 – November 2000 with appropriate recognition of seasonal changes: winter (16 November 1999 – 21 February 2000), summer (22 February 2000 – 15 May 2000) and rainy season (16 May 2000 – 31 October 2000)

3.1.3 Number of Samples

Tables 3.1 shows number of samples at each site. The sampling schedule of this study is shown in Table 3.2. PM10 samples were taken from five PCD sites namely, Chulalongkorn Hospital, Dindaeng, OEPP, Singharat School and Bangkok University. There were sampling every six or twelve day and two samples per month were taken from each PCD site. Both PM10 and SFPM samples were taken only at Chulalongkorn University site. All samples were analyzed for particulate matter concentration. All filter samples were prepared at the Center of Environmental Science Laboratory, Monash University. After sampling, the filters were returned, weighed and analyzed at Monash University.

Table 3.1 Number of samples

Sites	PM10 (Samples)	SFPM (Samples)
1. Chulalongkorn University	40	39
2. Chulalongkorn Hospital	19	
3. Dindaeng	24	
4. OEPP	26	
5. Singharat School	22	
6. Bangkok University	23	

Table 3.2 Schedule of PM10 sampling

Chulalongkorn University	Chulalongkorn Hospital	Dindaeng	OEPP	Singharat School	Bangkok University
12/11/99	5/11/99	11/11/99	5/11/99	5/11/99	17/11/99
18/11/99	14/11/99	17/11/99	23/11/99	17/11/99	26/11/99
25/11/99	26/11/99				
1/12/99		11/12/99	11/12/99	5/12/99	5/12/99
7/12/99		23/12/99	20/12/99	23/12/99	14/12/99
15/12//99					
23/12/99					
27/12/99					
10/1/00	4/1/00	16/1/00	10/1/00	10/1/00	
20/1/00	22/1/00	22/1/00	22/1/00	22/1/00	
25/1/00					
1/2/00	9/2/00	15/2/99	9/2/00		9/2/00
8/2/00	21/2/00	27/2/00	27/2/00		15/2/99
15/2/99					27/2/00
6/3/00	10/3/00	4/3/00	10/3/00		10/3/00
14/3/00	16/3/00	10/3/00	22/3/00		28/3/00
23/3/00					
27/3/00					
1/4/00	3/4/00	3/4/00	9/4/00	9/4/00	9/4/00
4/4/00	15/4/00	15/4/00	27/4/00	15/4/00	15/4/00
17/4/00					
25/4/00					
04/05/00	15/05/00	03/05/00	03/05/00	03/05/00	09/05/00
10/05/00	27/05/00	15/05/00	27/05/00	15/05/00	21/05/00

Table 3.2 Schedule of PM10 sampling (continued)

Chulalongkorn University	Chulalongkorn Hospital	Dindaeng	OEPP	Singharat School	Bangkok University
13/05/00 22/05/00					
03/06/00 15/16/00 27/06/00			03/06/00 20/06/00	08/06/00 20/06/00	08/06/00 26/06/00
09/07/00 21/07/00		08/07/00 19/07/00	02/07/00 20/07/00	08/07/00 19/07/00	20/07/00
02/08/00		01/08/00 19/08/00	19/08/00 25/08/00	07/08/00 19/08/00	31/08/00
07/09/00 19/09/00 25/09/00	06/09/00 18/09/00	06/09/00 18/09/00	12/09/00 24/09/00	12/09/00 30/09/00	06/09/00 24/09/00
01/10/00 13/10/00 19/10/00 24/10/00	06/10/00 24/10/00	07/10/00 12/10/00	07/10/00 18/10/00	06/10/00 18/10/00	06/10/00 24/10/00
23/11/00	05/11/00 23/11/00	11/11/00 17/11/00	11/11/00 23/11/00	11/11/00 17/11/00	11/11/00 23/11/00

3.1.4 Sampling Equipment

• High volume air sampler

This study employed high volume air sampler model Ecotech 2000, made in Australia. The sampler included flow control and sampling time programming devices. Ambient air is drawn into the size-selective inlet at a constant flow-rate of 1.13 standard m^3/min (67.8 m^3/hour). After installed on the sampling site, this high volume sampler was calibrated using calibrated orifice plate by Sittiporn Company staff. The sampler was then re-calibrated every three months. (Figure 3.8)

• High volume air sampler attached with PM10 inlet

The particles are accelerated through multiple acceleration nozzles. Particles larger than 10 micron gain sufficient momentum to cause impacting onto a greased collection shim, which should be periodically cleaned and re-greased. The PM10 particles, however, are smaller and having less momentum stay entrained in the airflow and pass to the filter, where they are collected. The symmetrical design of the inlet overcomes the effect of wind direction and the inlet design makes the collection efficiency independent cut point of 9.7 microns. (Figure 3.9)

Figure 3.8 Calibration of high volume sampler

Figure 3.9 High volume air sampler attached with PM10 inlet

• **Sized fractionating cascade impactor**

The high volume air sampler was incorporated with an Andersen series 235-cascade impactor for size fractionated sampling purposes (Figure 3.10). There were four size cutoff stages plus a base plate. All stage plates have an outside dimension of 23.5 cm (9.25") (W)×30.5 cm (12")(L) x 5.1 cm (2") (H) net weight 2.5 kg (5.5 lbs) and made of clear anodized aluminum to prevent corrosion and reduce possible sticking of collection substrates to the plates. The cutoff sizes are based on aerodynamic equivalent diameters, There were for size cutoff stages are 7.2 μm, 3.0 μm, 1.5 μm, 0.95 μm. These are the given experimental values by the manufacturer, which are obtained from calibrations with mono-dispersion aerosols. The stage plates have 10 parallel slotted impacting jets, expect stage 1 which has 9 slots to eliminate end effects. The centerlines of all slots were half inch apart. According the manufacturer 's suggestion, the highest particle cut-off size is nominally 10 μm. The base plate at the bottom was designed to mount a 8"×10" inches high volume filter paper as the backup filter for the cascade impactor to collect all particles smaller than the cutoff size of the last impactor stage(Figure 3.11).

Figure 3.10 High volume air sampler attached with SFPM impactor

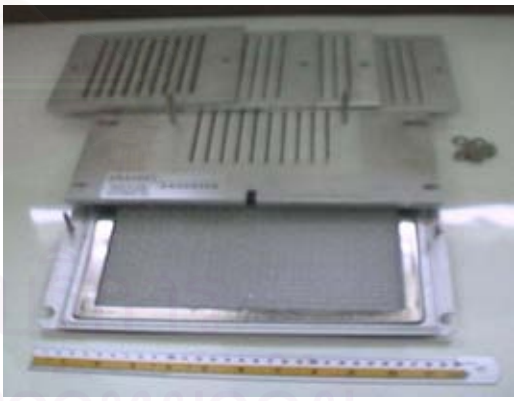


Figure 3.11 Sized fractionating cascade impactor

3.1.5 Sampling Apparatus

• PM10 sampling filters.

Whatman Glass fibre filters (8"×10") were used to collect the PM10 by the high volume air sampler. The filters were weighed prior to use and again afterwards to determine the amount of particulate matter. Approximately 1,700 m^3 of air passed through each filters over 24 hours.

• Size Fractionating collection filters

Two types of specially designed filter substrates were used for the size fractionating cascade impactor. One type was glassfibre (8" x 10") and the second was cellulose substrates. The substrates were thin flat sheets with 10 perforated slots exposing the slots in each stage. During the sampling, particles passing through the slotted jets in the impactor stages impact on the collected particles were kept for subsequent chemical and mass analysis. The collection substrates had a size of 5.625" × 5.375" (14cm ×13.5cm) and a low tare weight. (Figure 3.12)

Figure 3.12 Size fractionating collection filters

Aluminum foil

Glass fiber diameter 37 mm 0.8 micron (Environmental Express)

Cassettes PVC diameter 37 mm. (Environmental Express)

3.1.6 Source Sampling

The source emission samples from motor vehicles were identified and collected on a dynamometer system under a standard vehicle run cycle. The experiment was conducted at Automotive Emission Laboratory, PCD. The exhaust emissions from a range of vehicle types including heavy duty diesel vehicle (HDDV), light duty diesel vehicle (LDDV), light duty gasoline vehicle (LDGV), motor cycle and motorized tricycle (tuktuk) were tested and particle emission were collected.

The heavy and light diesel driving cycle included idle modes constant speed at 40 and 70 km/h plus acceleration and deceleration mode. All heavy diesel buses use diesel fuels PTT. All buses were from Bangkok. Figure 3.13 and 3.14 showed the HDDV and LDDV emission test .The emission characteristic of the vehicle test is presented in Table 3.4.

Figure 3.13 HDDV emission test

Figure 3.14 LDDV emission test

Fine particulate exhaust samples were collected downstream of the two parallel particulate holders (Figure 3.15). Two filter holders were loaded with glass fibre topped with filter 58 mm in diameter. First and second filters in two holders are shown in Figure 3.16.

Figure 3.15 Diesel vehicle filters holders

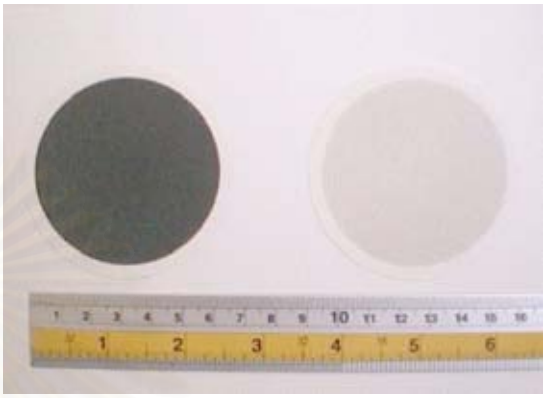


Figure 3.16 First and second samples from diesel vehicle

Tricycles (tuktuk) used two different type fuels, Compressed Natural Gas (CNG) and Gasoline (PTT). Tuktuks were tested according to a following procedure. Simulate urban diving condition for tuktuk, dynamometer was used (Figure 3.17). The diving cycle idle mode, constant driving, accelerate and deceleration modes. The particles exhaust samples were collected downstream, connected to the box sampling. Three of (8" x 10") glass fibre filters packed in box sampling (Figure 3.18). All filters were weighed and reweighed for determination of particulate matter. The constant humidity and temperature condition were kept in desiccator. The fibers were reserved for PAHs compound analysis. All filters are packed in aluminum foil.

Figure 3.17 Tuktuk emission test

Figure 3.18 Box sampling of tuktuk emission test

The gasoline automobile and motorcycles sampled by the author, (Figure 3.19-3.20). During sample collection, the vehicle was in idle mode only. An exhaust pipe sampler and low flow pump were used to collect these exhaust samples. The filter holder is a PVC cassette, 37 mm in diameter, and the glass fibre substrates were used (Figure 3.20-3.21).

Figure 3.19 Two-stroke motorcycle emission test

Figure 3.20 Gasoline vehicles sampling Figure 3.21 Low flow pump and PVC cassette

Three emission sources were sampled: vehicle, industry, road dust sources. There were six types of vehicle emission: heavy diesel, light diesel, gasoline vehicle, two and four-stroke motorcycle, and tuktuk. Boiler and incinerator stack emissions as well as road dust from four different areas were sampled. The numbers of source are shown in Table 3.3.

Table 3.3 Type of emission sources and number of source samples

Vehicles		Industry		Road dust	
HDDV	(3)	Boiler stack	(4)	Phahonyothin road	(2)
LDDV	(3)	Incinerator stack	(2)	Dindaeng road	(2)
LDGV	(3)			Bantadthong road	(2)
Two-stroke motorcycle	(1)			Ladya road	(2)
Four-stroke motorcycle	(1)				
Tuktuk (gasoline,CNG)	(2)				

* Number of sampled is in the bracket.

** Road dust samples size between <38 μm and 38-75 μm

Vehicle as Emission Source

There were three types of bus heavy diesel, three types of pick up light diesel, tuktuk using two different fuels types, three types of gasoline vehicle, two and four-stroke of motorcycle (Table 3.4).

Table 3.4 Type of vehicles, vehicle model, engine type and fuel type

Type	Vehicle Model	Engine Type	Fuel Type	Test Date	Dust (mg)
HDDV					
1. Benz	Benz Euro 2	Benz	PTT	23/08/00	0.683
2. Benz	Benz Euro 1	Benz	PTT	13/09/00	1.388
3. Hino	Hino/Red/A K176	Hino	PTT	15/09/00	2.240
LDDV					
1. Mitsubishi	Mitsu 2.4	Mitsubishi	PTT	02/02/00	0.905
2. Mitsubishi	Mitsu 2.8	Mitsubishi	Bangjak	21/06/00	1.235
3. Toyota	Toyota Hilux	Toyota Hilux 2L	PTT	11/08/00	0.432
Gasoline					
1. Honda	Honda Civic	Honda Civic	Unleaded 95	13/03/00	0.8830
2. BMW	BMW	BMW	Unleaded 91	13/03/00	0.7359
3. Mitsubishi	Mitsubishi	Mitsubishi	Unleaded 91	20/03/00	0.7975
2S-Motorcycle					
1. 1. Honda	Honda	Two-stroke	Unleaded 91	07/03/00	0.7200
4S-Motorcycle					
1. Honda	Yamaha	Four-stroke	Unleaded 91	06/04/00	0.5100
Tuktuk					
1. Tuktuk	Tuktuk	Tuktuk	PTT91	26/11/99	0.2308
2. Tuktuk	Tuktuk	Tuktuk	Gas CNG	15/03/00	0.7853

Industry as Emission Source

Six boiler and incinerator stack samples were from Thai Pure Drink factory (Table 3.5). The boiler stack used heavy oil whereas the incinerator stack samples used diesel oil for starting combustion.

Table 3.5 Boiler and incinerator stack samples

	Site	Boiler Heavy Oil	Incinerator	Dust (mg)	Sampling Date
1	Huamark	192 l/hr		39.8	30/10/00
2	Huamark	192 l/hr		31.0	30/10/00
3	Rangsit	185.3 l/hr		53.2	22/11/00
4	Rangsit	185.3 l/hr		46.6	22/11/00
5	Rangsit		150 kg/hr	106.6	20/11/00
6	Rangsit		150kg/hr	133.3	20/11/00

3.2 PM Quantitative Analysis

Filters were prepared and conditioned in the balance room 2W-210, Monash University, Gippsland Campus. This room was found to have stable ambient conditions, which were necessary to minimize weighing errors. The filters were pre-weighed in five decimal points, Mettler AE 240. Then, the filters were folded in half, wrapped in aluminum foil, placed in plastic bags and labeled prior to collect samples in Thailand. After sampling, the filters were reweighed at the exact condition in the same laboratory.

Initially, particulate laden filters were equilibrated for 7 days in the laboratory ambient conditions of 19-25 ° c and 40-60 %relative humidity (RH) as recommended by the Australia Standard. Filters were weighed in this room at temperature 19-24 ^{o}C and 38-51 % RH.

All filters were weighed for 3 minutes. For the particulate laden filters, the weight determination continued to decrease after this initial equilibration. The blank filter stabilized after 3 minutes (Panther, 1996).

Glass-fiber, size fractionated collection filters and teflon filters with particulate matter from Bangkok were weighed in the same conditions. The mass of the filter was approximately 2.7 g and the average mass of particulate per filter was approximately 60-200 mg for all samples.

The filters were reweighed after longer periods of desiccation. It was found that equilibration of seven days was generally sufficient to ensure that all excess moisture was removed from the filter. All filters on return to the laboratory were therefore placed in the desiccator for a period of seven days prior to weighing. Some filters were found to be still unstable and longer desiccation times were necessary. (Panther, 1996)

3.3 Analysis

3.3.1 Chemicals and Materials for PAHs Extraction

- Filter puncher (Inner diameter 22.8 mm)
- Ultrasonic Bath (Soniclean)
- A stainless microfilter apparatus
- Forceps
- Beakers
- Flask
- Acetronitrile HPLC Grade
- Cutter
- Vial 30 ml and cap
- Vial 5 ml and cap
- Plastic Syringe 5 ml
- Ruler
- Member fiber (Teflon filter)
  PTFE (polymer) 0.5 μm pore size with 13 mm diameter and white in color
- Methylated Spirits
- Dropper

3.3.2 Extraction of Filters

- **Glass fiber filters**

Average exposed area of filters were measured and recorded in Table 3.6. About 10% of filters area were cut into 10 circles with 22.8 mm diameter using cutter (Figure 3.22). These filters were placed in 30 ml vials with 5 ml acetonitrile and capped securely. Two sets of circles should be cut from blank filter and treated in the same way as samples. Each sample is extracted ultrasonically for 10 minutes and filtered approximately 1 ml of this sample through a stainless steel micro filter apparatus using a 0.5 μm Teflon filter into an auto sampler vial. Samples are then loaded into the auto sampler of the HPLC and recorded in batch schedule.

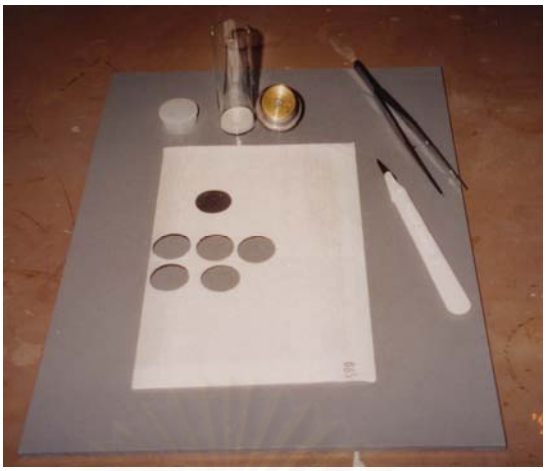


Figure 3.22 Cutting glass fiber filters

Ten circles were equivalent to an area of 409 mm^2. The percentage of filter in 10 circles was approximated 10% of the filters, which should be representative of PAH concentration on the whole filter. The diameter of the entire exposed surface for each site was calculated by measuring the exposed area of several filters from each site and finding the mean for each sampler. Results are shown in Table 3.6.

Table 3.6 Average exposed area of glass fibre filters for each sample

Site	Average exposed area of filter (mm^2)	Percentage of filter in 10 circles
Chulalongkorn University	39424	10.04
Chulalongkorn Hospital	40503	10.10
Dindaeng	40690	10.05
OEPP	39732	10.29
Singharat School	40932	9.99
Bangkok University	40901	10.00

● **Slot filters**

Half of slot filter was cut in small pieces and extracted in 20 ml of acetronitrile. The total extraction area was approximately 12,000 mm^2 (124.5 mm x10 mm x10) (Figure 3.23)

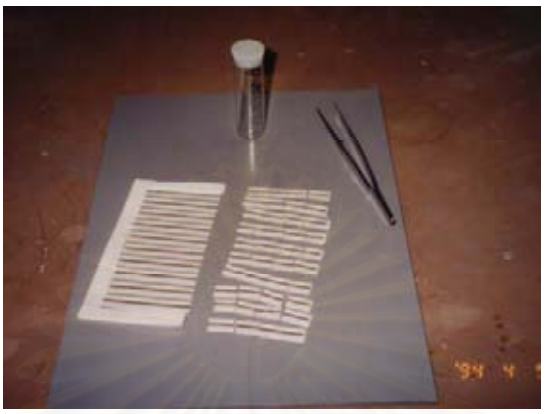


Figure 3.23 Cutting slot filters

● **Teflon coated glass fiber filters**

Ten of 22 mm diameter circles (10% of total filter) were cut from each filter for PAHs extraction with acetonitrile. These circles were placed with forceps carefully in 30 ml vials labeled, covered with 5 ml of acetonitrile and capped securely. Each sample is extracted ultrasonically for 10 minutes and filtered approximately 1 ml through a stainless steel micro filter apparatus using a 0.5 μm teflon filter into an auto sampler vial.

● **Emission source filters**

Two types of filters were used, namely glass fibre 37 mm in diameter for heavy and light diesel; and glass fibre filter with 8"x 10" in size for tuktuk emission samples. All filters were weighed before and again after sampling. PAHs extractions from tuktuk emission samples were performed as described for PM10 filters. The 7/8 of circle glass fibre filter was cut in small pieces and extracted in 10 ml of acetronitrile. Each sample is extracted ultrasonically for 10 minutes and approximately 1 ml of sample was filtered using a stainless steel micro filter apparatus.

3.3.3 PAHs Analysis

The PAHs analysis was carried out in the Center of Environmental Science laboratory at Monash University. The detail showed in appendix A. For sample preparation, PAHs were removed from the filter using ultrasonic extraction in acetonitrile. The separation and identification of twenty PAHs were achieved using a Shimadzu LC-10 Model CMB-10A HPLC with both UV and fluorescence detectors (Figure 3.17). Auto sampler was used to inject samples to the column. An injection volume was 40 μl.

Solvent HPLC Grade Acetonitrile and distilled Milli-Q water were used as mobile phases at a flow rate of 0.95 ml/min. The acetronitrile must be at a pH between 2 to 7.5 to protect the column. Because pH lower than 2, the bonded phase would be destroyed and at higher pH, the silica gel would be dissolved.

The degassed consists of helium gas, which was pumped into the solvent delivery containers to remove any dissolved oxygen from the solvents. It was operated for 40 minutes during each sample analysis.

The column used was a Merck LiChrospher PAH C18 reverse phase column 250-4. A pre-column with the same packing was placed in front of the column to protect the column from any impurities, which may damage or destroy the column. The temperature of the column was maintained at 30 °C. The UV detector was operated at λ 254 nm and the emission and extinction wavelength of the fluorescence detector were adjusted for maximum selectivity for each PAH.

The twenty PAHs determined were Naphthalene (Nap), Acenapthene (Ace), Acenapthylene (Acy), Fluorine (Flu), Phenanthrene (Phen), Anthracene (Anth), Fluoranthene (Flt), Pyrene (Pyr), Benzo(a)anthracene (BaA), Chrysene (Chr), Benzo(e)pyrene (BeP), Benzo(b)fluoranthene (BbF), Perylene (Per), Benzo(k)fluoranthene (BkF), Benzo(a)pyrene (BaP), Dibenzo(ah)anthracene (DBahA),

Benzo(ghi)perylene (BghiP), Indeno(123cd)pyrene (Ind), Anthanthrene (Ant) and Coronene (Cor).

High Performance Liquid Chromatography (HPLC)

HPLC, Shimazu LC-10 HPLC Model CBM-10A, was used to analyze PAHs. This consisted of pre-column cartridges, Column MERCH LiChrospher PAH C18 PAH 250-4 mm. The UV visible detector was operated at λ 254 nm and fluorescence detector was adjusted for each PAH. Chromatograms for each PAH were determined using automatic software supplied with the HPLC apparatus (Figure 3.17).

Figure 3.17 High Performance Liquid Chromatography
Shimazu LC-10 HPLC Model CBM-10A

CHAPTER 4

RESULTS

4.1 Particulate Matter

4.1.1 Particulate Matter less than 10 μm (PM10)

The fieldwork for the study was carried out between November 1999 and November 2000 in the urban and outer suburban area of Bangkok. The highest concentration of PM10 was at Chulalongkorn Hospital and Dindaeng whereas the lowest was at Bangkok University. The average, maximum and minimum of PM10 concentration for each site are shown in Figure 4.1.The results obtained varied markedly from a minimum of 23 $\mu g/m^3$ at Bangkok University to a maximum of 160 $\mu g/m^3$ at Chulalongkorn Hospital. The PM10 concentration at OEPP, Singharat School and Bangkok University were comparable with the average value of 55, 63 and 59 $\mu g/m^3$ respectively. Bangkok University is situated at the urban edge however the average PM10 concentration is similar to those for other sampling sites. The explanation for this is Bangkok University is closed to biomass (grass and agricultural) burning, resulting in the high PM10 level. Chulalongkorn Hospital and Dindaeng, which are roadside sites, showed the highest means (76 $\mu g/m^3$ and 72 $\mu g/m^3$ respectively).

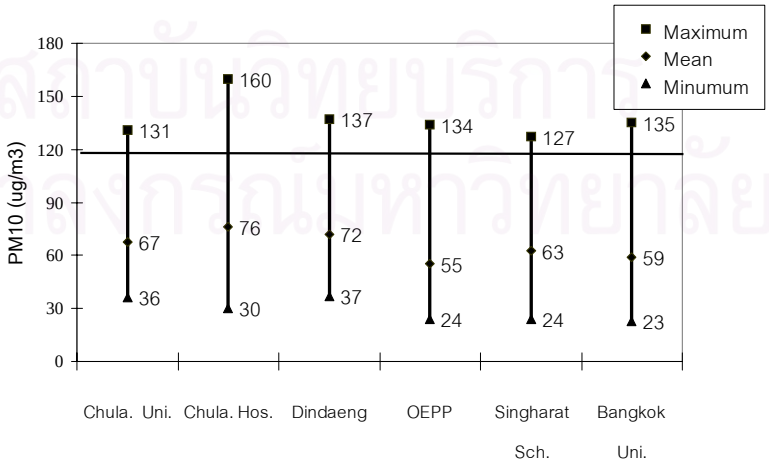


Figure 4.1 Statistical summary of daily PM10 concentration at each site ($\mu g/m^3$)

The discussion of PM10 data that shown in the Appendix B Table B-1 (page 150-152)

On 22nd January 2000, the PM10 concentration were 121, 151,134 and 127 μg/m^3 at Chulalongkorn Hospital, Dindaeng, OEPP and Singharat Site, respectively This value were exceptionally high and exceeded the national standard of air quality (120 μg/m^3).

Saturday 5th February 2000 was the Chinese New Year day and on Saturday 19th February 2000 was official holiday day (Religious day (Makhabucha)). During this time people moved to suburban for long vocation. Accordingly, the PM10 concentrations at Bangkok University (suburban site) were 111 and 135 μg/m^{3}on Chinese New Year and Makhabucha. The inner area of Bangkok, such as Dindaeng and Chulalongkorn University, the airborne PM was low 47 and 48 μg/m^3, respectively.

On 10th March 2000, the airborne PM at roadside area at Chulalongkorn Hospital, Dindaeng were 38 and 66 μg/m^3. Whereas the mixed area at Bangkok University and OEPP are 64 and 40 μg/m^3. The PM was less than these in February 2000 due to the rainfall 2 consecutive days of rainfall, hence the PM were removed rained.

Between 13th –15th April 2000, was the Water Festival holiday (Songkran). The PM10 droped as there was not many vehicles in the city. Furthermore, it rained on 13th-14th April 2000 at Dindaeng and Singharat 14.5, 14.5 (13th April) and 22.5, 18.0 (14th April) mm/hr, respectively. PM10 concentration on 15th April 2000 at Chulalongkorn Hospital, Dindaeng, Bangkok University and Singharat School were 31, 117, 23 and 69 μg/m^3, respectively.

15th May 2000 was Royal Ploughing Ceremony Day .The PM was decreased 42, 37 and 51 μg/m^3 at Chulalongkorn Hospital, Dindaeng and Singharat School respectively. It rained at Dindaeng and Singharat School, the PM were removed rained.

On 6th September 2000, at Chulalongkorn Hospital, Dindaeng and Bangkok University, the PM10 were at moderated; 65, 70 and 51 μg/m^{3}respectively. 4th–6th September 2000 it rained on 9,1 and 4 mm/hr at Dindeang and 23, 1 and 10 mm/hr at Singharat School.

On 18th September 2000, the PM10 concentration at roadside at Chulalongkorn Hospital and Dindaeng (roadside area) were 160 and 137 μg/m^3, which exceeded the National standard and it rained on 16th –18th September 2000.

On 24th October 2000, PM levels were considerably low; 45, 40 and 49 μg/m^3 Chulalongkorn University, Chulalongkorn Hospital and Bangkok University, respectively. It rained and that was long weekend 23rd October 2000 was Chulalongkorn Memorial day and 21st–22nd October were Saturday and Sunday.

4.1.2 Size Fractionating Particulate Matter (SFPM)

This study was carried out to collect SFPM on fraction <0.95 μm, 0.95-1.5 μm, 1.5-3.0 μm, 3.0-7.2 μm and >7.2 μm sample from November 1999 to November 2000 at Chulalongkorn University. These results are shown in Table B-4, Appendix B. The summed SFPM varied from 40 to 119 μg/m^3 on 25th-27th December 1999. The relative importance of selected size fractions can be evaluated on an individual basis and a comparison has been made across days of high, moderate and low particulate loading. High particulate levels were 111 and 119 μg/m^{3}on 23rdand 27th December, moderate particulate level were 81 and 82 μg /m^3 on 1st February 1999 and 12th November 2000 and low particulate level were 42 and 40 μg / on 13th March 2000 and 25th September 2000. The ratios (PM1.5/ΣSFPM) for each of these six days are 0.60, 0.60, 0.52, 0.65, 0.60 and 0.47, respectively. There is no obvious trend in this data set ,suggesting that relative loading is not a factor in influencing the percentage contribution of fine particles to the total load.

Table 4.1 showed the mean, minimum and maximum of SFPM concentration. The daily summed SFPM ranged from 39 to 119 μg /m^3. The mean in each fraction was 33, 6, 6, 12, 11 μg /m^3. The highest concentration of PM concentration was in the particulate matter < 0.95 μm. The airborne particulate in Bangkok resulted primarily from the traffic. There are two primary mechanisms for generation of particles in the air, namely combustion and mechanical processes.

Table 4.1 Statistical summary of daily SFPM concentration in each size fraction (μg/m^3)

	<0.95 μm	0.95-1.5 μm	1.5-3.0 μm	3.0-7.2 μm	>7.2μm	∑ SFPM
n	39	39	39	39	39	39
Mean	33	6	6	12	11	69
SD	10	3	3	4	4	17
Minimum	14	1	2	3	2	40
Maximum	61	15	24	22	18	119

4.2 Polycyclic Aromatic Hydrocarbons (PAHs)

4.2.1 ΣPAHs of PM10 Samples

Twenty individual PAHs have been identified and quantified. A statistical summary of the summed data, ΣPAHs, showing the mean, minimum and maximum, is presented in Figure 4.2. The highest concentration of ΣPAHs was 195 ng/m^3 on 27th December 1999 at Chulalongkorn University and the lowest PAHs was 6 ng/m^3 on 15th April 2000 at Bangkok University. Variation of average ΣPAHs concentration six sampling sites is observed. The means of ΣPAHs concentration were 63 ng/m^3 at Chulalongkorn University, and 76 and 61 ng/m^3 at roadside area such as Chulalongkorn Hospital and Dindaeng. While the range for most sites (maximum – minimum) is considerable. The average ΣPAHs levels vary in all sampling sites between 47 and 76 ng/m^3 with the lowest mean associated with the urban edge, such as Bangkok University, and the

highest associated with a roadside site as Chulalongkorn Hospital. In previous PAHs studies at Chulalongkorn University in 1993, daily ΣPAHs levels ranged from 4.97 to 74 ng/m^3. The annual average ΣPAHs was 61 ng/m^3. At OEPP in 1996, ΣPAHs (7 compounds) was 19.37 ng/m^3 (Garivait, 1999). In this study ΣPAHs (20 compounds) at OEPP site was 24.2 ng/m^3 in 1999. The ΣPAHs in 1999 is more than that in 1993 because of more traffic volume and climate condition. In the large cities, Jakarta (Indonesia), Mumbai (India) and Tokyo (Japan) the ΣPAHs concentration was high: 13-177, 25-139 and 71 ng/m^3, respectively (Caricchia, 1999), (Panther, 1996).

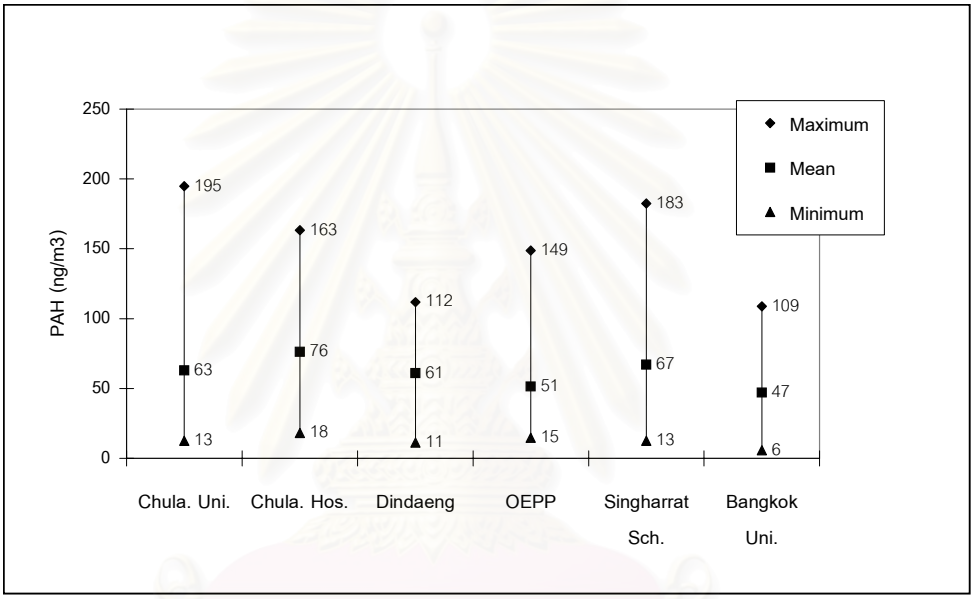


Figure 4.2 Statistical summary of daily ΣPAHs concentration at each site (ng/m^3)

4.2.2 Individual PAHs

The twenty PAHs compounds were determined. PAHs ranging was 0.6-35.3 ng/m^3 and the six most dominant PAHs that have been observed in this study are Benzo[ghi]perylene (BghiP), Indeno[123cd]pyrene (Ind), Benzo[e]pyrene (BeP), Benzo[b]fluranthene (BbF), Coronene (Cor) and Benzo[a]pyrene (BaP). The average concentrations of BghiP relative to other members were the highest at all sites, ranging from 10 to 17 ng/m^3. Ind and BeP are also major PAHs with means ranging across 7-14 and 5-10 ng/m^3 respectively. The mean ranges for PAH; i.e. BbF, Cor and BaP ranged across 3-8, 3-8 and 3-5 ng/m^3, respectively.

