BTEX EMISSION INVENTORY AND MODELING OF IMPACTS ON AIR QUALITY FOR THE MAP TA PHUT PETROCHEMICAL COMPLEX

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ข้อมูลการปล่อยสารมลพิษจำพวก BTEX และการใช้แบบจำลองทางคณิตศาสตร์ประเมินผลกระทบต่อคุณภาพอากาศในพื้นที่นิคมอุตสาหกรรมปิโตรเคมีมาบตาพุด

นายเดชา พิมพิสุทธิ์

วิทยานิพนธ์นี้เป็นส่วนหนึ่งของการศึกษาตามหลักสูตรปริญญาวิทยาศาสตรดุษฎีบัณฑิต
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เดชา พิมพิสุทธิ์ : ข้อมูลการปล่อยสารมลพิษจำพวก BTEXและการใช้แบบจำลองทางคณิตศาสตร์ประเมินผลกระทบต่อคุณภาพอากาศในพื้นที่นิคมอุตสาหกรรมปิโตรเคมีมาบตาพุด (BTEX EMISSION INVENTORY AND MODELING OF IMPACTS ON AIR QUALITY FOR THE MAP TA PHUT PETROCHEMICAL COMPLEX).
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สารอินทรีย์จำพวก Benzene, Toluene, Ethylbenzene และ Xylene (BTEX) ในบรรยากาศบริเวณนิคมอุตสาหกรรมมาบตาพุดได้ถูกศึกษาโดยการเก็บตัวอย่างอากาศตามจุดต่างๆด้วยปั๊มแบบพกติดตัวบุคคลและหลอดแก้วบรรจุผงถ่านกัมมันต์ในช่วงฤดูร้อน (22-28 ก.พ) ช่วงร้อนชื้น (29 เม.ย-5 พ.ค) และช่วงฤดูฝน (19-25 มิ.ย) พ.ศ 2545 ตัวอย่างที่เก็บได้ถูกนำไปสกัดด้วยสารคาร์บอนไดซัลไฟด์ และวิเคราะห์หาปริมาณสารแต่ละชนิดด้วยเทคนิคแก๊สโครมาโตกราฟฟี (GC/FID) พบว่าค่าความเข้มข้นเฉลี่ย ณ จุดตรวจวัดบริเวณใต้ลมมีค่าต่ำกว่าจุดตรวจวัดในบริเวณนิคมอุตสาหกรรมแต่สูงกว่าจุดตรวจวัดบริเวณเหนือลม แสดงว่าพื้นที่ในนิคมอุตสาหกรรมมาบตาพุดและพื้นที่ใกล้เคียงด้านใต้ลมได้รับผลกระทบจากการปล่อยสาร BTEX จากแหล่งกำเนิดในนิคมอุตสาหกรรม ข้อมูลการปล่อยสารมลพิษจำพวก BTEX จากแหล่งกำเนิดต่างๆในพื้นที่จึงได้ถูกรวบรวมและใช้แบบจำลองทางคณิตศาสตร์ (ISCST-3 Model) ประมาณผลกระทบจากการปล่อยสารดังกล่าวในช่วงเวลาเดียวกับการตรวจวัด ค่าที่ได้จากการใช้แบบจำลองนำมาเปรียบเทียบกับค่าที่ได้จากการตรวจวัด ณ เวลาและจุดตรวจวัดเดียวกัน พบว่ามีค่าความสัมพันธ์ที่เชื่อถือได้ ดังนั้น ข้อมูลการปล่อยสารดังกล่าวได้ถูกนำมาใช้กับแบบจำลองทางคณิตศาสตร์อีกครั้งเพื่อประมาณค่าความเข้มข้นเฉลี่ยรายปี ด้วยข้อมูลอุตุนิยมวิทยาในปี 2545 ซึ่งมีทิศทางลมพัดเข้าสู่บริเวณชุมชนมากที่สุดเมื่อเทียบกับข้อมูลในปี 2543 และ 2544 พบว่าค่าความเข้มข้นรายปีของสารอินทรีย์ทั้ง 4 ชนิดมีค่าต่ำกว่าค่าที่เกิดอันตรายได้เมื่อสัมผัสเป็นเวลานาน (Chronic Effects) และพบว่าความเข้มข้นของ benzene ณ จุดตรวจวัดในบริเวณนิคมอุตสาหกรรมจำนวน 2 จุดและบริเวณพื้นที่ใต้ลมที่เคยเป็นที่ตั้งโรงเรียนมาบตาพุดพันวิทยาคารมีค่าค่อนข้างสูงแต่ต่ำกว่าค่ามาตรฐานในบรรยากาศในเขตเมือง(5 ppbv) ที่กำหนดโดยองค์การอนามัยโลก เมื่อพิจารณาแหล่งกำเนิดพบว่าโรงกลั่นน้ำมันจำนวน 2 โรงและโรงงานอุตสาหกรรมปิโตรเคมีขั้นต้น 2 แห่ง เป็นแหล่งกำเนิดหลักและควรได้รับการกำกับดูแลการปล่อยสาร benzene สู่บรรยากาศ เพื่อให้มีระดับความเข้มข้นในบรรยากาศสำหรับพื้นที่นิคมอุตสาหกรรมมาบตาพุดและพื้นที่ใกล้เคียงมีค่าเป็นไปตามค่ามาตรฐานดังกล่าว

สหสาขาวิชา การจัดการสิ่งแวดล้อม. ลายมือชื่อนิสิต...
สาขาวิชาการจัดการสิ่งแวดล้อม ลายมือชื่ออาจารย์ที่ปรึกษา......................................
ปีการศึกษา 2547 ลายมือชื่ออาจารย์ที่ปรึกษาร่วม................................

4389657520 : MAJOR ENVIRONMENTAL MANAGEMENT

KEY WORD:BTEX / PETROCHEMICAL COMPLEX / EMISSION INVENTORY / ISCST-3 MODEL

DECHA PIMPISUT: BTEX EMISSION INVENTORY AND MODELING OF IMPACTS ON AIR QUALITY FOR THE MAP TA PHUT PETROCHEMICAL COMPLEX.

THESIS ADVISOR: ASSOC. PROF. DR. WANIDA JINSART, THESIS COADVISOR: ASSOC. PROF. DR. MARTIN A. HOOPER, 246 pp. ISBN 974-17-4066-2.

The aromatic compounds Benzene, Toluene, Ethylbenzene and Xylene (BTEX), all found at the Map Ta Phut Petrochemical Complex were studied. Ambient air samples were actively collected by personal air samplers attached to charcoal adsorbent tubes during the dry (22-28 February), the semi-wet (28 April-5 May) and the wet (19-25 June) periods in 2002. These samples were extracted by carbon disulfide and quantified for BTEX using GC/FID technique. Daytime and less commonly nighttime data from all monitoring sites were statistically analyzed. For daytime data, the average mean concentrations at two downwind sites were higher than those at two upwind sites but lower than those at two sites within the industrial area. The ambient measurement data indicated that BTEX concentrations at the industrial and downwind monitoring sites were affected by emission sources situated within the complex. Consequently, an emission inventory of BTEX in the complex was compiled and the air dispersion model ISCST-3, was used to predict its effects. The predicted values were compared with corresponding field measurement values and reasonable agreement was obtained. BTEX emission inventories were then simulated by ISCST-3 using 2002 meteorological data (as it is considered to result in higher BTEX concentrations than 2000 or 2001 data) to determine annual average predicted concentrations. The results at all monitoring sites were lower than their chronic benchmarks set by other studies. Benzene was found its high concentration at two monitoring sites within the complex and one downwind site but they were still lower than the ambient air quality guideline (5 ppb) set by WHO. Two refineries and two upstream aromatic petrochemical plants were identified as major BTEX emission sources and should be managed in order to maintain local ambient concentrations of benzene within the WHO guideline.

Inter-department Environmental Management Student's signature......................
Field of study Environmental Management Advisor's
Academic year 2004 Co-advisor's signature..............................

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ABBREVIATION

AAAQG	Arizona Ambient Air Quality Guidelines
BTEX	Benzene, Toluene, Ethylbenzene and Xylene
CS_2	Carbon disulfide
DIW	Department of Industrial Works
EIA	Environmental Impact Assessment
ERTC	Environmental Research and Training Center
EF	Emission Factors
GC/FID	Gas Chromatography/Flame Ionization Detector
g/s	Gram per second
HAPs	Hazardous Air Pollutants
HDDV	Heavy Duty Diesel-powered Vehicle or Bus, Truck etc.
IEAT	The Industrial Estate Authority of Thailand
IRIS	Integrated Risk Information System
ISCST	Industrial Source Complex Short Term
L	Liter
LDDT	Light Duty Diesel-powered Vehicle or Light commercial Car
LDGV	Light Duty Gasoline-powered Vehicle or Passenger Car
LPG	Liquid Petroleum Gas
LTD	Land Transportation Department
m	Meter
MACT	Maximum Achievable Control Technology
MC	Petrol Motorcycle
mg/m^3	Milligram per Cubic Meters
mL	Milliliter
NEDO	New Energy and Environmental Development Organization
NMVOCs	Non-methane Volatile Organic Compounds
NSPS	New Source Performance Standard
OEPP	The Office of Environmental Policy and Planing
ONSEDB	The Office of National Social and Economic Development Board

PAHs	Polycyclic Aromatic Hydrocarbons
PCD	Pollution Control Department
POPs	Persistent Organic Pollutants
ppb	Part per Billion
PTT	Petroleum Authority of Thailand
PTIT	Petroleum Institute of Thailand
QA/QC	Quality Control and Quality Assurance
sec	Second
SIC	Standard Industrial Code
SVOCs	Semi-volatile Organic Compounds
TAPM	The Air Pollution Model
TRI	Toxic Release Inventory
UNEP	United Nation Environment Programme
USEPA	United States Environmental Protection Agency
VKT	Vehicle Kilometer Travel
VOCs	Volatile Organic Compounds
WHO	World Health Organization
$\mu g/m^3$	Microgram per cubic meters
µL	Microliter

CHAPTER 1

INTRODUCTION

1.1 Background and Rationale

A cornerstone of the National Social and Economic Development plans, in particular the sixth and seventh plans, the Royal Thai government aimed at developing Thailand as a New Industrialized Country (NIC) (ONSEDB, 1987 and ONSEDB, 1991). The industrial sector has expanded in recent times, increased with 18,783 new factories being settled during 1997-2002 (DIW, 2002a). Many projects were established in order to achieve government goals and the Eastern Sea Board Development Project was one of the leading mega-projects created in that time. The project induced significant industrial activity in the area, particularly through the establishment of numerous industrial estates and individual large-scale industries (DIW, 2002a). Even though the industrial estate was used as a tool for policy makers to manage pollution discharge. The deterioration of natural resources still remains a severe problem. One of the major problems is air pollution, which has widespread impact since the pollutants rapidly and extensively disperse causing adverse effects to human health, animals, plants and ecosystems. The toxic effects of air pollution can be acute or chronic and result in both direct and indirect impacts. The breakdown of the human respiratory system and eye irritation are two common examples resulting from high levels of air pollution (Boubel et al, 1994 and Limpaseni et al, 1995). A consequence of this is the higher cost of public health care, which must be absorbed by the national economy.

The Map Ta Phut industrial estate in southeastern Thailand was established in 1984 and has been operating since the early 1990's. It serves as the upstream industrial estate for many petrochemical-related industries. At present, out of the 52 factories in the complex, 2 are refineries and 30 relate to the petrochemical industry comprising all 3 vertical stages of the industry (PTIT, 1999). The complexity and integration of the estate operations have caused various air pollution problems, including both odor and health-related issues. In June 1997, 120 students at a secondary school located to the northeast of the estate, were affected by chemical vapors released from factories in the estate. The students reported having dizziness, headaches, nasal inflammation, throat soreness and tiredness (DIW, 2001). Furthermore, offensive odors from factories in the estate are still recorded regularly especially during the monsoon period, with mitigation being handled on a case by case basis. These types of reports have heightened public concerns about gaseous emissions from the petrochemical industry in general. Recently, there have been protests against a natural gas pipeline and natural gas separation project in the south of Thailand due to concerns about potential emissions from proposed petrochemical plants (OEPP, 2002).

Some preliminary studies in the Map Ta Phut area have been completed. As reported in a the heath risk assessment study, factories situated in the complex were identified as emission sources of several hydrocarbon species including BTEX members that caused adverse health effects in the area (HSRI, 2000). There have been two studies to measure VOCs in the estate (NEDO, 1999; ERTC, 1999). The first study was done during a training program to quantify VOCs in ambient air using a thermal desorption/GC/MS technique. Among the 14 species of VOCs detected, the BTEX member concentrations were found in ranges 1.4-3.5, 0-22, 1.8-5.7 and 0.8-20 $\mu g/m^3$ respectively. The second investigation was done using duplicated samples in six locations and twelve C_2-C_9 hydrocarbon species were detected. The limitation in the number of samples and sampling sites did not allow adequate definition of spatial and temporal variations of species. Nevertheless, the abundance of species detected conforms to those from other studies elsewhere (Hawas et al., 2002; Na et al., 2001; Mohan Rao et al., 1997; Scheff and Wadden, 1993). Furthermore in 1999, the Thailand Environment Institute (TEI) was awarded a contract from NEDO to study sources of air pollution, primarily for air particulate matter and gaseous SO_x and NO_x species. TEI collected data via a factory survey and reported that 15 factories in the Map Ta Phut area emitted VOCs from fuel combustion, leakage from manufacturing processes, storage, and incineration (TEI, 1999). In addition, the Industrial Estate Authority of Thailand (IEAT) in cooperation with the Department of Industrial Works (DIW), the Pollution Control Department (PCD) and the Office of Environmental Policy and Planning (OEPP) are currently conducting a study on the carrying capacity of the area for particulates, SO_x and NO_x but are not addressing VOCs.

Because of ongoing concerns with these hazardous air pollutants, there was a need to quantify further their ambient concentrations and distribution patterns and to identify the relative importance of emission sources. The findings can be used by concerned regulatory agencies to develop effective management strategies, of which the establishment of emission standards or ambient air quality standards will be the key approaches.

1.2 Objectives

This research aimed to determine the emission loading of the petrochemical complex sources of Benzene, Toluene, Ethylbenzene and Xylene (BTEX) that impact ambient concentrations of these species in the study area. The results are verified via modeling before proposing the maximum speciation loading for sources in the area. The specific objectives of the study are as follows:

1.2.1 To quantify the BTEX concentrations in ambient air at and around the Map Ta Phut Petrochemical Complex

1.2.2 To develop an emission inventory of the BTEX species based on all stationary and mobile sources in the area of the complex

1.2.3 To utilize an air dispersion model to predict the effects of the inventory sources on the ambient air quality

1.2.4 To determine the maximum annual emission rates or loading associated with the industries within the complex, thus ensuring the ambient concentrations in the surrounding area remain below levels of health concerns.

1.3 Scope of the Study

This research focuses on the release of BTEX, a representative group of hazardous air pollutants (HAPs), from sources in the Map Ta Phut industrial complex. Emissions data of target species within the complex was compiled based on methods used elsewhere such as in the USA, European countries, Australia. Then coupled with on site meteorological data, a dispersion model (ISCST-3) was employed to simulate their ambient concentrations. The simulated concentrations were compared to those of the field monitoring data, which was conducted primarily based on OSHA's method. If there was a reasonable agreement between the two values, the emission inventory was used as actual emission loading of BTEX in the area. Based on the inventory and worse case meteorological data, the ISCST-3 was used to predict annual concentrations of BTEX at all monitoring sites. Health benchmarks and ambient air quality standards of BTEX were identified based on literature or guidelines and standards from other developed countries and international organizations. The simulate concentrations referring to these benchmarks were used to track back to propose maximum allowable annual emission rates.

1.4 Conceptual Framework

Through the careful application of modern air quality models, estimates of the impact of released air contaminants at a downwind location can provide useful information in answer to questions raised about the nature of those impacts. Air quality models are widely regarded as sufficiently capable of providing conservative estimates.

Since the estimation of emissions is often uncertain, these uncertainties should also be taken into account when reviewing and taking action based on model predictions. Contaminant emission rates that are grossly underestimated will produce modeled impacts that are also grossly underestimated. Air quality monitoring, having better inherent credit, was used to verify model predictions. The conceptual framework of this study is shown in Figure1.1.

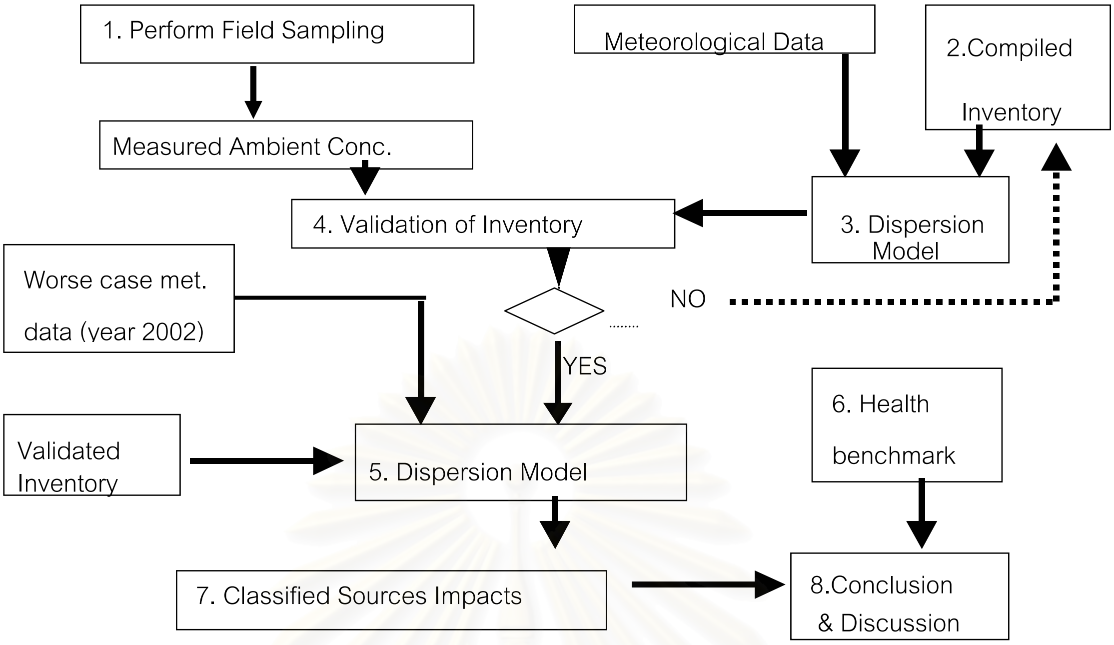


Figure 1.1: Schematic diagram of conceptual framework

1.5 Limitations of this Research

In this research, the accessibility of emission loading data is limited. Except for mobile sources, which were compiled from a counted traffic multiplied by emission factors, the compiled emission data was based primarily on secondary data from factories through either the Environmental Impact Assessment (EIA) or data gathered directly from the factories. The missing data was estimated following the manual developed by environmental protection agencies in developed countries based on their emission factors (such as USEPA and Environment Australia). Source profiles of concerned emission sources were based on other studies. The health concern concentrations at ground level were based on the standards and guidelines set by international agencies such as WHO, USEPA, etc.

1.6 Definitions of Terms in this Research

Point sources are sources that emitted combustion products or treated gases generated by industrial activities through stacks, chimneys, flares or vents.

Area sources are all sources that are not identified as point sources and emitted pollutants generated by industrial activities through leakage or evaporation including fugitive emissions. Examples of these sources are process fugitives, waste treatment plant, valve & fitting leakage, leakage from distributions and storage of petroleum products i.e tank farms.

Line Sources (Mobile Sources) include all moving sources that emitted air pollutants such as automobiles, trucks, trains, aircraft and ships.

Hazardous Air Pollutants, used interchangeably with “Air Toxics”, is a term used to describe gaseous, aerosol or particulate contaminants present in the ambient air in trace amounts with toxicity and persistence so as to be a hazard to human health, plant and animal life.

Volatile Organic Compounds (VOCs) are organic compounds and encompass a very large and diverse group of carbon-containing compounds, with boiling points of between 50 ^{o}C and 260 ^{o}C.

BTEX is the aromatic group of hydrocarbons namely benzene, toluene, ethylbenzene and xylene (mixed-isomer).

Chronic Effect means the adverse effect of human health when exposed to pollutants continuously for a period of time.

Carcinogenic Substances mean the substances that cause cancer to human health.

ISCST-3 is the mathematical air model developed by USEPA.

Stability Classes are the classifications of atmosphere to indicate the possibility of movement or a vertical mixing of pollutants with surrounding air.

Mixing Height is the thickness of boundary layer adjacent to the ground and whose atmospheric properties are well mixed due to the turbulence within the layer.

Worse Case Scenario means the meteorological condition of the year that has the most frequent wind directions blow toward residential areas when compared among three consecutive years.

1.7 Expected Outcomes

1.7.1 Spatial and temporal distributions of BTEX concentrations across the study area are illustrated.

1.7.2 A valid database for BTEX emission loading in the area is developed and used effectively for proposing the maximum allowable loading of sources.

1.7.3 The results can support the setting of emission standards and the managing of hazardous air pollutants in Thailand.

1.8 Research Outline

This research has involved a field study, laboratory analysis, a factory survey, the identification of sources, the gathering of EIA and activity data concerning the factories, and finally, modeling to predict the impacts of sources on ambient air concentrations. The steps of this research are summarized in the following:

1.8.1 An emission inventory of sources: To identify potential BTEX emission loading, two source categories were examined - stationary sources, which were classified to point and area sources, and mobile sources. For stationary sources, the data from an EIA report of each factory was used for the compilation of the inventory. The missing data was estimated using activity data directly gathered from factories and multiplied by emission factors, both generic and specific, which were available in AP-42 developed by USEPA and other literatures. For mobile sources, emission rates were calculated based on vehicle kilometers traveled (VKT) and multiplied by emission factors from literatures. The speciation profiles studied by others were used to calculate the speciated emission rates.

1.8.2 Simulation of the source effects using air dispersion model: The Gaussian plume model (ISCST3) developed by USEPA was used in coupling with compiled emission data and meteorological data to simulate the ambient concentration of BTEX in the study area.

1.8.3 Measurement of field data: Two areas, one within the industrial complex and one in the adjacent community, were monitored for ground level concentrations of BTEX species. Seven sites represented both areas and upwind-downwind phenomena were selected for collecting seven consecutive day samplers. The ambient air at the selected sites was actively collected in adsorption tubes via calibrated personal pumps. Those samples were brought back to the laboratory to be analyzed. The trapped BTEX were extracted by carbon disulfide (CS_2) and quantified individual species by GC/FID. Air samples were collected during dry, semi-wet and wet periods that resulted in 151 samples being collected.

1.8.4 Data analysis: The field and simulated data were analyzed to find their relationships by statistical parameters. The coefficient of correlation and determination were used to define the relationship of measured data and predicted data.

1.8.5 Assessing maximum emission rates: The health concern concentrations at ground level were identified based on the literature or from guidelines and standards from other developed countries and institutes' publications. The obtained concentrations were used as maximum ground levels at receptor sites. The emission rates of each source type were individually simulated in the worse case scenario of annual meteorological data to define the contributions of each source on ambient concentrations. If it was higher than the health concern concentration, it was rolled back to identify maximum allowable emission rates of the sources.

CHAPTER 2

LITERATURES REVIEW

2.1 Map Ta Phut Industrial Estate and Its Air Basin

Map Ta Phut Industrial Estate is the largest industrial estate in Thailand, located on the eastern seaboard region about 200 kilometers southeast of Bangkok, 12° 30’ N and 101° 35’ E, in Muang District, Rayong Province (Figure 2.1). It was established in 1984 and initially consisted of four major categories of industry namely gas separation plants, petrochemical plants, fertilizer plants and soda ash plants. Currently, the industrial area covers more than 10 square kilometers with 52 large-scale industrial plants and, out of them, 32 factories are petroleum-related industry (IEAT, 2002a). There also are other two industrial estates, Padaeng and the Eastern industrial Estate, located nearby at the southwest border of the estate, which makes for a total of 86 factories in the same subregional air basin. There is a deep-sea port within the estate and a major road, Sukhumvit road that passes close to the estate. This is the main road to the eastern part of Thailand, a very popular tourist area. The estate is located next to the seashore and is surrounded by existing dwellings. The important communities, clockwise from shore, are Nong Fab (southwest of the estate), Mapchalut (to northwest), Wat Sophon Wanaram (to the north-northeast) and Takuan-Ao Pradoo (to the East). During a monsoon period (March-September), summer and rainy season, winds blow from south-southwest to north-northeast, which carry pollutants from the estate to the downwind areas. As a result, complaints are always made by the affected communities such as Map Ta Phut Phan Wittayakarn School, Wat Sophon Wanaram and so on. In a winter during November to February, the affected site is the south or southeast areas such as Takuan-Ao Pradoo (DIW, 2001).

The Thai Meteorological Department has been recording wind direction for the past 30 years, showed in Figure 2.2. It is clearly showed that the typical wind direction blows from the south during January to April, from southwest during May to October and from northeast during November to December. Wind speed was typically less than 6.2 m/s.

Figure 2.1: Location of Map Ta Phut Industrial Estate

Source: Industrial Estate Authority of Thailand (Map Ta Phut Office), 2003.

As its definition, an air basin pertains to a large region that shares a common geographical area of sources and atmospheric conditions. The boundaries of an air basin are usually determined by mountains, large hill and bodies of water. In general, air quality depends on the total emissions of primary pollutants and the generation of secondary pollutants throughout the basin. A spatial and temporal variation in regional air quality always occur as a result of spatial distribution of sources, meteorology and topography in a given air basin. For example, while a prevailing wind from the ocean may maintain a good quality of air in communities adjoining the water, it also simultaneously transports primary pollutants from the shore to inland communities and provides times for secondary pollutants to form. Subregional air quality pertains to the air quality prevailing in subregional air basin, which encompasses a number of communities that share a uniform quality of air. The uniformity of air quality is also based on topographical features of the area, distribution of sources and meteorological. In this case, thus, sub-regional air basin covers coastal area around the city of Rayong Province including its east, north and west part. The minimum scale of air pollution is the local problem, in which a source and receptor are in close proximity. Controlling the identified source will reduce its adverse effects on the receptor (Boubel et al., 1984). Since Map Ta Phut area is surrounded by a body of water in the south, mountain in the north and west and mountain-hill in northeast, This area can be defined as local air basin under coastal conditions. Figure 2.3 showed the terrain of the study area with plume from petrochemical plant as a background.

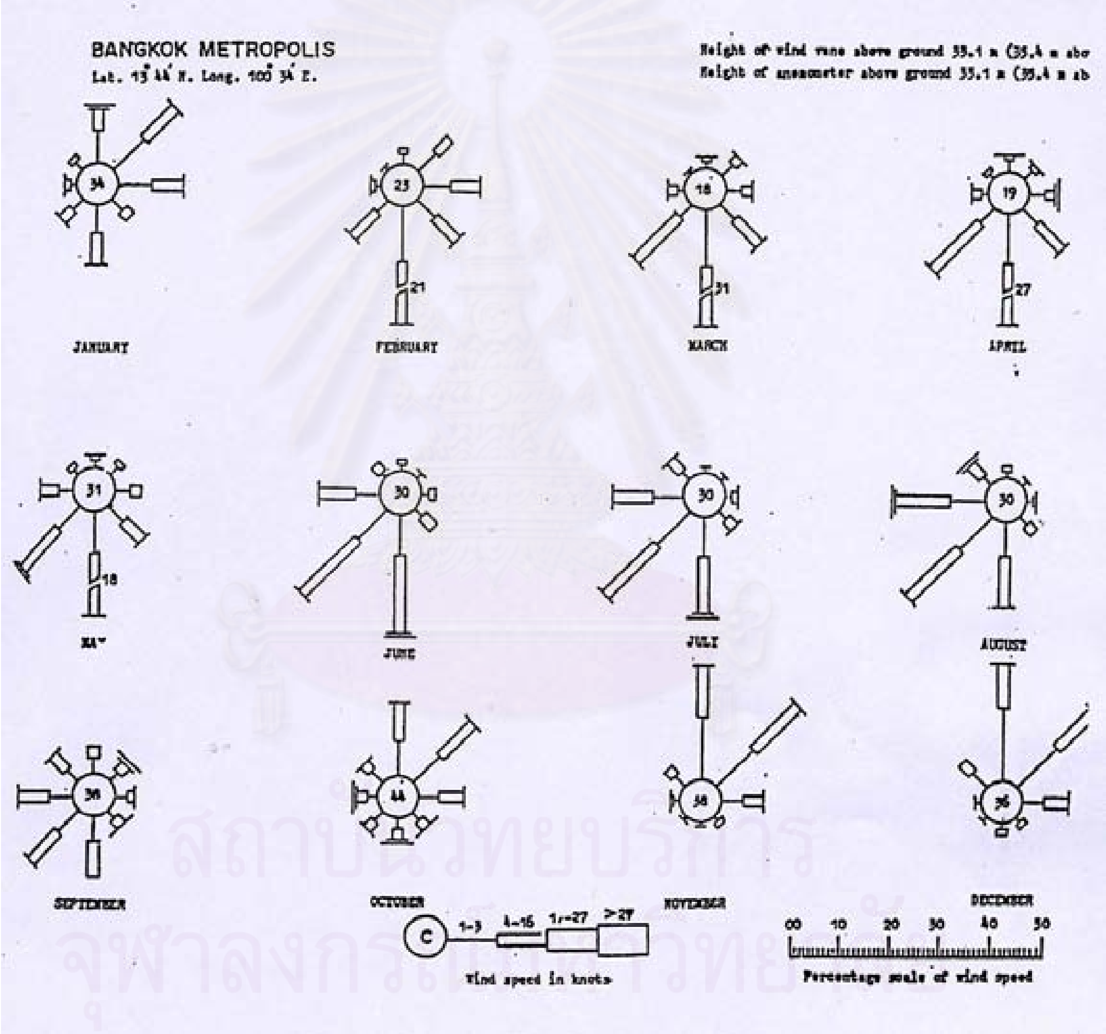


Figure 2.2: Wind direction in past 30 years in Thailand

Source: M.D, 1994a.

Figure 2.3: Study area with plume from petrochemical plant as a background

2.2 Mathematical Air Modeling

The scientific basis for making estimates of pollutant concentrations at down-wind locations has its roots in theoretical expressions of dispersion and theoretical work conducted in 1960s. Through the careful application of modern air quality models, estimates of the impact of the release of air contaminants can provide useful information when questions are raised and discussions are required relative to those impacts. Air quality models are widely regarded as capable of providing conservative estimates. As a general rule, model impacts are more accurate for the following: longer averaging periods, sources with well-defined emissions and release characteristics, and receptor areas that do not experience steep concentration gradients. The validity of air quality model depends on the quality of input data. Sources parameters must be carefully evaluated and specified as accurately as possible. Contaminant emission rates that are grossly underestimated will produce modeled impacts that are also grossly underestimated. Since the estimation of emissions is often uncertain, these uncertainties should also be taken into account when reviewing and taking action based on model predictions. In some circumstances, air quality monitoring, having better inherent credit, can be used to verify model predictions. Impacts of air pollution can frequently be established by a combined approach of using models to predict and installing carefully sited monitors to verify (LaGrega et al., 2001).

There are two types of model currently used, receptor and dispersion model. Receptor model (Watson et al., 2001), such as Chemical Mass Balance (CMB) and Multivariate Method, is extensively developed and used in accompany with Factor Analysis or Principle Component Analysis to determine contribution of each source on ambient concentration, source apportionment. But, it can not be used to predict effects of source emission on ambient air quality in the future, While dispersion model is widely used to simulate the effect of sources on receptor locations (Seinfield, 1988; Fraser et al., 1996, Jiang et al., 1997; Toll and Baldasano, 2000).

2.2.1. The Gaussian Dispersion Model

A Gaussian plume model is the solution of the Fickian diffusion equation in which pollutants are emitted continuously at a constant flow rate. The plume diffuse in y and z-directions and transport by convection of wind speed, u, in a x-direction. The diffusion and transport mechanism are in a steady state and diffusion in the x-direction is negligible when compared to transport by wind speed. The wind speed is also assumed stable at all locations in each direction. Mass diffusivity, Dx, Dy and Dz remains unchanged in each direction and set x=0 at stack height H. Solving Fickian's equation for all mentioned conditions yield:

$$C = Kx^{-1} \exp [-\{y^2/D_y + z^2/D_z\} u/4x] \qquad (2.10)$$

Where K is a constant and depends on meteorological conditions and stacks' properties.

Case 1. Point source at ground level; $K = Q/ 2 \pi(D_yD_z)^{1/2}$ (2.11)

Where Q is an emission rate of a source in mass/time called source strength. Then, the equation become to:

$$C (x,y,z) = [Q/ 2\pi x(D_yD_z)^{1/2}]\exp [-\{y^2/D_y + z^2/D_z\} u/4x] \qquad (2.13)$$

It illustrates the same characteristics as a Double Gaussian Distribution equation, which should yield a maximum concentration at ground level of a centerline. The phenomenon makes the u_y and u_z equal to zero, and the equation becomes:

$$F (y,z) = [1/2\pi x(D_yD_z)^{1/2}] \exp [-\{y^2/2\sigma_z^2+ z^2/2\sigma_y^2\}]$$

$$\text{If } \sigma_y^2= 2 D_yx/u \text{ and } \sigma_z^2= 2 D_zx/u$$

$$\text{Then, } C (x,y,z) = [Q/\pi u\sigma_y\sigma_z] \exp [-\{y^2/2\sigma_y^2+ z^2/2\sigma_z^2\}] \qquad (2.14)$$

The unit of concentration, C, depends on unit of Q, u, σ_y and σ_z. If assumed y and z =0, that means the ground level concentration on the center line of plume is equal to:

$$C\ (x,0,0) = Q/\pi u\sigma_y\sigma_z \qquad (2.15)$$

Case 2: Point source at elevation above ground with reflection

For elevated source, K in equation 2.11 remains half and Z is equal to z-H. If there is no reflection from the ground the equation becomes:

$$C(x,y,z) = [Q/2\pi u\sigma_y\sigma_z]\ \exp\ [\ -\{y^2/2\sigma_y^2 + (z\text{-}H)^2/2\sigma_z^2\}] \qquad (2.16)$$

But, at z=0, the other condition, earth surface reflects all pollutants back to the atmosphere, is set. Then, at any point after the plume touch the ground, the reflection plume makes up the concentration, shown in Figure 2.4, which make a general equation of Gaussian dispersion model to be:

$$C(x,y,z) = [Q/2\pi u\sigma_y\sigma_z]\ \exp[\ -\{y^2/2\sigma_y^2]\ \{\exp[\ (z\text{-}H)^2/2\sigma_z^2] + \exp[\ (z+H)^2/2\sigma_z^2]\} \qquad (2.17)$$

And, ground level concentration the equation becomes:

$$C(x,y,0) = [Q/\pi u\sigma_y\sigma_z]\ \exp\ [\ -\{y^2/2\sigma_y^2]\{\ \exp[\ (\text{-}H)^2/2\sigma_z^2] \qquad (2.19)$$

Or, for ground level concentration at center line, the equation becomes:

$$C(x,y,0) = [Q/\pi u\sigma_y\sigma_z]\ \exp[\ (\text{-}H)^2/2\sigma_z^2] \qquad (2.20)$$

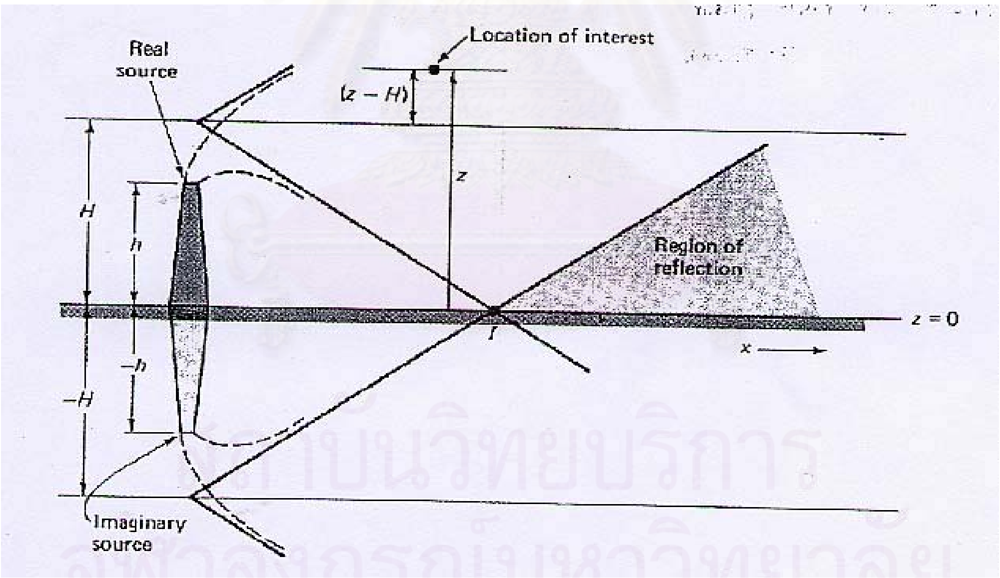


Figure 2.4: Mirror image of source

Source: Suadee, 1999.

Normally, the concentration in vertical a direction explicit normal distribution starting from He, effective stack height, and the downwind concentration reaches the maximum at x and then, gradually decrease to reach zero. In the lateral direction, y, the plume shows the same characteristics but different shape due to difference of σ_y and σ_z. Figure 2.5 showed distribution of plume in each direction.

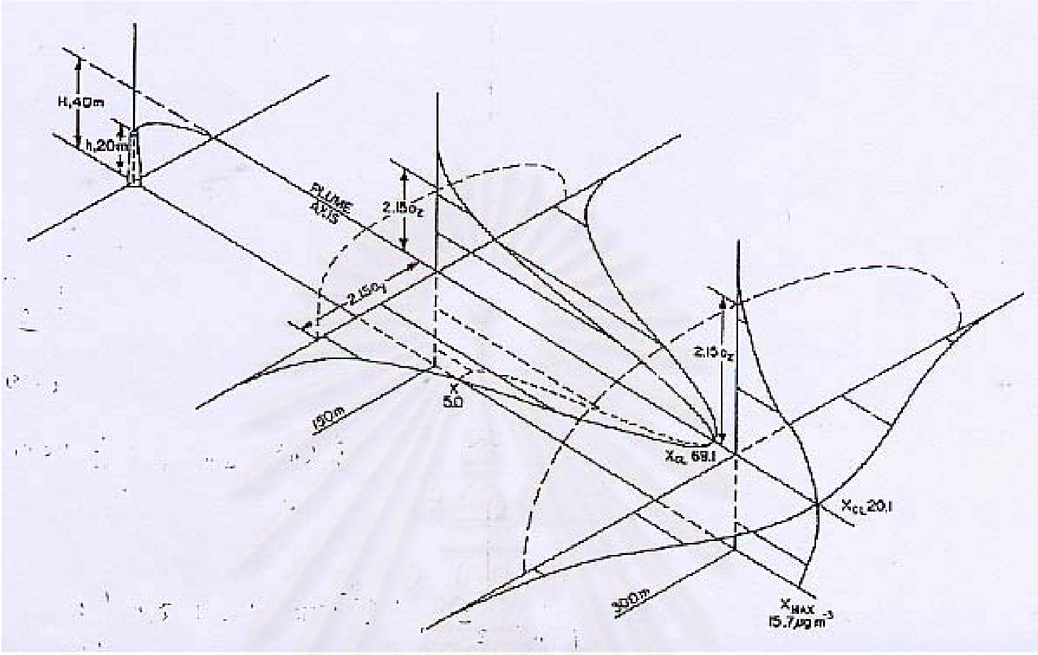


Figure 2.5: Normal distribution of plume in each direction

Source: Boubel et al., 1994.

2.2.2 Evaluation of Standard Deviation

The standard deviation, σ_y and σ_z, is a function of diffusion coefficient on wind speed, plume location and also stability classes. Turner had done the experiment in 1970, as shown in Figure 2.6, to set up the relationship of σ_y and σ_z with stability, which depends on the following conditions:

1. The relation applied for at least 10-minute sampling of pollutant concentration.
2. There is no obstruction of turbulence in both y and z-direction
3. The reliability of the relation is high at the location far away from source more than 200-300 meters

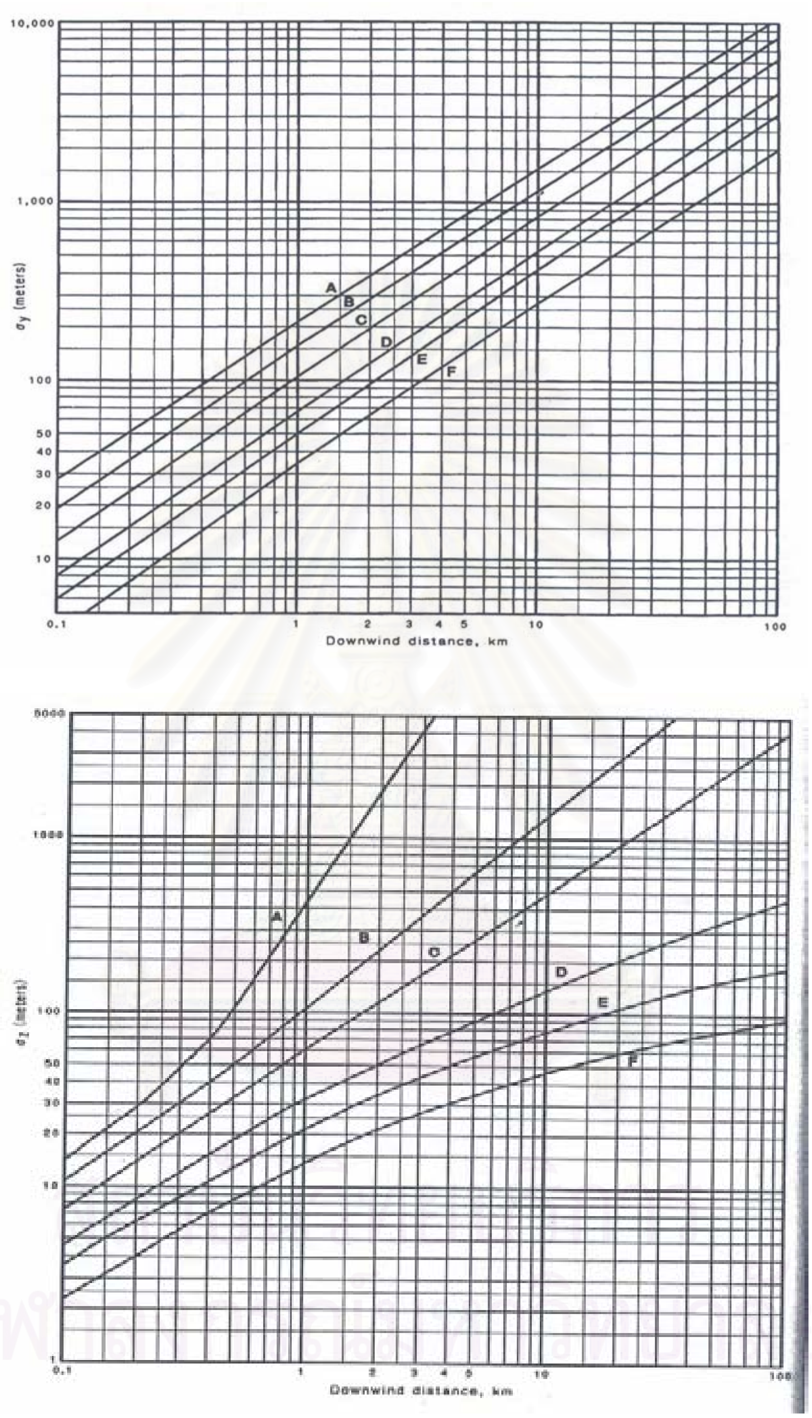


Figure 2.6 relationship of σ_y and σ_z with stability classes

Source: Boubel et al., 1994.

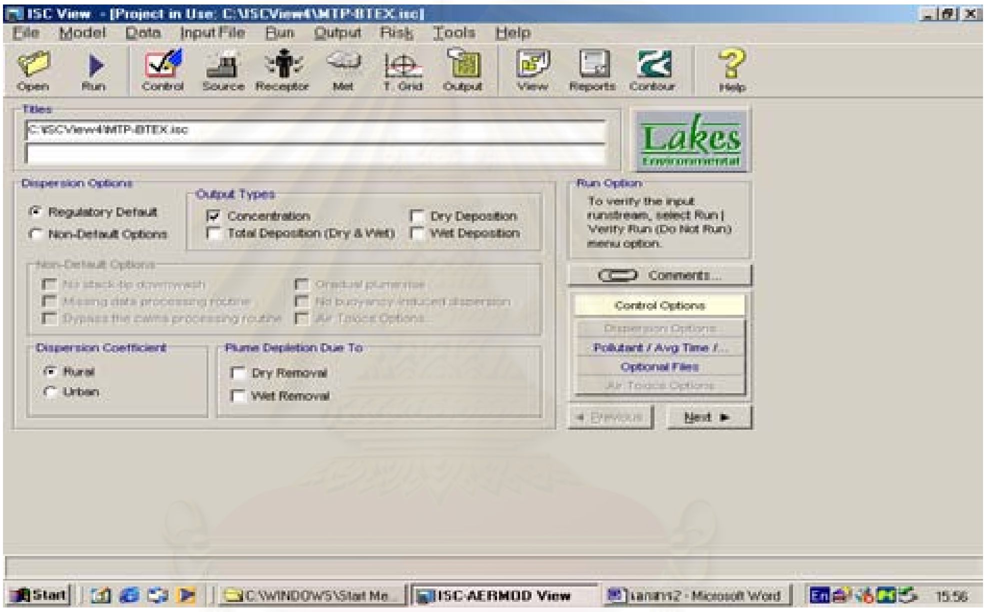
2.2.3 Industrial Source Complex- Short Term (ISCST-3) Model (Schnelle and Dey, 1999; USEPA, 1995c and USEPA, 1995d)

The industrial source complex (ISC) model is a steady-state bi-Gaussian plume most frequently used to assess downwind pollutant concentrations from a wide variety of sources such as chemical and petroleum processing plants. The ISC model has two forms differentiated by the averaging time to be used: ISC short-term (ISCST) and ISC long-term (ISCLT) models. The components of these model include: the bi-Gaussian formula with reflection from the ground and the elevated dispersion ceiling, the dispersion parameter formulas derived from the Pasquill-Gifford and McElroy-Pooler data, the plume rise formula of Briggs, and the wind speed power law correction formula. The manual for the ISC model, 1995 USEPA Volume I and II, are available on the internet through the Support Center for Regulatory Air Model (SCRAM): http://www.epa.gov/scram001/. In this research, interface for ISC-AERMOD View, Version 4.03 developed by © 1996-2001 Lakes Environmental Software was employed.

The industrial source complex short-term (ISCST) model provides options to model emissions from a wide range of sources that might be present at a typical industrial source complex. The basis of the model is the straight-line, steady-state Gaussian plume equation, which is used with some modification to model simple point source emissions from stacks, emission from stacks that experience the effects of aerodynamic downwash due to nearby buildings, isolated vents, multiple vents, storage piles, conveyor belts, and the link. Emission sources are categorized into four basic types of sources, i.e., point sources, volume sources, area sources, and open pit sources. The volume source option and the area source option may also be used to simulate the line sources. The algorithms used to model each of these source types are described in detail in volume II of the U.S.EPA User Guide (1995). The ISCST model accepts hourly meteorological data records to define the conditions for plume rise, transport, diffusion and deposition. The model estimates the concentration or deposition value for each source and receptor combination for each hour of input meteorology, and calculates user-selected short-term averages. The user also has the option of selecting averages for the entire period of input meteorology.

<u>Basic Input Data Requirement</u>. There are two basic types of inputs that are needed to run the ISC models. They are: (1) the input run-stream files and (2) the meteorological

data files. The run stream setup files contain the selected model options, as well as source location and parameter data, receptor locations, meteorological specifications, and output options. The ISC models offer various options for file formats of the meteorological data. A third type of input may also be used by the models when implementing the dry deposition and depletion algorithm. The user may optionally specify a file of gridded terrain elevations that are used to integrate the amount of plume material that has been depleted through dry deposition processes along the path of plume from the source to receptor. The user also has the option of specifying a separate file of hourly emission rates for the ISCST model. The window of control option is shown in Figure 2.7.



ISC View - [Project in Use: C:\ISCView4\MTP-BTEX.isc]

Titles: C:\ISCView4\MTP-BTEX.isc

Dispersion Options
● Regulatory Default
○ Non-Default Options

Output Types
☑ Concentration
☐ Total Deposition (Dry & Wet)
☐ Dry Deposition
☐ Wet Deposition

Non-Default Options
☐ No stack-tip downwash
☐ Missing data processing routine
☐ Bypass the calms processing routine
☐ Gradual plume rise
☐ No buoyancy-induced dispersion
☐ Air Toxics Options

Dispersion Coefficient
● Rural
○ Urban

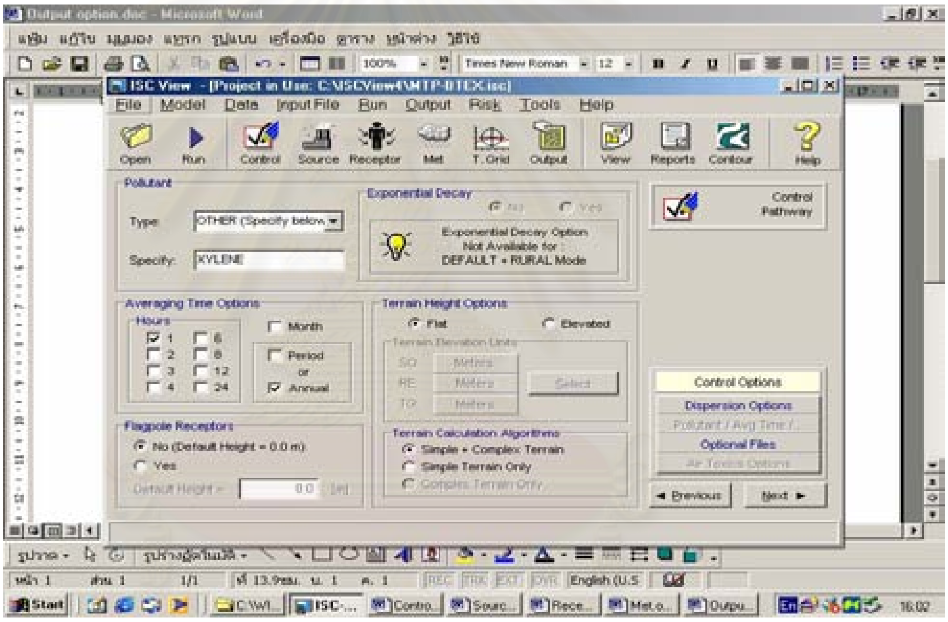
Plume Depletion Due To
☐ Dry Removal
☐ Wet Removal

Run Option
To verify the input runstream, select Run | Verify Run (Do Not Run) menu option.

Figure 2.7: Control options of ISCST3

<u>Dispersion option</u>. Since the ISC models are especially designed to support the USEPA's regulatory modeling programs, the regulatory modeling options, as specified in the "Guideline on Air Quality Models (Revised)", are the default mode of operation for the models. These option include the use of stack-tip downwash, buoyancy-induced dispersion, final plume rise (except for sources with building downwash), a routine for processing averages when calm winds occur, and default values for wind profile components and for the vertical potential temperature gradients. The user has the option of specifying only simple terrain calculations, only complex terrain calculations, or of using both simple and complex terrain algorithms. In the latter case, the model will select the

higher of the simple and complex-terrain calculations on an hour-by-hour, source-by-source, and receptor-by-receptor basis for receptors in intermediate terrain, i.e., terrain between release height and plume height. The user may select either rural or urban dispersion parameters, depending on the characteristics of source location. The user also has the option of calculating concentration values or deposition values for a particular run. For the short-term model, the user may select more than one output type (concentration and/or deposition) in a single run, depending on the setting for one of the array storage limits. The user can specify several short-term averages to be calculated in a single run of the ISCST model, as well as requesting the overall period (e.g. annual) averages. The window dispersion option is shown in Figure 2.8.



Pollutant
Type: OTHER (Specify below)
Specify: XYLENE

Exponential Decay ● No ○ Yes
Exponential Decay Option Not Available for DEFAULT + RURAL Mode

Averaging Time Options
Hours ☑ 1 ☐ 2 ☐ 3 ☐ 4 ☐ 6 ☐ 8 ☐ 12 ☐ 24
☐ Month
☐ Period or ☑ Annual

Terrain Height Options ● Flat ○ Elevated
Terrain Elevation Units
SO Meters
RE Meters
TG Meters

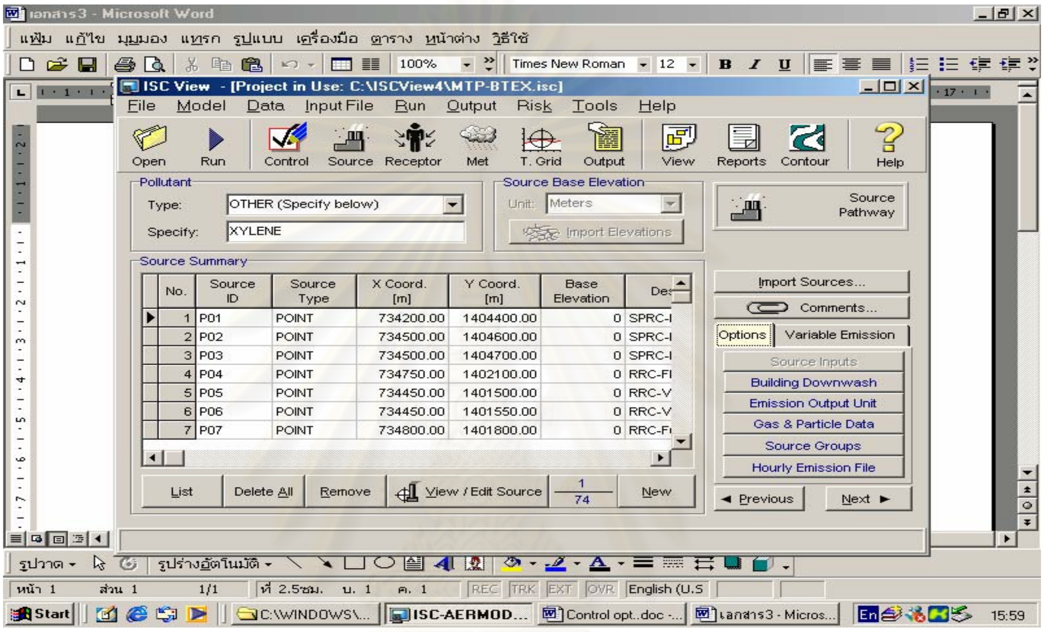
Flagpole Receptors
● No (Default Height = 0.0 m)
○ Yes
Default Height = 0.0 (m)

Terrain Calculation Algorithms
● Simple + Complex Terrain
○ Simple Terrain Only
○ Complex Terrain Only

Figure 2.8: dispersion options of ISCST3

<u>Source Options</u>. The model is capable of handling multiple sources, including point, volume, area, and open-pit source types. Line sources may also be modeled as a string of volume sources or as elongated area sources. Several source groups may be specified in a single run, with the source contributions combined for each group. This is particularly useful for Prevention of Significant Deterioration (PSD) applications when combined impacts may be needed for a subset of the modeled background sources that consume increment, while the combined impacts from all background sources (and the permitted source) are needed to demonstrate compliance with air quality standards.

Source emission rates can be treated as constant throughout the modeling period, or can be varied by month, season, hour of day, or other optional periods of variation. These variation emission rate factors can be specified for a single source or for a group of sources. For the short-term model, the user may also specify a separate file of hourly emission rates for some or all of the sources included in a particular model run. The window for source option of the model is shown in Fig. 2.9.



Pollutant

Type: OTHER (Specify below)

Specify: XYLENE

Source Base Elevation

Unit: Meters

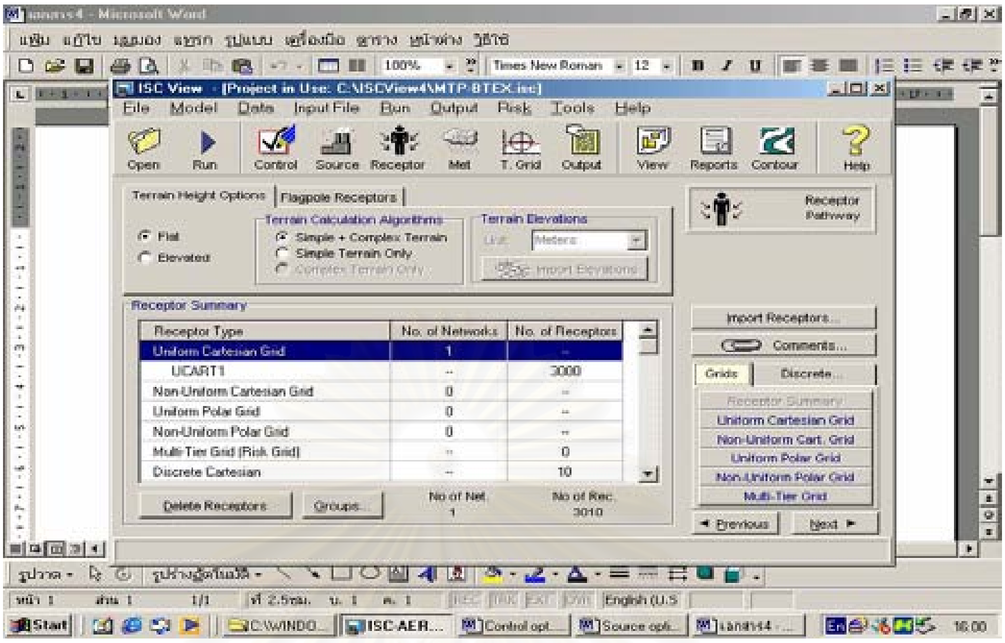
Source Summary

No.	Source ID	Source Type	X Coord. [m]	Y Coord. [m]	Base Elevation	Des
1	P01	POINT	734200.00	1404400.00	0	SPRC-I
2	P02	POINT	734500.00	1404600.00	0	SPRC-I
3	P03	POINT	734500.00	1404700.00	0	SPRC-I
4	P04	POINT	734750.00	1402100.00	0	RRC-FI
5	P05	POINT	734450.00	1401500.00	0	RRC-V
6	P06	POINT	734450.00	1401550.00	0	RRC-V
7	P07	POINT	734800.00	1401800.00	0	RRC-Fı

1/74

Figure 2.9: source options of ISCST3

Receptor Options. The ISC models have considerable flexibility in the specification of receptor locations. The user has the capability of specifying multiple receptor networks in a single run, and may also mix Cartesian grid-receptor networks and polar grid-receptor networks in the same run. This is useful for applications where the user may need a coarse grid over the whole modeling domain, but a denser grid in the area of maximum expected impacts. There is also flexibility in specifying the location of the origin for polar receptors, other than the default origin at (0,0) in x, y, coordinates. The window for receptor option of the model is shown in Fig. 2.10.



● Flat
○ Elevated

Terrain Calculation Algorithms
● Simple + Complex Terrain
○ Simple Terrain Only
○ Complex Terrain Only

Terrain Elevations
Unit: Meters

Receptor Summary

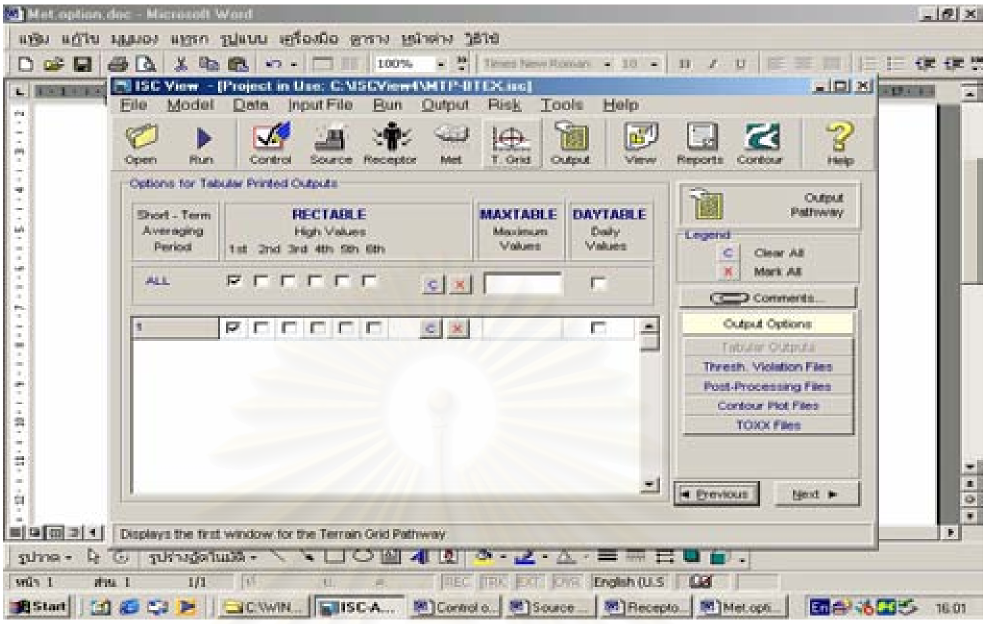
Receptor Type	No. of Networks	No. of Receptors
Uniform Cartesian Grid	1	--
UCART1	--	3000
Non-Uniform Cartesian Grid	0	--
Uniform Polar Grid	0	--
Non-Uniform Polar Grid	0	--
Multi-Tier Grid (Risk Grid)	--	0
Discrete Cartesian	--	10

No of Net. 1
No of Rec. 3010

Figure 2.10: Receptor options of ISCST3

Meteorology Options. The short-term model can utilize the unformatted, sequential files of meteorological data generated from preprocessors, provided the data file was generated by the same Fortran compiler as was used for the model and provided the deposition algorithms are not being used. The user also has considerable flexibility to utilize formatted ASCII files that contain sequential hourly records of meteorological variables. For these hourly ASCII files, the user may choose a default ASCII format, may specify the ASCII read format, or may select free-formatted reads for inputting the meteorological data. A utility program is provided with the ISC models to convert unformatted meteorological data files of several types to the default ASCII format used by ISCST. This greatly improves the portability of applications to different computer systems. The model will process all available meteorological data in the specified input file by default, but the user can easily specify selected days or ranges of days to process. The window for meteorological option of the model is shown in Fig. 2.11.

Output options. The basic types of printed output available with the short-term model are: (1) Summaries of high values (highest, second highest, etc.) by receptor for each averaging period and source group combination, (2) Summaries of overall maximum values (e.g., the maximum 50) for each averaging period and source group combination, and (3) The table of concurrent values summarized by receptor for each averaging period and source group combination for each day of data processed. The window for output option of the model is shown in Fig. 2.12.

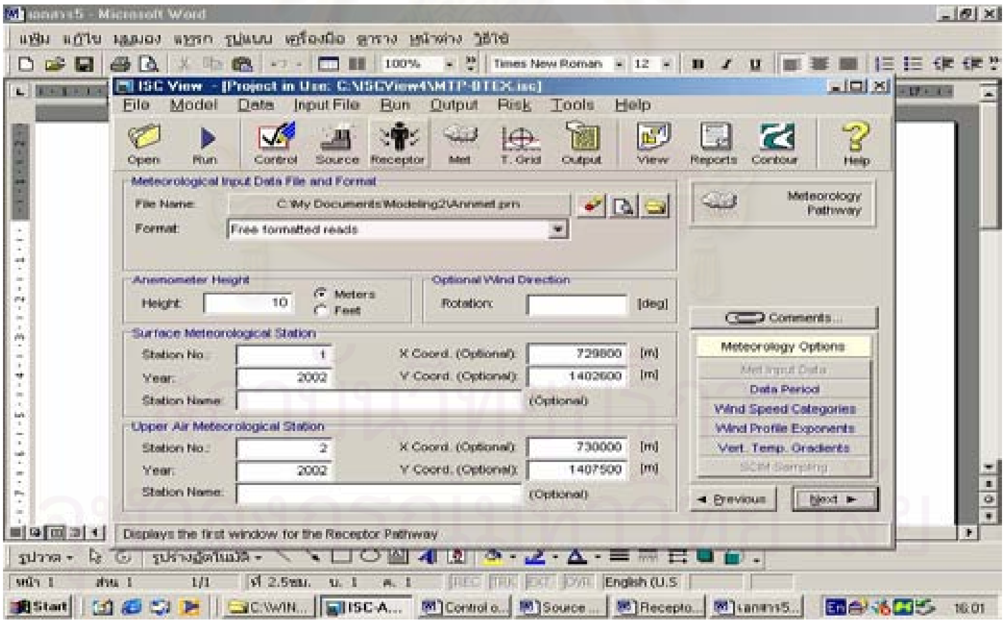

ISC View - [Project in Use: C:\ISCView4\MTP-BTEX.isc]

Options for Tabular Printed Outputs

Short - Term Averaging Period	RECTABLE High Values 1st	2nd	3rd	4th	5th	6th	MAXTABLE Maximum Values	DAYTABLE Daily Values
ALL	☑	☐	☐	☐	☐	☐		☐
1	☑	☐	☐	☐	☐	☐		☐

Displays the first window for the Terrain Grid Pathway

Figure 2.11: Meteorological options of ISCST3


ISC View - [Project in Use: C:\ISCView4\MTP-BTEX.isc]

Meteorological Input Data File and Format

File Name: C:\My Documents\Modeling2\Annmet.prn

Format: Free formatted reads

Anemometer Height

Height: 10 ● Meters ○ Feet

Optional Wind Direction

Rotation: [deg]

Surface Meteorological Station

Station No.: 1 X Coord. (Optional): 729800 [m]

Year: 2002 Y Coord. (Optional): 1402600 [m]

Station Name: (Optional)

Upper Air Meteorological Station

Station No.: 2 X Coord. (Optional): 730000 [m]

Year: 2002 Y Coord. (Optional): 1407500 [m]

Station Name: (Optional)

Displays the first window for the Receptor Pathway

Figure 2.12: Output options of ISCST3

2.3 BTEX Group of Aromatic Hydrocarbon

2.3.1 Properties and Environmental Fate of BTEX

BTEX, a group of aromatic hydrocarbons, is generated mainly from anthropogenic sources, point, area and mobile sources. These hydrocarbons are used extensively as solvents and raw materials in a petrochemical industry as well as a fuel for automobiles. BTEX released into the atmosphere are transported by the wind and dispersed as a function of many variables, including the characteristics of the atmosphere, of the surrounding terrain, and of the source of release. Concerns regarding BTEX released focus not only on the quantity of material that becomes airborne, but more importantly on the concentration of the BTEX when it reaches down wind receptors. In developed countries, health related, concentration based air quality standards have been established for many contaminants, and it is frequently of interest whether contaminants released will exceed applicable standards for working places and residential areas.

The characteristics, potential sources, hazard and environmental fate of BTEX can be summarized as the following (USEPA, 1995b and Sax et al., 1998):

2.3.2.1 Benzene; CAS: 71-43-2. C_6H_6

Benzene is a colorless to light-yellow, mobile, non-polar liquid of a highly refractive nature. It has an aromatic odor and its vapor burns with smoky flame. It has an auto-ignition temperature of 1044°F (562°C). It is also miscible with alcohol, ether, acetone, carbon tetrachloride, carbon disulfide, and acetic acid and is slightly soluble in water.

Benzene can be derived from many sources such as (a) a hydro-dealkylation of toluene or pyrolysis of gasoline, (b) a transalkylation of toluene by disproportionation reaction, (c) catalytic reforming of petroleum and (d) fractional distillation of coal tar. It can be used for manufacturing ethylbenzene (for styrene monomer), dodecylbenzene (for detergents), cyclohexane (for nylon), phenol, nitrobenzene (for aniline), malenic anhydride, chlorobenzene, diphenyl, benzene hexachloride and benzene-sulfonic acid and as a solvent.

2.3.2.2 Toluene: methylbenzene; phenylmethane. CAS: 108-88-3. $C_6H_5\,CH_3$

Toluene is a colorless liquid and benzene-like odor. Its auto-ignition temperature is 997 °F (536 °C). It is also soluble in alcohol, benzene and ether, but insoluble in water.

Toluene can be derived through catalytic reforming of petroleum and a fractional distillation of coal-tar light oil. It is used for aviation gasoline and its high-octane blending stock, benzene, phenol, and caprolactam. It is used as a solvent for paints and coatings, gums, resins, most oils, rubber, and vinyl organosols and as diluent and thinner in nitrocellulose lacquers. It is also used as an adhesive solvent in plastic toys and model airplanes or chemicals (benzoic acid, benzyl and benzoyl derivatives, sacharin, medicines, dyes, perfumes), and even as source of toluenedi-isocyanates (polyurethane resins), explosives (TNT), toluene sulfonates (detergents), and scintillation counters.

2.3.2.3 Ethylbenzene: Phenylethane. CAS: 100-41-4. C_6H_5 C_2H_5

Ethylbenzene is a colorless liquid, an aromatic odor. Its vapor is heavier than the air with its auto-ignition temperature at 810°F (432°C). It is soluble in alcohol, benzene, carbon tetrachloride, and ether, but almost insoluble in water.

Ethylbenzene can be derived through heating benzene and ethylene in the presence of aluminum chloride with subsequent distillation, and by fractionation directly from the mixed xylene stream in petroleum refining. It is used as the intermediate in production of styrene and as a solvent.

2.3.2.4 Xylene: Dimethylbenzene. CAS: 1330-20-7. C_6H_4 $(CH_3)_2$

A commercial mixture of the three isomers, o-, m-, and p-xylene, of which the last two are predominate. It is a clear liquid, soluble in alcohol and ether, and insoluble in water. Xylene can be derived through a fractional distillation from petroleum (90%), coal tar or coal gas, or by catalytic reforming from petroleum, followed by a separation of p-xylene by continuous crystallization and from toluene by transalkylation. It is used for aviation gasoline, synthesis of organic chemicals, and as a protective coating, solvent for alkyd resins, lacquers, enamels, and rubber cements.

The environmental fate of benzene is that it is broken down through reacting with chemical ions in the air, this process is greatly accelerated in the presence of other air pollutants such as nitrogen oxide or sulfur dioxide. Benzene is fairly soluble in water and is removed from the atmosphere in rain. As a volatile compounds, mainly released through fugitive emissions, benzene, toluene, and xylene in the lower atmosphere will react with other atmospheric components, contributing to the formation of ground level ozone and other air pollutants, which can contribute to respiratory illness in both the general and susceptible populations. Table 2.1 shows basic characteristics of BTEX.

Atmospheric oxidant production:

1. $NO + VOC \longrightarrow NO_2$ (nitrogen dioxide)
2. $NO_2 + UV \longrightarrow NO + O$ (nitrogen oxide + atomic oxygen)
3. $O + O_2 \longrightarrow O_3$ (ozone)
4. $NO_2 + VOC \longrightarrow$ PAN, etc. (peroxy-acetyl nitrate)

Net result: $NO + VOC + O_2 + UV \longrightarrow O_3$, PAN, and other oxidants

Table 2.1: Benzene-series hydrocarbon

Name	Formula	Mp. °C	Bp. °C	Sp.Gr. °20/°4	Rate Coefficient* $K_{oH} \times 10^{12}$
Benzene	C_6H_6	5.51	80.09	0.879	1.23
Toluene	$C_6H_5\,CH_3$	-95	110.8	0.866	5.96
Ethylbenzene	$C_6H_5\,C_2H_5$	-93.9	136.15	0.867	7.1
O-Xylene	$C_6H_4\,(CH_3)_2$	-29	144	0.875	13.7
M-Xylene		-53.6	138.8	0.864	23.6
P-Xylene		13.2	138.5	0.861	14.3

Source: Sawyer et al., 1994.

* Reaction rate coefficient with hydroxyl radical at 298 °K (Atkinson, 1990)

2.3.2 Health Benchmark of BTEX (Chun and Pratt, 2001)

Most health benchmark values are translated from controlled exposures in laboratory animals at high levels to exposures of human in the environment at much lower levels. The approach is highly conservative. Therefore, inherent uncertainties are associated with these health benchmarks. They tend to overstate pollutant's toxicity.

There are a wide variety of health effects. The level of concern for some end points, such as cancer and the human development system, may be much higher than eye irritation and nasal effect. Physical-chemical characteristics of pollutants can often provide an understanding of the potential for specific emissions to impact human health. These characteristics include chemical half-life, reactivity, solubility, Henry's law constant, hydrophobicity, bioaccumulation potential, and particle size. For this research, these attributes were not considered in the determination of health criteria. Ecological health benchmarks were also not included. In order to account for the toxicity of BTEX, three types of inhalation health benchmark were used: for cancer, for acute effects, and for chronic effects.

The health benchmarks for cancer represent the concentrations that are associated with an upper-bound excess lifetime cancer risk of 1 in 100,000. The health benchmarks for acute and chronic effects represent the exposure concentrations that do not cause significant risk of harmful effects for the specified length of exposure (i.e., one hour and more than one year, respectively). The Health benchmarks, as shown in Table 2.2, were obtained from the following hierarchy of information sources:

Table 2.2: Health benchmarks for cancer, acute, and chronic effects.