From the previous PAHs studies in Bangkok, the dominant PAHs in ambient air were BghiP, BeP, BaP, BkF, PYR and Cor (Panther, 1999). In the suburban Bangkok area, the significant PAHs were BeP, BghiP Ace, Acy (Oanh, 2000). In large cities Jarkata, Indonesia the dominant PAHs were NaP, Ace, Acy, BeP and BghiP (Panther, 1999).

Table 4.2 PAHs data for dominant species, BghiP, Ind, BeP, BbF, Cor and BaP for sampling sites – annual mean and range (ng/m^3)

	Chula. Uni.	Chula. Hos.	Dindaeng	OEPP	Singharat Sch.	Bangkok Uni.
BghiP (Mean)	12	15	13	12	17	10
(Range)	2.5-27.6	3.8-40.1	3.1-25.3	0.5-29.2	2.3-38.8	1.2-19.6
Ind (Mean)	10	10	7	10	14	9
(Range)	1.7-30.6	2.5-27.5	1.4-17.6	1.5-23.8	2.5-35.3	1.2-20.7
BeP (Mean)	10	10	9	7	7	5
(Range)	1.6-28.4	1.9-22.9	1.3-17.7	0.9-25.0	0.7-24.8	0.5-17.5
BbF (Mean)	8	6	5	4	4	3
(Range)	0.2-25.3	1.2-13.0	0.6-13.4	0.31-11.6	0.3-15.0	0.3-11.6
Cor (Mean)	4	5	3	5	8	4
(Range)	1.2-12.8	1.6-14.2	1.2-7.0	1.5-11.2	1.6-19.1	0.5-8.3
BaP (Mean)	4	5	4	3	3	3
(Range)	0.6-12.6	1.2-13.0	0.3-10.7	0.6-10.0	0.4-10.8	0.3-6.2

4.2.3 BaP of PM10 Samples

BaP level has often been used as an indicator of total PAHs concentrations in many city. It is the most carcinogenic PAHs, concentrations of this compound are of considerable interest. BaP was the sixth dominant PAHs. Daily average BaP concentrations in Bangkok rangd from 0.3 to 13.0 ng/m^3. A statistical summary of the summed data, BaP, showing the mean, minimum and maximum, is presented in Figure 4.3. The highest concentration of BaP was 13.0 ng/m^3 at Chulalongkorn Hospital and the lowest PAHs was 0.3 ng/m^3 at Dindaeng and Bangkok University. The mean of BaP concentration was 3.6 ng/m^3 at Chulalongkorn University, and 5.6 and 4.4 ng/m^3 at roadside sites as Chulalongkorn Hospital and Dindaeng. While the range for most sites(maximum – minimum) is considerable. The site means for BaP levels vary between 2.8 and 5.6 ng/m^3 with the lowest mean associated with the urban edge such as Bangkok University and the highest associated with a roadside, and central city area.

In previous BaP studies in Bangkok, the BaP concentration was lower than the results obtained in this study. In 1993 daily BaP levels was of 0.18-2.44 ng/m^3. Daily BaP concentration ranged from 0.5 to1.7 ng/m^3 in 1996 and with an average of 0.67 ng/m^3(Garivait, 1999) In Jakarta Indonesia the BaP concentration between 0.83–10.22 ng/m^3. In the tropical country, such as Hongkong (Panther, 1996); South Korea (Panther, 1996); India (Delhi) (Banerjee, 1991); Taiwan (Taipei) (Chang, 1991); Singapore (Ang, 1986), the BaP levels were high 0.00-0.78, 0.00 -1.2, 0.04-0.82, 0.04-0.81 and 1.65-3.55 ng/m^3. The BaP was the high most carcinogenic compound and at present is standard guideline for BaP level except the national Netherlands standard. The annual average guides value at 0.5 ng/m^3 (Panther, 1996).

Daily average exposure to BaP in Bangkok, based on a breathing rate of 18 m^3 per day and a deposition rate of 51% of the inhaled amount of BaP in the lungs, was 27.5-51.4 ng/day. This is comparable with the daily average exposure to BaP in Jakarta, which is 40.2 ng/day. USA exposure to BaP via inhalation routes has been estimated to be between 2 and 300 ng/day with an average of 5 ng/day based on a 100% deposition

rate (Panther, 1996). In this study the inhaled exposed BaP in Bangkok was 2.8-119 ng/day, a deposition rate of 51% of the inhaled amount of BaP in the lungs.

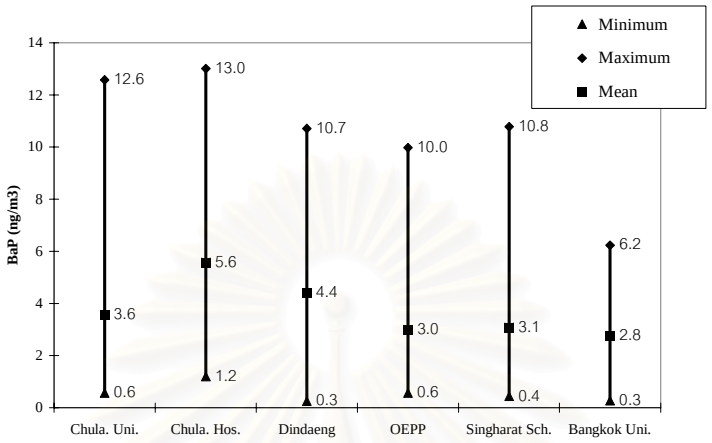


Figure 4.3 Statistical summary of daily BaP concentration (ng/m^3)

4.2.4 Σ PAHs of SFPM Samples

PAHs data for dominant species, BghiP, BeP, Ind, BbF, Flu and Cor for the SFPM samples at Chulalongkorn University – annual mean and range, is presented in Table 4.3. The concentration of BghiP ranged from 3.4 and 25.1 ng/m^3, with an average of 9 ng/m^3. At Chulalongkorn university, BghiP, BeP, Ind were dominant PAHs of SFPM samples.

Table 4.3 PAHs data for dominant species, BghiP, BeP, Ind, BbF, Flu and Cor for the SFPM samples at Chulalongkorn University site – annual mean and range (ng/m^3)

	Individual PAH Concentration (ng/m^3)
BghiP (Mean)	9
(Range)	3.4-25.1
BeP (Mean)	8
(Range)	2.0-25.1
Ind (Mean)	8
(Range)	3.1-26.4
BbF (Mean)	5
(Range)	0.7-17.4
Flu (Mean)	4
(Range)	1.4-20.1
Cor (Mean)	4
(Range)	(1.3-10.8)

A time series for the ΣPAHs data associated with the SFPM samples and percentage of PAHs concentrationis are shown in Figure 4.4 and Figure 4.5. The fine airborne PM carried high PAHs concentration. It should be noted that the scale on the left of the Figure 4.4 refer PAHs level for SFPM <0.95 μm whereas the right scale refer to PAH level of other PAHs level. Figure 4.5 more than 97% of PAHs were found in the small SFPM less than 0.95 μm. Other fractions, 0.95-1.5 μm; 1.5-3.0 μm; 3.0-7.2 μm and >7.2 μm contained 1.02, 0.52, 0.50 and 0.41 % of total PAHs, respectively.

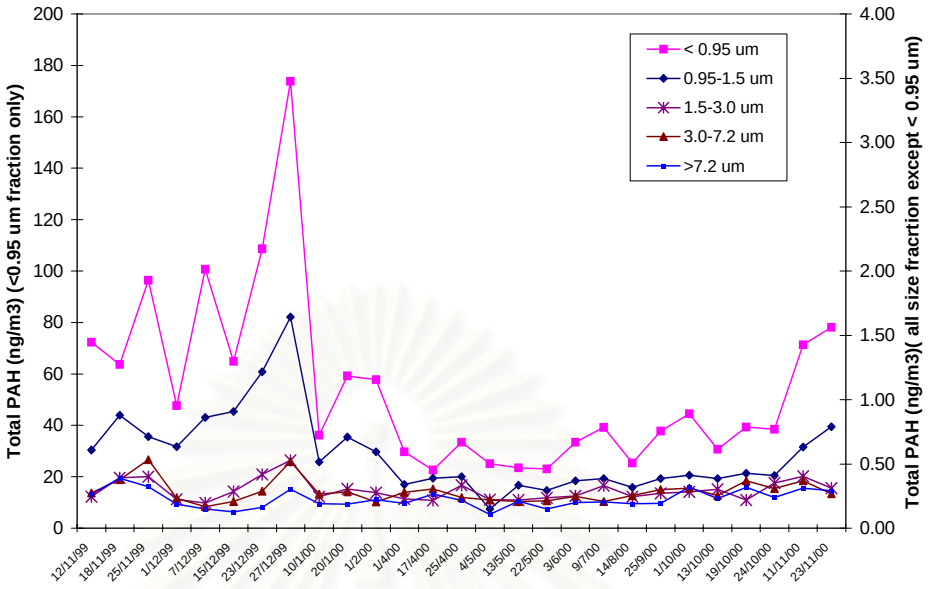


Figure 4.4 Time series data for the ΣPAHs in the SFPM samples

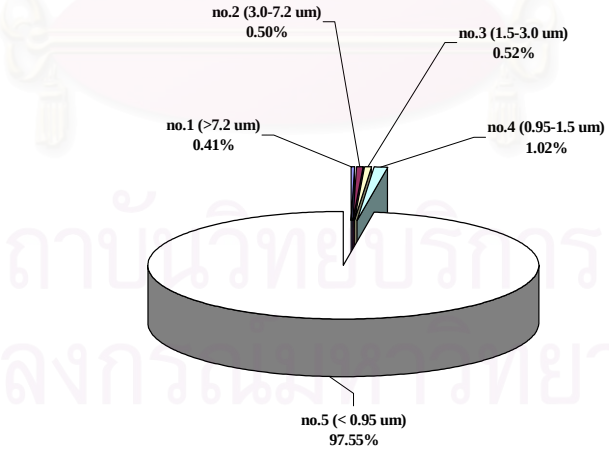


Figure 4.5 Percentage PAHs concentration in each SFPM samples

4.2.5 BaP of SFPM Samples

A statistical summary of the data SFPM and BaP, showing the number of samples (n), the mean, standard deviation, minimum and maximum, is presented in Table 4.4.The highest concentration BaP was highest (2.928 ng/m^3) and the lowest (0.004 ng/m^3) was found with PM < 0.95 μm and > 7.2 μm, respectively. More than 98% of BaP are found in the PM less than 0.95 μm. The fine airborne PM carried high BaP concentration. The mean for size fraction of 0.95-1.5 μm, 1.5-3.0 μm, 3.0-7.2 μm, >7.2 μm The mean 0.023, 0.006, 0.006 and 0.004 ng/m^3.

From the previous studies, BaP associated in small particle. The dominant mass fraction of the PAH bond particle was associated with small particles of less than 1 μm in diameter. The concentration of BaP(ng/m^3), in the particles of various sizes, each particle size distribution showed a major peak at 0.52 μm (Garivait, 1999).

Table 4.4 Statistical summary of BaP concentration in each size fraction (ng/m^3)

	<0.95 μm	0.95-1.5 μm	1.5-3.0 μm	3.0-7.2 μm	>7.2 μm
n	27	27	27	27	27
Mean	2.928	0.023	0.006	0.006	0.004
SD	2.088	0.019	0.005	0.004	0.004
Minimum	0.472	0.001	0.000	0.001	0.001
Maximum	9.750	0.086	0.020	0.015	0.018

The time series data for the BaP concentration in the SFPM samples are shown in Figure 4.6. In the smallest fraction, BaP level ranged from 0.47 to 9.75 ng/m^3. the scale on the left of the Figure 4.4 refer PAH level for SFPM <0.95 μm whereas the right scale refer to PAH level of other PAHs level. In small fraction (<0.95 μm, 0.95-1.5 μm) the BaP level particulate was high in (November- January) winter and low in summer and rainy season (February-October).

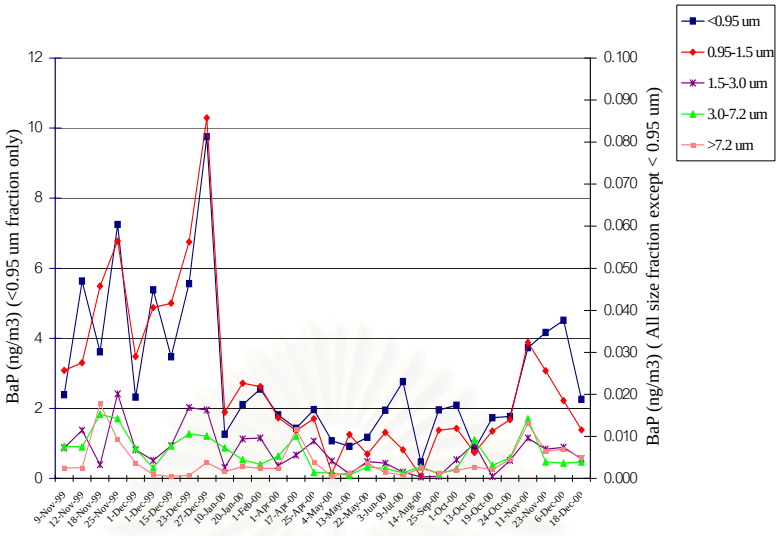


Figure 4.6 Time series data for BaP concentration in the SFPM samples (ng/m^3)

4.3 PAHs Profile of Different Emission Sources

4.3.1 Vehicle as Emission Sources

The PM from vehicle sources was sampled and 20 PAHs were analyzed. The summary of individual PAHs of vehicle emission is shown in Table 4.5. The PAHs profiles of many vehicle emissions are shown in Figure 4.7 to 4.16.

Table 4.5 Summary of individual PAHs in vehicle emission

PAHs Concentration (ng PAHs/mg Dust)													
	Diesel						Gasoline			Motorcycle		Tuk-Tuk	
	HDDV			LDDV			LDGV			2 stoke	4 stoke	Gasoline	CNG
PAH	1	2	3	1	2	3	1	2	3	1	1	1	2
Nap	5.31	8.70	2.19	4.55	10.34	5.86	0.15	1.14	1.59	16.08	1.69	4.58	3.30
Acy	17.26	91.20	13.97	214.87	28.23	58.48	0.56	4.91	3.21	149.30	5.20	30.89	0.00
Ace	23.81	72.48	28.39	28.38	6.22	12.88	0.22	2.19	1.52	3.32	0.11	1.31	0.56
Flu	15.80	44.67	14.00	109.93	67.32	139.48	5.31	12.49	9.92	25.05	2.05	7.57	6.18
Phen	5.04	17.11	3.01	17.59	3.23	6.69	1.66	5.85	4.92	45.98	2.27	7.59	6.00
Anth	9.33	29.28	10.12	11.83	1.36	2.83	8.91	3.59	1.85	9.94	2.82	0.80	1.43
Flt	2.82	10.85	3.95	29.46	5.93	12.29	8.26	5.92	7.33	55.69	1.49	18.90	17.51
Pyr	4.95	18.64	3.27	29.26	12.25	25.38	7.47	3.75	5.95	22.15	1.92	5.04	4.60
BaA	0.78	2.98	4.75	7.81	2.77	5.74	7.47	11.78	8.95	11.29	1.46	1.18	1.18
Chr	0.68	1.98	0.45	0.83	9.34	19.35	12.19	7.42	9.92	1.89	1.17	3.95	3.13
BeP	12.26	39.44	3.83	19.56	103.02	213.45	11.66	8.02	9.64	64.39	22.03	20.60	12.50
BbF	0.54	3.68	0.00	0.00	23.56	48.81	12.70	10.55	10.16	5.95	4.43	11.75	11.83
Per	0.00	0.00	0.00	0.00	2.82	5.84	0.50	0.23	0.46	2.00	1.11	1.54	1.08
BkF	0.22	0.16	0.05	0.20	2.49	5.15	11.73	11.17	9.65	1.31	1.94	0.15	0.13
BaP	0.62	0.52	0.88	1.98	17.60	36.46	12.14	8.31	8.94	17.45	9.16	0.74	1.07
DBahA	0.57	2.88	0.66	2.51	1.46	3.03	14.39	4.87	7.26	1.79	2.01	0.40	1.37
BghiP	0.93	1.79	0.66	1.05	90.89	188.32	33.86	17.88	17.90	32.99	48.00	13.29	21.71
Ind	0.00	0.00	0.00	0.00	58.62	121.45	1.30	2.02	0.89	11.90	41.41	12.05	14.72
Ant	0.09	0.54	0.27	0.51	8.04	16.66	0.80	0.83	0.76	1.75	5.62	3.27	1.95
Cor	0.70	2.51	1.22	1.74	13.94	28.89	9.75	9.29	8.85	7.99	36.35	18.22	22.64
Total	101.70	349.40	91.69	482.05	469.41	957.05	161.05	132.20	129.67	488.21	192.24	163.81	132.91

Figure 4.7 and 4.8 showed PAH profiles of heavy-duty diesel vehicle (HDDV) and light-duty diesel vehicle (LDDV) emission. For the HDDV, the small molecular weight PAHs (Ace, Acy, Flu, BeP and Anth) were dominant. With the LDDV, the dominant PAHs were BeP, Flu, Acy, BghiP and Ind.

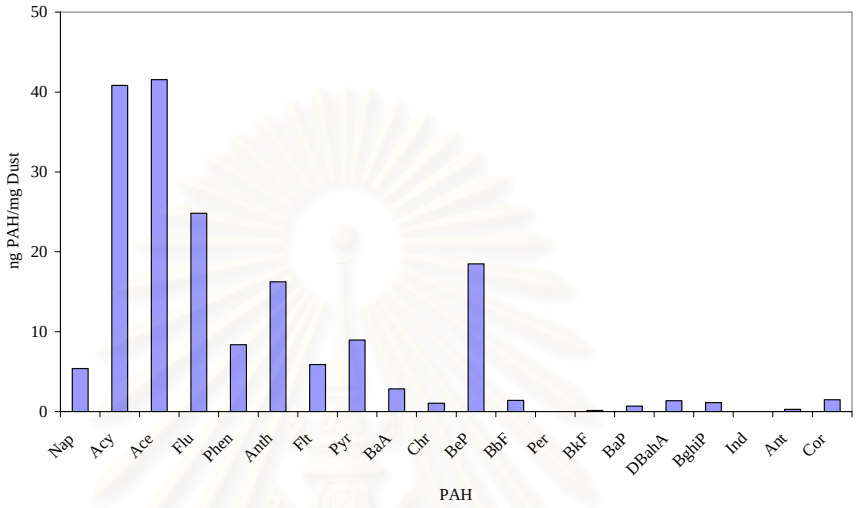


Figure 4.7 PAHs profile of HDDV emission

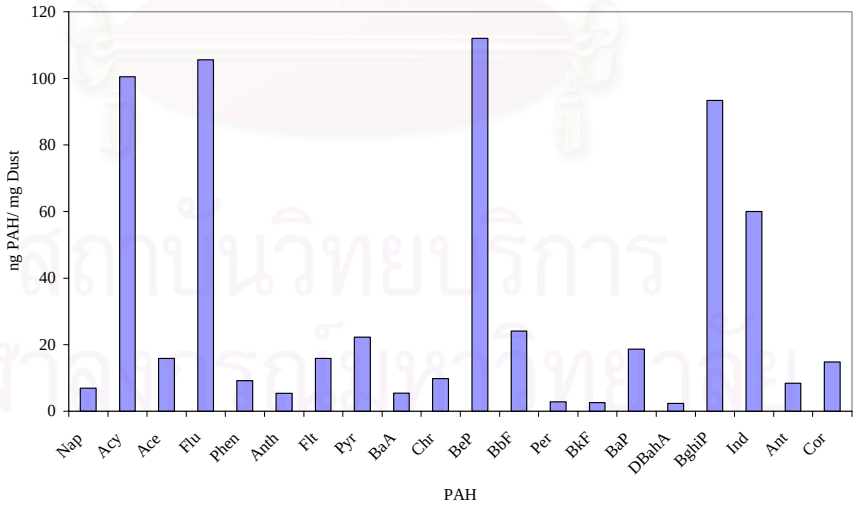


Figure 4.8 PAHs profile of LDDV emission

The PAHs profile of light-duty gasoline vehicle (LDGV) emission is shown in Figure 4.9. The result showed the BghiP was the most dominant.

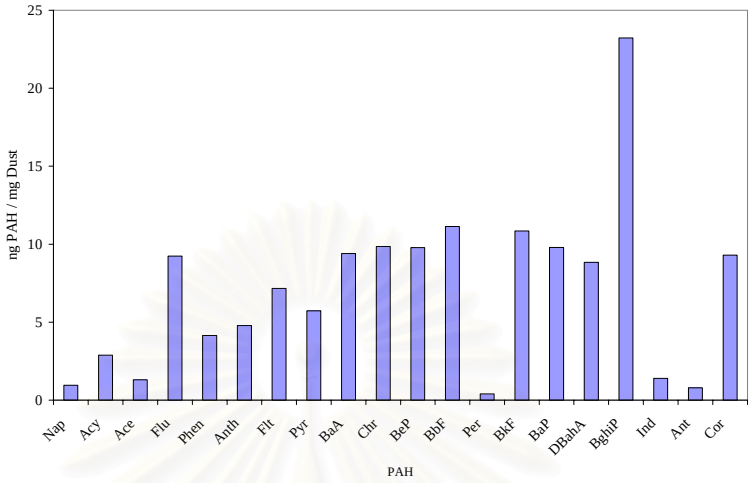


Figure 4.9 PAHs profile of LDGV emission

The PAHs profile of motorcycle emission is shown in Figure 4.10 and 4.11. Acy, Bep and Flt were dominant in two-stroke motorcycle emission samples. For four-stroke samples, the high molecular weight PAHs, BghiP; Ind; Cor and BeP were dominant.

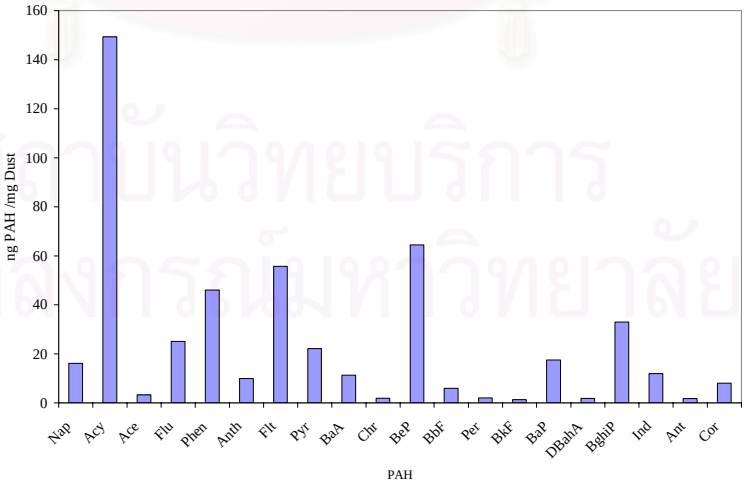


Figure 4.10 PAHs profile of two-stroke motorcycle emission

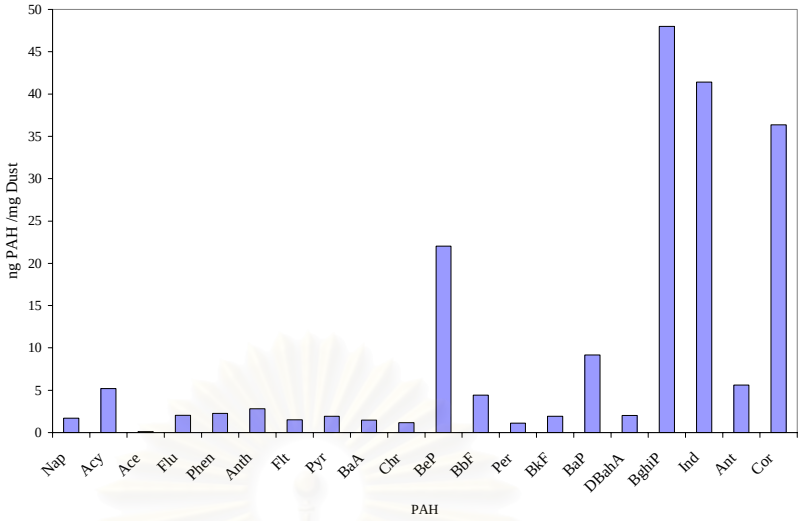


Figure 4.11 PAHs profile of four-stroke motorcycle emission

Two fuels types have been used for motorized tricycle (Tuktuk) (gasoline, CNG). The PAHs profile and percentage of PAHs profile of tuktuk are shown in Figure 4.12 and 4.13. It was found the major PAHs associated with gasoline tuktuk were Acy, BeP, Flt, Cor, BghiP, Ind and BbF. Whereas tuktuk using the compressed natural gas (CNG), Cor, BghiP, Flt, Ind, BeP and BeF were dominant.

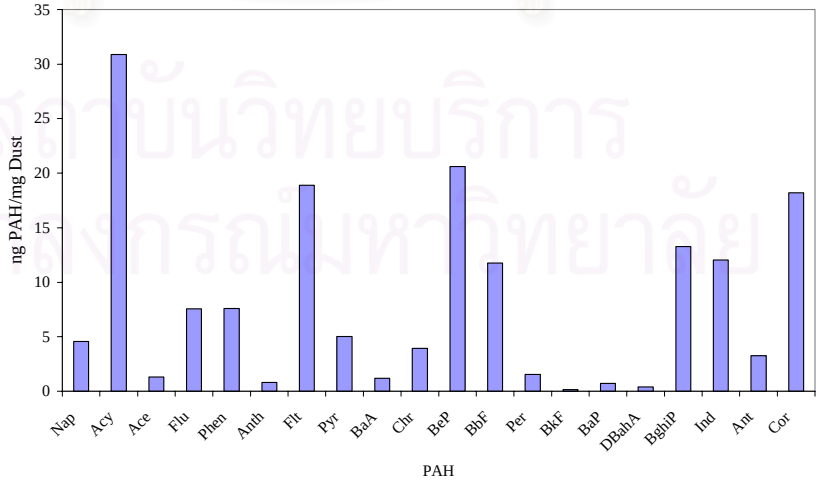


Figure 4.12 PAHs profile of gasoline tuktuk emission

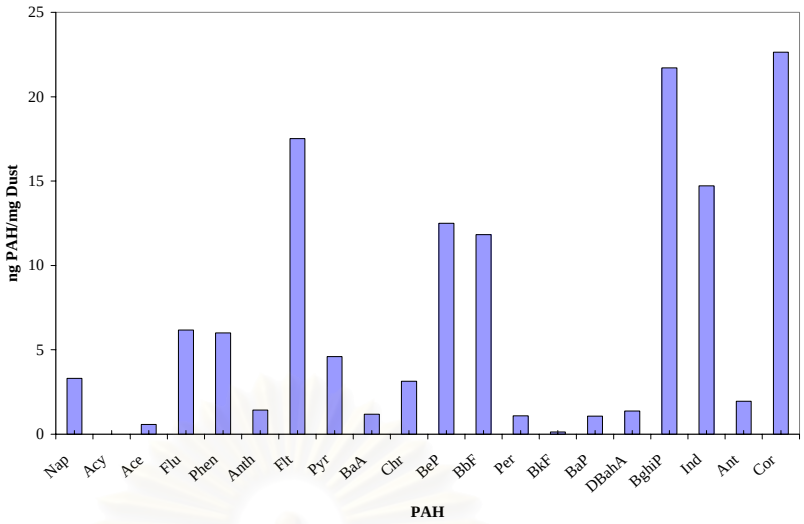


Figure 4.13 PAHs profile of CNG tuktuk emission

4.3.2 Industry as Emission Sources

The stack industry samples (Huamark, Rangsit) were collected sampled and PAHs were analyzed. The PAHs profiles of boiler stack samples are shown in Figure 4.14 and 4.15. Sample stack from industry at Huamark, using heavy fuel 192 l/hr, the major PAH were BeP, Pyr, Flt, Flu and Phen.

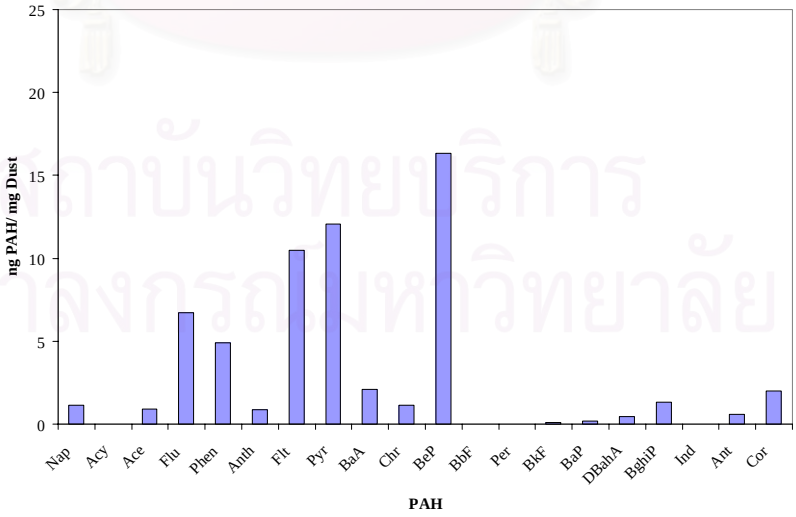


Figure 4.14 PAHs profile of heavy-fired boiler stack at Huamark

Similarities, stack from industry at Rangsit, which used at using heavy fuel at185.3 l/hr, the dominant PAH were Phen, BeP, Pyr, Flt and NaP.

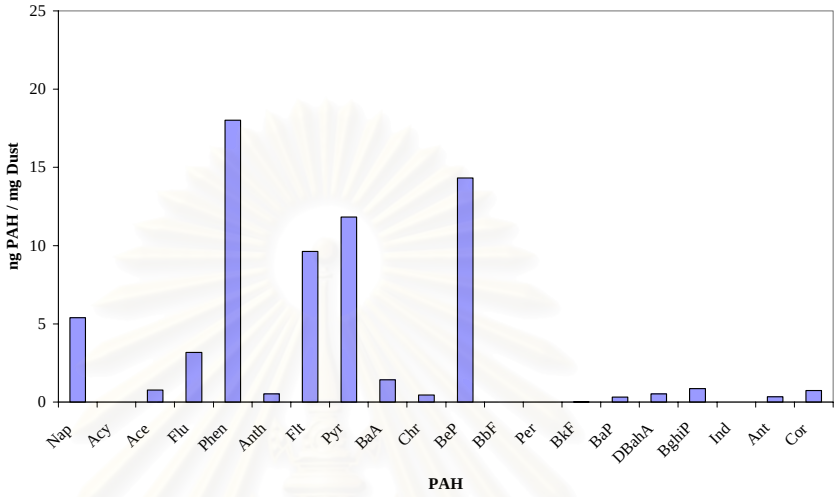


Figure 4.15 PAHs profile of heavy-fired boiler stack at Rangsit

For the general, garbage incinerator stack samples the dominant PAHs were Flt, Pyr, Acy, Phen and Flu.

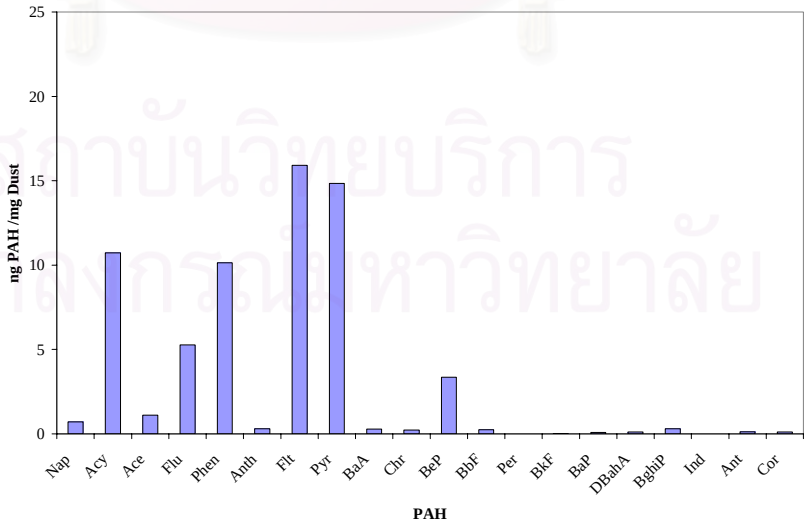


Figure 4.16 PAHs profile of garbage incineration stack samples

4.3.3 Road Dust as Emission Sources

Road dust samples were collected from four main roads, Phahonyothin, Dindaeng, Bantatthong, and Ladya in Bangkok cental area. The summary of total PAH in road dust <38 μm and 38-75 μm are shown in Figure 4.17 and 4.18.

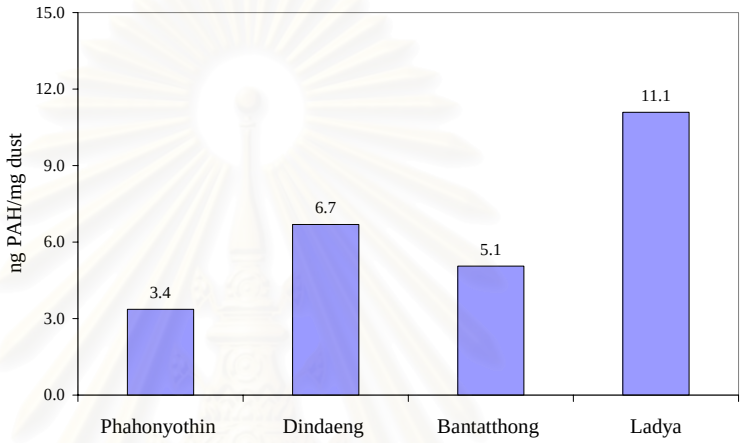


Figure 4.17 Summary of ΣPAHs in road dust < 38 μm

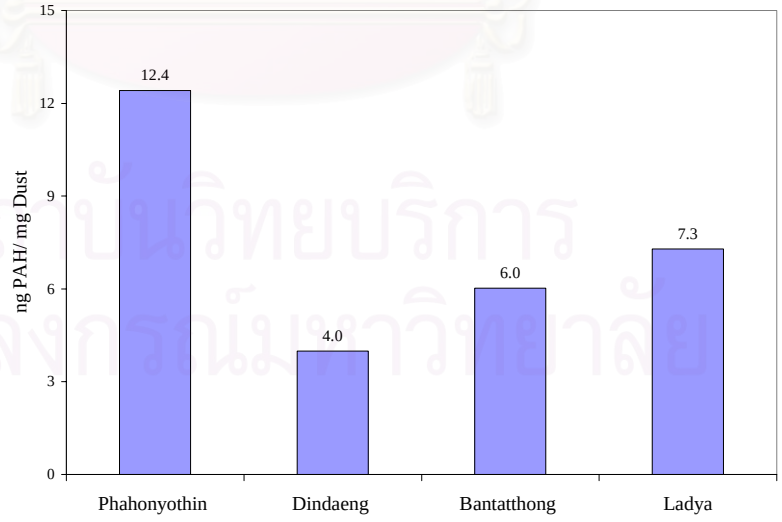


Figure 4.18 Summary of ΣPAHs in road dust 38-75 μm

Figure 4.19 and 4.20 showed PAHs profile of road dust <38 μm and 38-75 μm. In both samples, the dominant PAH were Acy, BeP, Flt and BghiP.

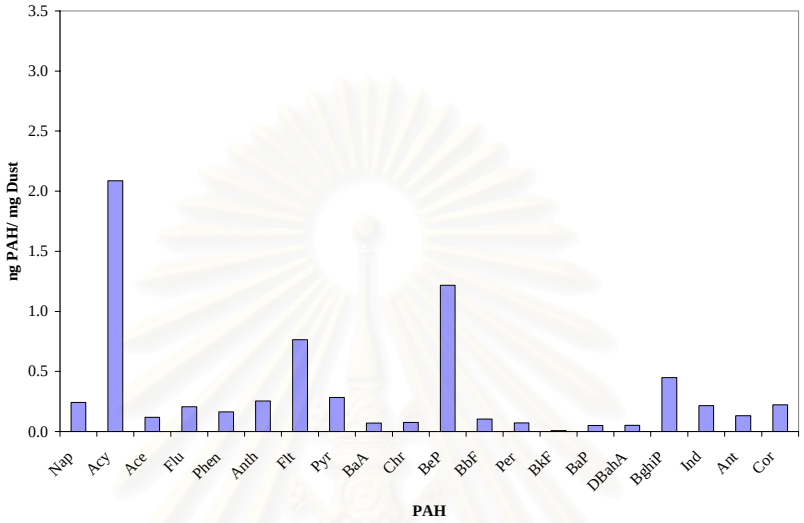


Figure 4.19 PAHs profile of road dust <38 μm

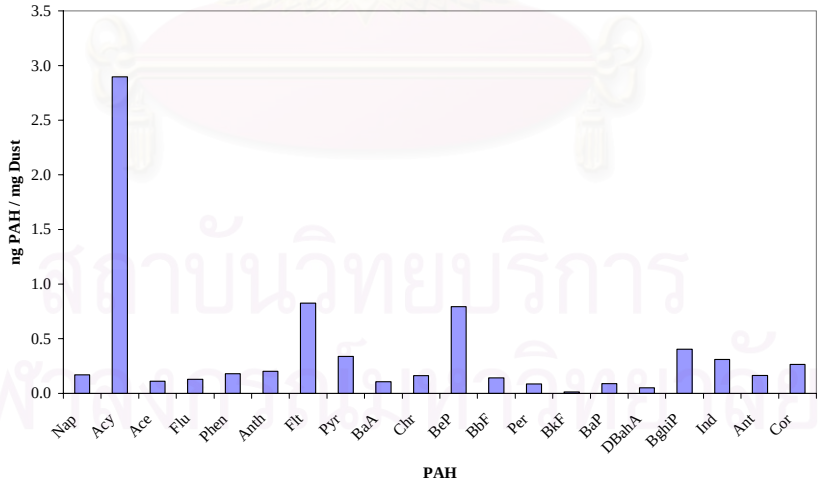


Figure 4.20 PAHs profile of road dust 38-75 μm

CHAPTER 5

DISCUSSION

5.1 Particulate Matter less than 10 μm (PM10)

5.1.1 Level and Distribution of PM10 in Bangkok

Table 5.1 and 5.2 show the n (number of data), mean, SD (standard deviation), minimum and maximum values of PM10 on working days (Monday-Saturday) and holiday (Sunday and official Holiday). On working days, the average PM10 concentration at Chulalongkorn University, Chulalongkorn Hospital, Dindaeng, OEPP, Singharat School and Bangkok University were at 68, 87, 70, 56, 63 and 63 $\mu g/m^3$, respectively. On Sunday and official holiday, the PM10 levels were at 55, 52, 69, 49, 65 and 48, $\mu g/m^3$, respectively. Generally, the average PM10 concentrations of samples on Sunday and holidays were considerably lower than those on working days. It is not surprising as Bangkok is a large city, which million of people heading for work on working days leading to the high level of traffic and people movement.

Chulalongkorn University, Chulalongkorn Hospital and Bangkok University were considered as educational area. Accordingly, the mean of PM10 concentration during working days was higher than those on of Sunday and official holidays. However, the numbers of data (n) for working days is higher than those for the weekend (2-12 times).

Table 5.1 Statistical summary of daily PM10 concentration on working days ($\mu g/m^3$)

	Chulalongkorn University	Chulalongkorn Hospital	Dindaeng	OEPP	Singharat School	Bangkok University
n	37	13	20	22	18	16
Mean	68	87	70	56	63	63
SD	21	35	23	28	28	28
Minimum	36	38	42	24	24	26
Maximum	131	160	137	134	127	135

Table 5.2 Statistical summary of daily PM10 concentration on Sunday and official holidays ($\mu g/m^3$)

	Chulalongkorn University	Chulalongkorn Hospital	Dindaeng	OEPP	Singharat School	Bangkok University
n	3	6	4	4	4	7
Mean	55	52	69	49	65	48
SD	13	26	44	20	31	27
Minimum	45	30	37	28	33	23
Maximum	69	88	120	68	106	100

The NAAQS for PM10 concentration for a 24 hour period is 120 $\mu g/m^3$. This NAAQS guideline is exceeded at least once at all sites (Table 5.3). The PM10 levels on roadside areas, such as Chulalongkorn Hospital and Dindaeng, were over the NAAQS limit by 16% and 8%, respectively. Similarly, the PM10 concentrations at the mixed areas, such as Chulalongkorn University; OEPP; and Singharat School, were also exceeded the NAAQS guideline by 5%, 4% and 5%, respectively. In contrast, the suburban site, such as Bangkok University, that located 30 km from the center of Bangkok, the PM10 level exceeded the NAAQS limit by 4%.

Based on the Report of the Office of the Commission for the Management of Road Traffic 2000 (Appendix D), the traffic densities at Chulalongkorn Hospital and Dindaeng are 109,400 and 116,622 vehicles/12 hour day. In contrast, there are only 21,300 vehicles /12 hour day at Bangkok University. The numbers of vehicles at the mixed areas, such as Chulalongkorn University; OEPP and Singharat School, were 38,803; 43,192 and 29,319/ 12 hour day, respectively.

From the discussion above, it can be concluded that the PM10 data were well correlated with the number of vehicles at all sampling sites, in which the higher number of vehicles, the higher particulate matter.

From the previous studies in 1999, the annual averages of PM10 levels were 55 and 53 $\mu g/m^3$ at Chulalongkorn University and Bangkok University, respectively (Kaewngam, 2000). In the present study, the average PM10 levels were 65 and 61$\mu g/m^3$, which were higher than those in 1999. The increase in PM10 levels was believed to be the results of traffic density and climate condition.

Table 5.3 Concentration of PM10 from six sampling sites and percentage of samples possessing PM10 level exceeded the NAAQS guidelines.

	Site	Range (Min-Max) ($\mu g/m^3$)	Percentage Exceeded NAAQS
Roadside site	Chulalongkorn Hospital	30-160	16 (3/19)
	Dindaeng	37-137	8 (2/24)
Mixed area site	Chulalongkorn University	36-131	5 (2/40)
	OEPP	24-134	4 (1/26)
	Singharat School	24-127	5 (1/22)
Outer Suburban	Bangkok University	23-135	4 (1/23)

Note: National Ambient Air Quality Standard (NAAQS) PM10 24-hour is 120 $\mu g/m^3$.

5.1.2 Monthly and Seasonal Variation of PM10

The monthly averages of PM10 concentrations are shown in Figure 5.1. These values varied from 26 μg/m^3 at OEPP to 131 μg/m^3 at Chulalongkorn University. A general trend of PM10 level in May, June, July (rainy season) was lower than those for other months at all sites. It seems like the several processes associated with rainfall and relative humidity are responsible for this variation. In winter, (November-February), however the PM10 concentrations are high at all sites.

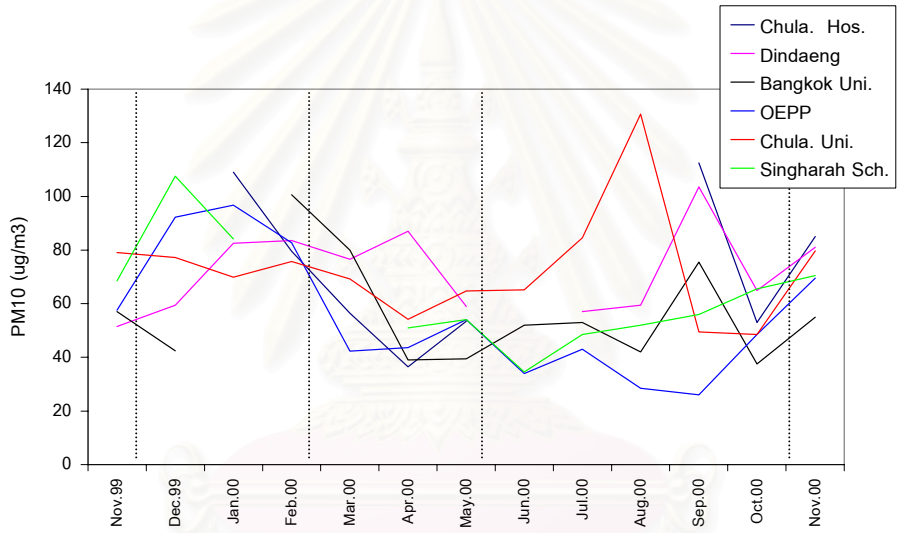


Figure 5.1 Monthly average PM10 concentration (μg/m^3)

Monthly averages of PM10 concentration at Dindaeng and OEPP are shown in Figure 5.2. Comparison of the average PM10 concentration at roadside (Dindaeng) and the mixed area (OEPP) was performed. At Dindaeng, PM10 level was ranging from 52 to 104 μg/m^3 and 26 to 97 μg/m^3 at OEPP. The general trend at the roadside was that PM10 level was high, this is probably because of the high traffic density and the closer of sampling site to the source.

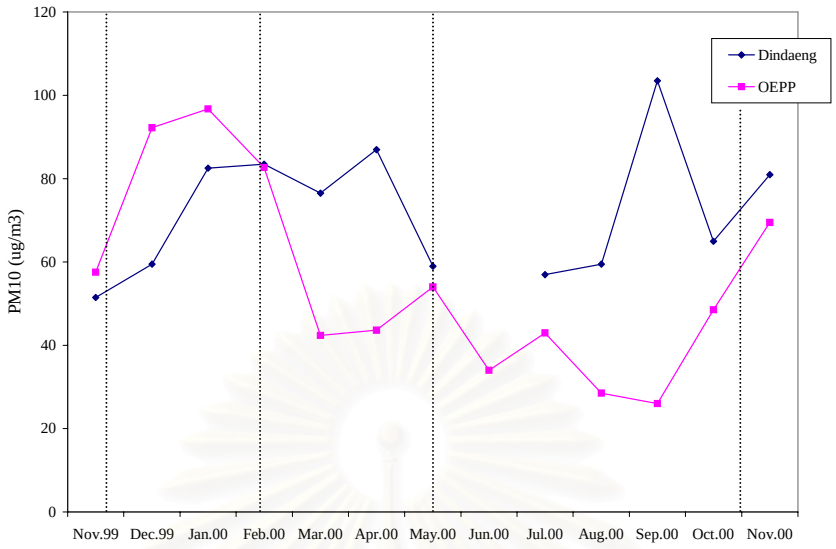


Figure 5.2 Monthly average PM10 concentration at Dindaeng and OEPP ($\mu g/m^3$)

The seasonal PM10 variations for all sites are shown in Figure 5.3. As a general observation, it is clearly seen that the highest concentrations occur during the winter period (mid Nov-mid Feb). Also, at the OEPP, Singharat School and Bangkok University, a general trend of lowest particulate loads in the rainy season (mid May- October) is observed. At the two Chulalongkorn sites, the particulate concentration seems relatively low during the summer period. This may be related to the seasonal holiday, which experiences fewer activities in the surrounding areas. Dindaeng roadside has all year round high traffic densities. These trends indicate that both source strengths and removal processes are important. Cities in temperate and colder zones experience considerable variability in source strengths due to demands associated with heating requirements. In tropical and sub-tropical cities, there is less variability in sources with season. The seasonal variation seen here is considered to be related to removal processes.

The mixed areas, such as OEPP and Singharat School, the ratios of PM10 concentration in winter and rainy season were 2.45 and 1.86, respectively. The ratios at roadside were 1.22 at Chulalongkorn Hospital and 1.32 at Dindeang. The ratio was 1.48 at suburban

site, Bangkok University. The ratios at roadside were generally lower than the other sites. These related to the high source emission all year. The ratio at commercial mixed area (Chulalongkorn University) was 1.15, which is low because of high source emission in winter and rainy season. The emissions drop during the semester break in summer.

In the previous study in 1994 at Chulalongkorn University, Total Suspended Particulate (TSP) concentrations measured during the rainy season were higher than those in the preceding winter (Panther, 1996). In 1999, the monthly PM10 variation in winter was higher than rainy season at Chulalongkorn Hospital, Chulalongkorn University and Bangkok University. Apparently, seasonal trends were important, higher PM10 levels during the winter and lower in the rainy season (Kaewngam, 2000).

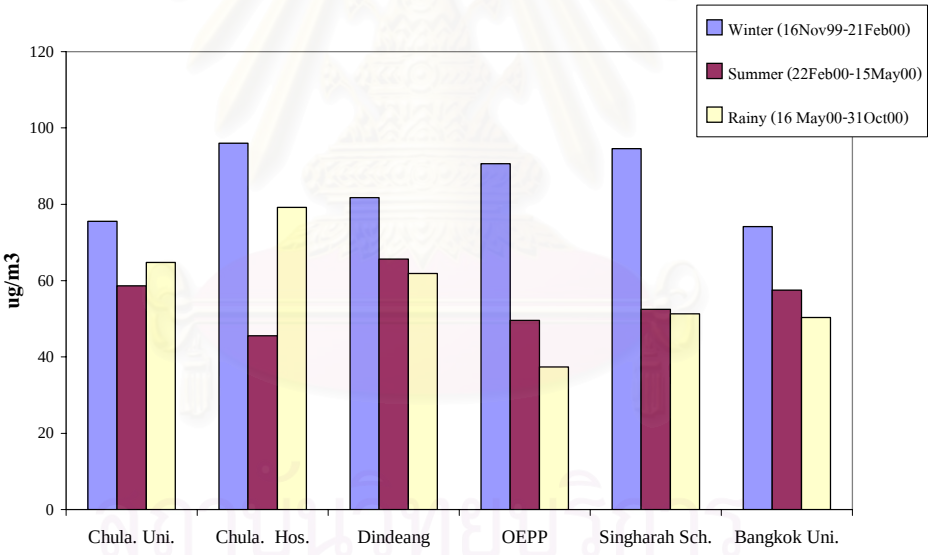


Figure 5.3 Block diagram showing seasonal PM10 variation ($\mu g/m^3$)

5.1.3 Monthly and Seasonal Variation of PM<0.95 μm, PM<1.5 μm, PM<3.0 μm, PM<7.2 μm and ∑SFPM

The monthly SFPM concentration is shown in Figure 5.4. In May, June, July, August and September, levels of PM<0.95 μm were lower than those for other months. In fraction <0.95, 0.95-1.5, 1.5-3.0, 3.0-7.2 and >7.2 μm the PM level were 26-43, 1-9, 5-11, 9-17 7-15 μm/m^3. Fine particle and surface area /mass is larger, therefore the particles are more susceptible to surface absorption, growth and subsequent removal high humidity or rain.

The concentration in five fractions can be divided into three groups. The highest level ranged from 27- 43 μm/m^3 in smallest diameter fraction size. The moderate level ranged 7-17 μm/m^3 in the PM more than 3.0 μm. The lowest level was 1-11 μm/m^3 in the PM 0.95-3.0 μm. These data appeared bimodal with 2 peaks below 1 μm and more than 3 μm.

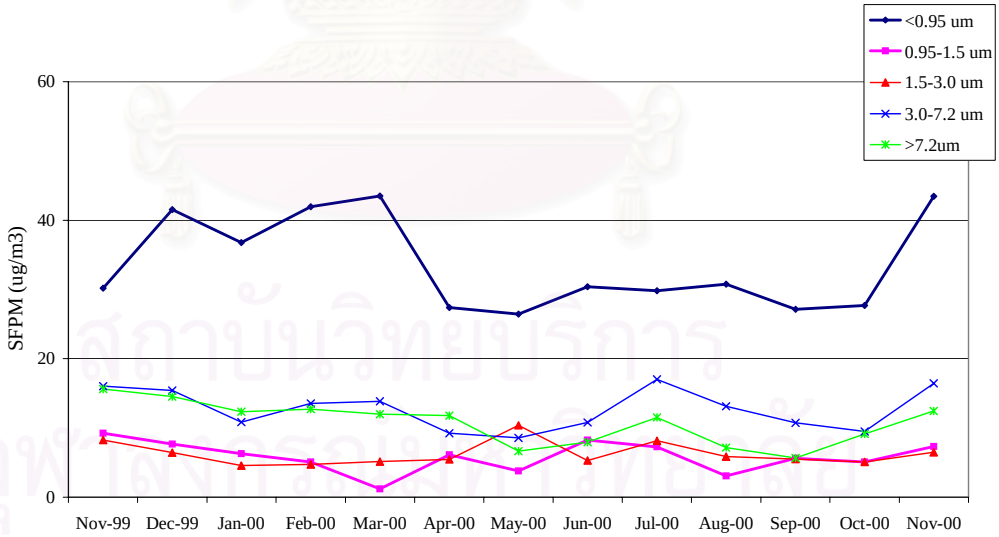


Figure 5.4 Monthly average SFPM concentration (μg /m^3)

Figure 5.5 showed the seasonal SFPM concentrations. The mean of PM<0.95 μm concentration were 38, 39 and 28 μm/m^3 in winter, summer and rainy season, respectively. In the smallest diameter fraction (<0.95 μm) and the largest fraction (>7.2 μm), the PM concentrations in rainy season were lower than those in winter.

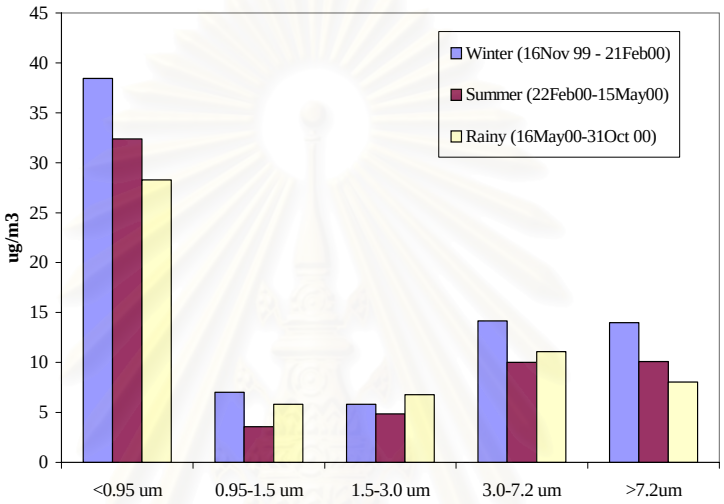


Figure 5.5 Block diagram showing seasonal SFPM concentration (μg/m^3)

Figure 5.6 presented yearly SFPM average concentration. The mean in fraction <0.95 μm, 0.95-1.5 μm, 1.5-3.0 μm, 1.5-3.0 μm, 3.0-7.2 μm and >7.2μm were 33, 6, 6, 12 and 11 μg/m^3 respectively.

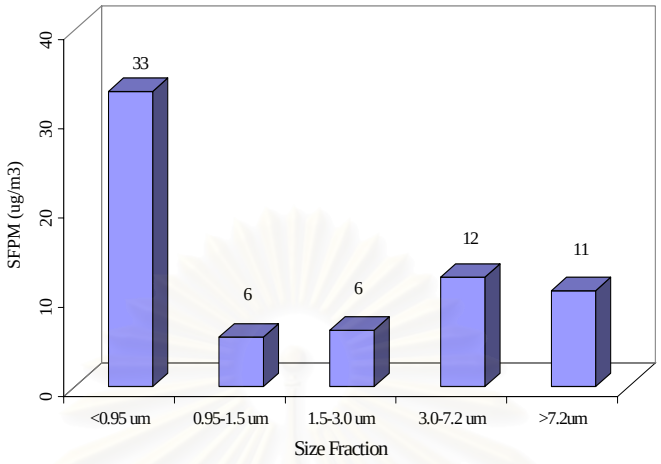


Figure 5.6 Yearly average SFPM concentration (μg/m^3)

The percentage of seasonal SFPM concentration is shown in Table 5.4. The percentage of PM <0.95 μm were 48, 48 and 47. In the percentage of PM >7.2 μm in winter and rainy was 18 and 13 because the particulate removal is important in big particulate matter size. The percentage of PM between 0.95 μm to 3.0 μm and between 3.0 μm to 7.2 μm was ranging 8-12 and 13-18 respectively.

The percentage of yearly SFPM <0.95 μm, 0.95-1.5 μm, 1.5-3.0 μm, 3.0-7.2 μm and >7.2 μm in each fraction were 48, 9, 9,18 and 16%. This is shown in Figure 5.7. The illustrating of mass size distribution particulate assesses the significance of airborne PAH in Bangkok urban air.

From the previous studies in 1996 at OEPP site, the mass size distribution of PM in Bangkok, is distributed in a bimodal form with a peak, the fine particle 0.43 –0.65 and the coarse particle 4.7-7.2 μm (Garivait, 1999).

Table 5.4 Percentage of seasonal SFPM concentration

	<0.95 μm	0.95-1.5 μm	1.5-3.0 μm	3.0-7.2 μm	>7.2μm	ΣSFPM
Winter (16Nov99-21Feb00)	48	9	8	17	18	100
Summer (22Feb00-15May00)	48	8	10	18	16	100
Rainy (16May00-31Oct00)	47	10	12	18	13	100

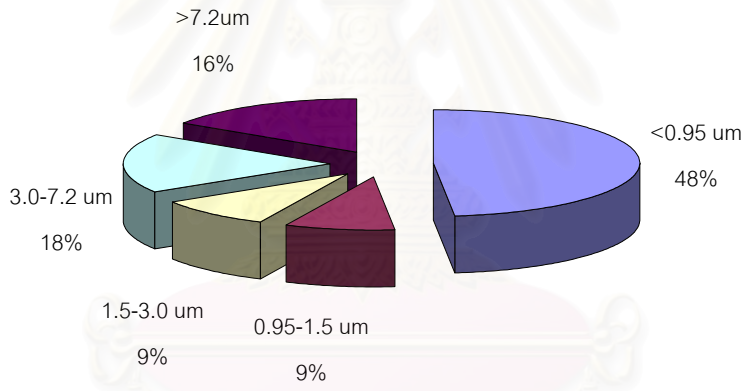


Figure 5.7 Percentage of yearly SFPM in each fraction

Monthly Variation of PM<0.95, PM <1.5, PM <3.0, PM<7.2 and Σ SFPM are shown in Table 5.5. The general observation in all fractions, can be seen the particulate matter was low in April to October because of the precipitate removal. The seasonal, yearly of SFPM concentration is shown in Table 5.6 The generally observation the PM concentration in rainy season was lower than in the winter season. In PM <0.95 μm, the percentage were 48, 48, 47 in winter, summer and rainy. In PM <1.5 μm the percentage were 57, 56, 57 respectively. In PM <3.0 μm the percentage were 64, 66, 68.

The coarser particulate matter <7.2 μm. The percentage was 82, 84 and 87. The yearly percentage of PM< 0.95, PM <1.5, PM <3.0, PM<7.2 were 48, 57, 66 and 84.

From the previous SFPM studies, PM <1.1, PM <3.3, PM <7 were 45, 55 and 86 in 1996 in Bangkok area. These result are closed to those obtained study in PM< 0.95, PM <3.0, PM<7.2 were 48, 66 and 84 (Garivait, 1999).

Table 5.5 Monthly cumulative of SFPM concentration ($\mu g/m^3$)

	<PM 0.95	<PM 1.5	< PM 3.0	< PM 7.2	∑SFPM
Nov-99	30	39	48	64	79
Dec-99	42	49	56	71	86
Jan-00	37	43	48	58	71
Feb-00	42	47	52	65	78
Mar-00	43	43	50	64	76
Apr-00	27	33	39	48	60
May-00	26	30	41	49	56
Jun-00	30	39	44	55	63
Jul-00	30	38	45	62	74
Aug-00	31	34	40	53	60
Sep-00	27	33	38	49	55
Oct-00	28	33	38	47	56
Nov-00	43	51	57	74	86

Table 5.6 Seasonal, yearly and percentage of SFPM concentrations ($\mu g/m^3$)

	<PM 0.95	<PM 1.5	<PM 3.0	<PM 7.2	∑SFPM
Winter (16Nov99 -21Feb00)	38 (48%)	45 (57%)	51 (64%)	65 (82%)	79 (100%)
Summer (22Feb00-15May00)	29 (48%)	34 (56%)	40 (66%)	51 (84%)	61 (100%)
Rainy (16May00-31Oct00)	28 (47%)	34 (57%)	41 (68%)	52 (87%)	60 (100%)
Yearly	33 (48%)	39 (57%)	45 (66%)	58 (84%)	69 (100%)

5.1.4 Comparison between PM<0.95 μm, PM<1.5 μm, PM<3.0 μm, PM<7.2 μm and ∑SFPM

There was moderate to good correlation of PM < 0.95 μm, PM< 1.5 μm, PM< 3.0 μm, PM<7.2 μm and ∑ SFPM with R^2 = 0.74, 0.84, 0.92, 0.97, respectively (n=39). The PM < 0.95 μm, PM< 1.5 μm, PM< 3.0 μm, PM<7.2 μm and ∑ SFPM can be calculated by using the equation the following

PM <0.95 ($\mu g/m^3$) = 0.51 x ∑ SFPM ($\mu g/m^3$)
PM <1.5 ($\mu g/m^3$) = 0.60 x ∑ SFPM ($\mu g/m^3$)
PM <3.0 ($\mu g/m^3$) = 0.66 x ∑ SFPM ($\mu g/m^3$)
PM <7.2 ($\mu g/m^3$) = 0.84 x ∑ SFPM ($\mu g/m^3$)

Based on cutoff point of around 2-2.5 um, it is estimated that about 60-65% of the airborne particulate matter in central Bangkok in the fine fraction with 35-40% in the coarse fraction. If combustion processes are considered primarily responsible for the fine fraction and motor vehicles the primary combustion source, then these results

indicate that traffic emission contribution approximately 60-65% of air particulate matter. Some small percentage would come from open cooking and litter (including biomass)burning. The coarse fraction can undoubtedly be associated with mechanical type actives including wind blower dust, traffic generated road dust, and sea salt.

5.1.5 Correlation of PM10 and ∑SFPM

At Chulalongkorn University both PM10 and ∑SFPM were sampling parallel. The average PM10 and SFPM concentration are 67 and 69 μg/m^3. The correlation is shown in Figure 5.8. between these 2 data sets. The good correlation between PM10 and SFPM is seen (Figure 5.8) with R=0.94, R^2 = 0.88.The ∑SFPM concentration can be calculated by the following

$$\sum \text{SFPM } (\mu g/m^3) = 1.03 \times \text{PM10 } (\mu g/m^3)$$

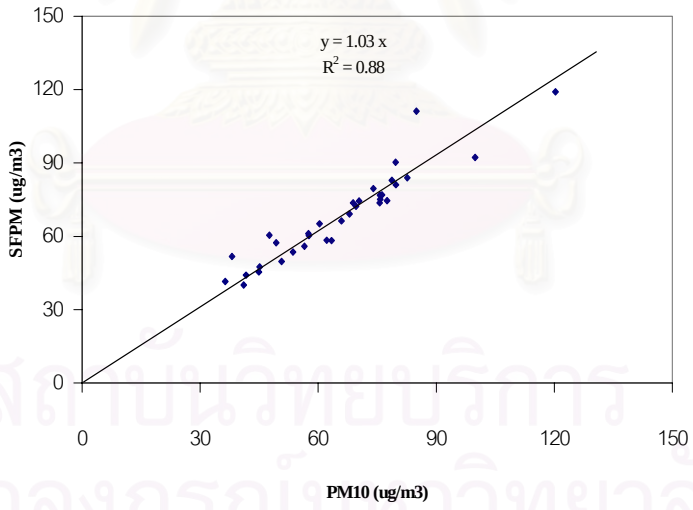


Figure 5.8 Scatter diagram showing the relationship between ∑SFPM and PM10

5.2 Polycyclic Aromatic Hydrocarbons (PAHs)

5.2.1 Monthly and Seasonal of ΣPAHs

The monthly variation of PAHs is shown in Figure 5.9. Generally, the high PAHs loading was found during the winter (mid November – mid February). This reflects the importance of removal mechanisms. Less variation in PAHs levels is seen between the summer and the rainy periods. The summer loading was marginally lower and associated with lower levels of activities. The seasonal of ∑PAHs is shown in Figure 5.10. From the seasonal data relating to PM10 sampling, the general trend for the ΣPAHs was highest in winter and lowest in the rainy season at all sites.The highest was 169 ng/m^3 at Singharat School in December 1999 and the lowest was 14 ng/m^3 at Bangkok University in April 2000. The precipitation removal was important for airborne particulate matter and PAHs particulate phase.