Pollutants Name	CAS No.	Acute $\mu g/m^3$	Acute data source	Acute End-point	Chronic $\mu g/m^3$	Chronic Data source	Chronic Endpoint	Cancer $\mu g/m^3$	Cancer Data source
Benzene	71432	1.0E+03	HRV	Develop-mental	6.0E+01	Cal EPA	Hemato-poietic	1.0E+00	HRV
Toluene	108883	3.7E+04	HRV	Central nervous	4.0E+02	HRV	Central nervous		
Ethyl-benzene	100414	1.0E+04	HRV	Develop-mental	1.0E+03	IRIS	Develop-mental		
Xylene	1330207	2.2E+04	HRV	Eye and respiratory	7.0E+02	Cal EPA	Central nervous		

Source: adapted from Table 1, (Chun and Pratt, 2001).

(1) Draft Minnesota Health Risk Values (HRV) from Minnesota Department of Health.

(2) Integrated Risk Information System (IRIS) from EPA.

(3) California Environmental Protection Agency, Office of Environmental Health Hazard Assessment (Cal EPA-OEHHA)

(4) Health Effects Assessment Summary Tables (HEAST) from EPA's Office of Solid Waste and Emergency Response and

(5) Other case-by-case toxicity values

2.4 Major Sources of BTEX in the Study Area

2.4.1 Stationary Sources

2.4.1.1 Petroleum Refinery (USEPA, 1995a and USEPA, 1995b)

The petroleum refining industry converts crude oil into more than 2500 refined products, including liquefied petroleum gas, gasoline, kerosene, aviation fuel, diesel fuel, fuel oils, lubricating oils, and feed stocks for the petrochemical industry. Petroleum refinery activities start with receipt of crude for storage at the refinery, including all petroleum handling and refining operations, and they terminate with storage preparatory to shipping the refined products from the refinery. The refineries in the study area with their annual products are listed in Table 2.3 (PTIT, 2000).

The petroleum refining industry employs a wide variety of processes. A refinery's processing flow scheme is largely determined by the composition of the crude oil feed stock and the chosen slate of petroleum products. The arrangement of these processes will vary among refineries, and few, if any, employ all of these processes. Categories of general refinery processes and associated operations are listed as follows:

1. Separation Processes. The first phase in petroleum refining operations is the separation of crude oil into its major constituents using 3 petroleum separation processes namely atmospheric distillation, vacuum distillation, and light ends recovery (gas processing). Crude oil consists of a mixture of hydrocarbon compounds including paraffinic, naphthenic, and aromatic hydrocarbons with small amounts of impurities including sulfur, nitrogen, oxygen, and metals. Refinery separation processes separate these crude oil constituents into common boiling-point fractions.

2. Conversion Processes. To meet the demands for high-octane gasoline, jet fuel, and diesel fuel, components such as residual oils, fuel oils, and light ends are converted to gasolines and other light fractions. Cracking, coking, and visbreaking processes are used to break large petroleum molecules into smaller ones. Polymerization and alkylation processes are used to combine small petroleum molecules into larger ones. Isomerization and reforming processes are applied to rearrange the structure of petroleum molecules to produce higher-value molecules of a similar molecular size.

Table 2.3: Refinery Plant in Map Ta Phut area

No.	Company	Raw Materials		Capacity/Products	
		Type	Annual rate	Operation Unit	Capacity (KBSD)
1.	Star Petroleum (SPRC-north)	Crude oil		Crude Distillation	160.0
				Vacuum Distillation	62.0
				Sat.LPG Sweetening (Ext.)	6.0
				Unsat. LPG Sweetening (Ext.)	11.0
				Light Straint Run Sweetening	22.0
				Naphtha Sweetening	15.0
				Naphtha Hydrotreating	17.5
				Distillate Hydrotreating	64.9
				Heavy Gas Oil Hydrotreating	34.7
				Unsat. LPG splitting	6.0
				Platforming	17.5
				Residual Fluid Cat.Cracking	46.0
				Sulphur Recovery (T/SD)	270.0
2.	Rayong Refinery (South Facility)	Crude Oil		Crude Distillation	148.0
				High Vacuum Distillation	67.0
				LPG Recovery/Treating (T/SD)	800.0
				Naphtha Hydrotreating	52.0
				Hydro Desulfurisation	65.5
				Plaforming	28.0
				Visbreaker	24.8
				Hydro Cracking	53.0
				Hydrogen Manufacturing (T/SD)	140.0
				Adip Regeneration (T/SD)	230.0
				Sulphur Recovery (T/SD)	224.0
3.	Rayong Purifier	Condensate Reside from ATC	17.0 KBSD or 12,600 BPD or 1,604.571 T/	Naphtha (T/d)	544.6
				Kerosene (T/)	162.6
				Diesel (T/d)	646.3
				Fuel oil (T/d)	251.0

Source: PTIT FOCUS, 2000. Note: KBSD = Thousand barrels per standard day,

BPD = Barrel per day, T/d = Ton per day

3. Treating processes. Petroleum treating processes stabilize and upgrade petroleum products by separating them from less desirable products and by removing objectionable elements. Undesirable elements such as sulfur, nitrogen, and oxygen are removed by hydrodesulfurization, hydrotreating, chemical sweetening, and acid gas

removal. Treating processes, employed primarily for the separation of petroleum products, include such processes as deasphalting. Desalting is used to remove salt, minerals, grit, and water from crude oil feed stocks before refining. Asphalt blowing is used for polymerizing and stabilizing asphalt to improve its weathering characteristics.

4. Feedstock and Product Handling. The feedstock refinery and product handling operations consist of unloading, storage, blending, and loading activities.

5. Auxiliary Facilities. A wide assortment of processes and equipment not directly involved in the refining of crude oil is used in functions vital to the operation of the refinery. Examples are boilers, wastewater treatment facilities, hydrogen plants, cooling towers, and sulfur recovery units. Products from auxiliary facilities (clean water, stream, and process heat) are required by most process units throughout the refinery.

2.4.1.2 Natural gas separation plant

Natural gas from high-pressure wells is usually passed through field separators at the well to remove hydrocarbon condensate and water. Natural gasoline, butane, and propane are usually present in the gas, and gas-processing plants are required for the recovery of these liquefiable constituents. Natural gas is considered “sour” if hydrogen sulfide (H_2S) is present in amounts greater than 5.7 milligrams per normal cubic meters (5.7 mg/Nm^3). The H_2S must be removed (called “sweetening” the gas) before the gas can be utilized. If H_2S is present, the gas is usually sweetened by absorption of the H_2S in an amine solution.

The major emission sources in the natural gas processing industry are (1) compressor engines, (2) acid gas wastes, (3) fugitive emission from leaking process equipment and if present, (4) glycol dehydrator vent stream. Regeneration of the glycol solutions used for dehydrating natural gas can release significant quantities of benzene, toluene, ethylbenzene and xylene, as well as a wide range of less toxic organic.

They are 3 phases of gas separation in the area owned by the Petroleum Authority of Thailand with capacity 350, 250 and 350 MMCFD respectively (PTIT, 2000).

2.4.1.3 Petrochemical Industry

The petrochemical industry is one of twelve industrial sectors that have been targeted by the Ministry of Industry to improve their competitiveness in the world market. In

Thailand, the petrochemical industry continually expanded until the economic crisis in July 1997. Internal demand of its product was affected by around 20% and 30 petrochemical projects in the planning and concept phase were cancelled in 1998 (OIE, 2001). In 1999, it was forecast for the industrial sector that the cycle of internal demand would return in 2002 and would peak in 2004. Thus, many companies planned to expand their production capacities. Thai Olefin Company limited (TOC), mainly shared by PTT, has expanded production capacity, using separated natural gas instead of Naphtha, from 385 KTA to 700 KTA. In order to maintain their market competitiveness, Thai Petrochemical Industry (TPI) and Siam Cement group have also tried to expand production to upstream processes, while Petroleum Authority of Thailand (PTT) expands its production to downstream processes. As the result, the Board of Investments (BOI) approved 8 projects, which were concerned mainly in the production of ethylene, polypropylene (PP), polyethylene (PE), polyvinyl chloride (PVC), and purified terephthalic acid (PTA) production (OIE, 2001).

The petrochemical industry in Thailand comprises all 3 vertical stages of the industry, namely raw material production, intermediate materials and final products (PTIT, 1999). The main groups of production companies have tried to span this vertical integration of production processes to reduce their production cost. At present, separated natural gas supplied by the Petroleum Authority of Thailand (PTT) has been used as the main source for raw material both in Olefins and Aromatics processes. The conceptual idea of all 3 vertical stages of the industry can be explained as the following (TPI, 2001);

A) The Upstream Petrochemical Industry

In this stage of the industry, these factories use products from gas separation plants and refineries such as ethane, propane, condensate and naphtha as raw materials. Stream cracking or pyrolysis to reduce a size of the molecule, catalytic reforming within molecules without changing its size, and dehydrogenating from the molecule are the main processes used. In Olefin processes, the National Petrochemical Company (NPC) located in Rayong province is the main producer. This process, naphtha from refineries and products from gas separation plants, i.e ethane, propane and butane, are treated by steam cracking or pyrolysis to reduce a size of the molecule to produce ethylene, propylene and butadiene. For Aromatic processes, the Thai Aromatics Company located in the area is the main producer. The process is to treat naphtha, from refineries, by catalytic reforming within the molecule without changing its size to produce benzene, toluene, p-xylene, o-xylene and mixed-xylene.

B) The Intermediate Petrochemical Industry

There are 11 factories in this stage located in Rayong province. They produce, mainly by chemical processes, raw materials for downstream processes using products from upstream processes. In Olefin processes, Olefin products from upstream processes are used to produce various chemical products for downstream processes such as methanol produces ammonia, formaldehyde and methyl methacrylate (MMA). Ethylene produces ethylene Glycol (EG), vinyl chloride monomer (VCM), styrene monomer (SM) and acrylic acid. Propylene produces acrylonitrile, propylene oxide (PO), iso-propanol. Butane produces n-butene, butadiene, and acetic acid. For Aromatics processes, aromatic products from upstream processes are used to produce various chemical products for downstream processes such as benzene produces phenol, linear alkylbenzene (LAB), and adipic acid. Toluene produces benzene, xylene, caprolactam and purified terephthalic acid (PTA). Xylene produces phthalic anhydride (PA) and terephthalic acid.

C) The Downstream Petrochemical Industry

These factories using products from upstream and intermediate processes to produce polymer products by polymerization and to produce the final products such as detergent through chemical process. In Olefin processes, factories are located mainly in Rayong province. The products currently produced are polyethylene (PE) such as LDPE, HDPE, LLDPE/MDPE and HDPE/LLDPE from ethylene, polyvinyl chloride (PVC) from propylene through vinyl chloride as the secondary raw material, polypropylene (PP), polymethyl methacrylate (PMMA) from propylene, methyl tertiary butyl ether (MTBE) from butane or butylene, butadiene rubber (BR) and styrene butadiene rubber (SBR) emulsion from styrene monomer (SM) and butadiene.

Table 2.4: Aromatics and upstream olefins facilities in Map Ta Phut area

No.	Company	Raw Materials		Products	
		Types	Amounts	Existing	Future (2003)
UAP1.	Thai Aromatics	-Naptha	450,630 T/y	Benzene 200,500 T/y	258,000 T/y
	(ATC)	-Condensated	1,180,020 T/y	Toluene 52,000 T/y	
		-Pyrolysis Gasoline	142,770 T/y	Mixed-xylene 15,000 T/y	65,000 T/y
				O-xylene 28,700 T/y	44,000 T/y
				P-xylene 322,120 T/y	175,000 T/y
UAP2.	Rayong Olefin	-Pyrolysis Gasoline		Benzene 180,000 T/y	
	Company	-Distillate Stripper		Toluene 180,000 T/y	
	(ROC)	-Debutanizer bottom			
UOP1.	Thai Olefins (TOC)	-Naptha		Ethylene 385,000 T/y	
		-Condensated		Propylene 190,000 T/y	
		-Pyrolysis Gasoline		Mixed C_4	
				Pyrolysis Gasoline	
				Cracker bottom	
				Tail gas	
UOP2.	NPC1			Ethylene 437,000 T/y	
				Propylene 173,800 T/y	
IAP1.	SSMC	-Benzene	273,000 T/y	Styrene Monomer (SM)	
		-Ethylene	98,500 T/y	300,000 T/y	
IAP2.	Tuntex Petro.	P-Xylene	250,000 T/y	PTA 420,000 T/y	
		Acetic Acid	24,570 T/y		
		Coal	302,400 T/y		
DAP1.	HMT Polystyrene	SM	85,500 T/y	Polystyrene (PS)	
		Ethylbenzene	109 T/y	90,000 T/y	
DAP2.	Siam Polystyrene	-SM	99,400 T/y	Polystyrene (PS)	
		-Polybutadine Rubber	4,300 T/y	120,000 T/y	
DAP3.	Bayer Polymer	Acrylonitrile		ABS/SAN 120,000 T/y	
		Butadiene			
		Styrene			
DAP4.	Tuntex (Thailand)	PTA		Polyesters 270,000 T/y	
		EG			
DAP5.	Thai Shinkong Co.	PTA		Polyesters 270,000 T/y	
		EG			

Source: PTIT FOCUS, 2000.

For Aromatic processes, most factories are located in Samut Prakarn province. The products currently produced are polystyrene from styrene monomer (SM), which are formed from ethylene and benzene, plasticizer from phthalic anhydride (PA) and polyesters from EG and PTA. In case of chemical processes, currently, linear alkylbenzene (LAB) was used to produce detergent. The aromatic and upstream olefin factories in the Map Ta Phut area are shown in Table 2.4 (PTIT, 2000).

Table 2.5: Emission Sources of BTEX for the Petroleum Related Industries (USEPA, 1991).

Source category	Potential Sources		
	Process point	Process Fugitive	Area Fugitive
Petroleum Refining Industry			
- Crude separation	G,J,L	F,H,M,N	I
- Light hydrocarbon processing	G,O	F,H	Q
- Middle and heavy distillate processing	G,O,P,R	F,H	I
- Residual hydrocarbon processing	G,O,B,K,R	H	I
- Auxiliary processes	G	F,H	I
Basic Petrochemical Industry			
- BTX production	G,K,O,R	F,Q	I

Source Key;

B = vis-breaker furnace
F = wastewater disposal (process drain, blow down, cooling water)
G = flare, incinerator, process heater, boiler H = storage, transfer and handling
I = pumps, valves, compressors, fittings, etc. J = absorber
K = process vent L = distillation/fractionation
M = hot wells N = stream ejectors
O = catalyst regeneration P = evaporation
Q = catalytic cracker R = stripper

The potential sources of HAPs in refinery and basic petrochemical industry processes were reported by USEPA in 1991. The sources are distillation/fractionating columns, catalytic cracking units, sulfur recovery processes, storage tanks, fugitives, combustion unit such as process heaters, which are summarized as shown in Table 2.5.

2.4.2 Mobile Sources

Traffic volume in the area was counted during the research cooperation at the estate between NEDO, DIW and JEMAI in 1998. The results were shown in Table 2.6. Sukhumvit Road (E) was used to represent the variation of traffic volume in the daytime and nighttime, 30202:13690 or about 2.2:1. The traffic volumes are adjusted by the increasing percentages computed from cars' registered numbers in regional portion of Thailand (DLT, 2002) as shown in Table 2.7.

Table 2.6:Traffic volumes in 1998

Link No.	Name	Coordinate				Length	Daily Traffic Volume			
		From		to			HDDV	LDDT	LDGV	MC
		X	Y	X	Y	(km)	(Car/d)	(Car/d)	(Car/d)	(Car/d)
1	Road I-4	732000	1405400	734000	1405600	2.20	743	1986	667	1547
2	Ta Kuan R. (S)	737000	1402000	735500	1403700	2.55	14	808	23	2757
3	Sukhumvit R. (W)	730000	1410000	733400	1407600	4.53	3624	18734	7269	8827
4	Sukhumvit R. (E)	733400	1407600	740500	1404500	5.46	2738	21782	10472	8900
5	Road I-1(S)	732000	1400800	732000	1403700	2.84	769	1647	984	892
6	Road I-1(M)	732000	1403700	732000	1406400	2.62	4771	9372	4099	2914
7	Road I-1(N)	732000	1406400	733000	1407700	1.9	5414	10751	4484	3202
8	Mab Kha R.	733400	1407600	735000	1410000	2.73	6983	11586	4887	7263
9	Nong Fab R.	729800	1402300	732000	1406400	4.44	215	1198	275	2260
10	Map Cha Lut R.	730000	1407500	732000	1406400	2.6	732	2586	977	3036
11	Ta Kuan R. (N)	735500	1403700	736200	1405900	2.7	754	5119	1714	6051
12	Entrance East*	735500	1403700	740500	1404500	5.25	743	1986	667	1547
13	Road I-2*	732000	1403700	735500	1403700	3.5	743	1986	667	1547
14	Road I-7*	734000	1403700	734000	1405600	1.75	743	1986	667	1547

Source: NEDO 1999, pp. III-34 and Fig. 3-2, pp. III-30, * = based on I-4 traffic volume

HDDV. = Heavy Duty Diesel-powered Vehicle or Bus, truck etc.

LDDT. = Light Duty Diesel-powered Vehicle or light commercial car

LDGV. = Light Duty Gasoline-powered Vehicle or Passenger car

MC. = Petrol-motorcycle

Table 2.7: Thailand's regional vehicle registered during 1998-2002.

Vehicle type	1998 cars	1999 cars	2000 cars	2001 cars	2002* cars	Increasing factor
HDDV	588,956	585,144 (-0.65%)	607,149 (3.76%)	624,458 (2.85%)	7,945	1.06
LDDT	2,184,711	2,433,751 (11.4%)	2,472049 (1.57%)	2,669,978 (9.22%)	44,140	1.24
LDGV	980,284	1,044,283 (6.53%)	1,128,893 (8.1%)	1,184,647 (4.94%)	59,411	1.21
MC**	10,817,761	11,584,842 (7.09%)	11,851,710 (2.3%)	13,382,293 (12.91%)	247,466	1.24

Source: http://www.dlt.motc.go.th/stats_cars41.htm, 2/09/02

* = Jan. to March only. ** 2-stroke motorcycle counted for 80%

2.5 Related Researches

There are a number of studies worldwide dealing with sources' profiles, ambient concentrations of VOCs and source's contribution in both industrial and mixed, urban-industrial areas as well as the applications of dispersion modeling.

2.5.1 Source of Air Toxics

2.5.1.1 Stationary sources

Given the broad range of chemicals used by industry in the manufacturing of products such as pesticides, paints and plastics and its energy requirements (largely based on combustion of fossil fuels), there is an obvious potential for industry to emit significant levels of air toxics. Some industrial sectors have a more direct potential for emissions of air toxics because of their manufacturing processes such as petroleum refinery, petrochemical industry, and etc. While the effects of some activities are likely to be localized, others result in the increased presence of air toxics in wider area of ambient air environment. USEPA's annual Toxics Release Inventory (TRI) provides information on the pollutant releases that are reported by the industries. Pursuant to the Emergency Planning and Community Right-to-know Act, TRI includes self-reported facility release and transfer data for over 600 toxic chemicals. Facilities within SIC codes 20 through 39 (manufacturing industries) that have more than ten employees and that are above weight-based reporting thresholds are required to report TRI on-site release and off-site transfers. TRI data provide the type, amount and media receptor of each chemical released or transferred.

Air toxics released from petroleum refining, reported in lbs/year can be summarized from 1993 TRI as showed in Table 2.8. This inventory is updated annually through self-estimation reports that all required facilities have to report to USEPA. To accomplish this task, USEPA provided Toxic Release Inventory Manuals for all involved facilities (USEPA, 2003).

Table 2.8: Air Toxics released from Petroleum Refining in 1993 TRI

Chemical Name	Fugitive air	Point air	Total Release to air	Average per facility
	lbs/year	lbs/year	lbs/year	lbs/year
Benzene	3,033,472	1,216,081	4,249,553	27,774.856
Toluene	6,447,238	2,525,056	8,972,294	61,454.068
Ethylbenzene	945,272	418,624	1,363,896	9,812.2
Xylene (mixed isomers)	3,631,186	1,454,332	5,085,518	37,393.515
O-xylene	224,674	98,181	322,855	20,178.438
P-xylene	244,792	282,361	527,153	32,947.063
M-xylene	297,605	55,255	352,860	25,204.286
Sulfuric acid	5,729	1,143,906	1,149,635	10,644.769
Propylene	3,508,496	1,139,819	4,648,315	43,852.028
Ammonia	1,856,861	4,858,416	6,715,277	65,196.864
Ethylene	1,182,544	453,633	1,636,177	17,979.967
MTBE	475,499	1,837,776	2,313,275	35,049.621
Methyl Ethyl Ketone	4,349,330	250,384	4,599,714	69,692.636
Others	4,057,907	2,113,308	6,171,215	38,812.673
Total	30,260,605	17,847,132	48,107,737	302,564.384

Source: Adapted from Exhibit 17, pp. 50-53, (USEPA, 1995a)

Data from Table 2.8 can be illustrated through Figure 2.13, which found that Benzene, Toluene, Ethylbenzene and Xylene (BTEX) contributes 9%, 18%, 11% and 14% respectively and makes a total 52% of the air toxics released from refinery to atmosphere. Fractions of pollutants released from fugitive sources of refinery in Thailand are shown in Figure 2.14.

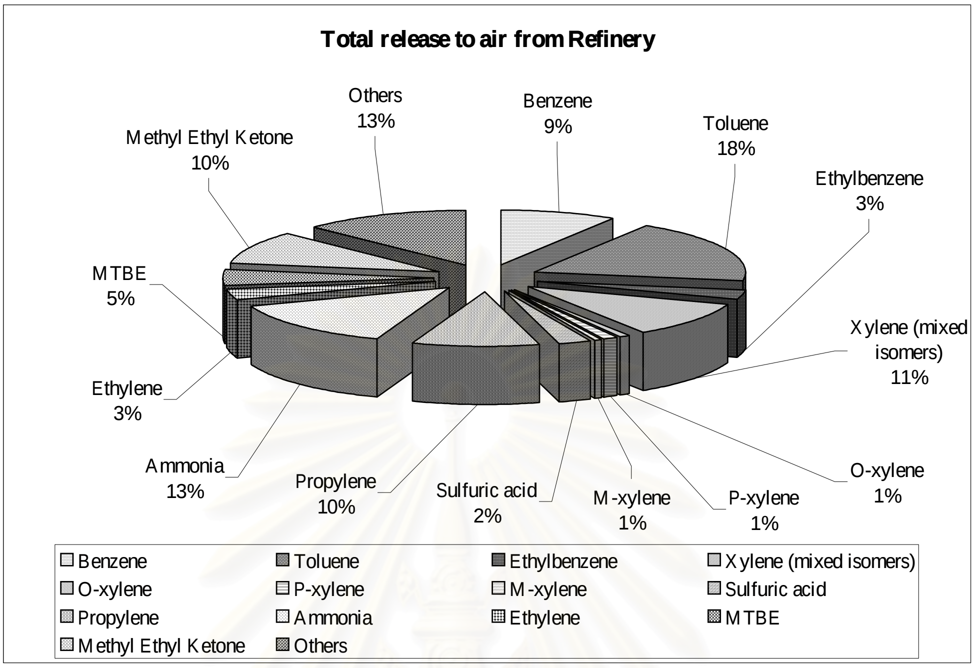


Figure 2.13: Major toxic pollutants released to air from refinery

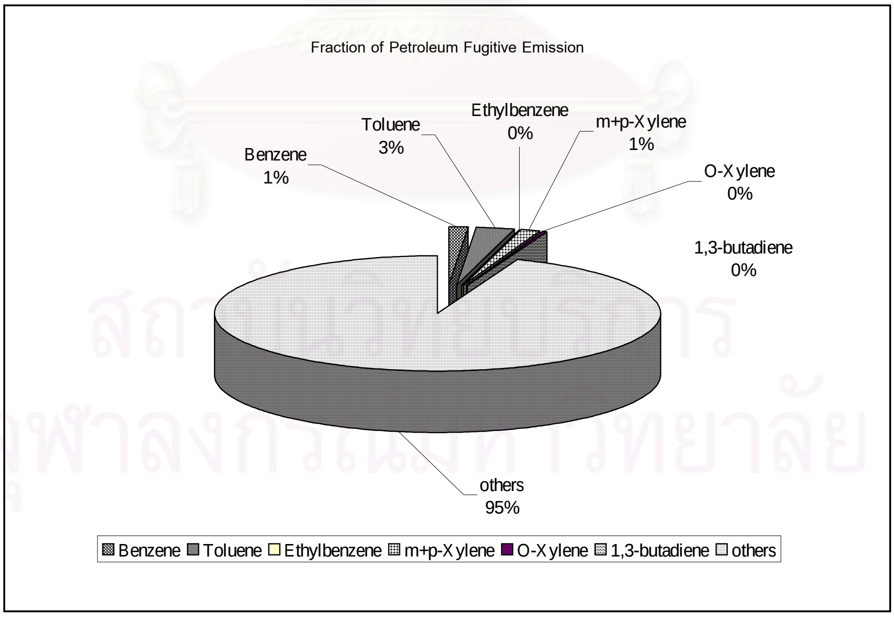


Figure 2.14: Fraction of pollutants from refinery fugitive

Sources: Limpaseni et al 2003.

2.5.1.2 Motor Vehicle

Due to the extensive use of vehicles, most people are exposed to potentially harmful air toxics from vehicle emissions. Some important examples of air toxics that are emitted by vehicles include benzene, 1,3-butadiene, formaldehyde, acetaldehyde, PAHs and particles (EA, 2001). Most of air toxics from cars arise from the by-products of the combustion process when fuel is burnt in the engine and then emitted via the exhaust system, and from evaporation of the fuel itself. Particles are also emitted from brakes and through tyre worn.

Various types of pollutants are produced in the combustion process. Formaldehyde and a range of VOCs, including acetaldehyde and 1,3-butadiene are produced because the fuel is not completely burnt during combustion. Oxides of nitrogen (NO_x) result from the oxidation of nitrogen at a high temperature and pressure in the combustion chamber. Carbon monoxide (CO) occurs when carbon in the fuel is partially oxidized rather than fully oxidized to carbon dioxide. Sulfur dioxide (SO_2) and lead are derived from the sulfur and lead in the fuel. Particles are produced from the incomplete combustion of fuel, additives in fuel and lubricants, and worn material that accumulate in the engine’s lubricant. These additives and worn materials also contain trace amounts of various metals and other compounds, which may be released as exhaust emissions.

Evaporative emissions come mainly from petrol fuel; diesel fuel has a much lower vapor pressure. Evaporative emissions from petrol consist of VOCs such as benzene, which is also a major component of exhaust emissions, and small amounts of lead. These emissions may occur in several ways: diurnal losses, running losses, hot soak losses and resting losses.

Factors affecting vehicle emissions are a vehicle type, type and composition of fuel used, age of a vehicle and types of roads on which a vehicle travels. Figure 2.15 and 2.16 illustrated fraction of pollutants from gasoline and diesel cars in Thailand. In a mega-city like Bangkok, as shown in Table 2.9, mobile sources contribute almost all of hydrocarbons that are present in the urban atmosphere.

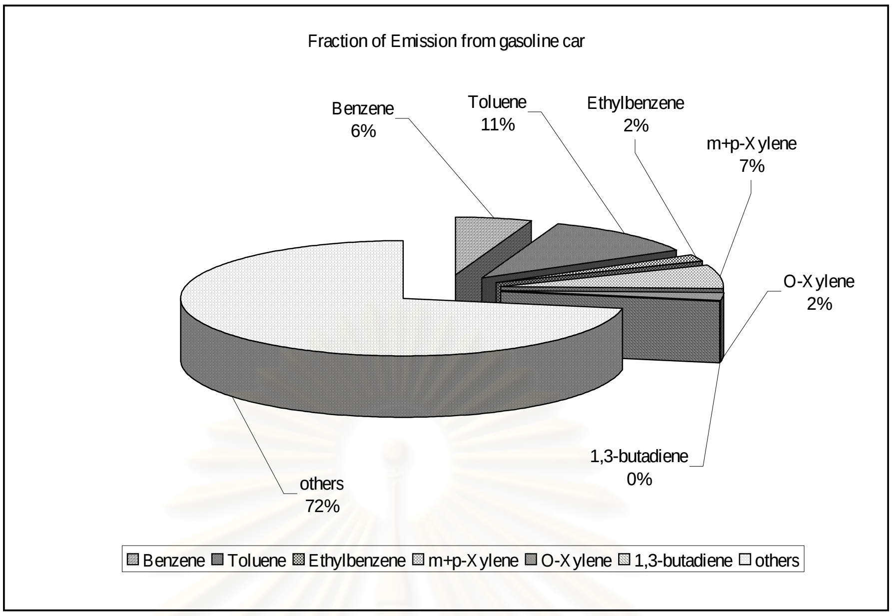


Figure 2.15: Fraction of Pollutants from a Gasoline Car

Source: Limpaseni et al 2003

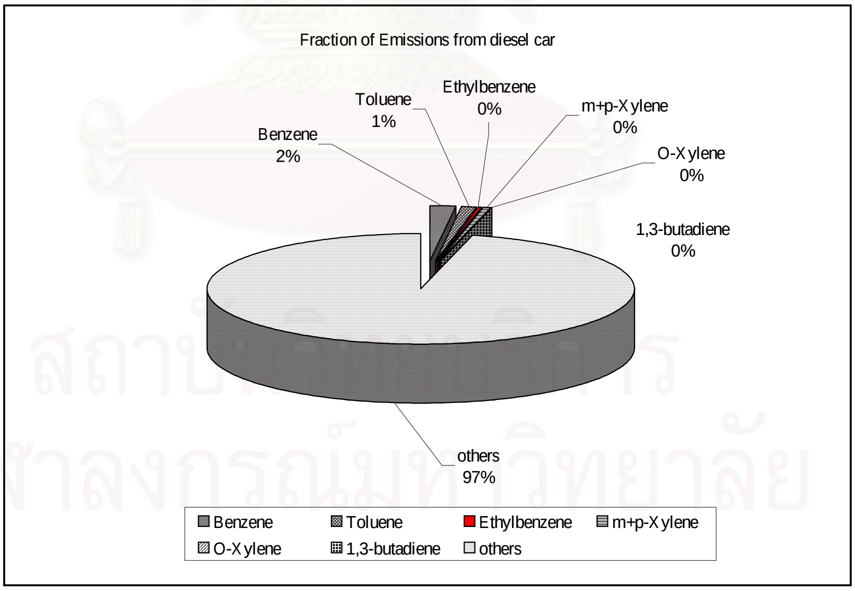


Figure 2.16: Fraction of Pollutants from a Diesel Car

Source: Limpaseni et al 2003

Table 2.9: Emission rate of NOx and HC by source type in Bangkok

Sources	Emission rate Of NOx		Emission rate of Hydrocarbon	
	g/s	%	g/s	%
Point Sources				
Factories (6,187 points)	1,758.0	13.3	32.4	0.1
Crematorium (653 points)	1.5	0.01	0.02	-
Area Sources				
Gasoline stations	-	-	319.4	1.0
Residential	18.1	0.1	777.0	2.4
Airport	185.8	1.4	23.0	0.1
Mobile Sources	11,246.5	85.1	30,457.1	96.4
Total	13,209.20	100	31,608.9	100

Source: PCD, 2003b

Scheff et al. (1989) had developed source fingerprints, based on 23 VOCs, for 10 sources: motorvehicles, gasoline vapor, petroleum refineries, architectural coatings, graphic arts, wastewater treatment, vapor degreasing, dry cleaning, automobile assembly (including body painting), and polyethylene production. The fingerprints have general applicability.

Scheff and Wadden (1993) studied source contributions of 23-NMOC in Chicago. The VOCs were collected for 15 days between July 1 and Septemper 9, 1987 by either Tenax traps or canisters. The Tenax trap samples were analyzed by thermal desorption, cryogenic concentration in a liquid nitrogen-cooled nickel capillary trap, followed by high-resolution gas chromatography-mass spectrometry (GC-MS). The gas canister samples were analyzed using a GC-FID system. The results were used to reconcile source contributions in the area and validate VOC emission inventories developed by traditional survey methods. Seven of eight source categories agreed well with the emission inventory. The other, petroleum refinery was found five times over the inventory values.

Doskey et al. (1999) developed profiles of sources for nonmethane organic compounds in Cairo, Egypt. The whole air samples of emissions were collected by passively withdrawing air into pre-evacuated Summa passivated stainless canisters. The air samples were cryogenically pre-concentrated and analyzed with Gas Chromatography-Flame Ionization detector, GC-FID. The source profiles for gasoline vapor, whole gasoline, roadway vehicle, cold start and hot soak emission, motorcycle, petroleum refinery, lead smelter, cast iron factory, and LPG and natural gas were developed and discussed with other profiles mainly from The USA.

2.5.2 Preliminary Studies in the Area

There are a few studies of VOCs concentrations in working area and ambient air of Map Ta Put petrochemical complex. The first, HSRI (2000) studied and reported that, since wind direction often blows to northeastern direction, sulfur dioxide and aromatic hydrocarbon were detected during March-August in a significant amount. Out of fifteen types of the detected VOCs, A BTEX group was found in the northeastern and northwestern areas and within the complex. Secondary, VOCs components in SPECTRA MIX-A, including BTEX, were taken as a training protocol during research cooperation between NEDO, DIW and JEMAI (NEDO, 1999). Six sampling locations were selected, three sites next to the polluters and the others that located at the possible affected areas. The results, analyzed by GC/MS, on December 1998 were shown in Table 2.10. Lastly, ERTC conducted a study of VOCs in Map Ta Put area (ERTC, 1999). Twenty-four samples were collected from six selected sites for two days and analyzed by a GC/MS QP-5000 equipped with a thermal desorption unit. The dispersion pattern of VOCs within Map Ta Put area, especially from waste disposal site, was also recently preliminary studied in April and June 2000. As the results, BTEX were found in significant amounts and was the most abundant group of VOCs in the area.

TEI (1999) studied the sources of air pollution in Map Ta Phut industrial estate using questionnaires to collect type and amounts of pollutants in the area. The report presented the amounts of SO_2, NO_X, particulate and VOCs in ton/year.

Table 2.10: 1998; BTEX concentrations in Map Ta Put area by NEDO, 1999.

Compound	Concentration $\mu g/m^3$					
	Site A	Site B	Site C	Site D	Site E	Site G
Benzene	1.5-1.6	1.8 –1.9	1.5-2.6	2.5-3.5	1.4-1.8	1.7-2.2
Toluene	ND-6.1	6.5-7.3	12-12	18-22	5.2-15	3.4-13
Ethylbenzene	1.8-8.1	1.9-3.5	2.8-3.5	2.5-5.1	3.8-4.5	4.4-5.7
1,4+1,3Xylene	0.62-3.6	0.76-1.2	0.8-1.3	0.76-0.84	1.2-4.9	1.6-2.0
1,2-Xylene	0.81-2.0	2.5-5.2	3.8-5.6	4.7-10	5.1-20	6.2-6.5

2.5.3 Ambient Air Monitoring

Leong et al (2002a) measured an ambient concentration of benzene in a Bangkok area using a Charcoal tubes (SKC Cat. No. 226-01) and a calibrated pump at a flow rate of 2.0 L/min. The absorbed benzene was extracted by acetonitrile and analyzed by Shimadzu 14A GC-FID with a packed column. The result found that ambient concentration fall within 15.1 to 42.4 $\mu g/M^3$ for peak hours and 16.3 $\mu g/m^3$ for non-peak hours. The results were used to verify the relation of benzene that was emitted from on road motorcycle in Bangkok traffic and ambient concentrations. It was found that motorcycle, both two and four stroke, have a high impact on benzene concentration levels in Bangkok.

Leong et al (2002b) studied the effects of BTX, formaldehyde and acetaldehyde emissions from automobiles when using E10 and E15 gasoline instead of traditional unleaded gasoline. The results showed wide variations in the average emission rates with different mileage, fuel types and catalytic converters (benzene: 3.33-56.48 mg/km, toluene: 8.62-124.66 mg/km, m-xylene: 2.97-51.65 mg/km, formaldehyde: 20.82-477.57 mg/km, and acetaldehyde: 9.46-219.86 mg/kg). The emission rate of benzene, toluene and m-xylene in cars using E10 and E15 fuels is decreased but it increases in formaldehyde and acetaldehyde emission rates.

Gee and Sollars (1998) studied the levels of an important group of VOCs in four cities in Latin America and two cities in Asia, Bangkok and Manila, where monitoring of these VOCs rarely had been conducted. Air samples were collected by stainless steel thermal desorption tubes, 250 mg of Carbopack B in front and Carbosieve SIII in back section, and a low flow pump with a flow rate of 50 mL/min. Eighteen VOCs were determined. The mean BTEX were found in Bangkok at 18.2 $\mu g/m^3$ for benzene, 186 $\mu g/m^3$ for toluene,36.6 $\mu g/m^3$ for ethylbenzene, 81 $\mu g/m^3$ for m&p-xylene and 28.9 $\mu g/m^3$ for o-xylene, which are considered possible health risks.

Schaffeler et al. (2002) used charcoal tubes and low flow pumps to measure BTEX in ambient air at Adelaide, South Australia. The results were intended to be used for modeling purpose and found typical low concentration in ambient air.

Hawas et al. (2002) studied VOCs and carbonyl concentration in an industrial area in Brisbane. The VOCs air samples were collected onto sorbent tubes with Tenax TA/Carboseive SIII using a SKC personal pump. At flow rate of 100 mL/min, a total of 12 L of air was collected for VOCs and 280 L of carbonyl were collected at a flow rate of 1 mL/min onto DNPH silica cartridges. VOCs were analyzed by GC-MS and carbonyl samples were analyzed by HPLC. The results found that the mean (max) concentrations in ppbv of BTEX were 3.29 (10), 10.6 (83), 1.36 (9.3), 4.89 (28), 1.91 (12) for benzene, toluene, ethylbenzene, m&p-xylene and o-xylene respectively.

Torre et al. (1996) studied ambient concentrations of VOCs in a Dandenong area, Melbourne, Australia. The collection of ambient samples and subsequent analysis was based on USEPA method TO-14. Ambient air samples were collected over 24 hours in SUMMA passivated stainless steel canisters and then analyzed by thermal desorption on to a capillary chromatography column for quantification and identification using mass spectrometry. The results found average concentrations for four sites in ppbv were 0.7, 2.0 and 0.3 ppbv for benzene, toluene, and ethylbenzene respectively.

Kalabokas et al. (2001) studied the effects of saturated and aromatic hydrocarbons emitted from refineries on ambient concentrations at various downwind sites in Greece. The ambient air was collected onto adsorption tubes filled with Tenax-TA at a flow rate of 100 mL/min for 20 min. The samples were analyzed by GC-FID with capillary column. The results found mean ambient concentrations at 0.81, 1.67, 0.31, 0.72 and 0.63 ppbv for benzene, toluene, ethylbenzene, m&p-xylene and o-xylene respectively, which is relatively lower than Greece’s urban area. These results incorporated with wind direction were used to quantify the contribution of the refinery on ambient air.

Na et al. (2001) studied the effects of volatile organic compounds emitted from Ulsan petrochemical complex on ambient concentrations in downtown and within the complex. Ambient air was collected to SUMMA canisters according to USEPA methods TO-14. The samples were analyzed by GC-FID with capillary column. The concentrations in this complex were found at 2.1, 3.9 and 2.7 ppb for benzene, toluene and p-xylene respectively, while at a Yohon complex they were found at 2.1, 2.0 and 1.3 ppb for benzene, toluene and p-xylene respectively.

Mohan Rao et al. (1997) studied ambient concentration of non-methane hydrocarbon in an industrial site in Bombay. 260 air samples were initially collected into 10-L tedlar bags by low flow pumps for 3 hours. The sample air was transferred to 0.5-L stainless steel canisters. Then analyzed by Shimazu-gas chromatography equipped with a FID detector and capillary column (OV-1). The result found that concentrations for benzene were 5.9, 12.1, 11.3, 7.7 and 2.1 ppb at sites 1,2,3,4 and 5 respectively. Toluene was found 5.2, 5.7, 8.9, 4.3 and 2.9 ppb at sites 1,2,3,4 and 5 respectively. Ethylbenzene was found 0.2, 0.3, 3.0, 0.2 and 0.1 ppb at sites 1,2,3,4 and 5 respectively. P-xylene was 0.5, 0.4, 0.5, 0.3 and 0.3 ppb at sites 1,2,3,4 and 5 respectively, and O-xylene was 0.9, 0.4, 0.8, 0.4 and 0.5 ppb at sites 1,2,3,4 and 5 respectively.

2.5.4 Emission Inventory

Chun et al. (2001) presented a brief description of the methodology used in the development of reliable air toxic emission inventories for the State of Minnesota in 1996. The inventory, confined to the 1996 Great Lakes Regional Air Toxics Emission Inventory and the MPCA Urban Air Toxics Study, included 109 chemicals: 16 PAHs, 80 non-metal compounds, and 13 metal compounds. The methodology used to compile point emission data included gathering direct reporting values from major sources, calculating it by multiplying an emission factor with an activity data, and a TRI report for some facilities that source-specific or generic emission factors were not available. The generic or specific emission factor can be obtained from EPA FIRE version 6.01 and SPECIATE version 1.5. For Area sources, The emission data were obtained from surveys, literature, and submittals for the National Emission Standards for HAPs. The activity data were pre-treated to a county-level and, then, toxics emission estimates were calculated by using the emission factor method and speciation method. For Mobile sources, which were still in progress, the data was divided into 4 categories: no-road vehicles, non-road mobile sources, locomotives, and aircraft. On-road vehicle emissions employed speciation factors from EPA SPECIATE version 1.5, emission factors based on vehicle miles traveled (VMT).

The result found that although QA/QC plans were established to ensure the best result, there are acknowledged uncertainties with the methodology used to compile the inventory. Source specific information was only collected for certain pollutants in selected facilities. Generic emission factors and control efficiencies were used for many facilities. These generic values may lead to good estimates of national total emission, but may not represent the real situation for individual facilities in Minnesota. Even source-specific emission factors may yield inaccurate results. This is because some source-specific emission factors were developed within data from stack testing for permit purposes, which may be based on testing under a worst case-operating scenario. In addition, generic emission factors are not adequate for a variety of processes and pollutants. The area source categories covered in this emission inventory are not comprehensive. Many other area sources need to be explored in the future.

Chun and Pratt (2001) presented the advantage of adding health benchmarks for cancer, acute, and chronic effects of pollutants on mass-based emission inventory. By adding those effects, a set of chemicals rises to the top of the list of concern that was not identified looking at mass alone. This method could be used as a tool in further targeting pollutants and source categories to control. The methodology used for mass-based emission inventory is the same as those used by Chun et al 2001. Accounting for the toxicity of pollutants in the emission ranking, three types of inhalation health benchmarks were used: for cancer, for acute effects, and for chronic effects.

The result found that eight pollutants namely benzene, formaldehyde, 1,3-butadiene, acrolein, manganese, nickel, chromium and arsenic were consistently ranked in the top five across the three types of endpoints. Six of the top eight pollutants identified by toxic-based emissions ranking were also identified to exceed inhalation health benchmarks based on environmental monitoring data, modeling data, or both.

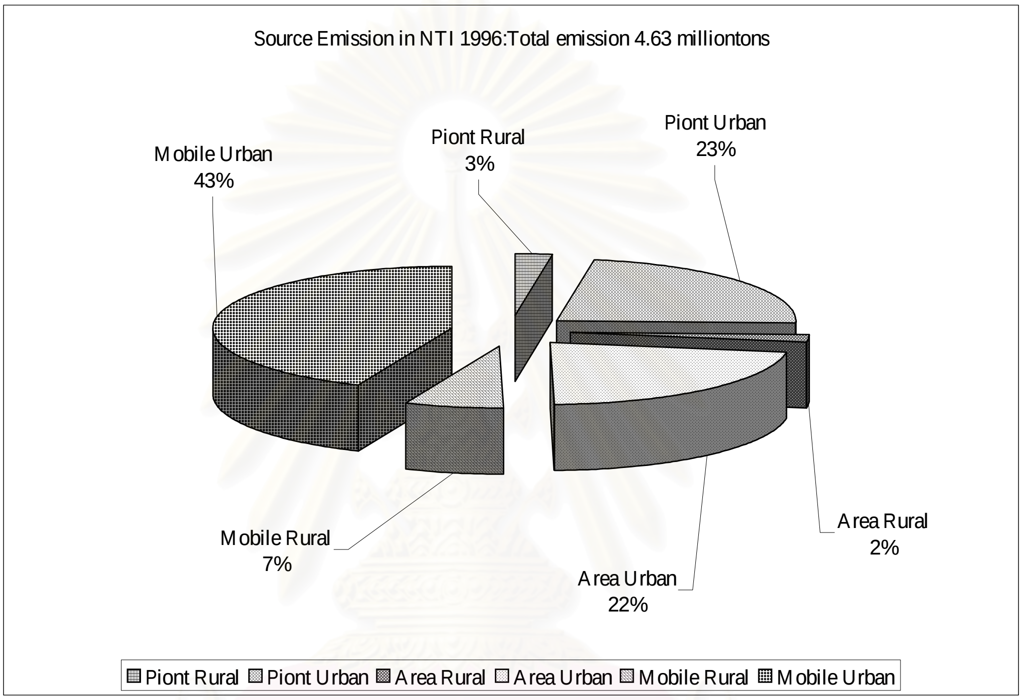


Figure 2.17: Source Emission from USEPA' 1996 NTI
Source: Pope et al., 2001.

Pope et al. (2001) discussed the success of 1996 National Toxics Inventory in the US and summarized emission data for the 1996 year. This inventory, implemented by OAQPS, was compiled using state-supplied HAP inventories as the core of the major source inventory. Additional facility-specific data were obtained for MACT categories, and TRI data were used to complete the major source inventory. The OAQPA developed the 1996 area source inventory from a number of data sources such as MACT and TRI data. The 1996 NTI was completed with the addition of mobile source inventory data developed in conjunction with the OMS. The NTI is a model-ready emission inventory that nor only can be used to predict ambient air concentrations and resultant risk to people, but EPA will also use the 1996 NTI to measure progress under the CAA in reducing HAP emission.

The national total of HAPs, shown in Figure 2.17, emitted from point, area and mobile sources are 1.182, 1.121 and 2.325 million tons respectively, which makes about 4.63 million tons in total.

Lagoudi et al. (2001) presented the system used to compile the emission inventory of VOCs in Greece. Since the inventory must cover the main needs of the European and International Organizations (EEA, OECD, etc.), the inventory system had been developed. The system included selection and classification of the sources to be investigated, determination of VOCs to be evaluated, determination of method used for estimating the emissions, sampling and measurement method used, and calculation techniques. Two types of questionnaires were developed and sent to facilities or on-site visits were conducted. The database and GIS system had been constructed. The QA/QC scheme based on the use of audit and control processes during the inventory was constructed to ensure a reliability of the inventory.

Derwent et al. (1995) summarized the interpretation of 1-year of air quality data at one monitoring site on a roadside in central London, which was measured by a mobile laboratory for NO, NO_2, SO_2, CO, CO_2 and 28-nonmethane hydrocarbons. After the data was analyzed using simple statistic, principle component analysis accompanied with source fingerprints were used to identify the contribution of sources on the ambient data. The Gaussian plume and box models were used to validate the published emission inventory estimates for London using the observed air quality. The observed values yielded predicted values, which exhibited excellent agreement to the published values for many of substances.

Kim and Kim (2000) developed a speciated, hourly, and gridded air pollutants emission system for a Seoul area in Korea. The system employed emission factors and speciation profiles from the USEPA to develop the emission inventory that is ready for modeling. The UAM model was used to validate the inventory of NO_2 and O_3 by comparing them to those from a monitoring data. The result found R^2 = 0.4289 and 0.4893 for NO_2 and O_3 (at peak ozone time) respectively.

Palacios et al. (2001) presented the methodologies that were used to compile the emission inventory of SO_2, NO_x, CH_4, CO, CO_2, N_2O, NH_3 and 18 different NMVOCs in Spain. The top-down strategy, taking as a starting point for official annual and provincial estimates based on CORENAIR, was used for point and area sources. Official statistic databases as well as important related literature and the experience of local experts were collected, reviewed, and evaluated to describe adequately the spatial and temporal distribution of the emissions. Emission profile considered as representative of each source was applied to estimate the NMVOCs contribution from the total NMVOC emission. For mobile sources, both top-down and bottom-up approaches were used to compile and verify the emission inventory from traffic. Some uncertainties were acknowledged and the result yielded reasonably well when it was used as an input for air dispersion modeling exercises.

2.5.5 Application of Air Model

Hogrefe and Rao (2001) addressed the problems, traditional statistical measures and other techniques that reveal how well the model reproduces the spatial and temporal features embedded in the observations of pollutants concentrations, in using models in the regulatory framework. The surface ozone observations were retrieved from the EPA's AIRS database, and the daily maximum 1-hr and 8-hr average ozone concentrations during summer time for three years, 469 data, were determined. The relative reduction factors were assigned. Two synoptic meteorological models, RAMS and MM5, and two photochemical models, UAM-V and SAQM, were used to simulate the reduction scenario. The results showed that the model-to-model differences in the predicted relative responses to emission reduction are much smaller than the model-to-model differences in the predicted absolute ozone concentrations. This finding supports an EPA's draft guidance for attainment demonstrations, which recommends using the model-predicted changes in a relative sense rather than in absolute. The use of extreme value statistics in estimating the probability of exceeding the NAAQS also was illustrated.

Harley and Cass (1995) had developed an Eulerian photochemical air quality model, CIT airshed model, to make it capable of predicting individual volatile organic compounds. The model was applied using monitoring data of Los Angeles, California area for the period 27-28 August 1987. The high-resolution emission inventories of speciated VOCs were supplied from the California Air Resource Board (CARB) and the South Coast Air Quality Management District (SCAQMD). The result of model performance analysis showed the ambient concentrations of most individual organic species are predicted to within a normalized bias of ±50%, with better performance in many cases.

Manju et al. (2002) used an ISCST3 model to study an assimilative capacity of the atmosphere at an industrial zone in Manali, Chennai, India for SO_2, NO_x and SPM. The surface meteorological data for hourly wind speed, wind direction and temperature were obtained at the site itself. The three hourly data for cloud cover, cloud amount and the daily recordings of radiosonde data were obtained from the Regional Meteorological Center, Chennai. The emission inventory for point sources were procured from 95 elevated point sources located in the study area. The data for mobile sources was obtained from the road transport authorities. The measured concentrations for comparison were obtained from the Tamil Nadu State Pollution Control Board, which monitored at Ambient Air Quality Monitoring (AAQM) station located in Manali. For 86 pairs of predicted and measured values, a correlation coefficient was 0.71 and 70% of them were found within a factor of two.

Sivacoumar et al. (2001) applied ISCST-3 model to assess the contribution of sources to ambient concentration of NO_x in industrial area in Jamshedpur region, India. The results found that industries contribute about 53% of NO_x pollution in the region, whereas domestic sources contribute about only 7% while automobiles contributed nearly 40%. Model performance evaluated using statistical analysis by comparing measured and predicted concentrations shows good agreement between the two with accuracy of 68%.

Choowichian, in 1999, implemented the ISCST3 model in Map Ta Phut area. She applied the model to calculate the dispersion of SO_2 from point sources. In comparison with an Ausplume model, both models were tested their sensitivities to meteorological conditions such as different mixing height, different stability classes and so on. The models worked well and yielded reasonable out-puts for the sensitivity test. The prediction average of ground level concentrations of SO_2 from point sources at 3 different monitoring sites over 1, 8, 12 and 24-hour periods were simulated. The performance of both models was compared. The paired comparisons of predictions of each model were presented with corresponding actual observed SO_2 ground level concentrations. The result found both dispersion models have the same accuracy despite predicted mean concentration yield significant differences. At a Map Ta Phut health center, meteorological station at Rayong

Telecommunication office, and a Huai Pong meteorological station, the 1-hour average of observed values and predicted values, by ISCST3 yielded R^2 = 0.063, 0.045 and 0.043 respectively. The 8-hour average of observed values and predicted values, by ISCST3 yielded R^2 = 0.059, 0.134 and 0.172 respectively. The 12-hour average of observed values and predicted values, by ISCST3 yielded R^2 = 0.167, 0.222 and 0.267 respectively. The 24-hour average of observed values and predicted values, by ISCST3 yielded R^2 = 0.108, 0.352 and 0.496 respectively.

Harley et al. (1997) used a CIT airshed model, a Eulerian approach model with revised chemical mechanism, to estimate the impacts of revised motor vehicle emissions on ozone concentrations in Southern California. The revised motor vehicle emission inventory was developed using gasoline sales and infrared remote sensing data for CO and measured ambient NMOC/CO and NO_x/CO ratios. The predicted ozone concentrations using the CIT airshed model matched the observations data from monitoring sites of California’s South Coast Air Basin on 27-28 August 1987 more closely, when the revised inventory was used in stead of the official emission estimates.

2.5.6 Health Effects

McConnell and Pollock (1994), commissioned by the city of Altona, determined ground level concentrations of benzene, 1,3-butadiene, acrylonitrile and styrene at an Altona area Southwest of Melbourne using an AUSPLUME dispersion model, which is a regulatory model for the Victoria EPA. The meteorological file was prepared by the VEPA from local stations. Air emission licenses were used to compile an emission inventory, which mainly came from Altona Chemical Complex, Mobile Refinery and Chemplex. The result found predicted annual concentration of benzene at 3-8 $\mu g/m^3$ in Altona. The predicted annual average ground level concentrations were used to assess potential adverse health effects. The toxicological information from Integrated Risk Information System (IRIS), USEPA database, 8.3×10^{-6} unit per $\mu g/m^3$ and Air Quality Guidelines for Europe, WHO 1987, 4.0×10^{-6} unit per $\mu g/m^3$, were used. The carcinogenic health effect was calculated from unit risk and multiplied by an adjusted exposure concentration. The result found that the estimated concentrations of benzene are in the order of maximum acceptable levels, but were less than the concentrations predicted from VEPA modeling of road vehicle emissions in the inner eastern suburbs of Melbourne.

2.5.7 Uncertainty

Isukapalli (1999) has studied uncertainty analysis of transport-transformation models. According to her work, Figure 2.18 summarizes the types and origins of the uncertainties.

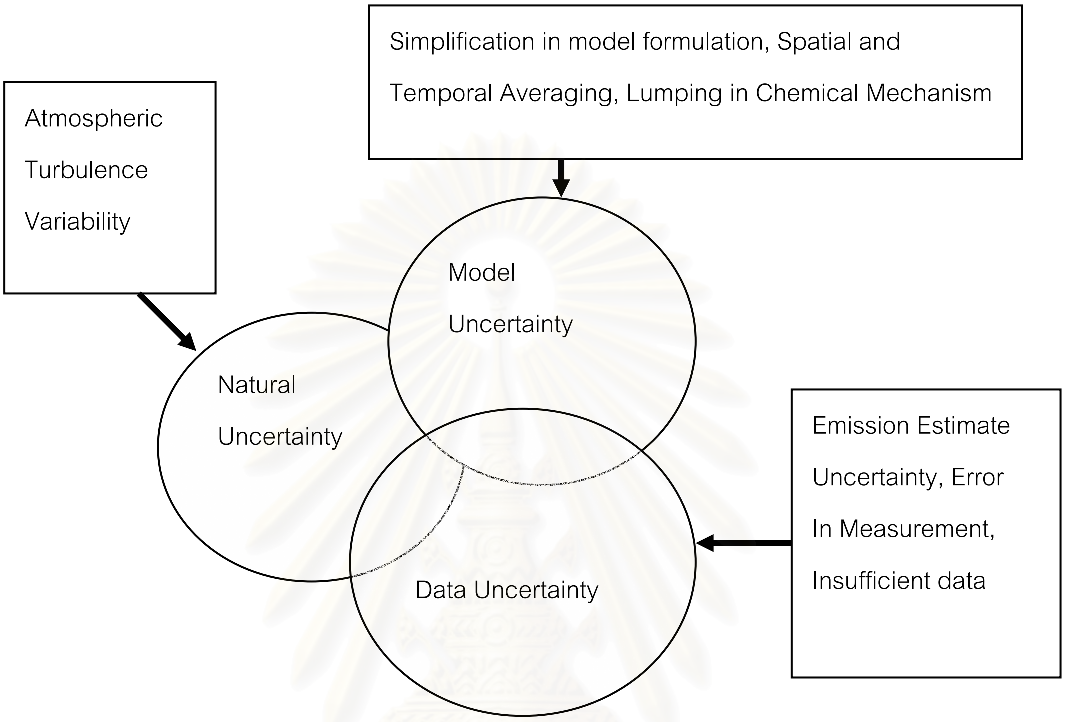


Figure 2.18: Origins and types of uncertainty present in a Photochemical Air Quality Simulation Model

Source: Adapted from Isukapalli, 1999.

Lindley et al. (2000) examined the nature and extent of uncertainties associated with spatially resolved emission inventory, which was estimated for the Northwest Region of England. The inventory was compared to alternative data, a sub-set of the Northwest Region and a set of regional-scale based on the UK's National Atmospheric Emissions Inventory (NAEI). The investigations found that there are a number of variations between inventory results in terms of overall emission magnitudes and spatial distribution. The observed differences between the estimates are attributable to different sources of activity data and emission factors and also as a result of the geographical data used to represent sources.

Dabberdt and Miller (2000) demonstrated uncertainties involved in forecasted modeling by applying a diagnostic mass-consistent wind field model and a non-steady-state puff-type dispersion model, TRIAD, to reconstruct the time-dependent surface concentration field of $H_2SO_{4.}$ The fuming resulted from an actual release of 9t of fuming sulfuric acid during offloading operations from a railroad tank car at a chemical plant in the city of Richmond in a San Francisco Bay Area. The dispersion modeling system was first used in the traditional manner in order to create “best-estimate” spatial fields of H_2SO_4 ambient concentrations at successive 15-min interval throughout and after the accident. It was found that the available meteorological measurements and ambient chemical measurements were not optimized to the problem. Then, they were used as reflected uncertainties in modeling, which were treated for 3 conditions: best estimate, plus 15-25%, and minus 15-25%. The result found uniform probabilities of occurrence.

Van Aardenne et al. (2002) demonstrated a method for finding inaccuracy in calculated emission inventories by using wind-direction-dependent differences. The method was applied for studying the inaccuracies of a European SO_2 emissions inventory for 1994, by plotting the calculated SO_2 concentrations from a long-term ozone simulation model with SO_2 concentrations measured in the EMEP network. Several areas within Europe include Sachsen/Brandenburg (Germany), Central England and the western part of the Russian Federation were identified in accuracies in the emission inventory.

CHAPTER 3

METHODOLOGY

3.1 Field Study and BTEX Ambient Concentration Measurement

3.1.1 Sampling Sites and Plan

Initially seven sites representing receptors within both the estate and residential areas were selected according to their accessibility and their potential to be impacted by sources situated in the Map Ta Phut petrochemical complex. Four locations: an IEAT's office (IEAT), TSK's guardhouse (TSK), Padaeng industry factory's guardhouse (PIG) and the National Fertilizer Company (NFC), represent the receptors at the boundary and within the complex. The locations at IEAT and PIG also represent upwind locations while TSK and NFC represent industrial locations. Three community locations are at the old site of a Map Ta Phut secondary school (School), Ta Kuan Public Health Center (THC) and Rayong Skills Development Center (SDC). The locations at School and SDC represent downwind sites during the monitoring periods. (Figure 3.1). Three sampling periods were used and for each period samples were collected on 7 consecutive days. Sampling periods were during the dry (22-28 February), the semi-wet (29 April- 5 May) and the wet season (19-25 June) in 2002. All sampling was done at ground level. The seasonal influences of wind directions consequently caused different impacts to any one location. Then, the 3 sampling periods were selected to be at times when impacts from the estate on the surrounding residential areas were likely at their maximum. Additionally, air was sampled at the Nong Fab monitoring station (Nong Fab), 3 kms southwest of the estate, during the first period, and at the Provincial Administrative Center (PAC), 4 kms northeast of the estate, for the last two periods to check the transportation of air mass from the estate. One further location at Thai Tank Terminal (Jetty) was also monitored during all three sampling periods to check spatial variation of BTEX in the area.

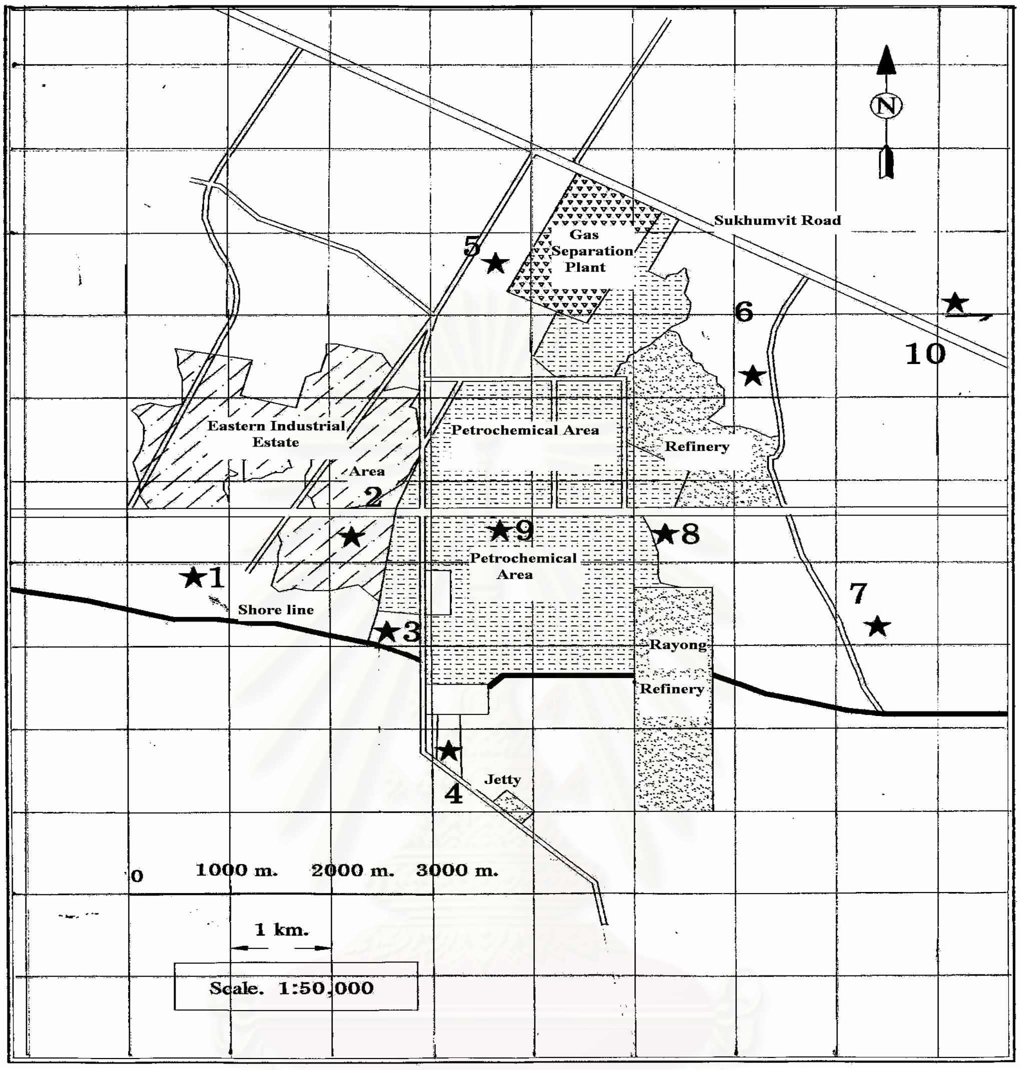


Figure 3.1: Sampling sites

Note: 1= Nong Fab site; 2= Padaeng site; 3= IEAT site; 4= Jetty site; 5= SDC site;

6= School site; 7= THC site; 8= TSK site; 9= NFC site; 10= PAC site

3.1.2 Sampling and Analytical Method

There are numerous standard methods from various environmental and control agencies that are used to quantify VOCs in ambient air (Mukund et al., 1995). Active sampling of ambient air into an adsorbent tube and carbon disulfide solvent extraction is a commonly used method. Recently, it has been used and reported upon for the successful quantification of ambient aromatics (Schaffeler et al., 2002; Leong et al., 2002). In this study, based on OSHA Method 12 (OSHA, 2002a and 2002b), the ambient air in the area was collected actively by a calibrated low flow pump (SKC Model 224-PCXR8) at flow rate 0.1 l min^{-1} for 100 min onto tubes containing sequentially 400mg and 200mg of charcoal (SKC No. 226-09). The 200mg section was used to ensure no loss of sample as a result of breakthrough under the sampling condition. Approximately 10 l of air was sampled for each tube. Field blanks were also prepared for each trip. These samples were transported in an insulated container and stored in a refrigerator as soon as practical after sampling. The trapped BTEX members were desorbed by 1 ml of carbon disulfide (purified and re-distilled) for each portion of the tube. Samples were analyzed by gas chromatography equipped with a flame ionization detector (GC/FID-Model Varian CP-3800). The Chrompack CP-8870 column was a WCOT fused silica type with 0.32 mm I.D and 60-m. length coated with CP-Sil 5 CB as stationary phase 1 μm film thickness. A 1 μl-aliquot was manually injected onto the analytical column and temperature ramping was used. The initial temperature was kept constant at 50°C for 3 min. This was then ramped to 100°C (rate 15°C min^{-1}), held constant for 2 min and then further ramped to 150°C (rate 10°C min^{-1}), held constant for 2 min and then finally ramped to 220°C (rate 25°C min^{-1}) and held at this temperature for 5 min. The carrier and make up gas was purified nitrogen at flow rate 30 ml min^{-1}; the FID unit temperature was set at 220°C. The split mode 1:10 ratio was turned on at 0.75 minute after injecting. The species of interest were eluted at 8.86 min (benzene), 11.47 min (toluene), 14.00 min (ethylbenzene) and 14.22 min (mixed-xylene). Performance criteria for sampling and analysis included field and laboratory blanks, precision testing, breakthrough testing and recovery testing. Figure 3.2a and 3.2b showed the sampling equipment while Figure 3.2c and 3.2d showed the sampling site at TSK and NFC respectively.


SAMPLER

(a)


SKC
DELUXE
MULTI CHARGER
POWER
FULL CYCLE
CHARGE ONLY
STATUS
DryCal
DC-Lite

(b)

(c)

(d)

Figure 3.2: Sampling Equipment (a and b) and Sampling Site (c) at TSK site and (d) at NFC site

3.1.3 Materials

- Sampling set; SKC-400/200-mg charcoal tube, SKC-personal pump, tube holder, flow calibrator and battery charger.
- Analytical set; GC/FID- Varian CP-3800, with 0.32 mm ID x 60-m length-CP-Sil5 CB-capillary column. The analytical set was shown in Figure 3.3.
- Standard set; Standard solution of BTEX as external standard
- Reagent; redistilled carbon disulfide (CS_2).
- Auxiliary; 0.1, 1 and 10 μL Hamilton syringes, 400 ea of 2 mL vials with solid caps, 1 and 2 mL pipettes, 2 of 50 mL and 10 of 5 mL volumetric flasks and 5 Convenient size beakers

Figure 3.3: Analytical equipment; GC/FID- Varian CP-3800, with 0.32 mm ID x 60-m length-CP-Sil5 CB-capillary column

3.1.4 Performance Criteria (Chung et al., 1999 and NIOSH, 1994)

a) Method detection limits

In order to obtain instrument detection limits, blanks and standards are run. Then, the detection limit (LOD) is the injected concentration that gave $S/N \geq 3$. Combing with calibration curve, method detection limits (MDLs) for target compounds were estimated from

$$MDL = X + SDt_{(0.01,n-1)}$$

Where X = mean area of repeated injections of the lowest standard that gave $S/N \geq 3$,

SD = the standard deviation of them,

$t_{(0.01,n-1)}$ = the 95th percentile of the student t distribution = 2.365

n = the number of blanks = 7

From result, the detection limit of BTEX was 31.81×10^{-3}, 7.63×10^{-3}, $17.07 \times 10^{-3}$and 27.46×10^{-3} μg/mL at area count of 110, 163, 164 and 261 respectively.

b) Standard calibration curve

To obtain standard calibration curves, 1 μL aliquot of standard solution was injected 5 times for each of the 5 covered target concentrations, 0.025, 0.05, 0.1, 1.0 and 5 ppm. Plot average peak area VS concentration, then, calibration curve for each analyte was created as shown in Figure 3.4-3.7.

$$Y_i = bX_i - a.$$

Where Yi = peak area and Xi = amount of analyte in $\times 10^{-6}$ μg/μL

From result, calibration curve of BTEX are as the following

Benzene: $Y = 9.9771X-167.8$; $R^2 = 0.9997$

Toluene: $Y = 9.7619X + 88.5$; $R^2 = 0.9999$

Ethylbenzene: $Y = 9.0149X + 182$; $R^2 = 0.9998$

Xylene: $Y = 9.0766X + 214$; $R^2 = 0.9997$

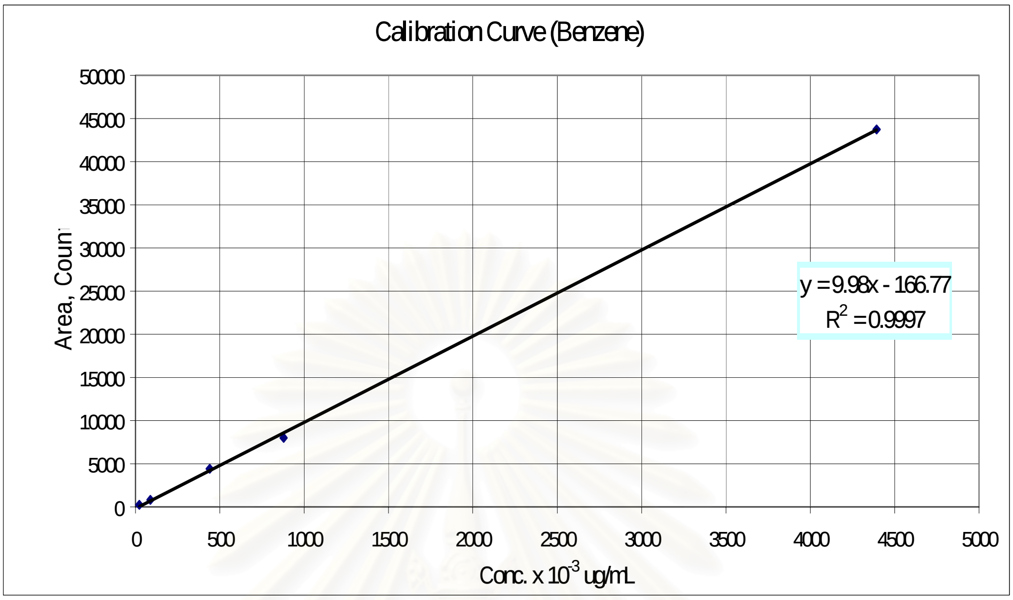


Figure 3.4: Standard Calibration Curve for Benzene, n = 25

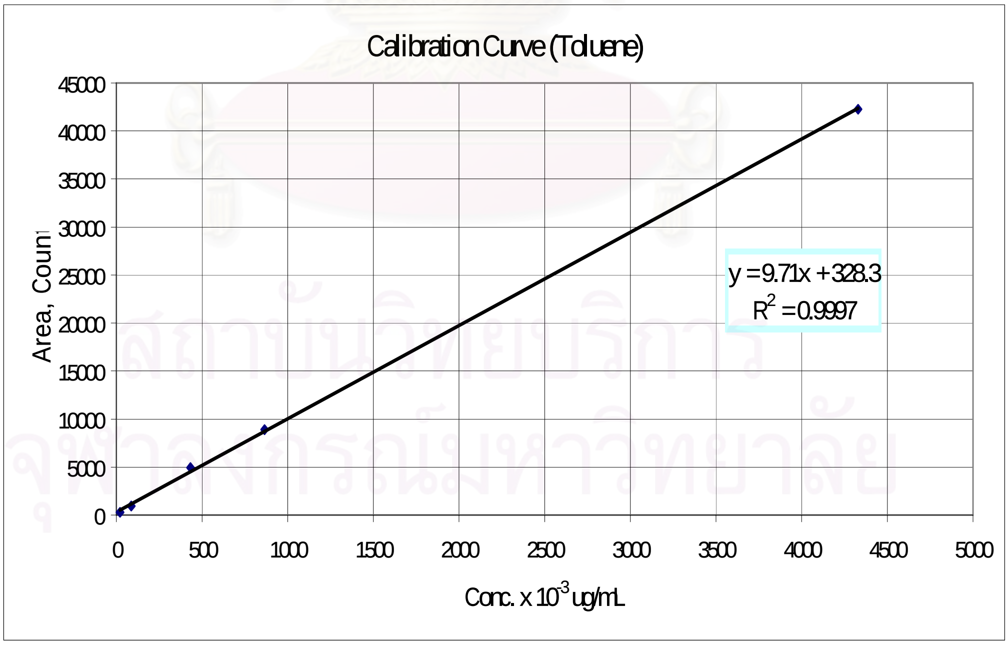


Figure 3.5: Standard Calibration Curve for Toluene, n= 25

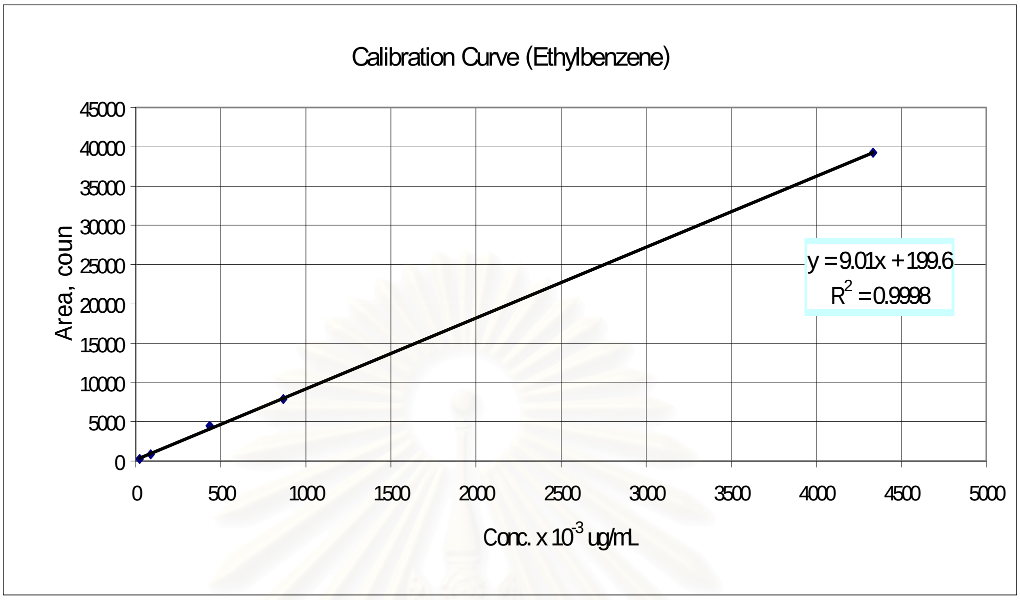


Figure 3.6: Standard Calibration Curve for Ethylbenzene, n= 25

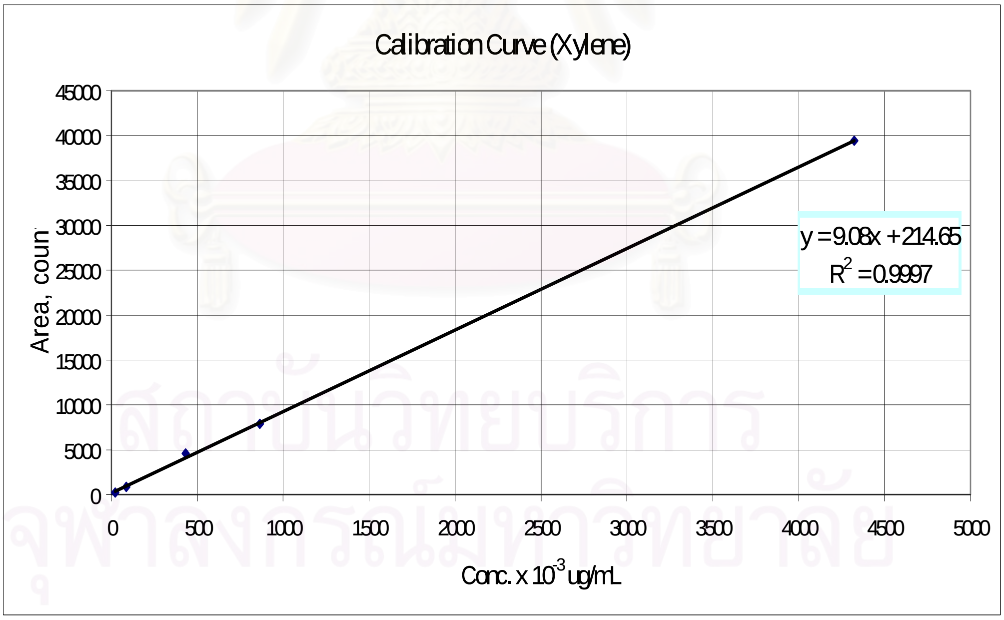


Figure 3.7: Standard Calibration Curve for Xylene, n= 25

b) Breakthrough test

Sampling tubes were connected to calibrated monitoring pumps and simultaneously sampling at least 3 different air volumes at pump flow rates between 10 to 200 mL/min with 2 replicates at each air sample volume. The experiment was carried out in the atmosphere to be monitored and, if possible, under worst-case conditions (i.e., highest natural humidity and highest typical VOC concentrations). The sampling points of all the tube pairs were placed close together in well-ventilated location to ensure that tubes were sampling the same atmosphere. Both the front and back-up tubes of each tube pair was subsequently analyzed by using capillary GC. If more than 10% of one or more of the target analytes was observed on any of the back-up tubes, breakthrough was shown to have occurred at that sample volume. Practically, the BV for a given sorbent/analyte combination was considered to be the sampling volume at which there was a 10% breakthrough of that analyte onto the back up tube. The SSV for that analyte/sorbent combination was then taken as two-thirds (66%) of the BV. The preliminary results are shown in Table 3.1, in which there is no analytes found in a backup section of a charcoal tube. Thus, SSV at 10 L was safely performed.