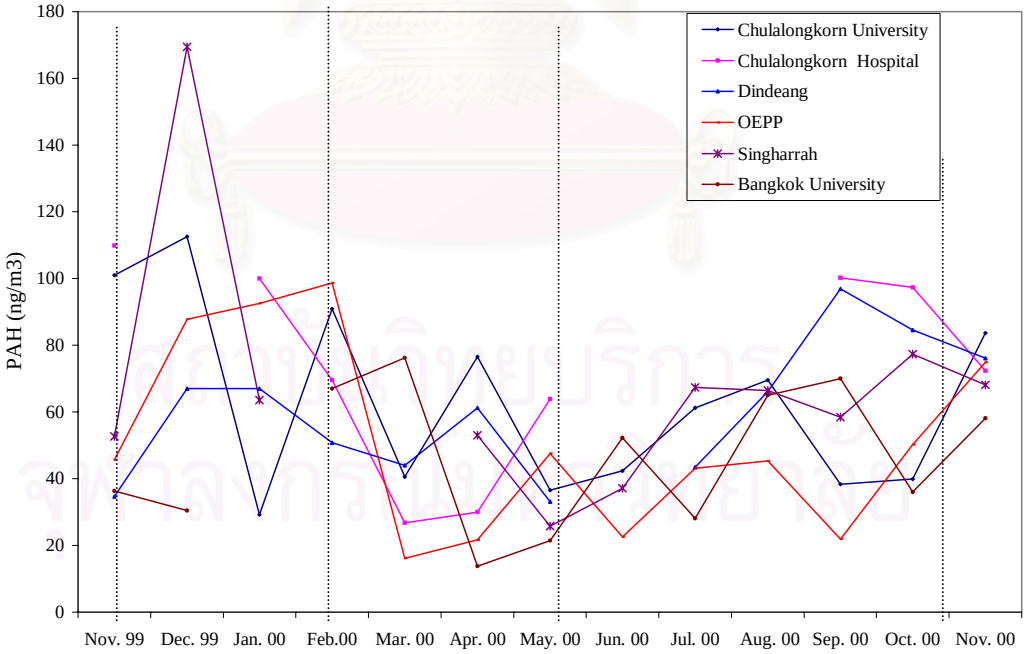


Figure 5.9 Monthly average Σ PAHs concentration (ng/m^3)

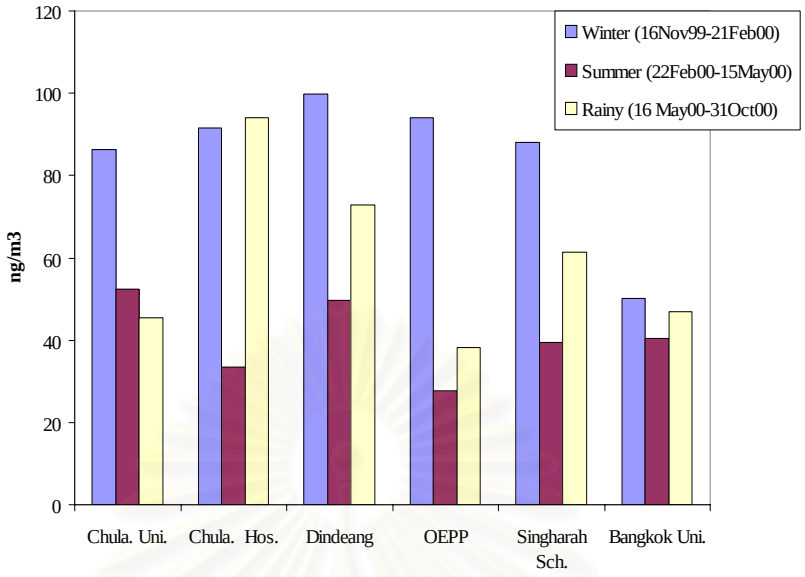


Figure 5.10 Block diagram showing seasonal ∑PAHs concentration (ng/m^3)

The yearly ΣPAHs average concentration has less variation in levels at all sites. The yearly ΣPAHs mean concentration at Chulalongkorn University, Chulalongkorn Hospital, Dindaeng, OEPP, Singharat School and Bangkok University were 75, 59, 45, 49, 62 and 67 ng/m^3, respectively. The data for PAHs concentrations collected in this study compares well with that seen in Seoul (mean=61 ng/m^3) and Jakarta (mean=61 ng/m^3) but is significantly higher than those observed in Hong Kong (mean=9 ng/m^3). Based on USEPA epidemiological data, the Bangkok data suggest that citizens are in a high risk category for developing cancer due to exposure to PAHs (Panther, 1999).

5.2.2 Individual PAHs

The percentages of average seasonal concentration of individual PAHs at all sites are presented in Figure 5.11, 5.12 and 5.13. The PAHs profiles at roadside areas are shown in Figure 5.11. The patterns of individual PAH at roadside areas were similar, indicating the similar emission sources. The six dominant PAHs were BghiP, Ind, BeP, BbF, Cor and BaP. The mean BghiP concentrations were 12 and 17 ng/m^3 and the mean BaP level was 9 and 11 ng/m^3 for Chulalongkorn University and Dindaeng, respectively.

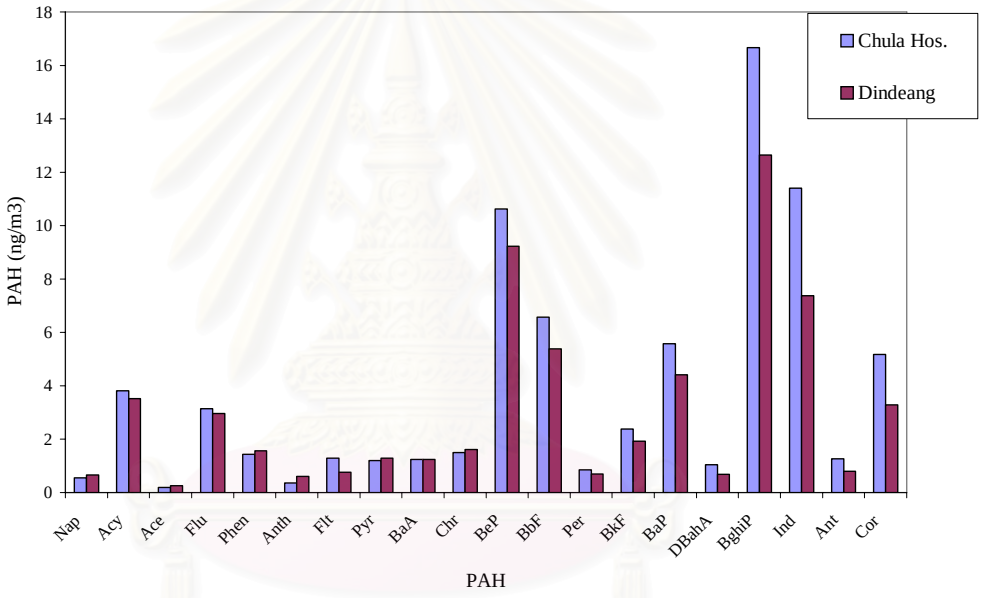


Figure 5.11 Average individual PAHs concentration at roadside areas
(Chulalongkorn Hospital and Dindaeng)

Figure 5.12 shows the ratios of individual PAHs at mixed areas, which have a very similar pattern. The six dominant PAHs were BghiP, Ind, BeP, BbF, Cor and BaP. Figure 5.13 shows average individual PAHs concentration at outer suburban area site. The dominant PAHs were similar to those in roadside and mixed areas.

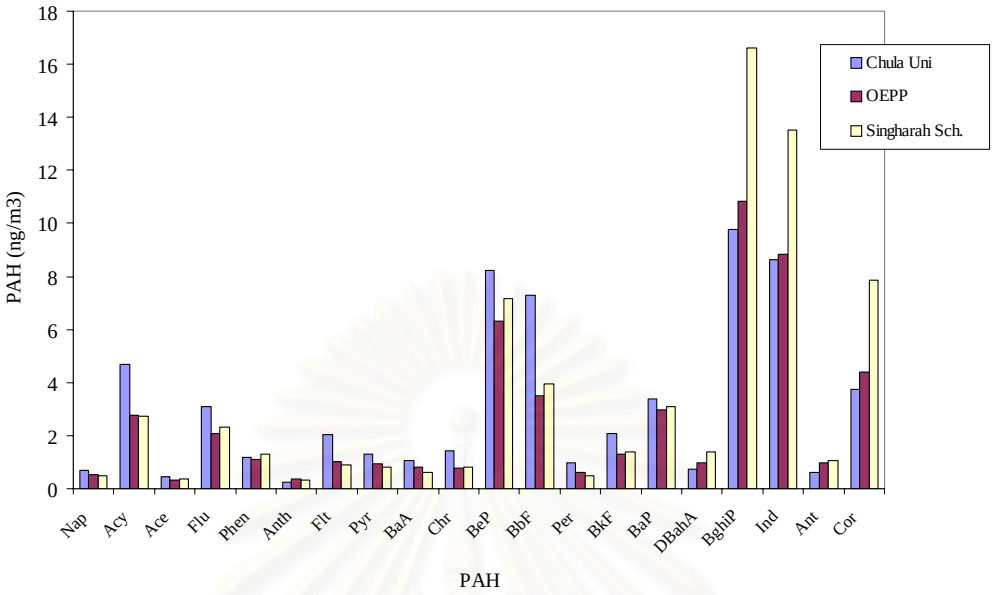


Figure 5.12 Average individual PAHs concentration at mixed areas (Chulalongkorn University, OEPP and Singharah School)

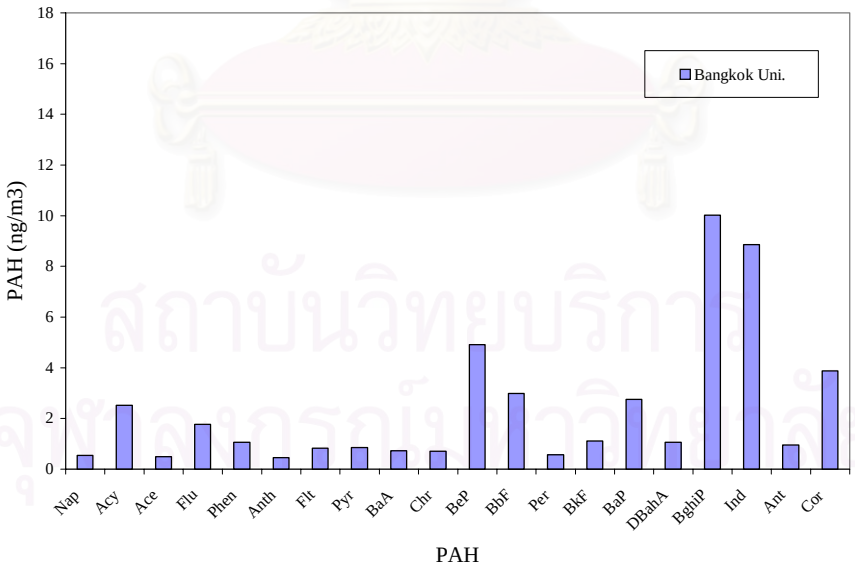


Figure 5.13 Average individual PAHs concentration at outer suburban area.

5.2.3 Benzo (a) pyrene (BaP)

Figure 5.14 shows monthly BaP concentration at all sites. Less variation was found. In March, April, May and June, the BaP levels were low at Chulalongkorn Hospital, OEPP, Singharat School and Bangkok University. In the suburban site, Bangkok University, the BaP concentration was also low in some months.

Table 5.7 showed the yearly and seasonal BaP Concentration. The variation of BaP concentration was high in winter and low in rainy season. The mean BaP levels in winter were 4.7, 5.6, 4.2, 4.6, 4.9 and 2.4 ng/m^3 and in rainy season were 2.8, 6.3, 4.5, 2.3, 2.4 and 2.7 ng/m^3at Chulalongkorn University, Chulalongkorn Hospital, OEPP, Dindaeng, Singharat School and Bangkok University, respectively. The highest BaP levels were found at the roadside areas, Chulalongkorn Hospital and Dindaeng, at all seasons.

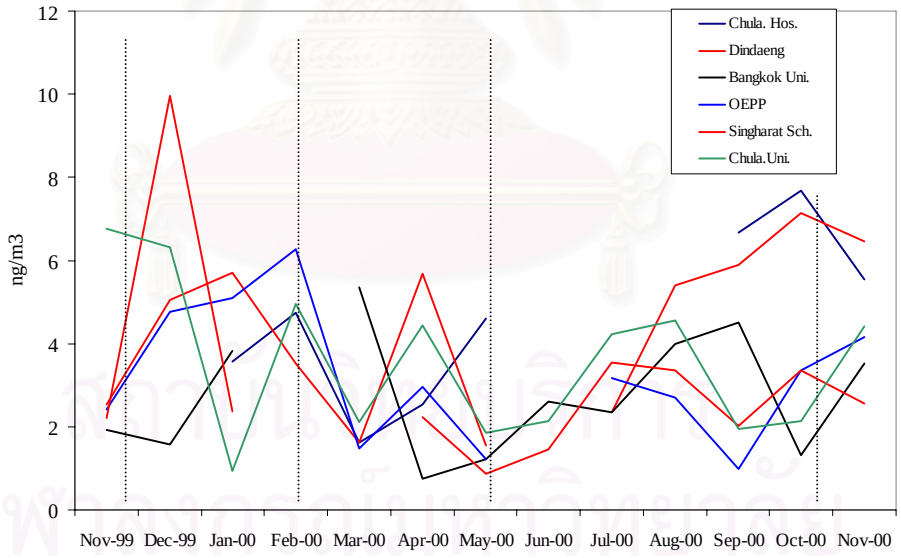


Figure 5.14 Monthly BaP concentration (ng/m^3)

Table 5.7 Seasonal and yearly BaP concentration (ng/m^3)

	Chulalongkorn University	Chulalongkorn Hospital	Dindaeng	OEPP	Singharat School	Bangkok University
Winter (16Nov99-21Feb00)	4.7	5.6	4.2	4.6	4.9	2.4
Summer (22Feb00-15May00)	3.3	3.4	3.1	3.0	1.6	2.4
Rainy (16May00-31Oct00)	2.8	6.3	4.5	2.3	2.4	2.7
Yearly	3.5	5.0	4.2	3.1	3.1	2.7

5.2.4 Correlation of PM10 and ΣPAHs at Chulalongkorn University

The correlation of PM10 and ΣPAHs is shown in Figure 5.15. There was moderate correlation of PM10 and ΣPAHs at Chulalongkorn University obtained with R^2 = 0.66. The ΣPAHs concentration from Bangkok can be calculated by the following

$$\Sigma PAHs\ (ng/m^3) = 0.86 \times PM10\ (\mu g/m^3)$$

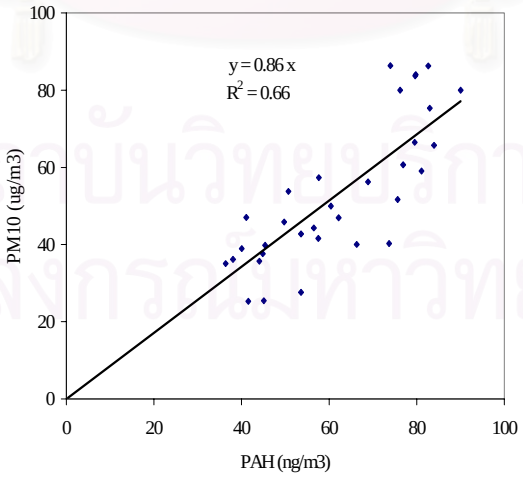


Figure 5.15 Scatter diagram showing the correlation between PM10 and ΣPAHs at Chulalongkorn University

5.2.5 Correlation of PM10 and ΣPAHs at Dindaeng

At Dindaeng, the general trend of both PM10 and ΣPAHs was in the same direction. The PM10 and ΣPAHs concentration was moderate correlation. This is shown in Figure 5.16. Both PM10 and ΣPAHs concentrations were high all year round, resulting from traffic densities. Monthly PM10 and ΣPAHs levels ranged from 52-104 μg/m^3 and 33-97 ng/m^3, respectively.

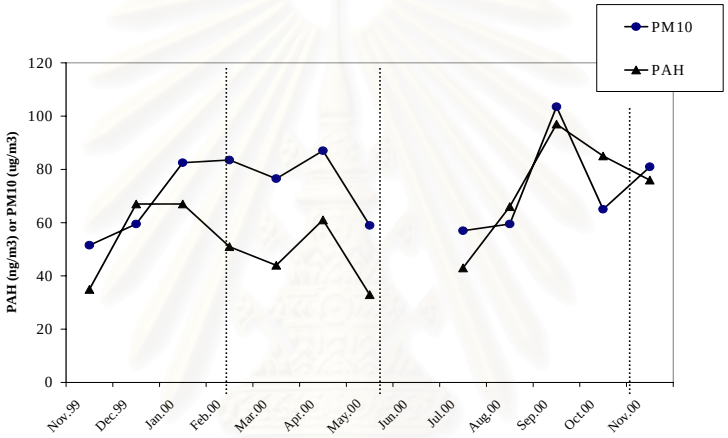


Figure 5.16 Monthly PM10 and ΣPAHs at Dindaeng

5.2.6 Correlation of PM10 and ΣPAHs at OEPP

At OEPP, the general trends of both PM10 and ΣPAHs was the same direction. The PM10 and PAH concentration were moderate correlation. This is shown in Figure 5.17. Both PM10 and ΣPAHs concentrations were high in winter and low in rainy season. Monthly PM10 and ΣPAHs levels ranged from 29-97 μg/m^3 and 16-99 ng/m^3, respectively.

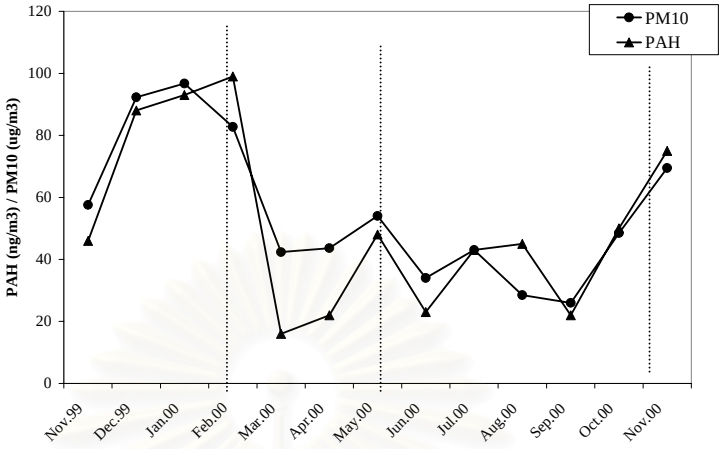


Figure 5.17 Monthly PM10 and Σ PAHs at OEPP

5.2.7 Correlation of PM10 and ΣPAHs at Bangkok University

At Bangkok University, the general trends of both PM10 and ΣPAHs were the same direction. The PM10 and ΣPAHs concentration were moderate correlation. This is shown in Figure 5.18. Both PM10 and ΣPAHs concentration were high in winter and low in rainy season. Monthly PM10 level ranged 38-101 μg/m^{3}and 14-76 ng/m^3, respectively.

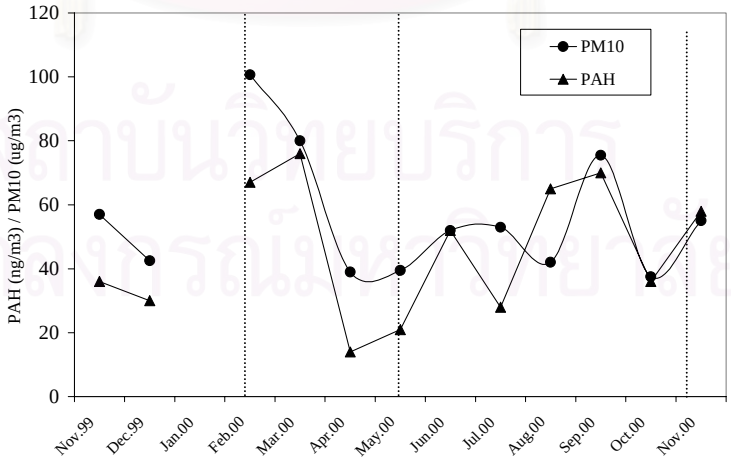


Figure 5.18 Monthly PM10 and ΣPAHs at Bangkok University

5.3 Correlation of Twenty PAHs at Chulalongkorn University

A correlation analysis was preformed on the PAHs data set related to the Chulalongkorn University ambient site. The result were the on the basis of 3 molecular weight grouping. The groups were the low molecular weight (128-178), the intermediate weight (202-252) and the high molecular weight molecular (276-300). Correlation coefficient was compare within the groups and across groups. It was observed that strong correlation between member only occurred for the high molecular group. These were moderate correlation within the intermediate group. With the low molecular group, weak correlation was seen (Table 5.8). It is suggested that these results can be explained on the basis of the relative constancy of contributing source and relative stability of the PAHs species once attached to an absorbed onto PM.

Table 5.8 Correlation of high molecular weight PAHs and PM10
at Chulalongkorn University

	BeP	Per	BkF	BaP	DBahA	BghiP	Ind	Ant	Cor
Bep	1.00	0.89	0.89	0.97	0.89	0.94	0.97	0.93	0.90
Per	0.89	1.00	0.65	0.90	0.91	0.85	0.90	0.87	0.89
BkF	0.89	0.65	1.00	0.87	0.69	0.83	0.84	0.84	0.75
BaP	0.97	0.90	0.87	1.00	0.89	0.95	0.94	0.94	0.87
DbahA	0.89	0.91	0.69	0.89	1.00	0.93	0.89	0.88	0.90
BghiP	0.94	0.85	0.83	0.95	0.93	1.00	0.91	0.92	0.90
Ind	0.97	0.90	0.84	0.94	0.89	0.91	1.00	0.94	0.95
Ant	0.93	0.87	0.84	0.94	0.88	0.92	0.94	1.00	0.92
Cor	0.90	0.89	0.75	0.87	0.90	0.90	0.95	0.92	1.00

5.4 Comparison of Ratios of Ambient Concentration of Selected PAHs with Reported in the Literature

Table 5.9 Comparison ratios of ambient concentration of selected PAHs with reported in the literature

Site	BaP/Cor	BaP/BghiP	BghiP/Ind	BaP/BeP	BghiP/BeP	Cor/BeP
Chula Uni	0.91	0.32	1.14	0.42	1.33	0.50
Chula Hos.	1.08	0.33	1.46	0.58	1.82	0.55
Dindaeng	1.01	0.33	1.70	0.45	1.65	0.53
OEPP	0.66	0.32	1.22	0.49	1.97	0.90
Singharat Sch.	0.36	0.17	1.23	0.49	3.00	1.56
Bangkok Uni.	0.77	0.28	1.12	0.61	2.32	0.97
Emission						
Traffic (street)	<0.4-1.0*	0.2-0.6*	1.8-3.3*	0.3-0.6*	1.3-3.0*	0.5-2.1*
Oil Burning	>1.7*	>0.8*	0.7-1.1*	0.1*	0.4*	0.2*

*(Brasser, 1980)

In the Table 5.8, the comparison of the ratio of BaP/Cor, BaP/BghiP, BghiP/Ind, BaP/BeP, BghiP/BeP, Cor/BeP, of six ambient sampling site with traffic emission. The comparison found the ratios were in the range of traffic emission, In indicate PAH from the traffic source emission.

From the previous study, the ratio of BaP/BeP indicated traffic emission (mobile source) or oil burning (stationary source). With the traffic emission the ratio ranged 0.3-0.6 whereas the ratio of stationary source was 0.1. Figure 5.19 showed BaP/BeP ratio at each site. These ratios of ambient samples were in range of traffic emission.

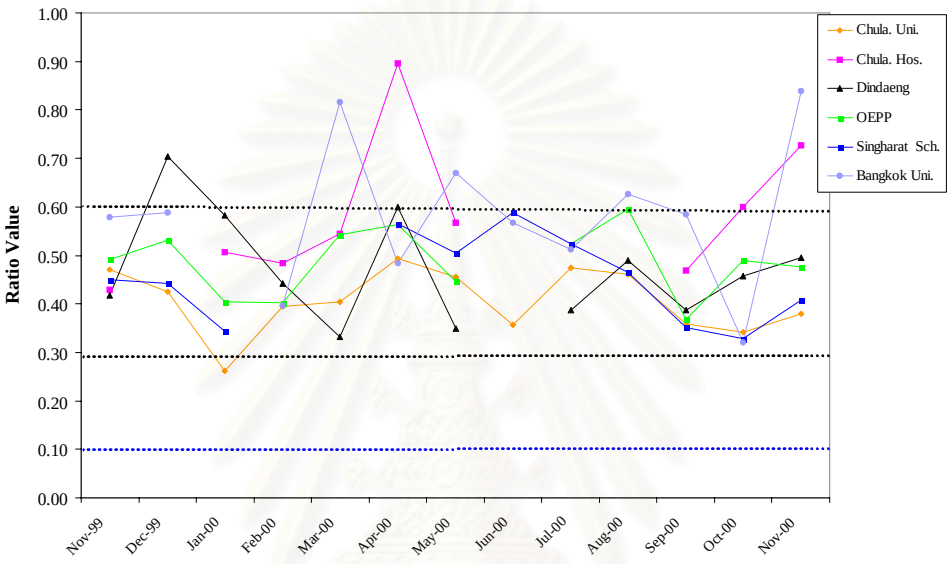


Figure 5.19 BaP/BeP ratio at each site

The ratio of BghiP/BeP, Cor/BeP indicated traffic emission (mobile source) or oil burning (stationary source). With the traffic emission the ratio ranged from 1.3-3.0 and 0.5-2.1 respectively. The stationary source was 0.4.and 0.2 respectively. Figure 5.20 and 5.21 are shown BghiP/BeP, Cor/BeP ratio at each site. These ratios of ambient samples were in range of traffic emission.

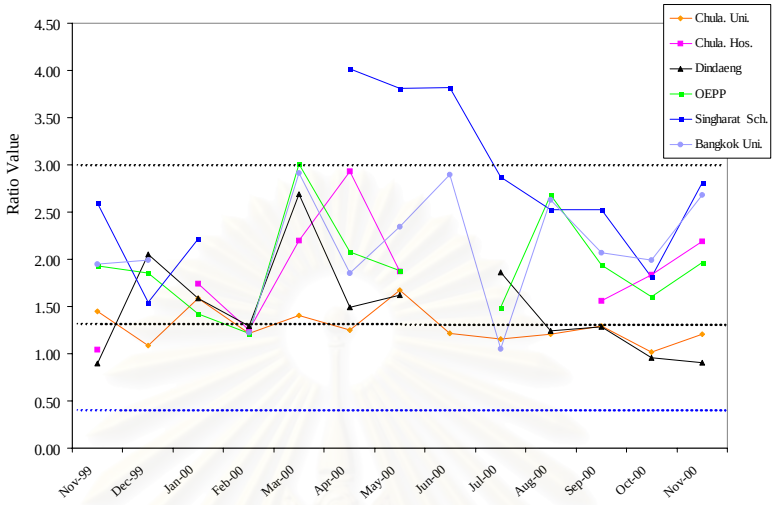


Figure 5.20 BghiP/BeP ratio at each site

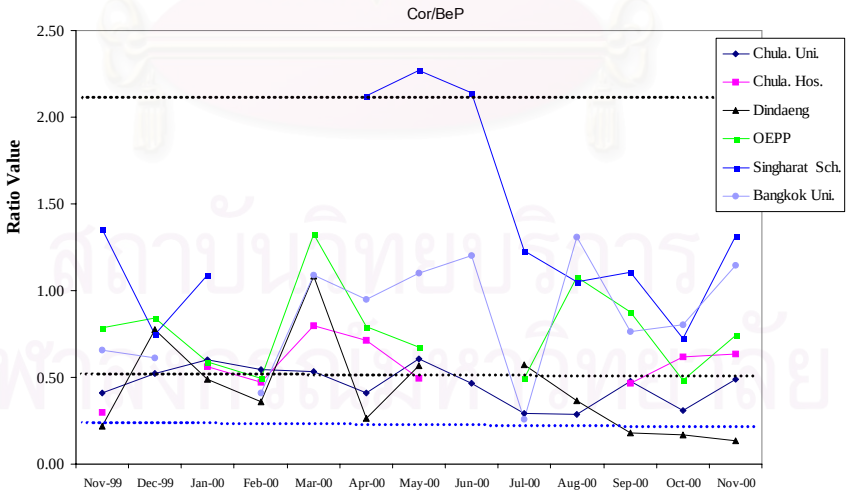


Figure 5.21 Cor/BeP ratio at each site

5.5 Emission Sources

5.5.1 Vehicle as Emission Sources

The particulate emissions, from a range of motor vehicles that used a variety of fuels, have been collected, weighed and analyzed for PAHs. A PAHs profile for each case, called a source profile, has been set up based on the percentage of individual PAHs species load per total PAHs load. Here, the total load has been calculated as the sum of the PAHs being measured. These vehicle source data are shown in Table 5.10.

Table 5.10 Source emission data for different vehicle types.

Motor Vehicle types	Fuel types	PM (mg)	Σ PAHs (ng PAH /mg dust)	Dominant PAHs
HDDV Bus	Diesel (PTT)	1.437	181	Ace, Acy, Flu, BeP, Anth, Pyr and Phen
LDDV Pick up	Diesel (Bangjak)	0.857	636	BeP,Flu, Acy, BghiP and Ind
LDGV	Gasoline (Unlead)	0.8055	141	BghiP, BbF, BkF,Chr, BaP, BeP, Flu and Cor
Motorcycle (Two-stroke)	Gasoline (Unlead 91)	0.720	488	Acy, BeP, Flt, Phen and BghiP
Motorcycle (Four-stroke)	Gasoline (Unlead 91)	0.510	192	BghiP,Ind, Cor and BeP
Tuktuk (Gasoline)	Gasoline (PTT91)	0.231	164	Acy, BeP, Flt, Cor and BghiP
Tuktuk (CNG)	CNG	0.785	133	Cor, BghiP,Flt,Ind, BeP and BbF

No individual PAHs for any of the cases that have been studied here is greater than 33% of the total PAHs load but it is common to see 3 or 4 members in each case contributing more than 10% of the PAHs load. A notable exception to this is the light duty motor vehicle on gasoline (petrol) whereas only one member was >10% (namely BghiP) and 6 others were >5%.

The source profile of a HDDV (bus) is shown in Figure 5.22 The smaller molecular PAHs such as Ace, Acy and Flu dominate this profile. These 3 PAHs are 3 ringed members with C_{12} or C_{13}. The percentages are 23.0, 22.6 and 13.7, respectively. Only one 5-member ring species, BeP (C_{20}), makes a significant contribution at 10.2 %. The other higher molecular weight species, such as BbF, BaP, BghiP, Ind and Cor which are commonly observed as dominant species in ambient particulate matter, are only small contributors here. The ∑PAHs concentration was 181 ng PAHs/mg PM. (Rogge et al, 1993), indicated that Pyr, Flt, Phen and Chr were the major PAHs for HDDV trucks and (Nelson, 1989), found that Nap, Ace, Phen, Pyr and Flu were presented in significant proportions.

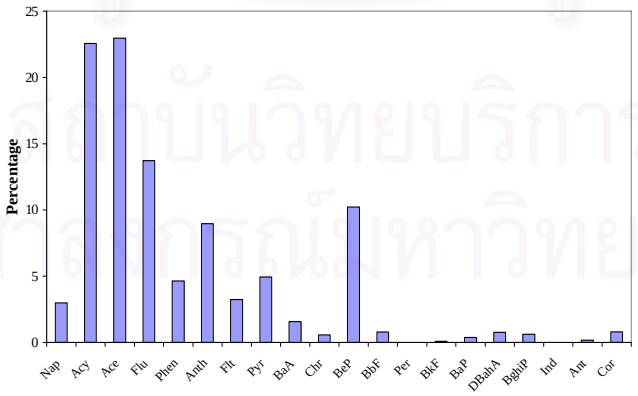


Figure 5.22 Percentage of individual PAHs of HDDV emission

In case of LDDV vehicles, the major PAHs were quite different from those resulting from HDDV vehicles. The PAHs profile percentage of individual PAHs species for LDDV is shown in Figure 5.23. Here some of the higher molecular weight specie, such as BeP was dominant with 17.6. Also one of the smaller species, Flu and Acy were a significant contributor at 16.6 and 15.8%. The ∑PAHs concentration was 636 ng PAHs/ mg PM and when considered alongside the particulate load, this resulted in a considerable contribution to the overall PAHs load.

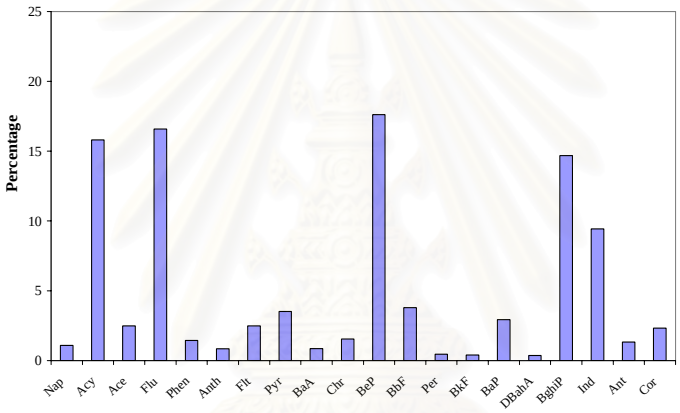


Figure 5.23 Percentage of individual PAHs of LDDV emission

The heavy and light diesel emissions in unit μg of PAHs per distance 1 km are shown in Table 5.11. The PAHs level concentrations of HDDV ranged from 0.00 to 79.59 μg PAHs / km respectively. The summed emission PAHs of three types of HDDV was difference. The summed emission PAHs of Euro 2, Euro 1 and Hino Red were 167.89, 304.91 and 324.19 59 μg PAHs/km. For HDDV, Hino red bus (non air-conditioned) emitted the highest PAHs emission. The PAHs level concentrations of LDDV ranged from 0.00 to 9.32 μg PAHs/km respectively. The summed emission PAHs of three types of LDDV was difference. The summed emission PAHs of Mitsubushi (Bangjak), Mitsabushi (PTT) and Toyota (PTT) were 20.17, 17.26 and 21.47 μg PAHs / km.

Table 5.11 Individual PAHs emission of types of HDDV and LDDV

	HDDV (ug/km)			LDDV (ug/km)		
	Euro 2 (PTT)	Euro 1 (PTT)	Hino Red (PTT)	Mitsubishi (Bangjak)	Mitsubishi (PTT)	Toyota (PTT)
Nap	4.00	7.59	24.14	0.44	0.11	0.17
Acy	25.59	79.59	69.50	1.21	1.05	9.32
Ace	51.99	63.25	77.05	0.27	0.23	1.15
Flu	25.63	38.98	37.25	2.89	2.52	4.31
Phen	5.51	14.93	10.72	0.14	0.12	0.96
Anth	18.54	25.56	19.04	0.06	0.05	0.74
Flt	7.23	9.47	9.38	0.25	0.22	1.54
Pyr	5.99	16.27	11.56	0.53	0.46	0.99
BaA	8.70	2.60	2.88	0.12	0.10	0.18
Chr	0.83	1.73	2.40	0.40	0.35	0.03
BeP	7.01	34.42	45.71	4.43	3.85	1.76
BbF	0.00	3.21	3.48	1.01	0.88	0.00
Per	0.00	0.00	0.00	0.12	0.11	0.00
BkF	0.10	0.14	0.62	0.11	0.09	0.01
BaP	1.62	0.46	1.78	0.76	0.66	0.04
DBahA	1.21	2.51	2.11	0.06	0.05	0.10
BghiP	1.21	1.56	5.00	3.91	3.40	0.07
Ind	0.00	0.00	0.00	2.52	2.19	0.00
Ant	0.49	0.47	0.25	0.35	0.30	0.02
Cor	2.23	2.19	1.32	0.60	0.52	0.07
Total	167.89	304.91	324.19	20.17	17.26	21.47

The profiles of HDDV and LDDV were difference. Figure 5.24 and 5.25 showed PAHs profiles of three types of HDDV emissions and three types of LDDV emissions in unit μg/km.

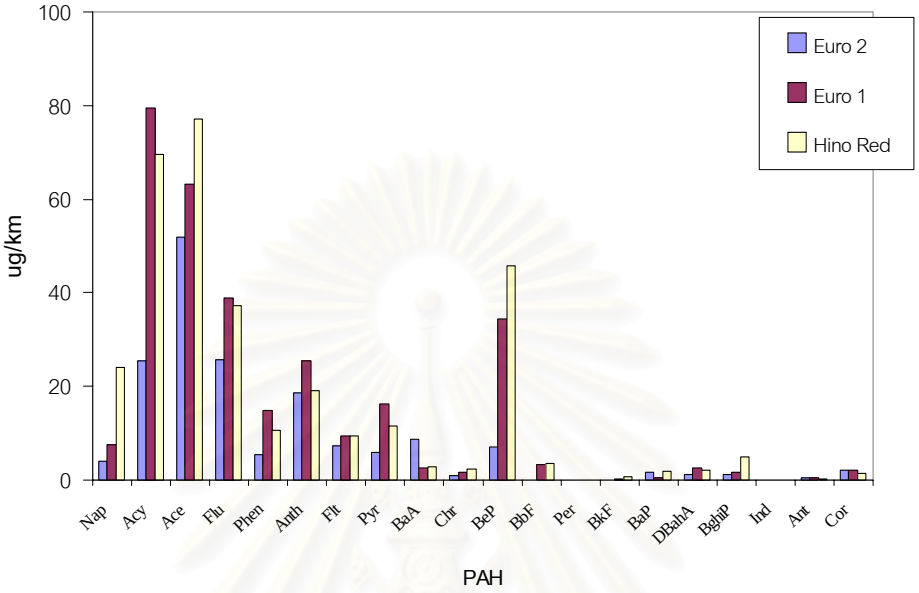


Figure 5.24 PAHs profile of three types of HDDV emissions (μg/km)

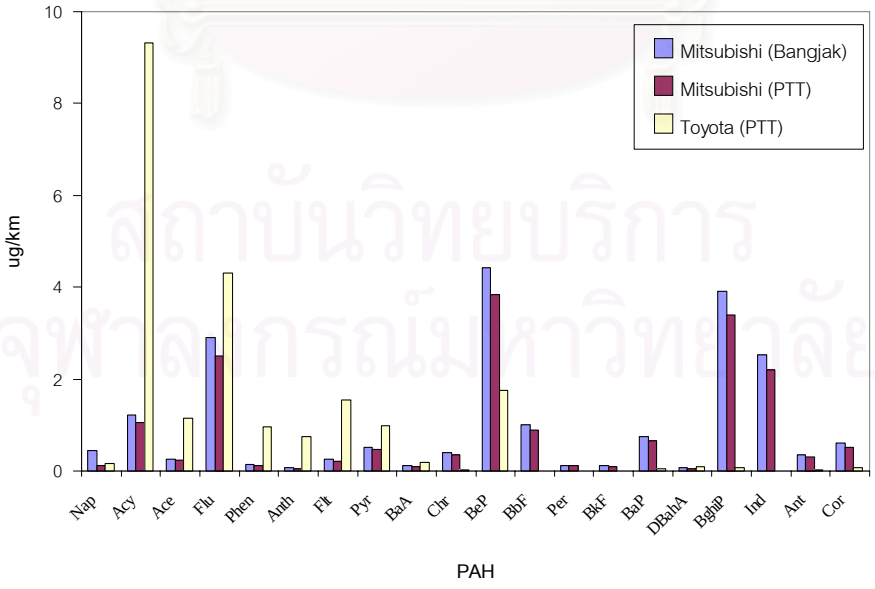


Figure 5.25 PAHs profile of three types of LDDV emissions (μg/km)

The PAHs profile and percentage of individual PAHs species for LDGV are shown in Figure 5.26. Compared with other cases that have been studied, this profile is relatively uniformed across the range of PAHs measured. A comparable spread particularly across the 4, 5 and 6 ringed members is observed with BghiP (6 rings), BbF (5 rings), BkF (5 rings), Chr (4 rings), BaP (5 rings), BeP (5 rings), Flu (3 rings) and Cor (6 rings) being the major PAHs. The percentages of were 16.5, 7.9, 7.7, 7.0, 6.6 and 6.6 respectively. The ∑PAHs concentration was 141 ng PAHs /mg PM. Rogge et al., 1993 found that BghiP, Chr, BbF and Pyr were the major PAHs for catalyst unleaded petrol motor vehicles.

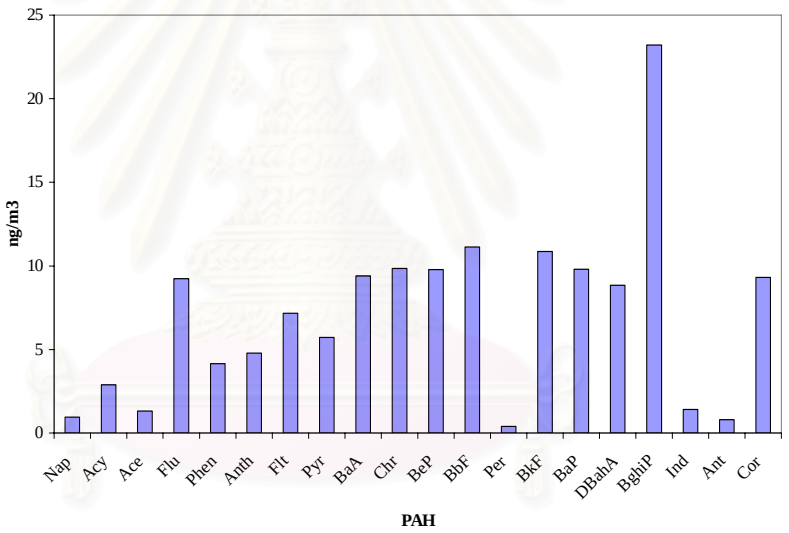


Figure 5.26 Percentage of individual PAHs of LDGV emission

Figure 5.27 showed percentage of individual PAHs of types of LDGV emission. Three LDGV were Honda, BMW and Mitsubishi. The profiles were difference.

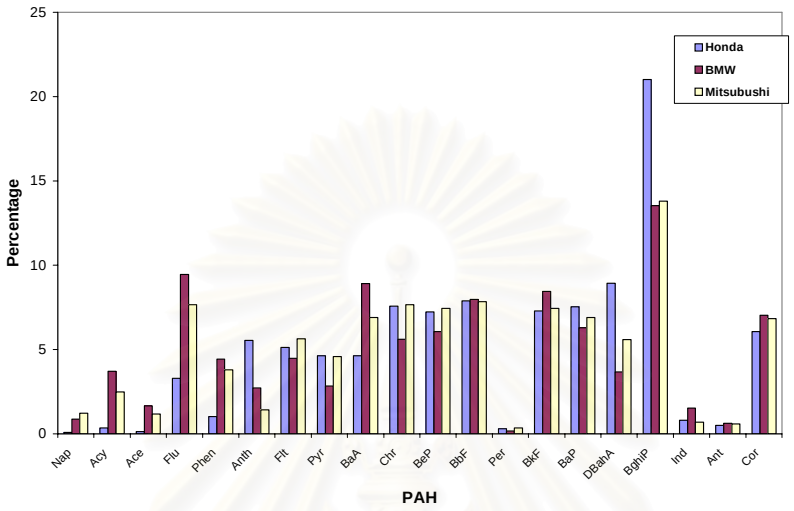


Figure 5.27 Percentage of individual PAHs of three types of LDGV emission

In Figures 5.28 and 5.29 the PAHs profile and percentages of PAHs species for two and four-stroke motorcycles are shown. There is quite a striking difference between the two profiles with the two-stroke motorcycle having a dominance of 3 and 4 ringed PAHs members while the four-stroke vehicle has its profile showed towards the 6 ringed PAHs species. The major PAHs of two-stroke motorcycle was Acy at 30.6% of the total. The ∑PAHs concentration was 488 ng PAHs/ mg PM

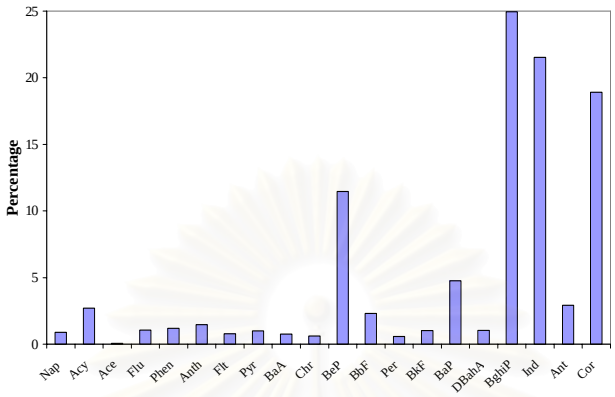


Figure 5.28 Percentage of individual PAHs of two-stroke motorcycle emission

In case of four-stroke motorcycle, the high molecular weight PAHs such as BghiP, Ind, Cor and BeP were dominant species. The percentages were 25.0, 21.5, 18.9 and 11.5 respectively. The ∑PAHs was 192 ng PAHs/mg PM which was considerable less than that generated by the two-stroke motorcycle.

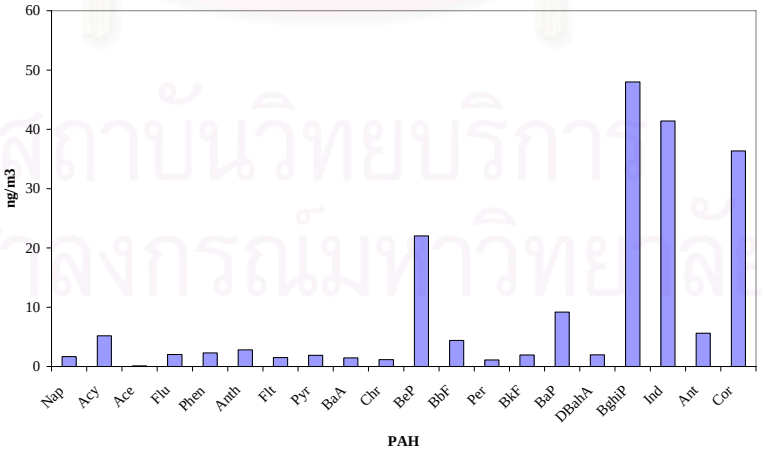


Figure 5.29 Percentage of individual PAHs of four-stroke motorcycle emission

In Figures 5.30 and 5.31, the PAHs profile and percentages of PAHs species for two fuels in used for the motorized tricycle fleet, Bangkok's famous, tuktuk. are shown. There are two fuels in used for tuktuk, Both cases have been investigated. With gasoline, it was found that quite a spread of PAHs was observed with the major members being Acy, BeP, Flt, Cor, BghiP, Ind and BbF. The percentages were 18.9, 12.6, 11.5, 11.1, 8.1, 7.9 and 7.5 respectively. The ∑PAH was 164 ng PAHs /mg particulate.

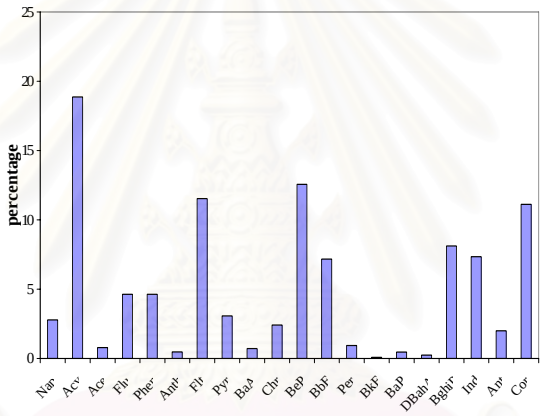


Figure 5.30 Percentage of individual PAHs of tuktuk used gasoline

With Compressed Natural Gas (CNG), there was more a preponderance of higher molecular weight members such as Cor, BghiP and Ind at 17.0, 16.3 and 11.9% respectively but also the middle range PAHs were evident with Flt, BeP and BbF at 13.2, 9.4 and 8.9% respectively. Ace was virtually absent from this case even though it was the dominant species in the gasoline-fuelled tuktuk. The ∑PAHs was 133 ng PAHs / mg particulate matter. The summed contribution from either fuel was comparable.

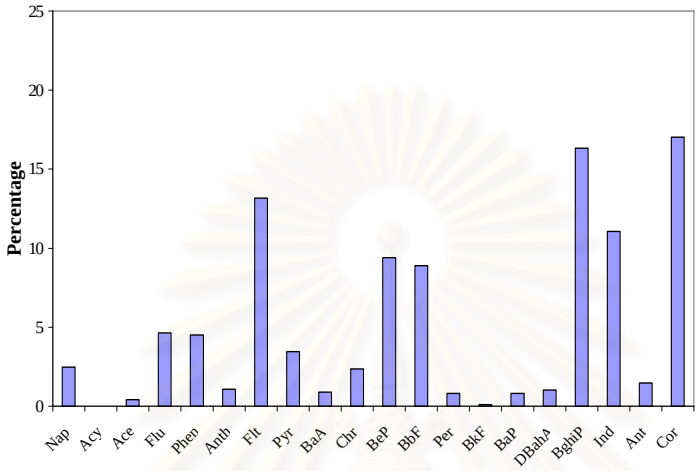


Figure 5.31 Percentage of individual PAHs of tuktuk used CNG

5.5.2.Industry as Emission Sources

The summary of individual PAHs in industry emission samples are shown in Table B-15. The boiler stack emission samples came from the two factories in Huamark and Rangsit. Heavy oil consumption is 186 and 192 l/hr, the ΣPAHs were 60 and 78 ng/mg dust respectively. In Figures 5.32 and 5.33 the PAHs profile and percentages of PAHs species for two factories are shown. At Huamark the percentage of individual PAHs, ranged 0.0 – 27.1. The five dominants PAHs were BeP (5 rings), Pyr (4 rings), Flt (4 rings), Flu (3 rings) and Phen (3 rings) with percentages were 27.1, 20.1, 17.4, 11.1 and 8.2 respectively. At Rangsit, the percentage of individual PAHs, ranged from 0.0 – 26.4. The five dominant PAHs were Phen (3 rings), BeP (5 rings), Pyr(4 rings), Flt (4 rings) and NaP (2 rings). The percentages were 26.4, 21.0, 17.3, 14.1 and 7.9 respectively. The previous studied PAHs identified as marker for the industrial oil burning samples were Flt, Pyr and Chr.

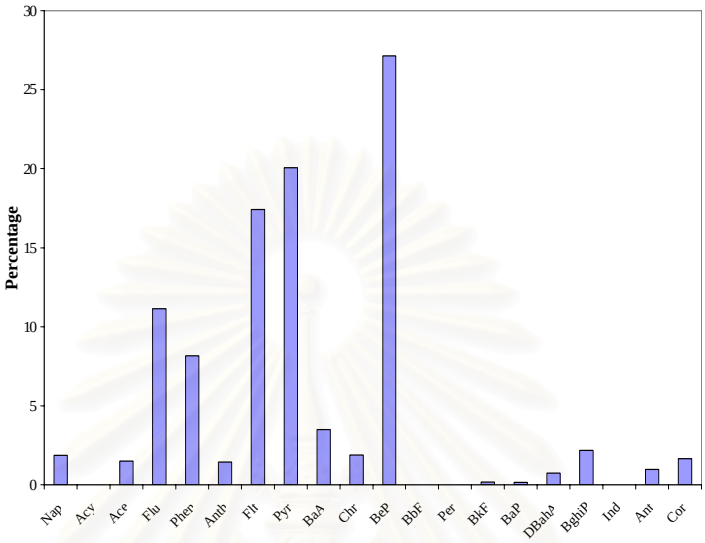


Figure 5.32 Percentage of individual PAHs of boiler stack emission at Huamark

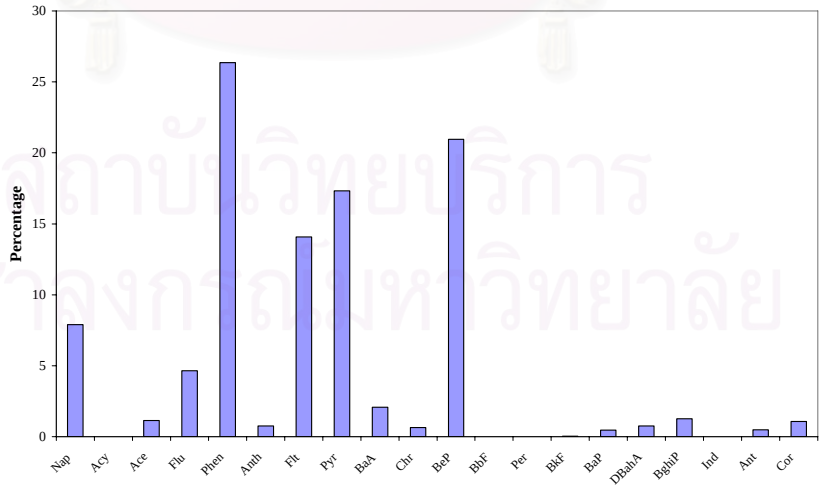


Figure 5.33 Percentage of individual PAHs of boiler stack emission at Rangsit

In Figures 5.34, the PAHs profile and percentages of PAHs species for garbage incinerator stack samples is shown. In garbage incinerator stack samples, the ΣPAHs concentrations were 64 ng/mg dust. The five dominants PAHs were Flt (4 rings), Pyr (4 rings), Acy (3 rings), Phen(3 rings) and BeP (5 rings) The percentages were 25.0, 23.3, 16.8, 15.9 and 5.3 respectively. In the previous studies the PAHs marker for incinerators were Pyr, Phen and Flt.

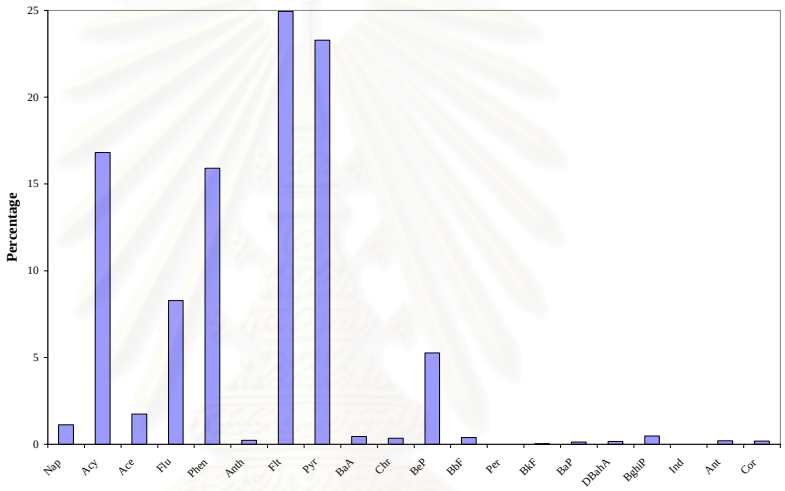


Figure 5.34 Percentage of individual PAHs of garbage incinerator stack emission

In Figure 5.35, PAHs profiles of heavy-fired boiler and incineration stack samples are shown.

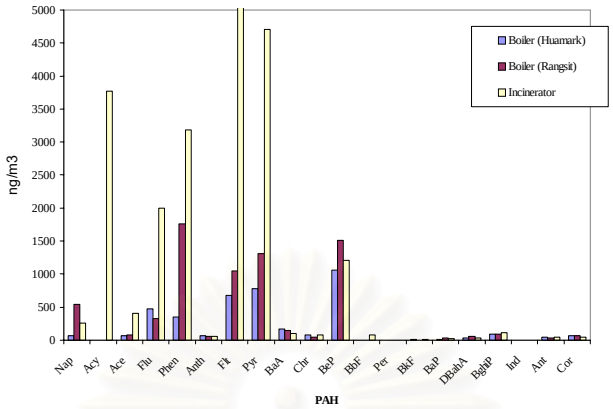


Figure 5.35 PAHs profiles of heavy-fired boiler and incineration stack samples

5.5.3 Road dust as Emission Sources

The road dust samples are from Phahonyothin, Dindaeng, Bantatthong and Ladya road in Bangkok area. The samples was swept and screened for size of road dust was<38 μm and 38-75 μm. In Figure 5.36 the PAHs profile and percentages of PAHs species for road dust emission sample is shown. The ΣPAHs was 6.8 ng PAHs /mg dust for the road dust size <0.38 μm and vary 7.9 ng PAHs/mg dust for road dust 3.8-0.75 μm. The most dominant PAHs species at all roads were Acy, BeP, Flt. The percentage of the most dominant PAHs in road dust size < 0.38 μm were 30.7, 17.9 and 11.3, in road dust size 0.38-75 μm were 40.9,11.4 and 8.2.

From the previous study, the average concentration of major PAHs found the dust sampled were Pyr, Flt and Phen.

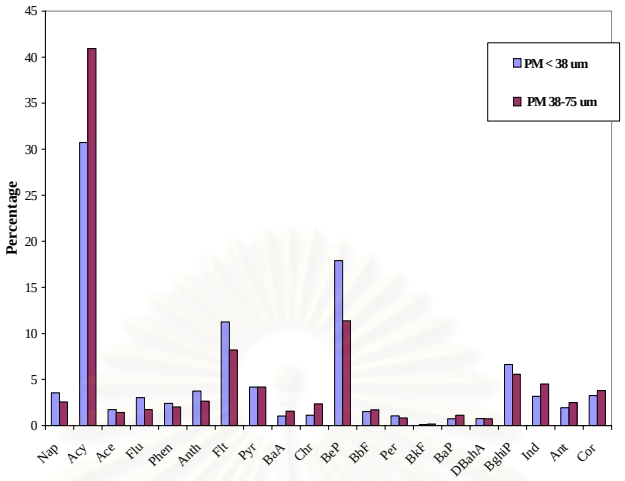


Figure 5.36 Percentage of individual PAHs of road dust emission

5.6 Source Contribution

5.6.1 Tables of Vehicle Source and Ambient PAHs Profiles Comparison

Table 5.12 showed percentage of individual PAHs of source emission. The mobile emission sources were HDDV, LDDV, LDGV, two and four-stroke motorcycle, tuktuk using gasoline and CNG. The stationary source emission was boiler stack emission and incinerator stack emission. The road dust was fugitive source emission. The dominant PAHs of each source showed in dark area.

Table 5.13 showed percentage of individual PAHs of ambient samples. The six sampling sites in Bangkok area were Chulalongkorn Hospital, Chulalongkorn University, Dindaeng, OEPP, Singharah School and Bangkok University. The PAHs profiles of six sites were similar, indicating from similar sources. The eight dominants PAHs, labeled in dark area, were BghiP, Ind, BeP, BbF, BaP, Cor, Acy and Flu.

The emission sources PAHs profiles were compared with the ambient samples. Acy found in both sources, mobile and stationary source. Mobile source was heavy and light diesel, two-stroke motorcycle and tuktuk. Stationary source was incinerator stack.

Flu was found from both source and mobile source. Mobile source was heavy and light diesel and stationary source was boiler stack and incinerator stack. Also BeP was found from both source and all sources except incinerator stack. BbF and BaP were found from gasoline vehicles. BghiP was found from of gasoline vehicle. Ind and Cor was found from of mobile source.

In Table 5.12, Pyr, Flt and Phen were dominant PAHs in industrial emission, In contrast low concentration in ambient samples. These observations were suggestion the major source of PAHs is mobile source.

Table 5.12 Percentage of individual PAHs of emission sources

	HDDV	LDDV	LDGV	Two-stroke Motorcycle	Four-stroke Motorcycle	Tuktuk(Gasoline)	Tuktuk (CNG)	Boiler Stack(Heavy Oil)	Incinerator Stack	Road Dust
Nap	2.98	1.09	0.68	3.29	0.88	2.79	2.49	4.88	1.12	3.06
Acy	22.55	15.80	2.05	30.58	2.70	18.86	0.00	0.00	16.82	35.84
Ace	22.97	2.49	0.93	0.68	0.06	0.80	0.42	1.32	1.74	1.58
Flu	13.72	16.60	6.55	5.13	1.06	4.62	4.65	7.89	8.28	2.38
Phen	4.63	1.44	2.94	9.42	1.18	4.64	4.52	17.27	15.91	2.22
Anth	8.98	0.84	3.39	2.04	1.47	0.49	1.08	1.11	0.23	3.20
Flt	3.25	2.50	5.08	11.41	0.78	11.54	13.17	15.76	24.95	9.75
Pyr	4.95	3.50	4.06	4.54	1.00	3.08	3.46	18.70	23.28	4.19
BaA	1.57	0.86	6.67	2.31	0.76	0.72	0.89	2.80	0.45	1.29
Chr	0.57	1.55	6.98	0.39	0.61	2.41	2.36	1.27	0.35	1.75
BeP	10.23	17.61	6.93	13.19	11.46	12.57	9.40	24.05	5.27	14.65
BbF	0.78	3.79	7.90	1.22	2.31	7.17	8.90	0.00	0.39	1.62
Per	0.00	0.45	0.28	0.41	0.58	0.94	0.82	0.00	0.00	0.94
BkF	0.08	0.41	7.70	0.27	1.01	0.09	0.10	0.11	0.03	0.15
BaP	0.37	2.94	6.95	3.57	4.77	0.45	0.80	0.32	0.13	0.94
DBahA	0.76	0.37	6.27	0.37	1.05	0.25	1.03	0.75	0.17	0.75
BghiP	0.62	14.68	16.47	6.76	24.97	8.11	16.33	1.73	0.48	6.09
Ind	0.00	9.44	0.99	2.44	21.54	7.35	11.07	0.00	0.00	3.84
Ant	0.17	1.32	0.57	0.36	2.92	2.00	1.47	0.73	0.20	2.22
Cor	0.82	2.34	6.60	1.64	18.91	11.12	17.03	1.37	0.19	3.53
Total	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00

Table 5.13 Percentage of individual PAHs of ambient samples

	Ambient Samples					
	Chula. Hos.	Chula. Uni.	Dindaeng	OEPP	Singharah Sch.	Bangkok Uni.
Nap	0.72	1.12	1.07	1.00	0.75	1.16
Acy	5.00	7.62	5.77	5.42	4.04	5.37
Ace	0.26	0.72	0.43	0.67	0.54	1.04
Flu	4.11	5.04	4.85	4.00	3.45	3.77
Phen	1.88	1.93	2.57	2.15	1.91	2.25
Anth	0.47	0.42	1.00	0.72	0.50	0.95
Flt	1.70	3.28	1.25	1.95	1.36	1.77
Pyr	1.57	2.09	2.13	1.86	1.18	1.80
BaA	1.62	1.69	2.05	1.57	0.93	1.55
Chr	1.96	2.30	2.66	1.49	1.24	1.51
BeP	13.93	13.37	15.14	12.27	10.64	10.44
BbF	8.62	11.81	8.84	6.81	5.85	6.33
Per	1.12	1.59	1.16	1.17	0.74	1.22
BkF	3.13	3.37	3.17	2.55	2.09	2.36
BaP	7.32	5.51	7.23	5.80	4.59	5.85
DBahA	1.38	1.20	1.12	1.90	2.07	2.26
BghiP	21.84	15.86	20.74	21.04	24.73	21.28
Ind	14.93	14.01	12.11	17.20	20.12	18.81
Ant	1.67	1.01	1.31	1.87	1.58	2.04
Cor	6.77	6.06	5.40	8.54	11.71	8.25
Total	100.00	100.00	100.00	100.00	100.00	100.00

5.6.2 A Vehicle Source/Ambient PAHs Profile Comparison

A vehicle source PAHs profile has been developed and compared with the ambient PAHs profile. The vehicle source profile is based on the concentration of individual PAHs per gram of collected dust from each type of vehicle, multiplied by a particulate emission factor times the traffic density (number of vehicles of that type passing a site).

Hence, the contribution of a vehicle type to the load in ng of PAHs/ VKT can be calculated as follows:

Individual PAHs Source Member Load, L (s,p) (ng PAHs/VKT) =
Concentration of PAHs 1 for Source1 (ng PAHs /mg PM) X Traffic number for source type 1 (Cars) X Particle emission factor for sources type 1 (mg dust / km).

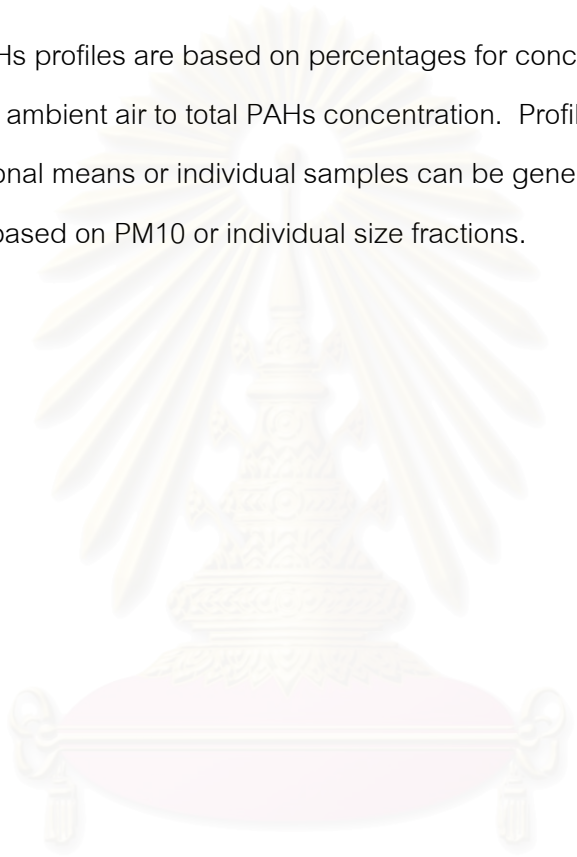
s = vehicle sources type (There are 6 vehicle source types)
p = individual PAHs species (There are 20 PAHs species)

These elements, L (s, p), allow the generation of a load matrix (6 X 20) based on vehicle source type and PAHs species type.

The sum of these loads across the range of vehicle source types for a particular PAHs species gives the total load to the environment for that particulate PAHs species. Comparison of this summed parameter (the species load) across PAHs species type allows an appreciation of the relative importance of any species to the total PAHs load. These species loads can be converted to a percentage of total PAHs load and a PAHs profile based on the collected vehicle sources is generated (called the vehicle source PAHs profile).