Table 3.1: Breakthrough Test

Tube No.	Time Min.	Flow rate mL/min	Air Vol. (L)	Front Section µg/m^3				Back Section µg/m^3			
				B	T	E	X	B	T	E	X
1	100	56.58	5.658	7.42	11.36	ND	2.66	ND	ND	ND	ND
2	100	56.79	5.679	7.48	9.63	ND	ND	ND	ND	ND	ND
3	100	101.70	10.170	5.07	30.83*	ND	0.45	ND	ND	ND	ND
4	100	99.48	9.948	5.19	14.26	ND	3.58	ND	ND	ND	ND
5	100	150.7	15.070	3.89	46.06*	0.78	5.6	ND	ND	ND	ND
6	100	150.8	15.080	3.9	17.04	0.27	2.78	ND	ND	ND	ND
Wb / Wf				< 0.1	< 0.1	< 0.1	< 0.1				

* possible contaminated from auto pipette

d) Recovery test

Five tubes were prepared and allowed to stand for at least overnight to assure complete absorption of specific compound onto the charcoal. A parallel blank tube was treated in the same manner except that no sample was added to it. The sample and blank tubes were desorbed and analyzed in exactly the same manner. Three standards, 0.5X, 1.0X and 2X, were prepared by injecting the same volume of compound into 1.0 mL of CS2 with the same syringe used in the preparation of the sample. These were analyzed with the samples. The desorption efficiency equals the difference between the average peak area of the samples and the peak area of the blank divided by the average peak area of the standards, or

Desorption efficiency = (Area sample-Area blank)/ Area standard

From the data; concentration at 0.2, 0.1 and 0.05 ppm_v spiked to 5 tubes each and extracted by CS_2 + distilled were done. The results are shown in Table 3.2.

Table 3.2: Recovery test

Tube	0.05 PPM				0.1 PPM				0.2 PPM			
No.	B	T	E	X	B	T	E	X	B	T	E	X
1	406	438	436	412	1118	1623	1118	1361	*	*	*	*
2	412	471	472	445	1010	1075	1110	1062	1724	1907	1837	1475
3	384	471	456	456	877	965	1010	1222	2126	2233	2209	2063
4	427	570	598	840	1005	1054	1106	1841	2176	2551	2190	1828
5	462	531	513	465	1054	1307	1682	1984	1773	1986	2369	1858
Avg.	418	496	495	524	1013	1205	1205	1494	1950	2169	2151	1806
SD	29	53	64	178	88	266	270	400	234	290	224	244
Blank	51	36	12	22	116	159	145	243	153	203	506	343
Std.	376	497	462	489	918	980	965	1224	1662	1949	1631	1590
%	97.66	92.7	105	102.6	97.71	107	110	102	108	101	101	92

* contaminated

e) Precision test

- Duplicate samples at the same location, same flow rate, same time period and condition, were collected to ensure the analytical precision of both sampling and analytical processes, including extraction. The analytical precision of duplicated analysis must not exceed 20%.

- The measure of precision used for this method is the absolute value of the relative difference between the distributed volume pair expressed as a percentage as follows:

The precision of a sampling and analytical method was determined using duplicate sampling with the same flow rate, 100 mL/min., at the same ambient condition for all sampling three sampling periods. The results are found as shown in Figure 3.8. The precision for ethylbenzene was neglected since there was not enough data and the concentrations were always found below detection limit.

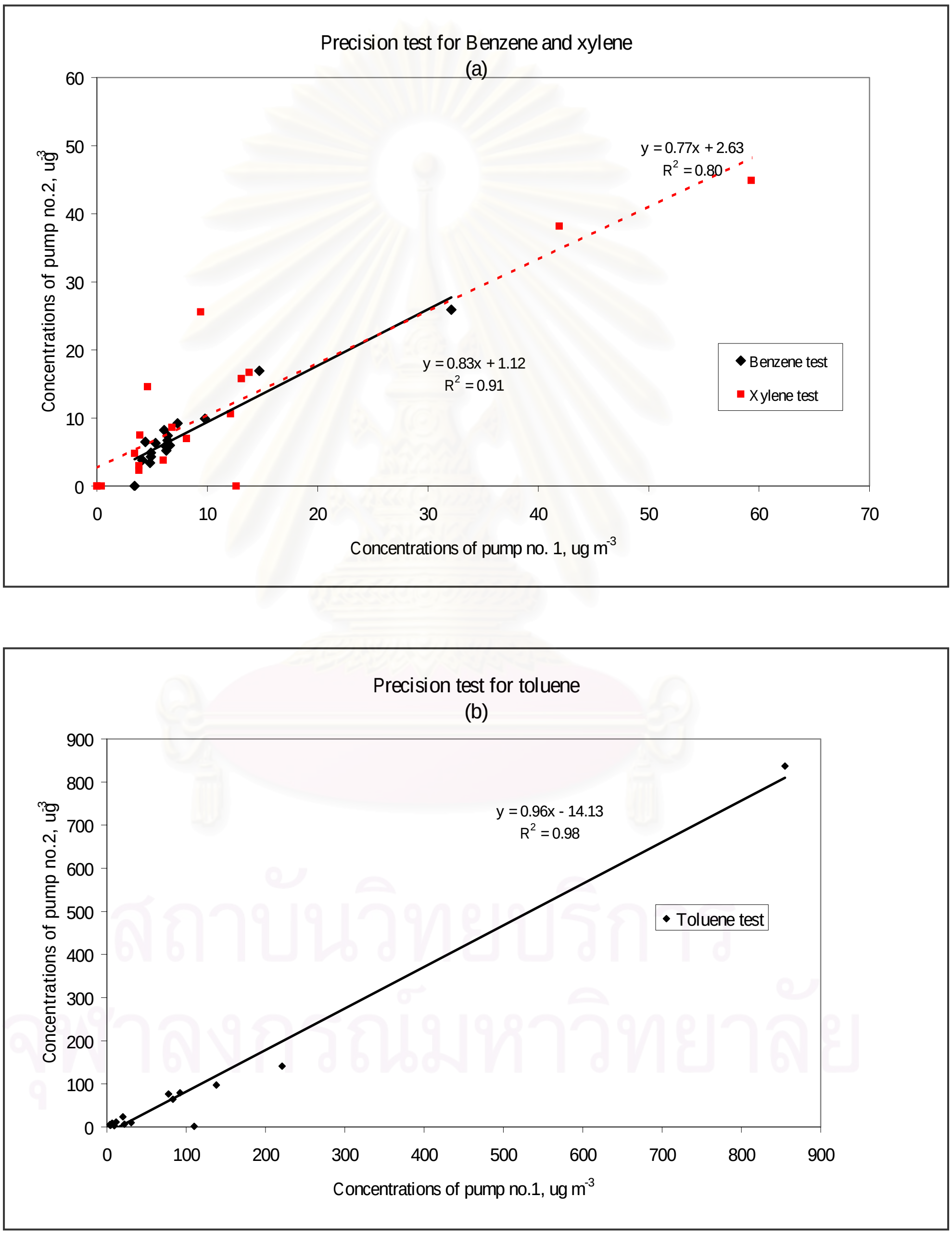


Figure 3.8: Precision test (a) for Benzene and xylene and (b) for toluene

f) Field and Laboratory blanks

Field blanks were collected during every sampling period and analyzed in the same manner as the samples. Results found that there was no contamination during all sampling periods. Laboratory blanks were systematically done by injecting 1 μL of desorbed solvent (CS_2) into the analytical equipment. Results confirm no significant levels of BTEX in the laboratory blanks.

g) Calculation

When 1 μL aliquot of sample was injected into a column manually, the integration unit of analytical system yielded chromatogram with area count at specific retention time for all four analytes. If the area count for BTEX was less than 110, 163, 164 and 261 respectively, the statistic was indicated as below the detection limit.

If the area count for BTEX was greater than 110, 163, 164 and 261 respectively, the concentration of each analyte was calculated using a standard calibration curve as the followings:

Benzene: $Y = 9.98X-167.8$; $R^2 = 0.9997$

Toluene: $Y = 9.76X + 88.5$; $R^2 = 0.9999$

Ethylbenzene: $Y = 9.01X + 182$; $R^2 = 0.9998$

Xylene: $Y = 9.08X + 214$; $R^2 = 0.9997$

Where Y_i = peak area, count

X_i = amount of analyte in $\times 10^{-6}$ μg/μL-injected or $\times 10^{-3}$ μg/mL-injected

Thus, amount of benzene per injection, $X_i = [(\text{Area}) - (-167.8)]/9.9771$

amount of Toluene per injection, $X_i = [(\text{Area}) - (88.5)]/9.7619$

amount of ethylbenzene per injection, $X_i = [(\text{Area}) - (182)]/9.0149$

amount of xylene per injection, $X_i = [(\text{Area}) - (214)]/9.9997$

The calculated amounts of analytes, in 10^{-6} μg per μL-injected, were, then, multiplied by 10^{3}μL/mL to yield total amounts of analytes per sample. The ambient concentrations were the total amounts of analytes per sample divided by the sampling volume in liters. Since the extraction efficiency approaches 1, the ambient concentrations were not adjusted. The calculation equations are as follows:

Benzene, μg/L = [(obtained10^{-6} μg /μL)(10^{3}μL/mL)]/ sampling volume

Toluene, μg/L = [(obtained10^{-6} μg /μL)(10^{3}μL/mL)]/ sampling volume

Ethylbenzene, μg/L = [(obtained10^{-6} μg /μL)(10^{3}μL/mL)]/ sampling volume

Xylene, μg/L = [(obtained10^{-6} μg /μL)(10^{3}μL/mL)]/ sampling volume

The concentrations were transformed to μg/m^3 by multiplying 10^3 L/m^3. The sample of chromatogram and field monitoring data are shown in Appendix A and B respectively.

3.2 Emission Inventory

Presently in Thailand, except for a Bangkok Metropolitan Region, there is no sufficient emission database (PCD, 2000b). Thus, a BTEX emission database for major sources in the study area was compiled by gathering data from available sources, which mainly focused on an Environmental Impact Assessment Report (EIA), previous study, a factory's consultation and monitoring reports. The compiled database initially classified anthropogenic sources into point, mobile and area sources. A top-down or bottom-up approach (Palacios et al., 2001) was employed when appropriated.

3.2.1 Mobile sources

Mobile source included vehicle emissions, but excluded non-road emission due to a data limitation. The vehicle kilometers traveled (VKT) method (USEPA, 1996) was employed. The normalized emission was estimated using equation 1.

$$Q_k = \sum(\mathrm{VKT}_i \text{ x } \mathrm{EF}_{ik}) \qquad (1)$$

Where Q_k is an emission rate of pollutant k in kg/year, VKT_i is the VKT of vehicle i in km/year, and EF_{ik} is the estimation factor of pollutant k and vehicles i, in kg/km.

Step1: The traffic volume was counted by a type of vehicles (NEDO, 1998) and an increasing rate of car registration reported by the Land Transportation Department (DLT, 2002) was used to project a current traffic volume.

Step2: Then, BTEX speciation were done by applying a speciation profile of individual source studied by Environment Australia (EA, 2000a).

VOCs' emission Factors and BTEX's speciation, Table 3.3, were adopted from an Australian National Pollutant Inventory (NPI), Environment Australia (EA) and then, employed together with vehicle kilometers travel (VKT) to calculate BTEX emission rates as shown in Table 3.3.

Speciation emission rate = VKT x VOCs' emission factor x speciation rate

Table 3.3: Emission Factors for Mobile Sources

Vehicle type		benzene (g/km)		toluene (g/km)		ethylbenzene (g/km)		xylene (g/km)	
		Exh.	Evap.	Exh.	Evap	Exh.	Evap.	Exh.	Evap.
^{a}VOCs	HDDV	1.01	NA	1.01	NA	1.01	NA	1.01	NA
speciation		0.0101	NA	0.0147	NA	NA	NA	0.0117	NA
^{a}VOCs	LDDT	0.554	NA	0.554	NA	0.554	NA	0.554	NA
speciation		0.0101	NA	0.0147	NA	NA	NA	0.0117	NA
^{a}VOCs	LDGV	1.26	0.535	1.26	0.535	1.26	0.535	1.26	0.535
^{b}speciation		0.0658	0.017	0.105	0.0224	0.015	0.0019	0.0759	0.00992
^{a}VOCs	MC*	1.23	0.803	1.23	0.803	1.23	0.803	1.23	0.803
^{b}speciation		0.0658	0.017	0.105	0.0224	0.015	0.0019	0.0759	0.00992

Source: ^{a}EA, 2000a.

Note; 1) ^{a,b} based on 100% catalytic converter equipped

2) Exh. = Exhaust emission, Evap. = Evaporative emission

3.2.2 Point and area sources

The potential stationary sources of benzene, toluene, ethylbenzene and xylene in the area were identified based on potential sources discussed in literatures (USEPA 1998, USEPA 1994a, USEPA 1994b, USEPA 1995b, USEPA 1991, EA, 1999 and EA, 2000b). Then, facilities in the area were listed according to the data from IEAT, DIW and PTIT.

Step 1: Sources classification

Fourteen factories such as refineries, power plants, gas separation, all 3 stages of aromatic petrochemical plants and upstream plants of olefin processes, intermediate aromatic process plants and power plants in the study area were studied. BTEX sources were identified according to their nature into:

- Point sources are sources that emitted combustion products or treated gases generated by industrial activities through stack, flare or vent and 33 point sources were identified.

- Area source emissions are sources that are not identified as point sources such as process fugitives, waste treatment plant, valve & fitting leakage, leakage from distributions and storage of petroleum products i.e tank farms. There were 27 area sources were identified.

Step 2: The emitted VOCs from EIAs data for both source types, which already approved by the national committee during licensing process, were gathered if available (ATC, 1994; ATC, 2001; HMT, 1999; HMC, 1997; Padaeng 1994; RPC, 1998; ROC, 1999; ROC, 2001; SSMC, 2000; Tuntex, 1995; Tuntex, 2000 and TTT, 1996). Previous study of VOCs loading in the area (RRC, 1999) was also used as data sources.

Step 3: The missing data were directly gathered from factories (ARC, 2002a). In this case, the estimation methods used were examined comparing to reliable methods (USEPA, 1996 and EA, 2000). The data were also rechecked their updated data through 6-month reports of environmental monitoring, which were conducted by factories (ARC, 2002b; RRC, 2002; ROC, 2002; SPRC, 2002; TTT, 2001) through their consultants. The VOCs/BTEX emission rates were adjusted if needed.

The loading data from steps 2 and 3, if they were already estimated for the targeted species and in appropriate loading unit, g/sec, they were directly used as the emission loading from these sources. For data that needed to be calculated, the calculation of these speciations can be estimated as follow;

$$E_x \text{ (g/sec)} = E_{vOC} \text{ (Ton/year)} * \text{speciation factor} * \text{Conversion factor}$$

Where: E_x (g/sec) = Emission rate of the specie X in g/sec;

E_{vOC} (Ton/year) = Emission rate of VOC in Ton/year;

Speciation factor = weight % of VOCs released from each process operation

Conversion factor; (g/sec) = 0.0317 (Ton/year).

In case of they were estimated in term of TOC loading in Ton/year, the VOCs loading were calculated in g/sec as follows;

$$E_{NMOCs} \text{ (g/sec)} = E_{TOC} \text{ (Ton/year)} * X_{NMOCs} * \text{Conversion factor}$$

Where: E_{NMOCs} (g/sec) = Emission rate of VOCs in g/sec;

E_{TOC} (Ton/year) = Emission rate of THC in Ton/year;

X_{NMOCs} = mass fraction of VOCs, approximately 0.30-0.35 (RRC, 2002); and

Conversion factor; (g/sec) = 0.0317 (Ton/year).

Step 4: The still missing data were done following manuals (EA, 1999; EA, 2000b; USEPA, 1995b) in three methods. The first is to directly gather activity data from factories i.e., power plants and other fuel combustion facilities, then, the emission factors from EA

(1999) were applied. The second is to obtain the monitoring data from 6-month EIA report (gas separation plant, vapor recovery unit of the refineries) and, then, the emission factors from USEPA or EA were applied, if needed. The third is to estimate using emission factors and their activity data obtained from PTIT (2000). The emission factor for refinery and petrochemical processes was shown in Table 3.4 and 3.5. The direct calculation was done as follows;

$$E_x = EF_x * Q$$

Where: E_x = Emission of pollutant X;

EF_x = Emission factor of pollutant X; and

Q = Activity or production rate i.e., annual consumption of coal for power plant

Example for coal fired power plant;

Consumption rate of coal = 2,542 ton/hr (data from factory)

Emission factors for black coal combustion (EA, 1999) were $EF_{benzene} = 6.5*10^{-4}$ kg/ton, $EF_{toluene} = 1.2*10^{-4}$ kg/ton, $EF_{ethylbenzene} = 4.7*10^{-5}$ kg/ton, and $EF_{xylene} = 1.9*10^{-5}$ kg/ton.

Then; $E_{benzene} = 2,542$ ton/hr * $6.5*10^{-4}$ kg/ton * (1,000/60*60) = 0.459 g/sec

$E_{toluene} = 2,542$ ton/hr * $1.2*10^{-4}$ kg/ton* (1,000/60*60) = 0.085 g/sec

$E_{ethylbenzene} = 2,542$ ton/hr * $4.7*10^{-5}$ kg/ton* (1,000/60*60) = 0.033 g/sec

$E_{xylene} = 2,542$ ton/hr * $1.9*10^{-5}$ kg/ton* (1,000/60*60) = 0.013 g/sec

In case of data directly gathered from monitoring reports, the average emission rates were used if possible.

Step 5: Then, BTEX speciation was done by applying a speciation profile of individual source studied by others as shown in Table 3.6 where appropriate. At TAC, percent by weight of the pollutant in the process gas stream was used. The calculation methods for speciated VOC emissions were done as the follows;

$$E_x = E_{voc} * X_x$$

Where: E_x = emission of pollutant X;

E_{voc} = total VOC, from steps 2 and 3 or 4; and

X_x = mass fraction of species X in VOC.

Example of calculation for SPRC process fugitives;

SPRC feed 0.2944 m^3/s while RRC has its feed rate 0.2676 m^3/s.

From Previous study (RRc, 1999) suggested that process drain account for 2.2% of total fugitives for RRC. Thus, TOCs for SPRC = 245.55 T/y

When, speciation data for refinery process sources, blow down system, (EA, 2000b) were

benzene = 0.38%, toluene = 0.44%, and xylene = 0.19%.

Then, $E_{benzene}$ = 245.55*0.3*0.0317 * 0.0038 = 0.01 g/sec

$E_{toluene}$ =245.55 *0.3* 0.0317*0.0044 = 0.0103 g/sec

E_{xylene} =245.55*0.3*0.0317* 0.0019 = 0.0044 g/sec

The emission rates were divided by the area to get emission rates in $g/m^2/s$.

Example of calculation for ATC tank farm fugitive;

Total VOCs emission from tank farm area of TAC (ATC, 2001);

A) Tanks contained raw material = 0.21917 g/sec

Hydrocarbon components for full range condensate (ATC, 2001) were benzene = 2.7%, toluene = 4.5%, ethylbenzene = 1.0%, and xylene = 5.1%.

Then, Benzene = 0.21917 * 0.027 = 0.00598 g/sec

Toluene = 0.21917 * 0.045 = 0.00986 g/sec

Ethyl benzene = 0.21917 * 0.0010 = 0.00022 g/sec

Xylene = 0.21917 * 0.051 = 0.0112 g/sec

B) Tanks contained products = 1.98618 g/sec

Since they are products, they were assumed as 100% of vapor of the filled product in each tank.

Then, Benzene = 0.07656 g/sec, Toluene = 0.01356 g/sec, Xylene = 1.8961 g/sec

Thus, the calculated loading of these species were;

Benzene = (0.00598 + 0.07656) = 0.08254 g/sec

Toluene = (0.00986 + 0.01356) = 0.02342 g/sec

Ethylbenzene = 0.0022 g/sec

Xylene = (0.0112 + 1.8961) = 1.9073 g/sec

The calculated loading were divided by area of tank farm plus space between tanks, approximately 15,000 square meter, to obtain the area loading of each species. The loading from these tank farms were $5.5027*10^{-6}$ $g/sec/m^2$, $1.5615*10^{-6}$ $g/sec/m^2$,

$1.4613*10^{-7}$ g/sec/m^2 and $1.2749*10^{-4}$ g/sec/m^2 for benzene, toluene, ethylbenzene and xylene respectively.

Table 3.4: Emission Factors for refinery plant

Item	Sources	Emission Factors		Speciation factor			
		Units	VOCs	B	T	E	X
1.	Process combustion						
	Boiler <30MW	Kg/m^3 oil fired		$2.57\text{x}10^{-5}$	$7.44\text{x}10^{-4}$	$7.63\text{x}10^{-6}$	$9.01\text{x}10^{-4}$
	HRSG	Kg/ 10^6m^3 gas fired	88	$3.4\text{x}10^{-2}$	$5.4\text{x}10^{-2}$	NA	NA
2.	Refinery process						
	RFCCU						
	- uncontrolled	Kg/m^3 feed to the unit	0.63	NA	NA	NA	NA
	- ESP&CO boiler	Kg/m^3 feed to the unit	neg.				
	MBCCU	Kg/m^3 feed to the unit	0.25	NA	NA	NA	NA
	Fluid coking unit						
	-uncontrolled	Kg/m^3 feed to the unit	0.046	0.38	0.44	NA	0.19
	- ESP&CO boiler	Kg/m^3 feed to the unit	neg.	0.38	0.44	NA	0.19
	Compressor engines						
	-reciprocating engines	Kg/ 10^3m^3 gas burned	21.8	NA	NA	NA	NA
	- gas turbines	Kg/m^3 gas burned	0.28	NA	NA	NA	NA
	Blowdown system						
	- Controlled	Kg/m^3 refinery feed	0.002	0.38	0.44	NA	0.19
	- uncontrolled	Kg/m^3 refinery feed	1662	0.38	0.44	NA	0.19
	VDU condensers						
	-uncontrolled	Kg/m^3 vacuum feed	0.14	0.38	0.44	NA	0.19
	- controlled (flare or heater)	Kg/m^3 vacuum feed	neg.	0.38	0.44	NA	0.19
	SRU						
	-uncontrolled	Kg/dscm process gas to	0.015	NA	NA	NA	NA
	- controlled	Kg/tonne S produced	NA	NA	NA	NA	NA
	Flares						
	- 37.2 MJ/m^3	Kg/GJ of flare gas burned	0.06	0.083	0.041	NA	0.041
3.	Process fugitives	NMVOCs					
	Connectors	Kg/hr/source					
	-Gas		0.0375	NA	NA	NA	NA
	-Liquid		0.0375	NA	NA	NA	NA
	-Heavy liquid		0.0375	NA	NA	NA	NA
	Flanges/valve	Kg/hr/source					
	-Gas		0.0375	0.14	0.7	NA	0.28
	-Liquid		0.0375	0.14	0.7	NA	0.28
	-Heavy liquid		0.0375	0.14	0.7	NA	0.28
	Compressor seal –Gas	Kg/hr/source	1.608	NA	NA	NA	NA
	Pump seals	Kg/hr/source					
	-Liquid		0.437	0.52	3.1	NA	1.34
	-Heavy liquid		0.3885	0.52	3.1	NA	1.34

Table 3.4: Emission Factors for refinery plant (continued)

Item	Sources	Emission Factors		Speciation factor			
		Units	VOCs	B	T	E	X
	Valves	Kg/hr/source					
	-Gas		0.2626	0.14	0.7	NA	0.28
	-Liquid		0.0852	0.14	0.7	NA	0.28
	-Heavy liquid		0.00023	0.14	0.7	NA	0.28
	Open ended lined-All	Kg/hr/source	0.01195	NA	NA	NA	NA
	Pressure relief valves-Gas	Kg/hr/source	0.16	NA	NA	NA	NA
	Sampling connections-All	Kg/hr/source	0.015	NA	NA	NA	NA
	Drains-All	Kg/hr/source	0.032	2.47	NA	NA	NA
	Oil/water separator	Kg/10^6 L. of feed water		0.16	NA	NA	NA
	-Heavy liquid						
4.	Tank farm fugitives						
	Fixed roof tanks						
	standing storage losses			4.1mg/L			
	working losses						
	-filling			10.3 mg/L			
	-emtying			4.1 mg/L			
	Floating roof tanks						
	- rim seal losses	Kg/y	Cal.				
	- withdrawal losses	Kg/y	Cal.				
	- deck fitting losses	Kg/y	Cal.				
	- deck seam losses	Kg/y	Cal.				
5.	Loading losses fugitives			L_L = 0.12 x SPM/T			
	-petrol	Kg/y	Cal.	L_L = VOCs loss (kg/m3 of liquid loded)			
	-diesel	Kg/y	Cal.	S = a saturation factor			
	-kerosene	Kg/y	Cal.	P = True vapour pressure of liquid loaded ,Kpa			
				M = molecular weight of vapour (kg/kg-mole)			
				T = temperature, °K			

Source: VOCs rates from AP-42, USEPA and speciation profile from NPI, 2000b.

http://www.npi.ea.gov.au

Table 3.5: Emission Factors for Aromatics and Olefin Processes

Item	Sources	Emission Factors		Speciation factor			
		Controlled device	units	B	T	E	X
1.	Production Process						
	Naptha's catalytic Reforming/separation						
	-process emission general		g/g produced	(1+0.1%)	$1.7\text{x}10^{-4}$		
	-Petroleum Refinery catalytic cracking		g/g produced		$2.0\text{x}10^{-5}$		
	Xylene production						
	-m-xylene process emissions		kg/Mg m-xylene produced				1.58
	-0-xylene process emissions		kg/Mg o-xylene produced				2.09
	-p-xylene process emissions		kg/Mg p-xylene produced				1.14
	-coal-derived mixed xylene treating tanks		kg/Mg xylene produced				0.5
	-ethylene cracking unit for mixed xylene from pyrolysis gasoline		kg/Mg xylene produced				0.07
	Ethylene production from pyrolysis gasoline						
	- compressor lube oil vent						
	- single compressor train	Uncontrolled	Kg/Mg	0.0003			
	- dual compressor train	Uncontrolled	Kg/Mg	0.0003			
	- secondary waste water treatment	Uncontrolled	Kg/Mg	0.0003			
	- intermittent emissions	Uncontrolled	Kg/Mg	0.0217			
	- single compressor train						
	- dual compressor train	flare	Kg/Mg	0.0792			
		Uncontrolled	Kg/Mg	0.7919			
		flare	Kg/Mg	0.0101			
		uncontrolled	Kg/Mg	0.1011			
	Toluene dealkylation and disproportionation	Included in Fugitives					
	Coke oven light oil distillation	NA	NA				

Table 3.5: Emission Factors for Aromatics and Olefin Processes (continued)

Item	Sources	Emission Factors		Speciation factor			
		Controlled device	units	B	T	E	X
	Ethylbenzene manufacturing						
	- Alkylation reactor vent	Process heater	Kg/Mg	0.0003			
		Uncontrolled	Kg/Mg	0.3			
	- benzene drying column vent	flare	Kg/Mg	0.48			
		uncontrolled	Kg/Mg	1.2			
	- polyethylbenzene recovery column-other vacuum vent	flare	Kg/Mg	0.005			
		uncontrolled	Kg/Mg	0.05			
	- process general		Kg/Mg xylene used				0.1
	Styrene manufacturing						
	-styrene production-general		Kg/Mg		1.52		
	-hydrogen separation vent	flare	Kg/Mg	0.0012			
		uncontrolled	Kg/Mg	0.003			
	-styrene purification(benzene-toluene vacuum vent)	flare	Kg/Mg	1.2			
		uncontrolled	Kg/Mg	3.0	1.17		
	Linear Alkylbenzene-benzene drying						
	benzene azeotropic column vent (point A)	Uncontrolled	G/Mg	3.7			
	HF scrubber column vent	Used as fuel	G/Mg	$7.5x10^{-4}$			
		Uncontrolled	G/Mg	11			
		Used as fuel	G/Mg	$2.2x10^{-3}$			
	- HCl adsorber vent	Flare	G/Mg	1.1			
		Uncontrolled	G/Mg	250			
	-Atmospheric wash/decanter vent	Used as fuel	G/Mg	0.05			
	- benzene stripping column vent	Uncontrolled	G/Mg	12.3			
		Used as fuel	G/Mg	$2.5x10^{-3}$			
		Uncontrolled	G/Mg	3.7			
		Used as fuel	G/Mg	7.4^{-4}			
	Phthalic anhydride production						
	-process emission		G/kg xylene used				0.14
	Maleic anhydride production						
	-process emission		G/kg maleic an. produced				11.6
	Terephthalic acid production						
	-process emissions		kg/Mg xylene used				2.54

Table 3.5: Emission Factors for Aromatics and Olefin Processes (continued)

Item	Sources	Emission Factors		Speciation factor			
		Controlled device	units	B	T	E	X
2.	Fugitive emissions						
	Process fugitives						
	-petroleum refining w/cracking and reforming (fugitives)		kg/ton produced		9.53		
	-petroleum refining w/o cracking and reforming (fugitives)		kg/ton produced		0.953		
	- styrene production-general (process fugitive)		Kg/process unit annually		10,358		
	-Phthalic anhydride-process fugitive		G/kg xylene used				0.04
	- Maleic anhydride-process fugitive		G/kg maleic an. Produced				0.4
	- Ethylbenzene-process fugitive		G/kg xylene used				0.05
	- m-xylene process fugitives		kg/Mg m-xylene produced				0.3
	- o-xylene process fugitives		kg/Mg 0-xylene produced				0.38
	- p-xylene process fugitives		kg/Mg p-xylene produced				0.24
	-coal-derived mixed-xylene process fugitives		kg/Mg xylene produced				0.15
	-pyrolysis gasoline mixed-xylene process fugitives		kg/Mg xylene produced				0.03
	-catalytic reforming mixed-xylene process fugitives		kg/Mg xylene produced				0.03
	-toluene disproportionation xylene process fugitives		kg/Mg xylene produced				0.05
	-Terephthalic acid reactor vent		k/kg terephthalic acid produced	Controlled			0.18
	- Terephthalic acid-process fugitives		kg/Mg xylene used	Uncontrolled			6.0

Table 3.5: Emission Factors for Aromatics and Olefin Processes (continued)

Item	Sources	Emission Factors		Speciation factor			
		Controlled device	units	B	T	E	X
	Equipment leak emission for all production processes			TOC	VOC		VOC
	- valves-gas		Kg/ source/ hr	$1.3x10^{-5}$	0.0056		0.0056
	-light liquid			$4.3x10^{-5}$	0.0071		0.0071
	-heavy liquid			NA	0.00023		0.00023
	- pump seals -gas			$6.5x10^{-5}$	0.104		0.104
	-light liquid			$5.4x10^{-5}$	0.0494		0.0494
	-heavy liquid			NA	0.0214		0.0214
	- compressors and others						
	-gas			$1.2x10^{-5}$	0.228		0.228
	-light liquid			$1.3x10^{-5}$	NA		NA
	- connectors and flanges						
	-gas			$4.2x10^{-5}$	0.015		0.00083
	-light liquid			$8.0x10^{-5}$	NA		NA
	Storage and handling for SOCMI processes						
	1.Breathing losses		See “tank”				
	- industrial organic chemical	kg/1000L throughput			0.43		
	- organic crude and intermediate	lb/1000gallon throughput			6		
	2.Working losses						
	- industrial organic chemical	kg/1000L throughput			0.079		
	- organic crude and intermediate	lb/1000gallon throughput			0.66		
	3.Total losses						
	3.1 Organic crude and intermediate						
	-Toluene storage	g/g T produced	Uncontrol.		$4.65x10^{-4}$		0.02
	-Phthalic anhydride storage	G/kg xylene used	controlled				0.2
		G/kg PA produced					0.002
	-Maleic anhydride storage	G/Mg maleic an. Produced					0.075
	-storage of mixed benzene	G/Mg xylene used					0.05

Table 3.5: Emission Factors for Aromatics and Olefin Processes (continued)

Item	Sources	Emission Factors		Speciation factor			
		Controlled device	units	B	T	E	X
	3.2 Industrial organic chemical						
	-m-xylene storage	kg/Mg					0.12
		m-xylene					
		produced					
	-o-xylene storage	kg/Mg					0.06
		o-xylene					
		produced					
	-p-xylene storage	kg/Mg					0.19
		p-xylene					
		produced					
	-coal-derived mixed-xylene storage	kg/Mg					0.6
		xylene					
	-pyrolysis gasoline mixed-xylene storage	produced					
		kg/Mg					0.3
	-catalytic reformate xylene storage	xylene					
		produced					
	-toluene disproportionation xylene	kg/Mg					0.06
	storage	xylene					
		produced					
	- mixed-xylene storage for Terephthalic	kg/Mg					0.1
	acid production	xylene					
	- p-xylene storage for Terephthalic acid	produced					
	production	g/kg xylene					0.11
		used					
		g/kg					0.11
		terephthalic					
		acid produced					

Source:1. USEPA, EPA-454/R-98-011, June 1998.

2. USEPA, EPA-454/R-93-047, March 1994.

3. USEPA, EPA-454/R-93-048, March 1994.

Table 3.6: Speciation Profiles for BTEX from Stationary Sources

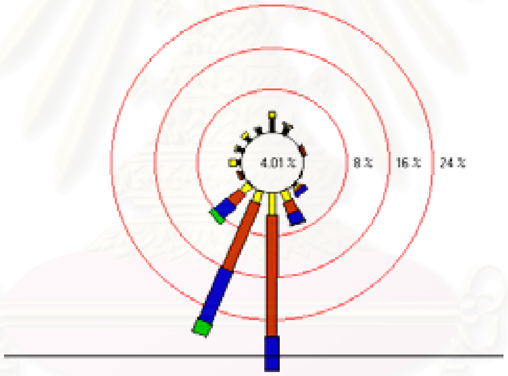
No.	Reference	Sources	Benzene	Toluene	Ethyl-benzene	Xylene
1.	EA., 1999	Fuel combustion				
		- Coal (kg/ton)	$6.5*10^{-4}$	$1.2*10^{-4}$	$4.7*10^{-5}$	$1.9*10^{-5}$
		- Fuel oil (kg/kL)	$2.6*10^{-5}$	$7.4*10^{-4}$	$7.6*10^{-6}$	$1.3*10^{-5}$
		- Natural gas ($kg/10^6\ m^3$)	$3.4*10^{-2}$	$5.4*10^{-2}$	N.A	N.A
2.	EA., 2000b	Wt % released from Blow Down System, Flare, Fluid coking	0.38	0.44	N.A	0.19
3.	Limpaseni et. al.,2003	% of BTEX in tank farm plume	0.7938	2.3054	0.051	0.8438
4.	Scheff and Wadden, 1993.	(Wt % of BTEX)				
		- gasoline vapor	0.5	0.9	0.04	0.08
		- refinery plume	1.4	4.7	0.6	2.25
		- wastewater	3.2	8.4	1.0	0.0
5.	Doskey et. al., 1999	(Wt % of BTEX)				
		- refinery plume	0.37	1.46	0.50	2.16
6.	Scheff et. al., 1989	(wt% of BTEX)				
		- refinery plume	1.12	3.77	0.47	2.84
		- pump seals	0.52	3.10	N.A	1.34
		- process drain	2.47	N.A	N.A	N.A
		- Crude oil tank	N.A	1.53	N.A	N.A
		- pipe & valve	N.A	0.70	N.A	0.29

Note: N.A = not applicable

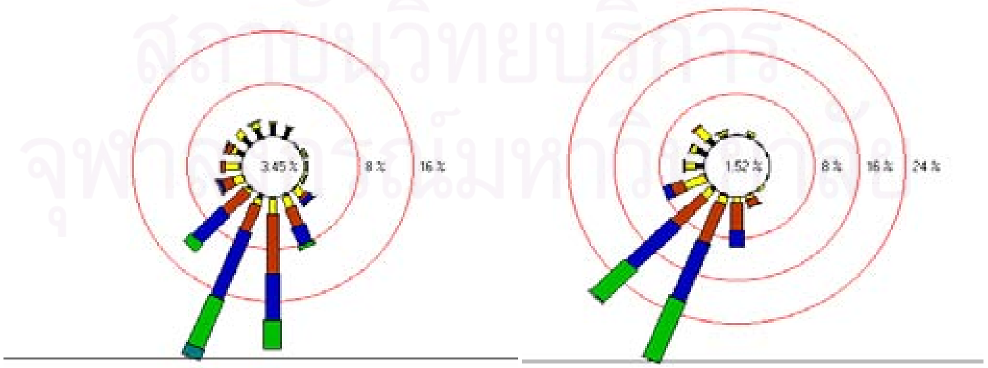
3.3 Source Modeling

3.3.1 Using ISCST3 Model to Predict Ambient Concentrations Generated by Major Sources in the Area

Step 1: Input parameters. In using an ISCST3 model, meteorological parameters like wind speed, wind direction, ambient temperature, mixing height and stability classes are important input data. The Map Ta Phut area, a coastal region with high fluctuations of meteorological parameters both spatially and temporally, has seven meteorological monitoring stations within and nearby area. They are: Huai Pong station, an agricultural meteorological station belonging to Meteorological Department, Map Ta Phut Health Center station, belonging to Pollution Control Department, and other four stations belonging to IEAT namely Wat Takuan, Wat MapChaLut, Wat NongFab and Map Ta Phut secondary school.



February 2002



May 2002

June 2002

Figure 3.9: Wind rose diagram for February, April, May and June 2002

Source: IEAT(Map Ta Phut office), 2002.

Thus, in this research, the validated surface meteorological data, such as hourly wind speed, wind direction and surface temperature were obtained from IEAT (IEAT, 2002b), NongFab station, to represent the surface meteorological data in the area. The three hour reading data of cloudiness, Huai Pong station's data, using for determining stability's' classes, was obtained from the Meteorological Department (MD, 2002). The three hour reading data of vertical temperature profile, by radiosonde at Map Cha Lut station, using for determining mean mixing height, was obtained from the Pollution Control Department (PCD, 2003a). Figure 3.9 showed monthly wind rose diagrams during the sampling periods.

Step2: Preparing meteorological input files. The obtained meteorological data were used to prepare the input file, which consists of hourly wind speed, wind direction, surface temperature (^{o}K), Pasquill-Gifford's stability classes, and mean mixing height. The ready-for-modeling file was prepared in free formatted file as shown in appendix C.

Step3: Running the model. Compiled source loading were put into the model, meteorological file was imported and all regulatory options of the model were selected. Then, the model was able to run successfully and the example file of the output is shown in appendix D. The running events were done for hourly concentrations at specified receptor sites in several scenarios as the following:

a) Normal mobile loading with three meteorological files during each sampling period separately
b) Normal point loading with three meteorological files during each sampling period separately
c) Normal area loading with three meteorological files during each sampling period separately
d) Combination of three normal loading with three meteorological files during each sampling period separately
e) Combination of normal mobile loading and increased area sources with three meteorological files during each sampling period separately

It made 15 runs for modeling in this step.

The ISCST3 model was developed by USEPA (USEPA, 1995c and USEPA, 1995d) and it is also accepted for regulatory agencies in Thailand. In this research did not include sensitivity tests for meteorological conditions since it had been tested by other for the meteorological data in the study area (Choowichian, 1999).

3.3.2 Performance of Modeling

The predicted values from normal rates of combined sources plus the background concentrations were compared to the measured concentrations at various monitoring sites. The statistical analysis that was used to illustrate the relation between the predicted and measured values was a coefficient of determination (R^2). The correlation between the predicted and measured value was also analyzed using the Pearson correlation, a factor of two, and a simple linear regression.

3.4 Determining allowable Loading from Involved Industries

Step 1: Worse case meteorological condition. The available meteorological data from IEAT for the years 2000, 2001, and 2002 were analyzed to find out the worse case meteorological year referring to the explicit parameters, frequency of wind direction blows toward residential area and frequency of calm condition. As shown in Table 3.7, it was found that the year 2002 had the most severe conditions.

Step 2: Preparing meteorological input files. The 2002 meteorological data were prepared for the annual input file, which consists of hourly wind speed, wind direction, surface temperature (^{o}K), Pasquill-Gifford's stability classes, mean mixing height.

Step 3: Running the model. Only mobile loading and combination of normal mobile, point and area loading of each pollutant were put into the model, annual meteorological file was imported and all regulatory options of the model was selected. The output data were obtained for maximum 24-hr average and annual average concentrations of BTEX in the area.

Step 4: Comparing the maximum 24-hr average and annual average concentrations to health benchmark. Since benzene has no safe limit, the WHO guidelines for European countries, 5 ppb or 16.2 $\mu g/m^3$, and its chronic benchmark (Chun and Pratt, 2001) at 60 $\mu g/m^3$ was used. For toluene, ethylbenzene and xylene, the chronic effect values(Chun and Pratt, 2001) at 400, 1000, and 700 μg/m^3 and their 24-hrs ambient standards set by Arizona Ambient Air Quality Guidelines (AAAQGs,1999) were used.

Step 5: In case of exceeding values, the interpolation between two simulations was applied to proposed the allowable emission loading.

Table 3.7: Comparison between meteorological condition for 2000, 2001, and 2002

Sector	Degree	Frequency of wind directions (%)		
		2000	2001	2002
1	0° - 22.5°	0	11.4	10.6
2	22.5° - 45°	11.3	4.6	2.8
3	45° - 67.5°	2.3	0.9	0.8
4	67.5° - 90°	0.8	0.7	0.5
5	90° - 112.5°	0.9	0.9	0.3
6	112.5° - 135°	1.2	1.4	1.1
7	135° - 157.5°	2.2	3	3.5
8	157.5° - 180°	5.8	8.6	11.4
9	180° - 202.5°	13.9	17.6	22.8
10	202.5° - 225°	14.8	19.4	17
11	225° - 247.5°	13	8.3	7.8
12	247.5° - 270°	4.9	4.1	4.1
13	270° - 292.5°	3.7	3.1	3.5
14	292.5° - 315°	3.8	4.7	4.6
15	315° - 337.5°	5.6	4.7	4.7
16	337.5° - 360°	4.5	5.4	4.4

Source: Industrial Estate Authority of Thailand (Map Ta Phut office), 2003.

CHAPTER 4
RESULTS

4.1 Introduction

In this chapter, the results are presented in four parts. The first part is the monitored BTEX ambient concentrations at and nearby the study area, which the monitoring sites located 2-upwind, 3-downwind, 2-site within the estate and other three sites around the estate. Daytime and nighttime concentrations are presented separately. The degree of contamination at all monitoring sites is clarified by the monitored concentrations at a reference site, 25 Kms east of the estate.

The second part is the compiled emission inventories from both mobile and stationary sources in the area. For stationary sources, point or area sources are distinguished.

The third part presents results of sources' modeling using an ISCST3 model. The predicted values are compared to the monitored values in the first part and the agreement of the comparison is illustrated.

In the last part, the annual average and maximum 24-hrs average concentrations of BTEX at the monitoring sites are predicted and two management options were demonstrated.

4.2 BTEX Concentrations in Ambient Air

4.2.1 Daytime Monitoring Sites

As described in Chapter 3, seven sites were selected to monitor the ambient concentrations of BTEX in the estate and its nearby area. Out of seven, three sites located downwind at Rayong Skill Development Center (SDC), Map Ta Phut Phanvittayakarn School (old site)(School), and Takuan Health Center (THC) and they are also representatives of a residential area. Two sites, Thai Shin Kong factory's guardhouse (TSK) and National Fertilizer factory's guardhouse (NFC) located within the estate and they are representatives of an industrial area. The other two sites, IEAT-office (IEAT) and Padaeng Industry's guardhouse (Padaeng) located upwind at southwest border of the estate. Three additional sites, Provincial Administrative Center (PAC), Thai Tank Terminal

(Jetty) and NongFab sites were also monitored to check contaminant flux and spatial variation of BTEX in the study area. The monitoring results for three sampling periods of all sites (Table 4.1-4.14) and one reference site (Table 4.15) were found as the follows:

A. Downwind Sites

A.1) Rayong Skill Development Center (SDC)

Table 4.1: Average daytime concentration of BTEX at SDC site; n=19

Pollutants	Period	Mean $\mu g/m^3$	Median $\mu g/m^3$	SD $\mu g/m^3$	Range $\mu g/m^3$
Benzene	22-27/02/02	7.0	4.6	5.7	4.1-18.6
	29/04-5/05/02	4.4	3.8	1.9	3.0-8.6
	19-25/06/02	3.1	1.4	4.6	BDL-11.7
	Average	4.8	4.1	4.3	BDL-18.6
Toluene	22-27/02/02	13.8	2.2	28.9	0.9-72.8
	29/04-5/05/02	8.6	3.1	14.8	0.8-41.9
	19-25/06/02	6.2	2.5	8.3	0.8-22.6
	Average	9.5	2.5	18.3	0.8-72.8
Ethyl benzene	22-27/02/02	0.9	BDL	1.5	BDL-3.5
	29/04-5/05/02	BDL	BDL	-	BDL
	19-25/06/02	BDL	BDL	-	BDL-0.1
	Average	0.3	BDL	0.9	BDL-3.5
Xylene	22-27/02/02	BDL	BDL	-	BDL
	29/04-5/05/02	BDL	BDL	-	BDL
	19-25/06/02	0.5	BDL	1.1	BDL -2.7
	Average	0.2	BDL	0.6	BDL -2.7

Note: BDL= Below Detection Limit

At the SDC site, benzene concentrations, range BDL-18.6 $\mu g/m^3$, were detected its highest concentration during the dry season at average 7.0 $\mu g/m^3$. The concentrations were detected lower during a semi-wet season and lowest during a wet season at average 3.1 $\mu g/m^3$. For toluene, range 0.8-72.8 $\mu g/m^3$, the highest concentration, average 13.8

μg/m^3, was detected during a dry season and the lowest concentration was detected during a wet season, average 6.2 μg/m^3. Ethylbenzene, range BDL-3.5 μg/m^3, was only detected during a dry season at average 0.9 μg/m^3. Xylene, range BDL-2.7 μg/m^3, was also only detected during a wet season at average 0.8 μg/m^3.

A.2) Map Ta Phut Phanvittayakarn School (old site)(School)

Table 4.2: Average daytime concentration of BTEX at School site; n=19

Pollutants	Period	Mean μg/m^3	Median μg/m^3	SD μg/m^3	Range μg/m^3
Benzene	22-27/02/02	4.3	4.4	1.4	2.1-6.0
	29/04-5/05/02	4.6	3.8	1.5	3.0-7.2
	19-25/06/02	3.3	3.5	0.4	2.9 -26.5
	Average	4.3	4.1	1.4	2.9 -26.5
Toluene	22-27/02/02	6.8	5.1	3.0	3.9-10.9
	29/04-5/05/02	3.8	2.7	1.9	2.1-7.1
	19-25/06/02	2.6	2.6	0.1	2.5-2.7
	Average	4.7	4.0	2.7	2.1-10.9
Ethyl benzene	22-27/02/02	0.6	1.6	1.4	BDL -3.1
	29/04-5/05/02	BDL	BDL	-	BDL
	19-25/06/02	BDL	BDL	-	BDL
	Average	0.2	BDL	0.8	BDL -3.1
Xylene	22-27/02/02	BDL	BDL	-	BDL
	29/04-5/05/02	0.5	BDL	0.6	BDL -1.6
	19-25/06/02	BDL	BDL	-	BDL
	Average	0.2	BDL	0.5	BDL -1.6

Note: BDL= Below Detection Limit

At the School site, benzene concentrations, range 2.9-26.5 μg/m^3, were detected its highest concentration during the semi-wet season at average 4.6 μg/m^3. The concentrations were detected lower during a dry season and lowest during a wet season, average 3.3 μg/m^3. For toluene, range 2.1-10.9 μg/m^3, the highest concentration, average 6.8 μg/m^3, was detected during a dry season and the lowest concentration was detected during a wet season, average 3.3 μg/m^3. Ethylbenzene, range BDL-3.1 μg/m^3, were detected during a dry season at average 0.6 μg/m^3. Xylene, range BDL-1.6 μg/m^3, was also detected slightly amounts in average of 0.2 μg/m^3 during a semi-wet season.

A.3) Takuan Health Centre (THC)

Table 4.3: Average daytime concentration of BTEX at THC site; n=19

Pollutants	Period	Mean μg/m^3	Median μg/m^3	SD μg/m^3	Range μg/m^3
Benzene	22-27/02/02	8.9	5.3	7.3	4.3-23.0
	29/04-5/05/02	5.1	4.9	1.3	3.2-7.2
	19-25/06/02	6.7	5.6	4.4	BDL -11.8
	Average	6.9	5.0	4.9	BDL -23.0
Toluene	22-27/02/02	70.4	10.4	147.1	7.1-370.5
	29/04-5/05/02	5.4	4.7	2.5	2.8-8.7
	19-25/06/02	9.0	8.5	5.3	4.1-19.8
	Average	27.2	7.9	83.2	2.8-370.5
Ethyl benzene	22-27/02/02	3.7	3.3	2.9	BDL -8.8
	29/04-5/05/02	BDL	BDL	-	BDL -0.1
	19-25/06/02	0.2	BDL	0.5	BDL -1.4
	Average	1.3	BDL	2.3	BDL -8.8
Xylene	22-27/02/02	8.8	5.0	10.6	2.7-30.3
	29/04-5/05/02	0.6	BDL	0.9	BDL -2.2
	19-25/06/02	2.3	1.4	2.6	BDL -7.6
	Average	3.8	2.2	6.8	BDL -30.3

Note: BDL= Below Detection Limit

At the THC site, benzene concentrations, range BDL-23.0 μg/m^3, were detected its highest concentration during the dry season, average 8.9 μg/m^3. The lower concentration was detected during a wet season and lowest during a semi-wet season, average 5.1 μg/m^3. For toluene, range 2.8-370.5 μg/m^3, the highest concentration of average 70.4

μg/m^3 was detected during a dry season and the lowest concentration was detected during a semi-wet season at average 5.4 μg/m^3. Ethylbenzene, range BDL-8.8 μg/m^3, was detected at average 3.7 μg/m^3 during a dry season and 0.2 μg/m^3 during a wet season. Xylene, range BDL-30.3 μg/m^3, was detected its highest concentration at average 8.8 μg/m^3 during a dry season and the lowest concentration at average 0.6 μg/m^3 during a semi-wet season.

B. Upwind Sites

B.1) IEAT-office (IEAT)

Table 4.4: Average daytime concentration of BTEX at IEAT site; n=19

Pollutants	Period	Mean μg/m^3	Median μg/m^3	SD μg/m^3	Range μg/m^3
Benzene	22-27/02/02	5.6	3.9	6.2	BDL -17.7
	29/04-5/05/02	3.7	2.2	5.2	BDL -13.2
	19-25/06/02	2.6	0	4.9	BDL -13.2
	Average	4.0	3.7	5.5	BDL -17.7
Toluene	22-27/02/02	3.2	1.9	2.9	1.2-8.6
	29/04-5/05/02	1.9	1.4	2.0	BDL -4.5
	19-25/06/02	1.6	1.4	1.9	BDL -4.5
	Average	2.3	1.6	2.3	BDL -8.6
Ethyl benzene	22-27/02/02	2.3	0	5.7	BDL -13.9
	29/04-5/05/02	BDL	BDL	-	BDL
	19-25/06/02	BDL	BDL	-	BDL
	Average	0.8	BDL	3.4	BDL -13.9
Xylene	22-27/02/02	1.8	BDL	3.1	BDL -7.4
	29/04-5/05/02	BDL	BDL	-	BDL
	19-25/06/02	BDL	BDL	-	BDL
	Average	0.6	BDL	1.9	BDL -7.4

Note: BDL= Below Detection Limit

At the IEAT site, benzene concentrations, range BDL-17.7 $\mu g/m^3$, were detected its highest concentration during the dry season at average 5.6 $\mu g/m^3$. The lower and lowest concentration was detected during a semi-wet season and a wet season, respectively. For toluene, range BDL-8.6 $\mu g/m^3$, its highest concentration at average 3.2 $\mu g/m^3$ was detected during a dry season and its lowest concentration was detected during a wet season, average 1.6 $\mu g/m^3$. Ethylbenzene, range BDL-13.9 $\mu g/m^3$, was detected only during dry season at average 2.3 $\mu g/m^3$. Xylene, range BDL-7.4 $\mu g/m^3$, was also detected only during dry season at average 1.8 $\mu g/m^3$.

B.2) Padaeng Industry Factory's Guardhouse (Padaeng)

Table 4.5: Average daytime concentration of BTEX at Padaeng site; n=13

Pollutants	Period	Mean $\mu g/m^3$	Median $\mu g/m^3$	SD $\mu g/m^3$	Range $\mu g/m^3$
Benzene	22-27/02/02	3.0	3.6	1.7	BDL -4.1
	29/04-5/05/02	1.3	BDL	2.2	BDL -3.8
	19-25/06/02	0.9	BDL	1.2	BDL -2.7
	Average	2.0	2.7	1.9	BDL -4.1
Toluene	22-27/02/02	2.7	2.8	1.9	BDL -5.1
	29/04-5/05/02	1.4	0.9	0.8	0.9-2.3
	19-25/06/02	0.9	1.3	0.8	BDL –1.5
	Average	1.9	1.5	1.6	BDL -5.1
Ethyl benzene	22-27/02/02	BDL	BDL	-	BDL
	29/04-5/05/02	BDL	BDL	-	BDL
	19-25/06/02	BDL	BDL	-	BDL
	Average	BDL	BDL	-	BDL
Xylene	22-27/02/02	0.6	BDL	1.4	BDL -3.1
	29/04-5/05/02	BDL	BDL	-	BDL
	19-25/06/02	BDL	BDL	-	BDL
	Average	0.3	BDL	0.9	BDL -3.1

Note: BDL= Below Detection Limit

At the Padaeng site, benzene concentrations, range BDL-4.1 $\mu g/m^3$, were detected and found its highest concentration during the dry season, average 3.0 $\mu g/m^3$. Its lower concentration was detected during a semi-wet season and the lowest was found during a wet season, average 0.5 $\mu g/m^3$. For toluene, range BDL-5.1 $\mu g/m^3$, its highest concentration at average 2.7 $\mu g/m^3$ was detected during a dry season and the lowest concentration was detected during wet season, average 0.9 $\mu g/m^3$. Ethylbenzene was detected at below detection limit. Xylene, range BDL-3.1 $\mu g/m^3$, was also detected in slight amounts during dry season at average 0.6 $\mu g/m^3$.

C. Industrial Sites

c.1) Thai Shin Kong Factory's Guard House (TSK)

Table 4.6: Average daytime concentration of BTEX at TSK site; n=19

Pollutants	Period	Mean $\mu g/m^3$	Median $\mu g/m^3$	SD $\mu g/m^3$	Range $\mu g/m^3$
Benzene	22-27/02/02	11.5	6.6	11.5	5.3-32.1
	29/04-5/05/02	7.1	5.9	4.6	3.5-16.9
	19-25/06/02	5.6	4.9	2.1	3.4-9.8
	Average	8.0	5.9	7.0	3.4-32.1
Toluene	22-27/02/02	128	110	56.6	77.9-221
	29/04-5/05/02	7.7	5.8	7.3	1.6-23.3
	19-25/06/02	22.8	8.0	34	4.4-83.4
	Average	47.5	8.6	63.3	1.6-220.8
Ethyl benzene	22-27/02/02	3.4	BDL	7.6	BDL -17.0
	29/04-5/05/02	BDL	BDL	-	BDL
	19-25/06/02	0.3	BDL	0.3	BDL -0.8
	Average	1.1	BDL	4.1	BDL -17.0
Xylene	22-27/02/02	14.5	12.1	16.3	BDL -41.9
	29/04-5/05/02	6.4	7.0	5.2	BDL -15.8
	19-25/06/02	5.1	6.0	5.0	BDL -12.6
	Average	8.7	7.0	9.9	BDL -41.9

Note: BDL= Below Detection Limit

At the TSK site, benzene concentrations, range 3.4-32.1 $\mu g/m^3$, were detected and found its highest concentration during the dry season at average 11.5 $\mu g/m^3$. Its lower concentration was detected during a semi-wet season and the lowest was found during a wet season at average 5.4 $\mu g/m^3$. For toluene, range 1.6-220.8 $\mu g/m^3$, its highest concentration at average 128 $\mu g/m^3$ was detected during a dry season and found the lowest concentration during a semi-wet season at 7.7 $\mu g/m^3$. Ethylbenzene, range BDL-17.0 $\mu g/m^3$, was detected at average 3.4 $\mu g/m^3$ during a dry season and 0.2 $\mu g/m^3$ during a wet season. Xylene, range BDL-41.9 $\mu g/m^3$, was detected its highest concentration at average 14.5 $\mu g/m^3$ during a dry season and the lowest concentration at 5.1 $\mu g/m^3$ was found during a wet season.

C.2) National Fertilizer Factory's Guardhouse (NFC)

At the NFC site, There were no samples during a dry season due to its accessibility. Benzene concentrations, range BDL-20.9 $\mu g/m^3$, were detected in higher concentration during the semi-wet season at average 6.1 $\mu g/m^3$, and its lower concentration was detected during a wet season at average 1.5 $\mu g/m^3$. For toluene, range BDL-220.8 $\mu g/m^3$, its higher concentration of average 4.1 $\mu g/m^3$ was detected during a wet season and its lower concentration was detected during a semi-wet season at average 1.2 $\mu g/m^3$. Ethylbenzene, range BDL-5.0 $\mu g/m^3$, was only detected during a semi-wet season at average 0.8 $\mu g/m^3$. Xylene, range BDL-24.5 $\mu g/m^3$, was detected in higher concentration at average 4.8 $\mu g/m^3$ during a semi-wet season and its lower concentration was detected at 0.1 $\mu g/m^3$ during a wet season.

Table 4.7: Average daytime concentration of BTEX at NFC site; n=12

Pollutants	Period	Mean $\mu g/m^3$	Median $\mu g/m^3$	SD $\mu g/m^3$	Range $\mu g/m^3$
Benzene	22-27/02/02	NA	NA	NA	NA
	29/04-5/05/02	6.1	3.5	7.9	BDL -20.9
	19-25/06/02	1.8	2.8	1.7	BDL -10.3
	Average	3.9	3.0	6.2	BDL -20.9
Toluene	22-27/02/02	NA	NA	NA	NA
	29/04-5/05/02	1.2	BDL	2.2	BDL -5.6
	19-25/06/02	4.1	3.3	3.7	1.2-10.3
	Average	2.5	1.4	3.2	BDL -10.3
Ethyl benzene	22-27/02/02	NA	NA	NA	NA
	29/04-5/05/02	0.8	BDL	2.0	BDL -5.0
	19-25/06/02	BDL	BDL	-	BDL
	Average	0.5	BDL	1.5	BDL -5.0
Xylene	22-27/02/02	NA	NA	NA	NA
	29/04-5/05/02	4.8	BDL	9.8	BDL -24.5
	19-25/06/02	0.1	BDL	0.3	BDL -0.7
	Average	2.7	BDL	7.3	BDL -24.5

Note: BDL= Below Detection Limit and NA = Not Applicable

D. Additional sites

D.1) Thai Tanks Terminal (Jetty)

At the Jetty site, benzene concentrations, range BDL-40.1 $\mu g/m^3$, were detected and found its highest concentration during the semi-wet season at average 16.1 $\mu g/m^3$. The lowest concentration was detected during a wet season at average 4.2 $\mu g/m^3$. For toluene, range BDL-65.4 $\mu g/m^3$, its highest concentration at average 19.7 $\mu g/m^3$ was detected during a dry season and the lowest concentration was detected during a wet season, average 3.2 $\mu g/m^3$. Ethylbenzene, range BDL-15.2 $\mu g/m^3$, was only detected during a dry season at average 3.7 $\mu g/m^3$. Xylene, range BDL-19.3 $\mu g/m^3$, was detected its higher concentration at average 4.8 μg/m^{3}during a dry season and lower concentration at average 1.8 μg/m^3 during a wet season.

Table 4.8: Average daytime concentration of BTEX at Jetty site; n=14

Pollutants	Period	Mean μg/m^3	Median μg/m^3	SD μg/m^3	Range μg/m^3
Benzene	22-27/02/02	4.6	2.8	6.9	BDL -16.7
	29/04-5/05/02	16.1	4.3	20.8	3.8-40.1
	19-25/06/02	3.0	2.0	4.2	BDL –8.8
	Average	7.0	3.8	11.5	BDL -40.1
Toluene	22-27/02/02	19.7	5.0	27.1	1.8-65.4
	29/04-5/05/02	8.2	8.8	7.9	BDL -15.8
	19-25/06/02	3.2	3.2	1.8	1.0-5.5
	Average	11.3	4.2	18.4	BDL -65.4
Ethyl benzene	22-27/02/02	3.7	BDL	6.6	BDL -15.2
	29/04-5/05/02	BDL	BDL	-	BDL
	19-25/06/02	BDL	BDL	-	BDL
	Average	1.5	BDL	4.0	BDL -15.2
Xylene	22-27/02/02	4.8	BDL	8.4	BDL -19.3
	29/04-5/05/02	BDL	BDL	-	BDL
	19-25/06/02	2.2	BDL	4.0	BDL -8.9
	Average	2.8	BDL	5.9	BDL -19.3

Note: BDL= Below Detection Limit

D.2) Rayong Provincial Administrative Center (PAC)

At the PAC site, There were no samples during a dry season. Benzene concentrations, range BDL-6.6 μg/m^3, were detected and found a higher concentration during the wet season at average 3.8 μg/m^3, and a lower concentration was detected during a semi-wet season at average 2.3 μg/m^3. For toluene, range BDL-98.5 μg/m^3, its higher concentration at average 30.8 μg/m^3 was detected during a wet season and a lower concentration was detected during a semi-wet season at average 4.1 μg/m^3.

Ethylbenzene, range BDL-0.9 μg/m^3, was only detected during a wet season at average 0.2 μg/m^3. Xylene, range BDL-4.9 μg/m^3, was only detected during a wet season at average 0.8 μg/m^3.

Table 4.9: Average daytime concentration of BTEX at PAC site; n=12

Pollutants	Period	Mean μg/m^3	Median μg/m^3	SD μg/m^3	Range μg/m^3
Benzene	22-27/02/02	NA	NA	NA	NA
	29/04-5/05/02	2.3	1.6	2.7	BDL -6.0
	19-25/06/02	4.8	4.8	1.5	BDL -6.6
	Average	2.8	3.1	2.7	BDL -6.6
Toluene	22-27/02/02	NA	NA	NA	NA
	29/04-5/05/02	4.1	4.4	3.6	BDL -8.6
	19-25/06/02	30.8	10.8	45.4	3.2-98.5
	Average	14.8	3.1	29.8	BDL -98.5
Ethyl benzene	22-27/02/02	NA	NA	NA	NA
	29/04-5/05/02	BDL	BDL	-	BDL
	19-25/06/02	0.2	BDL	0.5	BDL -0.9
	Average	BDL	BDL	-	BDL -0.9
Xylene	22-27/02/02	NA	NA	NA	NA
	29/04-5/05/02	BDL	BDL	-	BDL
	19-25/06/02	1.2	BDL	2.5	BDL -4.9
	Average	BDL	BDL	-	BDL -4.9

Note: BDL= Below Detection Limit and NA = Not Applicable

D.3) NongFab Monitoring Station (Nongfab)

At the Nongfab site, samples were collected during a dry season. Benzene concentration, range 3.8-6.4 μg/m^3, was detected at average 5.1 μg/m^3. For toluene, range 3.3-98.8 μg/m^3, was detected at average 24.9 μg/m^3. Ethylbenzene, range BDL-2.8 μg/m^3, was detected at average 0.6 μg/m^3. Xylene, range BDL-16.2 μg/m^3, was detected at average 3.2 μg/m^3.

Table 4.10: Average daytime concentration of BTEX at NongFab site; n=5

Pollutants	Period	Mean $\mu g/m^3$	Median $\mu g/m^3$	SD $\mu g/m^3$	Range $\mu g/m^3$
Benzene	22-27/02/02	5.1	4.6	1.1	3.8-6.4
Toluene	22-27/02/02	24.9	5.5	41.5	3.3-98.8
Ethyl benzene	22-27/02/02	0.6	BDL	1.3	BDL -2.8
Xylene	22-27/02/02	3.2	BDL	7.2	BDL -16.2

Note: BDL= Below Detection Limit

4.2.2 Nighttime Monitoring Sites

A diurnal variation of the pollutants was monitored at four monitoring sites. One site located at the southwest border of the estate, IEAT's office, for a dry season. Two stations located at Thai Shin Kong Factory's Guardhouse (TSK) representative an industrial area and at Map Ta Phut Phanvittayakarn School (old site)(School) representative a residential area for all three periods. The other, at Rayong Provincial Administrative Centre (PAC), located around 5 kms northeast of the estate for a semi-wet and wet season. The monitoring results were detected as the follows:

A. Residential site: Map Ta Phut Phanvittayakarn School (old site)(School)

At School site, benzene concentrations, range 2.5-10.2 $\mu g/m^3$, were detected and found its highest concentration during the wet season at average 8.0 $\mu g/m^3$. A lower concentration was found during a semi-wet season and the lowest concentration was found during a dry season at average 3.6 $\mu g/m^3$. For toluene, range BDL-52.6 $\mu g/m^3$, the highest concentration at average of 25.9 $\mu g/m^3$ was detected during a semi-wet season and the lowest concentration was detected during a dry season at average 1.8 $\mu g/m^3$. Ethylbenzene, range BDL-3.7 $\mu g/m^3$, was detected at average 0.9 $\mu g/m^3$ during a semi-wet season and 0.2 $\mu g/m^3$ during a wet season. Xylene, range BDL-16.1 $\mu g/m^3$, was also detected at average 5.4 $\mu g/m^3$ during semi-wet season and average 0.9 $\mu g/m^3$ during a wet season.

Table 4.11: Average nighttime concentration of BTEX at School site; n=12

Pollutants	Period	Mean $\mu g/m^3$	Median $\mu g/m^3$	SD $\mu g/m^3$	Range $\mu g/m^3$
Benzene	22-27/02/02	3.6	3.7	1.1	2.5-4.7
	29/04-5/05/02	5.4	4.2	2.5	3.6-10.2
	19-25/06/02	8.0	8.4	1.5	2.9-26.8
	Average	5.8	4.9	2.6	2.5-10.2
Toluene	22-27/02/02	1.8	2.0	1.8	BDL –3.5
	29/04-5/05/02	25.9	16.6	19.7	2.6-52.6
	19-25/06/02	12.4	9.9	11.5	2.9-26.8
	Average	15.4	7.6	17.8	BDL –52.6
Ethyl benzene	22-27/02/02	BDL	BDL	-	BDL
	29/04-5/05/02	0.9	BDL	1.6	BDL –3.7
	19-25/06/02	0.2	BDL	0.4	BDL –0.7
	Average	0.4	BDL	1.1	BDL –3.7
Xylene	22-27/02/02	BDL	BDL	-	BDL
	29/04-5/05/02	5.4	1.0	6.7	BDL –16.1
	19-25/06/02	0.9	BDL	1.8	BDL -3.6
	Average	2.1	BDL	4.6	BDL -16.1

Note: BDL= Below Detection Limit

B. Industrial site:Thai Shin Kong Factory's Guard House (TSK)

At this site, benzene concentrations, range 3.8-10.4 $\mu g/m^3$, were detected and found its highest concentration during the semi-wet season at average 8.4 $\mu g/m^3$. A lower concentration was detected during a wet season and the lowest concentration was detected during a dry season at average 5.2 $\mu g/m^3$. For toluene, range 8.5-100 $\mu g/m^3$, the highest concentration at average of 45.6 $\mu g/m^3$ was detected during a dry season and the lowest was detected during a semi-wet season at 26.7 $\mu g/m^3$. Ethylbenzene, range BDL-7.7 $\mu g/m^3$, was detected its highest concentration during a dry season at average 3.7

$\mu g/m^3$ and its lowest concentration at 0.6 $\mu g/m^3$ during a wet season. Xylene, range BDL-36.7 $\mu g/m^3$, was detected its highest concentration at average 13 $\mu g/m^3$ during a semi-wet season and the lowest concentration at 7.1 $\mu g/m^3$ during a wet season.

Table 4.12: Average nighttime concentration of BTEX at TSK site; n=13

Pollutants	Period	Mean $\mu g/m^3$	Median $\mu g/m^3$	SD $\mu g/m^3$	Range $\mu g/m^3$
Benzene	22-27/02/02	5.2	5.2	0.3	5.0-5.5
	29/04-5/05/02	8.4	9.0	1.9	5.3-10.4
	19-25/06/02	6.5	6.4	2.7	3.8-10.2
	Average	6.9	6.4	2.4	3.8-10.4
Toluene	22-27/02/02	45.6	27.4	48.4	8.9-100
	29/04-5/05/02	26.7	28.2	10.6	10.2-39
	19-25/06/02	45.0	49.5	37.5	8.5-98.7
	Average	38.1	28.2	31.5	8.5-100
Ethyl benzene	22-27/02/02	3.7	3.3	3.9	BDL -7.7
	29/04-5/05/02	2.8	2.3	2.5	0.2-7.5
	19-25/06/02	0.6	0.4	0.8	BDL -1.9
	Average	2.2	1.8	2.6	BDL -7.7
Xylene	22-27/02/02	8.9	10.5	3.5	4.8-11.3
	29/04-5/05/02	13	8.8	14.1	BDL -36.7
	19-25/06/02	7.1	4.1	8.8	1.3-22.5
	Average	9.8	6.3	10.7	BDL -36.7

Note: BDL= Below Detection Limit

C. Additional site:

C.1) IEAT's office

At this site, samples were collected during a dry season. Benzene concentrations, range BDL-2.6 $\mu g/m^3$, were detected at average 1.5 $\mu g/m^3$. For toluene, range 2.2-6.4 $\mu g/m^3$, was detected at average 3.7 $\mu g/m^3$. Ethylbenzene, range BDL-1.5 $\mu g/m^3$, was detected at average 0.5 $\mu g/m^3$. Xylene wasn't detected during this period.

Table 4.13: Average nighttime concentration of BTEX at IEAT site; n=3 for dry season

Pollutants	Period	Mean $\mu g/m^3$	Median $\mu g/m^3$	SD $\mu g/m^3$	Range $\mu g/m^3$
Benzene	22-27/02/02	1.5	2.0	1.4	BDL -2.6
Toluene	22-27/02/02	3.7	2.4	2.4	2.2-6.4
Ethyl benzene	22-27/02/02	0.5	BDL	0.9	BDL -1.5
Xylene	22-27/02/02	BDL	BDL	-	BDL

Note: BDL= Below Detection Limit

C.2) Rayong Provincial Administrative Center (PAC)

Table 4.14: Average nighttime concentration of BTEX at PAC site; n=10

Pollutants	Period	Mean $\mu g/m^3$	Median $\mu g/m^3$	SD $\mu g/m^3$	Range $\mu g/m^3$
Benzene	29/04-5/05/02	4.1	4.6	1.1	2.7-5.8
	19-25/06/02	6.6	6.0	1.6	5.1-8.8
	Average	5.4	5.4	1.9	2.7-8.8
Toluene	29/04-5/05/02	16	13.7	12.5	4.6-39.9
	19-25/06/02	27.4	30.9	13.7	5.9-39.8
	Average	21.7	18.5	14.4	4.6-39.9
Ethyl benzene	29/04-5/05/02	BDL	BDL	-	BDL
	19-25/06/02	0.2	0.1	0.2	BDL -0.5
	Average	0.1	BDL	0.2	BDL -0.5
Xylene	29/04-5/05/02	BDL	BDL	-	BDL
	19-25/06/02	1.4	1.8	1.2	BDL -2.9
	Average	0.7	1.8	1.1	BDL -2.9

Note: BDL= Below Detection Limit

At this site, samples were not collected during a dry season. Benzene concentrations, range 2.7-8.8 $\mu g/m^3$, were detected and its higher and lower concentration was found during a wet and semi-wet season at average 6.6 $\mu g/m^3$ and average 4.1 $\mu g/m^3$ respectively. For toluene, range 4.6-39.9 $\mu g/m^3$, its higher concentration at average 27.4 $\mu g/m^3$ was detected during a wet season and its lower concentration was detected during semi-wet season at average 16 $\mu g/m^3$. Ethylbenzene, range BDL-0.5 $\mu g/m^3$, was only detected during a wet season at average 0.2 $\mu g/m^3$. Xylene, range BDL-2.9 $\mu g/m^3$, was only detected at average 1.4 $\mu g/m^3$ during a wet season.

4.2.3 Reference Site

In order to identify the area as a polluted area, the referent site at Had Mae Ram Pueng around 20 Kms east of Rayong city or 25 Kms east of the study site was monitored and used the same flow rate as a normal sampling. The concentration was detected average 3.6, 4.7, 1.4 and 1.7 $\mu g/m^3$ for B, T, E and X respectively. The %composition of the species was 13:52:16:19 for B, T, E and X respectively. The analytical results were found as the follows:

Table 4.15: Average concentration of BTEX at referent site; n=6

Parameters	Benzene,	Toluene	Ethylbenzene	Xylene
Mean	3.6	4.7	1.4	1.7
Median	3.5	4.7	BDL	0.3
SD	0.8	1.2	3.4	2.9
Range	2.9-4.7	3.2-6.2	BDL -8.3	BDL -7.2

Note: BDL = Below Detection Limit, unit $\mu g/m^3$

4.3 Compiled Emission Inventory

4.3.1 Mobile Sources Loading

The mobile source loading for four types of vehicle namely HDDT, LDDT, LDGV and MC in the area were estimated using emission factors obtained from Australian National Pollutant Inventory (EA, 2000). The results for VOCs are shown in Table 4.16 and for BTEX speciation in Table 4.17.

Where: (D), km/d = (A), km x (C) cars/day

(F), (G), (H), (I) = $\{[(D) \times (E)_{exh.} \times \text{speciation}] + [(D) \times (E)_{evp.} \times \text{speciation}]\}$

Table 4.16: Vehicle Emission of BTEX in the area

Link No.	Name	Length (km)	Vehicle Type	Volume (Car/d)	VKT (km/d)	VOCs rate g/km	Emission rate			
							B (g/d)	T (g/d)	E (g/d)	X (g/d)
		(A)	(B)	©	(D)	(E)	(F)	(G)	(H)	(I)
1	Road I-4	2.2	HDDV	788	1734	1.01	17.69	25.74	0	20.49
			LDDT	2463	5419	0.554	30.32	44.13	0	35.12
			LDGV	807	1775	1.26+0.535	163.3	255.72	35.35	178.29
			MC	1918	4220	1.23+0.803	399.15	619.56	84.3	427.58
						Total	610.46	945.15	119.65	661.48
2	Ta Kuan Road (S)	2.55	HDDV	15	38	1.01	0.39	0.56	0	0.45
			LDDT	1002	2555	0.554	14.3	20.81	0	16.56
			LDGV	28	71	1.26+0.535	6.53	10.24	1.41	7.17
			MC	3418	8716	1.23+0.803	824.4	1282.44	174.11	883.13
						Total	845.62	1314.05	175.52	907.31
3	Sukhumvit Road (W)	4.53	HDDV	3841	17400	1.01	177.5	258.34	0	205.62
			LDDT	23230	105232	0.554	588.82	856.99	0	682.09
			LDGV	8795	39842	1.26+0.535	3665.58	5748.56	793.51	4021.7
			MC	10945	49580	1.23+0.803	4689.52	7295.06	990.4	5023.58
						Total	9121.42	14158.95	1783.91	9932.99
4	Sukhumvit Road (E)	5.46	HDDV	2902	15845	1.01	161.63	235.25	0	187.24
			LDDT	27010	147475	0.554	825.18	1201	0	955.9
			LDGV	12671	69814	1.26+0.535	6423.1	10069.45	1390.45	7047.11
			MC	11036	60257	1.23+0.803	5699.41	8866.05	1203.68	6105.4
						Total	13109.32	20371.75	2594.13	14295.65
5	Road I-1(S)	2.84	HDDV	815	2315	1.01	23.62	34.37	0	27.36
			LDDT	2042	5799	0.554	32.45	47.23	0	37.59
			LDGV	1190	3380	1.26+0.535	310.97	487.68	67.32	341.18
			MC	1106	3141	1.23+0.803	297.09	462.16	62.74	318.25
						Total	664.13	1031.44	130.06	724.38
6	Road I-1(M)	2.62	HDDV	5057	13249	1.01	135.15	196.71	0	156.56
			LDDT	11621	30477	0.554	170.53	248.2	0	197.55
			LDGV	4960	12995	1.26+0.535	1195.58	1874.97	258.81	1311.73
			MC	3613	9466	1.23+0.803	895.34	1392.8	189.09	959.12
						Total	2396.6	3712.68	447.9	2624.96
7	Road I-1(N)	1.9	HDDV	5739	10904	1.01	111.23	161.89	0	128.85
			LDDT	13331	25329	0.554	141.73	206.27	0	164.18
			LDGV	5426	10309	1.26+0.535	948.46	1487.42	205.32	1040.6
			MC	3970	7543	1.23+0.803	713.45	1109.86	150.68	764.28
						Total	1914.87	2965.44	356	2097.91

Table 4.16: Vehicle Emission of BTEX in the area (cont.)

Link No.	Name	Length (km)	Vehicle Type	Volume (Car/d)	VKT (km/d)	VOCs rate g/km	Emission rate			
							B (g/d)	T (g/d)	E (g/d)	X (g/d)
		(A)	(B)	©	(D)	(E)	(F)	(G)	(H)	(I)
8	Mab Kha Road	2.73	HDDV	7402	20208	1.01	206.14	300.03	0	238.79
			LDDT	14367	39222	0.554	219.46	319.42	0	254.23
			LDGV	5913	16142	1.26+0.535	1485.11	2329.03	321.49	1629.39
			MC	9006	24586	1.23+0.803	2325.47	3657.24	496.52	2518.48
						Total	4236.18	6605.72	818.01	4640.89
9	Nong Fab Road	4.44	HDDV	228	1012	1.01	10.32	15.03	0	11.96
			LDDT	1486	6598	0.554	36.92	53.73	0	42.77
			LDGV	333	1479	1.26+0.535	136.07	213.4	29.46	149.29
			MC	2802	12440	1.23+0.803	1176.64	1830.39	248.5	1260.46
						Total	1359.95	2112.55	277.96	1464.48
10	Map Cha lut Road	2.6	HDDV	776	2018	1.01	20.59	29.96	0	23.85
			LDDT	3207	8338	0.554	46.65	67.9	0	54.05
			LDGV	1182	3073	1.26+0.535	282.73	443.38	61.2	310.19
			MC	3765	9789	1.23+0.803	925.89	1440.33	195.54	991.85
						Total	1275.86	1981.57	256.74	1379.94
11	Ta Kuan Road (N)	2.7	HDDV	799	2157	1.01	22	32.02	0	25.49
			LDDT	6348	17340	0.554	97.02	141.21	0	112.39
			LDGV	2074	5600	1.26+0.535	515.22	790.35	111.53	565.27
			MC	7503	20258	1.23+0.803	1916.1	2980.7	404.67	2052.6
						Total	2550.34	3944.28	516.2	2755.75
12	Entrance east	5.25	HDDV	788	4137	1.01	42.2	61.42	0	48.89
			LDDT	2463	12930	0.554	72.35	105.3	0	83.81
			LDGV	807	4236	1.26+0.535	389.72	611.19	84.37	427.59
			MC	1918	10070	1.23+0.803	952.47	1481.67	201.16	1020.32
						Total	1456.74	2259.58	285.53	1580.61
13	Road I-2	3.5	HDDV	788	2758	1.01	28.13	40.95	0	32.59
			LDDT	2463	8620	0.554	48.23	70.2	0	55.87
			LDGV	807	2825	1.26+0.535	259.91	407.6	56.26	285.16
			MC	1918	6713	1.23+0.803	634.95	987.73	134.1	680.18
						Total	971.22	1506.48	190.36	1053.8
14	Road I-7	1.75	HDDV	788	1379	1.01	14.07	20.47	0	16.29
			LDDT	2463	4310	0.554	24.12	35.1	0	27.94
			LDGV	807	1412	1.26+0.535	129.91	203.73	28.12	142.53
			MC	1918	3356	1.23+0.803	317.42	493.79	67.04	340.04
						Total	485.52	753.09	95.16	526.8

Table 4.17: Mobile source loading

Link No.	Name	Coordinate				Speciation Emissions			
		From		to		B	T	E	X
		X	Y	X	Y	(g/s)	(g/s)	(g/s)	(g/s)
1	Road I-4	732000	1405400	734000	1405600	0.00707	0.01094	0.00138	0.00766
2	Ta Kuan R. (S)	737000	1402000	735500	1403700	0.00979	0.0152	0.00203	0.0105
3	Sukhumvit R. (W)	730000	1410000	733400	1407600	0.1056	0.1639	0.02065	0.11497
4	Sukhumvit R. (E)	733400	1407600	740500	1404500	0.1517	0.2358	0.03002	0.1655
5	Road I-1(S)	732000	1400800	732000	1403700	0.00769	0.0119	0.00151	0.00838
6	Road I-1(M)	732000	1403700	732000	1406400	0.0277	0.04297	0.00518	0.0304
7	Road I-1(N)	732000	1406400	733000	1407700	0.0222	0.0343	0.00412	0.0243
8	Mab Kha R.	733400	1407600	735000	1410000	0.049	0.0765	0.00947	0.0537
9	Nong Fab R.	729800	1402300	732000	1406400	0.0157	0.0245	0.00322	0.01695
10	Map Cha Lut R.	730000	1407500	732000	1406400	0.0148	0.0229	0.00297	0.01597
11	Ta Kuan R. (N)	735500	1403700	736200	1405900	0.0295	0.0457	0.00598	0.03189
12	Entrance East*	735500	1403700	740500	1404500	0.0169	0.0262	0.00331	0.01829
13	Road I-2*	732000	1403700	735500	1403700	0.0112	0.0174	0.0022	0.01219
14	Road I-7*	734000	1403700	734000	1405600	0.00562	0.00872	0.0011	0.00609

Emissions from four types of vehicle in major roads across the study area were estimated. Accounting for both evaporative and exhausted emissions, emission for benzene, toluene, ethylbenzene and xylene was estimated 0.47, 0.74, 0.09 and 0.52 g/s respectively. The ratio of B:T:E:X was found 26%:41%:5%:28% or 1: 1.58: 0.19: 1.08. The highest contribution was found from Sukhumvit road, which is the main road to eastern part of Thailand. Road I-1 and Ta kuan road are also the second and third significant contributor to the mobile loading in the area. The graphical result was shown in Figure 4.1.

4.3.2 Stationary Source Loading

There are three groups of major stationary sources in the area. The data of emission rates from the first group, two refineries, was directly gathered from an environmental section of the Alliance refinery co. ltd. Then, the missing data was estimated using Environment Australia (2000) manual. The gathered fugitive data also was rechecked with the two reports namely “Measures for Fugitive Emissions Abatement at Rayong Refinery “ and “ Air Emission Report and Environmental Quality Monitoring Report (Jan.-June 2002). The data were adjusted when appropriated.

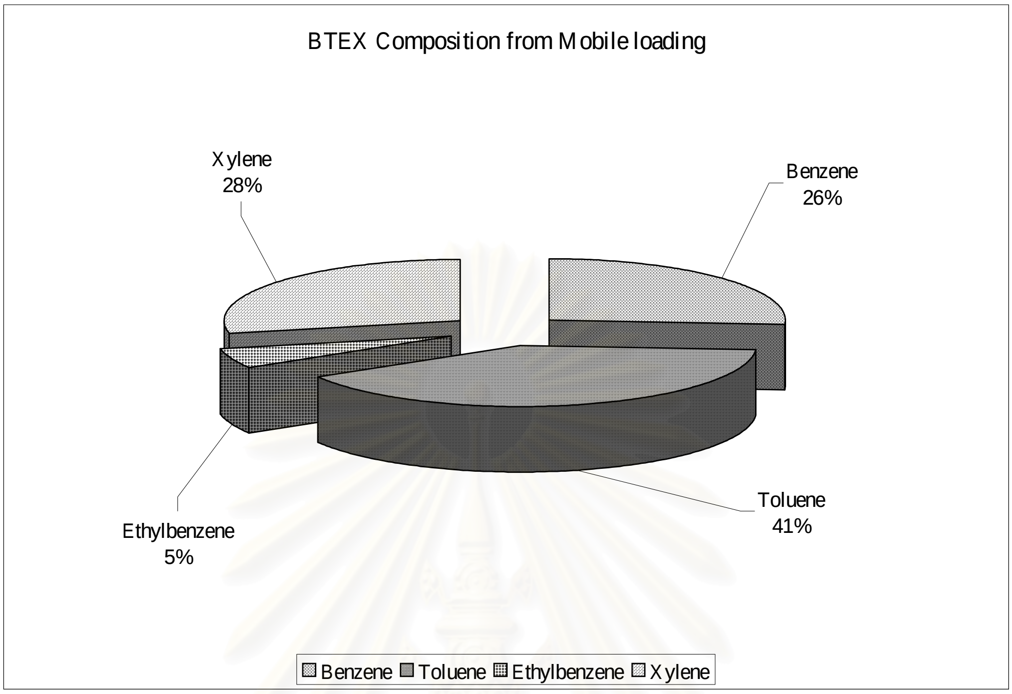


Figure 4.1: BTEX composition of Mobile Source Loading

The emission rates of second group, aromatic and olefin processes were gathered from the main report of Environmental Impact Assessment for each factory. Then, the missing data were estimated using Environment Australia manual (EA, 2000) and emission factors obtained from USEPA (USEPA, 1998; USEPA, 1994a; USEPA, 1994b and USEPA, 1995b). The speciation profiles were obtained from Limpaseni et al., 2003; Scheff et al., 1989; Doskey et al., 1999; PCD, 2002; and USEPA, 1977). The emission rates from third group, power plants and others, were compiled either by estimating using Environment Australia manual (EA, 2000) or by gathering measurement data from monitoring report and, then, multiplied by emission factors obtained from USEPA (USEPA, 1998; USEPA, 1994a and USEPA, 1994 b) if needed.

The calculation methods were illustrated in Chapter 3. Tables 4.18 -4.19 shows the emission loading of involved industries in the study area.

Table 4.18: BTEX Emission loading from refinery. This is the estimation of emission inventory using in this study only, which based on the available data in time.

No.	Sources	Source Identification	Source conditions[a]			VOCs emitted[b]	Speciation rate[c]							
			Height	Diameter	Area		B		T		E		X	
			m	m	m^2	Ton/y	$g/s/m^2$	g/s	$g/s/m^2$	g/s	$g/s/m^2$	g/s	$g/s/m^2$	g/s
1	Caltex Refinery	P1. Flaring	100	0.8		38.534[d]		0.0014		0.0016		NA		0.0007
		P2. Fuel oil	42.4	1.5		12.47[d]		0.003		0.0086		0.0001		0.00015
		P3. HRSG	21.7	3		2.54[d]		0.00003		0.00005		NA		NA
		A1. Process Fugitives	10		5000	245.55 [e*]	2E-6	0.01	2.32E-6	0.0116	NA	NA	1E-6	0.005
		A2. Valve & Fitting Fugitives	30		12500	2,200 [e*]	1.33E-05	0.166125	3.86E-05	0.48225	8.56E-07	0.0107	1.41E-5	0.1765
		A3. Tank Fugitives	15		62500	8,176 [e*]	1.117E-5	0.6983	3.245E-05	2.028	7.2E-07	0.045	1.188E-5	0.7423
		A4. Water treatment	5		150000	22.393 [g]	4.54E-08	0.0068145	1.19E-07	0.017895	1.42E-08	0.00213	NA	NA
		A10. Truck SPRC	5		2500	104.94 [e*]	1.06E-05	0.0264	3.07E-05	0.07675	6.786E-07	0.001697	1.12E-05	0.0281
		A13. Crude SPRC	15		25000	520.69 [d]	5.87E-08	0.0014675	1.71E-07	0.004275	3.77E-09	9.43E-05	6.24E-08	0.00156
	Subtotal (1)							0.914		3.112		0.06		0.955

Table 4.18: BTEX Emission loading from refinery (continued).

No.	Sources	Source Identification	Source conditions[a]			VOCs emitted[b]	Speciation rate[c]							
			Height	Diameter	Area		B		T		E		X	
			m	m	m^2	Ton/y	$g/s/m^2$	g/s	$g/s/m^2$	g/s	$g/s/m^2$	g/s	$g/s/m^2$	g/s
2	Rayong Refinery	P4. Flaring	110	1		34.174[d]		0.0012		0.0014		0		0.0006
		P5. VRU 1	5.0	0.15		[f]		0.6452		3.097		0.2258		0.6452
		P6. VRU 2	5.0	0.15		[f]		0.6452		3.097		0.2258		0.6452
		P7. Fuel gas	60	2.5		18.11[d]		0.00022		0.00035		0		0
		A5. Process Fugitives	10		5000	223.23 [e]	1.82E-6	0.0091	2.12E-6	0.0106	0	0	9.2E-7	0.0046
		A6. Valve & Fitting Fug.	30		12500	2,000 [e]	1.21E-05	0.151	3.51E-05	0.4385	7.76E-07	0.0097	1.28E-05	0.1605
		A7. Tank Fugitives	15		62500	3,593 [e]	4.34E-06	0.2711875	1.26E-05	0.7875	2.784E-07	0.0174	4.61E-06	0.288313
		A8. Water treatment	5		50000	19.858 [g]	1.28E-07	0.0064	3.18E-07	0.0159	3.776E-08	0.001888	0	0
		A11. Truck RRC	5		2500	93.06 [e]	2.81E-06	0.007025	8.16E-06	0.0204	1.81E-07	0.000453	2.99E-06	0.007468
		A14. Crude RRC	15		25000	461.75 [d]	5.34E-08	0.001335	1.55E-07	0.003875	3.43E-09	8.58E-05	5.68E-08	0.00142
		A09. Jetty	5		8000	492.69 [e]	5.16E-05	0.41288	0.00015	1.1992	3.32E-06	0.02656	5.49E-05	0.4392
		A12. Rail	5		2500	91.5[e]	3.24E-06	0.0081	9.36E-06	0.0234	0.0000002	0.0005	6.76E-06	0.0169
	Subtotal (2)							1.739		7.471		0.48		1.755

Table 4.18: BTEX Emission loading from refinery (continued).

No.	Sources	Source identification	Source conditions[a]			VOCs emitted[b]	Speciation rate[c]							
			Height	Diameter	Area		B		T		E		X	
			m	m	m^2	Ton/y	$g/s/m^2$	g/s	$g/s/m^2$	g/s	$g/s/m^2$	g/s	$g/s/m^2$	g/s
3	Rayong Purifyer	P8. Boiler, oil 1100 L/h	30	0.95		0.0104[d]		0.0001		0.00023		NA		0.00005
		A15. Tank &process fugitives	20		28000	0.0186 [g]	2.5E-08	0.0007	1.07E-07	0.002996	3.214E-08	0.0009	1.43E-07	0.004004
	Subtotal (3)							0.001		0.003		0.001		0.004

Note: A = area source, P = point source, Blank = not applicable, N.A = no data available

[a] Height and diameter of point sources obtained from DIW.

Released heights and area for area sources were estimated based on factory layout.

[b] VOCs emission rates in ton/year were directly gathered or estimated as noted .

[c] BTEX speciations were obtained by using source profiles as shown in Table 3.6.

[d] VOCs rates were obtained from monitoring report and factory report.

[e] VOCs rates were collected from the previous study (RRC, 1999).

[e*] VOCs rates for SPRC were prorated after the previous study (RRC, 1999).

[f] All data for VRU were directly obtained from monitoring report (RRC, 2002).

[g] VOCs rates were estimated using emission factors based on their production rates.

Table 4.19: BTEX emission loading from petrochemical related industry. This is the estimation of emission inventory using in this study only, which based on the available data in time.

No.	Sources	Source identification	Source conditions[a]			VOCs emitted[b]	Speciation rate[c]							
			Height	Diameter	Area		B		T		E		X	
			m	m	m^2	g/s	g/s/m^2	g/s	g/s/m^2	g/s	g/s/m^2	g/s	g/s/m^2	g/s
1.	Thai aromatic (ATC)	P9. Flaring	150	1.06		0.1208[f]		0.00114		0.0019		0.00042		0.00216
		P10. Feed prep.	52	1.42		0.0699[f]		0.00066		0.0011		0.00024		0.00125
		P11. Heavy Napth.	27	1.62		0.054[f]		0.00051		0.00085		0.00019		0.00096
		P12. CCR-Platform.	84	3.5		0.3077[f]		0.0029		0.0048		0.0011		0.0055
		P13. Feed Fract.	52	1.69		0.0631[f]		0.0088		0.0133		NA		NA
		P14. Tatory	26	1.98		0.0787[f]		0.011		0.0165		NA		NA
		P15. Xylene 1	41	2.13		0.0156[f]		NA		NA		NA		0.00546
		P16. Xylene 2	32	1.38		0.0376[f]		NA		NA		NA		0.01316
		P17. Xylene 3	44	2.58		0.2021[f]		NA		NA		NA		0.070735
		P18. Isomer	36	1.84		0.0789[f]		NA		NA		NA		0.02762
		A16. Tank Fugitives	15		15000	2.2054[f]	5.5E-06	0.0825405	1.56E-06	0.023423	1.461E-07	0.002192	0.000127	1.907235
		A17. Process, valve & fitting Fugitives	30		45000	[e]	0.000141	6.345	6.2E-06	0.279	NA	NA	2.44E-4	10.98
	Subtotal (1)							6.45		0.34		0.004		13.01

Table 4.19: BTEX emission loading from petrochemical related industry (continued).

No.	Sources	Source identification	Source conditions[a]			VOCs emitted[b]	Speciation rate[c]							
			Height	Diameter	Area		B		T		E		X	
			m	m	m^2	g/s	$g/s/m^2$	g/s	$g/s/m^2$	g/s	$g/s/m^2$	g/s	$g/s/m^2$	g/s
2.	Rayong olefin (ROC)	P19. Combined stack	37.5	2		[f]		0.2505		0.4175		0.0928		0.4732
		P20. GHU	20	0.76		0.0044[f]		0.0026		0.0018		NA		NA
		A18. Process Fugitives	30		50000	[e]	9.19E-05	4.5965	1.94E-05	0.97	NA	NA	NA	NA
		A19. Tank Fugitives (1)	15		30000	[e]	7.5E-06	0.225	2.18E-05	0.654	4.83E-06	0.1449	7.97E-06	0.2391
		A20. Tank Fugitives (2)	15		10000	[e]	2.11E-05	0.211	6.12E-05	0.612	0.0000014	0.014	2.24E-05	0.224
	Subtotal (2)							5.29		2.66		0.25		0.94
3.	Thai olefin	P21. Combined stack	33.5	1.5		[f*]		0.4285		0.6806		NA		NA
		A21. Process Fugitives	30		10000	[e]	1.24E-06	0.01239	NA	NA	NA	NA	NA	NA
	Subtotal (3)							0.44		0.68		NA		NA
4.	Thai petroche.	P22. Combined stack	42	1.5		[f*]		0.4285		0.6806		NA		NA
		A22. Process Fugitives	30		10000	[e]	1.24E-06	0.01239	NA	NA	NA	NA	NA	NA
	Subtotal (4)							0.44		0.68		NA		NA

Table 4.19: BTEX emission loading from petrochemical related industry (continued).

No.	Sources	Source identification	Source conditions[a]			VOCs emitted[b]	Speciation rate[c]							
			Height	Diameter	Area		B		T		E		X	
			m	m	m^2	g/s	$g/s/m^2$	g/s	$g/s/m^2$	g/s	$g/s/m^2$	g/s	$g/s/m^2$	g/s
5.	SSMC	P23. Vent & Flare	51	1.48		[f]		0.0476		NA		0.0081		NA
		A23. Process Fugitives	30		5000	[f]	7.18E-05	0.3592	4.62E-06	0.0231	0.0000548	0.274	NA	NA
		A24. Tank Fugitives	20		2500	[f]	3.32E-06	0.0083	NA	NA	0.0000778	0.1945	NA	NA
	Subtotal (5)							0.415		0.023		0.4685		NA
6.	Tuntex petroche.	P24. Coal fired	80	3		0.208[g]		0.0054		0.001		0.0004		0.0002
		A25. PTA-01	20		50000	[e]	NA	NA	NA	NA	NA	NA	0.00014	7
	Subtotal (6)							0.005		0.001		0.0004		7.0002
7.	Gas sep. plants.	P26. Waste heat	20	2.8		[f]		0.00125		0.00198		NA		NA
		P27. Aux. boiler	40	2.3		[f]		0.000475		0.000755		NA		NA
		P28. Combined stack1	20	2.8		[f]		0.00245		0.00389		NA		NA
		P29. Combined stack2	25	0.4		[f]		0.00159		0.00249		NA		NA
	Subtotal (7)							0.0058		0.0091		NA		NA
8.	Thai Tank	A26. Area1	15		20000	0.034[e*]	2.04E-09	4.088E-05	5.92E-09	0.000118	1.31E-10	2.62E-06	2.16E-09	4.32E-05
		A27. Area2	15		50000	7.44[e*]	1.75E-07	0.008745	5.13E-07	0.025635	1.134E-08	0.000567	1.88E-07	0.00938
	Subtotal (8)							0.009		0.026		0.0006		0.0094

Table 4.19: BTEX emission loading from petrochemical related industry (continued).

No.	Sources	Source identification	Source conditions[a]			VOCs emitted[b]	Speciation rate[c]							
			Height	Diameter	Area		B		T		E		X	
			m	m	m^2	g/s	g/s/m^2	g/s	g/s/m^2	g/s	g/s/m^2	g/s	g/s/m^2	g/s
9.	COCO3	P25. Coal fired stack	100	0.7		17.653[g]		0.459		0.0847		0.0332		0.0134
	COCO2	P33. Combined stack	35	3.75		[g]		0.12379		0.19661		0		0
	Padaeng	P32. Preheater	20	1.5		[g]		4.15E-07		1.37E-05		1.41E-07		2.41E-07
	Others	P30. HRSG	46	3.75		714[g]		0.002361		0.00375		0		0
		P31. HRSG	35	3.25		4.33[g]		0.0007274		0.001155		0		0
	Subtotal (9)							0.586		0.286		0.033		0.0134

Note: A = area source, and P = point source, Blank = not applicable, N.A = no data available

[a] Height and diameter of point sources obtained from DIW.

Released heights and area for area sources were estimated based on factory layout.

[b] VOCs emission rates in ton/year were gathered from latest EIA reports or estimated using emission factors (as noted).

[c] BTEX speciations were obtained by using source profiles as shown in Table 3.6.

[e, e*] VOCs or BTEX emission rates were estimated using emission factors (USEPA 1994a; 1994b and 1998) as shown in chapter 3.

[f] VOCs rates were obtained from latest EIA reports.

[g] VOCs or BTEX emission rates were estimated using raw material used multiplied by emission factors (EA, 1999).

Emission rates of involved industries in the study area were estimated. The 27 identified area sources were calculated of total 13.64, 7.71,0.75 and 22.24 g/s for BTEX respectively. The 33 point sources were estimated of total 3.07, 8.32,0.59 and 1.90 g/s for BTEX respectively. The significant area sources were the process fugitives of both upstream aromatic petrochemical plants. The composition of BTEX from stationary sources is shown in Table 4.20, Figures 4.2 and 4.3. The total load of stationary sources was calculated as 16.71, 15.03,1.34 and 24.14 g/s for BTEX respectively or 29%: 28%: 2%: 41% for B: T: E: X and The B/T ratio was 1.04.

Table 4.20: Contributions of stationary sources in the study area.

No.	Name	B	T	E	X
		g/s	g/s	g/s	g/s
1	Caltex Refinery	0.91	3.11	0.06	0.96
2	Rayong Refinery	1.74	7.47	0.48	1.76
3	Thai Aromatic	6.45	0.34	0.004	13.01
4	Rayong Olefin	5.29	2.66	0.25	0.94
5	Other Sources	2.32	1.45	0.55	7.48

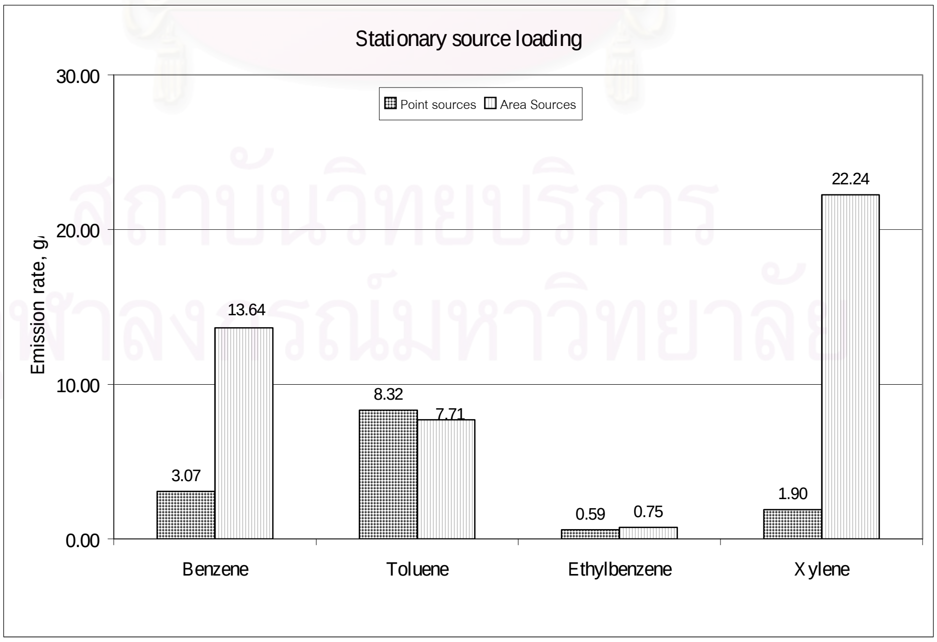


Figure 4.2: Stationary Source Loading

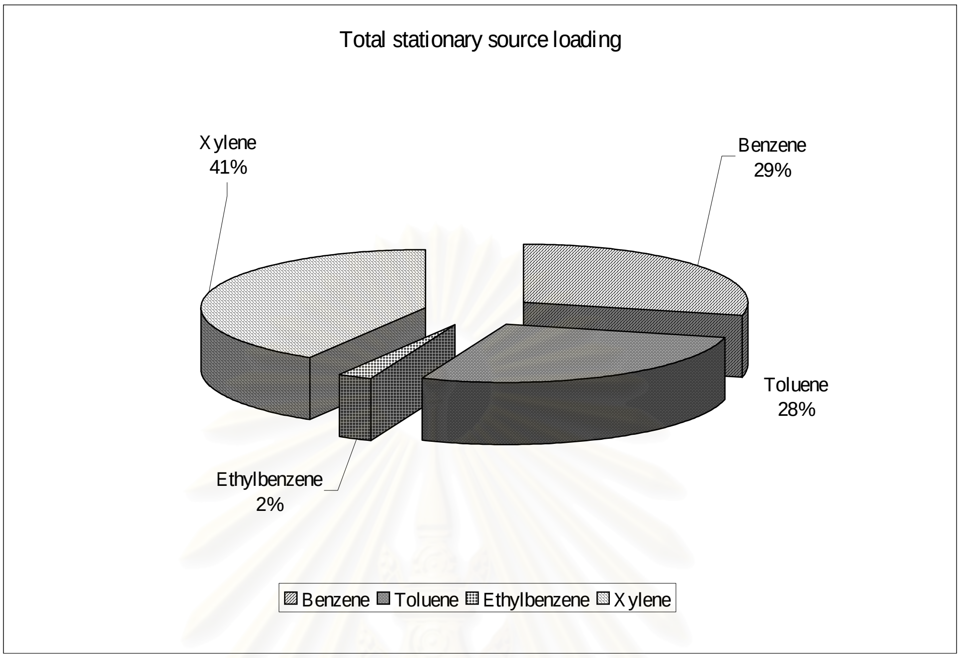


Figure 4.3: BTEX Composition from Stationary Sources

4.3.3 Total Loading from All Mobile and Stationary Sources

The total compiled loading from all potential sources in the area are the sums of mobile and stationary source loading as shown in Table 4.21 and Figure 4.4.

Table 4.21: Total loading from all mobile and stationary sources in the study area.

Sources	Benzene g/s	Toluene g/s	Ethylbenzene g/s	Xylene g/s
Mobile	0.47	0.74	0.09	0.52
Point	3.07	8.32	0.59	1.90
Area	13.64	7.71	0.75	22.24
Total	17.18	16.77	1.43	24.66

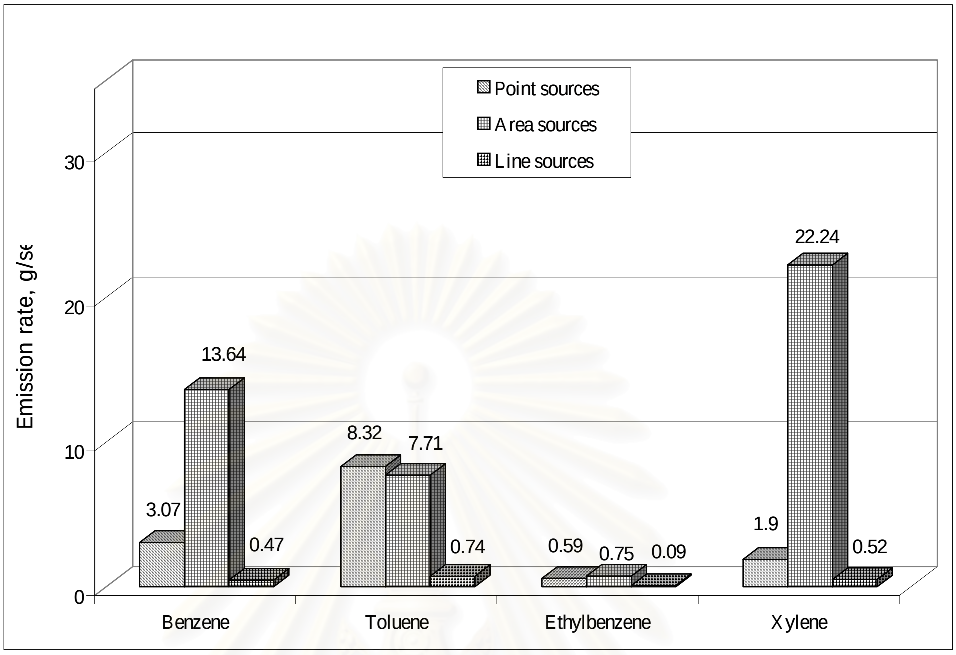


Figure 4.4: Compiled mobile and stationary source loading

These emission rates were the input of an ISCST3 model and the results were described in the next section.

4.4 Source Modeling

4.4.1 Preliminary Results Using a TAPM Version2 Model

The Air Pollution Model (TAPM) Version 2 model, which was developed by CSIRO Atmospheric Research, Australia, was used to simulate the effects of the compiled emission inventory on ambient concentrations of BTEX in the area. This model consists of coupled prognostic meteorological and air pollution concentration components. The predicted meteorological component provided by synoptic analysis eliminates the need to have site-specific meteorological observations, which generally required by a Gaussian model. The air pollution component of TAPM consists of four modules namely the Eulerian Grid Module (UGM), the Lagrangian Particle Module (LPM), the Plume Rise Module, and the Building Wake Module. This alternative approach, which has a friendly Guidance user interface (GUI) and other advantages, can be used to perform a yearlong simulation. The examples of simulating results using a TAPM model were shown in Appendix E.

4.4.2 Why was ISCST-3 used instead of TAPM in this research?

TAPM version 2.0 CD comes with a setup.exe directory, which uses for installing TAPM in any PC. It also comes with a GIS directory for output visualization. Some databases are provided on CD free of charge to TAPM users, and included terrain height, vegetation and soil type, sea-surface temperature, and synoptic-scale meteorology. A condition of use of these data sets with TAPM is that the data sources must be acknowledged in any publications, and that the data cannot be passed on to or used by unlicensed TAPM users.

TAPM with its components, prognostic meteorological and air pollution models, has some verification studied for various regions throughout Australia, for two US tracer experiments used for international model inter-comparison, and for wind-tunnel building wakes. The meteorological and pollution results showed that TAPM performs well in any cases (Hurley, 2002b).

The important limitation of applying TAPM in this research is the GRS photochemistry option in the model may not be suitable for examining small perturbations in emissions inventories, particularly in VOC emissions, due to the highly lumped approach taken for VOCs in this mechanism (Hurley, 2002a). In the optional Input-pollution of TAPM, There are six options: no pollution calculations (None), one tracer mode (TR1), two tracer mode (TR1, TR2), four tracer mode (TR1, TR2, TR3, TR4), a chemistry mode without sulfur and fine particle chemistry (APM, NO_x, NO_2, O_3), and a chemistry mode with sulfur and fine particle chemistry (APM, NO_x, NO_2, O_3 , SO_2, FPM).

In addition, during the one-month training at CSIRO, emission inventory was not well prepared even though the model was successfully run. The first week, Dr. Peter Hurley lectured how the TAPM and its components can perform for two days and the skills of manipulating the model were practiced. In the second week, input meteorological and pollution files were created and input in to the model and the skills of verification of the results were practiced. The results were not satisfied on the meteorological results when compared to the on-site observed data. In the third week, Dr. Ian Galbally lectured about the compilation of an emission inventory for BTEX and all data sources were suggested. For the forth week, the rough emission inventories were input into the model and four tracer mode, which not include chemistry or deposition processes. The predicted pollutant concentrations are output in units of $\mu g\ m^{-3}$. Thus, the TAPM simulations in this case just provided the overview of the simulating results. Furthermore, TAPM consumed longer time when near source option was selected since its Lagrangian approach (LPM mode) was run and followed by the Eulerian transport equation (EGM mode) within the definite grid (Hurley 2002a).

The ISCST-3 model was used in this research since it is free of charge, maintains continuously by USEPA, and its availability. The ISCST-3 also was widely used throughout the world and it has been accepted as a regulatory model in Thailand.

4.4.3 Predicted Concentrations during Monitoring Periods using an ISCST3 Model

An industrial Source Complex Short-term version 3 (ISCST-3) model was used to simulate the effects of the compiled emission rates on ambient concentrations of BTEX in the area. The meteorological data was prepared from the observed data of NongFab meteorological station, a one of three meteorological stations operated by the Industrial Estate Authority of Thailand (IEAT). As reported by IEAT, the data was audit using the Collocated Transfer Standard (CST) method, which installed the auditing sensors on meteorological measuring systems. The audited data included wind speed, wind direction, temperature and solar radiation. The stability classes of atmosphere were determined according to a Pasquill-Gifford method, which relied on an observed wind speed and a solar radiation for daytime and on an observed wind speed and cloudiness in nighttime. The cloudiness data was observed by the Thai Meteorological Department (MD) at Hauy pong meteorological station, 2 kms north of the study area. Mean mixing height of the atmosphere was determined using an observed maximum surface temperature and a vertical temperature profile on adiabatic diagram. The vertical temperature profile was measured by Pollution Control Department (PCD) using radiosonde at a Map Cha lut station within the area. The model was separately run for all sources in scenario of normal loading and higher loading and also run for individual source of line, point and area sources of normal loading. The higher loading was a compiled emission loading that fugitive emissions from two refineries were adjusted 10 times, which accounted for fugitive loading studied in 1998 from normal loading data. The modeling results and the comparison of the predicted values to measured values were found as follows:.

A. Downwind or residential sites

A.1 Rayong Skill Development Center (SDC)

As shown in Table 4.22 and 4.23, predicted concentrations of BTX at SDC and School site for normal and higher loading scenarios were the same except for the day that was influenced by points or area sources. The ambient concentrations were mainly influenced by mobile sources.

Table 4.22: Predicted values of BTX using two loading scenarios with detailed predicted for point, line and area sources at SDC site

Date	Benzene						Toluene						Xylene					
	Mea-sured	Predicted values				higher load	Mea-sured	Predicted values				higher load	Mea-sured	Predicted values				higher load
		Line	Point	Area	Total			Line	Point	Area	Total			Line	Point	Area	Total	
22/2/02	18.6	0.15	0.00	0.00	0.2	0.2	3.3	0.3	0.00	0.00	0.3	0.3	0					
23/2/02	4.7	0.26	0.00	0.00	0.3	0.2	1.1	0.2	0.00	0.00	0.2	0.2	0					
24/2/02	5.8	0.16	0.00	0.00	0.2	0.2	72.8	0.4	0.00	0.00	0.4	0.4	0					
25/2/02	4.4	0.18	0.00	0.00	0.2	0.2	3.5	0.5	0.00	0.00	0.5	0.5	0					
26/2/02	4.1	0.17	0.00	0.00	0.2	0.2	0.9	0.3	0.00	0.00	0.3	0.3	0					
27/2/02	4.1	0.26	0.00	0.00	0.3	0.2	1.1	0.3	0.00	0.00	0.3	0.3	0					
28/2/02																		
29/4/02	3	0.3	0.00	0.00	0.3	0.2	2.2	0.5	0.00	0.00	0.6	0.5	0					
30/4/02	3.8	0.16	0.00	0.00	0.2	0.2	7.3	0.4	0.00	0.00	0.4	0.4	0					
1/5/02	8.6	0.5	0.00	0.00	0.5	0.5	0.9	0.6	0.00	0.00	0.6	0.6	0					
2/5/02	3.2	0.4	0.00	0.00	0.4	0.4	0.8	0.3	0.00	0.00	0.3	0.3	0					
3/5/02	3.7	0.3	0.00	0.00	0.3	0.3	3.1	0.4	0.00	0.00	0.4	0.4	0					
4/5/02	4.2	0.8	1.8	5.3	7.9	11.2	41.9	0.2	3.9	3.2	7.5	14.7	0					
5/5/02	4	0.2	0.00	0.00	0.2	0.2	4	0.5	0.00	0.00	0.5	0.5	0					
19/6/02	0						22.6	0.4	0.00	0.00	0.4	0.4	0					
20/6/02	0						0.8	0.7	0.00	0.00	0.7	0.7	0					
21/6/02																		
22/6/02	0						1.5	0.3	0.00	0.00	0.3	0.3	0					
23/6/02	11.7	0.5	0.00	0.00	0.5	0.5	7.2	0.7	0.00	0.00	0.7	0.7	0					
24/6/02	2.7	0.1	0.00	0.00	0.1	0.1	2.5	0.2	0.00	0.00	0.2	0.2	0					
25/6/02	4.4	0.4	0.00	0.00	0.4	0.4	2.5	0.8	0.00	0.00	0.8	0.8	0.5	0.6	0.00	0.00	0.6	0.6

Note: 1. Without background concentrations

2. Blanks mean no measured data to compare

A.2 Map Ta Phut Phanvittayakarn School (School)

Table 4.23: Predicted values of BTX using two loading scenarios with detailed predicted for point, line and area sources at School site

Date	Benzene						Toluene						Xylene					
	Mea-sured	Predicted values				higher load	Mea-sured	Predicted values				higher load	Mea-sured	Predicted values				higher load
		Line	Point	Area	Total			Line	Point	Area	Total			Line	Point	Area	Total	
22/2/02	2.1	0.1	0.00	0.00	0.10	0.10	10.9	0.10	0.00	0.00	0.1	0.1	0					
23/2/02	6	0.2	0.00	0.00	0.20	0.20	9.1	0.1	0.00	0.00	0.1	0.1	0					
24/2/02	4.3	0.09	0.00	0.00	0.1	0.10	4.9	0.1	0.00	0.00	0.14	0.14	0					
25/2/02	4.8	0.08	0.00	1.0	1.1	1.4	5.1	0.09	0.00	2.80	2.9	3.2	0					
26/2/02	4.4	0.12	0.00	0.00	0.1	0.12	3.9	0.1	0.00	0.00	0.1	0.1	0					
29/4/02	3.5	0.07	0.00	0.8	0.9	1.0	2.7	0.15	0.00	1.1	1.3	1.8	0					
30/4/02	3.8	0.08	0.00	0.00	0.1	0.1	2.6	0.4	0.00	0.00	0.40	0.4	0					
1/5/02	3.7	0.09	0.00	0.05	0.14	0.14	2.1	0.14	0.00	4.1	4.3	5.8	0					
2/5/02	6	0.12	0.00	0.00	0.12	0.12	4.1	0.19	0.00	0.00	0.20	0.2	1	0.1	0.00	0.00	0.1	0.1
3/5/02	3	0.05	0.00	0.07	0.12	0.12	2.3	0.07	0.00	0.10	0.20	0.2	0					
4/5/02	5	0.37	0.00	0.60	1.0	2.3	7.1	0.53	0.00	2.50	3.0	6.7	0.7	0.37	0.00	0.00	0.4	5.5
5/5/02	7.2	0.08	0.00	0.5	0.6	0.1	5.6	0.29	0.00	0.00	0.3	0.3	1.6	0.06	0.00	0.8	0.9	2.5
19/6/02	3.2	0.1	0.00	0.00	0.1	0.1	2.5	0.2	0.00	0.00	0.2	0.2	0					
22/6/02																		
23/6/02	3.8	0.1	0.17	21.3	21.6	24.3	2.7	0.14	0.00	7.0	7.1	15	0					
24/6/02																		
25/6/02																		

Note: 1. Without background concentrations

2. Blanks mean no measured data to compare

A.3 Ta Kuan Health Center (THC)

As shown in Table 4.24, predicted concentrations of BTX at THC site exhibited the differences when the higher loading scenario was used instead of normal loading scenario. At this site, there are more effects from point and area sources on the ambient concentrations, which mainly affected by mobile sources.

Table 4.24: Predicted values of BTX using two loading scenarios with detailed predicted for point, line and area sources at THC site

Date	Benzene						Toluene						Xylene					
	Mea-sured	Predicted values				higher load	Mea-sured	Predicted values				higher load	Mea-sured	Predicted values				higher load
		Line	Point	Area	Total			Line	Point	Area	Total			Line	Point	Area	Total	
22/2/02	23	0.1	0.00	0.00	0.1	0.1	18.7	0.08	0.00	0.00	0.1	0.1	3.2	0.05	0.00	0.00	0.1	0.1
23/2/02	4.9	0.05	0.00	0.00	0.1	0.1	7.1	0.07	0.00	0.00	0.1	0.1	6.8	0.05	0.00	0.00	0.1	0.1
24/2/02	5.6	0.15	0.00	0.00	0.1	0.2	12.7	0.24	0.00	0.00	0.24	0.25	5.9	0.17	0.00	0.01	0.2	0.2
25/2/02	5	0.62	0.50	0.5	1.6	4.8	7.4	0.6	0.00	0.40	1.0	2	4	0.16	0.04	0.00	0.2	0.1
26/2/02	4.3	0.07	0.00	0.00	0.1	0.1	8.1	0.06	0.00	0.00	0.1	0.1	2.7	0.04	0.00	0.00	0.1	0.1
27/2/02	10.3	0.1	0.00	0.00	0.1	0.14	370.5	0.21	0.00	0.00	0.2	0.2	30.3	0.15	0.00	0.00	0.2	0.2
28/2/02																		
29/4/02																		
30/4/02	3.2	0.13	0.00	0.00	0.1	0.1	3.7	0.2	0.00	0.00	0.2	0.2	0					
1/5/02	4.9	0.95	0.00	4.3	5.3	8.7	3.5	1.48	0.00	3.0	3.5	3.9	0					
2/5/02	4.8	0.13	0.00	0.00	0.1	0.1	7.9	0.11	0.00	0.06	0.2	0.2	1.1	0.1	0.00	0.0	0.1	0.1
3/5/02	4.9	0.1	0.00	0.00	0.1	0.1	5.7	0.19	0.00	0.3	0.5	2.3	0					
4/5/02	7.2	0.1	0.00	0.00	0.1	0.1	8.7	0.15	0.00	0.00	0.2	0.2	2.2	0.1	0.00	0.00	0.1	0.1
5/5/02	5.5	0.2	0.00	0.00	0.2	0.2	2.8	0.1	0.00	0.10	0.2	0.2	0					
19/6/02	0						4.1	0.12	0.00	0.00	0.1	0.1	0					
20/6/02	4.2	0.12	0.00	0.00	0.12	0.1	8.8	0.18	0.00	11.6	11.8	15	3.4	0.13	0.00	0.00	0.1	0.1
21/6/02	11.8	0.08	0.00	0.00	0.08	0.1	19.8	0.13	0.00	0.00	0.1	0.1	7.6	0.09	0.00	0.00	0.1	0.1
22/6/02	11.3	0.07	0.00	0.00	0.07	0.1	4.9	0.05	0.00	0.00	0.1	0.1	0					
23/6/02	4	0.18	0.65	0.6	1.4	7.2	8.5	0.16	1.13	4.70	6.0	11.9	1.4	0.36	0.04	2.0	2.4	6
24/6/02	5.6	0.04	0.00	0.00	0.1	0.1	6.2	0.05	0.00	0.00	0.1	0.1	1.4	0.1	0.00	0.00	0.1	0.1
25/6/02	9.8	0.15	0.00	8.9	9.1	15	10.4	0.2	0.18	1.00	3.7	5	2.3	0.1	0.00	0.5	0.8	2.7

Note: 1. Without background concentrations

2. Blanks mean no measured data to compare

B. Industrial sites within the complex

For the two industrial sites, TSK and NFC, the predicted concentrations of BTX for normal and higher loading scenarios were quite different. The ambient concentrations were clearly affected by all sources and the fluctuation of concentrations relied mainly on emissions from point and area sources rather than mobile sources. The results for both sites were shown in Tables 4.25 and 4.26.

B.1 Thai Shin Kong Factory's guardhouse (TSK)

Table 4.25: Predicted values of BTX using two loading scenarios with detailed predicted for point, line and area sources at TSK site

Date	Benzene						Toluene						Xylene					
	Mea-sured	Predicted values				higher load	Mea-sured	Predicted values				higher load	Mea-sured	Predicted values				higher load
		Line	Point	Area	Total			Line	Point	Area	Total			Line	Point	Area	Total	
22/2/02	32.1	0.18	0.19	3.0	3.4	45.5	220.8	0.3	0.23	31.5	32	102.6	41.9	0.12	0.17	6.5	6.8	29.1
23/2/02	7.3	0.21	0.26	2.1	2.6	42.3	110	0.4	0.03	23.0	23.5	111.7	0					
24/2/02	6.6	0.18	0.5	3.6	4.3	17.3	138.3	0.24	0.34	15.4	16.0	31.6	4.6	0.22	0.25	2.6	3.1	6.3
25/2/02	5.3	0.28	0.47	1.95	2.7	3.2	77.9	0.31	0.8	7.6	8.7	25.5	13.8	0.4	0.41	2.1	2.9	13
26/2/02																		
27/2/02	6.4	0.18	0.49	4.3	5.0	19.2	92.3	0.29	0.09	19.6	20	44.3	12.1	0.22	0.03	7.9	8.2	17.6
28/2/02																		
29/4/02	3.5	0.22	0.51	4.2	4.9	6.3	1.6	0.28	0.39	3.5	4.2	4.6	3.6	0.2	0.23	1.3	1.8	1.4
30/4/02	5.2	0.15	0.33	4.7	5.2	20.3	6.3	0.23	0.27	6.3	6.8	27	15.8	0.16	0.28	5.3	5.7	11.8
1/5/02	5.9	0.2	0.37	0.13	0.7	7.8	3.1	0.66	0.43	1.4	2.5	4.1	0					
2/5/02	6.5	0.25	0.24	3.6	4.1	16.9	5.8	0.66	0.03	7.4	8.1	11.7	7.5	0.47	0.00	5.6	6.1	4.1
3/5/02	3.8	0.17	0.47	2.7	3.4	3.4	5	0.39	0.95	6.3	7.7	5.2	7	0.28	0.78	3.2	4.3	1.9
4/5/02	16.9	0.00	0.44	2.8	3.3	10.8	23.3	0.00	3.3	12.0	15.3	33.4	2.3	0.00	0.69	0.9	1.6	4.2
5/5/02	8.2	0.16	0.47	7.5	8.1	9.0	8.6	0.29	0.73	2.2	3.3	3.7	8.6	0.21	0.42	1.2	1.8	1.5
19/6/02	4.8	0.30	0.00	4.6	4.9	16.2	8	0.46	0.00	22.1	22.6	45.3	9.4	0.33	0.00	8.8	9.1	16.7
20/6/02	3.4	0.24	0.5	2.9	3.6	25.3	83.4	0.48	0.15	26.0	26.6	149.4	12.6	0.34	0.12	10.5	11.0	19.9
21/6/02	4.9	0.18	0.00	6.2	6.4	16.1	6.5	0.5	0.00	10.7	11.2	44.5	3.4	0.36	0.00	6.3	6.7	16.5
22/6/02																		
23/6/02	4.9	0.35	1.75	4.4	6.5	8.7	4.4	0.59	2.73	1.2	4.5	4.6	0.4	0.4	0.00	0.9	1.3	3.5
24/6/02	9.8	0.22	0.00	2.2	2.4	29.7	11.6	0.31	0.01	12.2	12.5	107	6	0.22	0.00	6.1	6.3	21.8
25/6/02																		

Note: 1. Without background concentrations

2. Blanks mean no measured data to compare

B.2 National Fertilizer Factory’s guardhouse (NFC)

Table 4.26: Predicted values of BTX using two loading scenarios with detailed predicted for point, line and area sources at NFC site

Date	Benzene						Toluene						Xylene					
	Measured	Predicted values				higher load	Measured	Predicted values				higher load	Measured	Predicted values				higher load
		Line	Point	Area	Total			Line	Point	Area	Total			Line	Point	Area	Total	
29/4/02																		
30/4/02																		
1/5/02	8.6	0.38	1.35	0.1	1.7	1.9	0						4.1	0.3	0.00	0.00	0.3	0.3
2/5/02	3.6	0.25	0.58	1.9	2.7	3.1	1.4	0.58	0.87	3.7	5.1	5.8	0					
3/5/02																		
4/5/02	20.9	0.00	0.26	4.1	4.4	7.8	5.6	0.00	1.93	5.7	7.6	8.6	0					
5/5/02	3.4	0.16	0.48	2.3	2.9	3.3	0						0					
19/6/02																		
20/6/02																		
21/6/02	3	0.17	0.64	7.1	7.9	9.3	3.9	0.48	0.61	10.5	11.6	12.8	0					
22/6/02	0						1.6	0.26	1.25	2.2	3.7	12.8	0					
23/6/02	3.4	0.50	2.20	0.3	3.0	3.0	3.3	0.59	3.50	0.00	4.1	6.5	0.7	0.3	0.00	0.00	0.3	0.3
24/6/02	0						1.2	0.28	0.74	4.0	5.1	7.4	0					
25/6/02	2.8	0.39	1.4	0.1	1.9	1.9	10.3	0.58	0.1	3.2	3.9	7.4	0					

Note: 1. Without background concentrations

2. Blanks mean no measured data to compare

C. Upwind sites

At the two upwind sites, IEAT and Padaeng, BTX predicted concentrations were found slightly affected by mobile sources for whole monitoring periods, while point and area sources slightly contributed effects during a dry and wet season. At these monitoring sites, average concentrations were almost the same as those at a referent site. The predicted concentrations for load normal and higher loading scenarios were found almost the same amounts. The simulation results for these two sites were shown in Tables 4.27 and 4.28.

C.1 IEAT office (IEAT)

Table 4.27: Predicted values of BTX using two loading scenarios with detailed predicted for point, line and area sources at IEAT site

Date	Benzene						Toluene						Xylene					
	Mea-sured	Predicted values				higher load	Mea-sured	Predicted values				higher load	Mea-sured	Predicted values				higher load
		Line	Point	Area	Total			Line	Point	Area	Total			Line	Point	Area	Total	
22/2/02	17.7	0.17	0.1	0.07	0.3	0.3	4.3	0.21	0.1	1.0	1.3	1.3	0					
23/2/02	0						1.6	0.19	0.3	0.00	0.5	1	3.4	0.17	0.00	0.01	0.2	0.2
24/2/02	4	0.08	0.00	0.00	0.1	0.1	2.1	0.11	0.6	0.00	0.7	0.7	0					
25/2/02	3.7	0.02	0.3	0.00	0.4	0.03	1.2	0.16	0.00	0.01	0.2	0.2	0					
26/2/02	3.8	0.08	0.1	0.00	0.19	0.19	1.6	0.14	0.28	0.31	0.7	0.7	0					
27/2/02	4.1	0.08	0.2	0.00	0.24	0.24	8.6	0.12	0.25	0.5	0.9	0.9	0					
28/2/02																		
29/4/02	4.7	0.09	0.00	0.00	0.1	0.1	4	0.13	0.04	0.00	0.3	0.3	0					
30/4/02	0						0						0					
1/5/02	4.3	0.09	0.00	0.00	0.1	0.1	0											
2/5/02	0						2	0.25	1.86	1.2	3.4	3.4	0					
3/5/02	0						0.7	0.13	0.00	0.6	0.8	1.0	0					
4/5/02	13.2	0.07	0.00	2	2.1	2.6	4.5	0.1	0	2.3	2.4	8	0					
5/5/02																		
19/6/02	0						2.1	0.2	0.5	4.3	5.0	8.8	0					
20/6/02																		
21/6/02	0						0						0					
22/6/02	0						1.4	0.1	0.48	0.00	0.6	4.1	0					
23/6/02	0						0						0					
24/6/02	13.2	0.08	0.6	2.9	3.1	3.1	4.5	0.11	0.68	0.9	1.7	1.7	0					
25/6/02																		

Note: 1. Without background concentrations

2. Blanks mean no measured data to compare

Table 4.28: Predicted values of BTX using two loading scenarios with detailed predicted for point, line and area sources at Padaeng site

Date	Benzene						Toluene						Xylene					
	Measured	Predicted values				higher load	Measured	Predicted values				higher load	Measured	Predicted values				higher load
		Line	Point	Area	Total			Line	Point	Area	Total			Line	Point	Area	Total	
22/2/02																		
23/2/02	0						2	0.06	0.00	0.00	0.1	0.1						
24/2/02	3.9	0.04	0.00	0.00	0.04	0.04	3.7	0.15	0.00	0.00	0.1	0.1	3.1	0.1	0.1	0	0.2	0.2
25/2/02	4.1	0.04	0.00	0.00	0.04	0.04	0	0.06	0.00	0.00	0.06	0.06						
26/2/02	3.6	0.04	0.00	0.00	0.04	0.04	5.1	0.08	0.00	0.00	0.1	0.1						
27/2/02	3.6	0.04	0.06	0.00	0.1	0.1	2.8	0.06	0.00	0.1	0.2	0.1						
28/2/02																		
29/4/02																		
30/4/02																		
1/5/02																		
2/5/02	0						0.9	0.28	0.3	2.0	2.6	2.6						
3/5/02	3.8	0.03	0.00	0.00	0.07	0.07	0.9	0.12	0.00	0.00	0.1	0.1						
4/5/02	0						2.3	0.01	0.00	1.6	1.7	8.2						
5/5/02																		
19/6/02																		
20/6/02																		
21/6/02	0						0											
22/6/02	0						1.3	0.2	0.00	1.1	1.3	1.3						
23/6/02																		
24/6/02	2.7	0.08	0.00	0.00	0.08	0.08	1.5	0.13	0.00	0.00	0.1	0.1						
25/6/02																		

Note: 1. Without background concentrations

2. Blanks mean no measured data to compare

4.4.4 Comparison of Predicted and Measured Values during Monitoring Periods

The predicted values obtained from normal and higher loading scenarios were compared to observed values described in part 1. The results found that there was slightly correlation coefficient (r=0.35) at two upwind monitoring sites and a higher correlation coefficient (r=0.35) was found at two downwind sites and the highest correlation coefficient (r=0.76) was found at two industrial sites. The both data were analyzed and found a linear regression of Y = 0.15X + 2.99, Y = 0.13X + 7.15 and Y = 0.11X + 3.18 with the coefficient of determination (R^2) of 0.12, 0.58 and 0.13 for 2-upwind, 2-industrial and 2-

downwind sites respectively. Since it was found significant local sources at the THC site, the data of this site was determined separately and found a negative correlation coefficient (r= 0.17) with a linear regression of Y = 0.11X + 2.87 and a coefficient of determination (R^2) 0.03. The predicted and measured values for all six monitoring sites were found the factor of two of 72%. Detailed results were presented in Table 4.29 and the example of modeling results were illustrated in Figures 4.5 and 4.6 (a),(b),(c).

Table 4.29: Predicted vs Measured values for 2-upwind, 2-industrial and 2-downwind sites for normal loading scenario

Sites	method	No. of data	Corr. Coeff. (r)	Factor of two	Coeff. of determ. (R^2)	a	b
2-upwind sites	Predicted Measured	37 37	0.35	72%	0.12	0.15	2.99
2-industrial sites	Predicted Measured	62 62	0.76		0.58	0.13	7.15
2-downwind sites	Predicted Measured	66 66	0.35		0.13	0.11	3.18
THC site	Predicted Measured	46 46	0.17	61%	0.03	0.11	2.87

When using higher loading scenario, which has much higher of fugitive emissions from refineries than the normal loading. The R^2 for 2-industrial sites went down to 0.42 with correlation coefficient 0.65. In addition, there were slightly effects on predicted concentrations at two downwind sites but for two upwind sites. The factor of two between the two values decreased from 0.65 to 0.61.

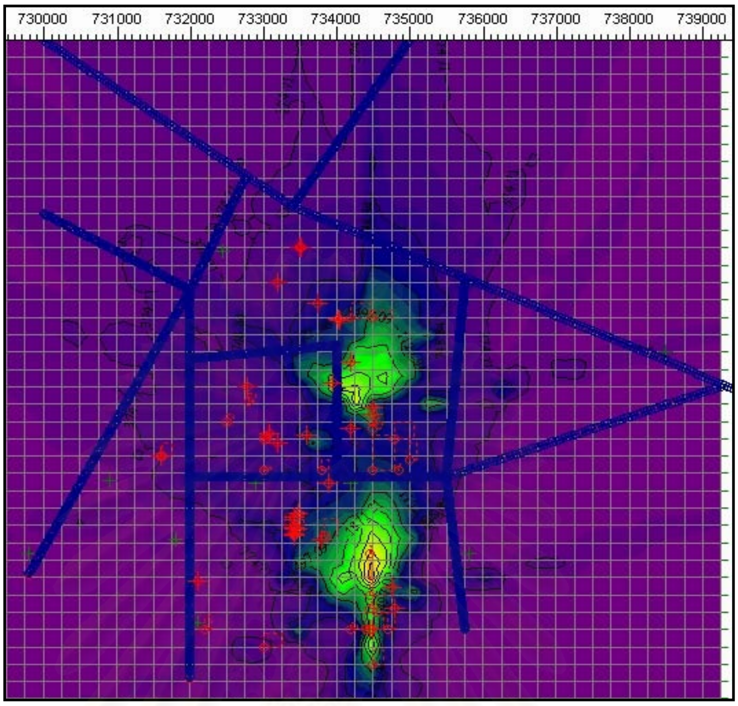
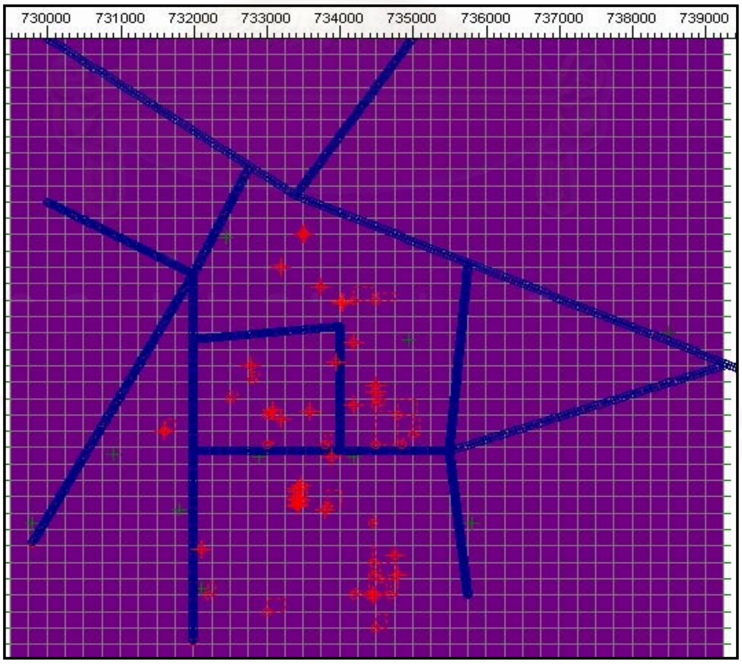
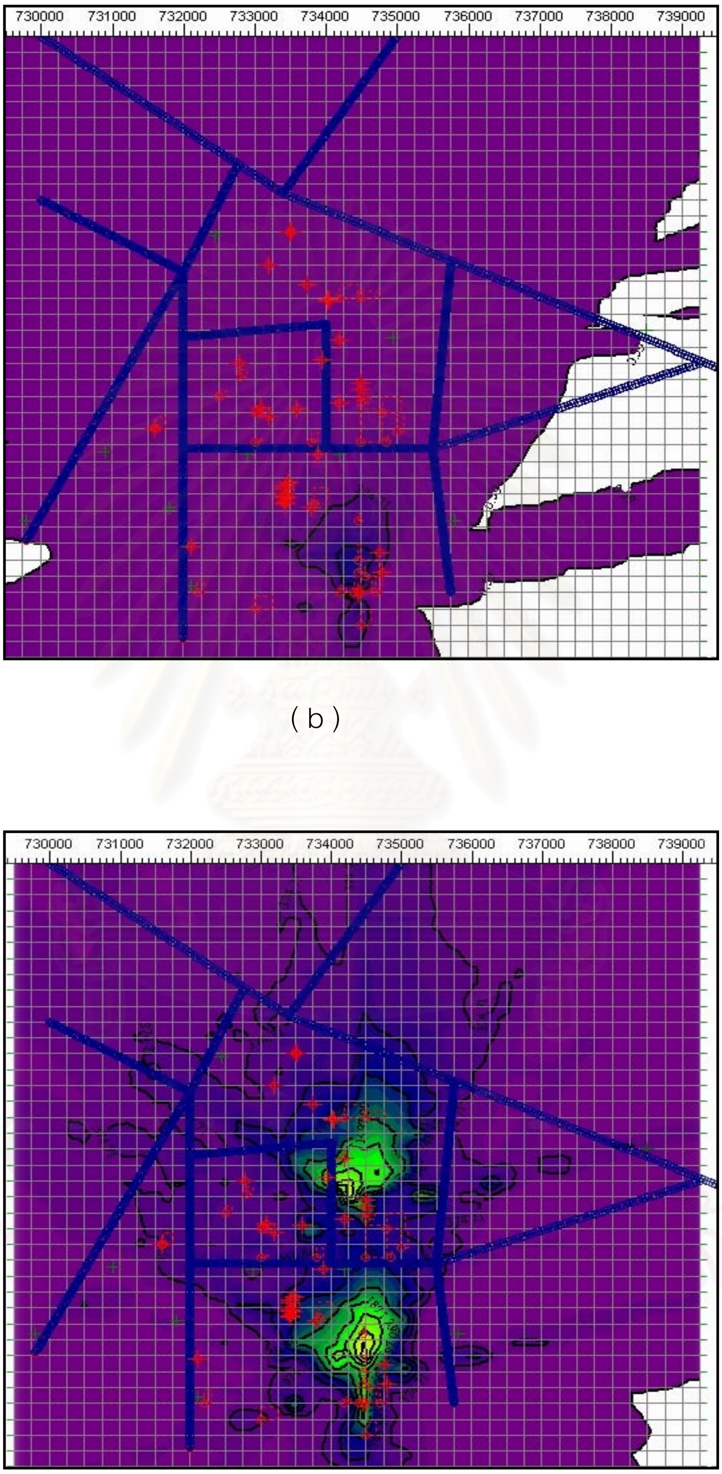


Figure 4.5: Isoplete Diagram of Benzene concentrations from all sources during 29 Apr-5 May 2002.



(a)



(c)

Figure 4.6: Isoplete Diagram of benzene concentrations from (a) line, (b) point and (c) area sources during 29 Apr. – 5 May 2002.

4.5 Predicted Annual and Maximum 24-hrs Average Concentrations using an ISCST3 Model

The compiled emission in normal loading scenario was simulated using the 2002 meteorological data, a worse case meteorological condition, to predict annual average concentrations of BTEX at all monitoring sites. The highest annual concentrations for BTX species were found at the industrial site, TSK of 10.8, 31.2, and 24.3 $\mu g/m^3$ respectively. The other site within the estate, NFC, was found the highest concentrations of ethylbenzene 3.2 $\mu g/m^3$ and found the second rank for xylene. A downwind site, School site was the second rank of highest concentrations for BT at 9.9 and 29.3 $\mu g/m^3$ respectively, while THC had slightly effects from these sources. At 2-upwind sites, BTEX annual averages were found in the same range and found concentrations of 5.2, 8.1, 0.9 and 10.6 $\mu g/m^3$ at IEAT. At two checking sites, NongFab and PAC, annual BTEX were found higher concentration at NongFab, while PAC was found slightly affected by emission sources in the area. Detailed results were exhibited in Tables 4.30 (a), (b), (c) and (d). The isoplete diagram for the year 2002 of benzene from all sources was shown in Figure 4.7, of toluene from line sources in Figure 4.8, of ethylbenzene from point sources in Figure 4.9 and of xylene from area sources in Figure 4.10.