Similarly the sum of loads down the range of PAHs species types for a particular source type gives the total PAHs load being contributed by that source type. A source profile can be generated. This PAHs load for different source type can be compared and the relative importance of a particulate source to the total PAHs load can be calculated.

The ambient PAHs profiles are based on percentages for concentrations of individual PAHs species in ambient air to total PAHs concentration. Profiles relative to annual, monthly or seasonal means or individual samples can be generated. Also these profiles can be based on PM10 or individual size fractions.



There were six types of vehicles, heavy diesel, light diesel, gasoline vehicle, tuktuk, two-stroke and four-stroke motorcycles. The PAHs concentrations (ng PAHs/ mg PM) for each vehicle type are shown in Table 5.14.

Table 5.14 The PAHs concentration in each types of vehicle (ng PAHs/ mg PM)

	HDDV	LDDV	PDGV	Tuktuk	2S Motorcycle	4S Motorcycle
Nap	3.63	6.91	0.96	3.94	16.08	1.69
Acy	40.81	100.53	2.89	15.45	149.30	5.20
Ace	41.56	15.83	1.31	0.93	3.32	0.11
Flu	24.82	105.58	9.24	6.87	25.05	2.05
Phen	8.38	9.17	4.14	6.80	45.98	2.27
Anth	16.25	5.34	4.78	1.12	9.94	2.82
Flt	5.87	15.89	7.17	18.21	55.69	1.49
Pyr	8.95	22.30	5.73	4.82	22.15	1.92
BaA	2.84	5.44	9.40	1.18	11.29	1.46
Chr	1.04	9.84	9.85	3.54	1.89	1.17
BeP	18.51	112.01	9.77	16.55	64.39	22.03
BbF	1.41	24.12	11.14	11.79	5.95	4.43
Per	0.00	2.89	0.39	1.31	2.00	1.11
BkF	0.15	2.61	10.85	0.14	1.31	1.94
BaP	0.68	18.68	9.80	0.90	17.45	9.16
DBahA	1.37	2.33	8.84	0.89	1.79	2.01
BghiP	1.13	93.42	23.21	17.50	32.99	48.00
Ind	0.00	60.02	1.40	13.38	11.90	41.41
Ant	0.30	8.40	0.80	2.61	1.75	5.62
Cor	1.48	14.86	9.30	20.43	7.99	36.35
Total	179.16	636.17	140.97	148.36	488.21	192.24

The numbers of vehicle have been extracted from the year 2000 Report of the Office of the Commission for the Management of Road Traffic. (Appendix D) The traffic density at Chulalongkorn University showed in Table 5.15. The overall motor cycle split between two-stroke and four-stroke have been estimated at 60:40. This split is based on anecdotal information from the industry and owners.

Table 5.15 Traffic volume at Chulalongkorn University (Cars / 12 hours)

Types of Vehicle	Traffic Density
Heavy Diesel	3,186
Light Diesel	7,377
Gasoline Car	26,880
Two-stroke Motorcycle	7,352
Four-stroke Motorcycle	4,902
Tuktuk	1,360

(Office of the Commission for the Management of Road Traffic, 2000.)

Particulate emission factors for each vehicle type are shown in table 5.16. In reference report, motorcycle data are based on the average of 10 vehicles and in generating that average there is no attempt to distinguish between two-stroke and four-stroke vehicles. From the raw data, it appears as though 9 of the 10 motorcycles are two-stroke and only 1 is four-stroke. Further it appears that the value associated with the four-stroke is considerable lower than other values. No information has been provided for the tuktuk and the motor cycle emission factor has been adopted.

Table 5.16 Particulate emission factors for each vehicle type (mg dust/ km)

Types of Vehicle	Emission Factor
Heavy Diesel	1.855
Light Diesel	0.398
Gasoline Car	0.055
Motorcycle	0.150
Tuktuk	0.150

(Radian International LLC, 1998)

For the Chulalongkorn University site the individual emission PAH loading of each types of vehicle have been calculated based on these data (Table 5.13–5.15) using Equation 1. (Table 5.17).

Table 5.17 PAH loading of each types of vehicle at Chulalongkorn University

(ng PAHs /km-day)

	HDDV	LDDV	PDGV	Tuktuk	2S Motorcycle	4S Motorcycle
Nap	21445	20302	1290	929	17740	1244
Acy	241183	295146	3889	43834	164674	3821
Ace	245619	46469	1760	5790	3660	84
Flu	146692	309970	12419	22425	27634	1504
Phen	49548	26921	5568	3588	50720	1672
Anth	96015	15679	6430	2414	10963	2070
Flt	34700	46659	9631	6009	61424	1098
Pyr	52917	65463	7695	5969	24429	1412
BaA	16774	15971	12632	1593	12448	1075
Chr	6124	28885	13232	169	2089	860
BeP	109397	328861	13136	3991	71024	16189

Table 5.17 PAH loading of each types of vehicle at Chulalongkorn University (ng PAHs /km-day) (Continued)

	HDDV	LDDV	PDGV	Tuktuk	2S Motorcycle	4S Motorcycle
BbF	8317	70822	14966	0	6567	3259
Per	0	8480	530	0	2205	813
BkF	863	7667	14587	40	1443	1425
BaP	3993	54839	13169	404	19251	6734
DBahA	8088	6854	11881	512	1974	1477
BghiP	6650	274284	31200	214	36390	35277
Ind	0	176230	1882	0	13122	30437
Ant	1770	24666	1073	104	1933	4132
Cor	8728	43622	12497	354	8808	26716
ΣPAH	1,058,824	1,867,788	189,467	98,337	538,498	141,299

The ΣPAH from Row 22 in Table 5.17 gives an indication of the relative importance of each vehicle source type for total PAH emitted. The sum of these sums is 3,752,914. These results suggest that LDDV contribute approximately 48% of the total PAH and HDDV and LDDV combined are responsible for in excess of 75% of PAH load (Figure 5.37). Row 16 gives an indication of the relative importance of each mobile source type for BaP emission, with BaP being the most carcinogenic of the PAH species measured. The percentage of BaP from each type of vehicle were 56% (LDDV), 20%, (M/c-2-stroke), 13% (LDGV), 7% (Mc-4stroke), 4% (HDDV), <1% (Tuk-tuk) (Figure 5.38).

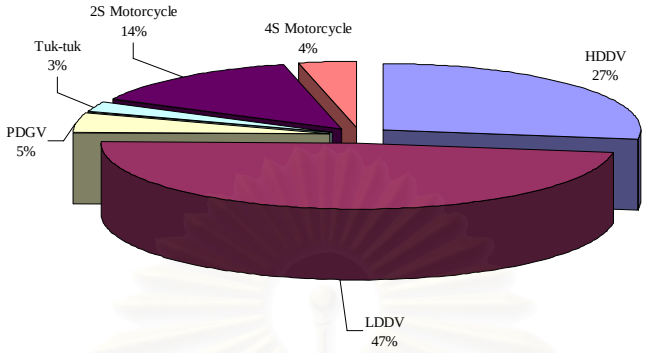


Figure 5.37 Percentage of total PAHs from each type of vehicle

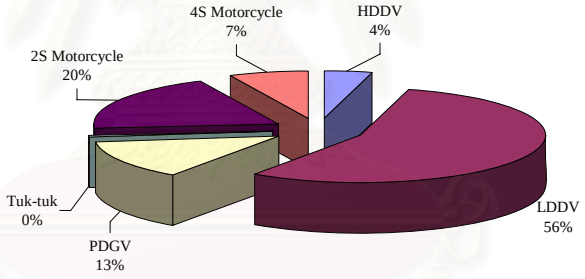


Figure 5.38 Percentage of BaP from each type of vehicle

In Figure 5.39, a bar graph is displayed of the calculated source and ambient PAH profiles related to the Chulalongkorn site. The ambient profile is based on PM10 data. From this comparison of profiles, it would appear that for the source profile, the higher molecular weight PAHs are under-represented and the lower molecular weight PAHs are over- represented. Alternatively, it could be viewed as the higher molecular weight

PAHs being over- represented and the lower molecular weight PAHs under-represented in the ambient profile.

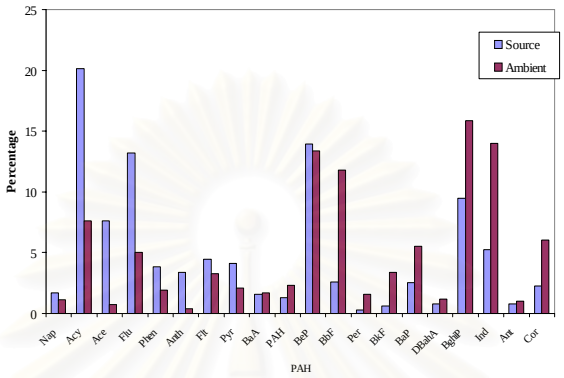


Figure 5.39 Comparison of source and ambient PAHs profiles

Possible reasons for this mismatch maybe associated with a number of factors as follows:

1. There are missing PAH sources that are contributing to the ambient load. Only mobile sources have been included in this comparison. Stationary sources would cover industrial processes, including a variety of combustion boilers, and incineration. Incinerators may involve general garbage or particular waste. Biomass burning - involving leaf litter, rice stubble and other rural waste and plant materials - may also contribute. Some of these stationary sources would involve longer-range transport and this itself may introduce further complications concerning lifetimes of particular PAHs.

2. The lifetime of a PAH in the atmosphere depends on a variety of factors covering both the nature of the individual PAH species and its particular environment. As general rules, the larger the molecular weight the more stable the PAH species and the greater the association of the PAH within airborne particulate matter, the longer

the lifetime. So the larger 6- and 7-ringed members that exist as part of the particulate phase are the most stable and long lived in the atmospheric environment. The smaller 2- and 3-ringed members are distributed, in an atmospheric sample, between the vapour and particulate phase according their volatility and environmental factors such as temperature. There is a greater concentration in the vapour phase. The lifetime of a vapour phase molecule can be quite short because of increased reactivity. While their lifetime is increased when associated with particulate matter, there are still issues of potential re-distribution and loss due to volatility. As a consequence, lower molecular weight PAHs can be under-represented in the aged ambient particulate phase relative to freshly emitted matter from a source.

3. There is a potential influence from sampling method. With the 24-hour ambient sampling, there may be a tendency for loss of low molecular PAHs and the continuous drawing of air for those 24 hours through the sample may exacerbate this situation.

4. Some of the source sampling was undertake on the vehicle in idle mode as opposite to a standardized run mode where acceleration, deceleration and cruise as well as idle are taken into account. This probably means that the source profile is not an adequate representation of the vehicle type.

5. In any sampling exercise the question of how representative of the actual population is the sample. In the source sampling, the number of vehicles tested in any one class of vehicle was quite small (1-3) and it may be questionable as to how representative of the particular vehicular fleet that might be. Observations based on continuous fine particle monitoring in moving traffic point to the relatively high importance of some vehicles within a class in contributing a disproportionate amount to the particle load. If source sampling has not taken this aspect into consideration

that the adequacy of the sample source profile for the real fleet source profile may be questioned.

In view of these considerations, some modifications to the input data were made and the outputs have been examined. As an example see Figure 5.40. These modifications involved making some allowance from possible loss of lower molecular weight PAH, adding possible missing sources, and focussing on more stable higher molecular weight members only. Some improvements in profile comparisons can be noted but, in general, the profile comparisons are still quite poor.

Ultimately, to obtain a better appreciation of relationships between ambient and source PAHs, it may be necessary that concurrent vapour phase and particulate phase sampling is undertaken for both sources and the ambient air.

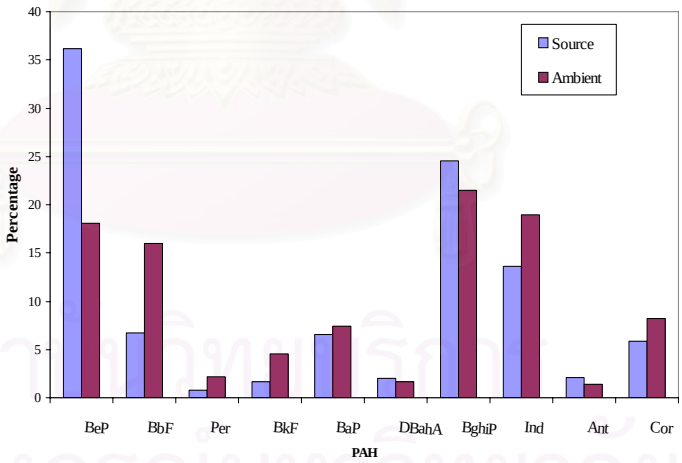


Figure 5.40 Comparison source and ambient 5-7 rings PAHs profiles

5.7 Develop and Propose a Strategy for an Air Pollution Control

The PAHs and PM emissions of three types of HDDV and three types of LDDV in unit μg/ km and μg/ l of fuel were presented in Table 5.18. The PAHs emission of HDDV(Bus), such as Euro2; Euro1 and red bus were 168, 305 and 324 μg/km-car, respectively and 180, 384 and 412 μg/l of fuel-car, respectively. For HDDV, red bus (non air-conditioned bus) emitted the highest PAHs emission. Euro 2 (air-conditioned bus) emitted PAHs lower than Euro 1 (air-conditioned bus). The PM emissions of HDDV ranged from 873-3604 mg/km-car and 934-4577 mg/l of fuel-car. The PAHs emission of LDDV, such as, Mitsubishi (Bangjak), Mitsubishi (PTT) and Toyota (PTT) were 20, 17 and 21 μg/km-car, respectively and 138, 110 and 211 μg/l of fuel-car, respectively. The PAHs emissions of LDDV ranged from 92-103 mg/km-car and 590-1009 mg/l of fuel-car.

Table 5.18 The PAHs and PM emissions of HDDV and LDDV

	HDDV			LDDV		
	Euro 2 (PTT)	Euro 1 (PTT)	Red Bus (PTT)	Mitsubishi (Bangjak)	Mitsubishi (PTT)	Toyota (PTT)
PAH Emission						
(μg/km-car)	168	305	324	20	17	21
(μg/l of fuel-car)	180	384	412	138	110	211
PM Emission						
(mg/km-car)	873	2052	3604	103	92	102
(mg/l of fuel-car)	934	2585	4577	708	590	1009

In Figure 5.37, the results LDDV contribute approximately 48% of the total PAHs and HDDV and LDDV combined are responsible for in excess of 75% of PAHs load. In Figure 5.38, the percentage of BaP from each type of vehicle were 56% (LDDV), 20%, (M/c-2-stroke), 13% (LDGV), 7% (Mc-4stroke), 4% (HDDV), <1% (Tuk-tuk). From these

results the PAHs load of HDDV and LDDV were high. Table 5.19 showed the number of diesel vehicles registered in Bangkok in 2001.

Table 5.19 The number of HDDV and LDDV registered in Bangkok in 2001.

	HDDV				LDDV
	BMTA				
	Euro 2	Euro 1	Red Bus	Other buses	Pick-up & Van
PAH Emission	1,297	1,315	416	26,128	737,476

(BMTA, 2001.)

An average HDDV and LDDV travels per year were 54,750 kilometer/year and 20,700 kilometer/year (Pongprueksa, 2001)

The load of HDDV & LDDV in tons of PAHs/year can be calculated as follows:

The PAHs emission load, (Tons of PAHs/ year) =
Concentration of PAHs emission (μg/kilometer-car) (Table 5.18) X Number of traffic (Cars) (Table 5.19) X Average HDDV and LDDV kilometer traveled per year (kilometer/year)

From this equation the PAHs emission load, (Tons of PAHs/ year) are shown in Table 5.20. For the other buses, the concentration of PAHs emission of red bus was used and for the LDDV, the average concentration of PAHs emission of three types LDDV were used.

Table 5.20 The PAHs emission load of HDDV and LDDV (Tons of PAHs/ year)

	HDDV				LDDV
	BMTA				
	Euro 2	Euro 1	Red Bus	Other buses	Pick-up & Van
PAHs Emission	11.9	22.0	7.4	463.48	290.0

In Table 5.20, the PAHs emission load of HDDV and LDDV in Bangkok area was 420.4 and 290.0 tons of PAHs/ year. For three types of BMTA, such as Euro2, Euro1 and red bus, PAHs emissions were 11.9, 22.0 and 7.4 tons of PAHs/ year. The fixed route bus such as Euro 1 and red bus (non-air-conditioned bus) were changed to bus model Euro 2. The PAHs emission load of BMTA bus will reduced by13.4 tons of PAHs/ year from 41.3 tons of PAHs/ year. The percentage of reduction was 32.4.

CHAPTER 6

CONCLUSIONS

This study presents the state of PM10 concentration in Bangkok. PM10 level were generally high at roadside areas (Chulalongkorn Hospital and Dindaeng) and low at urban edge of Bangkok (Bangkok University). The data ranged and mean for the 3 sites, OEPP; Singharat School and Bangkok University, were comparable. The mean of PM10 of these three sites were 55, 63 and 59 $\mu g/m^3$, respectively. These sites are less impacted by traffic. This variable data ranged across all six sites, highlighting the importance of motor vehicles as a major source of air particulate matter. At all sites, a general trend of PM10 concentration in May June, July (rainy season) was lower than the other months because of the particulate removal by rainfall.

This study also determined the level of SFPM <0.95 μm, 0.95-1.5 μm, 1.5-3.0 μm, 3.0-7.2 μm and >7.2 μm at Chulalongkorn University. The percentage of annual SFPM was 48, 9, 9, 18 and 16, respectively. The highest concentration of PM level was in the SFPM < 0.95 μm, suggesting that the primary source of airborne particulate in Bangkok was the traffic. The data appeared bimodal with a peak below 1 μm and more than 3 μm.

The present state of the PAHs concentration in ambient air in Bangkok was investigated. The highest and lowest concentrations of ΣPAH were 195 ng/m^3 at Chulalongkorn University and 6 ng/m^3 at Bangkok University, respectively. The six dominants PAHs were BghiP, Ind, BeP, BbF, Cor and BaP. The mean of BghiP and BaP concentrations ranged from 12-17 ng/m^3 and 3 and 5 ng/m^3, respectively. The patterns of individual PAH at all sites were compared and the results indicated that emission sources were similar. More than 97% of PAHs were found in the small particle <0.95 μm.

There was moderate to good correlation of PM < 0.95 μm, PM< 1.5 μm, PM< 3.0 μm, PM<7.2 μm and ∑SFPM with R^2 = 0.74, 0.84, 0.92, 0.97, respectively (n=39). The levels of PM <0.95 μm, PM<1.5 μm, PM< 3.0 μm, PM<7.2 μm and ∑SFPM can be calculated by using the following equations.

PM <0.95 ($\mu g/m^3$) = 0.51 x ∑SFPM ($\mu g/m^3$)

PM <1.5 ($\mu g/m^3$) = 0.60 x ∑SFPM ($\mu g/m^3$)

PM <3.0 ($\mu g/m^3$) = 0.66 x ∑SFPM ($\mu g/m^3$)

PM <7.2 ($\mu g/m^3$) = 0.84 x ∑SFPM ($\mu g/m^3$)

The good correlation between PM10 and SFPM is seen with R = 0.94, R^2 = 0.88. The ∑SFPM concentration can be calculated by ∑SFPM ($\mu g/m^3$) = 1.03 x PM10 ($\mu g/m^3$).

The comparisons of the ratios of BaP/Cor, BaP/BghiP, BghiP/Ind, BaP/BeP, BghiP/BeP, Cor/BeP, at six ambient sampling sites with those from traffic emission were performed. It was found that the ratios were similar in both six sampling sites and traffic emissions, indicating that BaP, Cor, BghiP, Ind and BeP were the results from the traffic source emission.

PAH source profiles from six vehicle types were determined. Light duty diesel vehicles (small pick-up trucks) have the potential to contribute to a disproportionate amount of both air PM and PAHs concentrations. The dominant small molecular weight PAHs was found in the heavy diesel emission. BghiP was the major PAH in the gasoline automobile emission.

The five dominants PAHs, BeP (5 rings); Pyr (4 rings); Flt (4 rings); Flu (3 rings) and Phen (3 rings), were found in the boiler stack emission. The five dominant PAHs, Flt (4 rings); Pyr (4 rings); Acy (3 rings); Phen(3 rings) and BeP (5 rings), were found in incinerator stack emission. In contrast, Acy BeP and Flt were found in road dust samples. The PAH profiles from different emission sources were compared with those from ambient samples. The results indicated that PAHs were from mobile sources.

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APPENDIX A

PAHs Analysis Condition

1. Instrumental HPLC conditions

The samples are analyzed using a High Performance Liquid Chromatography (HPLC) system with ultraviolet and fluorescence detection. Acetonitrile/water was the mobile phase and the column was Merck LiChrospher PAH 250-4. The column was heated in an oven to 30°C. After separation, the PAHs, were detected using either a UV-vis detector at 254 nm or fluorescence detector with excitation and emission wavelengths appropriate to the peak being detected. This detector has a higher noise level than the fluorescence detector, so is only uses to calculate samples that are not easily measured on the fluorescence detector. The minimum area of a peak detected is 30 units. The PAHs measured on this detector along with their detection limits are shown in Table A-1 The Fluorescence detector is used at emission and excitation wavelengths appropriate to the peaks being detected. These wavelengths are shown in Table A-2.

Table A-1. PAHs analyzed by UV-vis detector.

PAHs	Retention Time (Approximate)	Wavelength	Detection Limit
Acenapthylene	12.4 min	254 nm	7.11 ng/ml
Fluorene	14.2 min		0.77 ng/ml
Fluoranthene	16.9 min		1.69 ng/ml
Benzo(b)fluoranthene	23.3 min		1.06 ng/ml
Perylene	23.5 min		3.27 ng/ml
Indeno(123cd)pyrene	34.0 min		0.55 ng/ml

Table A-2. PAHs analyzed by fluorescence detector

PAHs	Retention Time (Approximate)	Wavelength	Detection Limit
Napthalene	11.4 min	Em = 340 nm	0.29 ng/ml
Acenapthene	14.1 min	Ex = 280 nm	0.67 ng/ml
Phenanthrene	15.3 min	Em = 370 nm	0.34 ng/ml
		Ex = 240 nm	
Antracene	16.2 min	Em = 450 nm	0.22 ng/ml
		Ex = 250 nm	
Pyrene	17.8 min	Em = 390 nm	0.59 ng/ml
		Ex = 270 nm	
Benzo(a)antracene	20.0 min	Em = 380 nm	0.87 ng/ml
Chrysene	20.8 min	Ex = 265 nm	0.28 ng/ml
Benzo(e)pyrene	23.0 min	Em = 420 nm	5.16 ng/ml
		Ex = 290 nm	
Benzo(k)fluorantene	25.2 min		0.53 ng/ml
Benzo(a)pyrene	27.2 min		0.58 ng/ml
Dibenzo(ah)Anthracene	30.3 min		1.66 ng/ml
Benzo(ghi)perlene	32.4 min	Em =460 nm	6.5 ng/ml
		Ex = 300 nm	
Anthanthrene	39.6 min	Em = 433 nm	0.3 ng/ml
		Ex = 307 nm	
Coronene	44.3 min	Em = 444 nm	0.46 ng/ml
		Ex = 299 nm	

2. PAH Processing

- Integrate all standards on both detectors.
- Edit quantitation to make sure peak labeling is at correct retention times.
- Create a batch with only the standards in it. Sample type should be for the three standards used in the calibration and U for the other standards. Processing should be C (for calculate)
- Once calibration is satisfactory save method under a new name I.e. PAH01.met
- Integrate all samples.
- Run batch from original sample schedule. Change the method to new one saved (i.e. PAH01.met)(Table A-3). Sample type should be S for standards and U for unknowns and processing should be R.
- To print results out select "Report Output" under File menu before running the batch.

Table A-3. Time Function Table of LC program Method = PAH01.MET

Time (min)	FUNCTION	VALUE
0.10	Degas OFF/Purge/Operate	2
3.00	B.Conc	50.0
12.68	B.Conc	90.0
14.85	Ch2-Ex.Wavelength	250
14.85	Ch2-Em.Wavelength	370
15.79	Ch2-Em.Wavelength	406
15.79	Ch2-Em.Wavelength	450
16.73	Ch2-Ex.Wavelength	280
17.44	Ch2-Ex.Wavelength	390
17.44	Ch2-Em.Wavelength	270
19.27	Ch2-Ex.Wavelength	265
19.27	Ch2-Em.Wavelength	380
22.13	Ch2-Ex.Wavelength	290
22.13	Ch2-Em.Wavelength	430
29.22	Ch2-Em.Wavelength	410
33.48	Ch2-Ex.Wavelength	500
33.48	Ch2-Em.Wavelength	300
35.59	T.Flow	0.950
36.00	T.Flow	1.500
37.04	Ch2-Ex.Wavelength	307
37.04	Ch2-Em.Wavelength	433
42.44	Ch2-Ex.Wavelength	299
42.44	Ch2-Em.Wavelength	444
47.00	B.Conc	100.0
47.00	T.Flow	1.500
47.00	Degas OFF/Purge/Operate	0
47.10	B.Conc	50.0
47.10	T.Flow	1.000
55.00	STOP	

3. Dust Standard and PAHs Standard

3.1 Dust Standard

Standard reverence material 1649a (Red. 26599), urban dust NIST, us department of commerce, National institute of standard and technology gastherburg MID 20899.

The detail standard dust shows in Table A-4.

Table A-4. Dust Standard

PAHs	Purity	Brand
1. Naphthalene(NAP)	99.5%	Chem service
2. Acenapthene(ACE)	99.0%	Chem service
3. Acenapthylene(ACY)	95.0%	Chem service
4. Fluorene(FLU)	98.0%	Chem service
5. Phenanthrene(PHEN)	98.0%	Aldrich
6. Anthracene(ANTH)	99.9%	Aldrich
7. Pyrene(PYR)	99.0%	Aldrich
8. Fluoranthene(FLT)	98.0%	Aldrich
9. Benzo(a)anthracene(BaA)	99.0%	Aldrich
10. Chrysene(CHR)	98.0%	Aldrich
11.Benzo(e)pyrene(BeP)		Commission of the European com. No.211
12.Benzo(b)fluoranthene(BbF)		Commission of the European com. No.172
13 Perylene(PER)	99.0%	Aldrich
14.Benzo(k)fluoranthene(BkF)		Commission of the European com. No.175
15. Benzo(a)pyrene (BaP)	99.0%	Aldrich
16.Dibenzo(ah)anthracene(DBahA)	97.0%	Aldrich
17. Benzo(ghi)perylene(Bghip)		Commission of the European com. No.176
18. Indeno(123cd)pyrene(IND)		Commission of the European com. No.252
19. Anthanthrene(ANT)		Commission of the European com. No.02
20. Coronene(COR)	98.0%	Aldrich

3.2 PAHs Standard

The PAHs standard concentration was prepared in four dilutions. This is show in Table A-5.

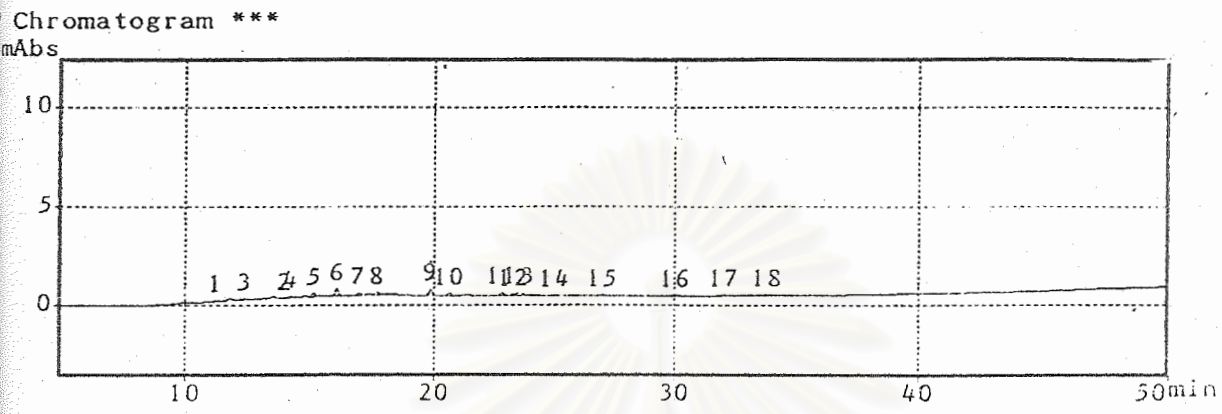
Table A-5. PAHs Standard Concentrations

PAHs	PAHs Standard Concentrations (ng/ml)			
	Standard 1	Standard 2	Standard 3	Standard 4
Nap	5.8	29.0	58.0	145.0
Ace	5.5	27.6	55.2	138.0
Acy	19.6	98.0	196.0	490.0
Flu	2.5	12.5	25.0	62.5
Phen	2.2	11.1	22.2	55.5
Anth	2.1	10.5	21.0	52.5
Pyr	7.0	35.2	70.4	176.0
Flt	6.7	33.5	67.0	167.4
BaA	10.6	52.8	105.6	264.0
Chr	3.7	18.3	36.6	91.5
BeP	14.5	72.4	144.8	362.0
BbF	3.8	18.8	37.6	94.0
Per	6.1	30.7	61.4	153.4
BkF	0.7	3.7	7.4	18.5
BaP	2.9	14.3	28.5	71.3
DbahA	6.8	33.8	67.6	169.0
BghiP	11.1	55.6	111.2	278.0
Ind	5.3	26.4	52.8	132.0
Anth	0.9	4.6	9.2	23.0
Cor	3.2	16.1	32.2	80.5

2.3 UV-Vis and Fluorescence Detector Output for Standard PAHs Mixture

Figure A-1 Typical UV-vis Detector Output for Standard 1 PAHs Mixture

Data: A2706101.D01

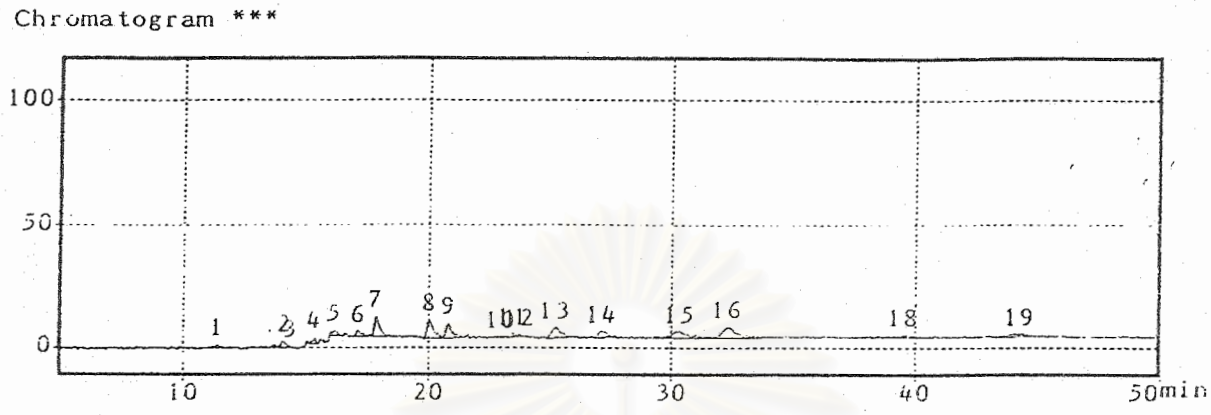


Peak Report

ID NO.	NAME	TIMF	CONC. (ng/ml)
1	Nap	11.22	9.24
3	Acy	12.36	18.26
2	Ace	13.95	7.97
4	Flu	14.20	3.14
5	Phen	15.14	2.57
6	Anth	16.06	2.23
7	Flt	16.95	7.65
8	Pyr	17.67	8.32
9	BaA	19.86	10.28
10	Chr	20.62	3.93
11	BeP	22.80	13.25
12	BbF	23.28	2.89
13	Per	23.52	5.46
14	BkF	25.02	0.70
15	BaP	26.99	3.01
16	DbahA	30.01	8.83
17	BghiP	32.07	8.93
18	Ind	33.89	5.07