Table 4.30: Annual predicted values at monitoring sites

Table 4.30a: Average Conc. of Benzene in $\mu g/m^3$ (without background concentrations)

Site No.	Max. 24 hrs average	Predicted Annual average	Average Measured conc. For all 3 periods	Ambient Standard		Health Benchmark	
				24 hrs Average	Annual	Chronic effects	Acute effect
1	-	2.6	5.1	44	16.2	60	1000
2	-	3.8	1.7				
3	-	5.2	3.8				
4	-	7.0	7.1				
5	-	6.4	4.8				
6	-	9.9	4.1				
7	-	1.5	6.9				
8	-	10.8	7.7				
9	-	9.8	3.8				
10	-	1.6	3.0				

Table 4.30b: Average Conc. of Toluene in $\mu g/m^3$ (without background concentrations)

Site No.	Max. 24 hrs average	Annual average Normal loading	Average Measured conc. For all three periods	Ambient Standard		Health benchmark	
				24 hrs average	Annual average	Chronic effect	Acute effect
1	41.5	3.8	24.9	3,000	-	400	3.7×10^4
2	70.8	7.1	1.9				
3	100.4	8.1	2.2				
4	103.1	10.6	11.3				
5	56.1	8.3	9.5				
6	153.6	29.3	4.7				
7	79.8	3.2	27.2				
8	196.9	31.2	47.5				
9	107.1	18.0	2.5				
10	22.1	2.5	14.8				

Table 4.30c: Average Conc. of Ethylbenzene in $\mu g/m^3$ (without background concentrations)

Site No.	Max. 24 hrs average	Annual average Normal loading	Average Measured conc. For all three periods	Ambient Standard		Health benchmark	
				24 hrs Average	Annual average	Chronic effect	Acute effect
1	2.7	0.3	0.6	3,500	-	1,000	1.0x10^4
2	4.5	0.6	0				
3	6.3	0.86	0.7				
4	6.4	0.87	1.4				
5	6.3	0.7	0.3				
6	7.4	1.3	0.2				
7	5.8	0.2	1.3				
8	13.0	1.6	1.0				
9	10	3.2	0.4				
10	2.1	0.4	0.1				

Table 4.30d: Average Conc. of Xylene in $\mu g/m^3$ (without background concentrations)

Site No.	Max. 24 hrs average	Annual average Normal loading	Average Measured conc. For all three periods	Ambient Standard		Health benchmark	
				24 hrs average	Annual average	Chronic effect	Acute effect
1	67.2	5.4	3.2	3,500	-	700	2.2x10^4
2	74.7	7.5	0.2				
3	92.8	10.6	0.6				
4	76.8	14.4	2.5				
5	89.8	9.6	0.2				
6	91.8	13.6	0.2				
7	40.8	1.5	3.8				
8	134.5	24.3	8.3				
9	128.1	23.4	2.4				
10	29.5	2.0	0.4				

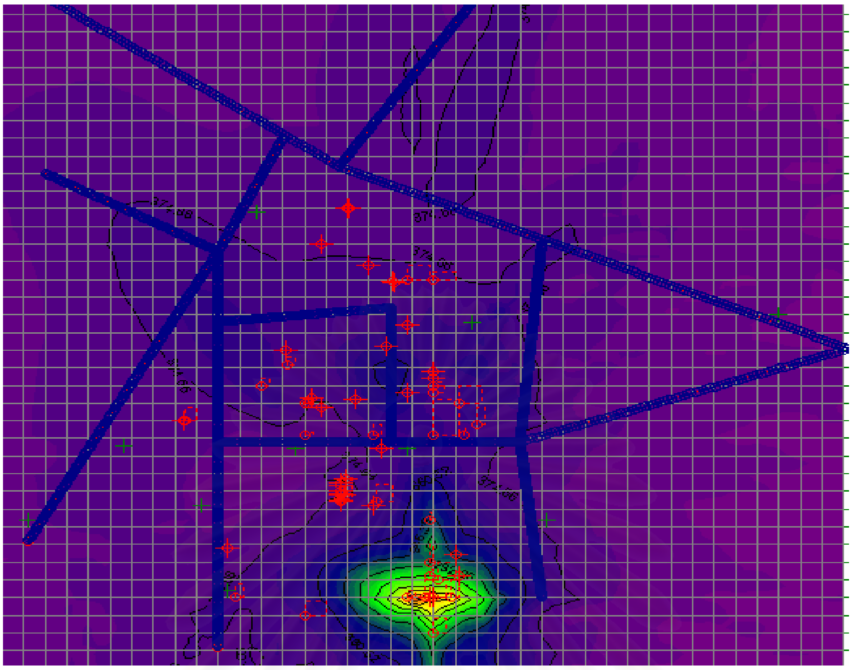


Figure 4.7: Isoplete Diagram for Benzene from all sources for the year 2002.

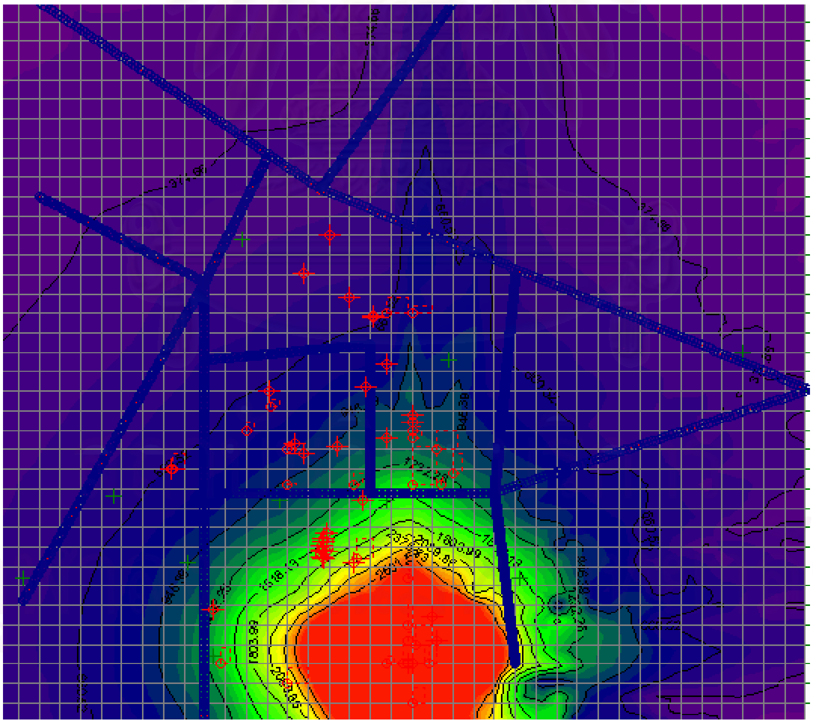


Figure 4.8: Isoplete Diagram for Toluene from all sources for the year 2002.

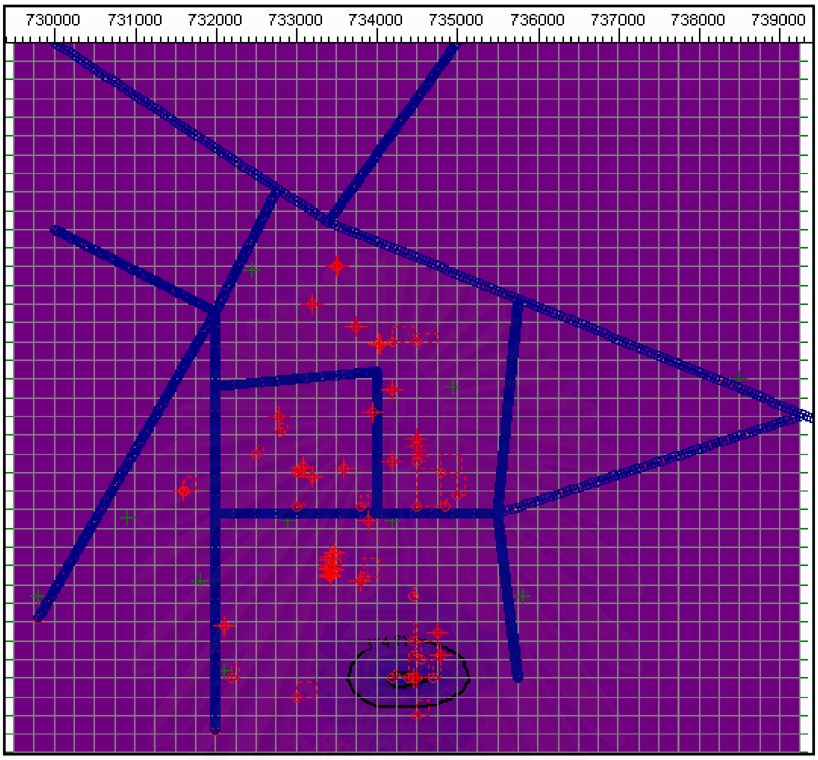


Figure 4.9: Isoplete Diagram for Ethylbenzene from all sources for the year 2002.

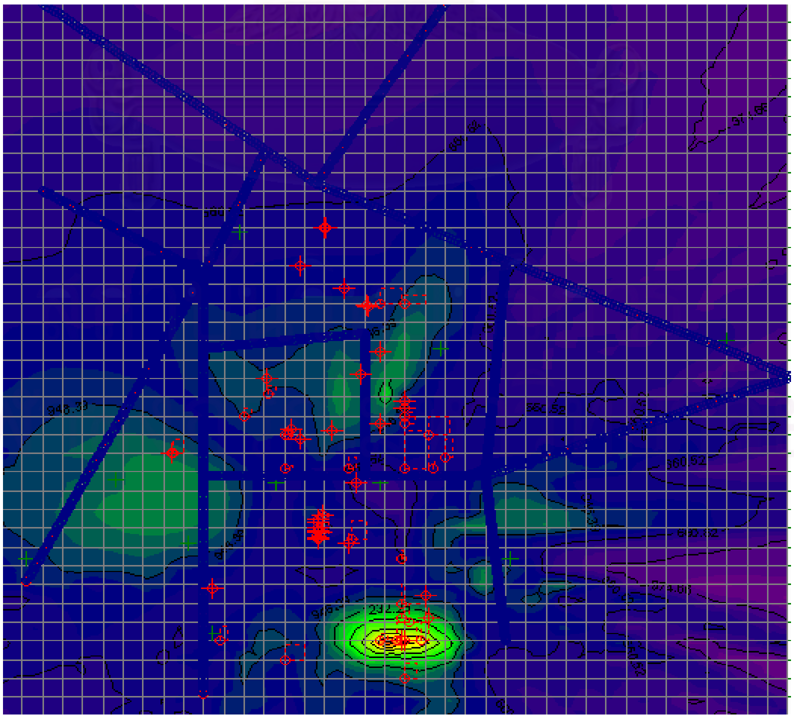


Figure 4.10: Isoplete Diagram for Xylene from all sources for the year 2002

CHAPTER 5
DISCUSSIONS

5.1 Distribution Patterns of BTEX in Ambient Air

5.1.1 Spatial and Temporal Distribution of BTEX in the Study Area

The mean, median and range of the BTEX concentrations across the three sampling periods as measured at all monitoring sites, including the reference site for day-time sample are shown in Table 5.1. The highest mean concentration for benzene, 8.0 μg/m^3, was found at the TSK site located within the complex and was followed by 7.0 μg/m^3 recorded from the jetty site and 6.9 μg/m^3 at THC, a residential site 2 kms outside the complex and downwind from a tank farm area and the loading jetty. The lowest mean concentration for benzene, 2.0 μg/m^3, was found at the Padaeng site located outside the Map Ta Phut complex and generally upwind on the western border of the complex. A mean benzene concentration of 2.8 μg/m^3 was recorded at PAC, a site 4 kms east from the complex. The highest individual concentration of benzene, 40.1 μg/m^3, was recorded at the Jetty site. A benzene concentration of 32.1 μg/m^3 was found during the dry season at the TSK site. Toluene is the most abundant species found and the highest mean concentration found was 47.5 μg/m^3, at the industrial TSK site, followed by 27.2 μg/m^3 at the THC site. The lowest mean concentration,1.9 μg/m^3, for toluene was found at the Padaeng site followed by 2.3 μg/m^3 at the IEAT site, which are both located upwind from the border of the complex. The highest individual toluene concentration, 370.5 μg/m^3, was found at the THC site during the dry period. This is associated with the second highest concentration at TSK site on the same day. Ethylbenzene was detected only occasionally but was found at quite low levels at the TSK, THC, School, SDC, Jetty and NFC sites. The highest concentration, 17.0 μg/m^3, was found at the TSK site during the dry season while there was always lower than the detection limit of ethylbenzene at the Padaeng and PAC sites. Xylene which is a mixed-xylene, was detected with the highest mean concentration of 8.3 μg/m^3, at the TSK site followed by 3.8 μg/m^3 at the THC site, and 2.8 μg/m^3 at the Jetty site. The lowest mean concentration for xylene, 0.2 μg/m^3, was found at two sites, namely School and SDC and wasn't detected at the PAC site. The highest individual xylene concentration, 41.9 μg /m^3, was found at the TSK site during the dry season. The reference background site at Had Mae Ram Pueang is approximately 25 kms east of the Map Ta Phut study area. The ranges of concentrations at this site are benzene (2.9–4.7 µg/m^3), toluene (3.2–6.2 µg /m^3), ethylbenzene (BDL–8.3 µg/m^3) and xylene (BDL–7.2 µg/m^3).

Table 5.1: Daytime Measurement of BTEX at all monitoring stations and at the reference site (unit µg m^{-3})

Site Name	Benzene			Toluene			Ethylbenzene			m&p-Xylene		
	Mean	Med	Range	Mean	Med	Range	Mean	Med	Range	Mean	Med	Range
Padaeng N=11	2.0	2.7	BDL - 4.1	1.9	1.5	BDL - 5.1	BDL	BDL	BDL	0.3	BDL	BDL - 3.1
IEAT N=17	4.0	3.7	BDL–17.7	2.3	1.6	BDL - 8.6	0.8	BDL	BDL - 13.9	0.6	BDL	BDL - 7.4
Jetty N=12	7.0	3.8	BDL - 40.1	11.3	4.2	BDL - 65.4	1.5	BDL	BDL - 15.2	2.8	BDL	BDL - 19.3
SDC N=19	4.8	4.1	BDL - 18.6	9.5	2.5	0.8-78.2	0.3	BDL	BDL - 3.5	0.2	BDL	BDL - 2.7
School N=14	4.3	4.1	BDL - 26.5	4.7	4.0	2.1-28.3	0.2	BDL	BDL - 3.1	0.2	BDL	BDL - 5.6
THC N=19	6.9	5.0	BDL - 23.0	27.2	7.9	2.8-370.5	1.3	BDL	BDL - 8.8	3.8	2.2	BDL - 30.3
TSK N=17	8.0	5.9	3.4-32.1	47.5	8.6	1.6-220.8	1.0	BDL	BDL - 17.0	8.3	6.5	BDL - 41.9
NFC N=11	3.9	3.0	BDL - 20.9	2.5	1.4	BDL - 10.3	0.5	BDL	BDL - 5.0	2.7	BDL	BDL - 24.5
PAC N=10	2.8	3.1	BDL - 6.6	14.8	5.6	BDL - 98.5	BDL	BDL	BDL	BDL	BDL	BDL
Ref. N=6	3.6	3.5	2.9-4.7	4.7	4.7	3.2-6.2	1.4	BDL	BDL-8.3	1.7	0.3	BDL-7.2

Note: N = no. of samples and BDL = below detection limits where detection limit of benzene = 31.81 x 10^{-3} µg ml^{-1}, toluene = 7.63 x 10^{-3} µg ml^{-1}, ethylbenzene = 17.07 x 10^{-3} µg ml^{-1}, and xylene = 27.46 x 10^{-3} µg ml^{-1} for 10 litres of air sample

As shown in Table 5.2 and Figure 5.1, for seven of the major monitoring sites, benzene was found at highest concentrations during a dry season at SDC, THC, TSK, IEAT and Padaeng. At School, concentrations during a dry and semi-wet period were found to be almost identical and the lowest concentration was found during a wet season. SDC, TSK, IEAT and Padaeng sites showed the same pattern of concentration, being highest during a dry period and lowest during a wet period. For downwind sites, School and SDC showed different patterns. This can be explained by the location of these sampling sites, since SDC is located within a centerline of a major wind direction (157.5° - 202.5°) during the dry season. Thus, the contributions from stationary sources were added to the effects from line sources and made ambient concentrations at the SDC site higher than those at the School site. At the THC site, concentrations were found to be higher during a wet season than a semi-wet season. This is supported by the fact that during a wet season, wind blew more frequently toward this monitoring site. For industrial sites, at which stationary sources were major contributors, the TSK site showed the same trend as SDC, a downwind site. This phenomenon can be explained in the sense of meteorological conditions, in which higher temperatures and lower humidity during a dry period caused more evaporative emissions from both mobile and stationary sources. The other industrial site, NFC, at which no samples were done during a dry period, was found to have higher concentrations during a semi-wet period than during a wet period. The upwind sites, which were slightly affected by both mobile and stationary sources, showed the same trend as TSK, an industrial site and SDC, a downwind site. The meteorological conditions such as mixing height, stability classes and humidity are the major factors for this phenomenon. The PAC site, which was totally affected by mobile sources, showed higher concentrations during a wet season than during a semi-wet season. This was due to a greater frequency of stable conditions occurring during the wet period, which yield less mixing capacity of ambient air during that period.

Table 5.2: Average concentrations of BTEX at different sites and seasons

Sites	Benzene			Toluene			Ethylbenzene			Xylene		
	#1	#2	#3	#1	#2	#3	#1	#2	#3	#1	#2	#3
SDC	7	4.4	3.1	13.8	8.6	6.2	0.9	BDL	BDL	BDL	BDL	0.5
School	4.3	4.6	3.3	6.8	3.8	2.6	0.6	BDL	BDL	BDL	0.5	BDL
THC	8.9	5.1	6.7	70.4	5.4	9	3.7	BDL	0.2	8.8	0.6	2.3
TSK	11.5	7.1	5.4	127.9	7.7	22.8	3.4	BDL	0.2	14.5	6.4	5.1
NFC	NA	6.1	1.5	NA	1.2	4.1	NA	0.8	BDL	NA	4.8	0.1
IEAT	5.6	3.7	2.3	3.2	1.9	1.6	2.3	BDL	BDL	1.8	BDL	BDL
Padaeng	3	1.3	0.5	2.7	1.4	0.9	BDL	BDL	BDL	0.6	BDL	BDL
PAC	NA	2.3	3.8	NA	4.1	30.8	NA	BDL	0.2	NA	BDL	0.8
Jetty	4.6	16.1	4.2	19.7	8.2	3.2	3.7	BDL	BDL	4.8	BDL	1.8

Note: NA= not applicable, BDL = below detection limit

#1 = dry season, #2 = semi-wet season, #3 = wet season

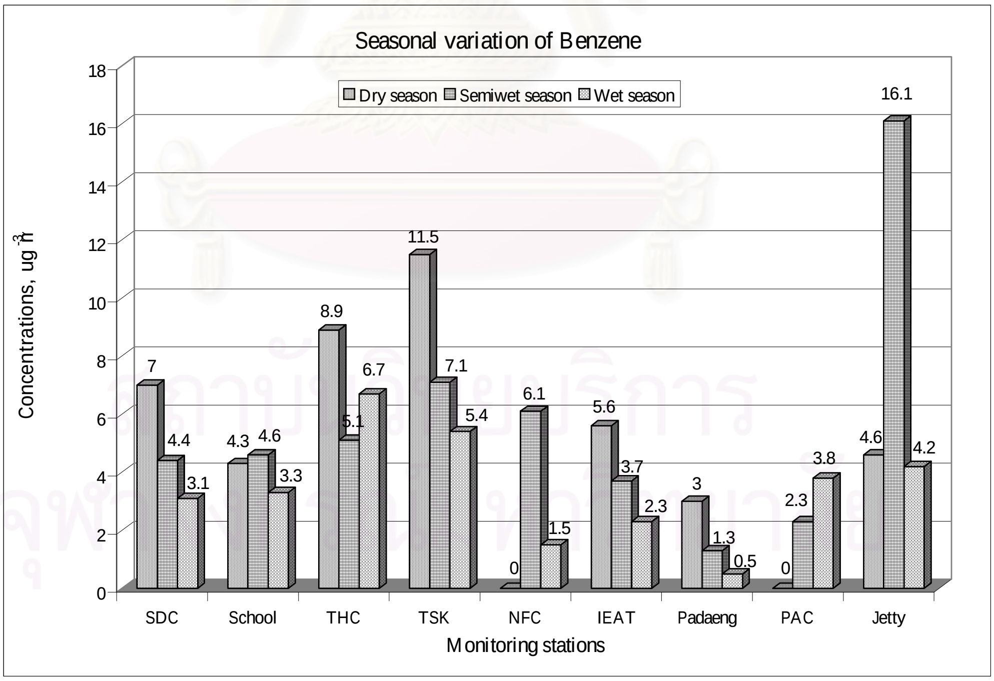


Figure 5.1: Variation of Benzene concentrations at different sites and time

For toluene, as shown in Table 5.2 and Figure 5.2 at the seven major monitoring sites, the same pattern was found at the downwind sites of SDC and School and the upwind sites of IEAT and Padaeng, that concentrations were highest during a dry period and lowest during a wet period. The meteorological conditions of which temperatures and lower humidity during a dry period, caused more evaporative emissions from both mobile and stationary sources and were the major factors in determining this pattern. In contrast, THC, a downwind site, and the industrial sites of TSK and NFC showed higher concentrations during a wet season than during a semi-wet season. It was found that wind blew more frequently from potential sources toward the THC site during a wet season than during a semi-wet season. The more calm conditions during a wet season may have caused higher concentrations at the near-source sites of TSK and NFC.

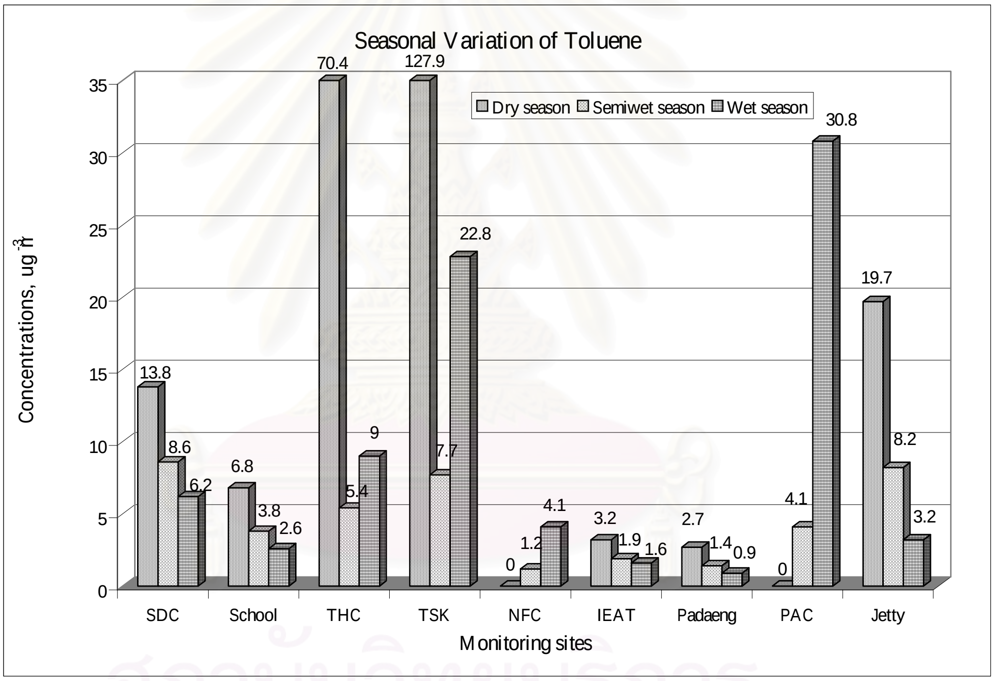


Figure 5.2: Variation of Toluene concentrations at different sites and time

Ethylbenzene, as shown in Table 5.2 and Figure 5.3 at the seven major monitoring sites, was found in slight concentrations with the same pattern occurring at all sites, except for the NFC site where concentrations were highest during a dry period and lowest during a semi-wet period. Meteorological conditions such as high temperatures and lower humidity during a dry period, caused more evaporative emissions from both mobile and stationary sources and were the major factors. THC, a downwind site, and TSK, an industrial site, showed higher concentrations during a wet season than during a semi-wet season. It was found that wind blew more frequently from potential sources toward the THC site during a wet season than during a semi-wet season. The more calm conditions during a wet season may have caused higher concentrations at the near-source site of TSK.

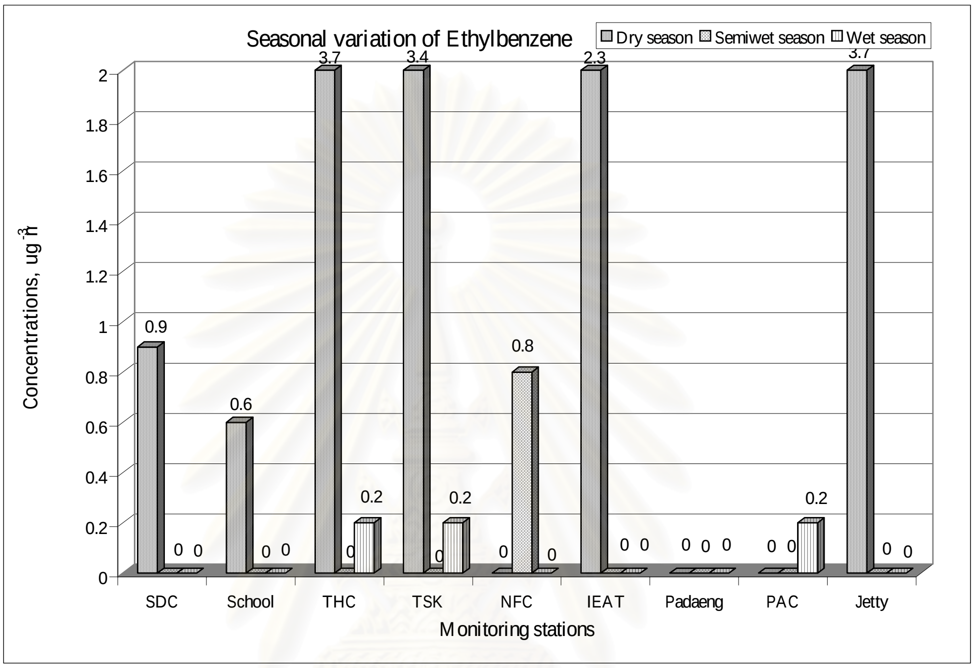


Figure 5.3: Variation of Ethylbenzene concentrations at different sites and time

Xylene, as shown in Table 5.2 and Figure 5.4 at the seven major monitoring sites, was found in slight concentrations with the same pattern at the downwind site of THC, industrial site of TSK, and upwind sites of Padaeng and IEAT. The concentrations were highest during a dry period and lowest during a semi-wet period. Meteorological conditions such as higher temperatures and lower humidity during a dry period caused more evaporative emissions from both mobile and stationary sources and were the major factors. The downwind sites of SDC and THC, and the industrial site of TSK, showed higher concentrations during a wet season than during a semi-wet season. It was found that wind blew more frequently from potential sources toward the SDC and THC sites during a wet season than during a semi-wet season. The more calm conditions during a wet season may have caused higher concentrations at the TSK site.

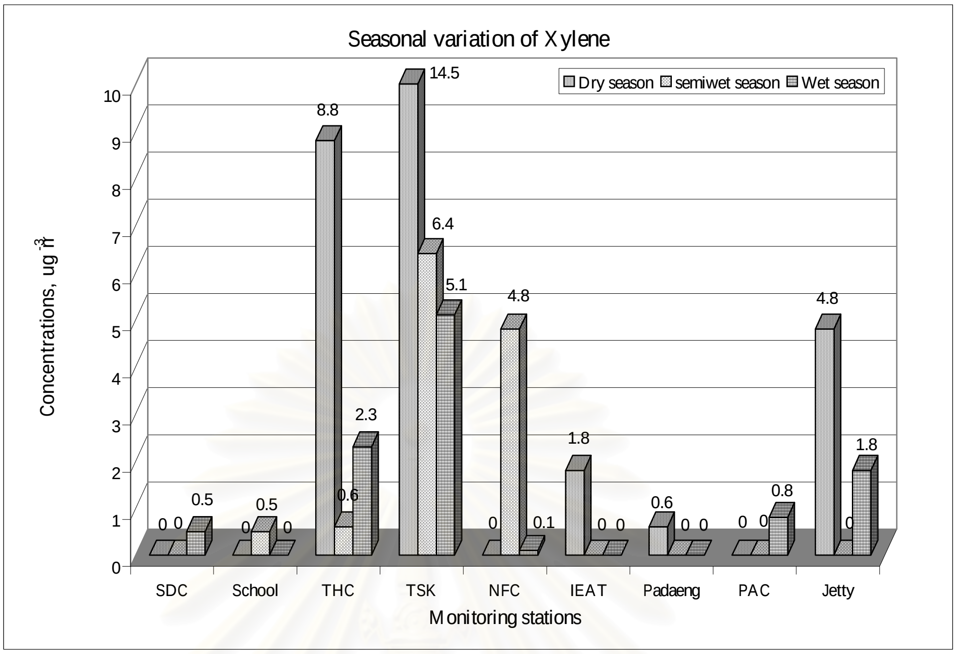


Figure 5.4: Variation of Xylene concentrations at different sites and time

BTEX results based on nighttime sampling and comparable daytime data are presented in Table 5.3. Diurnal variations of the pollutants were detected during all sampling periods at the TSK site, representing an industrial area, and at School site, representing a residential area. The PAC site was monitored during both the semi-wet and wet period and the IEAT site was monitored only during the dry period. It appears that daytime: nighttime concentration ratios for benzene and toluene depend on the sampling period. The general observations are that for period 1, the dry season, average daytime concentrations are higher than nighttime concentrations and the reverse is the case for periods 2 and 3, i.e. the semi-wet and wet periods. These findings are due to the differences in meteorological conditions during each period. Lower temperatures, high humidity due to rain and more calm conditions in periods 2 and 3 (Figure 5.9) may cause a lower mixing height during nighttime for both periods. The lower mixing height obstructs the dispersion of pollutants and resulted in higher concentrations (Manju, 2002 and Sivacoumar et al 2001)). During the first period, all species generally have high detected values and the B:T ratio is quite low. Unusual loading in the area during the first period might cause this phenomenon. The diurnal variation of benzene, toluene, ethylbenzene and xylene are shown in Figures 5.5-5.8.

Table 5.3: Diurnal variation of BTEX at Industrial, Residential, and 2-checking sites

Sites	Time	Benzene			Toluene			Ethylbenzene			Xylene		
		#1	#2	#3	#1	#2	#3	#1	#2	#3	#1	#2	#3
School	Day	4.3	4.6	3.3	6.8	3.8	2.6	0.6	BDL	BDL	BDL	0.5	BDL
	Night	3.6	5.4	8	1.8	25.9	12.4	BDL	0.9	0.2	BDL	5.4	0.9
TSK	Day	11.5	7.1	5.4	128	7.7	22.8	BDL	BDL	0.2	14.5	6.4	5.1
	Night	5.2	8.4	6.5	45.6	26.7	45	0.6	2.8	0.6	8.9	13	7.1
IEAT	Day	5.6	3.7	2.3	3.2	1.9	1.6	2.3	BDL	BDL	1.8	BDL	BDL
	Night	1.5	NA	NA	3.7	NA	NA	0.5	NA	NA	BDL	NA	NA
PAC	Day	NA	2.3	3.8	NA	4.1	30.8	NA	BDL	0.2	NA	BDL	0.8
	Night	NA	4.1	6.6	NA	16	27.4	NA	BDL	0.2	NA	BDL	1.4

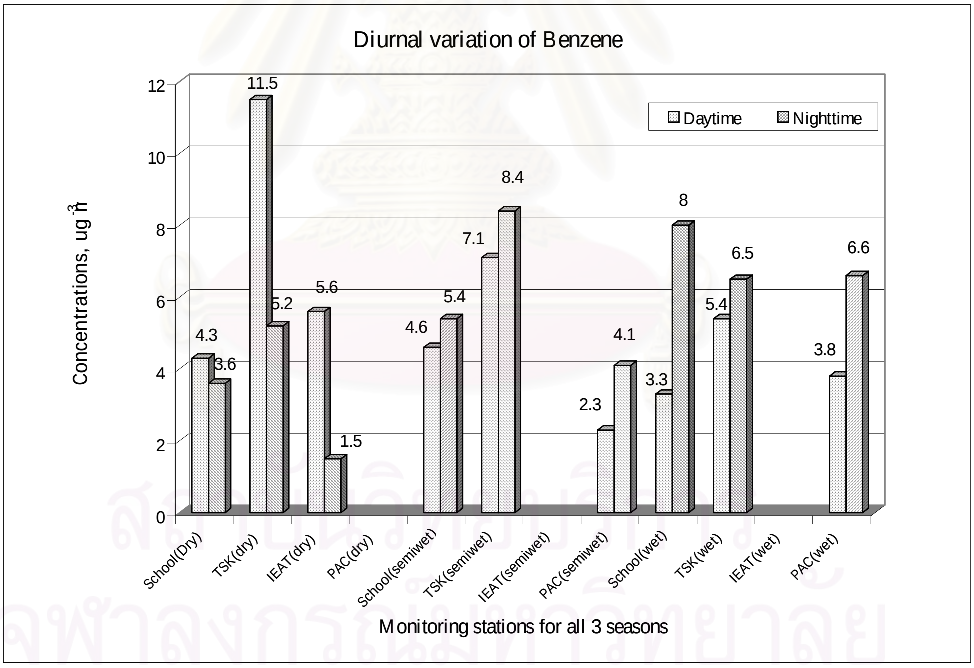


Figure 5.5: Diurnal variation of Benzene

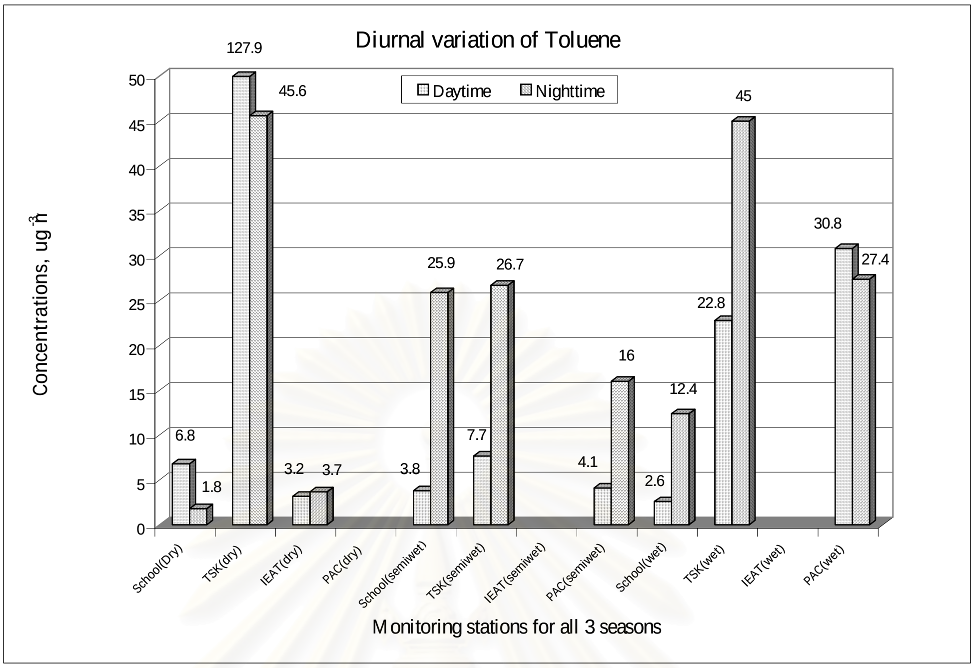


Figure 5.6: Diurnal variation of Toluene

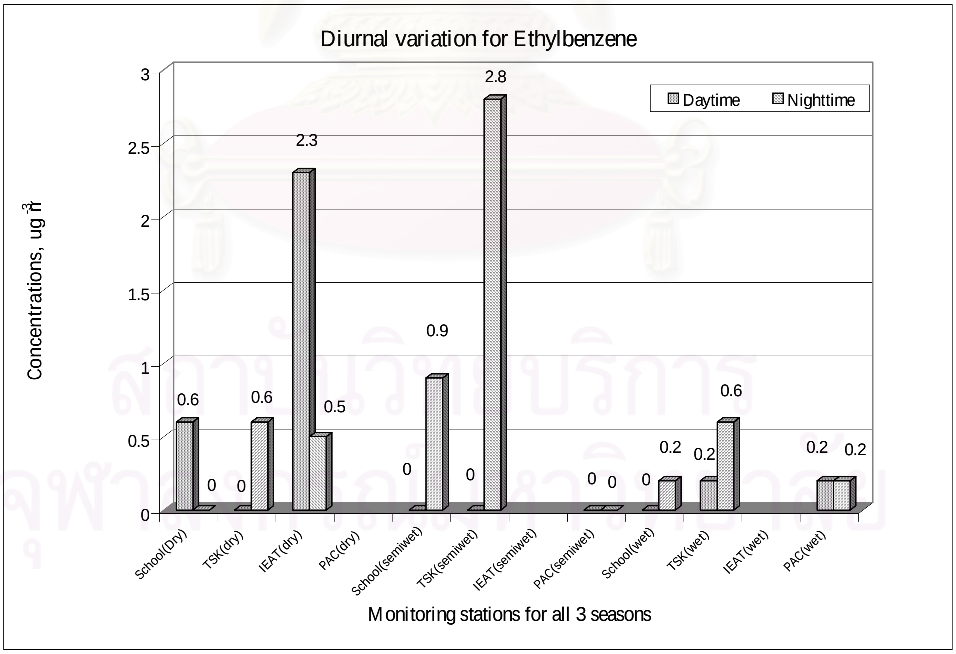


Figure 5.7: Diurnal variation of Ethylbenzene

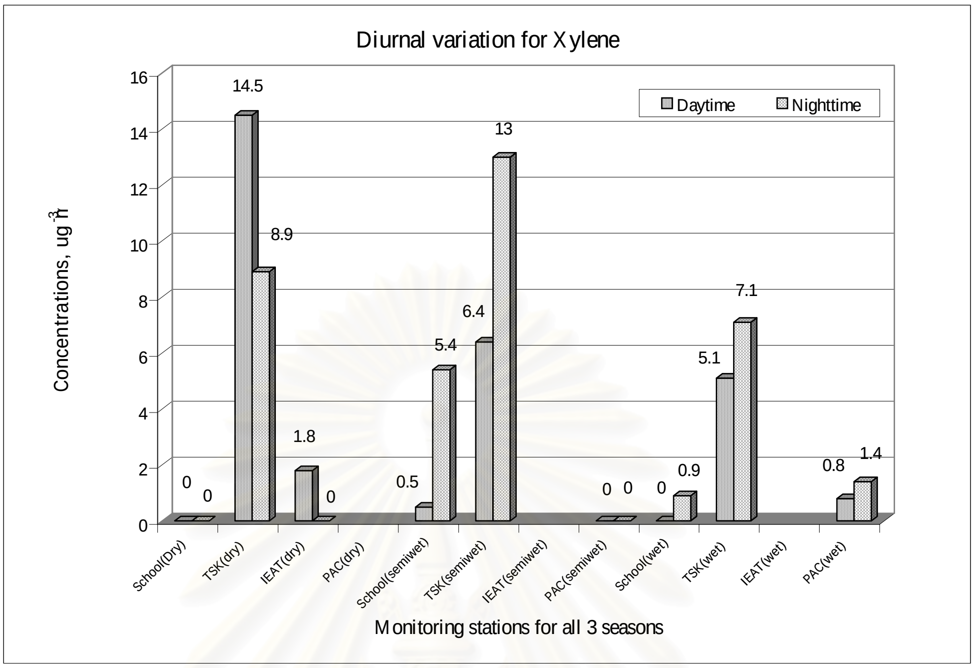


Figure 5.8: Diurnal variation of Xylene

5.1.2 BTEX Concentrations at Upwind, Downwind, and Industrial sites

The main sampling sites have been classified as industrial within the complex, downwind from the complex or upwind from the complex and the results based on this classification are grouped and presented in Table 5.4. The average mean concentrations for benzene and toluene for the industrial area - based on the two industrial sites, TSK and NFC - at 6.4 and 29.8 μg/m^3, showed higher concentrations than those representative of the downwind residential site - based on sites, SDC and School - at 4.5 and 7.4 μg/m^3. The average mean concentrations for these two species at the upwind sites, IEAT and Padaeng, at 2.9 and 2.0 μg/m^3, were found to be comparable to the concentrations found at the reference background site, 3.6 and 4.7 μg/m^3. These results illustrate clearly that the south-southwest winds dominant during these sampling periods (Figure 5.9) carry contaminants from the estate to downwind receptor sites. The data relevant to ethylbenzene and xylene, in general, support this observation although these two species display considerable range and often returned a below detection limit value.

Table 5.4: BTX concentrations at upwind and downwind vs industrial sites.

Type	Site	Benzene	Toluene	B/T	Ethylbenzene	Xylene
Downwind	SDC	4.8	9.5	0.5	0.3	0.2
	School	4.1	4.7	0.9	0.2	0.2
	Average	**4.5**	**7.1**	0.6	**0.25**	**0.2**
Industrial	TSK	7.7	47.5	0.2	1	8.3
	NFC	3.8	2.5	1.5	0.4	2.4
	Average	**5.8**	**25**	0.2	**0.7**	**5.4**
Upwind	IEAT	3.8	2.3	1.7	0.7	0.6
	Padaeng	1.7	1.9	0.9	0	0.2
	Average	**2.8**	**2.1**	1.3	**0.4**	**0.4**

Figure 5.9: Wind rose diagram during monitoring periods

On comparing the BTEX concentrations measured at the upwind sites and at the reference background site to those at the downwind and industrial sites, it is readily recognized that all downwind and industrial monitoring sites are being impacted to some degree. Upwind sites appear to reflect general over land background averages and are not being impacted by local stationary sources (Figure 5.10). For the modeling purposes, background values of 3.1 µg/m^3 for benzene and 2.5 µg/m^3 for toluene have been adopted, based on averaging across the upwind and reference sites.

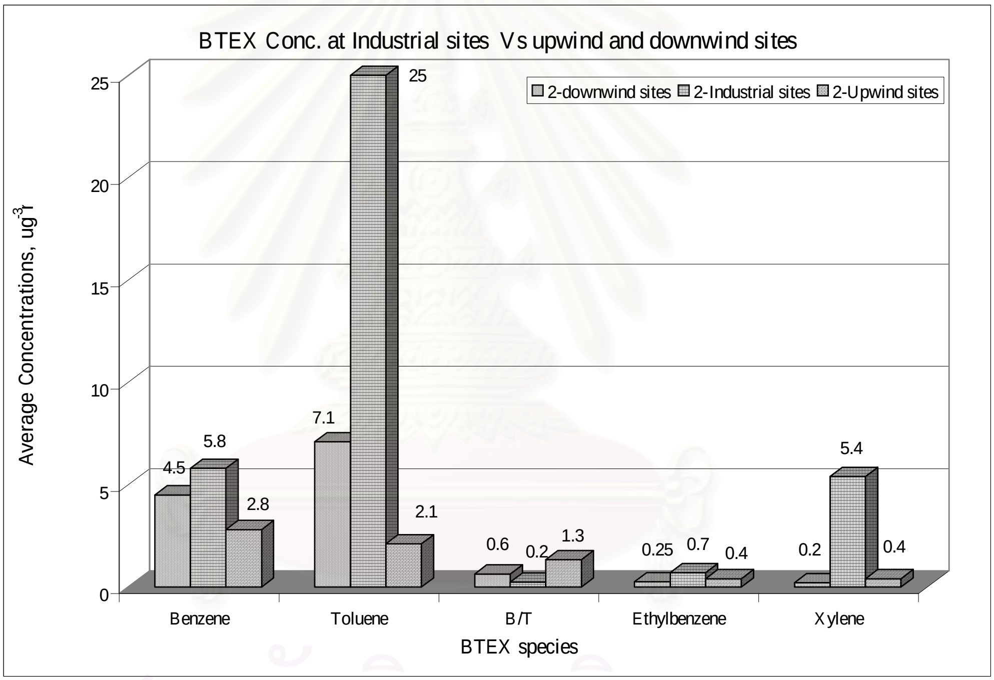


Figure 5.10: Comparison of BTEX concentrations at upwind, industrial and downwind sites

5.1.3 Dispersion of Pollutants from Study Area to nearby Area

BTEX concentrations at the industrial site TSK, as shown in Table 5.5, were found to be higher than those concentrations at the checking site, NongFab. Even though it was found in relatively high concentrations at NongFab, modeling results showed that NongFab station was affected primarily by mobile source emissions. During a semi-wet and wet season, the PAC site was monitored for comparison. It was found that the BTEX concentrations at PAC were typically lower than at TSK except for toluene during a wet season. Nevertheless, modeling results showed that PAC was totally affected by mobile source emissions. Figures 5.11-5.13 show the comparison of concentrations at these sites.

Table 5.5: BTEX concentrations at Southwest, within and Northeast locations

Sites	Benzene			Toluene			Ethylbenzene			Xylene		
	#1	#2	#3	#1	#2	#3	#1	#2	#3	#1	#2	#3
NongFab	5.1	NA	NA	24.9	NA	NA	0.6	NA	NA	3.2	NA	NA
TSK	11.5	7.1	5.4	127.9	7.7	22.8	3.4	BDL	0.2	14.5	6.4	5.1
PAC	NA	2.3	3.8	NA	4.1	30.8	NA	BDL	0.2	NA	BDL	0.8

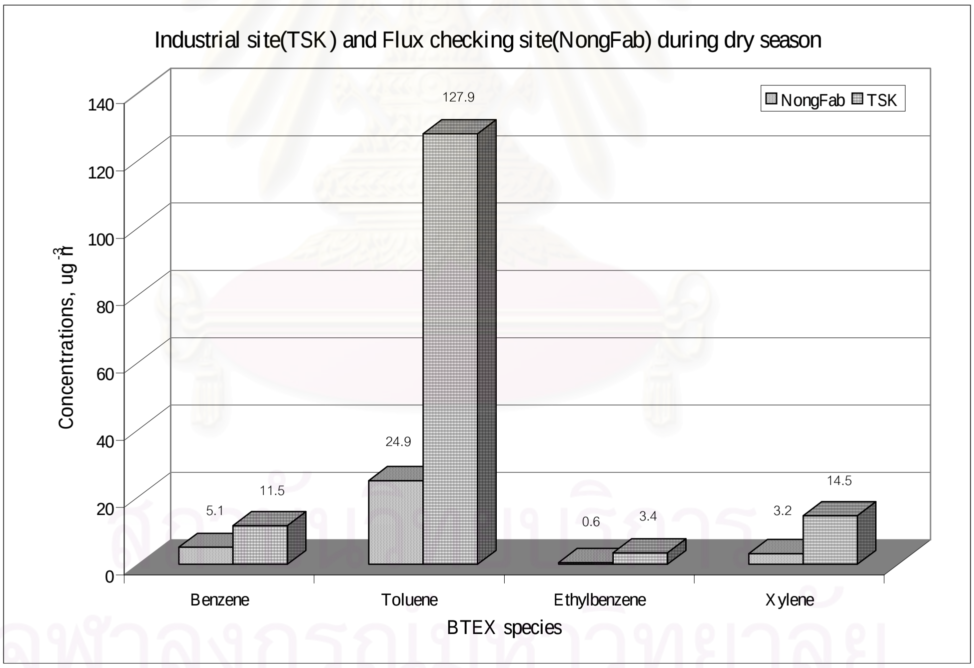


Figure 5.11: Comparison of BTEX concentrations between NongFab and TSK site

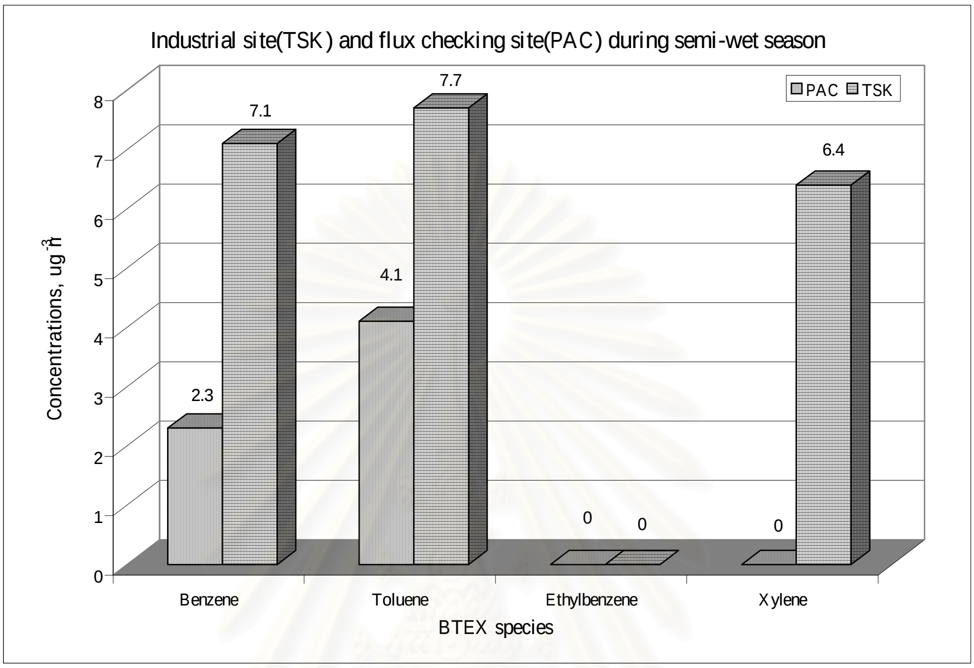


Figure 5.12: Comparison of BTEX concentrations between PAC and TSK site during semi-wet season

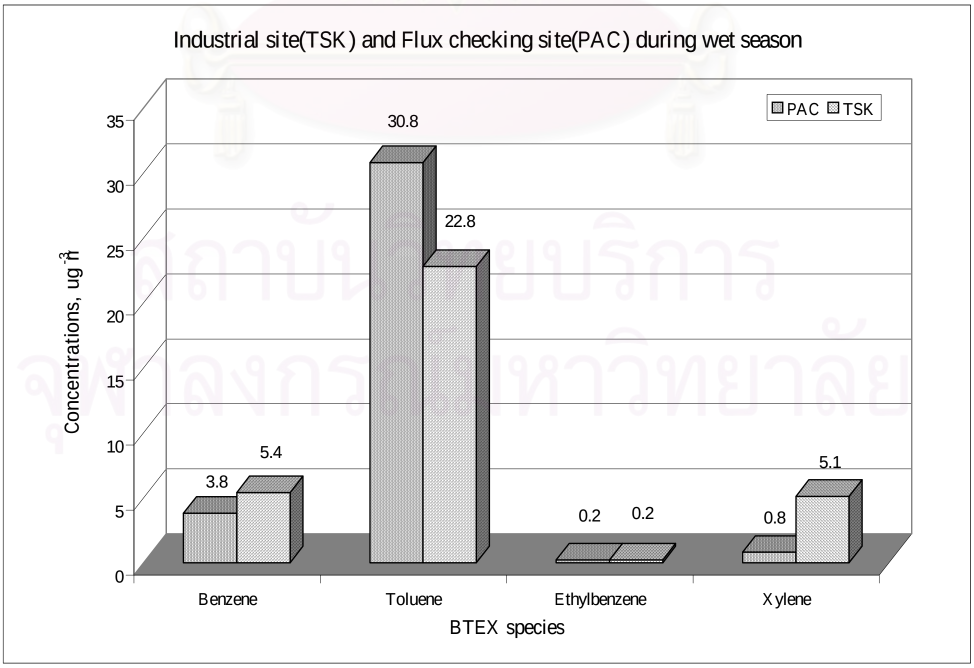


Figure 5.13: Comparison of BTEX concentrations between PAC and TSK site during wet season

5.2 Comparison to Other Studies/areas

The results from this study have been compared to other studies as shown in Table 5.6 and Figure 5.14a. The MTP is shown to scale against these study sites in Figure 5.14b. Its BTEX concentrations are comparable to those in ambient air at petrochemical complexes in Korea and an industrial zone in Chicago. Concentrations were found to be higher than those at the Altona petrochemical, an industrial complex in Melbourne. This difference can be explained by the different nature of the two complexes. The Altona complex has a larger geographical area with greater means of dispersal and has fewer sources located within the complex relative to Map Ta Phut. When compared to a petrochemical complex in India and some mega-city urban areas including Bangkok, the Map Ta Phut results clearly indicate lower benzene concentrations. The B/T ratio as shown in Table 5.6 highlights similarities and differences of BTEX concentrations in various industrial and urban areas.

Table 5.6: BTEX concentrations at various cities and industrial sites

Site name	Area	Sources of	B	T	B/T	E	m&p-Xyl.	o-Xyl.
	Type	References	µg/m3	µg/m3	ratio	µg/m3	µg/m3	µg/m3
MTP	Ind.	This study	6.4	29.8	0.21	0.7	5.4	NA
Ulsan	Ind.	Na et al,	6.53	14.67	0.45	NA	11.7	NA
Yochon	Ind.	2001	6.53	7.53	0.87	NA	NA	5.64
Brisbane	Ind.	Hawas et al, 2002	10.23	39.89	0.26	5.89	21.2	8.28
Sydney	Ind.	EA,2001	8.08	33.49	0.24	5.64	16.91	1.73
Melbourne	Ind.	Torre, 2001.	2.18	7.53	0.29	1.3	NA	NA
Bombay	Ind.	Rao et al, 1997	27.97	20.51	1.36	1.08	1.95	2.82
Chicago	Ind.	Scheff and Wadden,	8.27	10.97	0.75	3.46	6.57	2.19
Chicago	Urban	1989	10.9	10.3	1.06	2.38	4.7	1.65
Manila	Urban	Gee and Sollars,	12.6	168	0.08	21.9	55.8	16.8
Bangkok		1998	18.2	186	0.1	36.6	81	28.9
Sao Paulo			16.7	28.1	0.6	6	18.5	6.2

Note: NA = not applicable

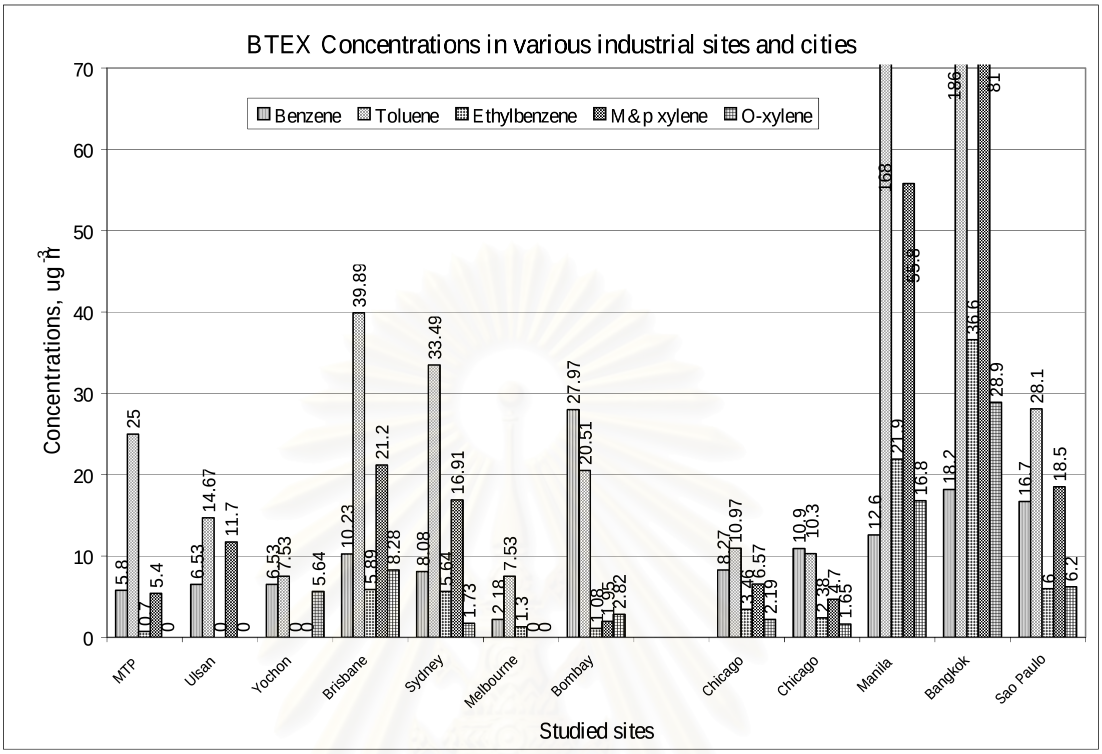


Figure 5.14a: Comparison of BTEX concentrations at various cities and industrial sites

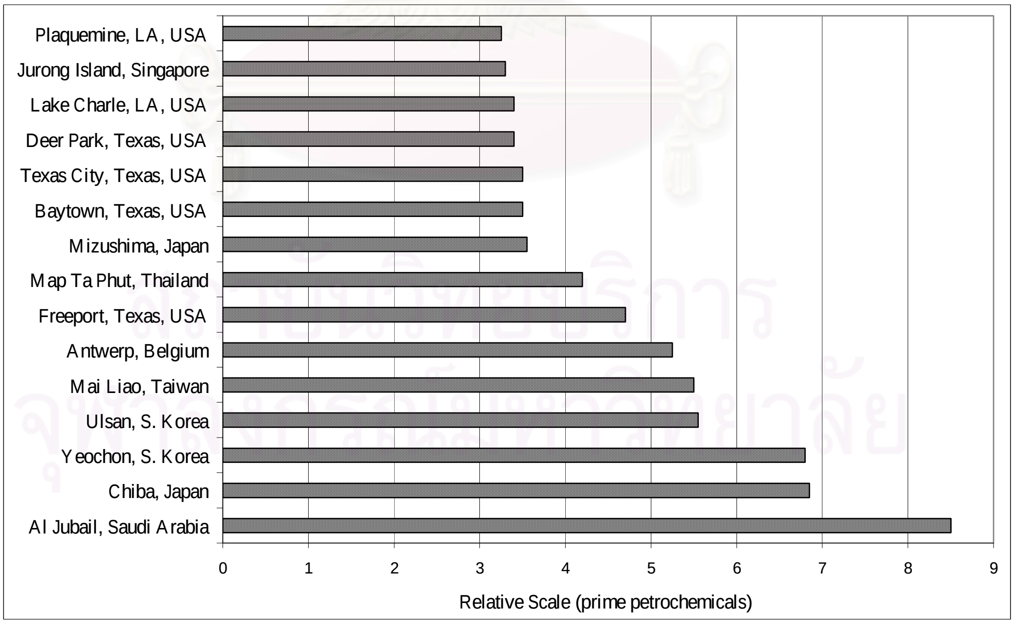


Figure 5.14b: Leading Global Petrochemical Sites by Scale as of August 2003

Source: Adapted from Figure 1, PTIT, 2003.

5.3 Relation of Ambient Concentrations and Emission Loading in the Area

5.3.1 Emission Loading for BTEX Species in the Area

Best estimated annual BTEX emissions loading from the Map Ta Phut locality have been compiled. For the three source types (point, line and area) it can be readily seen that area sources have the most potential to impact the ambient air. For the mobile source, the BTEX species were compiled at 0.47, 0.74, 0.09 and 0.52 g/s respectively, which gives a B: T: X relationship of 1: 1.6: 1.1. For point (stack) sources including the power plants, emission rates of BTEX have been determined as 3.08, 8.32, 0.59 and 1.91 g/s respectively, with a B: T: X relationship of 1: 2.7: 0.6. The highest emission loading in and around the Map Ta Phut complex comes from area sources, which contribute 13.64, 7.71, 0.75 and 22.24 g/s for BTEX respectively, with a B: T: X relationship of 1: 0.73: 1.25. As shown in Table 5.7, two refineries and two upstream aromatic plants contribute 70%, 87%, 56%, and 70% of BTEX respectively. This inventory falls within norm of these business that emitted VOCs should not more than 0.1% of their throughput (RRC,1999).

Table 5.7: Percent of compiled stationary source loading from three group sources

Sources		Benzene %	Toluene %	Ethylbenzene %	Xylene %
1.Area	- Two Refineries	10.4	34.6	8	7.6
	- Two upstream Aromatic plants	51	15.2	10.5	54.2
	- Others	2.3	7.8	32.9	30.3
2. Point	- Two Refineries	7.6	37	31.5	3.95
	- Two upstream Aromatic plants	1.6	2.7	6.3	3.95
	- Others	27.1	2.7	10.8	0
Subtotal for Area sources		63.7	57.6	51.4	92.1
Subtotal for point sources		36.3	42.4	48.6	7.9
Total		100	100	100	100

It is noted that the emission of xylene was mainly from fugitive source emissions associated with the xylene production plants and refinery activities including the distribution and storage of their products. The contribution of fugitive emissions from tank farms, refinery processes and product distribution and upstream aromatic processes contributed significant amounts of BTEX to the airshed. The most important point and area sources for BTEX species are listed in Table 5.8.

Table 5.8: Major Sources of BTEX in the area

Item	Source Type	Processes	Speciation (g s^{-1})		
			Benzene	Toluene	Xylene
1.	Area	BTX Process Fugitives	6.345	0.279	10.98
2.	Area	BT Process Fugitives	4.597	0.97	NA
3.	Area	Refinery Tank Fugitives	0.7	2.03	0.74
4.	Area	Refinery Valve & Fitting Leakage	0.17	0.48	0.18
5.	Area	BTX Tank Fugitives	0.08	0.023	1.91
6.	Area	Refinery Blow Down (1)	0.01	0.012	0.005
7.	Area	Refinery Blow Down (2)	0.009	0.011	0.005
8.	Point	Refinery Vapor Recovery Unit 1	0.645	3.097	0.645
9.	Point	Refinery Vapor Recovery Unit 2	0.645	3.097	0.645
10.	Point	Cogen-stacks	0.459	0.085	0.013
11.	Point	Combined Stacks of Olefin Processes (1)	0.43	0.68	NA
12.	Point	Combined Stacks of Olefin Processes (2)	0.43	0.68	NA
13.	Point	Stacks of BT Processes	0.251	0.418	0.473
14.	Point	Power plant combined stacks	0.124	0.197	NA

Remark: NA= Not Applicable

It is worth noting that these emissions loading are the average loading during a period of one year. All facilities were assumed to work 24 hrs per day and 365 days per year and the fluctuation of these emission sources was not taken into account. In the case of tank farm fugitives that seem to have diurnal variation due to changes of impact factors such as temperature, wind speed and humidity, it was found that this variation did not have a significant effect. The BTEX loading from the tank farm were compiled as 1.69, 5.72, 0.78 and 3.65 g/s, which account for 6, 21.1, 43.8 and 11% of total BTEX loading respectively. Emissions from these sources occur because of evaporative losses of liquid during storage (standing losses) and as a result of changes in liquid level (working losses). Working losses can be assumed to be the same for a one-year period, while impact factors for standing losses in the area have a little variation.

5.3.2 Source Contributions

Despite the overall relative importance of different sources, the source-receptor relationship and impact can vary significantly as a function of source geometry and wind direction. Furthermore, the B:T ratios based on source strengths may provide little help in identifying contributing sources. Indeed, it appears that the B:T ratio as reported for studies in urban and industrial areas can vary considerably. This is undoubtedly related to the strength, variety and type of sources, nearness of sampling point to particular emitters and the prevailing meteorology. Even for an urban area where the major source is mobile vehicles there does not appear to be a common B:T ratio (e.g. Table 5.6, B:T range 0.1-0.6). A B:T ratio of 0.1 has been reported in the Bangkok urban area (Gee and Sollars,1998), which is mainly dominated by mobile sources (PCD, 2003). This Bangkok value appears at the low end of the scale and may reflect additional sources of toluene or a high toluene in petroleum situation. The study of Hydrocarbon Related to Ozone Air Pollution Problem in Bangkok in 2002 (Limpaseni et al., 2003) revealed that B:T ratios at roadside and background park areas were found to be 0.28 and 0.17 respectively. In the same study, B:T ratios were measured and reported for a variety of source environments including refinery fugitive (0.47), petroleum vapor (0.65), petrol exhaust (0.45) and print-shop vapors (0.24). For diesel vapor, a B:T value of 0.44 was calculated but in diesel exhaust virtually no toluene was measured.

The B:T ratios based on both measured and modeled results have been calculated for all daytime samples in all three periods. Results associated with measurement at the TSK site are shown in Table 5.9 and average B:T ratios for each of the three periods were calculated to be 0.08, 1.2 and 0.67 respectively. From the data, the benzene concentrations appear in general, to be less variable, whereas toluene concentrations exhibit considerable variation. So the very low B:T ratio observed in the first period is due to relatively high toluene concentrations.

Table 5.9: B:T Ratios for measured and predicted values at TSK site

Date	Measured Values			Predicted Values				
	Benzene	Toluene	B:T Ratio	Benzene Sources	Benzene *	Toluene Sources	Toluene *	B:T Ratio
22/2/2002	32.1	220.8	0.15	3.4	6.6	32	34.5	0.19
23/2/2002	7.3	110	0.07	2.6	5.8	23.5	26	0.22
24/2/2002	6.6	138.3	0.05	4.3	7.4	16	18.5	0.4
25/2/2002	5.3	77.9	0.07	2.7	5.8	8.7	11.2	0.67
27/2/2002	6.4	92.3	0.07	5.0	8.1	20	22.5	0.36
29/4/2002	3.5	1.6	2.19	4.9	8	4.2	6.7	1.2
30/4/2002	5.2	6.3	0.83	5.2	8.3	6.8	9.3	0.9
1/5/2002	5.9	3.1	1.9	0.7	3.8	2.5	5	0.76
2/5/2002	6.5	5.8	1.12	4.1	7.2	8.1	11.6	0.62
3/5/2002	3.8	5	0.76	3.4	6.5	7.7	10.2	0.64
4/5/2002	16.9	23.3	0.73	3.3	6.4	15.3	17.8	0.36
5/5/2002	8.2	8.6	0.95	8.1	11.2	3.3	5.8	1.93
19/6/2002	4.8	8	0.6	4.9	8	22.6	25.7	0.31
20/6/2002	3.4	83.4	0.04	3.6	6.7	26.6	29.1	0.23
21/6/2002	4.9	6.5	0.75	6.4	9.5	11.2	13.7	0.69
23/6/2002	4.9	4.4	1.11	6.5	9.6	4.5	7	1.37
24/6/2002	9.8	11.6	0.84	2.4	5.5	12.5	15	0.37

Note: * = predicted contributions from sources plus background concentrations

At the downwind receptor site, School, the average B:T ratios for the three sampling periods were found to be 0.76, 1.33 and 1.34. The ratios shown here for this downwind site are similar to those from the industrial site for periods 2 and 3 while the actual measurement levels have decreased markedly which is consistent with the dispersion of the contaminants as the air mass moves downwind. However the very high toluene values for Period 1 at TSK are not reflected at the downwind sites. From the individual downwind ratios, it is evident that the downwind monitoring sites were influenced at times, by specific nearby sources. These higher ratios conformed more with the ratios studied at the refinery plume, petrochemical plant and tank farm fugitives (Scheff et al., 1989; Doskey et al., 1999; Limpaseni et al., 2003). The lower ratio in the dry period was ascribed to the higher amount of toluene detected, which is clearly affected by specific sources in the area.

5.3.3 Source Modeling and Correlation of Predicted and Measured Values

The Industrial Sources Complex (ISCST-3) model was used to predict the effects of emissions from sources at receptor sites. The model computed the effect of the compiled emission loading at each monitoring site. For many conditions, the dispersion coefficients can be approximated by $\sigma_y = Ax^{\alpha}$ and $\sigma_z = Gx^{\gamma}$, where x is the downwind distance (or travel time) and A, G, α, γ are empirically determined. For long downwind distances, the empirical terms will become ~1.0. If in addition it is assumed that u is relatively constant, then it can be found that

$$C \propto Q_i/x^{\alpha+\gamma}$$

Where $1 \leq \alpha+\gamma \leq 2$. Consequently, if $\alpha+\gamma = 1$, the concentration should be proportional to the emission rate divided by the downwind distance from source to receptor (or travel time). The total concentration allocated to all sources at a particular receptor site is the sum of each of the emission contributions from upwind sources adjusted for upwind distance. In modeling, ethylbenzene has been neglected since there is insufficient monitoring data for a reasonable comparison. The individual source loading and total loading of BTX were simulated for the same three periods during which the field monitoring was conducted. The modeling results indicated that mobile source emissions contributed to ambient concentrations at all monitoring sites, whereas point and area sources sometimes make no contribution but do on occasions, play a more significant role in affecting the ambient concentrations. At the industrial sites TSK and NFC located near the sources, the BTX concentrations were dominated mainly from area sources (Table 5.9). The downwind sites SDC and School also showed evidence of impacts from point and area sources. Some results are shown in Table 5.10 for benzene and toluene at the School site for period 2. From the modeling predictions, the additional contribution from area and point sources to these downwind sites is generally in the range 3-10% for benzene and 4–20 % for toluene but can be on occasions, as high as 30% for benzene and 60% for toluene. The BTX concentration at two upwind sites IEAT and Padaeng, and at the THC site was only occasionally affected by point and area sources. The predicted and measured values for the THC site are shown in Table 5.10. This table also shows the relative importance of the three source types for the individual sampling.

Table 5.10: Measured and Predicted Values at School and THC site

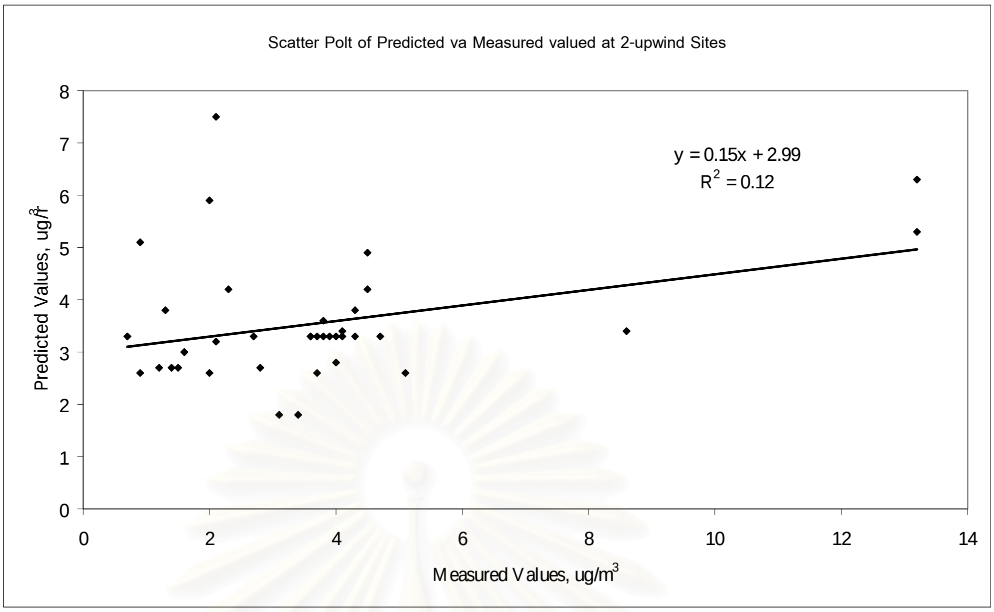
Site	Date	Benzene						Toluene					
		Line	Point	Area	Total Load	Pre-dicted	Mea-sured	Line	Point	Area	Total Load	Pre-dicted	Mea-sured
School	29/4/02	0.07	0.00	0.8	0.9	3.2	3.5	0.15	0.00	1.1	1.3	2.6	2.7
	30/4/02	0.08	0.00	0.00	0.1	3.2	3.8	0.4	0.00	0.00	0.40	2.6	2.6
	1/5/02	0.09	0.00	0.05	0.14	3.2	3.7	0.14	0.00	4.1	4.3	2.7	2.1
	2/5/02	0.12	0.00	0.00	0.12	3.2	6	0.19	0.00	0.00	0.20	2.7	4.1
	3/5/02	0.05	0.00	0.07	0.12	3.2	3	0.07	0.00	0.10	0.20	2.7	2.3
	4/5/02	0.37	0.00	0.60	1.0	4.0	5	0.53	0.00	2.50	3.0	6.2	7.1
	5/5/02	0.08	0.00	0.5	0.6	3.2	7.2	0.29	0.00	0.00	0.3	2.6	5.6
THC	30/4/02	0.13	0.00	0.00	0.1	3.2	3.2	0.2	0.00	0.00	0.2	2.7	3.7
	1/5/02	0.95	0.00	4.3	5.3	4.5	4.9	1.48	0.00	3.0	3.5	4.6	3.5
	2/5/02	0.13	0.00	0.00	0.1	3.2	4.8	0.11	0.00	0.06	0.2	2.7	7.9
	3/5/02	0.1	0.00	0.00	0.1	4.2	4.9	0.19	0.00	0.3	0.5	4.0	5.7
	4/5/02	0.1	0.00	0.00	0.1	4.5	7.2	0.15	0.00	0.00	0.2	4.0	8.7
	5/5/02	0.2	0.00	0.00	0.2	3.8	5.5	0.1	0.00	0.10	0.2	3.5	2.8

A comparison between predicted and measured values at all monitoring sites has been undertaken. For the combined two industrial sites and the combined two downwind sites, the correlation coefficients for measured and predicted data are 0.76 (n = 62) and 0.35 (n = 66) respectively, with 72% of data points falling within a factor of two. Figure 5.15, shows a scatter plot of the predicted and measured values for the industrial sites, TSK and NFC. The coefficient of determination (R^2) for the combined industrial sites, the combined downwind sites and the combined upwind sites is 0.58, 0.13 and 0.12, respectively. This implies that there is little or no relationship between the measured values and the predicted values at the upwind sites, while 58% of the variability observed within the complex and 13% of the variability observed downwind of the complex can be explained by the model. The findings confirmed that specific nearby sources have a significant impact and result in the ambient concentration of BTEX at the industrial sites to be higher than at the downwind sites.