Figure A-2 Typical Fluorescence Detector Output for Standard 1 PAHs Mixture

Data: B2706101.D01

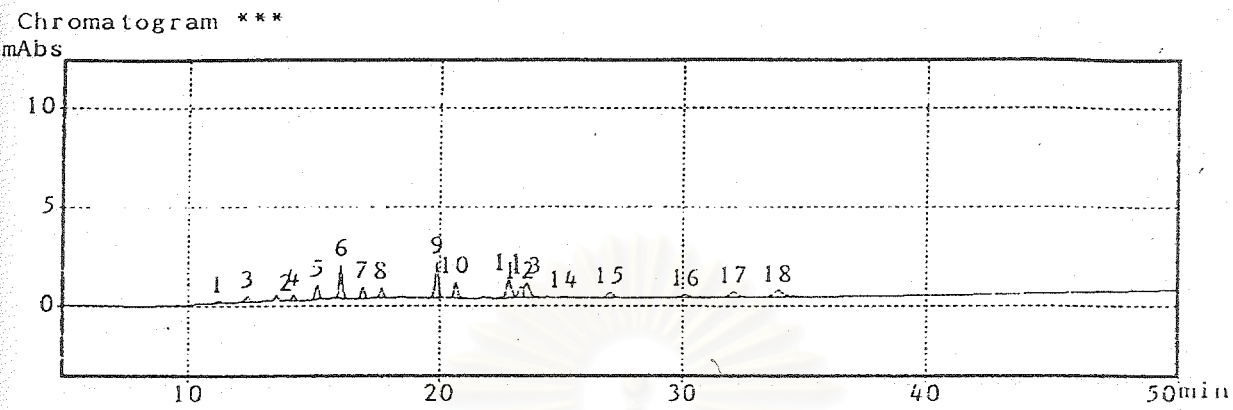


Peak Report

ID NO.	NAME	TIME	CONC. (ng/ml)
1	Nap	11.38	5.67
2	Ace	14.06	5.91
3	Flu	14.30	3.50
4	Phen	15.35	1.88
5	Anth	16.13	2.39
6	Flt	17.11	7.68
7	Pyr	17.85	7.79
8	BaA	20.04	11.52
9	Chr	20.81	3.38
10	BeP	22.97	7.50
11	BbF	23.47	2.18
12	Per	23.73	3.31
13	BkF	25.20	0.8
14	BaP	27.10	2.56
15	DbahA	30.32	6.15
16	BghiP	32.29	12.34
18	Ant	39.53	1.35
19	Cor	44.33	4.59

Figure A-3 Typical UV-vis Detector Output for Standard 2 PAHs Mixture

Data: A2706102.D01

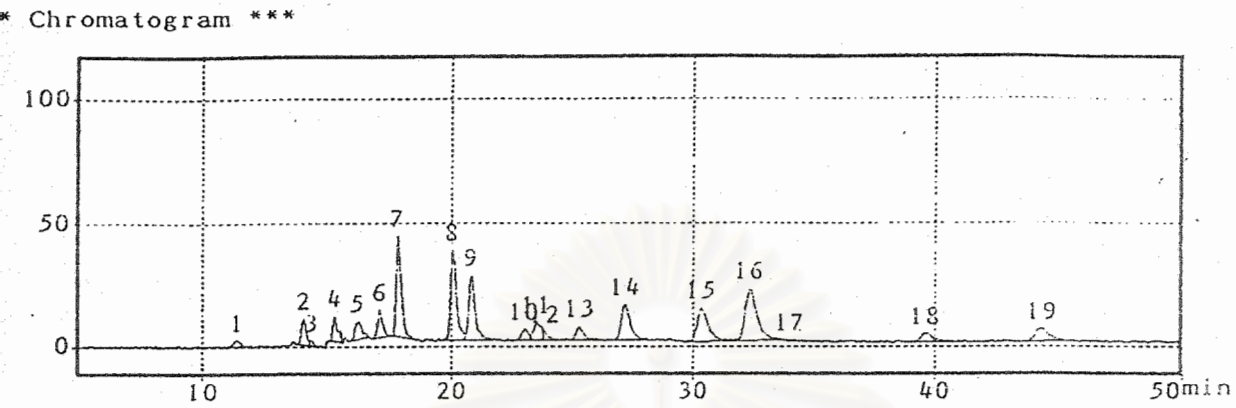


Peak Report

ID NO.	NAME	TIME	CONC. (ng/ml)
1	Nap	11.21	30.88
3	Acy	12.36	99.91
2	Ace	13.90	25.43
4	Flu	14.21	12.82
5	Phen	15.14	10.98
6	Anth	16.07	10.46
7	Flt	16.95	33.58
8	Pyr	17.68	35.42
9	BaA	19.89	52.98
10	Chr	20.67	18.45
11	BeP	22.86	71.29
12	BbF	23.35	17.86
13	Per	23.60	31.44
14	BkF	25.10	0.68
15	BaP	27.03	16.76
16	DbahA	30.24	29.17
17	BghiP	32.25	53.89
18	Ind	34.10	27.00

Figure A-4 Typical Fluorescence Detector Output for Standard 2 PAHs Mixture

Data: B2706102.D01

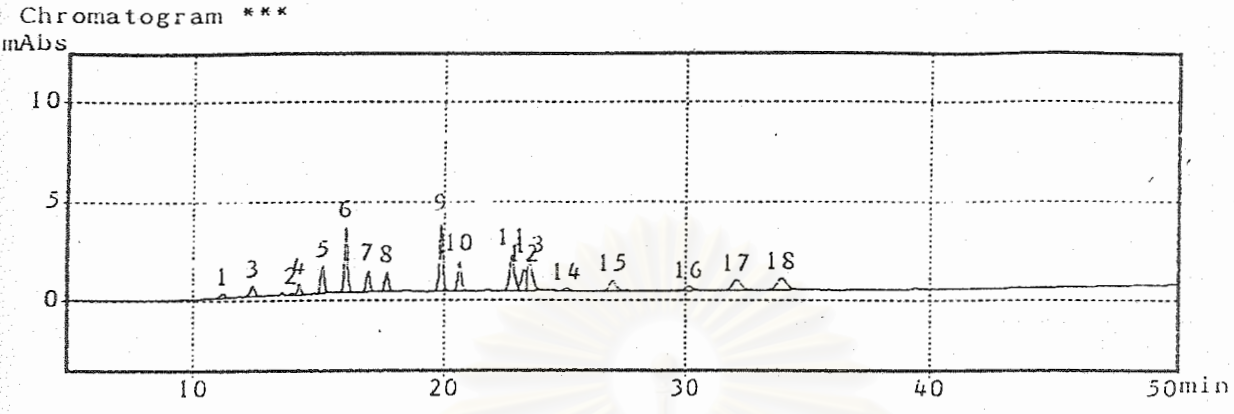


Peak Report

ID NO	NAME	TIME	CONC. (ng/ml)
1	Nap	11.37	34.94
2	Ace	14.06	29.64
3	Flu	14.35	15.85
4	Phen	15.31	11.78
5	Anth	16.22	8.44
6	Flt	17.12	30.51
7	Pyr	17.85	42.65
8	BaA	20.07	54.61
9	Chr	20.85	17.60
10	BeP	23.05	66.24
11	BbF	23.56	17.38
12	Per	23.83	37.97
13	BkF	25.31	3.64
14	BaP	27.25	13.99
15	DbahA	30.43	34.16
16	BghiP	32.46	55.78
17	Ind	39.72	3.34
18	Ant	39.92	3.56

Figure A-5 Typical UV-vis Detector Output for Standard 3 PAHs Mixture

Data: A2706103.D01

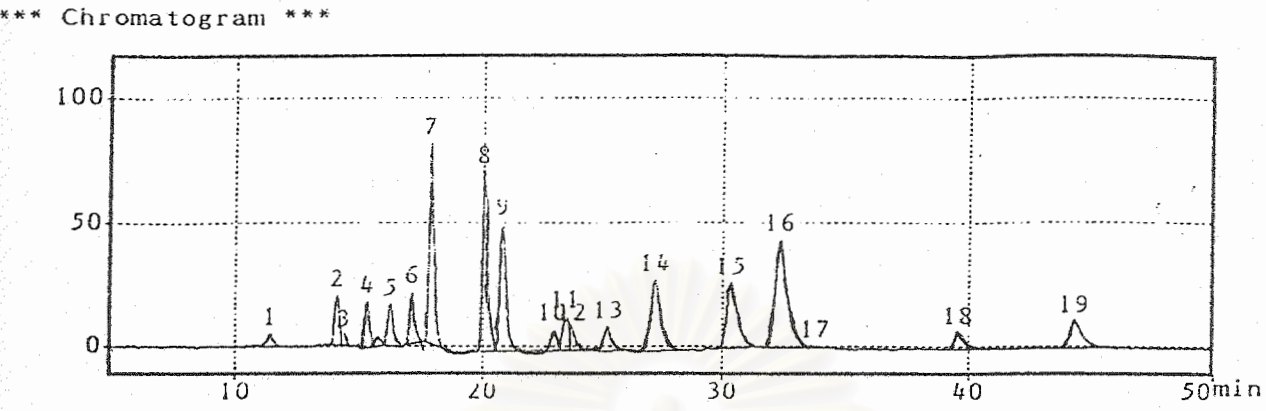


Peak Report

ID NO	NAME	TIME	CONC. (ng/ml)
1	Nap	11.25	55.86
3	Acy	12.40	187.30
2	Ace	13.94	53.52
4	Flu	14.25	25.08
5	Phen	15.19	22.36
6	Anth	16.12	21.06
7	Flt	17.00	66.98
8	Pyr	17.73	70.43
9	BaA	19.96	105.36
10	Chr	20.75	36.58
11	BeP	22.97	143.68
12	BbF	23.48	34.86
13	Per	23.72	62.08
14	BkF	25.28	6.64
15	BaP	27.22	28.14
16	DbahA	30.48	66.14
17	BghiP	32.50	108.75
18	Ind	34.40	52.07

Figure A-6 Typical Fluorescence Detector Output for Standard 3 PAHs Mixture

Data: B2706103.D01

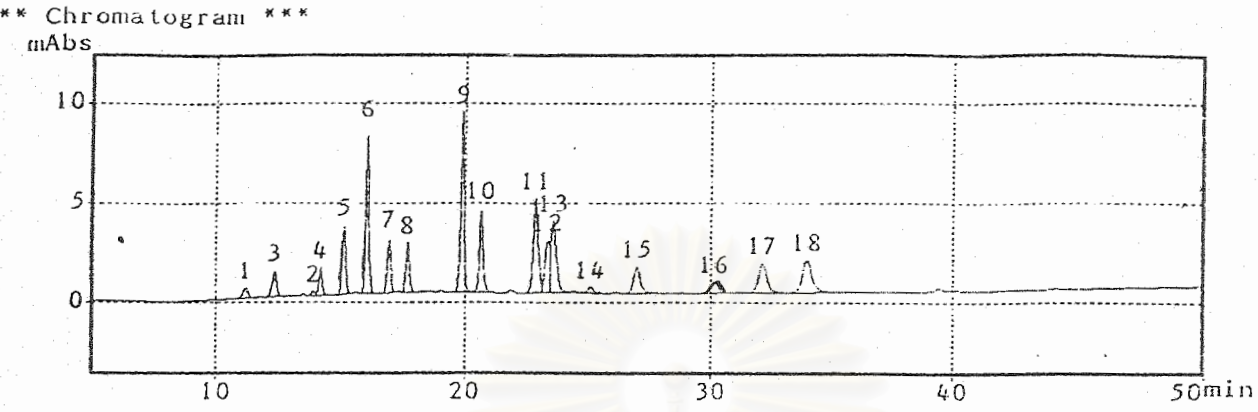


Peak Report

ID NO	NAME	TIME	CONC. (ng/ml)
1	Nap	11.41	54.29
2	Ace	14.10	56.08
3	Flu	14.37	27.65
4	Phen	15.35	32.97
5	Anth	16.28	18.04
6	Flt	17.17	68.12
7	Pyr	17.90	85.21
8	BaA	20.13	106.61
9	Chr	20.93	35.73
10	BeP	23.15	147.30
11	BbF	23.69	135.91
12	Per	23.69	37.97
13	BkF	25.48	7.40
14	BaP	27.42	27.44
15	DbahA	30.71	70.63
16	BghiP	32.71	114.43
17	Ind	34.00	3.07
18	Ant	39.92	8.79
19	Cor	44.75	34.40

Figure A-7 Typical UV-vis Detector Output for Standard 4 PAHs Mixture

Data: A2706104.D01

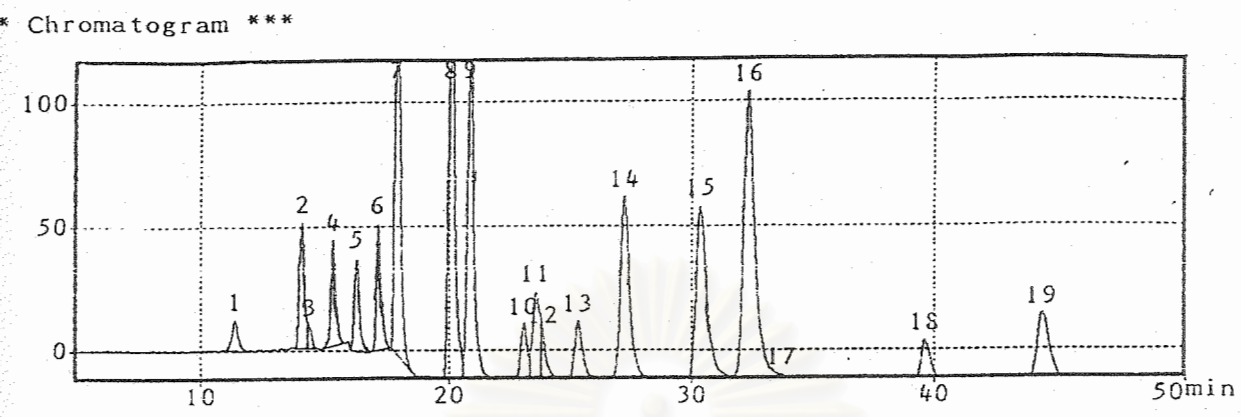


Peak Report

ID NO	NAME	TIME	CONC. (ng/ml)
1	Nap	11.23	139.85
3	Acy	12.39	494.32
2	Ace	13.93	146.39
4	Flu	14.23	63.27
5	Phen	15.16	56.08
6	Anth	16.09	52.79
7	Flt	16.97	168.58
8	Pyr	17.70	177.77
9	BaA	19.90	265.95
10	Chr	20.68	92.48
11	BeP	22.88	362.54
12	BbF	23.39	91.07
13	Per	23.61	157.31
14	BkF	25.15	19.15
15	BaP	27.06	70.63
16	DbahA	30.26	171.59
17	BghiP	32.28	279.84
18	Ind	34.13	132.19

Figure A-8 Typical Fluorescence Detector Output for Standard 4 PAHs Mixture

Data: B2706104.D01

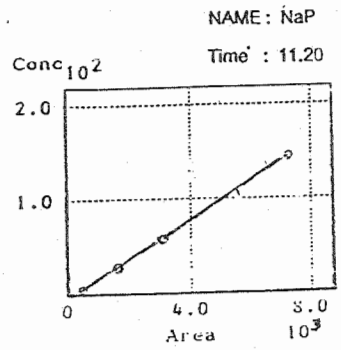


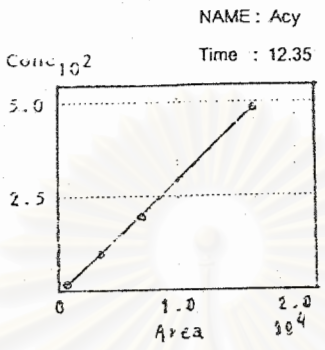
Peak Report

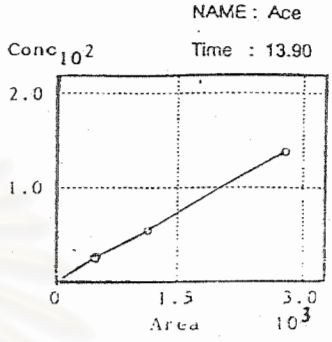
ID NO	NAME	TIME	CONC. (ng/ml)
1	Nap	11.40	141.78
2	Ace	14.09	141.56
3	Flu	14.40	67.24
4	Phen	15.33	58.50
5	Anth	16.26	54.46
6	Flt	17.13	165.40
7	Pyr	17.87	196.39
8	BaA	20.08	268.48
9	Chr	20.86	92.01
10	BeP	23.07	360.58
11	BbF	23.57	82.23
12	Per	23.80	223.75
13	BkF	25.34	19.30
14	BaP	27.26	70.21
15	DbahA	30.48	172.54
16	BghiP	32.50	285.95
17	Ind	34.11	169.94
18	Ant	39.71	20.87
19	Cor	44.47	81.17

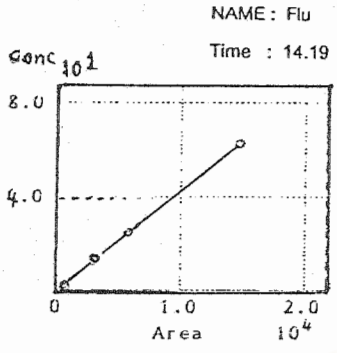
3. Calibration Curves for UV-Vis and Fluorescence Channel

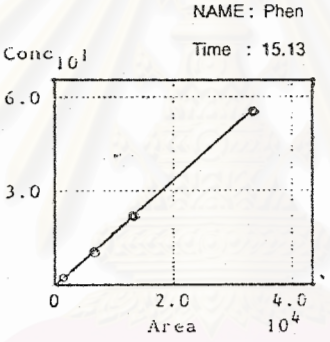
Table A-6 Typical Calibration Curves for UV-Vis Channel

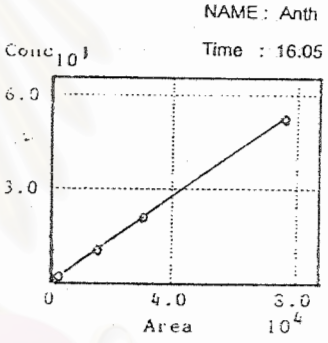


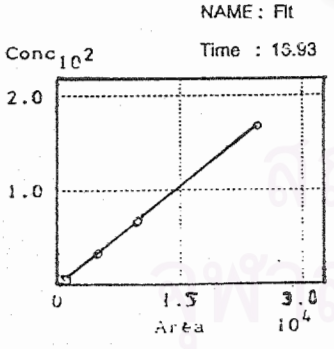


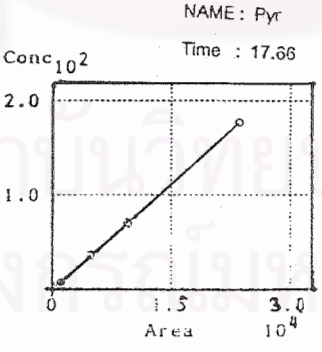












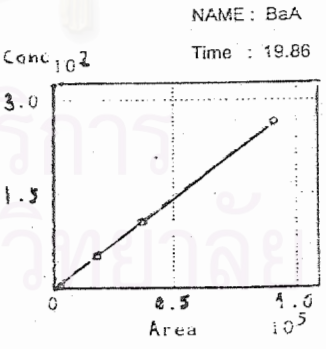
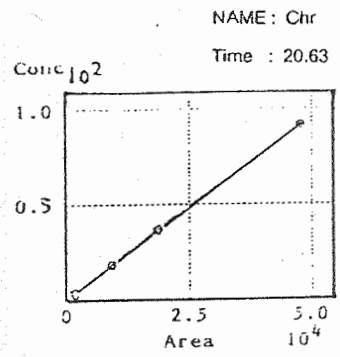
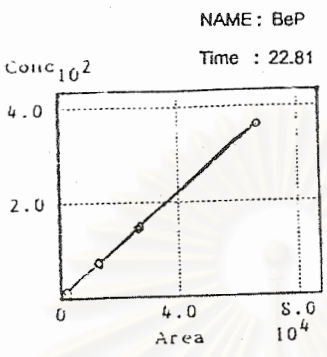
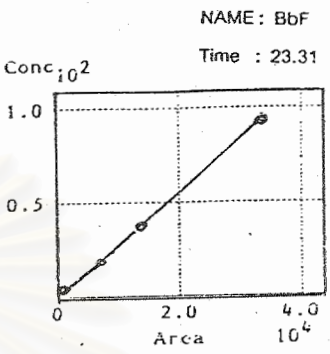
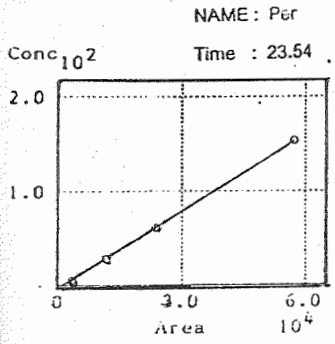


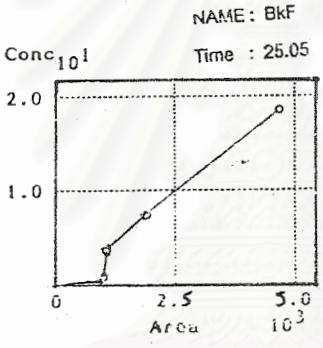
Table A-6 Typical Calibration Curves for UV-Vis Channel (Continued)

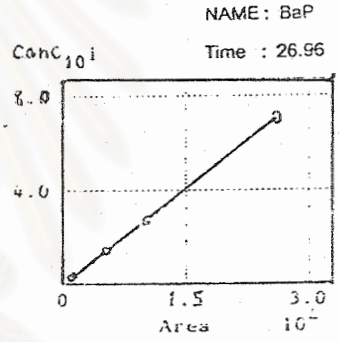


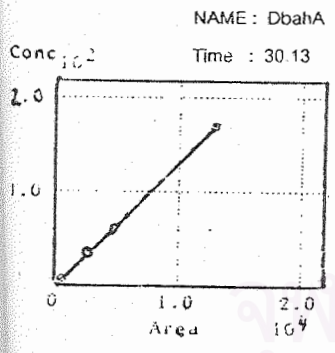


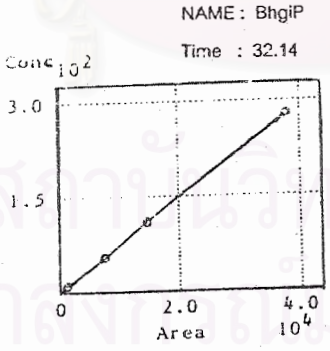












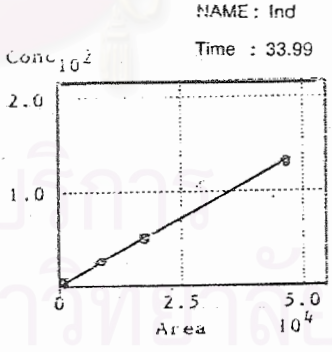
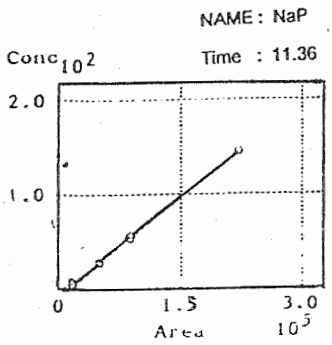
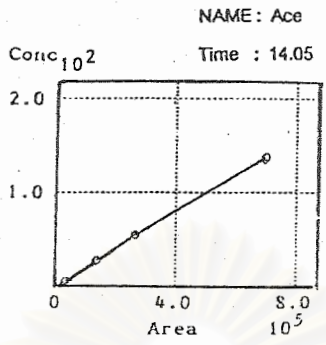
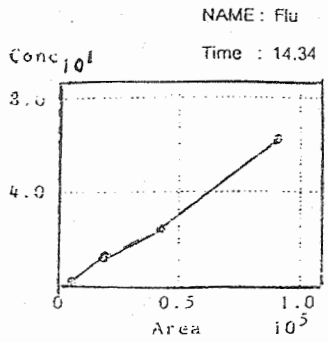
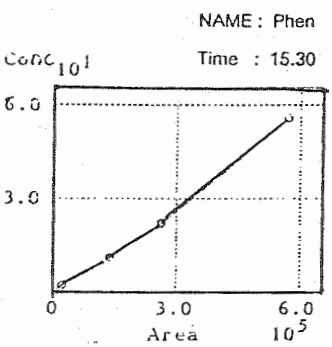


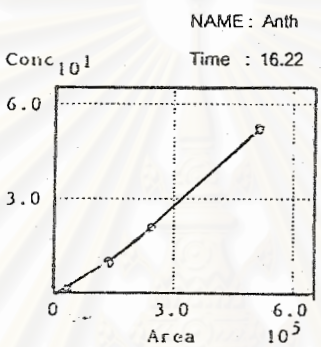
Table A-7 Typical Calibration Curves for Fluorescence Channel

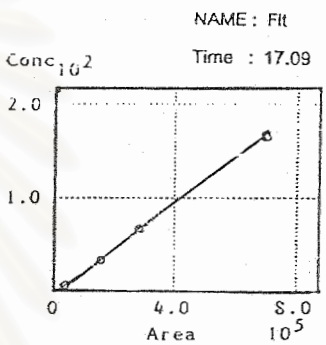


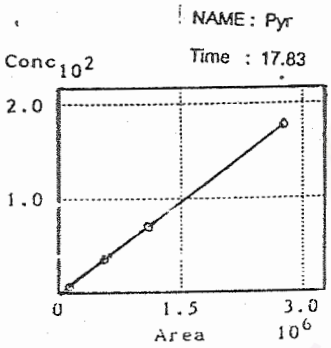


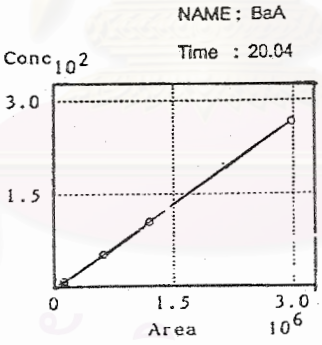


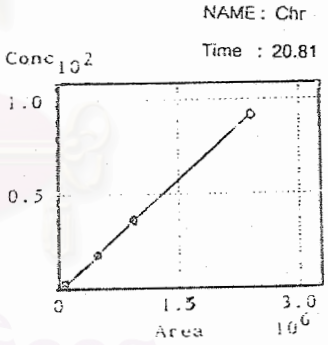


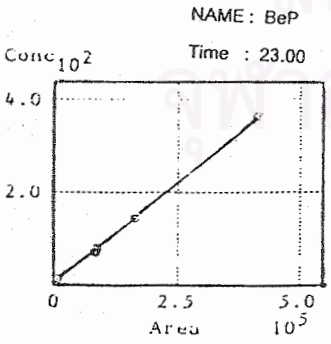


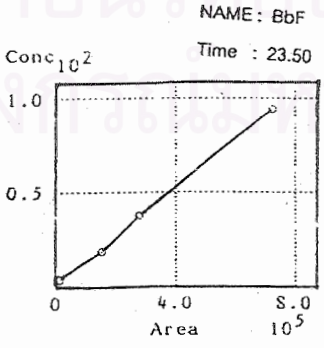












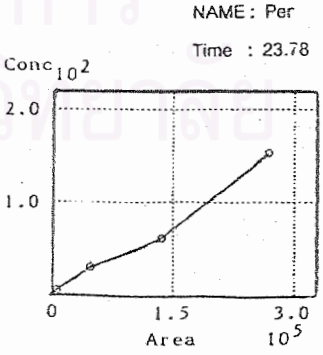
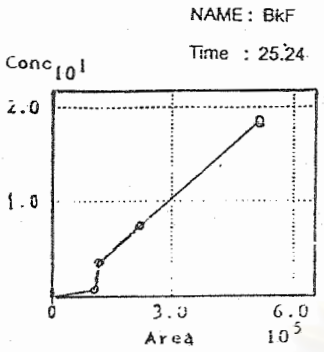
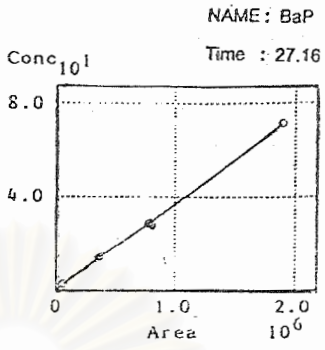
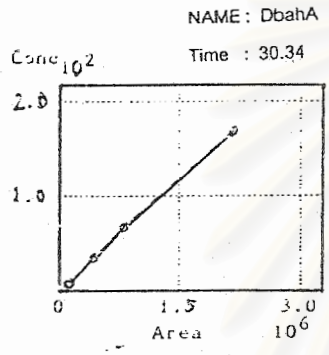
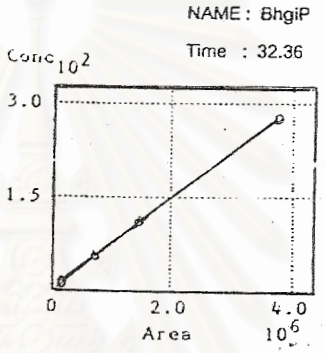


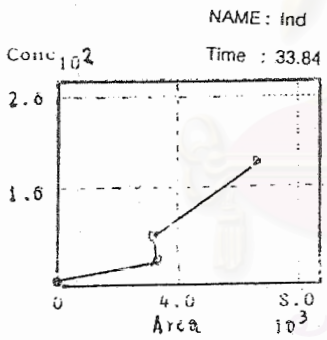
Table A-7 Typical Calibration Curves for Fluorescence Channel (Continued)

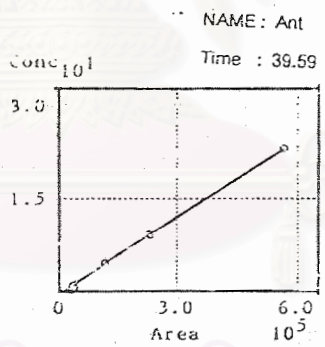


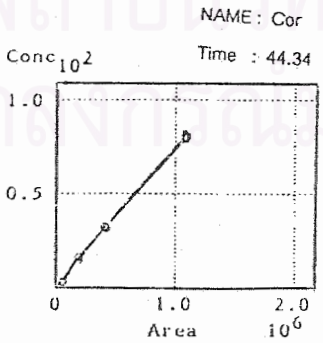












4. Calculations of Particulate Matter and PAHs

The total particulate matter is calculated as follows

$$\text{Total particulate matter} = 1{,}000 \times (m / t) \times f$$

Where m = mass loading (mg)

f = flow rate (m^3/hr)

t = time (hrs)

Size fractionating cascade impactor

The particle size cut-off (Dp, 50) at 50% collection efficiency for spherical particle can be calculate as:

$$D_{p,50} = \sqrt{st}\ w \sqrt{\frac{9\eta L}{C\rho_p Q}}$$

Where

$\sqrt{st}$ = The square root of the Stoke's number, which depends on jet throat length, and jet Reynold' s number

w = slot width ,cm

η = gas velocity (1.8×10^{-4} g cm^{-1} .sec 25°C, 760 mmHg)

L = slot length, cm

ρ_p = particle mass density, g cm^{-3}

C = Cunningham slip correction (nominally C = 1 for large Dp)

= flow rate

The output from the HPLC gives the concentration of PAHs in the sample as injected into the instrument. PAHs results are generally expressed as ng/m^3 of air passed through the filter paper. The results are calculated as follows

$$PAHs = CVA/nav$$

Where PAHs = Concentration (ng/m^3)

C = Concentration in sample (ng/ml)

V = Sample volume (5 ml)

A = Total exposed area of filter paper (mm^2)

n = Number of circles extracted (10)

a = Area of each circle (mm^2)

b = Volume of air passed through filter (m^3)

Source emission PAHs results are calculated in unit ng PAH/ mg of dust. The results are calculated as follows

$$\text{Source emission PAHs} = CVA/ag$$

Where PAHs = Concentration (ng PAH/ mg dust)

C = Concentration in sample (ng/ml)

V = Sample volume (5 or 10 ml)

A = Total exposed area of filter (mm^2)

a = Area of extracted filter (mm^2)

g = Weight of dust (mg)

Source emission PAHs results are generally expressed as ng PAH/ km and ng PAH/ l of fuel consumed. The results are calculated as follows

Source emission PAHs = CVBA/abd

Where PAHs = Concentration (ng PAH/ km)

C = Concentration in sample (ng/ml)

V = Sample volume (5 or 10 ml)

A = Total exposed area of filter (mm^2)

B = Volume of vehicle total air emission (m^3)

a = Area of extracted filter (mm^2)

b = Volume of air passed through filter (m^3)

d = Distance (km)

Source emission PAHs = (CVBA/abd)*F

Where PAHs = Concentration (ng PAH/ l of fuel consumed)

C = Concentration in sample (ng/ml)

V = Sample volume (5 or 10 ml)

A = Total exposed area of filter (mm^2)

B = Volume of vehicle total air emission (m^3)

a = Area of extracted filter (mm^2)

b = Volume of air passed through filter (m^3)

d = Distance (km)

F = Fuel consumed (km/l)

5. Qualify Control

At least one duplicate sample is run with each batch of samples. Two sets of 10 circles are cut from the filter paper and treated in exactly the same manner for duplicate analysis. A blank sample was also prepared in the same manner, using an unexposed filter to ensure nothing is extracted from the filter paper itself. One standard was chosen and analyzed at intervals throughout batch being sampled to test reproducibility of results.