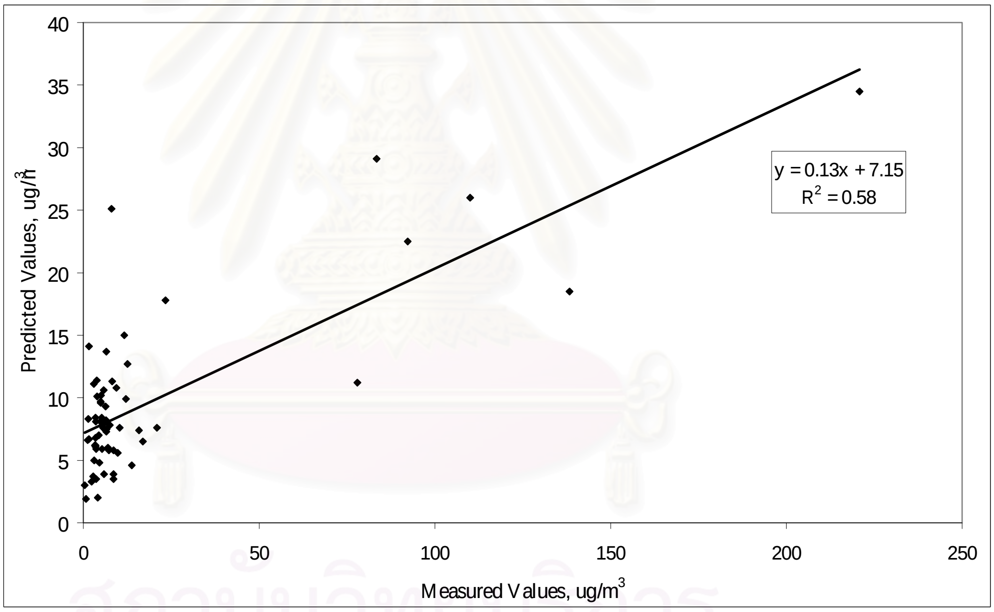
As can be seen in the emission inventory, xylene has more limited sources and hence the results from modeling of this species should display less variability. A comparison between measured and predicted values at the TSK site, close to the dominant xylene sources, was found some association (Figure 5.16). At the downwind and upwind sites, samples often returned a very low or BDL reading for xylene. Figure 5.17 shows the weak relationship between predicted and measured values, which caused by the local sources (garbage truck garage) at the THC site. Figures 5.18-5.20 show the relationship of predicted and measured values of BTX at downwind, upwind and industrial sites. In Figure 5.19, it is shown that high toluene levels were detected during the first period. This episode explained the unusual emission loading of sources, which may have been caused by emissions due to abnormal leakage or the failure of controlled equipment in the upwind area, near the shore.

There has been some debate in the factory documentation for the refineries concerning the adequacy of the loading associated with fugitive emissions. The predicted values at the two industrial sites were observed to be quite source strength dependent. When fugitive loading from refineries were increased by a factor of 10, the modeling calculation showed the resulting coefficients of association, between measured and predicted values, decreasing from R = 0.76 (R^2 = 0.58) to R = 0.65 (R^2 = 0.42) as shown in Figure 5.21 but there was no significant impact on values associated with the downwind sites (Figure 5.22).

In this research, it is worth noting that there are no 24-hr measurement data or annual average measurement data, which considered yield better results in comparison with predicted concentrations the computed by the model.



Scatter Polt of Predicted va Measured valued at 2-upwind Sites



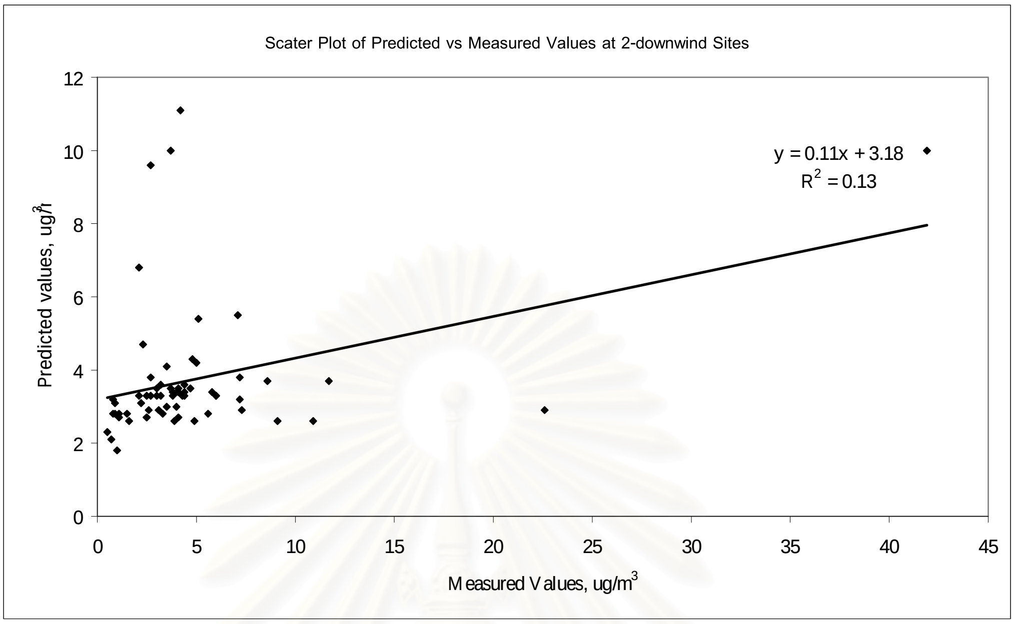


Figure 5.15: Relation of BTX predicted vs measured values at (a) 2-upwind, (b) 2-industrial and (c) 2-downwind sites

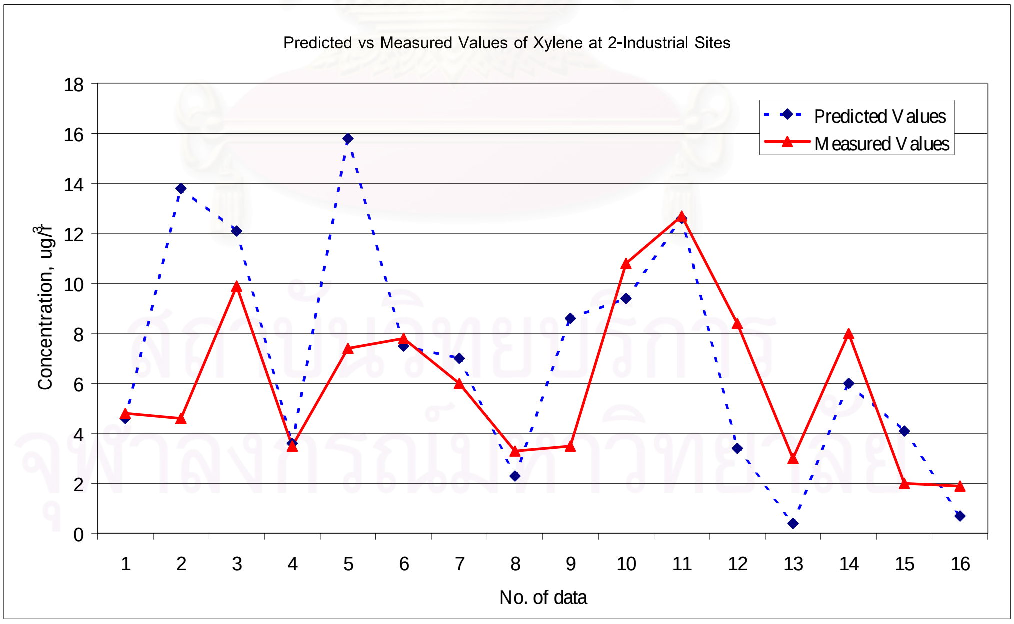


Figure 5.16: Predicted and Measured Values of Xylene at TSK site

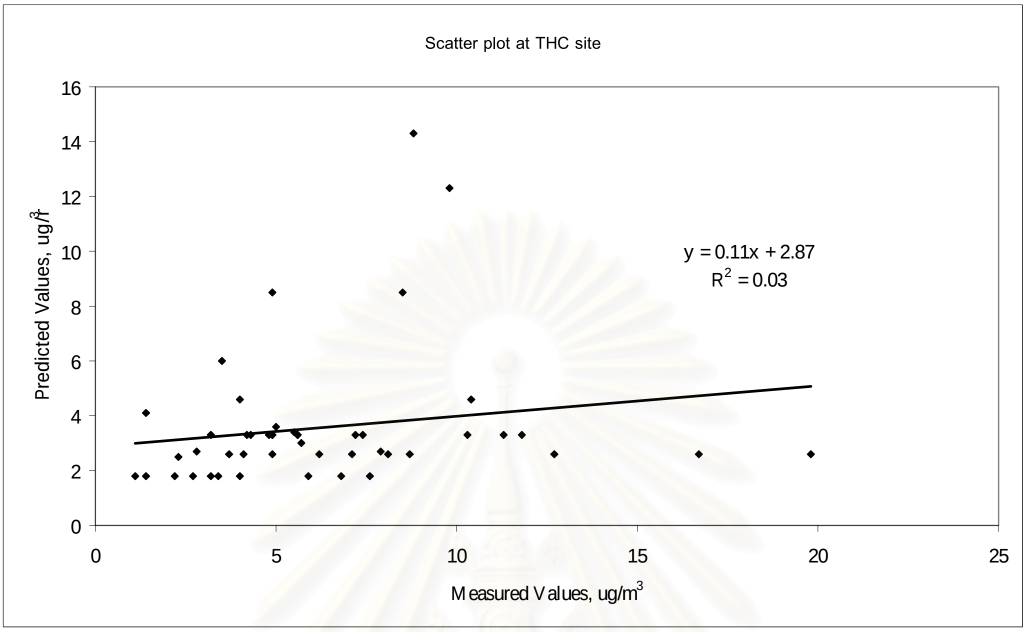


Figure 5.17: Predicted vs measured values of BTX at THC site

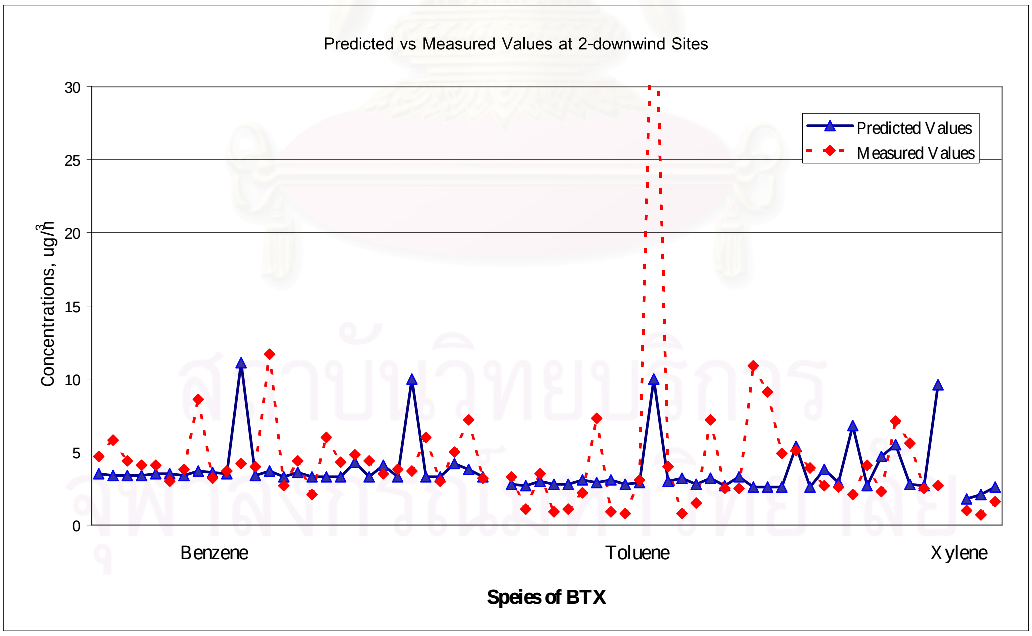


Figure 5.18: Measured vs predicted values for BTX at 2-downwind sites

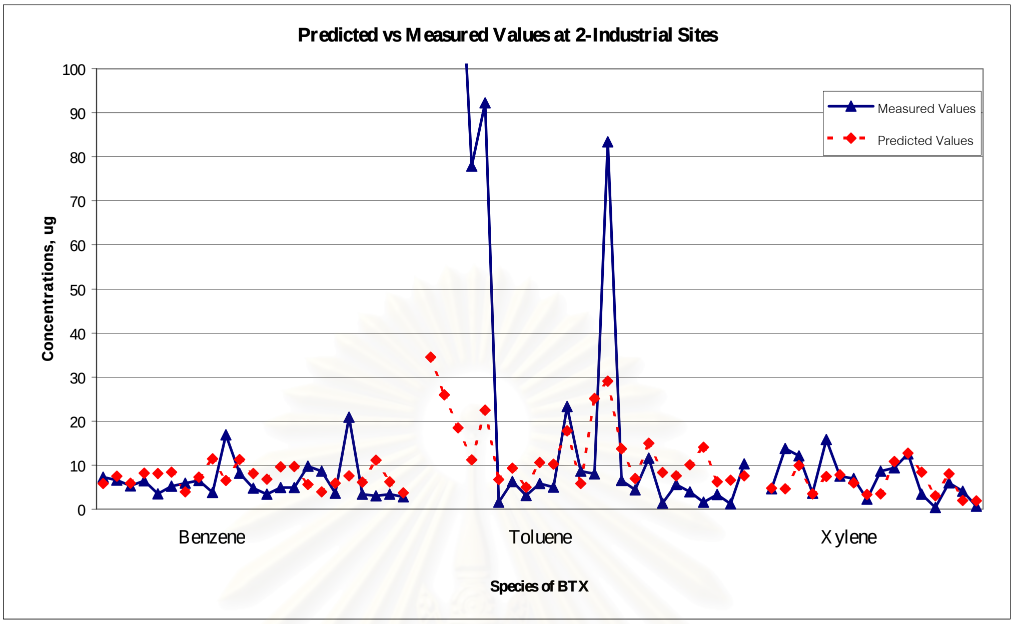


Figure 5.19: Measured vs predicted values for BTX at 2-industrial sites

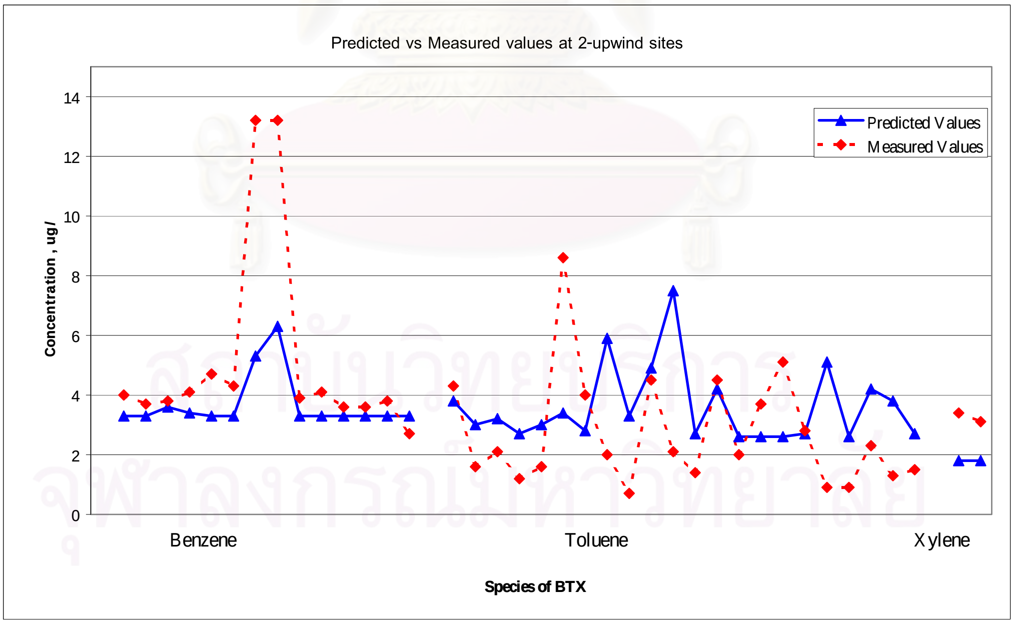


Figure 5.20: Measured vs predicted values for BTX at 2-upwind sites

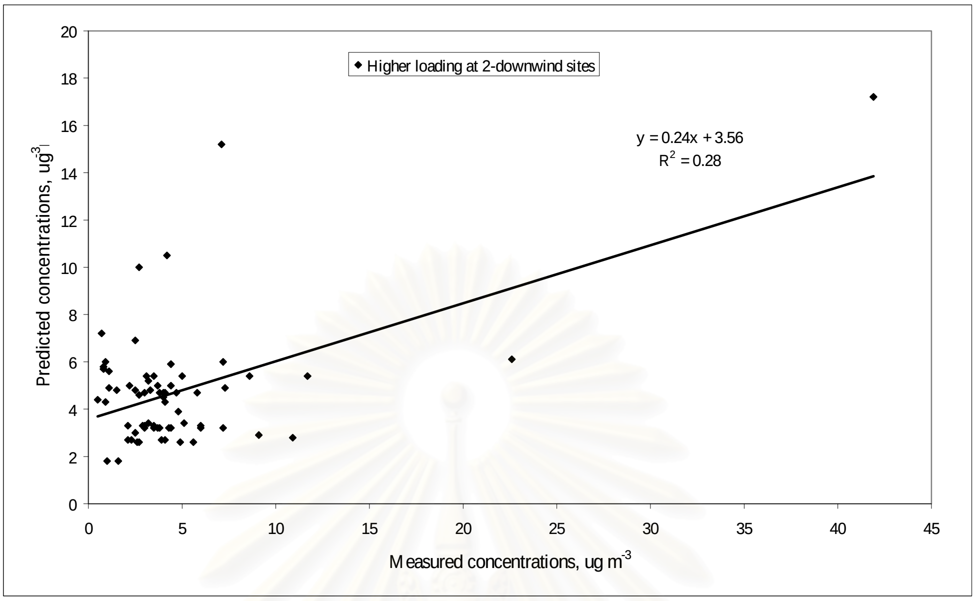


Figure 5.21:Relation of BTX predicted vs measured values at 2-industrial (for higher loading)

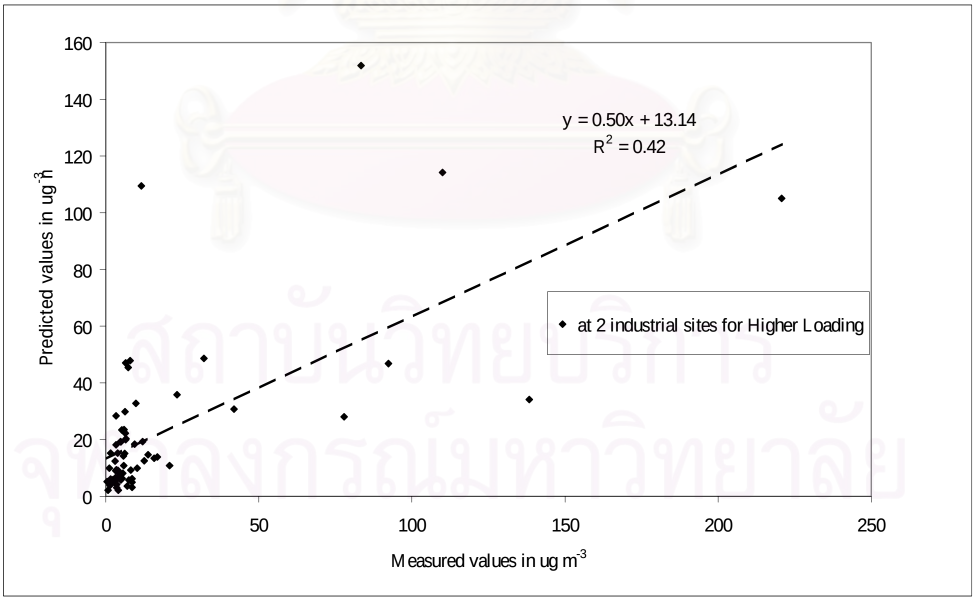


Figure 5.22: Measured and predicted values at 2-downwind sites (Higher loading)

5.4 BTEX Predicted Concentrations vs Health Benchmarks

As described in Chapter 3, year 2002 meteorological data was selected as a worse case scenario. The meteorological data in coupling with compiled emission loading were then simulated with the ISCST3 model. The results for all source loading and only line source loading are showed in Table 5.11.

Table 5.11: Annual average for BTEX at all monitoring sites (w/o B.G concentrations)

Site	Benzene ($\mu g/m^3$)		Toluene ($\mu g/m^3$)		Ethylbenzene ($\mu g/m^3$)		Xylene ($\mu g/m^3$)	
	Total	Line	Total	Line	Total	Line	Total	Line
SDC	6.4	2.7	8.3	4.2	0.7	0.5	9.6	3
School	9.9	0.8	29.3	1.2	1.3	0.2	13.6	0.9
THC	1.5	1.9	3.2	3	0.2	0.2	1.5	1.5
TSK	10.8	0.5	31.2	0.8	1.6	0.1	24.3	0.6
NFC	9.8	0.5	18.0	0.8	3.2	0.1	23.4	0.6
IEAT	5.2	0.3	8.1	0.5	0.9	0.1	10.6	0.4
Padaeng	3.8	0.2	7.1	0.4	0.6	0.1	7.5	0.3
Jetty	7.0	0.3	10.6	0.4	0.9	0.1	14.4	0.3
PAC	1.6	1.3	2.5	1.9	0.4	0.3	2.0	1.4
NongFab	2.6	0.3	3.8	0.5	0.3	0.1	5.4	0.3

The predicted annual concentrations from all sources were compared to their chronic benchmarks and ambient air quality standards. The results are shown in Figures 5.23-5.26.

As shown in Figure 5.23, the predicted annual average concentrations of benzene were found to be below its chronic benchmark of 60 $\mu g/m^3$, at all sites. A high concentration of benzene was found at three sites, TSK (10.8 $\mu g/m^3$), NFC (9.8 $\mu g/m^3$) and School (9.9 $\mu g/m^3$). These predicted annual average concentrations were well below the ambient air quality standard of 5 ppb or 16.2 $\mu g/m^3$, set by World Health Organization (WHO).

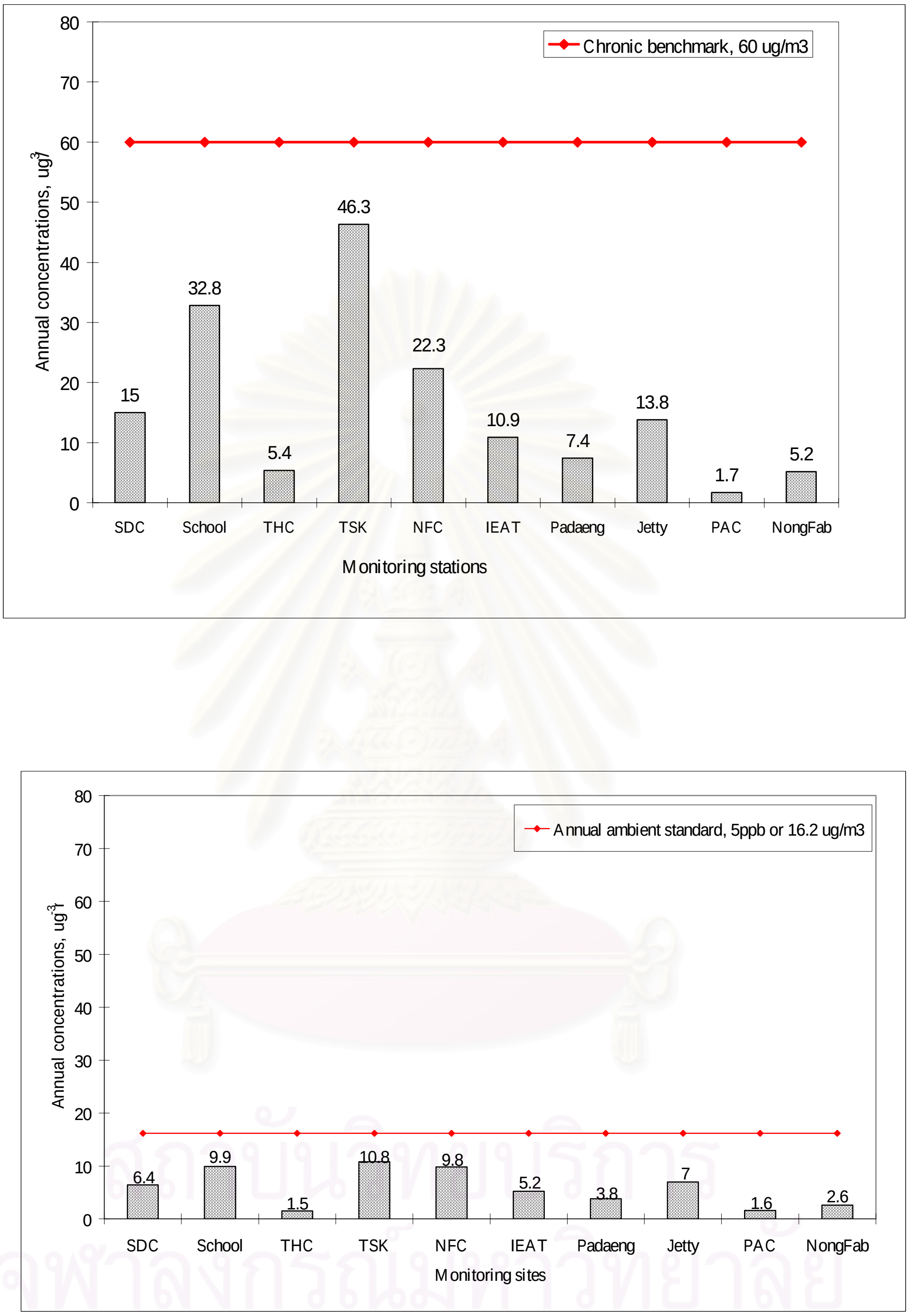


Figure 5.23: Predicted annual average of benzene vs its chronic benchmark and ambient standard

For toluene (Figure 5.24) the predicted annual average concentrations were found to be lower than the chronic benchmark of 400 $\mu g/m^3$, at all sites. The highest predicted value was 31.2 $\mu g/m^3$, which is significantly lower than the benchmark. The maximum 24-hr average of predicted value, 196.9 $\mu g/m^3$, at the TSK site was also lower than the 24-hr average standard, 3000 $\mu g/m^3$.

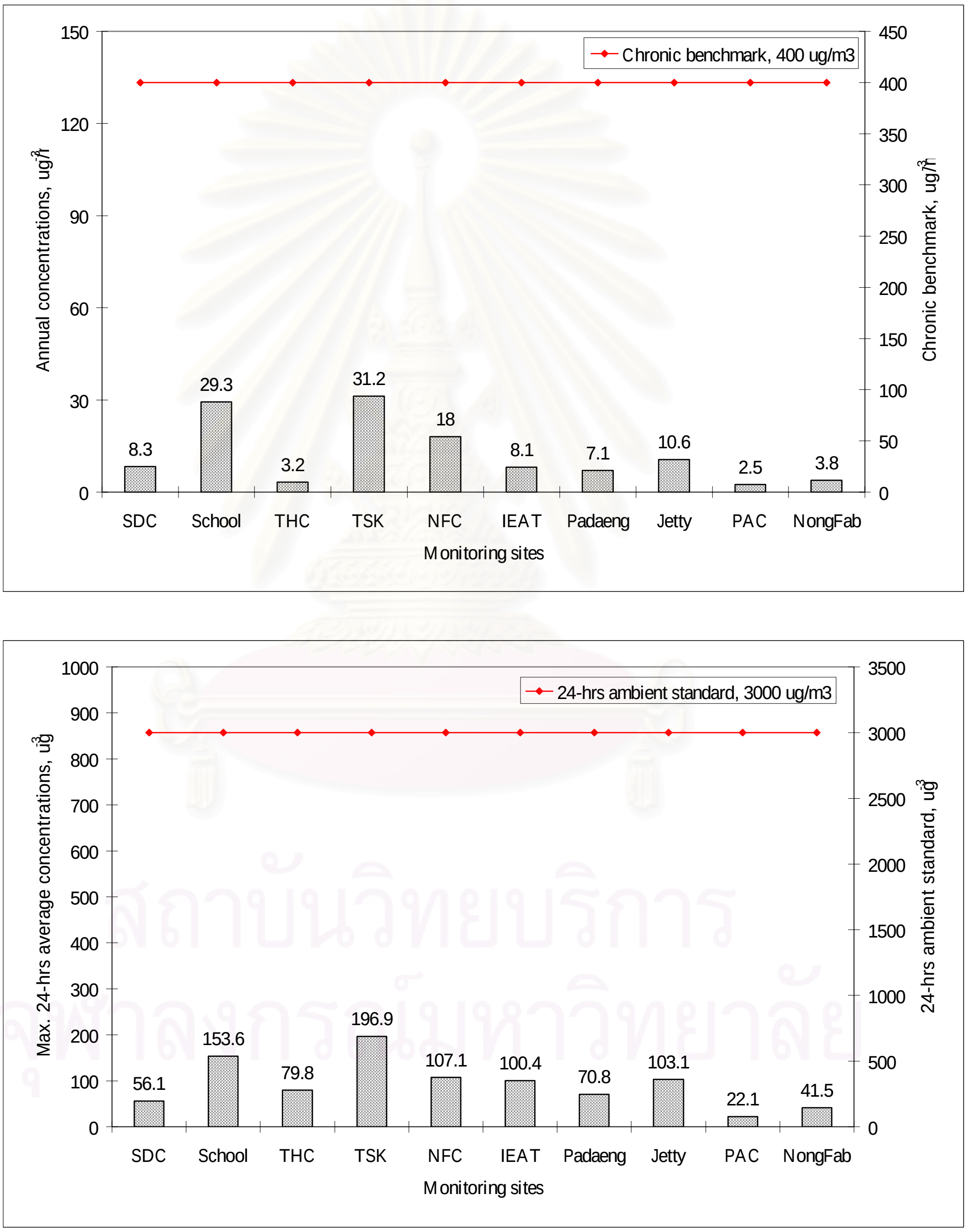


Figure 5.24: Predicted annual averages of toluene vs its chronic benchmark and max. 24-hr average vs 24-hrs ambient standard

For ethylbenzene (Figure 5.25) the predicted annual average concentrations were found to be lower than a chronic benchmark of 1000 μg/m^3 at all sites. The highest predicted value was 3.2 μg/m^3, which is significantly lower than the benchmark. The maximum 24-hr average of predicted value, 13.0 μg/m^3, at the TSK site was also compared to the 24-hr average standard, 3500 μg/m^3.

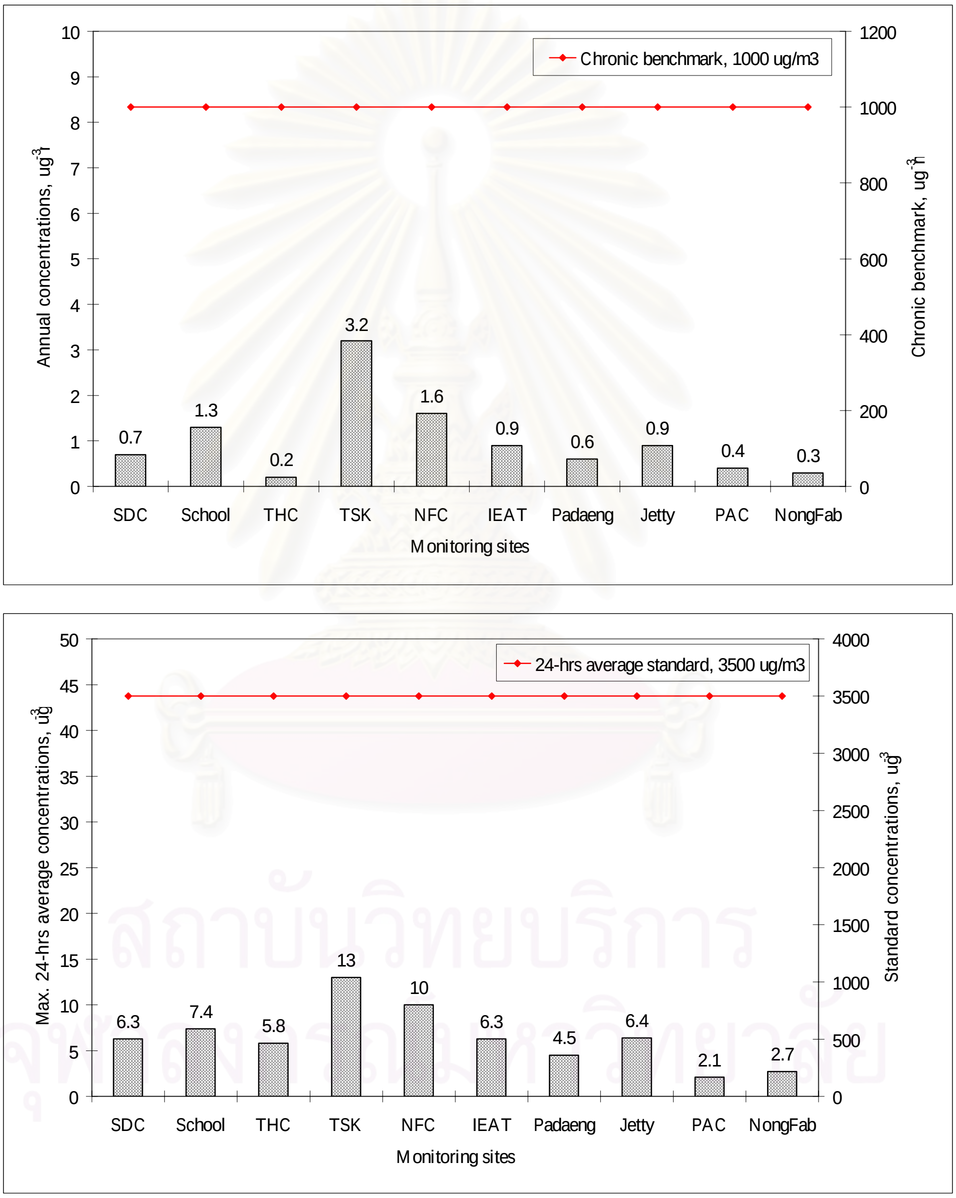


Figure 5.25: Predicted annual average of ethylbenzene vs its chronic benchmark and max.24-hrs average vs 24-hrs standard

For xylene (Figure 5.26), the predicted annual average concentrations were found to be lower than the benchmark, 700 μg/m^3, at all sites. The highest predicted value was 24.3 μg/m^3, which is significantly lower than the benchmark. The maximum 24-hr average of predicted value, 134.5 μg/m^3, at the School site was also compared to the 24-hr average standard, 3500 μg/m^3.

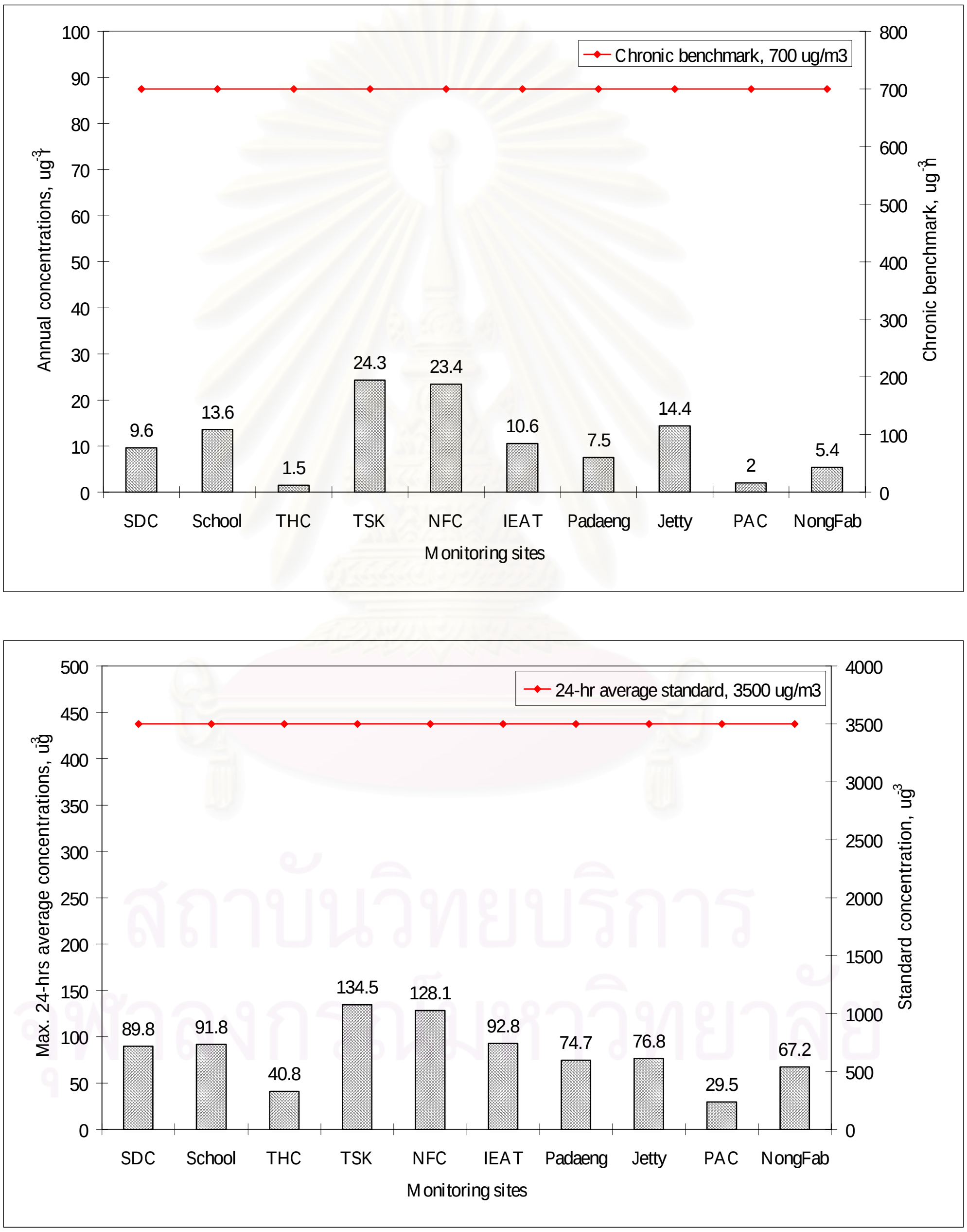


Figure 5.26: Predicted annual average of xylene vs its chronic benchmark and max.24-hrs average vs 24-hrs standard

Thus in general, the atmosphere in the Map Ta Phut area still has an assimilative capacity for all species. The regulatory agencies should focus primarily on benzene, which is the most toxic and carcinogenic, of this group of hydrocarbons.

5.5 Predicted Allowable Loading

As shown in Table 5.11, without adding up the background concentrations, it was found that line sources contributed small amounts to the predicted annual concentrations at all monitoring sites except SDC and PAC sites. It was also found that annual predicted benzene in three sites, TSK, school and NFC, were considerably high comparing to the WHO guidelines of 16.2 $\mu g/m^3$ and were lower than its chronic effect, 60 $\mu g/m^3$. Thus, in order to maintain the ambient air quality within health concern limit, the maximum ambient concentration of benzene at TSK site was clarified by review an exposure assessment and, then, compares to WHO guideline. The lower value was used as a health concern limit for benzene.

The USEPA exposure assessment assumptions have been adopted in determining an average and a reasonably maximum exposure level as shown in Table 5.13. The standard USEPA assumptions related to inhalation of airborne contaminants are expected to reasonable reflect the actual conditions within each of the residential areas and have been based on extensive human behavior studies in the US. (McConnell and Pollock, 1994).

(a) Carcinogenic effects: Incremental Lifetime Risk of Cancer (Risk)

$$\text{Risk} = C_{adj} \text{ X Unit risk}$$

Where C_{adj} = Adjusted exposure concentration ($\mu g/m^3$), which is the lifetime average concentration of benzene in the air that would give the same total dose as the exposure scenario outlined in Table 5.12.

$$\text{Unit risk} = 4 \text{ X } 10^{-6} \text{ per } \mu g/m^3 \text{ (WHO guideline)}$$

(b) Non-carcinogenic effects: Hazard Index (HI)

$$HI = C/R_fC$$

Where C = Actual modeled or monitored long term average air concentration

Risk characterization was defined as:

R_fC = Reference concentration that chronic effects were used as 400, 1000 and 700 μg/m^3 for toluene, ethylbenzene and xylene respectively.

Table 5.12: Summary of Exposure Assessment Parameters

Parameter	Reasonable maximum	Average
Body Weight (kg)	70	70
Exposure frequency (d/yr)	350	350
Exposure duration (yr)	30	9
Lifetime (yr)	70	70
Inhalation rate – Indoor (m^3/hr)	0.71	0.63
- Outdoors (m^3/hr)	1.67	1.40
Exposure duration - Indoors (hr/d)	21.0	16.43
- Outdoors (hr/d)	3.0	0.44

Source: Table 4, McConnell and Pollock, 1994

If the HI exceeds 1, then the actual concentration exceed the reference concentration, and adverse human health effects may potentially be observed. Although it should be noted that the R_fC is an estimate only with uncertainty spanning an order of magnitude or greater, and therefore incorporates a significant degree of conservatism.

Predicted ambient concentrations of benzene at industrial and residential areas, TSK, NFC and School were 10.8, 9.8 and 9.9 μg/m^3 including mobile sources, which posed incremental risk at TSK, NFC and School for 0.5, 0.4 and 0.4 in 100,000 respectively. The risk considered higher than the lower bound of acceptable risk limit of 0.1 in 100,0000 at TSK site. Toluene, ethylbenzene and xylene were found their hazard index lower than acceptable index. Thus, Benzene has to be regulated in order to make its effects within a health concern limit.

The proposed acceptable concentration at TSK, the highest, is calculated as:

A = Lifetime inhalation air = 1,399,440 m^3

B = Exposure inhalation air = 599,760 m^3

C = Concentration $\mu g/m^3$

D = unit risk = 4×10^{-6} per $\mu g/m^3$

Where, $1 \times 10^{-5} = [(B \times C)/A] \times 4 \times 10^{-6}$

Then, C = 19.4 $\mu g/m^3$, which is close to WHO guidelines for European countries, 16.2 $\mu g/m^3$ or 5 ppb. Thus, we used the WHO guideline’s value as a benchmark.

Table 5.13: Preliminary Health risk assessment with maximum exposure

Parameter	Pollutant	Residential Sites			Acceptable Risk/Hazard index
		TSK	School	NFC	
Predicted annual average ($\mu g/m^3$) for BTEX		10.8, 31.2, 3.2, 24.3	9.9, 29.3, 1.6, 13.6	9.8,18.0, 1.6, 23.4	
Cancer Risk	Benzene	0.5 in 100,000	0.4 in 100,000	0.4 in 100,000	0.1 to 1 in 100,000
Hazard Index	Toluene	31.2/400 = 0.08	29.3/400 = 0.07	18.0/400 =0.05	1.0
	Ethylbenzene	3.2/1000 = 0.003	1.6/1000 = 0.002	1.6/1000 = 0.002	1.0
	Xylene	24.3/700 = 0.03	13.6/700 = 0.02	23.4/700 = 0.03	1.0

The WHO guidelines for European countries of 16.2 $\mu g/m^3$ (or 5 ppb) was used as a benchmark to find out the proper emission rates from stationary sources in the area. To accomplish this exercise, two scenarios of compiled benzene loading and its corresponding predicted ambient value at TSK were demonstrated. The first point is the loading that increased the process fugitive of the two refineries and yielded 28.16 g/sec of benzene, versus its predicted annual concentration, 46.3 $\mu g/m^3$. The second point is the actual loading used in this research, which yield loading of benzene at 17.2 g/sec, versus its predicted annual concentration, 10.8 $\mu g/m^3$.

As shown in the Figure 5.27, proposed emission loading at ambient concentration = 16.2 $\mu g/m^3$ is 18.9 g/sec. the stationary sources in the area

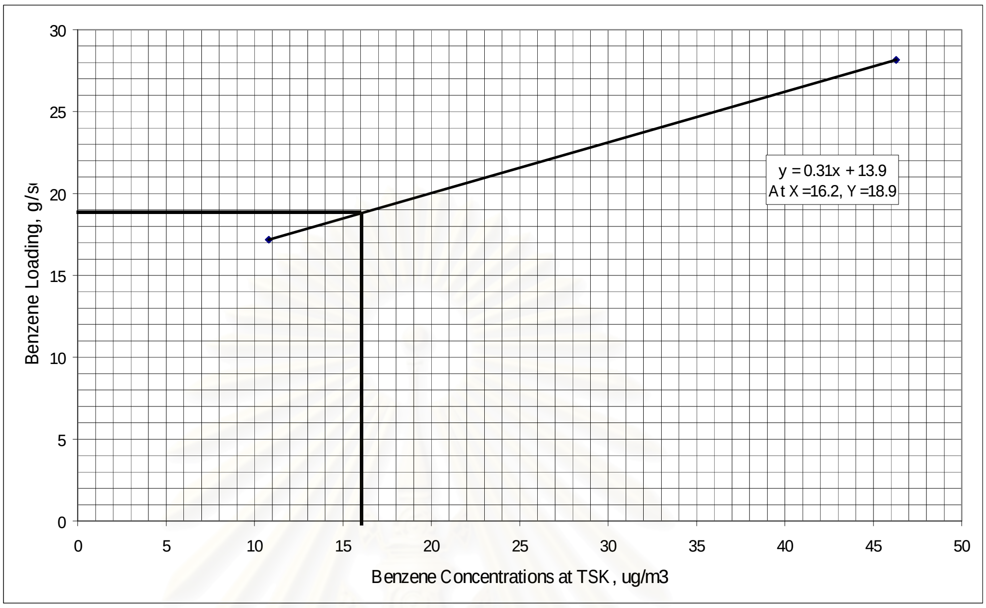


Figure 5.27: Linear regression of benzene loading and its corresponding predicted value

5.6 Associated Uncertainties

Since this research deals with the assessment of regulatory options in identifying the level of pollutants for the management strategy in a specific area, the associated uncertainties and the judgments associated with a modeling process, have to be discussed and acknowledged. This can provide an illuminating role in helping to identify how robust the conclusions about the model results are.

As studied by Isukapalli in 1999, there are three sources of associated uncertainties in a modeling process namely model uncertainty, natural uncertainty and data uncertainty. Model uncertainty involves simplification in a model formulation, which arises in several conditions including; (a) when alternative sets of scientific or technical assumptions for developing a model exist (model structure), (b) when models are simplified for purposes of tractability (model detail) and (c) when a coarse numerical discretization is used to reduce the computation demands of a model (model resolution). For the ISCST3 model, even though it is a regulatory model that is widely used around the world, there are still some assumptions and limitations used when applying this model. A steady state ISCST plume model is a trajectory model that describes short-term behavior of the plume of emissions from their sources. One of main assumptions is that air pollutants have to remain unchanged. In reality however, BTEX can react with other pollutants to form secondary pollutants such as ozone even though they were not highly reactive.

Natural uncertainty involves atmospheric conditions and its variability. The meteorological data that are inputted to the model was assumed to remain in a steady state. Wind direction and wind speed has to remain unchanged during a simulation time (i.e 1 hr) and mean observed values were used since turbulence of atmosphere can occur any time. Calm conditions (wind speed lower than 0.5 m/sec) was found to be higher in 10% of the area. This condition yields lower accuracy in modeling due to higher surface resistance. The variability of mixing height also caused some uncertainties. Since there was no direct measurement of mixing height in the area, it was calculated as a mean mixing height for daytime and nighttime.

Data uncertainty is uncertainty in any of the emission's estimation, error in measurement, or insufficient data. Error in measurement of the ambient data for model validation associated some uncertainties in a whole process, such as in sampling, equipment and analysis even though QA/QC was employed. Emission estimation can be a major source of uncertainty, since it inherits uncertainties in any of emission factor used, source profiles and activity data. Emission estimations reported in an EIA report for each factory are the main sources of emission inventory and missing data was estimated by means of emission factor and all emission factors were adopted from studies in the US. When they were applied here, they needed some robustness. For line sources, the compositions of cars were counted and the average number of each type of car was used to represent both nighttime and daytime and here the emission factors studied in Australia were applied. Furthermore, all input emission rates were assumed to be steady, which is quite different to reality. The fluctuation of emission rates can occur at all times due to a failure of control equipment or a leakage of pipes and valves.

Thus, it was reported that the best accuracy in modeling was ±15% for flat terrain with uniform wind speed, uniform emission rates and within 100-2000 meters of the source. Typically it yielded an accuracy of ±30-50% or even worse in some cases (PCD, 1999). Nevertheless, It was widely used to assess the impact of sources on ambient concentrations since its costs are cheaper than field monitoring and it can predict concentrations in all cases.

5.7 Management options

In order to maintain the ambient concentration of benzene within the WHO guideline, two management options associated with emission loading from stationary sources are demonstrated and discussed.

5.7.1 Controlling of Sources' Emissions

The possible methods to controlling sources' emissions are; (1) controlling the process fugitives from blow down systems and other processes by increasing the percentage collection of these emissions and (2) implementing a Leak Detection and Repair (LDAR) program to prevent fugitive emissions from significant sources. In this research, two options were demonstrated to determine whether they are effective methods to maintain the benzene ambient concentration at the most polluted site, TSK, within the WHO guideline. The first option is based on the assumption of 10% of estimation error for fugitive area sources, which yield 18.4 g/s of benzene. The second option is based on the estimated of 97% efficiency for process fugitive emissions from these two refineries were collected, which yields total benzene 28.2 g/s. The two options were simulated by the model with the 2002 meteorological data. The results comparing to its chronic/WHO guideline are shown in Table 5.14.

It was found that annual predicted concentration of benzene at the TSK site increased from 10.8 $\mu g/m^3$ to 13.0 $\mu g/m^3$ for option 1 and to 46.3 $\mu g/m^3$ for option 2 respectively and it also increased automatically at all monitoring sites. Thus, benzene ambient concentration in the area can be managed through controlling sources' emissions at major identified sources.

Table 5.14: Predicted Benzene Ambient Concentrations at All Monitoring Sites Using Different Scenarios

Site	Benzene Concentrations ($\mu g/m^3$)				
	Line Source Loading (1)	Total Normal Source Loading (2)	Option 1 (3)	Option 2 (4)	Chronic/WHO Guideline
SDC	2.7	6.4	7.2	15.0	60/16.2
School	0.8	9.9	9.6	32.8	
THC	1.9	1.5	2.8	5.4	
TSK	0.5	10.8	13.0	46.3	
NFC	0.5	9.8	11.2	22.3	
IEAT	0.3	5.2	5.8	10.0	
Padaeng	0.2	3.8	3.8	7.4	
Jetty	0.3	7.0	7.7	7.0	
PAC	1.3	1.6	1.5	1.7	
NongFab	0.3	2.6	2.8	2.6	

Note: (1) Using normal loading for line sources

(2) Using total normal loading = 17.2 g/sec

(3) Option 1 scenario, loading of benzene = 18.4 g/sec

(4) Option 2 scenario, loading of benzene = 28.2 g/sec

5.7.2 Setting Emission Standards of HAPs

As demonstrated, annual ambient concentration of benzene can be managed through reducing sources' emissions at major sources. In order to sustain the ambient air quality, emission standards for this species need to be set. In setting the emission standard for HAPs, a technology based, Maximum Achievable Control Technology (MACT) has been applied in the United States (USA). The USEPA was directed to develop MACT standards for reducing 189 HAP emissions and sources were listed into two categories: (a) large sources including sources that emitted individual HAPs of more than 10 tons/year or total HAPs of more than 25 tons/year and (b) area sources. The MACT is defined as

"The emission limitation which is not less stringent than the emission limitation achieved in practice by the best controlled similar source and which reflects the maximum degree of reduction in emissions of HAPs (including the prohibition of emissions) that the permitting authority, taking into consideration the cost of achieving such emission reduction and any non-air quality health and environmental impacts and energy requirements, determined achievable by the constructed or reconstructed major sources".

In determining which emission limitation is best, USEPA evaluated both existing and new sources. For existing sources, the MACT floor is determined by the average emission limitation achieved by the best performing 12% of existing USA sources. If fewer than 30 sources exist, the performance of the best 5 sources is averaged. If there is no data for sources, the EPA has to evaluate. For new sources, MACT is equal to the best emission limitation achieved in practice by a similar source.

For stack emission standards, there are many countries that have set the stack emission standards in units of concentration of specific pollutants in waste gasses. Korea has set the concentration of benzene in waste gas from stacks at not more than 50 ppm for benzene and for total hydrocarbons at 50-100 ppm depending on a size of a factory. Japan has set the stack emission standard for benzene, one of 22 substances requiring priority action, at 50-600 mg/Nm^3 for new sources and 100-1500 mg/Nm^3 for existing sources depending on a size of a factory (DIW, 2002b).

Fugitive emission standards have been set by the European Commissioner, which issued an EU-Directive 98/C248/01 on the limitation of an emission of volatile organic compounds (VOC-directive), June 1998. The directive required large sources, which using solvent of more than 1000 tons/year, to emit not more than 3% of the solvent used and not more than 5% of the solvent used for medium sources (which are defined as these using 100-1000 tons/year of solvent). The varieties of emission standards for HAPs are showed in Table 5.15 (DIW 2002b).

Thus, for Map Ta Phut industrial estate, once the proposed maximum loading from involved industries in the area has been defined, production facilities in the area have to be selected as a representative to set up the Maximum Achievable Control Technology scenario. Then, following the USEPA method, stack emission standards and fugitive emission standards can be set. The setting of emission standards requires much effort and needs more cooperation from industries, as shown in Figure 5.28. The results from this study are applicable in setting the emission standards of HAPs in the area, as it was an environmental impact assessment.

Table 5.15: Emission Standards of HAPs in various countries (DIW, 2002b).

Item	Country	Parameter	Emission rate	Remark
1.	Japan	Benzene	New facilities:50-600 mg/Nm^3	Depend on size of facilities, http://www.env.go.jp/en/lar/regulation/air.html
			Existing facilities: 100-1,500 mg/Nm^3	
2.	Korea	Benzene	50 ppm from general processes	
3.	European Countries	Total VOCs	Stack emission 150 mg C/Nm^3 for facility using solvent $\geq$ 100 tons/y	EU-Directive 98/C248/01
			Fugitive Emission 3% of solvent used	for facility using solvent $\geq$ 1,000 tons/y
			Fugitive Emission 5% of solvent used	for facility using solvent between 100-1,000 ton/y
4.	USA	Air Toxics	MACT	Large Facilities that emitted individual air toxic more than 10 ton/y or total air toxics more than 25 tons/y
			efficiency of vapor recovery system more than 95%	Floating roof of liquid petroleum tank

Table 5.13: Emission Standards of HAPs in various countries (continued)

Item	Country	Parameter	Emission rate	Remark
5.	Thailand	Xylene	870 mg/Nm^3 or 200 ppm for emission from general processes	Ministry of Industry, Notification No.2, B.E 2536
		Total VOCs	17 mg total VOCs/L in emitted vapor from liquid petroleum storage tanks and Transportation via pipes or trucks	Ministry of Science, Technology and Environment, Notification No.2, B.E 2545

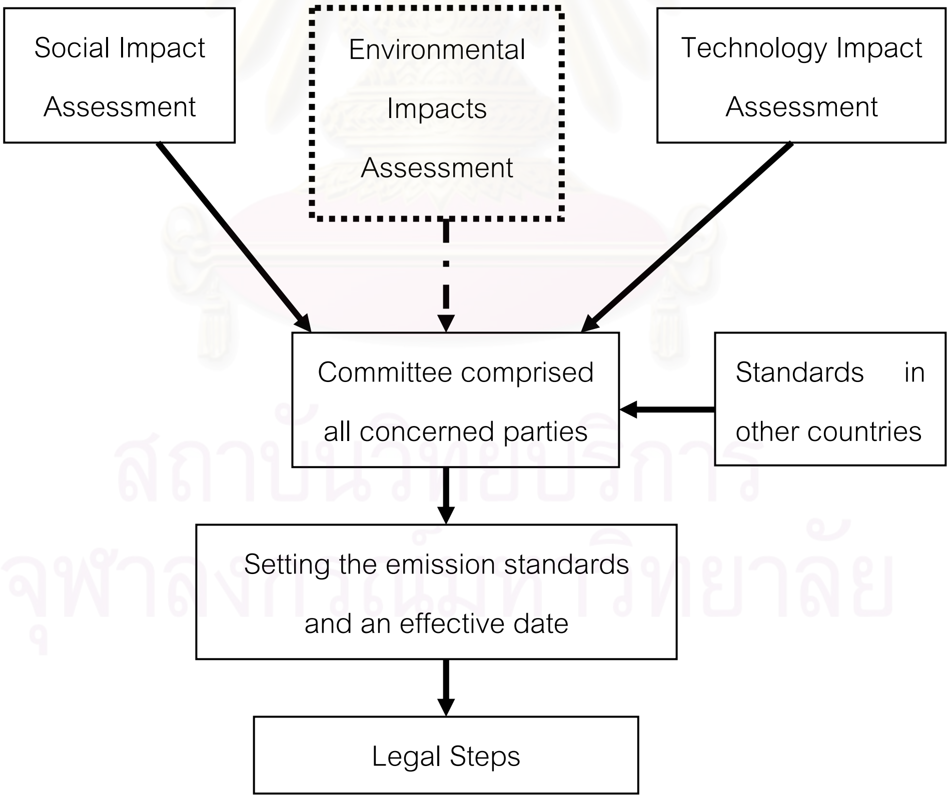


Figure 5.28: Typical Process for Setting Emission Standard in Thailand

CHAPTER 6

CONCLUSIONS AND RECOMMENDATIONS

6.1 Conclusions

6.1.1 Ambient Concentrations of BTEX in the Study Area

BTEX concentrations in the Map Ta Phut area were found to be comparable to those studied in industrial areas elsewhere. The average concentration of benzene at industrial sites (6.4 µg/m^3) was about three times lower than that found in Bangkok ambient air, 18 µg/m^3. Toluene was the most abundant species found (with an average of 29.8 µg/m^3) and was at its highest concentration during the dry season. Ethylbenzene and xylene were found at an average of 0.7 and 5.4 µg/m^3 respectively. The highest individual concentration of benzene, 40.1 µg/m^3, was recorded at the Jetty site and a benzene concentration of 32.1 µg/m^3 was found during the dry season at the TSK site. The highest mean concentration of toluene was 47.5 µg/m^3, at the industrial TSK site, followed by 27.2 µg/m^3 at the THC site. The lowest mean concentration for toluene,1.9 µg/m^3, was found at the Padaeng site followed by 2.3 µg/m^3 at the IEAT site, which are both located upwind from the border of the complex. The highest individual toluene concentration, 370.5 µg/m^3, was found at the THC site during the dry period. Ethylbenzene was detected only occasionally, but was found at quite low levels at the TSK, THC, School, SDC, Jetty and NFC sites. The highest concentration, 17.0 µg/m^3, was found at the TSK site during the dry season while it was found always below detection limit at both the Padaeng and PAC sites. Xylene, which is a mixed-xylene, was detected with a highest mean concentration, 8.3 µg/m^3, at the TSK site followed by 3.8 µg/m^3 at the THC site, and 2.8 µg/m^3 at the Jetty site. The lowest mean concentration for xylene, 0.2 µg/m^3, was found at two sites, namely School and SDC and was detected below the detection limit at the PAC site. The highest individual xylene concentration, 41.9 µg /m^3, was found at the TSK site during the dry season.

The results indicate that concentrations of BTEX at the downwind monitoring sites (SDC and School) are lower than those concentrations at monitoring sites within the complex (TSK and NFC) but higher than those concentrations at the upwind monitoring sites (Padaeng and IEAT). The concentrations of BTEX at the upwind monitoring sites were found comparable to the reference-monitoring site. From these results, it is concluded that the ambient air quality within the complex was affected by emissions from sources situated in the complex and that the downwind residential area was also affected by emissions from these sources. The ambient air quality in area was found more vulnerable to be affected by emissions from sources during the dry season.

6.1.2 Emission Sources and Loading of BTEX in the Study Area

Compiled emission loading in the study area from mobile sources was 0.47, 0.74, 0.09 and 0.52 g/sec for BTEX respectively. For point (stack) sources, emission rates of BTEX have been determined as 3.08, 8.32, 0.59 and 1.91 g/s respectively. The highest emission loading in the Map Ta Phut complex comes from area sources, which contribute 13.64, 7.71, 0.75 and 22.24 g/s for BTEX respectively. Two refineries and two upstream aromatic plants contribute 70%, 86%, 56%, and 70% of benzene, toluene, ethylbenzene and xylene loading respectively through both their point and area sources.

In order to identify sources of BTEX in ambient air in the area, a B:T ratio technique was used. The B:T ratio of measured values at industrial and downwind sites were compared to the B:T ratio of the sources profile. Results at the TSK site were calculated to be 0.08, 1.2 and 0.67 respectively. From the data, the benzene concentrations appear, in general, to be less variable, whereas toluene concentrations exhibit considerable variation. The very low B:T ratio observed in the first period is due to relatively high toluene concentrations. At the downwind receptor site, the School, the average B:T ratios for the three sampling periods were found to be 0.76, 1.33, 1.34. These higher ratios conformed more to the ratios studied at the refinery plume (0.47), petrochemical plant and tank farm fugitives when compared to the B:T ratio at roadside and background park areas of Bangkok (0.28 and 0.17).

From these results it can be concluded that the ambient concentrations of BTEX in the area are source-dependent and mobile sources are considered not to be the significant source of these pollutants.

6.1.3 Effects of Sources on Ambient Concentrations

The ISCST-3 air dispersion model was effectively used to simulate the effects of compiled emission loading in the area. It was observed that the stationary industrial sources, through either point or area emissions dominated the ambient concentrations of target species. ISCST-3 was used to model the effects of the inventory on ambient air at the same time of field measurement. The comparison of predicted and measured values was reasonable. The coefficient of determination (R^2) was found to be 0.58 and 0.13 for two industrial sites and two downwind sites respectively while there was little relation at two upwind sites. When looking at the individual modeling result of line, point and area source, it was found that all monitoring sites were constantly and slightly affected by mobile sources. Point and area sources were found to have a significant influence on ambient concentrations when wind blew from the estate toward the measuring point. At the THC site, the coefficient of determination (R^2) was quite low at 0.03. This monitoring site was affected only slightly by mobile sources. It was also found later that there were local sources of BTEX nearby at the THC site, which may have had some influence on the observed values.

The predicted annual average concentrations of BTEX were simulated by the ISCST-3 model under meteorological data of the year 2002, which was selected as a worse case condition. Benzene was found below its chronic benchmark, 60 $\mu g/m^3$, at all monitoring sites. However, concentrations of benzene at three sites, TSK (10.8 $\mu g/m^3$), NFC (9.8 $\mu g/m^3$) and School (9.9 $\mu g/m^3$) were found to be considerably high comparing to the ambient air quality standard, 5 ppb or 16.2 $\mu g/m^3$, set by World Health Organization (WHO). The predicted annual average concentrations of TEX were found lower than their chronic benchmarks, 400 $\mu g/m^3$, 1000 $\mu g/m^3$ and 700 $\mu g/m^3$ respectively at all monitoring sites. The maximum 24-hr average of predicted values of TEX, 359.5 $\mu g/m^3$, 14.3 $\mu g/m^3$ and 194.6 $\mu g/m^3$, at the TSK site are also below the 24-hr average standard set by AAAQGs at 3000 $\mu g/m^3$, 3500 $\mu g/m^3$ and 3500 $\mu g/m^3$ respectively.

It was found that only ambient concentrations of benzene at monitoring sites located within the complex and downwind of major sources were considerably high comparing to the ambient air quality standard. The other species are well below their chronic benchmark and corresponding ambient air quality standards.

6.1.4 Determination of the Allowable Emission Loading of Sources

The proposed emissions loading of major sources that result in ambient concentrations of benzene remaining within health concern limits (5 ppb) was determined based on interpolation of two modeling results. The proposed emission rate of benzene in the area was found to be 18.9 g/sec, while its current emission rate is 17.2 g/sec. The other three pollutants were not considered since they were well below their chronic effects and ambient quality standards.

6.2 Recommendations

The main sources of BTEX in the area were point and area sources of the two upstream aromatic processes and two refineries. Consequently, predicted annual values of benzene were found to be comparable to the standard at some monitoring sites. In order to manage the ambient concentrations of the target species within health concern limits, there are several management options that can be considered in this area, as follows;

1. Any projects that may be settled in the area have to clarify their additional impacts on benzene ambient concentrations.
2. Self-controlling of emissions from identified major sources by improving the percent collection of these emission to nearly 100%, to treat these at suitable treatment facilities such as a vapor recovery unit or flare and to implement a leak detection and repair (LDAR) program.
3. End of pipe control through setting emission standards for these species.

The findings from this study showed that the management option on self-controlling of emissions from identified major sources seems to be an effective option in managing the ambient concentration of benzene in the study area to maintain levels below the health concern limit.

While the results from this study show trends of ambient concentrations of BTEX in the Map Ta Phut area, it is acknowledged that the modeling method embedded some inherent uncertainties. Thus, long-term or continuous measurements to confirm the ambient concentrations, such as 24-hr measurement data and longer monitoring periods, along with a higher degree of accuracy for an emission inventory should be carried out to continually improve the understanding of impacts of the complex on the surrounding environment.

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APPENDICES

Appendix A

Example of Chromatogram

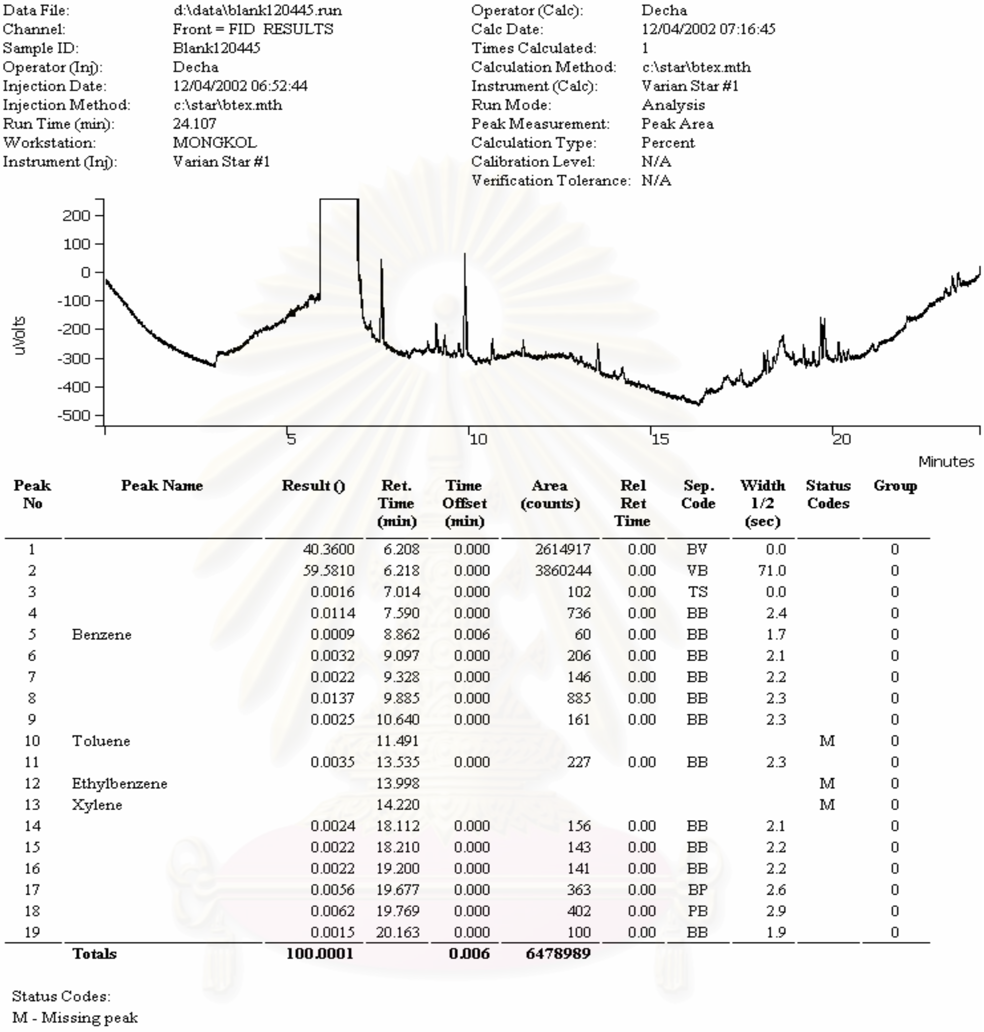
(a) and (b) for Blank,

(c) and (d) for 0.025 ppm Standard,

and

(e) and (f) for back-up part of sample,

(g), (h) and (i) for front part of sample



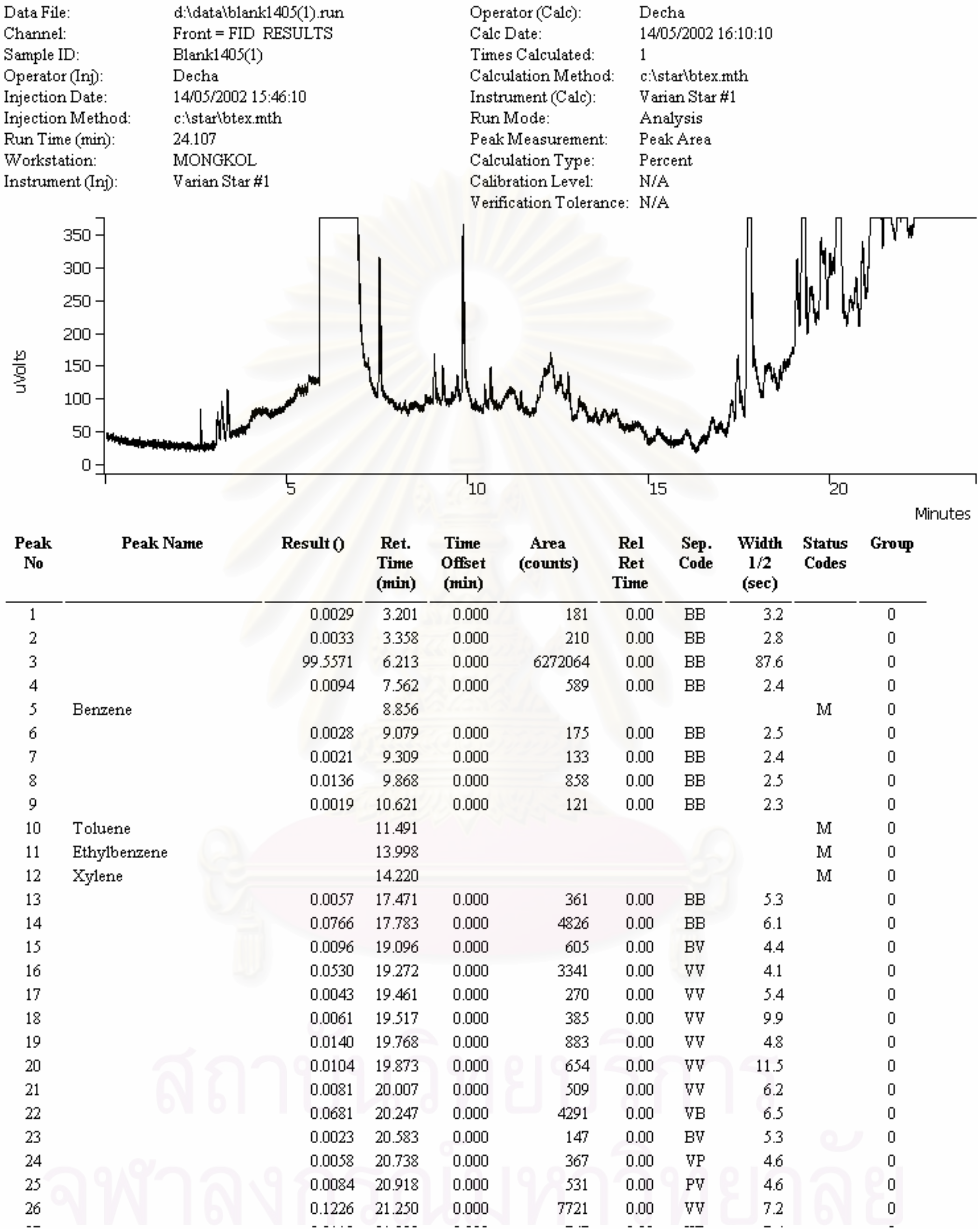
Data File: d:\data\blank120445.run
Channel: Front = FID RESULTS
Sample ID: Blank120445
Operator (Inj): Decha
Injection Date: 12/04/2002 06:52:44
Injection Method: c:\star\btex.mth
Run Time (min): 24.107
Workstation: MONGKOL
Instrument (Inj): Varian Star #1

Operator (Calc): Decha
Calc Date: 12/04/2002 07:16:45
Times Calculated: 1
Calculation Method: c:\star\btex.mth
Instrument (Calc): Varian Star #1
Run Mode: Analysis
Peak Measurement: Peak Area
Calculation Type: Percent
Calibration Level: N/A
Verification Tolerance: N/A

Peak No	Peak Name	Result ()	Ret. Time (min)	Time Offset (min)	Area (counts)	Rel Ret Time	Sep. Code	Width 1/2 (sec)	Status Codes	Group
1		40.3600	6.208	0.000	2614917	0.00	BV	0.0		0
2		59.5810	6.218	0.000	3860244	0.00	VB	71.0		0
3		0.0016	7.014	0.000	102	0.00	TS	0.0		0
4		0.0114	7.590	0.000	736	0.00	BB	2.4		0
5	Benzene	0.0009	8.862	0.006	60	0.00	BB	1.7		0
6		0.0032	9.097	0.000	206	0.00	BB	2.1		0
7		0.0022	9.328	0.000	146	0.00	BB	2.2		0
8		0.0137	9.885	0.000	885	0.00	BB	2.3		0
9		0.0025	10.640	0.000	161	0.00	BB	2.3		0
10	Toluene		11.491						M	0
11		0.0035	13.535	0.000	227	0.00	BB	2.3		0
12	Ethylbenzene		13.998						M	0
13	Xylene		14.220						M	0
14		0.0024	18.112	0.000	156	0.00	BB	2.1		0
15		0.0022	18.210	0.000	143	0.00	BB	2.2		0
16		0.0022	19.200	0.000	141	0.00	BB	2.2		0
17		0.0056	19.677	0.000	363	0.00	BP	2.6		0
18		0.0062	19.769	0.000	402	0.00	PB	2.9		0
19		0.0015	20.163	0.000	100	0.00	BB	1.9		0
	Totals	**100.0001**		**0.006**	**6478989**					

Status Codes:
M - Missing peak

(a) Blank (1)

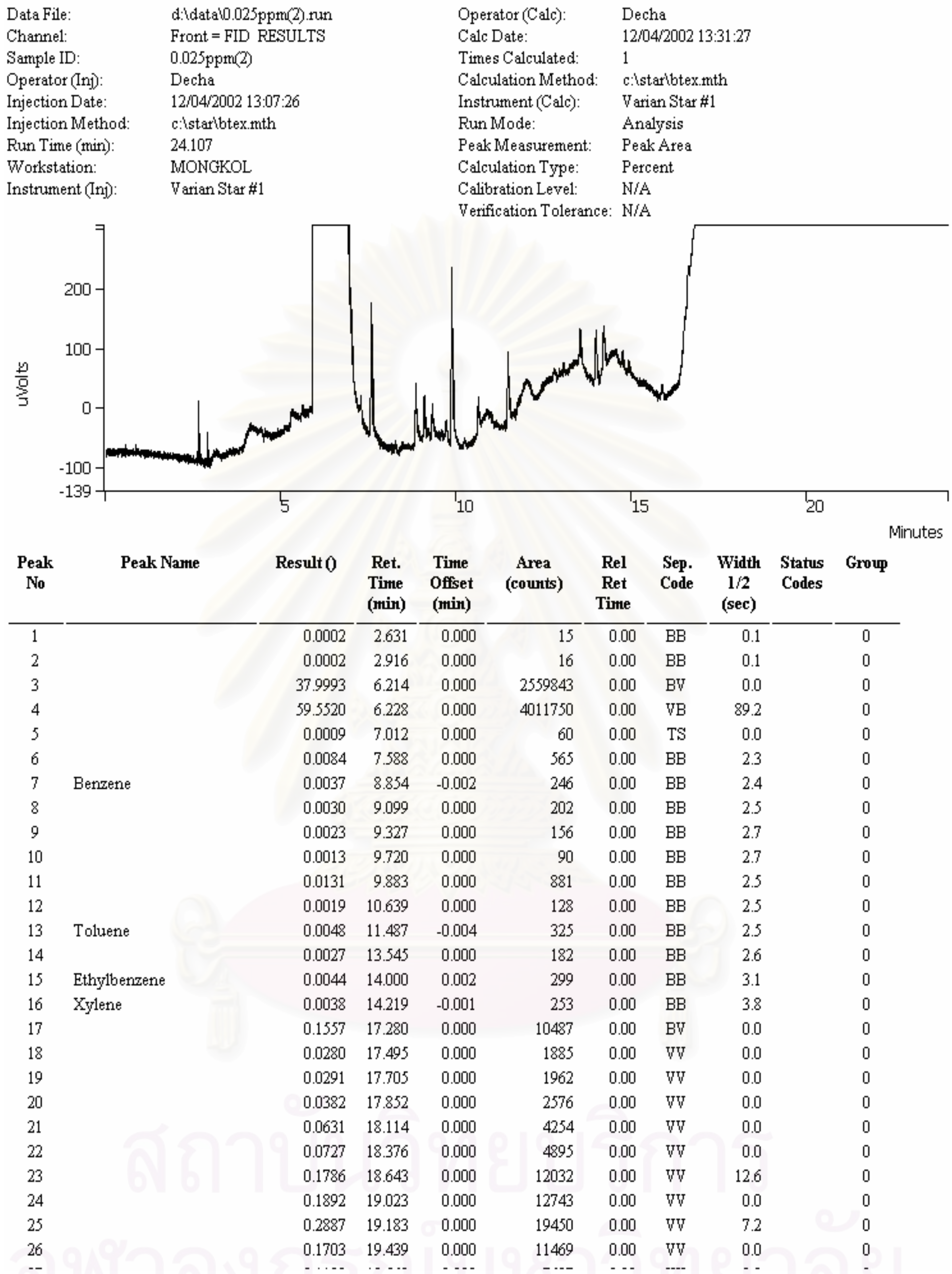


Data File: d:\data\blank1405(1).run
Channel: Front = FID RESULTS
Sample ID: Blank1405(1)
Operator (Inj): Decha
Injection Date: 14/05/2002 15:46:10
Injection Method: c:\star\btex.mth
Run Time (min): 24.107
Workstation: MONGKOL
Instrument (Inj): Varian Star #1

Operator (Calc): Decha
Calc Date: 14/05/2002 16:10:10
Times Calculated: 1
Calculation Method: c:\star\btex.mth
Instrument (Calc): Varian Star #1
Run Mode: Analysis
Peak Measurement: Peak Area
Calculation Type: Percent
Calibration Level: N/A
Verification Tolerance: N/A

Peak No	Peak Name	Result ()	Ret. Time (min)	Time Offset (min)	Area (counts)	Rel Ret Time	Sep. Code	Width 1/2 (sec)	Status Codes	Group
1		0.0029	3.201	0.000	181	0.00	BB	3.2		0
2		0.0033	3.358	0.000	210	0.00	BB	2.8		0
3		99.5571	6.213	0.000	6272064	0.00	BB	87.6		0
4		0.0094	7.562	0.000	589	0.00	BB	2.4		0
5	Benzene		8.856						M	0
6		0.0028	9.079	0.000	175	0.00	BB	2.5		0
7		0.0021	9.309	0.000	133	0.00	BB	2.4		0
8		0.0136	9.868	0.000	858	0.00	BB	2.5		0
9		0.0019	10.621	0.000	121	0.00	BB	2.3		0
10	Toluene		11.491						M	0
11	Ethylbenzene		13.998						M	0
12	Xylene		14.220						M	0
13		0.0057	17.471	0.000	361	0.00	BB	5.3		0
14		0.0766	17.783	0.000	4826	0.00	BB	6.1		0
15		0.0096	19.096	0.000	605	0.00	BV	4.4		0
16		0.0530	19.272	0.000	3341	0.00	VV	4.1		0
17		0.0043	19.461	0.000	270	0.00	VV	5.4		0
18		0.0061	19.517	0.000	385	0.00	VV	9.9		0
19		0.0140	19.768	0.000	883	0.00	VV	4.8		0
20		0.0104	19.873	0.000	654	0.00	VV	11.5		0
21		0.0081	20.007	0.000	509	0.00	VV	6.2		0
22		0.0681	20.247	0.000	4291	0.00	VB	6.5		0
23		0.0023	20.583	0.000	147	0.00	BV	5.3		0
24		0.0058	20.738	0.000	367	0.00	VP	4.6		0
25		0.0084	20.918	0.000	531	0.00	PV	4.6		0
26		0.1226	21.250	0.000	7721	0.00	VV	7.2		0

(b) Blank (2)

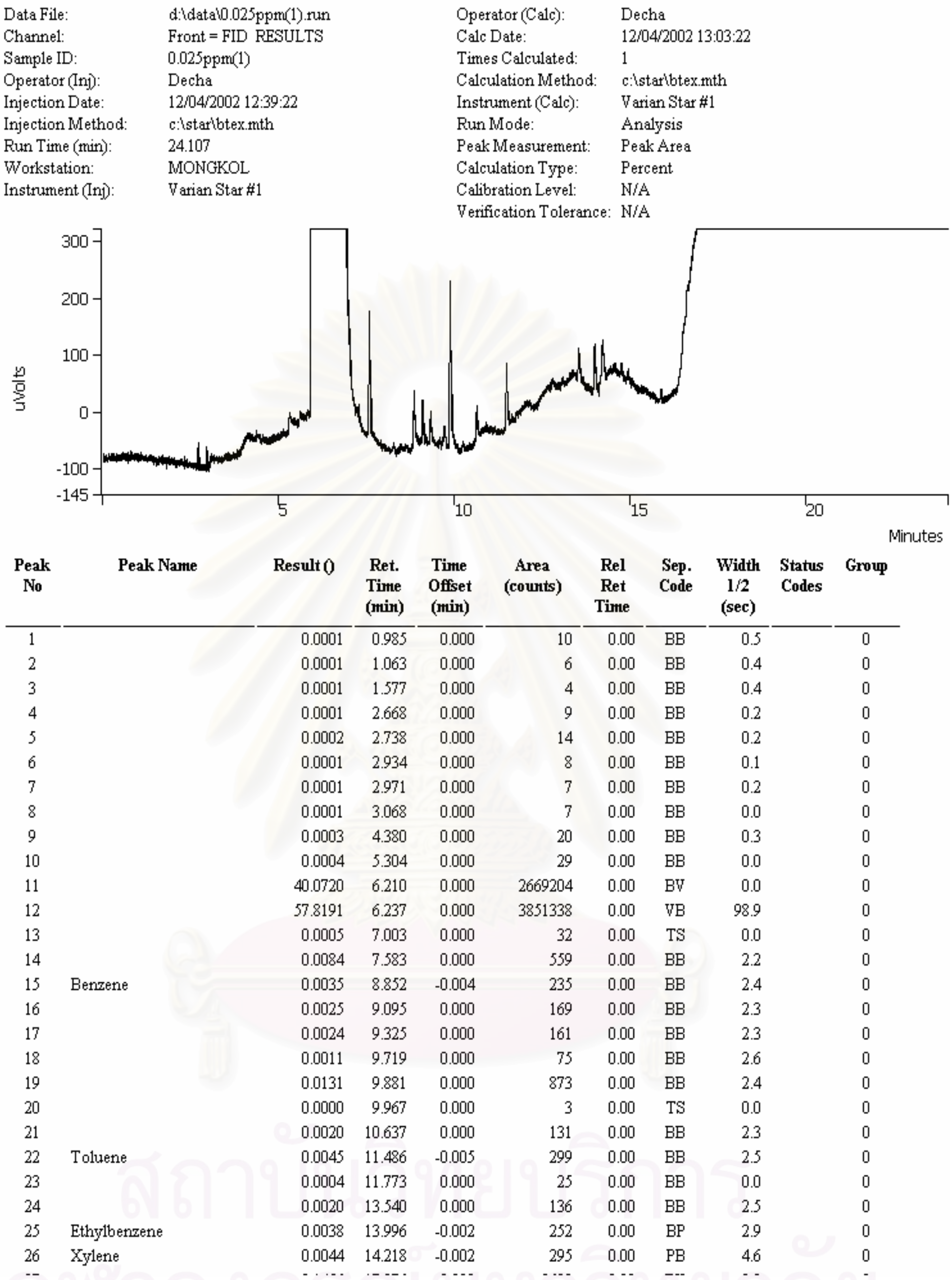


Data File: d:\data\0.025ppm(2).run
Channel: Front = FID RESULTS
Sample ID: 0.025ppm(2)
Operator (Inj): Decha
Injection Date: 12/04/2002 13:07:26
Injection Method: c:\star\btex.mth
Run Time (min): 24.107
Workstation: MONGKOL
Instrument (Inj): Varian Star #1

Operator (Calc): Decha
Calc Date: 12/04/2002 13:31:27
Times Calculated: 1
Calculation Method: c:\star\btex.mth
Instrument (Calc): Varian Star #1
Run Mode: Analysis
Peak Measurement: Peak Area
Calculation Type: Percent
Calibration Level: N/A
Verification Tolerance: N/A

Peak No	Peak Name	Result ()	Ret. Time (min)	Time Offset (min)	Area (counts)	Rel Ret Time	Sep. Code	Width 1/2 (sec)	Status Codes	Group
1		0.0002	2.631	0.000	15	0.00	BB	0.1		0
2		0.0002	2.916	0.000	16	0.00	BB	0.1		0
3		37.9993	6.214	0.000	2559843	0.00	BV	0.0		0
4		59.5520	6.228	0.000	4011750	0.00	VB	89.2		0
5		0.0009	7.012	0.000	60	0.00	TS	0.0		0
6		0.0084	7.588	0.000	565	0.00	BB	2.3		0
7	Benzene	0.0037	8.854	-0.002	246	0.00	BB	2.4		0
8		0.0030	9.099	0.000	202	0.00	BB	2.5		0
9		0.0023	9.327	0.000	156	0.00	BB	2.7		0
10		0.0013	9.720	0.000	90	0.00	BB	2.7		0
11		0.0131	9.883	0.000	881	0.00	BB	2.5		0
12		0.0019	10.639	0.000	128	0.00	BB	2.5		0
13	Toluene	0.0048	11.487	-0.004	325	0.00	BB	2.5		0
14		0.0027	13.545	0.000	182	0.00	BB	2.6		0
15	Ethylbenzene	0.0044	14.000	0.002	299	0.00	BB	3.1		0
16	Xylene	0.0038	14.219	-0.001	253	0.00	BB	3.8		0
17		0.1557	17.280	0.000	10487	0.00	BV	0.0		0
18		0.0280	17.495	0.000	1885	0.00	VV	0.0		0
19		0.0291	17.705	0.000	1962	0.00	VV	0.0		0
20		0.0382	17.852	0.000	2576	0.00	VV	0.0		0
21		0.0631	18.114	0.000	4254	0.00	VV	0.0		0
22		0.0727	18.376	0.000	4895	0.00	VV	0.0		0
23		0.1786	18.643	0.000	12032	0.00	VV	12.6		0
24		0.1892	19.023	0.000	12743	0.00	VV	0.0		0
25		0.2887	19.183	0.000	19450	0.00	VV	7.2		0
26		0.1703	19.439	0.000	11469	0.00	VV	0.0		0

(c) 0.025 ppm-Standard Solution (1)

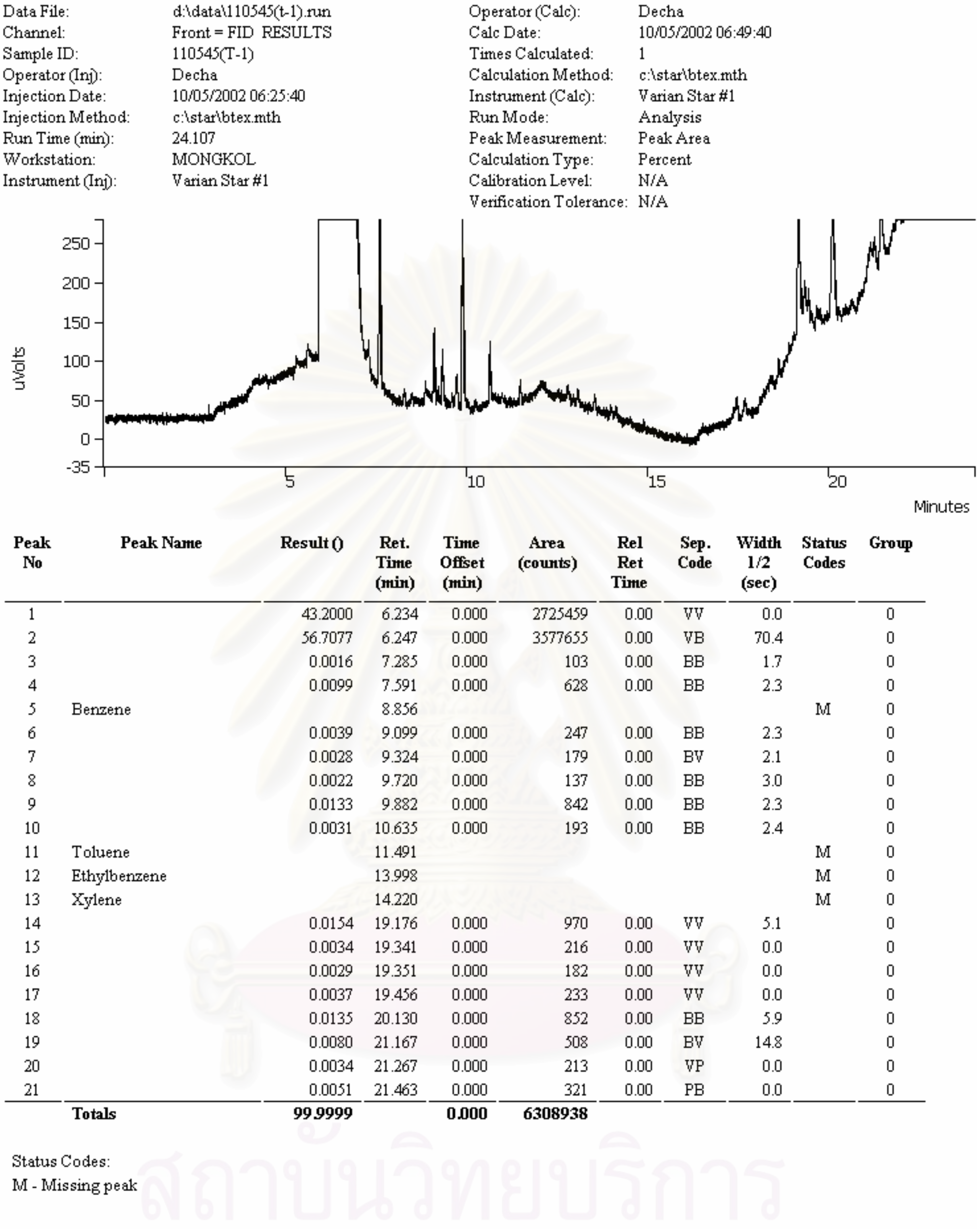


Data File: d:\data\0.025ppm(1).run
Channel: Front = FID RESULTS
Sample ID: 0.025ppm(1)
Operator (Inj): Decha
Injection Date: 12/04/2002 12:39:22
Injection Method: c:\star\btex.mth
Run Time (min): 24.107
Workstation: MONGKOL
Instrument (Inj): Varian Star #1

Operator (Calc): Decha
Calc Date: 12/04/2002 13:03:22
Times Calculated: 1
Calculation Method: c:\star\btex.mth
Instrument (Calc): Varian Star #1
Run Mode: Analysis
Peak Measurement: Peak Area
Calculation Type: Percent
Calibration Level: N/A
Verification Tolerance: N/A

Peak No	Peak Name	Result ()	Ret. Time (min)	Time Offset (min)	Area (counts)	Rel Ret Time	Sep. Code	Width 1/2 (sec)	Status Codes	Group
1		0.0001	0.985	0.000	10	0.00	BB	0.5		0
2		0.0001	1.063	0.000	6	0.00	BB	0.4		0
3		0.0001	1.577	0.000	4	0.00	BB	0.4		0
4		0.0001	2.668	0.000	9	0.00	BB	0.2		0
5		0.0002	2.738	0.000	14	0.00	BB	0.2		0
6		0.0001	2.934	0.000	8	0.00	BB	0.1		0
7		0.0001	2.971	0.000	7	0.00	BB	0.2		0
8		0.0001	3.068	0.000	7	0.00	BB	0.0		0
9		0.0003	4.380	0.000	20	0.00	BB	0.3		0
10		0.0004	5.304	0.000	29	0.00	BB	0.0		0
11		40.0720	6.210	0.000	2669204	0.00	BV	0.0		0
12		57.8191	6.237	0.000	3851338	0.00	VB	98.9		0
13		0.0005	7.003	0.000	32	0.00	TS	0.0		0
14		0.0084	7.583	0.000	559	0.00	BB	2.2		0
15	Benzene	0.0035	8.852	-0.004	235	0.00	BB	2.4		0
16		0.0025	9.095	0.000	169	0.00	BB	2.3		0
17		0.0024	9.325	0.000	161	0.00	BB	2.3		0
18		0.0011	9.719	0.000	75	0.00	BB	2.6		0
19		0.0131	9.881	0.000	873	0.00	BB	2.4		0
20		0.0000	9.967	0.000	3	0.00	TS	0.0		0
21		0.0020	10.637	0.000	131	0.00	BB	2.3		0
22	Toluene	0.0045	11.486	-0.005	299	0.00	BB	2.5		0
23		0.0004	11.773	0.000	25	0.00	BB	0.0		0
24		0.0020	13.540	0.000	136	0.00	BB	2.5		0
25	Ethylbenzene	0.0038	13.996	-0.002	252	0.00	BP	2.9		0
26	Xylene	0.0044	14.218	-0.002	295	0.00	PB	4.6		0

(d) 0.025 ppm-Standard Solution (2)



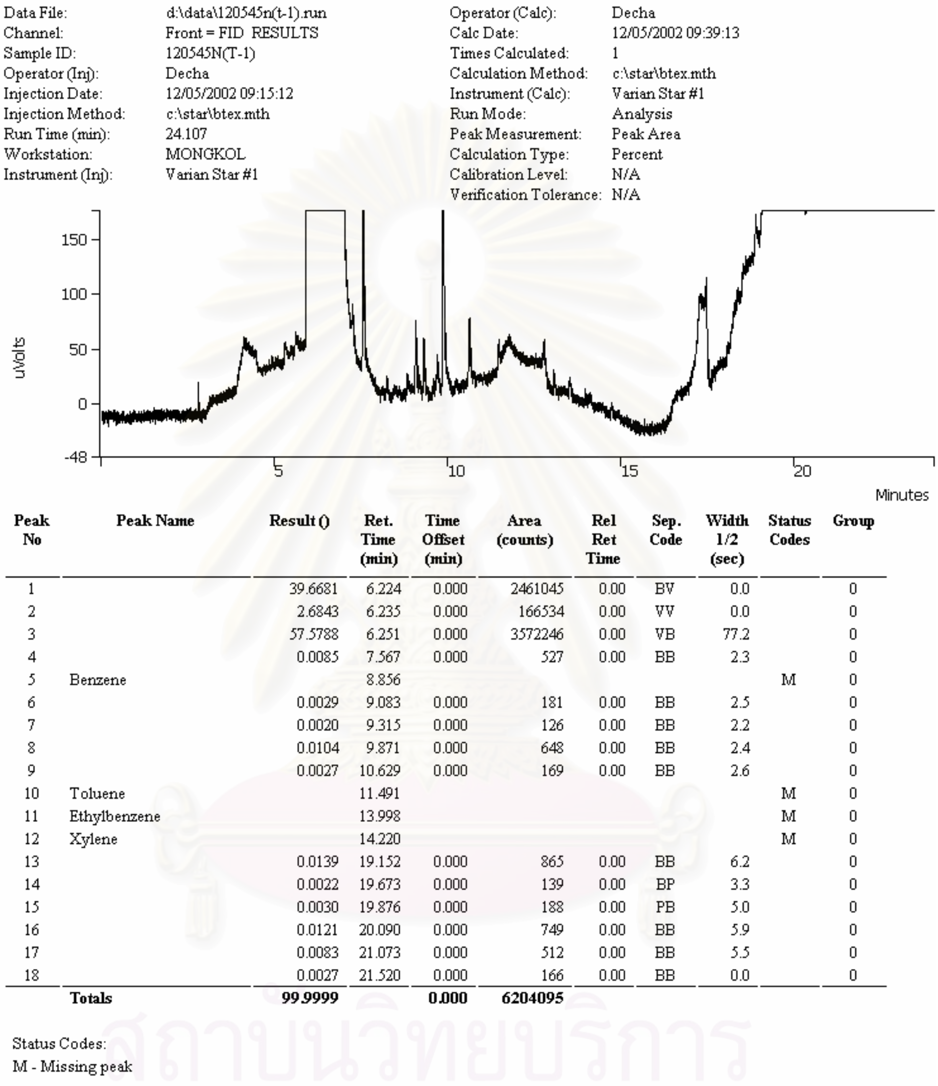
Data File: d:\data\110545(t-1).run
Channel: Front = FID RESULTS
Sample ID: 110545(T-1)
Operator (Inj): Decha
Injection Date: 10/05/2002 06:25:40
Injection Method: c:\star\btex.mth
Run Time (min): 24.107
Workstation: MONGKOL
Instrument (Inj): Varian Star #1

Operator (Calc): Decha
Calc Date: 10/05/2002 06:49:40
Times Calculated: 1
Calculation Method: c:\star\btex.mth
Instrument (Calc): Varian Star #1
Run Mode: Analysis
Peak Measurement: Peak Area
Calculation Type: Percent
Calibration Level: N/A
Verification Tolerance: N/A

Peak No	Peak Name	Result ()	Ret. Time (min)	Time Offset (min)	Area (counts)	Rel Ret Time	Sep. Code	Width 1/2 (sec)	Status Codes	Group
1		43.2000	6.234	0.000	2725459	0.00	VV	0.0		0
2		56.7077	6.247	0.000	3577655	0.00	VB	70.4		0
3		0.0016	7.285	0.000	103	0.00	BB	1.7		0
4		0.0099	7.591	0.000	628	0.00	BB	2.3		0
5	Benzene		8.856						M	0
6		0.0039	9.099	0.000	247	0.00	BB	2.3		0
7		0.0028	9.324	0.000	179	0.00	BV	2.1		0
8		0.0022	9.720	0.000	137	0.00	BB	3.0		0
9		0.0133	9.882	0.000	842	0.00	BB	2.3		0
10		0.0031	10.635	0.000	193	0.00	BB	2.4		0
11	Toluene		11.491						M	0
12	Ethylbenzene		13.998						M	0
13	Xylene		14.220						M	0
14		0.0154	19.176	0.000	970	0.00	VV	5.1		0
15		0.0034	19.341	0.000	216	0.00	VV	0.0		0
16		0.0029	19.351	0.000	182	0.00	VV	0.0		0
17		0.0037	19.456	0.000	233	0.00	VV	0.0		0
18		0.0135	20.130	0.000	852	0.00	BB	5.9		0
19		0.0080	21.167	0.000	508	0.00	BV	14.8		0
20		0.0034	21.267	0.000	213	0.00	VP	0.0		0
21		0.0051	21.463	0.000	321	0.00	PB	0.0		0
	Totals	**99.9999**		**0.000**	**6308938**					

Status Codes:
M - Missing peak

(e) Back-up Part of Sample (1)



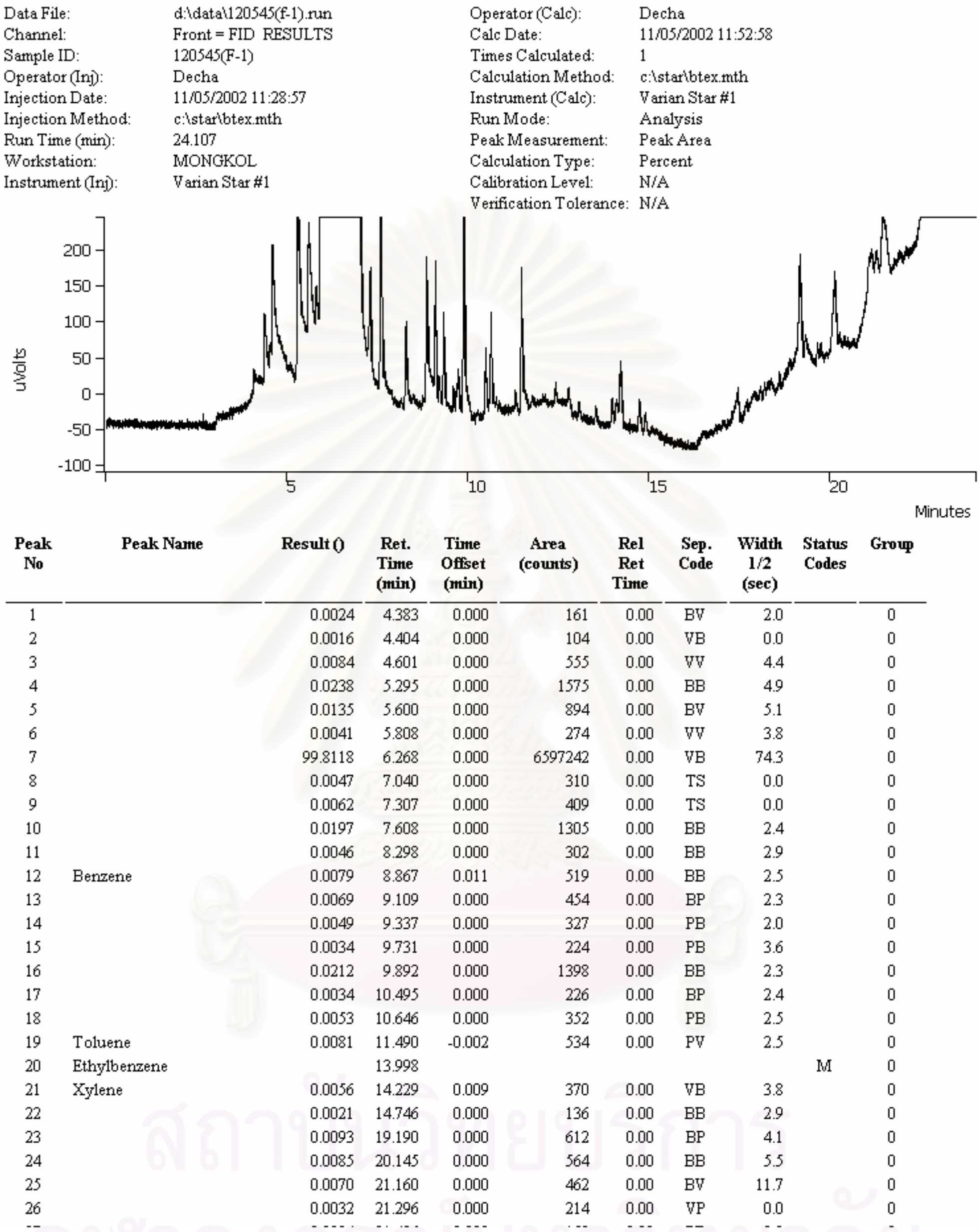
Data File: d:\data\120545n(t-1).run
Channel: Front = FID RESULTS
Sample ID: 120545N(T-1)
Operator (Inj): Decha
Injection Date: 12/05/2002 09:15:12
Injection Method: c:\star\btex.mth
Run Time (min): 24.107
Workstation: MONGKOL
Instrument (Inj): Varian Star #1

Operator (Calc): Decha
Calc Date: 12/05/2002 09:39:13
Times Calculated: 1
Calculation Method: c:\star\btex.mth
Instrument (Calc): Varian Star #1
Run Mode: Analysis
Peak Measurement: Peak Area
Calculation Type: Percent
Calibration Level: N/A
Verification Tolerance: N/A

Peak No	Peak Name	Result ()	Ret. Time (min)	Time Offset (min)	Area (counts)	Rel Ret Time	Sep. Code	Width 1/2 (sec)	Status Codes	Group
1		39.6681	6.224	0.000	2461045	0.00	BV	0.0		0
2		2.6843	6.235	0.000	166534	0.00	VV	0.0		0
3		57.5788	6.251	0.000	3572246	0.00	VB	77.2		0
4		0.0085	7.567	0.000	527	0.00	BB	2.3		0
5	Benzene		8.856						M	0
6		0.0029	9.083	0.000	181	0.00	BB	2.5		0
7		0.0020	9.315	0.000	126	0.00	BB	2.2		0
8		0.0104	9.871	0.000	648	0.00	BB	2.4		0
9		0.0027	10.629	0.000	169	0.00	BB	2.6		0
10	Toluene		11.491						M	0
11	Ethylbenzene		13.998						M	0
12	Xylene		14.220						M	0
13		0.0139	19.152	0.000	865	0.00	BB	6.2		0
14		0.0022	19.673	0.000	139	0.00	BP	3.3		0
15		0.0030	19.876	0.000	188	0.00	PB	5.0		0
16		0.0121	20.090	0.000	749	0.00	BB	5.9		0
17		0.0083	21.073	0.000	512	0.00	BB	5.5		0
18		0.0027	21.520	0.000	166	0.00	BB	0.0		0
	Totals	**99.9999**		**0.000**	**6204095**					

Status Codes:
M - Missing peak

(f) Back-up Part of Sample (2)

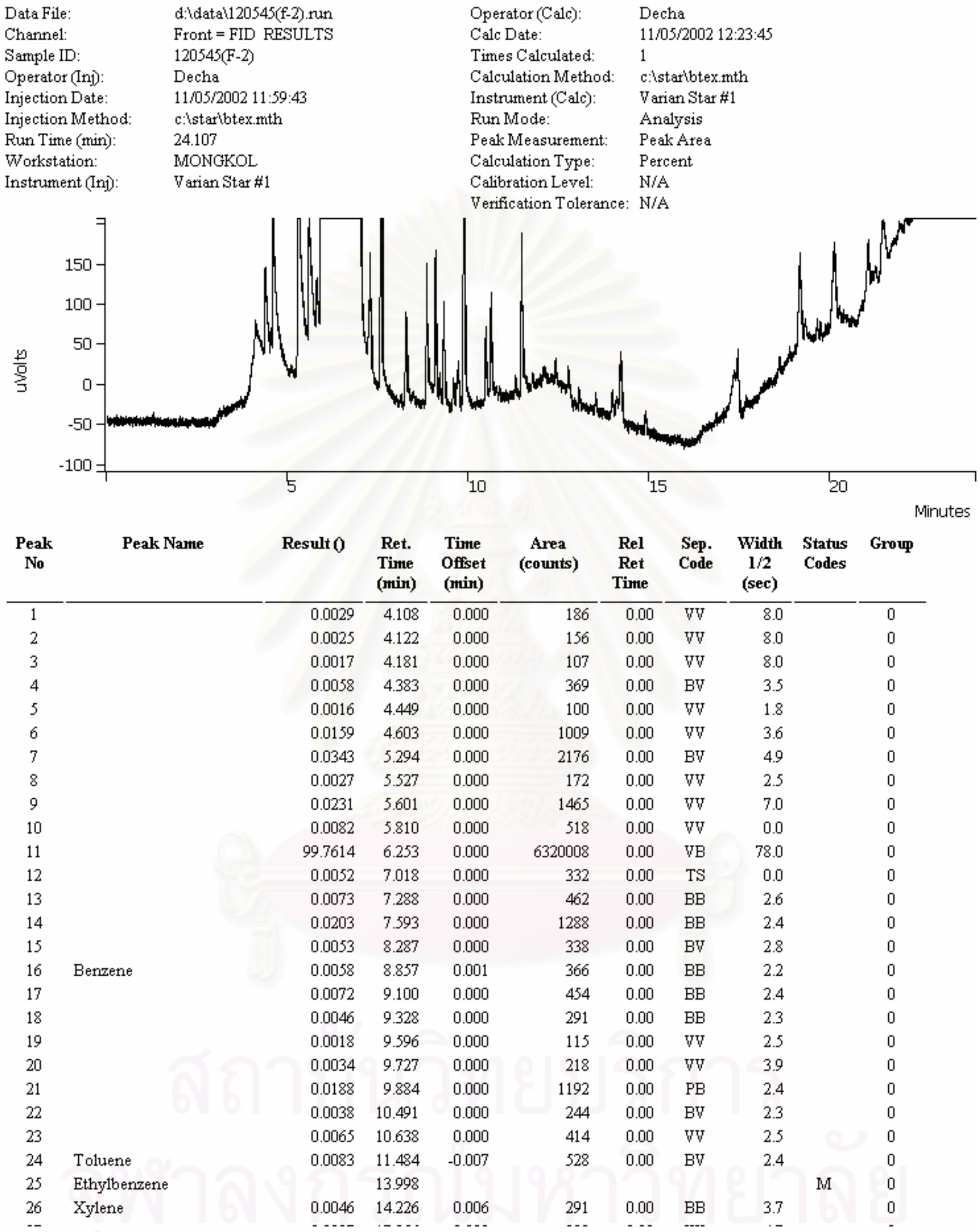


Data File: d:\data\120545(f-1).run
Channel: Front = FID RESULTS
Sample ID: 120545(F-1)
Operator (Inj): Decha
Injection Date: 11/05/2002 11:28:57
Injection Method: c:\star\btex.mth
Run Time (min): 24.107
Workstation: MONGKOL
Instrument (Inj): Varian Star #1

Operator (Calc): Decha
Calc Date: 11/05/2002 11:52:58
Times Calculated: 1
Calculation Method: c:\star\btex.mth
Instrument (Calc): Varian Star #1
Run Mode: Analysis
Peak Measurement: Peak Area
Calculation Type: Percent
Calibration Level: N/A
Verification Tolerance: N/A

Peak No	Peak Name	Result ()	Ret. Time (min)	Time Offset (min)	Area (counts)	Rel Ret Time	Sep. Code	Width 1/2 (sec)	Status Codes	Group
1		0.0024	4.383	0.000	161	0.00	BV	2.0		0
2		0.0016	4.404	0.000	104	0.00	VB	0.0		0
3		0.0084	4.601	0.000	555	0.00	VV	4.4		0
4		0.0238	5.295	0.000	1575	0.00	BB	4.9		0
5		0.0135	5.600	0.000	894	0.00	BV	5.1		0
6		0.0041	5.808	0.000	274	0.00	VV	3.8		0
7		99.8118	6.268	0.000	6597242	0.00	VB	74.3		0
8		0.0047	7.040	0.000	310	0.00	TS	0.0		0
9		0.0062	7.307	0.000	409	0.00	TS	0.0		0
10		0.0197	7.608	0.000	1305	0.00	BB	2.4		0
11		0.0046	8.298	0.000	302	0.00	BB	2.9		0
12	Benzene	0.0079	8.867	0.011	519	0.00	BB	2.5		0
13		0.0069	9.109	0.000	454	0.00	BP	2.3		0
14		0.0049	9.337	0.000	327	0.00	PB	2.0		0
15		0.0034	9.731	0.000	224	0.00	PB	3.6		0
16		0.0212	9.892	0.000	1398	0.00	BB	2.3		0
17		0.0034	10.495	0.000	226	0.00	BP	2.4		0
18		0.0053	10.646	0.000	352	0.00	PB	2.5		0
19	Toluene	0.0081	11.490	-0.002	534	0.00	PV	2.5		0
20	Ethylbenzene		13.998						M	0
21	Xylene	0.0056	14.229	0.009	370	0.00	VB	3.8		0
22		0.0021	14.746	0.000	136	0.00	BB	2.9		0
23		0.0093	19.190	0.000	612	0.00	BP	4.1		0
24		0.0085	20.145	0.000	564	0.00	BB	5.5		0
25		0.0070	21.160	0.000	462	0.00	BV	11.7		0
26		0.0032	21.296	0.000	214	0.00	VP	0.0		0

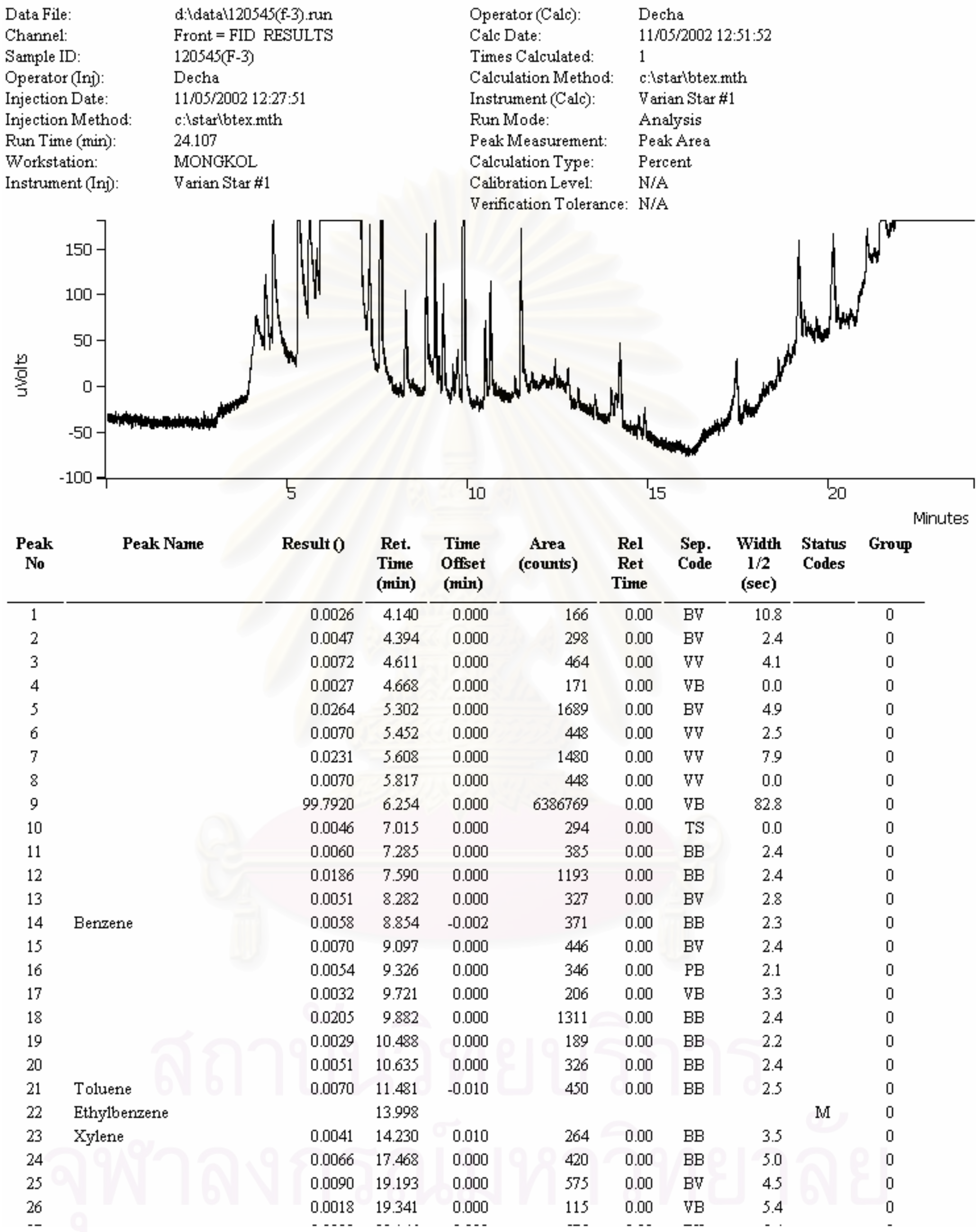
(g) Front Part of Sample (1)



Data File:	d:\data\120545(f-2).run	Operator (Calc):	Decha
Channel:	Front = FID RESULTS	Calc Date:	11/05/2002 12:23:45
Sample ID:	120545(F-2)	Times Calculated:	1
Operator (Inj):	Decha	Calculation Method:	c:\star\btex.mth
Injection Date:	11/05/2002 11:59:43	Instrument (Calc):	Varian Star #1
Injection Method:	c:\star\btex.mth	Run Mode:	Analysis
Run Time (min):	24.107	Peak Measurement:	Peak Area
Workstation:	MONGKOL	Calculation Type:	Percent
Instrument (Inj):	Varian Star #1	Calibration Level:	N/A
		Verification Tolerance:	N/A

Peak No	Peak Name	Result ()	Ret. Time (min)	Time Offset (min)	Area (counts)	Rel Ret Time	Sep. Code	Width 1/2 (sec)	Status Codes	Group
1		0.0029	4.108	0.000	186	0.00	VV	8.0		0
2		0.0025	4.122	0.000	156	0.00	VV	8.0		0
3		0.0017	4.181	0.000	107	0.00	VV	8.0		0
4		0.0058	4.383	0.000	369	0.00	BV	3.5		0
5		0.0016	4.449	0.000	100	0.00	VV	1.8		0
6		0.0159	4.603	0.000	1009	0.00	VV	3.6		0
7		0.0343	5.294	0.000	2176	0.00	BV	4.9		0
8		0.0027	5.527	0.000	172	0.00	VV	2.5		0
9		0.0231	5.601	0.000	1465	0.00	VV	7.0		0
10		0.0082	5.810	0.000	518	0.00	VV	0.0		0
11		99.7614	6.253	0.000	6320008	0.00	VB	78.0		0
12		0.0052	7.018	0.000	332	0.00	TS	0.0		0
13		0.0073	7.288	0.000	462	0.00	BB	2.6		0
14		0.0203	7.593	0.000	1288	0.00	BB	2.4		0
15		0.0053	8.287	0.000	338	0.00	BV	2.8		0
16	Benzene	0.0058	8.857	0.001	366	0.00	BB	2.2		0
17		0.0072	9.100	0.000	454	0.00	BB	2.4		0
18		0.0046	9.328	0.000	291	0.00	BB	2.3		0
19		0.0018	9.596	0.000	115	0.00	VV	2.5		0
20		0.0034	9.727	0.000	218	0.00	VV	3.9		0
21		0.0188	9.884	0.000	1192	0.00	PB	2.4		0
22		0.0038	10.491	0.000	244	0.00	BV	2.3		0
23		0.0065	10.638	0.000	414	0.00	VV	2.5		0
24	Toluene	0.0083	11.484	-0.007	528	0.00	BV	2.4		0
25	Ethylbenzene		13.998						M	0
26	Xylene	0.0046	14.226	0.006	291	0.00	BB	3.7		0

(h) Front Part of Sample (2)



Data File: d:\data\120545(f-3).run
Channel: Front = FID RESULTS
Sample ID: 120545(F-3)
Operator (Inj): Decha
Injection Date: 11/05/2002 12:27:51
Injection Method: c:\star\btex.mth
Run Time (min): 24.107
Workstation: MONGKOL
Instrument (Inj): Varian Star #1

Operator (Calc): Decha
Calc Date: 11/05/2002 12:51:52
Times Calculated: 1
Calculation Method: c:\star\btex.mth
Instrument (Calc): Varian Star #1
Run Mode: Analysis
Peak Measurement: Peak Area
Calculation Type: Percent
Calibration Level: N/A
Verification Tolerance: N/A

Peak No	Peak Name	Result ()	Ret. Time (min)	Time Offset (min)	Area (counts)	Rel Ret Time	Sep. Code	Width 1/2 (sec)	Status Codes	Group
1		0.0026	4.140	0.000	166	0.00	BV	10.8		0
2		0.0047	4.394	0.000	298	0.00	BV	2.4		0
3		0.0072	4.611	0.000	464	0.00	VV	4.1		0
4		0.0027	4.668	0.000	171	0.00	VB	0.0		0
5		0.0264	5.302	0.000	1689	0.00	BV	4.9		0
6		0.0070	5.452	0.000	448	0.00	VV	2.5		0
7		0.0231	5.608	0.000	1480	0.00	VV	7.9		0
8		0.0070	5.817	0.000	448	0.00	VV	0.0		0
9		99.7920	6.254	0.000	6386769	0.00	VB	82.8		0
10		0.0046	7.015	0.000	294	0.00	TS	0.0		0
11		0.0060	7.285	0.000	385	0.00	BB	2.4		0
12		0.0186	7.590	0.000	1193	0.00	BB	2.4		0
13		0.0051	8.282	0.000	327	0.00	BV	2.8		0
14	Benzene	0.0058	8.854	-0.002	371	0.00	BB	2.3		0
15		0.0070	9.097	0.000	446	0.00	BV	2.4		0
16		0.0054	9.326	0.000	346	0.00	PB	2.1		0
17		0.0032	9.721	0.000	206	0.00	VB	3.3		0
18		0.0205	9.882	0.000	1311	0.00	BB	2.4		0
19		0.0029	10.488	0.000	189	0.00	BB	2.2		0
20		0.0051	10.635	0.000	326	0.00	BB	2.4		0
21	Toluene	0.0070	11.481	-0.010	450	0.00	BB	2.5		0
22	Ethylbenzene		13.998						M	0
23	Xylene	0.0041	14.230	0.010	264	0.00	BB	3.5		0
24		0.0066	17.468	0.000	420	0.00	BB	5.0		0
25		0.0090	19.193	0.000	575	0.00	BV	4.5		0
26		0.0018	19.341	0.000	115	0.00	VB	5.4		0

(i) Front Part of Sample (3)

Appendix B

Field Monitoring Data

A. Two downwind sites

Date/Site	Skill Develop. Center				School			
	B	T	E	X	B	T	E	X
22/2/2002	18.6	3.3	0	0	2.1	10.9	3.1	0
23/2/2002	4.7	1.1	3.5	0	6	9.1	0	0
24/2/2002	5.8	72.8	0	0	4.3	4.9	0	0
25/2/2002	4.4	3.5	1.8	0	4.8	5.1	0	0
26/2/2002	4.1	0.9	0	0	4.4	3.9	0	0
27/2/2002	4.1	1.1	0	0				
28/2/2002								
Average	7.0	13.8	0.9	0	4.3	6.8	0.6	0.0
SD	5.7	28.9	1.5	0	1.4	3.0	1.4	0
Median	4.6	2.2	0.0	0	4.4	5.1	0.0	0
29/4/2002	3	2.2	0	0	3.5	2.7	0	0
30/4/2002	3.8	7.3	0	0	3.8	2.6	0	0
1/5/2002	8.6	0.9	0	0	3.7	2.1	0	0
2/5/2002	3.2	0.8	0	0	6	4.1	0	1
3/5/2002	3.7	3.1	0	0	3	2.3	0	0
4/5/2002	4.2	41.9	0	0	5	7.1	0	0.7
5/5/2002	4	4	0	0	7.2	5.6	0	1.6
Average	4.4	8.6	0	0	4.6	3.8	0	0.5
SD	1.9	14.8	0	0	1.5	1.9	0	0.6
Median	3.8	3.1	0.0	0.0	3.8	2.7	0.0	0.0
19/6/2002	0	22.6	0	2.7	3.2	2.5	0	0
20/6/2002	0	0.8	0	0				
21/6/2002								
22/6/2002	0	1.5	0	0				
23/6/2002	11.7	7.2	0.1	0	3.8	2.7	0	0
24/6/2002	2.7	2.5	0	0				
25/6/2002	4.4	2.5	0	0.5				
Average	3.1	6.2	0	0.5	3.3	2.6	0	0
SD	4.6	8.3	0	1.1	0.4	0.1		
Median	1.4	2.5	0.0	0.0	3.5	2.6	0.0	0.0
Total								
N	19	19	19	19	14	14	14	14
Average	4.8	9.5	0.3	0.2	4.3	4.7	0.2	0.2
SD	4.3	18.3	0.9	0.6	1.4	2.7	0.8	0.5
Median	4.1	2.5	0	0	4.1	4	0	0

Note: Blank = no data available

Zero (0) = below detection limits

B. Two industrial sites

Date/Site	TSK-Guardhouse				NFC-Guardhouse			
	B	T	E	X	B	T	E	X
22/2/2002	32.1	220.8	17	41.9				
23/2/2002	7.3	110	0	0				
24/2/2002	6.6	138.3	0	4.6				
25/2/2002	5.3	77.9	0	13.8				
26/2/2002								
27/2/2002	6.4	92.3	0	12.1				
28/2/2002								
Average	11.5	127.9	3.4	14.5				
SD	11.5	56.6	7.6	16.3				
Median	6.6	110.0	0.0	12.1				
29/4/2002	3.5	1.6	0	3.6				
30/4/2002	5.2	6.3	0	15.8	0	0	0	0
1/5/2002	5.9	3.1	0	0	8.6	0	0	4.1
2/5/2002	6.5	5.8	0	7.5	3.6	1.4	0	0
3/5/2002	3.8	5	0	7	0	0	0	0
4/5/2002	16.9	23.3	0	2.3	20.9	5.6	5	24.5
5/5/2002	8.2	8.6	0	8.6	3.4	0	0	0
Average	7.1	7.7	0	6.4	6.1	1.2	0.8	4.8
SD	4.6	7.3	0	5.2	7.9	2.2	2.0	9.8
Median	5.9	5.8	0.0	7.0	3.5	0.0	0.0	0.0
19/6/2002	4.8	8	0.8	9.4				
20/6/2002	3.4	83.4	0.6	12.6				
21/6/2002	4.9	6.5	0	3.4	3	3.9	0	0
22/6/2002					0	1.6	0	0
23/6/2002	4.9	4.4	0	0.4	3.4	3.3	0	0.7
24/6/2002	9.8	11.6	0	6	0	1.2	0	0
25/6/2002					2.8	10.3	0	0
Average	5.6	22.8	0.3	5.1	1.8	4.1	0	0.1
SD	2.1	34	0.3	5	1.7	3.7	0	0.3
Median	4.9	8.0	0.0	6.0	2.8	3.3	0.0	0.0
Total								
N	17	17	17	17	11	11	11	11
Average	8.0	47.5	1.1	8.7	3.9	2.5	0.5	2.7
SD	7.0	63.3	4.1	9.9	6.2	3.2	1.5	7.3
Median	5.9	8.6	0	7	3	1.4	0	0

Note: Blank = no data available

Zero (0) = below detection limits

c. Two upwind sites

Date/Site	IEAT-Office				Padaeng-Guardhouse			
	B	T	E	X	B	T	E	X
22/2/2002	17.7	4.3	13.9	7.4				
23/2/2002	0	1.6	0	3.4	0	2	0	0
24/2/2002	4	2.1	0	0	3.9	3.7	0	3.1
25/2/2002	3.7	1.2	0	0	4.1	0	0	0
26/2/2002	3.8	1.6	0	0	3.6	5.1	0	0
27/2/2002	4.1	8.6	0	0	3.6	2.8	0	0
28/2/2002								
Average	5.6	3.2	2.3	1.8	3.0	2.7	0	0.6
SD	6.2	2.9	5.7	3.1	1.7	1.9	0	1.4
Median	3.9	1.9	0.0	0.0	3.6	2.8	0	0.0
29/4/2002	4.7	4	0	0				
30/4/2002	0	0	0	0				
1/5/2002	4.3	0	0	0				
2/5/2002	0	2	0	0	0	0.9	0	0
3/5/2002	0	0.7	0	0	3.8	0.9	0	0
4/5/2002	13.2	4.5	0	0	0	2.3	0	0
5/5/2002								
Average	3.7	1.9	0	0	1.3	1.4	0	0
SD	5.2	2.0	0	0	2.2	0.8	0	0
Median	2.2	1.4	0.0	0.0	0.0	0.9	0.0	0.0
19/6/2002	0	2.1	0	0				
20/6/2002								
21/6/2002	0	0	0	0	0	0	0	0
22/6/2002	0	1.4	0	0	0	1.3	0	0
23/6/2002	0	0	0	0				
24/6/2002	13.2	4.5	0	0	2.7	1.5	0	0
25/6/2002								
Average	2.6	1.6	0	0	0.9	0.9	0.0	0.0
SD	4.9	1.9	0	0	1.2	0.8	0	0
Median	0.0	1.4	0.0	0.0	0.0	1.3	0.0	0.0
Total								
N	17	17	17	17	11	11	11	11
Average	4.0	2.3	0.8	0.6	2.0	1.9	0	0.3
SD	5.5	2.3	3.4	1.9	1.9	1.6	0	0.9
Median	3.7	1.6	0	0	2.7	1.5	0	0

Note: Blank = no data available

Zero (0) = below detection limits

D. Checking sites

Date/Site	Takuan Health Center				Jetty			
	B	T	E	X	B	T	E	X
22/2/2002	23	16.7	3.4	3.2				
23/2/2002	4.9	7.1	4.8	6.8	16.7	23.7	15.2	19.3
24/2/2002	5.6	12.7	3.1	5.9	0	2.7	0	0
25/2/2002	5	7.4	2.3	4	0	1.8	0	0
26/2/2002	4.3	8.1	0	2.7	2.8	65.4	3.2	4.9
27/2/2002	10.3	370.5	8.8	30.3	3.7	5	0	0
28/2/2002								
Average	8.9	70.4	3.7	8.8	4.6	19.7	3.7	4.8
SD	7.3	147.1	2.9	10.6	6.9	27.1	6.6	8.4
Median	5.3	10.4	3.3	5.0	2.8	5.0	0.0	0.0
29/4/2002								
30/4/2002	3.2	3.7	0	0				
1/5/2002	4.9	3.5	0	0				
2/5/2002	4.8	7.9	0	1.1	4.3	0	0	0
3/5/2002	4.9	5.7	0	0	40.1	15.8	0	0
4/5/2002	7.2	8.7	0.1	2.2	3.8	8.8	0	0
5/5/2002	5.5	2.8	0	0				
Average	5.1	5.4	0.0	0.6	16.1	8.2	0	0
SD	1.3	2.5	0.0	0.9	20.8	7.9	0	0
Median	4.9	4.7	0.0	0.0	4.3	8.8	0.0	0.0
19/6/2002	0	4.1	0	0				
20/6/2002	4.2	8.8	0	3.4				
21/6/2002	11.8	19.8	1.4	7.6	0	5.5	0	0
22/6/2002	11.3	4.9	0	0	8.1	3.4	0	8.9
23/6/2002	4	8.5	0	1.4	3.9	2.9	0	0
24/6/2002	5.6	6.2	0.1	1.4	0	1	0	0
25/6/2002	9.8	10.4	0	2.3				
Average	6.7	9	0.2	2.3	3.0	3.2	0	2.2
SD	4.4	5.3	0.5	2.6	4.2	1.8	0	4
Median	5.6	8.5	0.0	1.4	2.0	3.2	0.0	0.0
Total								
N	19	19	19	19	12	12	12	12
Average	6.9	27.2	1.3	3.8	7.0	11.3	1.5	2.8
SD	4.9	83.2	2.3	6.8	11.5	18.4	4.4	5.9
Median	5	7.9	0	2.2	3.8	4.2	0	0

Note: Blank = no data available

Zero (0) = below detection limits

E. Other sites

Date/Site	NongFab Station				Provin. Admin. Cent.			
	B	T	E	X	B	T	E	X
22/2/2002								
23/2/2002	6	98.8	2.8	16.2				
24/2/2002	4.6	5.5	0	0				
25/2/2002	6.4	5.1	0	0				
26/2/2002	4.5	11.6	0	0				
27/2/2002	3.8	3.3	0	0				
28/2/2002								
Average	5.1	24.9	0.6	3.2				
SD	1.1	41.5	1.3	7.2				
Median	4.6	5.5	0.0	0.0				
29/4/2002								
30/4/2002					0	5	0	0
1/5/2002					3.2	8.6	0	0
2/5/2002					0	0	0	0
3/5/2002					0	0	0	0
4/5/2002					6	7.2	0	0
5/5/2002					4.8	3.8	0	0
Average					2.3	4.1	0	0
SD					2.7	3.6	0	0
Median					1.6	4.4	0.0	0.0
19/6/2002								
20/6/2002					6.6	15.3	0	0
21/6/2002								
22/6/2002					2.9	3.2	0	0
23/6/2002					4.8	6.2	0	0
24/6/2002					4.7	98.5	0.9	4.9
25/6/2002								
Average					4.75	30.8	0.2	1.2
SD					1.5	45.4	0.5	2.5
Median					4.8	10.8	0.0	0.0
Total								
N	5	5	5	5	10	10	10	10
Average	5.1	24.9	0.6	3.2	2.83	14.8	0.0	0.0
SD	1.1	41.5	1.3	7.2	2.7	29.8	0.0	0.0
Median	4.6	5.5	0	0	3.05	5.6	0	0

Note: Blank = no data available

Zero (0) = below detection limits

Emission rates of two refineries

1. The data for process fugitive of both refineries were estimated after RRC report (1999). The factory report that directly gathered from factory didn't include this type of emission.
2. The speciation profile of sources used were B=0.38%, T=0.44% and X=0.19%
3. Data sources were shown in Table below.

Item	Description	1999's study for RRC	ARC report 2001	
			RRC	SPRC
1.	Capacity (1 barrel = 42 gallon = 0.1589873 m^3)		145,000 Bpd or 7.22 mil.ton/y or 23,053 m^3/d	160,000 Bpd 7.97 mil.ton/y or 25,438 m^3/d
2.	Fugitive emission			
	2.1 Process drain	2.2% of total fugitive (223.23t/y)	(223.23 t/y)	(245.55 t/y)
	2.2 valve, flange and fitting			
	2.3 Storage	2,000 t/y or 5.2% of throughput	651.46 t/y	734.63 t/y
	- products	3,593 t/y plus 3,840 t/y to VRU	188.65 t/y	212.73 t/y
	- crude	17.68 t/y	461.75 t/y	520.69 t/y
	2.4 transport		93.055 t/y	104.935 t/y
	- Road		total 91.5 t/y	
	- Rail	181 t/y		
	- Coastal	43 t/y	total 492.69 t/y	included
	2.5 Miscellaneous	472 t/y	19.86 t/y	included
	- water treatment	self estimate		22.39 t/y
	- VRU of tank fugitive	3% of 3,840 t/y = 115 t/y	(direct measurement)	-
	Total (2.2-2.4)	(10,146.68 t/y)		
4.	Data for point sources		Factory report	Factory report
5.	NMOC/TOC	0.29	-	-

Appendix C

Meteorological Data File

Example file: 22-28 February 2002

1 2002 2 2002

2002	2	22	1	194.102	2.3510	301.6	6	720	720
2002	2	22	2	198.418	2.0120	301.5	6	720	720
2002	2	22	3	192.208	1.8300	301.5	6	720	720
2002	2	22	4	179.295	1.7170	301.5	6	720	720
2002	2	22	5	170.029	1.3200	301.5	6	720	720
2002	2	22	6	120.607	0.7770	301.1	6	720	720
2002	2	22	7	349.245	0.6990	299.9	6	720	720
2002	2	22	8	310.893	0.8320	300.8	2	850	850
2002	2	22	9	299.541	0.9290	303.3	2	850	850
2002	2	22	10	214.220	2.2160	303.6	2	850	850
2002	2	22	11	204.846	2.8520	304.1	2	850	850
2002	2	22	12	197.116	3.4020	304.1	2	850	850
2002	2	22	13	190.568	3.4460	304.4	2	850	850
2002	2	22	14	193.496	4.1770	304.2	3	850	850
2002	2	22	15	203.016	4.6390	304.2	3	850	850
2002	2	22	16	202.166	4.3210	304.0	3	850	850
2002	2	22	17	200.957	4.0210	303.5	4	850	850
2002	2	22	18	205.836	3.9190	302.9	4	850	850
2002	2	22	19	199.699	3.4870	302.3	4	720	720
2002	2	22	20	190.823	2.6960	302.2	5	720	720
2002	2	22	21	190.895	2.8250	302.1	5	720	720
2002	2	22	22	186.192	2.8500	302.1	6	720	720
2002	2	22	23	180.560	2.7090	302.1	6	720	720
2002	2	22	24	177.657	2.7970	302.1	6	720	720
2002	2	23	1	179.593	2.5000	302.1	6	720	720
2002	2	23	2	180.091	2.3980	301.9	6	720	720
2002	2	23	3	186.398	2.7600	301.8	6	720	720
2002	2	23	4	190.296	2.6290	301.6	6	720	720
2002	2	23	5	185.266	2.4440	301.6	6	720	720
2002	2	23	6	187.838	1.8590	301.7	6	720	720

2002	2	23	7	208.949	1.7540	301.8	6	720	720
2002	2	23	8	299.109	1.0100	301.5	2	850	850
2002	2	23	9	288.801	0.7940	302.8	2	850	850
2002	2	23	10	201.172	2.4970	303.7	2	850	850
2002	2	23	11	200.365	3.2520	304.0	2	850	850
2002	2	23	12	193.823	3.4760	304.2	3	850	850
2002	2	23	13	192.502	3.7450	304.2	3	850	850
2002	2	23	14	201.425	3.3820	304.2	3	850	850
2002	2	23	15	198.683	3.9450	304.2	3	850	850
2002	2	23	16	194.644	4.2530	303.8	3	850	850
2002	2	23	17	192.980	3.5570	303.4	4	850	850
2002	2	23	18	197.932	3.3450	302.7	4	850	850
2002	2	23	19	194.591	2.8410	302.2	6	720	720
2002	2	23	20	183.410	2.4130	302.1	6	720	720
2002	2	23	21	177.632	2.2590	302.2	6	720	720
2002	2	23	22	177.618	2.4280	302.1	6	720	720
2002	2	23	23	179.495	2.2060	302.1	6	720	720
2002	2	23	24	179.054	2.8460	302.1	6	720	720
2002	2	24	1	196.205	2.7810	301.8	6	720	720
2002	2	24	2	201.101	2.6900	301.8	6	720	720
2002	2	24	3	187.690	2.6700	301.7	6	720	720
2002	2	24	4	193.449	2.6110	301.7	5	720	720
2002	2	24	5	204.607	2.9820	301.6	5	720	720
2002	2	24	6	203.302	2.7360	301.8	5	720	720
2002	2	24	7	187.463	2.5760	301.8	5	720	720
2002	2	24	8	190.172	2.0880	302.2	3	850	850
2002	2	24	9	189.716	2.3500	303.1	3	850	850
2002	2	24	10	189.275	2.6050	303.8	2	850	850
2002	2	24	11	193.409	2.6490	304.1	2	850	850
2002	2	24	12	183.755	2.8470	304.4	2	850	850
2002	2	24	13	185.401	3.0840	304.5	2	850	850
2002	2	24	14	183.964	3.5030	304.6	2	850	850

2002	2	24	15	190.041	3.8000	304.2	3	850	850
2002	2	24	16	196.948	4.2420	304.0	3	850	850
2002	2	24	17	199.043	3.8380	303.7	4	850	850
2002	2	24	18	198.228	3.3750	303.0	4	850	850
2002	2	24	19	192.344	2.7690	302.5	5	720	720
2002	2	24	20	185.933	2.5650	302.4	5	720	720
2002	2	24	21	184.567	2.5090	302.3	5	720	720
2002	2	24	22	186.359	2.3800	302.3	5	720	720
2002	2	24	23	171.627	2.6770	302.3	5	720	720
2002	2	24	24	173.605	2.3590	302.2	5	720	720
2002	2	25	1	183.011	2.4890	302.1	5	720	720
2002	2	25	2	181.851	2.5280	301.9	5	720	720
2002	2	25	3	191.914	2.3950	301.8	5	720	720
2002	2	25	4	188.012	1.8400	301.8	6	720	720
2002	2	25	5	214.710	1.0130	301.7	6	720	720
2002	2	25	6	267.178	0.6080	301.4	6	720	720
2002	2	25	7	203.928	1.9830	301.8	6	720	720
2002	2	25	8	229.013	1.5000	301.9	2	850	850
2002	2	25	9	224.206	1.2840	302.4	2	850	850
2002	2	25	10	189.690	2.2450	303.7	3	850	850
2002	2	25	11	162.868	3.3040	303.0	3	850	850
2002	2	25	12	170.291	3.1360	303.2	3	850	850
2002	2	25	13	166.477	2.2400	303.6	2	850	850
2002	2	25	14	173.002	3.0900	304.0	2	850	850
2002	2	25	15	188.701	3.5170	303.8	2	850	850
2002	2	25	16	188.754	3.3190	303.8	3	850	850
2002	2	25	17	185.300	2.9330	303.3	3	850	850
2002	2	25	18	182.985	2.7940	303.0	3	850	850
2002	2	25	19	182.602	2.9830	302.4	5	720	720
2002	2	25	20	179.794	2.7560	302.3	5	720	720
2002	2	25	21	180.649	2.7750	302.4	5	720	720
2002	2	25	22	171.917	3.4670	302.4	4	720	720

2002	2	25	23	169.175	3.3240	302.2	4	720	720
2002	2	25	24	174.737	3.1330	302.1	4	720	720
2002	2	26	1	174.973	3.0530	302.0	5	720	720
2002	2	26	2	176.674	2.8470	302.0	6	720	720
2002	2	26	3	178.678	2.5120	302.0	6	720	720
2002	2	26	4	184.009	2.3670	301.9	6	720	720
2002	2	26	5	184.454	2.1810	301.8	6	720	720
2002	2	26	6	186.298	2.2660	301.9	6	720	720
2002	2	26	7	186.097	2.0650	301.9	6	720	720
2002	2	26	8	185.951	1.8530	302.5	2	850	850
2002	2	26	9	166.855	1.7740	303.6	2	850	850
2002	2	26	10	189.507	2.1800	303.9	2	850	850
2002	2	26	11	191.698	2.9370	304.0	2	850	850
2002	2	26	12	185.834	2.9390	304.2	2	850	850
2002	2	26	13	191.162	3.3600	304.2	2	850	850
2002	2	26	14	195.488	2.9320	304.4	2	850	850
2002	2	26	15	193.018	3.9760	304.1	3	850	850
2002	2	26	16	193.359	3.8770	304.0	3	850	850
2002	2	26	17	193.966	3.5210	303.5	4	850	850
2002	2	26	18	194.107	3.1100	302.8	4	850	850
2002	2	26	19	195.279	2.4550	302.3	6	720	720
2002	2	26	20	188.173	2.2760	302.2	6	720	720
2002	2	26	21	186.489	2.1930	302.2	6	720	720
2002	2	26	22	185.894	2.3640	302.1	6	720	720
2002	2	26	23	190.204	2.0600	302.0	6	720	720
2002	2	26	24	190.836	2.3700	302.0	6	720	720
2002	2	27	1	206.375	2.4020	302.0	6	720	720
2002	2	27	2	187.025	3.3480	301.6	4	720	720
2002	2	27	3	187.913	3.2630	301.7	4	720	720
2002	2	27	4	188.018	3.3220	301.8	4	720	720
2002	2	27	5	193.594	3.0720	301.7	4	720	720
2002	2	27	6	197.774	2.8150	301.7	5	720	720

2002	2	27	7	199.697	2.7200	301.7	5	720	720
2002	2	27	8	199.131	2.6960	302.2	3	850	850
2002	2	27	9	206.949	2.2600	303.1	3	850	850
2002	2	27	10	197.357	2.0750	304.0	2	850	850
2002	2	27	11	193.890	2.2520	304.2	2	850	850
2002	2	27	12	200.822	2.6240	304.5	2	850	850
2002	2	27	13	186.296	3.0740	304.6	2	850	850
2002	2	27	14	191.220	3.5840	304.6	2	850	850
2002	2	27	15	191.433	3.6010	304.7	3	850	850
2002	2	27	16	192.296	3.7640	304.3	3	850	850
2002	2	27	17	204.419	3.7040	303.3	4	850	850
2002	2	27	18	199.911	3.2480	302.9	4	850	850
2002	2	27	19	198.552	2.9890	302.3	6	720	720
2002	2	27	20	194.388	2.5030	302.2	6	720	720
2002	2	27	21	186.351	2.6390	302.1	6	720	720
2002	2	27	22	183.648	2.4440	302.1	6	720	720
2002	2	27	23	177.073	2.2480	302.1	6	720	720
2002	2	27	24	173.115	2.5880	302.0	6	720	720
2002	2	28	1	170.735	2.7420	301.9	6	720	720
2002	2	28	2	172.361	2.9120	301.9	6	720	720
2002	2	28	3	183.181	2.9190	301.8	6	720	720
2002	2	28	4	188.225	2.8510	301.8	6	720	720
2002	2	28	5	187.234	2.7870	301.8	6	720	720
2002	2	28	6	192.052	2.7380	301.8	6	720	720
2002	2	28	7	194.641	2.4720	301.8	6	720	720
2002	2	28	8	202.533	2.3550	302.5	3	850	850
2002	2	28	9	199.417	2.4950	303.4	3	850	850
2002	2	28	10	196.761	2.7190	304.0	2	850	850
2002	2	28	11	194.431	3.0650	304.3	2	850	850
2002	2	28	12	193.614	3.2290	304.5	2	850	850
2002	2	28	13	192.705	3.7320	304.6	2	850	850
2002	2	28	14	189.803	3.9720	304.8	3	850	850