APPENDIX B

Table B-1 Daily PM10 Concentration (ug/m3)

		Chula Uni	Chula Hos.	Dindaeng	OEPP	Singharat Sch.	Bangkok Uni.
5/11/99	F		86		47	48	
9/11/99	TU						
11/11/99	TH			55			
12/11/99	F	79					
14/11/99	SU		88				
17/11/99	W			48		89	57
18/11/99	TH	83					
23/11/99	TU				68		
25/11/99	TH	76					
26/11/99	F		103				57
1/12/99	W	58					
5/12/99	SU					106	28
7/12/99	TU	49					
11/12/99	SA			44	101		
14/12/99	TU						57
15/12/99	W	74					
20/12/99	M				84		
23/12/99	TH	85		75		109	
27/12/99	M	120					
4/1/00	TU		97				
10/1/00	M	66			60	42	
16/1/00	SU			50			
20/1/00	TH	76					
22/1/00	SA		121	115	134	127	
25/1/00	TU	68					
1/2/00	TU	80					
8/2/00	TU	100					
9/2/00	W		129		97		111
15/2/00	TU	48		47			135
21/2/00	M		30				
27/2/00	SU			120	68		56
4/3/00	SA			87			
6/3/00	M	70					
10/3/00	F		38	66	40		64
14/3/00	TU	54					
16/3/00	TH		75				
22/3/00	W				45		

Table B-1 Daily PM10 Concentration (ug/m3) (continue)

		Chula Uni	Chula Hos.	Dindaeng	OEPP	Singharat Sch.	Bangkok Uni.
23/3/00	TH	76					
27/3/00	M	76					
28/3/00	TU						96
1/4/00	SA	77					
3/4/00	M		42	57			
4/4/00	TU	40					
9/4/00	SU				63	33	55
15/4/00	SA		31	117		69	23
17/4/00	M	58					
25/4/00	TU	42					
27/4/00	TH				24		
03/05/00	W			81	57	57	
04/05/00	TH	54					
10/05/00	W	62					
09/05/00	TU						51
13/05/00	SA	36					
15/05/00	M		42	37		51	
21/05/00	SU						28
22/05/00	M	70					
27/05/00	SA		65		51		
03/06/00	SA	76			29		
08/06/00	TH					30	56
15/16/00	TH	63					
20/06/00	TU				39	39	
26/06/00	M						48
27/06/00	TU	57					
02/07/00	SU				37		
08/07/00	SA			42		37	
09/07/00	SU	69					
19/07/00	W			72		60	
20/07/00	TH				49		53
21/07/00	F	100					
01/08/00	TU			65			
02/08/00	W	131					
07/08/00	M					66	
14/08/00	M						
19/08/00	SA			54	28	38	

Table B-1 Daily PM10 Concentration (ug/m3) (continue)

		Chula Uni	Chula Hos.	Dindaeng	OEPP	Singharat Sch.	Bangkok Uni.
25/08/00	F				29		
26/08/00	SA						
31/08/00	TH						42
06/09/00	W		65	70			51
07/09/00	TH	62					
12/09/00	TU				24	24	
18/09/00	M		160	137			
19/09/00	TU	45					
24/09/00	SU				28		100
25/09/00	M	41					
30/09/00	SA					88	
01/10/00	SU	51					
06/10/00	TH		66			71	26
07/10/00	SA			64	47		
12/10/00	TH			66			
13/10/00	F	60					
18/10/00	W				50	60	
19/10/00	TH	38					
24/10/00	TU	45	40				49
31/10/00	TU						
05/11/00	SU		82				
11/11/00	SA			78	73	78	63
17/11/00	F			84		63	
23/11/00	TH	80	88		66		47

Table B-2 Daily PAH Concentration (ng/m3)

DATE		Chula. Uni.	Chula. Hos.	Dindaeng	OEPP	Singharat Sch.	Bangkok Uni.
5/11/99	F		100		36	37	
9/11/99	TU						
11/11/99	TH			35			
12/11/99	F	104					
14/11/99	SU		111				
17/11/99	W			35		69	27
18/11/99	TH	86					
23/11/99	TU				55		
25/11/99	TH	113					
26/11/99	F		118				46
1/12/99	W	57					
5/12/99	SU					183	22
7/12/99	TU	91					
11/12/99	SA			46	100		
14/12/99	TU						39
15/12/1999	W	86					
20/12/99	M				76		
23/12/99	TH	134		88		156	
27/12/99	M	195					
4/1/00	TU		83				
10/1/00	M	36			41	31	
16/1/00	SU			35			
20/1/00	TH	26					
22/1/00	SA		117	112	144	96	
25/1/00	TU	25					
1/2/00	TU	84					
8/2/00	TU	59					
9/2/00	W		113		149		109
2/15/00	TU	120		30			59
21/2/00	M		26				
27/2/00	SU			71	49		33
4/3/00	SA			48			
6/3/00	M	13					
10/3/00	F		18	39	15		70
14/3/00	TU	48					
16/3/00	TH		35				
22/3/00	W				18		

Table B-2 Daily PAH Concentration (ng/m3) (continue)

DATE		Chula. Uni.	Chula. Hos.	Dindaeng	OEPP	Singharat Sch.	Bangkok Uni.
23/3/00	TH	80					
27/3/00	M	21					
28/3/00	TU						82
1/4/00	SA	129					
3/4/00	M		32	11			
4/4/00	TU	64					
9/4/00	SU				24	13	22
15/4/00	SA		28	111		93	6
17/4/00	M	42					
25/4/00	TU	72					
27/4/00	TH				19		
03/05/00	W			48	41	24	
04/05/00	TH	43					
10/05/00	W	32					
09/05/00	TU						30
13/05/00	SA	35					
15/05/00	M		53	18		28	
21/05/00	SU						13
22/05/00	M	37					
27/05/00	SA		75		54		
03/06/00	SA	52			18		
08/06/00	TH					43	29
15/16/00	TH	31					
20/06/00	TU				27	31	
26/06/00	M						75
27/06/00	TU	44					
02/07/00	SU				39		
08/07/00	SA			39		42	
09/07/00	SU	56					
19/07/00	W			48		93	
20/07/00	TH				48		28
21/07/00	F	66					
01/08/00	TU			74			
02/08/00	W	70					
07/08/00	M					95	
14/08/00	M						
19/08/00	SA			58	43	38	

Table B-2 Daily PAH Concentration (ng/m3) (continue)

DATE		Chula. Uni.	Chula. Hos.	Dindaeng	OEPP	Singharat Sch.	Bangkok Uni.
25/08/00	F				48		
26/08/00	SA						
31/08/00	TH						65
06/09/00	W		100	100			70
07/09/00	TH	47					
12/09/00	TU				19	29	
18/09/00	M		100	94			
19/09/00	TU	25					
24/09/00	SU				25		70
25/09/00	M	47					
30/09/00	SA					88	
01/10/00	SU	54					
06/10/00	TH		163			85	21
07/10/00	SA			92	43		
12/10/00	TH			77			
13/10/00	F	32					
18/10/00	W				58	69	
19/10/00	TH	36					
24/10/00	TU	38	31				51
31/10/00	TU						
05/11/00	SU		70				
11/11/00	SA			60	79	69	55
17/11/00	F			92		67	
23/11/00	TH	84	75		70		61

Table B-3 Size Fractionate Particulate Matter Concentration at Chulalongkorn University								
Number	Date	flow rate	Concentration					
		m3/hr	<0.95 um	0.95-1.5 um	1.5-3.0 um	3.0-7.2 um	>7.2um	Total -SFPM
			ug/m3	ug/m3	ug/m3	ug/m3	ug/m3	ug/m3
1	09/11/99	66.90	31	9	9	15	12	75
2	12/11/99	62.35	34	9	8	15	16	83
3	18/11/99	66.90	29	11	8	18	18	84
4	25/11/99	62.00	27	8	8	16	16	75
5	01/12/99	65.75	22	7	6	12	13	60
6	07/12/99	67.65	26	4	4	11	12	57
7	15/12/99	67.35	41	7	6	13	13	80
8	23/12/99	63.35	57	10	8	18	18	111
9	27/12/99	58.70	61	10	8	22	17	119
10	10/01/00	66.70	29	6	4	12	14	66
11	20/01/00	64.60	41	7	5	11	13	77
12	25/01/00	62.50	39	6	5	10	10	69
13	01/02/00	62.50	47	6	5	13	11	81
14	08/02/00	64.70	49	8	5	16	15	92
15	15/02/00	63.90	30	1	4	12	13	60
16	06/03/00	63.75	43	1	5	13	12	74
17	23/03/00	59.00	44	2	5	14	12	77
18	01/04/00	63.80	33	9	6	16	11	75
19	17/04/00	63.35	29	6	6	3	17	61
20	25/04/00	66.15	20	4	4	9	7	44
21	04/05/00	65.75	36	1	4	7	6	54
22	13/05/00	65.25	21	3	3	8	6	42
23	22/05/00	62.00	22	7	24	11	8	72
24	03/06/00	60.00	33	7	8	14	11	74
25	15/06/00	56.00	28	15	2	3	10	58
26	27/06/00	58.00	30	3	6	15	2	56
27	09/07/00	58.00	30	7	8	17	11	74
28	14/08/00	59.80	27	5	6	9	9	56
29	26/08/00	60.00	35	2	6	17	5	64
30	07/09/00	54.90	46	7	6	9	8	58
31	19/09/00	62.40	22	4	3	16	3	48
32	25/09/00	52.60	14	5	8	7	6	40
33	01/10/00	67.20	24	4	5	9	8	50
34	13/10/00	67.80	33	6	7	10	10	65
35	19/10/00	67.70	23	4	5	9	11	52

Table 8-4 Size Fractionate Particulate Matter Concentration at Chulalongkorn University							
Number	Date	flow rate	PM Concentration				
			PM 0.95	PM 1.5	PM 3.0	PM 7.2	ΣSFPM
			ug/m3	ug/m3	ug/m3	ug/m3	ug/m3
1	09/11/99	66.90	31	39	49	63	75
2	12/11/99	62.35	34	43	51	67	83
3	18/11/99	66.90	29	40	48	66	84
4	25/11/99	62.00	27	35	43	59	75
5	01/12/99	65.75	22	29	36	48	60
6	07/12/99	67.65	26	30	34	45	57
7	15/12/99	67.35	41	48	54	67	80
8	23/12/99	63.35	57	67	75	93	111
9	27/12/99	58.70	61	71	79	102	119
10	10/01/00	66.70	29	36	40	52	66
11	20/01/00	64.60	41	48	53	64	77
12	25/01/00	62.50	39	45	50	60	69
13	01/02/00	62.50	47	53	57	70	81
14	08/02/00	64.70	49	57	62	78	92
15	15/02/00	63.90	30	32	36	48	60
16	06/03/00	63.75	43	44	49	62	74
17	23/03/00	59.00	44	46	51	65	77
18	01/04/00	63.80	33	42	48	64	75
19	17/04/00	63.35	29	35	41	44	61
20	25/04/00	66.15	20	24	28	37	44
21	04/05/00	65.75	36	37	41	48	54
22	13/05/00	65.25	21	25	28	36	42
23	22/05/00	62.00	22	29	53	64	72
24	03/06/00	60.00	33	40	48	62	74
25	15/06/00	56.00	28	43	45	48	58
26	27/06/00	58.00	30	32	38	54	56
27	09/07/00	58.00	30	37	45	62	74
28	14/08/00	59.80	27	32	37	47	56
29	26/08/00	60.00	35	36	42	59	64
30	07/09/00	54.90	46	53	59	68	76
31	19/09/00	62.40	22	26	29	45	48
32	25/09/00	52.60	14	19	27	34	40
33	01/10/00	67.20	24	28	33	42	50

Table B- 5 Annual Average Concentration of Individual PAH (ng/m3)						
	Chula Uni.	Chula Hos.	Dindaeng	OEPP	Singharat Sch.	Bangkok Uni.
Nap	0.7	0.5	0.7	0.5	0.5	0.5
Acy	5.3	3.5	3.5	3.0	2.7	2.4
Ace	0.3	0.2	0.3	0.4	0.4	0.4
Flu	3.5	2.7	3.0	2.1	2.3	1.6
Phen	1.4	1.3	1.6	1.1	1.3	1.0
Anth	0.3	0.4	0.6	0.3	0.3	0.4
Flt	2.1	1.1	0.8	1.1	0.9	0.8
Pyr	1.5	1.1	1.3	1.0	0.8	0.8
BaA	1.2	1.1	1.2	0.8	0.6	0.7
Chr	1.8	1.4	1.6	0.8	0.8	0.7
BeP	9.8	9.5	9.2	6.8	7.1	4.8
BbF	7.9	6.0	5.4	3.7	3.9	2.8
Per	0.9	0.7	0.7	0.6	0.5	0.5
BkF	2.7	2.3	1.9	1.4	1.4	1.1
BaP	4.0	5.1	4.4	3.2	3.1	2.7
DBahA	0.9	0.9	0.7	1.0	1.4	1.0
BghiP	12.0	15.3	12.6	11.8	16.6	10.0
Ind	9.9	10.1	7.4	9.6	13.5	8.9
Ant	0.8	1.2	0.8	1.0	1.1	1.0
Cor	4.3	4.7	3.3	4.7	7.9	4.0
Summed PAH	71.5	69.0	60.9	55.3	67.2	46.2

APPENDIX C

Climatological data for the year 1999													
Station : DON Muang Airport						Elevation of station above MSL. 4 Meters							
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
Pressure (HPA)													
Mean	1010.82	1012.45	1006.90	1007.57	1007.95	1007.19	1005.82	1007.88	1007.95	1009.69	1010.93	1013.83	1009.08
Mean Max.	10013.21	1015.06	1009.56	1009.97	1009.94	1008.86	1007.55	1009.72	1009.92	1011.83	1013.15	1016.28	1011.25
Mean Min.	1006.65	1010.17	1004.50	1004.76	1005.55	1004.99	1003.65	1005.52	1005.28	1007.13	1008.53	1011.27	1006.66
Ext. Max.	1017.61	1018.63	1014.54	1013.21	1012.53	1011.18	1010.50	1013.21	1012.19	1014.56	1017.61	1022.69	1022.69
Date	16	5	1	6	13	11,27	6,7	30	30	22	17,18	24	
Ext. Min	1005.08	1007.11	1001.35	1000.00	1003.05	1002.71	1001.02	1001.69	1002.37	1004.40	1006.10	1007.11	
Date	26,27	27	8	26	25	5	30	21,22	15,16	25	1,6	17	
Temperature (Celsius)													
Mean	26.9	27.3	29.1	28.4	27.6	28.4	28.8	28.3	28.3	27.6	27.1	23.7	27.6
Mean Max.	31.8	32.2	34.9	33.7	32.5	32.8	33.5	32.8	33.3	31.8	30.9	28.1	32.4
Mean Min.	22.8	22.8	24.5	24.5	24.4	25.2	25.4	25.2	25.0	24.3	23.9	19.6	24.0
Ext. Max.	35.7	35.5	37.1	36.6	34.4	34.6	36.3	35.4	35.4	34.9	34.7	32.7	37.1
Date	24	27	21	2	16	29	8	21	5	8	25	31	
Ext. Min	19.4	18.1	21.2	21.7	22.4	22.8	22.8	22.8	23.5	22.4	21.0	11.7	11.7
Date	7	5	10	7,11	5	12	20	20	11	21	4	25	
Relative Humidity (%)													
Mean	70	75	76	85	87	83	69	76	80	82	77	66	77
Mean Max.	90	96	95	96	97	96	86	90	92	93	91	83	92
Mean Min.	49	49	50	65	71	66	47	58	61	66	59	46	57
Ext. Min.	31	36	19	49	60	53	30	40	49	53	44	30	19
Date	24	10	8	2	7	23	6	7	13	11	28	24,25	
Dew Point (Celsius)													
Mean	20.5	21.8	23.7	25.3	25.1	25.0	21.9	23.4	24.1	24.1	22.4	16.5	22.6
Evaporation (mm)													
Monthly totals													
Cloudiness (0-10)													
Mean	5.4	4.5	4.9	7.5	6.0	7.6	7.6	7.9	7.3	7.4	6.1	4.7	6.6
Sunshine Duration (Hr.)													
Monthly totals													
Visibility (km.)													
Mean	7.2	6.6	8.4	8.6	8.6	9.4	9.5	9.7	9.2	8.9	8.5	8.1	8.6
Wind(Knots)													
Mean wind speed	4.3	4.7	6.7	6.4	7.5	9.8	11.1	6.1	6.2	5.0	3.9	4.7	6.4
Previaling wind	S	S	S	S	S	SW	SW	SW	SW	S	W	N	
Max. Wind Speed	18	17	27	23	27	34	26	30	24	25	18	14	34
Direction	SSW	ESE,E	E	SW,E	SW	WSW	SSW,SW	WNW	WNW	SE	E	vary	
Date	2	14,20	5	7,25	23	12	9,22	9	18	3	13	5	
Rainfall (mm.)													
Monthly totals	33.8	46.6	36.3	223.9	533.4	127.6	115.3	149.1	236.3	267.7	59.2	2.4	1631.6
Number of rainy days	1	3	2	19	22	14	16	15	18	17	5	1	133
Daily maximum	33.6	32.8	21.6	48.1	210.7	39.4	29.6	45.9	55.8	50.8	18.6	2.4	210.7
Date	29	3	23	29	4	18	19	9	17	29	1	3	
Number of days with													
Fog	0	6	1	0	0	0	0	0	0	0	0	0	7
Haze	27	26	17	8	1	0	9	1	0	2	11	27	129
Hail	0	0	0	0	0	0	0	0	0	0	0	0	0
Thunderstorm	1	1	3	15	18	4	7	8	10	13	3	0	83
Squall	0	0	0	0	0	0	0	0	0	0	0	0	0
(n) n is number of days with same occurrence													
Data Processing Sub-division, Climatology Division, Meteorological Department													

Climatological data for the year 2000													
Station : DON Muang Airport						Elevation of station above MSL. 4 Meters							
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
Pressure (HPA)													
Mean	1011.71	1010.53	1009.13	1007.98	1007.20	1007.13	1005.98	1006.59	1008.63	1008.68	1011.07	1011.30	1008.82
Mean Max.	1014.17	1013.13	1011.71	1010.28	1009.13	1008.76	1007.66	1008.38	1010.62	1010.86	1013.30	1013.56	1010.96
Mean Min.	1009.43	1007.96	1006.71	1005.31	1004.63	1004.99	1003.85	1004.21	1006.19	1005.93	1008.95	1009.13	1006.44
Ext. Max.	1019.30	1019.30	1014.90	1012.53	1013.21	1011.18	1010.50	1011.18	1013.55	1013.55	1016.59	1016.59	1019.30
Date	31	2	2	3	5	23	12	13,14	30	1	4	25	
Ext. Min	1006.10	1003.76	1003.39	1003.05	1000.68	1001.36	1000.03	1000.34	1002.03	1002.71	1007.45	1006.77	1000.03
Date	14	13	17	1,25	13	2	3	21	10,11	13,14	4	19	
Temperature (Celsius)													
Mean	27.4	27.4	29.2	29.1	29.1	28.0	28.1	28.1	27.5	27.5	26.6	27.2	27.9
Mean Max.	32.4	33.5	35.0	34.4	34.2	33.1	32.8	33.2	32.5	32.4	30.8	32.0	33.0
Mean Min.	23.1	22.6	24.6	25.4	25.3	24.6	24.8	24.5	24.1	24.5	22.5	22.8	24.1
Ext. Max.	34.8	36.6	37.7	39.0	36.7	35.3	35.7	36.7	34.7	35.5	34.0	34.0	39.0
Date	10,12	24	23	8	1,9	30	31	1	26	5	27	30	
Ext. Min	19.2	17.4	22.0	23.1	23.3	22.9	23.1	22.7	22.2	22.8	16.4	16.0	17.4
Date	28	2	14,24	10	21	21,24	20	13	26	13	6	25	
Relative Humidity (%)													
Mean	74	73	75	85	81	85	84	84	86	87	74	72	80
Mean Max.	93	93	95	96	95	95	95	94	95	96	91	91	94
Mean Min	51	47	48	66	60	7	67	67	68	70	53	49	60
Ext. Min	29	17	19	46	46	57	48	53	48	59	35	34	17
Date	23	6	16	8	9	21	30	1	17	10	7	27	
Dew Point (Celsius)													
Mean	21.9	21.3	23.5	25.9	25.2	25.1	24.9	24.9	24.7	25 121.1	21.3	23.7	
Evaporation (mm)													
Monthly totals													
Cloudiness (0-10)													
Mean	5.1	5.4	6.2	7.3	7.4	8.1	7.8	7.8	8.0	7.6	4.7	4.7	6.7
Sunshine Duration (Hr.)													
Monthly totals													
Visibility (km.)													
Mean	6.9	7.3	7.6	6.9	9.5	9.4	9.4	9.7	8.9	9.3	9.4	9.0	8.6
Wind(Knots)													
Mean wind speed	6.2	4.8	5.4	6.0	7.2	8.8	8.6	6.4	5.1	4.3	4.0	4.3	5.9
Previaling wind	SW,S	S	S	S	S	S	SW	SW	S	S	N	W	
Max. Wind Speed	18	15	35	23	40	33	28	26	26	22	16	16	40
Direction	SSW	vary	ESE	SSE	S	SSW	SW	WSW	WSW	SSW	NNW	NW	
Date	13	3	24	16	3	26	13	29	26	22	24	28	
Rainfall (mm.)													
Monthly totals	0.0	8.5	66.9	261.0	249.5	188.4	101.6	151.9	273.0	79.1	0.8	T	1390.9
Number of rainy days	1	4	13	18	23	15	23	17	17	1			132
Daily maximum	0.0	8.5	30.2	121.1	74.6	35.2	25.5	24.7	72.6	20.9	0.8	T	121.1
Date	29	4	16	3	21	2	7	26	22	20	10		
Number of days with													
Fog	2	1	0	0	0	0	0	0	0	0	0	0	3
Haze	29	20	26	10	3	0	0	1	4	0	9	17	19
Hail	0	0	0	0	1	0	0	0	0	0	0	0	1
Thunderstorm	0	0	3	6	13	3	1	8	10	7	0	0	51
Squall	0	0	0	0	0	0	0	0	0	0	0	0	0
(n) n is number of days with same occurrence													
Data Processing Sub-division, Climatology Division, Meteorological Department													

Climatological data for the year 1999

Station : Bangkok Metropolis — Elevation of station above MSL 2 Meters

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
Pressure (HPA)													
Mean	1010.60	1012.21	1006.66	1007.18	1007.56	1006.63	1005.63	1007.66	1007.78	1009.40	1010.46	1013.30	1008.77
Mean Max.	1012.96	1014.78	1009.25	1009.47	1009.39	1008.43	1007.27	1009.44	1009.69	1011.53	1012.76	1015.79	1010.89
Mean Min.	1008.42	1009.99	1004.38	1004.52	1005.21	1004.84	1003.64	1005.49	1005.21	1006.85	1008.14	1010.86	1006.46
Ext. Max	1017.12	1018.19	1013.49	1011.94	1011.39	1011.33	1010.32	1012.12	1012.00	1014.32	1016.97	1022.20	1022.20
Date	16	5	1	6	27	11	6,7	29	23	22	17	24	
Ext. Min	1005.01	1007.14	1001.66	999.82	1002.90	1002.24	1001.37	1001.46	1002.52	1003.99	1005.50	1006.58	999.82
Date	26	27	8	26	25	30	30	21	16	25	6	17	
Temperature (Celsius)													
Mean	27.8	28.4	30.3	29.7	28.6	29.1	29.6	28.9	28.6	28.0	27.7	24.5	28.4
Mean Max	33.0	33.1	35.4	33.9	32.7	32.9	33.3	32.6	33.0	32.3	32.0	29.3	32.8
Mean Min.	23.7	24.5	26.5	26.2	25.4	26.3	26.6	25.7	25.5	25.0	24.4	20.4	25.0
Ext. Max	37.6	35.6	37.6	36.3	34.4	35.2	35.1	35.0	35.0	35.1	35.2	35.0	37.6
Date	24	11	7,19	18	18	29	16	22	5	8	28	31	
Ext. Min	20.8	19.5	22.7	23.5	23.6	25.1	24.4	23.9	24.2	23.4	21.3	13.2	13.2
Date	6	6	9	6	5	23	20	17	8	21	4	25	
Relative Humidity (%)													
Mean	71	76	70	77	81	77	72	75	78	80	72	59	74
Mean Max.	83	90	87	91	93	90	84	89	91	92	85	70	87
Mean Min	58	60	48	61	66	62	59	61	62	63	56	47	59
Ext. Min	40	52	21	49	54	50	50	50	52	48	41	33	21
Date	6	9,10	8,19	3	6	30	2	18	14,20	10	25	25	
Dew Point (Celsius)													
Mean	21.6	23.5	23.5	24.9	24.9	24.5	23.9	23.8	24.2	23.9	22.0	15.6	23.0
Evaporation (mm)													
Monthly totals	114.7	109.2	154.1	120.4	94.3	120.1	133.6	115.3	114.7	99.3	101.4	114.9	1392
Cloudiness (0-10)													
Mean	5.9	5.1	5.2	7.5	8.5	8.1	7.8	8.4	8.0	7.8	6.7	5.3	7.0
Sunshine Duration (Hr.)													
Monthly totals	193.7	218.5	254.2	137.9		140.8	181.4	136.7	159.7	156.2	166.4	192.5	
Visibility (km.)													
Mean	8.3	7.7	9.4	10.2	10.8	12.2	12.6	12.1	11.1	10.2	10.1	9.3	10.3
Wind(Knots)													
Mean wind speed	1.8	2.2	3.2	2.3	2.0	2.3	3.0	2.3	1.9	2.1	1.7	1.9	2.2
Prevailing wind	E	E	S	S	S	SW	SW	SW	W	E	NE	NE	
Max. Wind Speed	16	18	25	28	25	23	20	22	16	13	14	26	
Direction	S	E	E	W	SSW	W	WNW	WSW	ESE,W	S,E	N	E	
Date	30	20	30	22	22	12	14	3	18,21	13,16	29	16	
Rainfall (mm.)													
Monthly totals	35.1	52.3	50.9	189.6	409.6	104.1	72.3	158.7	211.2	383.8	88.1	0.5	1756.2
Number of rainy days	4	3	4	15	18	14	15	19	16	17	8	1	134
Daily maximum	17.3	33.5	44.0	43.6	114.5	24.1	13.5	48.2	51.8	96.4	28.2	0.5	114.5
Date	29	2	28	6	4	4	19	29	21	3	1	5	
Number of days with													
Fog	0	0	0	0	0	0	0	0	0	0	0	0	0
Haze	20	19	16	6	0	0	2	0	1	2	8	23	97
Hail	20	19	16	6	0	0	2	0	1	2	8	23	97
Thunderstorm	0	1	2	1	13	11	5	7	11	14	5	0	70
Squall	0	0	0	0	0	0	0	0	0	0	0	0	0

(n) n.ls number of days with same occurrence

Data Processing Sub-division, Climatology Division, Meteorological Department

Climatological data for the year 2000													
Station : Bangkok Metropolis						Elevation of station above MSL. 2 Meters							
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
Pressure (HPA)													
Mean	1011.25	1010.12	1008.81	1007.56	1006.85	1006.80	1005.73	1006.42	1008.35	1008.40	1010.66	1010.85	1008.48
Mean Max.	1013.71	1012.74	1011.40	1009.82	1008.68	1008.50	1007.40	1008.20	1010.29	1010.59	1013.09	1013.12	1010.62
Mean Min.	1009.06	1007.73	1006.56	1005.12	1004.37	1004.75	1003.76	1004.28	1006.04	1005.81	1008.56	1008.73	1006.23
Ext. Max.	1018.52	1018.93	1014.35	1012.36	1012.76	1011.02	1009.39	1011.43	1012.72	1013.43	1017.17	1015.00	1018.99
Date	31	2	2	30	6	23	12	13	24	1	9	25	
Ext. Min	1005.57	1005.87	1003.77	1003.33	1001.17	1001.22	100.67	999.97	1001.71	1002.74	1006.77	1006.16	999.97
Date	14	13	17	14	11	2	4	21	10	14	15	19	
Temperature (Celsius)													
Mean	28.0	28.1	29.7	29.5	29.9	28.9	28.8	29.0	28.5	28.4	27.8	28.5	28.6
Mean Max	33.0	33.5	34.3	33.5	34.0	32.6	32.5	32.6	32.8	32.6	32.6	33.4	33.1
Mean Min.	24.1	23.7	26.0	26.2	26.3	25.9	26.0	25.6	25.4	25.3	23.8	24.3	25.2
Ext. Max.	35.5	35.7	37.0	37.1	36.1	34.4	35.1	34.8	35.1	35.1	35.0	35.6	37.1
Date	5	28	14	8	29	6	31	1,12	26	26	28	2	
Ext. Min	20.4	18.6	22.6	23.4	23.2	23.4	24.2	23.5	24.0	23.9	20.4	20.0	18.6
Date	29	2	24	17	4	21	6	13	3	8	4,6	25	
Relative Humidity (%)													
Mean	67	67	69	78	75	78	76	75	77	80	64	63	72
Mean Max.	82	84	85	90	89	91	89	88	89	93	78	78	86
Mean Min.	49	47	50	63	60	63	60	61	60	63	49	47	55
Ext. Min.	31	27	27	48	48	55	40	52	40	55	35	40	27
Date	23	6	12,16	6	9	4	26	16	17	3,27	7	19	
Dew Point (Celsius)													
Mean	20.8	20.8	23.0	25.1	24.7	24.4	23.8	23.8	23.9	24.5	20.0	2.3	22.9
Evaporation (mm)													
Monthly totals	123.5	120.9	156.1	118.4	147.2	104.8	125.5	134.8	114.3	97.1	118.9	124.8	1486.3
Cloudiness (0-10)													
Mean	5.5	5.4	6.4	7.4	7.6	8.5	8.3	8.2	8.6	8.1	5.0	5.2	7.0
Sunshine Duration (Hr.)													
Monthly totals	217.4	196.5	221.7	165.4	203.6	116.7	130.5	168.8	125.8	135.6	210.4	229.4	2121.6
Visibility (km.)													
Mean	7.9	8.2	9.0	10.5	11.7	11.0	11.1	12.2	10.3	10.8	11.2	9.5	10.3
Wind(Knots)													
Mean wind speed	2.4	2.2	2.9	2.6	2.2	2.1	2.5	2.4	1.9	1.3	1.7	1.5	2.1
Previaling wind	S	S	S	S	S	S	SW	SW	SW	S	N	NE	
Max. Wind Speed	18	17	16	24	22	25	23	21	23	25	13	14	25
Direction	ENE	ESE	SSE,S	SSW	W	W	SSW	WSW	ESE	SSE	ESE	ENE,N	
Date	31	29	18,28	16	18	17	13	15	22	8	15	19,23	
Rainfall (mm.)													
Monthly totals	0.0	40.0	43.9	209.3	257.3	263.0	261.0	226.0	214.6	358.8	T	4.4	1678.3
Number of rainy days		2	3	14	20	21	23	22	19	21		1	146
Daily maximum	0.0	39.9	34.5	61.8	65.8	52.2	55.3	39.3	34.1	88.1	T	4.4	88.1
Date		29	24	14	21	3	5	12	28	16	26,29	10	
Number of days with													
Fog	0	1	0	0	0	0	0	0	0	0	0	0	1
Haze	28	21	17	6	2	0	0	1	3	2	9	20	109
Hail	0	0	0	0	0	0	0	0	0	0	0	0	0
Thunderstorm	0	0	2	15	16	15	9	12	16	19	0	0	104
Squall	0	0	0	0	0	0	0	0	0	0	0	0	0
(n) n is number of days with same occurrence													
Data Processing Sub-division, Climatology Division, Meteorological Department													

APPENDIX D

Table D-1. Traffic volume at all sites on 2000 (car/12 hour day)

Types of Vehicles	Chula. Uni.	Chula. Hos.	Dindaeng	OEPP	Singharat Sch.	Bangkok Uni.
Heavy Diesel Vehicle						
1. Truck	175	635	1,564	259	939	221
2. Big Bus	2,263	3,153	3,700	658	461	66
3. Small Bus	748	1,090	832	114	484	10
Light Diesel Vehicle						
4. Van,Pick Up	7,377	25,178	32,690	10,211	12,484	9,166
Gasoline Vehicle						
5. Car	26,880	77,569	76,461	30,701	10,448	11,850
6. Tuk-Tuk	1,360	1,748	1,375	1,249	4,503	6
Total	38,803	109,373	116,622	43,192	29,319	21,319
Date	05/09/00	14/05/00	07/02/00	22/07/00	13/12/00	04/12/00

- The office of the commission for the Management of Road Traffic, Bangkok
- No motor cycle data

Biography

Ms. Pajaree Thongsanit was born on October 30, 1971 in Phitsanulok, Thailand. She received her Bachelor of Science Degree in Public Health from Faculty of Public Health, Mahidol University, Bangkok Thailand in 1993. She has continued studies in Environmental Engineering, Graduate school, Kasetsart University. Then in 1996, she worked as lecturer at faculty of Engineering, Naresuan University for 2 years. At the present, she studies in doctoral degree of Environmental Engineering, Faculty of Engineering, Chulalongkorn University. She also receives a Thailand Research Fund scholarship under the Royal Golden Jubilee Ph.D. Program.