2002	2	28	15	189.565	3.8620	304.7	3	850	850
2002	2	28	16	193.874	3.7680	304.5	3	850	850
2002	2	28	17	197.542	3.4010	303.9	4	850	850
2002	2	28	18	187.004	2.6280	303.1	3	850	850
2002	2	28	19	176.995	2.2120	302.7	6	720	720
2002	2	28	20	165.602	2.1150	302.5	6	720	720
2002	2	28	21	165.880	2.4820	302.4	6	720	720
2002	2	28	22	161.656	2.5100	302.4	6	720	720
2002	2	28	23	167.779	3.0000	302.3	5	720	720

Appendix D

ISCST-3 Output

Example file: Noon of Day 55 (24 Feb. 2002)

```
** ISCST3 Input Produced by:
** ISC-AERMOD View Ver. 4.03
** Lakes Environmental Software Inc.
** Date: 26/2/2003
** File: C:\ISCView4\MTP-BTEX.INP
****************************************
** ISCST3 Control Pathway
****************************************
CO STARTING
   TITLEONE C:\ISCView4\MTP-BTEX.isc
   MODELOPT DFAULT CONC  RURAL
   AVERTIME 1 PERIOD
   POLLUTID BENZENE
   TERRHGTS FLAT
   RUNORNOT RUN
CO FINISHED
****************************************
** ISCST3 Source Pathway
****************************************
SO STARTING
** Source Location **
** Source ID - Type - X Coord. - Y Coord. **
   LOCATION P01 POINT 734200.000 1404400.000
   LOCATION P02 POINT 734500.000 1404600.000
   LOCATION P03 POINT 734500.000 1404700.000
   LOCATION P04 POINT 734750.000 1402100.000
   LOCATION P05 POINT 734450.000 1401500.000
   LOCATION P06 POINT 734450.000 1401550.000
```

```
*** ISCST3 - VERSION 00101 ***    *** C:\ISCView4\MTP-BTEX.isc ***  02/26/03*** *** 15:45:24
**MODELOPTs:                                                                   PAGE 863
CONC                  RURAL  FLAT        DFAULT
*** CONCURRENT  1-HR AVERAGE CONCENTRATION   VALUES ENDING WITH HOUR 12 FOR DAY  55
OF 2002 ***
                 FOR SOURCE GROUP: ALL
                 INCLUDING SOURCE(S):     P01     , P02     , P03     , P04     , P05     , P06     , P07     ,
P08     , P09     , P10     , P11     , P12     , P13     , P14     , P19     , P20     , P23     , P24     , P25     , P26     ,
P27     , P28     , P29     , P30     , P31     , P32     , P15     , P16     , P17     , P18     ,  . . . ,
               *** NETWORK ID: UCART1   ;  NETWORK TYPE: GRIDCART ***
                      ** CONC OF BENZENE  IN MICROGRAMS/M**3
  Y-COORD  |                                X-COORD (METERS)
  (METERS) |   732500.00   732750.00   733000.00   733250.00   733500.00   733750.00   734000.00   734250.00   734500.00
- - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - -
 1402250.00 |     1.20987    16.93503   148.78094   548.24475   745.39404   333.47998    59.46964    15.36370    14.07323
 1402000.00 |     3.32379    31.99648   173.60370   464.47266   556.18372   283.48914    69.45325    16.85700    18.54107
 1401750.00 |     7.45913    47.74989   183.45921   390.22919   431.60370   243.05608    74.53716    19.46637   606.69128
 1401500.00 |    12.95044    61.49084   182.33278   328.66275   344.81503   208.38565    76.44806   264.17212   221.73056
 1401250.00 |    19.67374    71.45925   174.81187   278.54868   281.91833   179.91156    75.43224    90.32964   138.89067
 1401000.00 |    26.07855    77.98959   164.15404   238.61220   235.23381   157.53609    74.92809    70.53894    82.59307
 1400750.00 |    32.00298    81.39539   151.97725   205.51201   199.31056   138.05212    74.65089    62.75962    64.25929
 1400500.00 |    37.01353    82.24675   139.56554   178.82983   171.11555   122.17078    73.11830    55.62058    46.30749
 1400250.00 |    40.64872    81.60593   133.27480   156.97372   148.67305   109.57422    69.91743    50.37473    36.84777
 1400000.00 |    43.52359    80.16922   125.91282   140.66803   130.74774    99.13322    66.46668    46.36675    31.24388
 1399750.00 |    45.38982    78.02622   113.08948   125.22152   116.48940    90.36125    62.93346    43.05432    27.69004
 1399500.00 |    46.71658    75.29262   102.97268   112.86056   104.91457    83.13042    59.09801    40.53036    25.31507
 1399250.00 |    47.82316    73.02489    95.00011   102.75552    95.53893    77.11007    55.99803    37.98224    23.63478
 1399000.00 |    48.41474    70.37474    88.40138    94.47903    87.87888    72.10415    53.46901    36.48596    22.56983
 1398750.00 |    48.40473    67.79720    83.20378    87.71567    81.62065    67.74699    50.61626    34.60931    21.65307
 1398500.00 |    48.72762    66.00531    78.39220    82.17266    76.41084    63.87085    48.03958    33.71621    21.37021
 1398250.00 |    49.08654    63.96281    74.73812    77.58890    72.05961    60.58873    46.41676    32.72923    20.75291
 1398000.00 |    48.71934    62.46540    71.58083    73.73589    68.35073    57.79837    45.09497    31.60900    20.74455
 1397750.00 |    49.09436    60.99102    68.78135    70.45313    65.16761    55.40588    43.48259    31.31010    20.37433
```

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*** ISCST3 - VERSION 00101 ***     *** C:\ISCView4\MTP-BTEX.isc *** 02/26/03*** *** 15:45:24
**MODELOPTs:                                                          PAGE 864
CONC                    RURAL  FLAT         DFAULT
*** CONCURRENT  1-HR AVERAGE CONCENTRATION   VALUES ENDING WITH HOUR 12 FOR DAY  55
OF 2002 ***
                     FOR SOURCE GROUP: ALL
                     INCLUDING SOURCE(S):      P01     , P02     , P03     , P04     , P05     , P06     , P07     ,
P08     , P09     , P10     , P11     , P12     , P13     , P14     , P19     , P20     , P23     , P24     , P25     , P26     ,
P27     , P28     , P29     , P30     , P31     , P32     , P15     , P16     , P17     , P18     , . . . ,
              *** NETWORK ID: UCART1   ;  NETWORK TYPE: GRIDCART ***
                 ** CONC OF BENZENE  IN MICROGRAMS/M**3  **
  Y-COORD  |                                      X-COORD (METERS)
  (METERS) |    734750.00    735000.00    735250.00    735500.00    735750.00    736000.00    736250.00    736500.00    736750.00
- - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - -
 1412250.00 |     0.00000     0.00000     0.00000     0.00000     0.00000     0.00000     0.00000     0.00000     0.00000
 1412000.00 |     0.00000     0.00000     0.00000     0.00000     0.00000     0.00000     0.00000     0.00000     0.00000
 1411750.00 |     0.00000     0.00000     0.00000     0.00000     0.00000     0.00000     0.00000     0.00000     0.00000
 1411500.00 |     0.00000     0.00000     0.00000     0.00000     0.00000     0.00000     0.00000     0.00000     0.00000
 1411250.00 |     0.00000     0.00000     0.00000     0.00000     0.00000     0.00000     0.00000     0.00000     0.00000
 1411000.00 |     0.00000     0.00000     0.00000     0.00000     0.00000     0.00000     0.00000     0.00000     0.00000
 1410750.00 |     0.00000     0.00000     0.00000     0.00000     0.00000     0.00000     0.00000     0.00000     0.00000
 1410500.00 |     0.00000     0.00000     0.00000     0.00000     0.00000     0.00000     0.00000     0.00000     0.00000
 1410250.00 |     0.00000     0.00000     0.00000     0.00000     0.00000     0.00000     0.00000     0.00000     0.00000
 1410000.00 |     0.00000     0.00000     0.00000     0.00000     0.00000     0.00000     0.00000     0.00000     0.00000
 1409750.00 |     0.00000     0.13487     0.00000     0.00000     0.00000     0.00000     0.00000     0.00000     0.00000
 1409500.00 |     0.65305     0.06316     0.00004     0.00000     0.00000     0.00000     0.00000     0.00000     0.00000
 1409250.00 |     0.21318     0.03926     0.00052     0.00000     0.00000     0.00000     0.00000     0.00000     0.00000
 1409000.00 |     0.11492     0.02801     0.00132     0.00001     0.00000     0.00000     0.00000     0.00000     0.00000
 1408750.00 |     0.07370     0.02157     0.00203     0.00004     0.00000     0.00000     0.00000     0.00000     0.00000
 1408500.00 |     0.05208     0.01743     0.00253     0.00012     0.00000     0.00000     0.00000     0.00000     0.00000
 1408250.00 |     0.03918     0.01455     0.00284     0.00024     0.00001     0.00000     0.00000     0.00000     0.00000
 1408000.00 |     0.03081     0.01245     0.00301     0.00038     0.00002     0.00000     0.00000     0.00000     0.00000
 1407750.00 |     0.02503     0.01085     0.00309     0.00053     0.00005     0.00000     0.00000     0.00000     0.00000
 1407500.00 |     0.02086     0.00959     0.00310     0.00066     0.00009     0.00001     0.00000     0.00000     0.00000
 1407250.00 |     0.01773     0.00858     0.00308     0.00078     0.00013     0.00001     0.00000     0.00000     0.00000
 1407000.00 |     0.01533     0.00775     0.00303     0.00088     0.00018     0.00003     0.00000     0.00000     0.00000
```

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1406750.00 |    0.34923    0.67490    0.00296    0.00096    0.00023    0.00004    0.00001    0.00000    0.00000
1406500.00 |    0.16971    0.21813    0.36500    0.58069    0.00028    0.00006    0.00001    0.00000    0.00000
1406250.00 |    0.10974    0.13422    0.22135    0.20256    0.29058    0.51204    0.07488    0.00000    0.00000
1406000.00 |    0.08127    0.11403    0.16493    0.11766    0.14609    0.19239    0.27185    0.45842    1.10670
1405750.00 |    0.06530    0.11458    0.13346    0.08244    0.09441    0.11289    0.14034    0.18372    0.25560
1405500.00 |    0.09084    0.12457    0.11257    0.06400    0.06925    0.07879    0.09166    0.10943    0.13527
1405250.00 |    0.36828    0.14180    0.09746    0.05290    0.05453    0.06016    0.06751    0.07696    0.08936
1405000.00 |    0.81470    0.16972    0.08595    0.04558    0.04496    0.04849    0.05318    0.05898    0.06619
1404750.00 |    1.19867    0.17827    0.10802    0.04041    0.03832    0.04053    0.04373    0.04763    0.05231
1404500.00 |    3.59075   19.51338    0.64901    0.03656    0.03348    0.03479    0.03706    0.03984    0.04310
1404250.00 |   11.59829   34.53317    0.31984    0.03377    0.02983    0.03047    0.03211    0.03417    0.03657
1404000.00 |   22.42496   23.84441    0.64791    0.03441    0.02700    0.02712    0.02831    0.19570    0.11190
1403750.00 |   25.05478   14.13101    1.16573    1.53753    0.27393    0.12039    0.08374    0.06829    0.06022
1403500.00 |   22.91710    9.13027    1.40310    0.40053    0.06889    0.05711    0.05046    0.04652    0.04420
1403250.00 |   19.34057    6.91394    1.39775    0.23875    0.04737    0.04075    0.03826    0.03685    0.03608
1403000.00 |   15.98935    5.81821    1.37699    0.22776    0.04446    0.03315    0.03179    0.03116    0.03092
1402750.00 |   13.27837    5.18486    1.36993    0.25783    0.52340    0.02867    0.02761    0.02727    0.02723
1402500.00 |   11.12156    4.73294    1.38473    0.30305    0.25625    0.02749    0.02464    0.02440    0.02444
```

```
 *** ISCST3 - VERSION 00101 ***    *** C:\ISCView4\MTP-BTEX.isc  ***  02/26/03***     *** 15:45:24
**MODELOPTs:                                                         PAGE 865
                              CONC                    RURAL  FLAT         DFAULT
*** CONCURRENT  1-HR AVERAGE CONCENTRATION   VALUES ENDING WITH HOUR 12 FOR DAY  55
OF 2002 ***
                                        FOR SOURCE GROUP: ALL
                   INCLUDING SOURCE(S):     P01     , P02     , P03     , P04     , P05     , P06     ,
P07     ,P08     , P09     , P10     , P11     , P12     , P13     , P14     , P19     , P20     , P23     , P24     , P25     ,
P26     , P27     , P28     , P29     , P30     , P31     , P32     , P15     , P16     , P17     , P18     ,  . . . ,
                  *** NETWORK ID: UCART1   ;  NETWORK TYPE: GRIDCART ***
                          ** CONC OF BENZENE  IN MICROGRAMS/M**3      **
  Y-COORD  |                                       X-COORD (METERS)
  (METERS) |    734750.00    735000.00    735250.00    735500.00    735750.00    736000.00    736250.00    736500.00    736750.00
                - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - -
1402250.00 |    9.43637    4.34988    1.40681    0.34632    0.16572    0.02804    0.02242    0.02218    0.02223
1402000.00 |    8.09158    4.01611    1.43184    0.39930    0.15027    0.03364    0.02098    0.02042    0.02045
```

```
1401750.00 |   11.24228   3.71215   1.45001   0.44590   0.15432   0.33339   0.02125   0.01901   0.01899
1401500.00 |   22.28950   3.49960   1.45649   0.49381   0.16541   0.09173   0.02182   0.01788   0.01780
1401250.00 |   19.57051   3.56907   1.45000   0.53430   0.18844   0.07694   0.02286   0.01760   0.01684
1401000.00 |   22.18881   3.66987   1.43533   0.57178   0.20542   0.07496   0.02603   0.01788   0.01605
1400750.00 |   27.95540   3.71739   1.42549   0.60474   0.23203   0.08282   0.03076   0.01850   0.01547
1400500.00 |   19.25695   3.80127   1.42913   0.63407   0.25362   0.09607   0.03778   0.01857   0.01579
1400250.00 |   16.07585   3.89854   1.44930   0.66167   0.27702   0.10768   0.04108   0.02050   0.01596
1400000.00 |   14.46768   4.37778   1.64397   0.68471   0.29997   0.12257   0.04816   0.02514   0.01661
1399750.00 |   13.30936   4.62542   1.67598   0.70601   0.32532   0.14150   0.05931   0.02765   0.01635
1399500.00 |   12.64282   4.77579   1.72531   0.76640   0.35184   0.15577   0.06684   0.03077   0.01791
1399250.00 |   12.22201   5.18621   2.04789   0.92152   0.37776   0.17364   0.07561   0.03385   0.02224
1399000.00 |   12.01637   5.41174   2.22648   0.95537   0.40925   0.19222   0.08844   0.04293   0.02270
1398750.00 |   11.85627   5.61037   2.39023   0.95892   0.49119   0.20995   0.10195   0.04814   0.02564
1398500.00 |   11.84620   5.83874   2.57592   1.19036   0.56869   0.23047   0.11298   0.05446   0.02723
1398250.00 |   12.08532   6.04399   2.97297   1.34402   0.61577   0.25373   0.12613   0.06054   0.03332
1398000.00 |   12.09137   6.37942   3.13865   1.45427   0.58268   0.35620   0.13926   0.07169   0.03845
1397750.00 |   12.25315   6.73220   3.33685   1.55730   0.74737   0.37257   0.15705   0.08197   0.04244
1397500.00 |   12.37047   6.92210   3.62114   1.74250   0.91342   0.43686   0.17044   0.08991   0.04735
```

```
 *** ISCST3 - VERSION 00101 ***    *** C:\ISCView4\MTP-BTEX.isc ***  02/26/03***  *** 15:45:24
**MODELOPTs:                                                    PAGE 866
CONC                  RURAL  FLAT         DFAULT
*** CONCURRENT  1-HR AVERAGE CONCENTRATION   VALUES ENDING WITH HOUR 12 FOR DAY  55
OF 2002 ***
                FOR SOURCE GROUP: ALL
                INCLUDING SOURCE(S):     P01     , P02     , P03     , P04     , P05     , P06     ,
P07     ,P08     , P09     , P10     , P11     , P12     , P13     , P14     , P19     , P20     , P23     , P24     , P25     ,
P26     , P27     , P28     , P29     , P30     , P31     , P32     , P15     , P16     , P17     , P18     , . . . ,
                          *** NETWORK ID: UCART1   ;  NETWORK TYPE: GRIDCART ***
                            ** CONC OF BENZENE  IN MICROGRAMS/M**3          **
  Y-COORD  |                                X-COORD (METERS)
  (METERS) |   737000.00   737250.00   737500.00   737750.00   738000.00   738250.00   738500.00   738750.00   739000.00
            - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - -
1412250.00 |    0.00000   0.00000   0.00000   0.00000   0.00000   0.00000   0.00000   0.00000   0.00000
1412000.00 |    0.00000   0.00000   0.00000   0.00000   0.00000   0.00000   0.00000   0.00000   0.00000
```

1411750.00	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
1411500.00	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
1411250.00	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
1411000.00	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
1410750.00	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
1410500.00	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
1410250.00	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
1410000.00	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
1409750.00	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
1409500.00	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
1409250.00	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
1409000.00	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
1408750.00	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
1408500.00	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
1408250.00	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
1408000.00	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
1407750.00	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
1407500.00	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
1407250.00	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
1407000.00	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
1406750.00	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
1406500.00	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
1406250.00	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
1406000.00	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
1405750.00	0.41532	1.02639	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
1405500.00	0.17566	0.24122	0.37976	0.86336	0.00000	0.00000	0.00000	0.00000	0.00000
1405250.00	0.10626	0.13056	0.16815	0.22837	0.34934	0.72480	0.00000	0.00000	0.00000
1405000.00	0.07532	0.08721	0.10328	0.12615	0.16114	0.21683	0.32315	0.62144	0.00000
1404750.00	0.05798	0.06497	0.07376	0.08515	0.10045	0.12203	0.34851	0.28997	0.15388
1404500.00	0.04695	0.05153	0.05703	0.12442	0.17317	0.14347	0.14047	0.14948	0.06836
1404250.00	0.03934	0.17031	0.11523	0.09769	0.09159	0.09070	0.09382	0.09485	0.04164
1404000.00	0.08583	0.07456	0.06891	0.06640	0.06615	0.06761	0.07029	0.06568	0.02939
1403750.00	0.05545	0.05291	0.05182	0.05179	0.05260	0.05417	0.05553	0.04824	0.02247
1403500.00	0.04292	0.04237	0.04240	0.04291	0.04386	0.04513	0.04513	0.03708	0.01806
1403250.00	0.03576	0.03580	0.03615	0.03677	0.03765	0.03849	0.03738	0.02953	0.01502
1403000.00	0.03094	0.03118	0.03161	0.03222	0.03294	0.03333	0.03144	0.02419	0.01281
1402750.00	0.02738	0.02769	0.02812	0.02867	0.02922	0.02916	0.02679	0.02028	0.01114
1402500.00	0.02463	0.02493	0.02534	0.02581	0.02616	0.02572	0.02311	0.01731	0.00983

```
 *** ISCST3 - VERSION 00101 ***    *** C:\ISCView4\MTP-BTEX.isc  ***  02/26/03***   *** 15:45:24
 **MODELOPTs:                                                         PAGE 867
CONC                    RURAL  FLAT         DFAULT
 *** CONCURRENT  1-HR AVERAGE CONCENTRATION   VALUES ENDING WITH HOUR 12 FOR DAY  55
OF 2002 ***
                  FOR SOURCE GROUP: ALL
                  INCLUDING SOURCE(S):      P01     , P02     , P03     , P04     , P05     , P06     , P07     ,
P08     , P09     , P10     , P11     , P12     , P13     , P14     , P19     , P20     , P23     , P24     , P25     , P26     ,
P27     , P28     , P29     , P30     , P31     , P32     , P15     , P16     , P17     , P18     ,  . . . ,
                             *** NETWORK ID: UCART1   ;  NETWORK TYPE: GRIDCART ***
                                  ** CONC OF BENZENE  IN MICROGRAMS/M**3        **
  Y-COORD  |                                 X-COORD (METERS)
  (METERS) |   737000.00   737250.00   737500.00   737750.00   738000.00   738250.00   738500.00   738750.00   739000.00
               - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - -
 1402250.00 |    0.02242     0.02270     0.02306     0.02344     0.02359     0.02285     0.02014     0.01501     0.00877
 1402000.00 |    0.02061     0.02086     0.02117     0.02144     0.02139     0.02042     0.01773     0.01318     0.00791
 1401750.00 |    0.01912     0.01933     0.01957     0.01973     0.01950     0.01836     0.01575     0.01171     0.00720
 1401500.00 |    0.01789     0.01805     0.01822     0.01825     0.01787     0.01661     0.01411     0.01051     0.00660
 1401250.00 |    0.01687     0.01698     0.01707     0.01699     0.01646     0.01513     0.01275     0.00952     0.00609
 1401000.00 |    0.01604     0.01608     0.01609     0.01590     0.01526     0.01388     0.01163     0.00870     0.00567
 1400750.00 |    0.01536     0.01534     0.01527     0.01498     0.01424     0.01284     0.01070     0.00804     0.00532
 1400500.00 |    0.01480     0.01473     0.01459     0.01420     0.01339     0.01197     0.00994     0.00749     0.00503
 1400250.00 |    0.01437     0.01424     0.01402     0.01355     0.01267     0.01126     0.00932     0.00705     0.00480
 1400000.00 |    0.01411     0.01383     0.01354     0.01301     0.01208     0.01067     0.00881     0.00669     0.00462
 1399750.00 |    0.01473     0.01350     0.01315     0.01255     0.01158     0.01018     0.00840     0.00641     0.00447
 1399500.00 |    0.01480     0.01324     0.01283     0.01217     0.01117     0.00978     0.00806     0.00618     0.00435
 1399250.00 |    0.01544     0.01315     0.01255     0.01185     0.01082     0.00944     0.00778     0.00599     0.00427
 1399000.00 |    0.01508     0.01387     0.01232     0.01158     0.01053     0.00916     0.00755     0.00584     0.00420
 1398750.00 |    0.01631     0.01386     0.01213     0.01134     0.01027     0.00892     0.00736     0.00572     0.00415
 1398500.00 |    0.02003     0.01438     0.01212     0.01113     0.01005     0.00871     0.00719     0.00561     0.00411
 1398250.00 |    0.01978     0.01411     0.01281     0.01094     0.00985     0.00853     0.00705     0.00552     0.00408
 1398000.00 |    0.02242     0.01513     0.01276     0.01079     0.00967     0.00837     0.00693     0.00545     0.00405
 1397750.00 |    0.02284     0.01810     0.01310     0.01080     0.00950     0.00822     0.00681     0.00538     0.00403
 1397500.00 |    0.02763     0.01739     0.01301     0.01144     0.00935     0.00808     0.00671     0.00532     0.00401
```

```
 *** ISCST3 - VERSION 00101 ***    *** C:\ISCView4\MTP-BTEX.isc *** 02/26/03***  *** 15:45:24
 **MODELOPTs:                                                        PAGE 868
CONC                  RURAL  FLAT        DFAULT
 *** CONCURRENT  1-HR AVERAGE CONCENTRATION   VALUES ENDING WITH HOUR 12 FOR DAY  55
OF 2002 ***
                  FOR SOURCE GROUP: ALL
                  INCLUDING SOURCE(S):     P01     , P02     , P03     , P04     , P05     , P06     , P07     ,
P08     , P09     , P10     , P11     , P12     , P13     , P14     , P19     , P20     , P23     , P24     , P25     , P26     ,
P27     , P28     , P29     , P30     , P31     , P32     , P15     , P16     , P17     , P18     , . . . ,
                            *** NETWORK ID: UCART1   ;  NETWORK TYPE: GRIDCART ***
                                ** CONC OF BENZENE  IN MICROGRAMS/M**3        **
  Y-COORD  |                                X-COORD (METERS)
  (METERS) |   739250.00   739500.00   739750.00   740000.00   740250.00
- - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - -
 1412250.00 |    0.00000    0.00000    0.00000    0.00000    0.00000
 1412000.00 |    0.00000    0.00000    0.00000    0.00000    0.00000
 1411750.00 |    0.00000    0.00000    0.00000    0.00000    0.00000
 1411500.00 |    0.00000    0.00000    0.00000    0.00000    0.00000
 1411250.00 |    0.00000    0.00000    0.00000    0.00000    0.00000
 1411000.00 |    0.00000    0.00000    0.00000    0.00000    0.00000
 1410750.00 |    0.00000    0.00000    0.00000    0.00000    0.00000
 1410500.00 |    0.00000    0.00000    0.00000    0.00000    0.00000
 1410250.00 |    0.00000    0.00000    0.00000    0.00000    0.00000
 1410000.00 |    0.00000    0.00000    0.00000    0.00000    0.00000
 1409750.00 |    0.00000    0.00000    0.00000    0.00000    0.00000
 1409500.00 |    0.00000    0.00000    0.00000    0.00000    0.00000
 1409250.00 |    0.00000    0.00000    0.00000    0.00000    0.00000
 1409000.00 |    0.00000    0.00000    0.00000    0.00000    0.00000
 1408750.00 |    0.00000    0.00000    0.00000    0.00000    0.00000
 1408500.00 |    0.00000    0.00000    0.00000    0.00000    0.00000
 1408250.00 |    0.00000    0.00000    0.00000    0.00000    0.00000
 1408000.00 |    0.00000    0.00000    0.00000    0.00000    0.00000
 1407750.00 |    0.00000    0.00000    0.00000    0.00000    0.00000
 1407500.00 |    0.00000    0.00000    0.00000    0.00000    0.00000
 1407250.00 |    0.00000    0.00000    0.00000    0.00000    0.00000
 1407000.00 |    0.00000    0.00000    0.00000    0.00000    0.00000
 1406750.00 |    0.00000    0.00000    0.00000    0.00000    0.00000
```

```
 1406500.00 |     0.00000    0.00000    0.00000    0.00000    0.00000
 1406250.00 |     0.00000    0.00000    0.00000    0.00000    0.00000
 1406000.00 |     0.00000    0.00000    0.00000    0.00000    0.00000
 1405750.00 |     0.00000    0.00000    0.00000    0.00000    0.00000
 1405500.00 |     0.00000    0.00000    0.00000    0.00000    0.00000
 1405250.00 |     0.00000    0.00000    0.00000    0.00000    0.00000
 1405000.00 |     0.00000    0.00000    0.00000    0.00000    0.00000
 1404750.00 |     0.00000    0.00000    0.00000    0.00000    0.00000
 1404500.00 |     0.00029    0.00000    0.00000    0.00000    0.00000
 1404250.00 |     0.00143    0.00000    0.00000    0.00000    0.00000
 1404000.00 |     0.00260    0.00003    0.00000    0.00000    0.00000
 1403750.00 |     0.00337    0.00012    0.00000    0.00000    0.00000
 1403500.00 |     0.00380    0.00028    0.00001    0.00000    0.00000
 1403250.00 |     0.00399    0.00048    0.00002    0.00000    0.00000
 1403000.00 |     0.00403    0.00068    0.00006    0.00000    0.00000
 1402750.00 |     0.00399    0.00086    0.00011    0.00001    0.00000
 1402500.00 |     0.00390    0.00102    0.00017    0.00002    0.00000
```

```
 *** ISCST3 - VERSION 00101 ***    *** C:\ISCView4\MTP-BTEX.isc   ***  02/26/03*** *** 15:45:24
 **MODELOPTs:                                                              PAGE 869
CONC                    RURAL  FLAT        DFAULT
 *** CONCURRENT  1-HR AVERAGE CONCENTRATION   VALUES ENDING WITH HOUR 12 FOR DAY  55
OF 2002 ***
                   FOR SOURCE GROUP: ALL
                   INCLUDING SOURCE(S):     P01     , P02     , P03     , P04     , P05     , P06     , P07     ,
P08     , P09     , P10     , P11     , P12     , P13     , P14     , P19     , P20     , P23     , P24     , P25     , P26     ,
P27     , P28     , P29     , P30     , P31     , P32     , P15     , P16     , P17     , P18     ,  . . . ,
                              *** NETWORK ID: UCART1   ;  NETWORK TYPE: GRIDCART ***
                                   ** CONC OF BENZENE  IN MICROGRAMS/M**3          **
   Y-COORD  |                                      X-COORD (METERS)
   (METERS) |    739250.00    739500.00    739750.00    740000.00    740250.00
- - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - -
 1402250.00 |     0.00378    0.00114    0.00023    0.00003    0.00000
 1402000.00 |     0.00365    0.00125    0.00031    0.00005    0.00001
 1401750.00 |     0.00352    0.00132    0.00037    0.00008    0.00001
```

```
1401500.00 |    0.00338   0.00138   0.00044   0.00011   0.00002
1401250.00 |    0.00326   0.00143   0.00050   0.00014   0.00003
1401000.00 |    0.00315   0.00146   0.00056   0.00017   0.00004
1400750.00 |    0.00305   0.00149   0.00061   0.00021   0.00006
1400500.00 |    0.00297   0.00151   0.00066   0.00024   0.00008
1400250.00 |    0.00290   0.00153   0.00070   0.00028   0.00009
1400000.00 |    0.00285   0.00156   0.00075   0.00032   0.00011
1399750.00 |    0.00282   0.00159   0.00080   0.00035   0.00014
1399500.00 |    0.00280   0.00162   0.00084   0.00039   0.00016
1399250.00 |    0.00279   0.00166   0.00089   0.00043   0.00019
1399000.00 |    0.00279   0.00169   0.00094   0.00047   0.00021
1398750.00 |    0.00279   0.00173   0.00099   0.00051   0.00024
1398500.00 |    0.00280   0.00177   0.00104   0.00056   0.00027
1398250.00 |    0.00282   0.00181   0.00108   0.00060   0.00030
1398000.00 |    0.00283   0.00185   0.00113   0.00064   0.00034
1397750.00 |    0.00285   0.00189   0.00118   0.00068   0.00037

*** ISCST3 - VERSION 00101 ***    *** C:\ISCView4\MTP-BTEX.isc *** 02/26/03*** *** 15:45:24
**MODELOPTs:                                                PAGE 870
CONC                 RURAL  FLAT       DFAULT
 *** CONCURRENT  1-HR AVERAGE CONCENTRATION   VALUES ENDING WITH HOUR 12 FOR DAY  55
OF 2002 ***
              FOR SOURCE GROUP: ALL
              INCLUDING SOURCE(S):     P01    , P02    , P03    , P04    , P05    , P06    ,
P07    ,P08    , P09    , P10    , P11    , P12    , P13    , P14    , P19    , P20    , P23    , P24    , P25    ,
P26    , P27    , P28    , P29    , P30    , P31    , P32    , P15    , P16    , P17    , P18    ,  . . . ,
                              *** DISCRETE CARTESIAN RECEPTOR POINTS ***
                              ** CONC OF BENZENE  IN MICROGRAMS/M**3  **
X-COORD (M)  Y-COORD (M)    CONC       X-COORD (M)  Y-COORD (M)      CONC
-    - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - -
729800.00   1402600.00      0.00940          730900.00   1403650.00      0.04384
731800.00   1402800.00      0.09982          732100.00   1401600.00      0.60507
732450.00   1406950.00      1.67196          734950.00   1405400.00      0.09094
735800.00   1402600.00      0.20330          734200.00   1403650.00      15.41775
732900.00   1403650.00      1.00904          738500.00   1405400.00      0.00000
```

Appendix E

TAPM Results

Figure: Predicted concentrations of benzene using meteorological data predicted by TAPM at TSK site

DATE	HOUR	TIME	CONC ($\mu g/m^3$)	CMAX ($\mu g/m^3$)	CLOC ($\mu g/m^3$)
20020617	1	1	546	716	546
20020617	2	2	182	974	314
20020617	3	3	95	1169	240
20020617	4	4	139	1323	412
20020617	5	5	111	1450	379
20020617	6	6	32	1555	244
20020617	7	7	176	1051	241
20020617	8	8	277	459	277
20020617	9	9	310	440	310
20020617	10	10	314	443	314
20020617	11	11	267	421	267
20020617	12	12	252	441	252
20020617	13	13	241	447	241
20020617	14	14	203	458	203
20020617	15	15	149	494	169
20020617	16	16	167	515	207
20020617	17	17	225	507	274
20020617	18	18	334	512	334
20020617	19	19	447	705	447
20020617	20	20	321	923	378
20020617	21	21	181	1023	366
20020617	22	22	124	1025	234
20020617	23	23	44	1030	218
20020617	24	24	24	1144	342

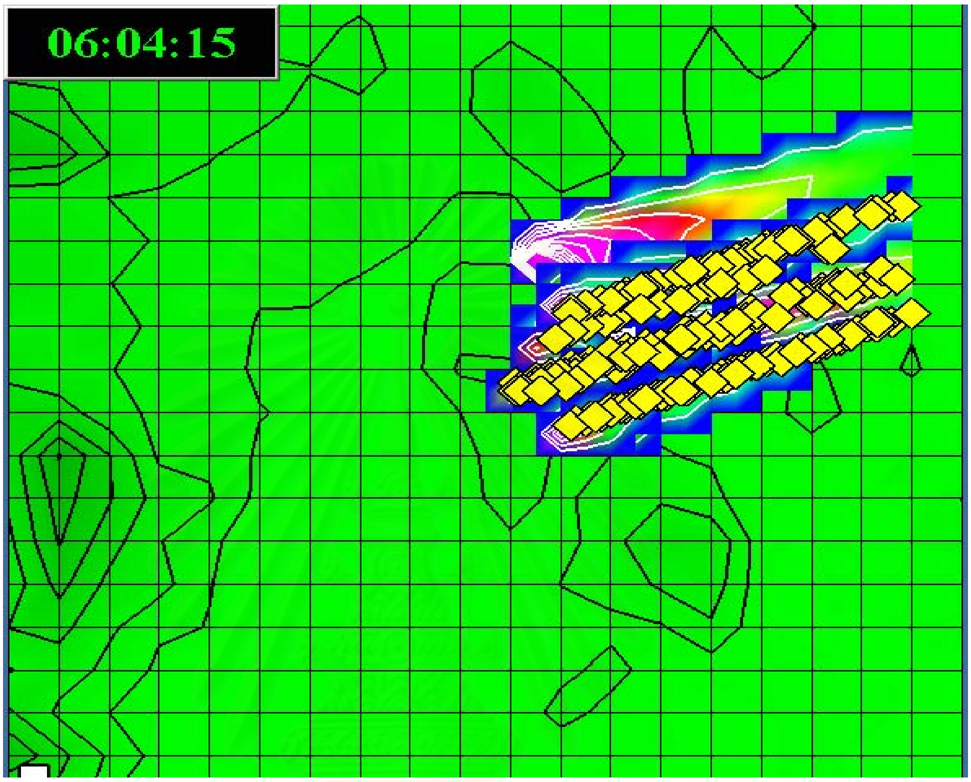

Figure: TAPM simulation of point sources

Appendix F

Two Proceedings of Oral Presentation

5-014 (O)

Proceedings of the 2nd Regional Conference on Energy Technology Towards a Clean Environment 12-14 February 2003, Phuket, Thailand

Ambient Air Levels and Sources of BTEX at a Petrochemical Complex in Thailand

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Abstract

Concern for health hazards from volatile organic compounds from the Map Ta Phut Petrochemical Estate has resulted in a study of the concentrations of benzene, toluene, ethylbenzene and xylene (BTEX) species in the ambient air surrounding and within the industrial complex. Ambient air samples have been collected at numerous locations during the dry (22-28 February), the semi-wet (29 April-5 May) and the wet season (19-25 June) in 2002. Collection was via personal pumps onto charcoal adsorbent tubes. The samples were extracted and analysed by gas chromatography equipped with a flame ionization detector (GC/FID). The data have been analysed statistically and comparisons made between levels from upwind, downwind and within the complex. For daytime concentrations, the median and maximum at two upwind monitoring sites were respectively 3.9 and 17.7 $\mu g/m^3$ for benzene, and 2.1 and 8.6 $\mu g/m^3$ for toluene. These data can be compared with two downwind monitoring sites where the results were 5.2 and 26.5 $\mu g/m^3$ for benzene, and 6.0 and 370.5 $\mu g/m^3$ for toluene. The variability observed across the data set highlights the importance of (1) source type and location, (2) fugitive emissions and episodal events, and (3) the meteorological conditions. The mean benzene concentrations at any site did not exceed the WHO annual air quality standards, 5 ppbv (16.2 $\mu g/m^3$). The levels of BTEX measured have been found to be comparable to those from studies elsewhere. Emissions from the Petrochemical complex including the oil refineries, and to a lesser extent those from motor vehicles, are the dominant contributors to the BTEX ambient concentrations.

Keywords

BTEX; Petrochemical Complex; Charcoal Adsorbent Tubes; GC/FID; Thailand

Introduction

The BTEX hydrocarbons are present in both industrial and urban air primarily as a result of human activities, involving motor vehicle and other combustion processes utilizing fossil fuels, petrol storage and distribution, solvent usage and other industrial processes [1]. Aromatic hydrocarbons, such as benzene, toluene and xylene, are known to be toxic or carcinogenic [2-3]. During the last two decades, Thailand has become more industrialized and this has resulted in air quality problems in some areas. People are now seriously concerned about the detrimental health effects from exposure to atmospheric pollutants including volatile organic compounds (VOCs).

There have been complaints concerning various offensive odors during the monsoon season from people who live adjacent to the Map Ta Phut industrial estate [4]. The protest against natural gas pipeline project in the south of Thailand also originated from the concerns of people on emissions from petrochemical industry [5]. Map Ta Phut industrial estate located on the eastern seaboard about 200 kilometers southeast of Bangkok, 12° 30'N and 101° 35'E, is the major petrochemical complex in Thailand. 30 factories out of 52 in the complex are related to the petrochemical industry, and comprise all 3 vertical stages of the industry as well as refineries [6]. As reported by several governmental agencies, these factories emitted several hydrocarbon species [7]. There is a deep-sea port within the estate and a major road, Sukhumvit Road, passes close to the estate. This is the main road to the eastern part of Thailand, a very popular tourist area. There have been some studies to measure VOCs in the area [8,9]. The first study was done during the training program in quantifying VOCs in ambient air and 14 species of VOCs were detected. Another was done using duplicated samples in six locations and twelve species were detected. Despite the limitation in numbers of samples, which make unclear spatial as well as temporal variations, the species, C_2-C_9 hydrocarbons, detected in these studies conform to those from other studies elsewhere [10-13]. Among the detected hydrocarbons, the aromatic BTEX members have been found in significant amounts. Because of concerns with these hazardous materials, there was a need to quantify their ambient concentrations and distribution patterns, and to identify the emission sources in order to develop effective management strategies. Thus, in this study, BTEX species in the ambient air in and around the industrial estate have been studied and the results used to identify the effects of each anthropogenic source on BTEX ambient concentrations. A site map of the Map Ta Phut complex with its various industries is shown in Figure 1.

Sampling plan and sites

Initially seven sites representing receptors within both the estate and residential areas were selected for the study. Three sampling periods were used and for each period samples were collected on 7 consecutive days. Sampling periods were during the dry (22-28 February), the semi-wet (29 April - 5 May) and the wet season (19-25 June) in 2002. All sampling was done at ground level. The seasons influence wind directions and consequently cause different impacts to any one location. The 3 sampling periods were selected to be at times when impacts from the estate on the surrounding residential areas were likely at their maximum. Four locations at IEAT's office (IEAT), TSK's guardhouse (TSK), Padaeng industry factory's guardhouse (PIG) and National Fertilizer Company (NFC) represent the receptors at the boundary and within the complex. The locations at IEAT and PIG also represent upwind locations while TSK and NFC represent industrial locations. Three community locations at Map Ta Phut are the old site of the secondary school (School), Ta Kuan Public Health Center (THC) and Rayong Skills Development Center (SDC). The locations at School and THC also represent downwind sites during the monitoring periods (Figure 1). Additionally, air was sampled at the Nong Fab monitoring station (Nong Fab), 3 kms southwest of the estate, during the first period, and at the Provincial Administrative Center(PAC), 5 kms northeast of the estate, for the last two periods to check the transportation of air mass from the estate.

One further location at Thai Tank Terminal (Jetty) was also monitored for all three sampling periods to check spatial variation of BTEX in the area. Since the estate is located next to the seashore, the sea breeze and land breeze may affect the concentrations of BTEX in the area. Thus, some nighttime samples were collected at midnight during all three sampling periods at School, a residential area, and at TSK, an industrial area. The nighttime samples at IEAT (22-28 Feb.) and at PAC (28 April-5 May and 19-25 June) were also used to check diurnal fluctuation of the species. There were a total of 151 daytime samples during the early afternoon and 38 nighttime samples. 6 background samples at a location 25 kms east of study area, 18 duplicated samples and associated field blanks were also taken. All sampling locations are illustrated in Figure 1.

Materials and methods

There are many standard methods from various agencies that are used to quantify VOCs in ambient air [14]. Active sampling of ambient air into adsorbent tube and CS_2 solvent extraction is a commonly used method. Recently, it was successfully used to quantify ambient aromatics [15-16]. In this study, based on OSHA Method 12 [17] the ambient air in the area was collected actively by a calibrated low flow pump (SKC Model 224-PCXR8) at flow rate 0.1 L/min for 100 min onto 400/200-mg charcoal tubes (SKC No. 266-09).

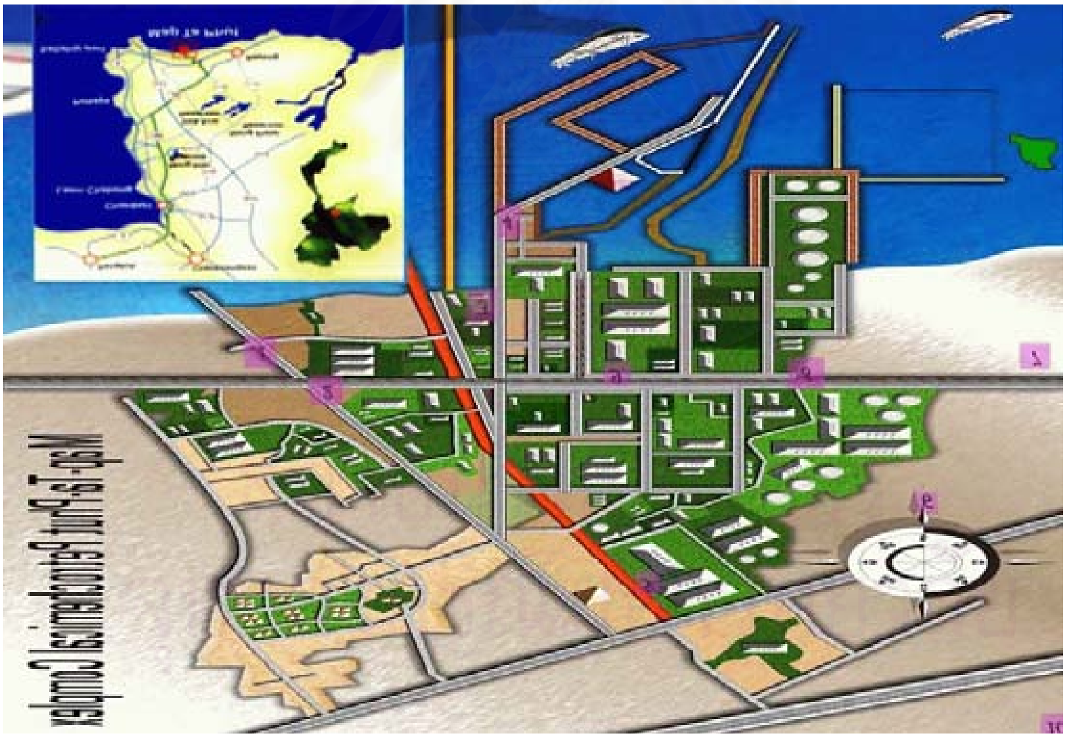

Figure 1. Site map and sampling sites
Note: 1 = NongFab; 2= Padaeng; 3= IEAT; 4= Jetty; 5= SDC; 6= School; 7 = NFC; 8=TSK; 9= THC; 10= PAC.

These samples were stored in a refrigerator before transporting to the laboratory for analysis. The trapped BTEX were desorbed by 1 ml of carbon disulfide (purified and re-distilled) and analyzed by Gas Chromatography equipped with a flame ionization detector (GC/FID-Model Varian CP-3800). The Chrmpack CP-8870 column was WCOT fused silica type with 0.32 mm I.D and 60-m. length coated with CP-Sil 5 CB as stationary phase 1 µm film thickness. A 1 µL-aliquot was manually injected onto the analytical column, and temperature ramping was used. The carrier gas was purified nitrogen at flow rate 30 mL/minute. The split mode 1:10 ratio was turned on at 0.75 minute after injecting. Peaks were eluted at 8.860 min (benzene), 11.474 min (toluene), 13.998 min (ethylbenzene) and 14.220 min (mixed-xylene). Performance criteria include method detection limits, standard calibration curve, breakthrough test, recovery test, precision test, field and laboratory blanks.

Results and discussions

BTEX concentrations in ambient air of the estate and its characteristics are presented and discussed with regard to meteorology and source locations and profiles. Mean, median and range of BTEX concentrations measured at all monitoring stations and background location are shown in Table 1. The highest mean concentrations for benzene, 7.7 and 7.8 µg/m^3, were found at TSK and Jetty sites located within the complex following by 6.9 µg/m^{3}at THC site, the 2 kms downwind site of the complex. The lowest mean concentrations for benzene, were 1.7 µg/m^3, at Padaeng site located upwind border of the complex, and 2.8 µg/m^{3}at PAC site, 5 kms downwind from the complex. The largest range for benzene, 32.1 µg/m^3, was found during dry season at TSK site. Toluene is the most abundant specie found and highest mean concentrations were 44.8 µg/m^3, at TSK site, and 27.2 µg/m^3 at THC site. The lowest mean concentration for Toluene, 1.9 µg/m^3, was found at Padaeng site following by 2.2 µg/m^3 at IEAT site, located upwind border of the complex. The highest concentration, 370.5 µg/m^3, was found at THC site during the dry period. Ethylbenzene was only occasionally detected but found at quite low levels at TSK, THC, School, Jetty and NFC sites. The highest concentration, 17.0 µg/m^3, was found at TSK during the dry period while there was no ethylbenzene detected at Padaeng. Xylene, which is a combination of m&p xylene, was detected with highest mean concentration, 8.0 µg/m^3, at TSK site following by 3.8 µg/m^3 at THC site. The lowest mean concentration for xylene, 0.2 µg/m^3, was found at Padaeng and SDC sites. The highest concentration, 41.9 µg/m^3, was found at TSK site during dry period. All downwind and within the complex monitoring sites were determined as impacted (often only lightly) compared to BTEX concentrations measured at the background location which is 25 kms east of the complex.

Table 1. Statistics of daytime measurements of BTEX at nine monitoring stations in the study area and at the background site (unit µg/m^3)

Sites	B			T			E			X		
	mean	median	range	mean	median	range	mean	median	range	mean	median	Range
SDC N=19	4.8	4.1	BDL - 18.6	9.5	3.3	0.8-78.2	0.3	0.9	BDL - 3.5	0.2	0.5	BDL - 2.7
School N=19	5.1	3.8	BDL - 26.5	7.4	4.9	2.1-28.3	0.2	1.0	BDL - 3.1	0.5	1.1	BDL - 5.6
THC N=19	6.9	5.0	BDL - 23.0	27.2	7.4	2.8-370.5	1.3	2.7	BDL - 8.8	3.8	3.2	BDL - 30.3
TSK N=19	7.7	6.1	3.4-32.1	44.8	11.6	1.6-220.8	1.0	0.7	BDL - 17.0	8.0	7.0	BDL - 41.9
IEAT N=19	3.8	4.1	BDL - 17.7	2.2	2.0	BDL - 8.6	0.7	7	BDL - 13.9	0.6	3.4	BDL - 7.4
NFC N=12	3.8	3.4	BDL - 20.9	3.1	3.3	BDL - 10.3	0.4	2.5	BDL - 5.0	2.4	2.4	BDL - 24.5
Padaeng N=13	1.7	3.7	BDL - 4.1	1.9	2.0	BDL - 5.1	BDL	BDL	BDL	0.2	1.6	BDL - 3.1
PAC N=12	2.8	4.7	BDL - 6.6	13.5	6.6	BDL - 98.5	0.1	0.5	BDL - 0.9	0.4	2.5	BDL - 4.9
Jetty N=14	7.8	4.3	BDL - 40.1	12.3	5.3	BDL - 65.4	1.3	3.2	BDL - 15.2	2.6	4.9	BDL - 19.3
N.F; N=5	5.1	4.6	3.8-6.4	24.9	5.5	3.3-98.8	0.6	1.4	BDL - 2.8	3.2	8.1	BDL - 16.2
B.G; N=6	1.2	3.2	BDL-3.9	4.7	4.7	3.2-6.2	1.4	4.2	BDL-8.3	1.7	1.4	BDL-7.2

Note: N = no. of samples and BDL = below detection limits

Diurnal variations of the pollutants were detected during all sampling periods at TSK, representing industrial area, and at School, representing residential area. The other site at PAC, around 5 kms to the northeast of the estate, was monitored for semi-wet and wet season. Benzene and Toluene concentrations in night-time at PAC, 5.4 and 21.7 µg/m^3, and School, 5.8 and 15.4 µg/m^3, were found to be higher than daytime at PAC, 2.8 and 13.5 µg/m^3 and School, 5.1 and 7.4 µg/m^3. At TSK, benzene and toluene were found to be slightly lower than those taken in daytime, while ethylbenzene and xylene were found to be slightly higher. It is worth noting that benzene and toluene concentrations at PAC and School were higher than those detected during daytime. These findings are due to the effect of the land breeze circulating contaminant air back to the estate and also there is a potential contribution from mobile sources on the Sukhumvit road. Average concentrations of benzene and toluene at industrial sites, TSK, NFC and Jetty, 6.4 and 20.0 µg/m^3, showed slightly higher than those for downwind sites, THC and School, 6.0 and 17.3 µg/m^3. While average concentrations at upwind sites, IEAT and Padaeng, 2.8 and 2.1 µg/m^3, found almost the same level as those found at background location, 1.2 and 4.7 µg/m^3. These results illustrated clearly that the south-southwest winds bring contaminants from the estate to downwind receptor locations.

The results from this study have been compared to other studies as shown in Table 2. BTEX concentrations are comparable to those in ambient air at petrochemical complexes in Korea, industrial areas in Australia and an industrial zone in Chicago. Concentrations were found to be higher than those at the Altona petrochemical and industrial complex in Melbourne. This difference can be explained by the different nature of the two complexes.

The Altona complex has a larger geographical area with more dispersed and fewer sources located within the complex relative to Map Ta Phut. When compared to a petrochemical complex in India and some mega-city urban areas including Bangkok, the Map Ta Phut results indicate clearly lower benzene concentrations. The Benzene/Toluene ratio as shown in Table 2 highlights similarities and differences of BTEX concentrations in various industrial and urban areas.

Table 2. BTEX conc. in the study area vs BTEX conc. in other industrial and urban areas

Site name	Area Type	Sources of references	Concentration					
			B µg/m^3	T µg/m^3	B/T ratio	E µg/m^3	m&p-Xyl. µg/m^3	o-Xyl. µg/m^3
MTP	Ind.	This study	6.4	20.0	0.32	0.9	4.3[c]	NA
Ulsan[a]	Ind.	[11]	6.53	14.67	0.45	NA	11.7	NA
Yochon[a]	Ind.		6.53	7.53	0.87	NA	NA	5.64
Brisbane[a]	Ind.	[10]	10.23	39.89	0.26	5.89	21.2	8.28
Melbourne[a]	Ind.	[20]	2.18	7.53	0.29	1.3	NA	NA
Bombay[a,b]	Ind.	[12]	27.97	20.51	1.36	1.08	1.95	2.82
Chicago, USA	Ind.	[13]	8.27	10.97	0.75	3.46	6.57	2.19
	Urban		10.9	10.3	1.06	2.38	4.7	1.65
Manila	Urban	[18]	12.6	168	0.08	21.9	55.8	16.8
Sao Paulo			16.7	28.1	0.6	6.0	18.5	6.2
Bangkok			18.2	186	0.1	36.6	81	28.9
Bangkok	Urban	[16]	15.1-42.4	NA	NA	NA	NA	NA

Note: a = converted to µg/m^3; µg/m^3= (MW/24.45) x ppbv, where MW for individual BTEX members; b = average from site 1 and 2 data; c = detected as mixed-xylene; NA = not applicable.

Source fingerprints, relative source strengths and meteorological conditions can account for the measured ambient concentrations including episodic event during dry period. The source-receptor impact can vary significantly as a function of source geometry and wind direction. At downwind receptor sites, the B/T ratio for each sampling period was found to be 0.13, 1.0, 0.74 for THC and 0.63, 1.2, 0.54 for School. Comparing to typical B/T ratio, 0.1, in urban area [18-19], which mainly came from scatter (and mobile) sources, it was evident that these monitoring sites were influenced, at times, by specific nearby sources. Wind direction around 180° dominated the effects of sources and made the lower ratio in the first period at THC than that at School, which was directly affected by point sources in the area. The ratios were found to be higher close to sources during strong wind period, semi-wet and wet season. These ratios also conformed to the ratios studied in refinery plume, petrochemical plant and tank farm fugitives [19]. The lower ratio in dry period was ascribed to higher toluene detected, which clearly affected by specific sources in the area. Typical ratio of B/T from mobile source cannot yield such a high ratio. This episode confirmed sources and its unusual emission loadings, which may be caused by emissions due to the abnormal leakage or failure of controlled equipment in upwind area, near shore.

It was found that the careful use of ground-based trajectories could be helpful for the identification of contributing sources to short-term grab samples [13]. A qualitative assessment has been made for a number of samples. For samples collected in the early afternoon, with dominant wind directions from the south or southwest and wind speed 2-5 m/s, the contributing sources to the their concentrations can be determined. For the School and THC receptor sites, sources within the back-plume area based on a ± 25° arc were determined. The appropriate distance and time between source and receptor were estimated. These qualitative trajectory analyses allowed the refineries, BTEX plant and tank farm to be identified as major emission sources.

Conclusions

BTEX concentrations in the Map Ta Phut area were found to be comparable to those studied in industrial areas elsewhere. The average concentration of benzene, 6.8 $\mu g/m^3$, was about three times lower than that found in Bangkok ambient air, 18 $\mu g/m^3$, which is dominated by mobile source emissions. Toluene was the most abundant species found, average 20 $\mu g/m^3$, and had the highest concentration during dry season. Ethylbenzene and xylene were found at average 0.9 and 4.3 $\mu g/m^3$ respectively. From a survey of the potential impacts of the industrial sources, it was evident that downwind sites had higher than background levels while the upwind monitoring stations had average concentrations quite close to background concentrations. The higher the urban B/T ratios support the finding that mobile sources are not primarily responsible for above average levels. Relating sources to wind direction, it was observed that the stationary industrial sources through either point or fugitive emissions dominated the ambient concentrations of target species. These measured concentrations and their sources will be more useful quantified when they were compared to predicted concentrations using air dispersion model on compiled emission inventory in the area. This step of work is currently being undertaken.

No benzene concentrations detected in this area exceeded WHO and European standards and guidelines, 5 ppbv (16.20 $\mu g/m^3$) [3], but benzene did exceed the Japanese standard, 0.95 ppbv (3 $\mu g/m^3$) [8]. Nevertheless, no safe guidelines for airborne benzene can be recommended, as benzene is carcinogenic to humans and there is no known safe threshold level.

Acknowledgement

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Modeling of BTX Based on an Emission Inventory at the Map Ta Phut Industrial Estate in Thailand

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Abstract

This paper reports on aspects of a study concerned with the impact of air emissions from the Map Ta Phut petrochemical complex in southeastern Thailand on surrounding areas. One focus of the research has been on the development of an emission inventory of the volatile organic compounds, benzene, toluene and xylene (BTX). Emission sources have been identified and the loading from all mobile and stationary sources have been compiled. Using this emissions database and the local meteorology as input data, the Industrial Source Complex Short-Term (ISCST-3) air model has been used to predict BTX values and to assess their impacts on background ambient air quality in and around the complex. In this presentation, the methodology adopted for emission inventory will be described and evaluated with the shortcomings and areas of uncertainty discussed. The relative importance of point, line and area sources and the influence of the local meteorology on the timing and place of impacts are discussed. Computed results are compared with measurement data. The value in having some species unique to some sources is seen. The coincidences and differences observed highlight the importance of (1) appropriate knowledge of all source types and location, (2) understanding the nature and possibility of fugitive emissions and episodal events, and (3) adequate information on the meteorological conditions. In particular, this research highlights the importance of area emissions from the petrochemical and petroleum industries such as the oil refineries and tank farms and identified them as potential major contributors to the BTX ambient concentrations.

Introduction

The Map Ta Phut complex, a typical industrial estate in Thailand, was established in 1991 and serves as the upstream industrial estate for many petrochemical-related industries. The complexity of the estate causes many air pollution problems, especially ones associated with volatile organic compounds (VOCs). It is situated in the Rayong Province about 200 kilometers southeast of Bangkok and occupies about 6,000 Rai (960 hectare) with approximately 10,000 workers. The estate was established under the Eastern Seaboard Program during the Fifth National Economic and Social Development Plan when Thailand planned to make use of natural gas from the Gulf of Thailand. Currently, the estate has 52 factories of which 32 are petroleum-related (IEAT, 2002). There are other two industrial estates located nearby at the southwest border of the petrochemical estate, which make for a total of 86 factories in the same sub-regional air basin. There is a deep-sea port within the estate and a major road, Sukhumvit road that passes close to the estate. The estate is surrounded by existing dwellings.

The regional is coastal and there are basically three seasons: the hot season, the rainy season and the dry (or cool) season. Average temperatures are between 23.9 and 37.1 degree Celsius; the highest monthly rainfall is about 370 millimeters; humidity is around 60-95 percent. The area is influenced by sea breezes which sweep from the southwest to the northeast with speeds typically less than 6m/s.

This paper presents the methodologies used for development of an emission inventory for benzene, toluene and xylene (BTX) and in the application of the Industrial Source Complex Short-Term (ISCST-3) air model to assess the impacts of the inventory on ambient air quality in and around the complex. The predicted values are compared to field monitoring data. The database is expected to be used extensively in planning effective measures for manage air pollution problems in the area as well as providing a basic approach dealing with VOCs emissions in other areas.

Methodology

This emission inventory was designed to be used as input data into an air dispersion model which is used to quantify the effects of BTX emissions and to allow evaluation of the state of the environment in the area. The inventory is importance for environmental researchers and regulators because it highlights the information required for regulatory purposes and provides the best form of that information.

Compilation of an Emission Inventory

The methodologies for compiling hazardous air pollutants have been reported in various studies (Pope et al., 2001; and Lagoudi et al., 2001). As summarized by Lagoudi, the main classes for determination of emissions include:

Class M: emission data that are based on measurements using standardized or accepted methods; often additional calculations are needed to convert the results of measurements into annual emission data.

Class C: emission data that are based on calculations using nationally or internationally accepted estimation methods and emission factors, which are representive for the industrial sectors.

Class E: emission data that are based on non-standardized estimations derived from best assumptions or expert opinions/ quesses.

In this research, both top-down and bottom-up approach (Palacios et al., 2001) were used. The methodologies used include: (1) identification of the anthropogenic sources of BTEX and classification as point, area and line sources; (2) site visits for information gathering and consulting with factories; (3) collection of detailed information about the industrial units concerned; (4) the collected data were cross checked if they were estimated using accepted methods; (5) estimation of BTEX emissions using emission factors and speciation profiles, mass balances and process simulation software; and (5) data handling.

Area and point sources: Stationary sources in the area were determined if they are sources of BTX. The locating and estimating of air emissions from sources of benzene, toluene and xylene were done using the following references as guides for identifying and quantifying sources(USEPA, 1998; USEPA 1995a and 1995b). Three refineries, four upstream petrochemical plants and all intermediate and downstream aromatic plants as well as their storage area were identified as potential sources and classified into area and point sources. Point sources include emitted gas through stacks of all potential sources while area sources represent the fugitive emissions from processes, storage and distributions of petroleum raw materials and products. Stack parameters for point sources and locations of area sources were gathered from the Industrial Estate Authority of Thailand (IEAT) and were cross-checked by the data from monitoring reports.

Information on the emitted VOCs from each factory for both source types were collected from an Environmental Impact Assessment (EIA), which already was approved by a National Committee set by OEPP during licensing process (ATC, 2001; ROC, 2001; SSMC, 2000; TUNTEX, 2000 and TTT, 1996). Any missing data were directly gathered from factories. In this case, the estimation methods used were examined and compared to reliable methods (USEPA 1995 and EA 2000). The VOCs emission rates were adjusted if needed. Then, BTX speciation was done by applying a speciation profile of individual source studied by others (Limpaseni et al., 2003; USEPA 1995; Scheff et al., 1989 and EA, 2000) as appropriate.

Line sources: The mobile source covered on-road vehicle emissions, but excluded non-road emission due to limited information and data (although this latter emission is not judged to be significant). The vehicle kilometers traveled (VKT) method (USEPA, 1996) was employed. The normalized emission was estimated using equation 1.

$$Q_k = \sum(VKT_i \text{ x } EF_{ik}) \qquad (1)$$

Where Q_k is emission rate of pollutant (k) in kg year^{-1}, VKT_i is the VKT of vehicle (i) in km year^{-1}, and EF_{ik} is the emission factor of pollutant (k) and vehicles (i), in kg km^{-1}. The traffic volume was based on a count by type of vehicles, HDDV, LDDT, LDGV and MC, (NEDO, 1998) and modified using increased rate of car registration reported by Land Transportation Department (LTD). Then, BTX speciation was done by applying speciation profile of exhaust and evaporative emissions from comparable vehicle types studied in Australia (EA, 2000).

Source Modeling

The Industrial Source Complex Short-Term Version 3 (ISCST-3) model developed by USEPA (USEPA, 1995 a, b) was used to predict the effects of the emission inventory of BTX on ground level ambient concentrations. The ISCST-3 model is a regulatory model that is widely used and accepted for the process of environmental impact assessment in Thailand. As described in the ISCST-3 User's manual guide, the model is capable of handling multiple sources, including point, volume, area and open pit source types. Line sources are modeled as a string of volume sources or as elongated area sources. Several source groups can be specified in a single run, with the source contributions combined for each group.

The ISCST-3 model for elevated continuous point sources uses the steady-state Gaussian plume equation given as equation (2)

$$C(x,y,z,H) = [Q_i/2\pi u\sigma_y\sigma_z][_e\text{-}y^2/2\sigma^2_y][_e\text{-}(z+H)^2/2\sigma^2_z +_e\text{-}(z-H)^2/2\sigma^2_y] \qquad (2)$$

Where Q_i is the emission rate from sources, u is the wind velocity, σ_y and σ_z are the dispersion coefficients in the horizontal (y) and vertical (z) direction, and H is the source height and plume rise. The model employs Brigg's formulae to compute plume rise, and it makes use of the power law to determine wind speed corresponding to the stack height. In general, the input to the model included: (1) hourly meteorological data for wind speed, wind direction, ambient temperature, mixing height and stability class, (2) stack characteristics such as height, diameter, exit gas velocity, exit gas temperature and emission rate, and (3) co-ordinates of sources and receptors.

For area sources, the ISC area source algorithms were used to model low or ground level releases with no plume rise. The emission rate for an area source is an emission rate per unit area (g s^{-1}m^{-2}), which is different from the point and volume source emission rates, which are total emission for the source. In case of line sources, modeled as a string of volume source, the ISC volume source algorithms are used. The volume emission rate in g s^{-1} and the initial lateral dimensions for line sources were input in the model. Choowichain (1999) has tested the sensitivities of the ISCST-3 model in the area using SO_2 emitted from point sources in different meteorological conditions such as different mixing height, stability classes. The model worked well and yielded reasonable outputs.

The surface meteorological data based on hourly meteorological information for wind speed, wind direction and ambient temperature were obtained from the Thai Meteorological Department. Daily maximum temperature data and vertical temperature profile data were used to calculate the mean maximum mixing height on adiabatic diagrams and stability classes were classified following the Pasquill-Gifford method, which uses cloudiness and wind speed for nighttime and solar radiation and wind speed for daytime. The stack height characteristics and co-ordinates of sources and receptors were obtained. Both individual and combination of the complied annual average emission rates from mobile, point and area sources were used as inputs into the model. The output option in concentration mode and 1-hr average was selected as well as regulatory default in rural dispersion coefficient.

Results and Discussion

Emission Inventory

Based on the emission inventory methodology described, best estimated annual BTX emission loadings from the Map Ta Phut locality have been compiled. For the three source types (point, line and area) it can be seen that area sources have the most potential to impact the ambient air. For the mobile (line) source, the BTX species were compiled at 0.47, 0.74 and 0.52 g s^{-1} respectively, which gives a B:T:X relationship of 1:1.6:1.1. For point (stack) sources including the power plants, emission rates of BTX have been determined as 3.08, 8.32 and 1.91 g s^{-1} respectively, with a B:T:X relationship of 1:2.7:0.6. The highest emission loading in and around the Map Ta Phut complex comes from area sources, which contribute 24.61, 17.99 and 30.70 g s^{-1} for BTX respectively, with a B:T:X relationship of 1:0.73:1.25. The most important point and area sources for BTX species are listed in Table 1.

Table 1. Major Sources of BTEX in the area

Item	Source Type	Processes	Speciation (g s^{-1})		
			Benzene	Toluene	Xylene
1.	Area	BTX Process Fugitives	6.345	0.279	13.77
2.	Area	BT Process Fugitives	4.597	0.97	NA
3.	Area	Refinery Process Fugitives	0.320	0.930	0.341
4.	Area	BTX Tank Fugitives	0.082	0.023	1.907
5.	Area	Refinery Tank Fugitives	0.055	0.160	0.058
6.	Point	Stacks of Olefin Processes	0.965	1.361	NA
7.	Point	Refinery Vapor Recovery Unit 1	0.645	3.097	0.645
8.	Point	Refinery Vapor Recovery Unit 2	0.645	3.097	0.645
9.	Point	Cogen-Processes	0.459	0.085	0.013
10.	Point	Stacks of BT Processes	0.251	0.418	0.473

Remark: NA= Not Applicable

It is noticed that the emission of xylene was mainly from fugitive sources emissions associated with the xylene production plants and refinery activities including the distribution and storage of their products. The contribution of fugitive emissions from tank farms, the distribution and processes of refineries and upstream aromatic processes contributed significant amounts of BTX to the airshed.

Source Modeling

The Industrial Sources Complex (ISCST-3) model was used to predict the effects of emissions from sources at receptor sites. The model computed the effect of the compiled emission loading at each monitoring site, C, based on equation 2. For many conditions, the dispersion coefficients can be approximated by $\sigma_y = Ax^{\alpha}$ and $\sigma_z = Gx^{\gamma}$, where x is the downwind distance (or travel time) and A, G, α, γ are empirically determined. For long downwind distances, the empirical terms in equation 2 become 1.0. If, in addition, it is assumed that u is relatively constant, then it can be found from equation 2 that

$$C \quad Q_i/x^{\alpha+\gamma} \qquad (3)$$

Where $1 \leq \alpha+\gamma \leq 2$. Consequently, if $\alpha+\gamma = 1$, the concentration should be proportional to the emission rate divided by the downwind distance from source to receptor (or travel time). Hence, the total concentration allocated to all sources at a particular receptor site is the sum of each of the emission contributions from all upwind sources adjusted for the upwind distances.

The modeling results indicated that mobile source emissions contributed to ambient concentrations at all monitoring sites, whereas point and area sources only sometimes make a contribution but they do, on occasions, played a more significant role in affecting the ambient concentrations. Impacts clearly depend on whether sites are located close to sources, are upwind or are downwind. Results associated with two sites are presented in Table 2.

From the modeling predictions, the additional contribution from area and point sources to the downwind sites is generally in the range 3-10% for benzene and 4–20 % for toluene but can be, on occasions, as high as 30% for benzene and 60% for toluene. This table also shows the relative importance of the three source types for the individual modeling.

Comparing of computed results and measurement data.

In order to verify the model predictions, air quality monitoring of BTX at a range of sites was carried out. A comparison between predicted and measured values at all monitoring sites has been undertaken. For the combined industrial and downwind sites, the correlation coefficients for measured and predicted data are 0.69 (n = 66) and 0.56 (n = 66) respectively, with 68% of data points falling within a factor of two. The coefficients of determination (R^2) for the combined industrial sites, the combined downwind sites and combined upwind sites are 0.47, 0.32 and 0.001, respectively. This implies that there is little or no relationship between the measured values and the predicted values at the upwind sites, while 47% of the variability observed within the complex and 32% of the variability observed downwind of the complex can be explained by the model. The findings confirmed that specific nearby sources impact and make the ambient concentration of BTX at the industrial sites higher than at the downwind sites. There has been some debate in the factory documentation for the refineries concerning the adequacy of the loading associated with fugitive emissions. The predicted values at the two industrial sites were observed to have some source strength dependence. When fugitive loadings from refineries were increased by a factor of 10, the modeling calculation showed the resulting coefficients of association, between measured and predicted values, decreasing from R = 0.69 (R^2 = 0.47) to R = 0.65 (R^2 = 0.42) but there was no significant impact on values associated with the downwind sites.

Table2. Predicted Values at School and THC site during monitoring (period #2)

Site	Date	Benzene						Toluene					
		Line	Point	Area	Total Load	Pre-dicted	Mea-sured	Line	Point	Area	Total Load	Pre-dicted	Mea-sured
School	29/4/2002	0.07	0.00	0.02	0.1	3.2	3.5	0.11	0.00	0.02	0.1	2.6	2.7
	30/4/2002	0.08	0.00	0.00	0.1	3.2	3.8	0.12	0.00	0.00	0.1	2.6	2.6
	1/5/2002	0.09	0.00	0.05	0.14	3.2	3.7	0.14	0.00	0.06	0.2	2.7	2.1
	2/5/2002	0.12	0.00	0.00	0.12	3.2	6	0.19	0.00	0.00	0.2	2.7	4.1
	3/5/2002	0.05	0.00	0.07	0.12	3.2	3	0.07	0.00	0.06	0.2	2.7	2.3
	4/5/2002	0.37	0.00	0.5	0.9	4.0	5	0.53	0.00	3.10	3.70	6.2	7.1
	5/5/2002	0.08	0.00	0.00	0.1	3.2	7.2	0.09	0.00	0.01	0.10	2.6	5.6
THC	30/4/2002	0.13	0.00	0.00	0.1	3.2	3.2	0.2	0.00	0.00	0.2	2.7	3.7
	1/5/2002	0.95	0.00	0.38	1.4	4.5	4.9	1.48	0.00	0.60	2.1	4.6	3.5
	2/5/2002	0.13	0.00	0.00	0.1	3.2	4.8	0.19	0.00	0.06	0.2	2.7	7.9
	3/5/2002	0.58	0.00	0.5	1.1	4.2	4.9	0.91	0.00	0.56	1.5	4.0	5.7
	4/5/2002	1.36	0.00	0.00	1.4	4.5	7.2	1.49	0.00	0.00	1.5	4.0	8.7
	5/5/2002	0.56	0.00	0.15	0.7	3.8	5.5	0.8	0.00	0.20	1.0	3.5	2.8

As can be seen in the emission inventory, xylene has more limited sources and hence modeling of this species should display less variability. In support of this, a comparison of measured and predicted values for this species showed a quite strong association. From the predicted and monitoring data, it was seen that benzene showed over-prediction in both industrial and downwind areas while toluene exhibited under-prediction in both areas. Xylene was found close to prediction at the two industrial sites. The model performance in term of bias and gross error is shown in Table 3.

Table 3. Analysis of model performance for individual BTX. at TSK and School site

Species	Average ambient Concentrations, µg m^{-3}	Bias		Gross error	
		µg m^{-3}	%	µg m^{-3}	%
Benzene	7.97	+1.41	14	7.94	137
Toluene	47.46	+0.28	0.6	23.62	50

Note: 1. Total number of samples at this site equal to 17 (N=17).
2. Bias is defined as the mean residual (predicted minus observed) concentration. The percent bias statistic is computed by normalizing each residual to the corresponding observed concentration before averaging.
3. Gross error is defined as the mean absolute value of the residuals.

Conclusion

The emission inventory results demonstrate the overwhelming importance of area sources for the ambient air in and nearby the complex. The ISCST-3 air dispersion model, which is widely regarded as capable of providing conservative estimates, was used to identify the effects of the compiled emission loading in the area. The predicted values were compared to the measured values and a reasonable association was found across the BTX concentrations. It was observed that the stationary industrial sources, through either process related or tank farm fugitive emissions, dominate the ambient concentrations of target species. As a general rule, model impacts are more accurate for the following: longer averaging periods, sources with well-defined emissions and release characteristics, and receptor areas that do not experience steep concentration gradients. The validity of air quality model depends on the quality of input data. Sources parameters must be carefully evaluated and specified as accurately as possible. Pollutant emission rates that are grossly underestimated will produce modeled impacts that are also grossly underestimated. Since the estimation of emissions is often uncertain, these uncertainties should also be taken into account when reviewing and taking action based solely on model predictions. While acknowledging the limitations with regard to the modeling method and the uncertainties associated with the emission data, the results found from this study have value for regulatory agencies in setting up ambient air quality standards and emission standards either for point or area sources.

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