การรับสัมผัสสารประกอบคาร์บอนิลและบีเทคผ่านการหายใจและการประเมินความเสี่ยงสุขภาพของพนักงานในสถานีบริการน้ำมันเชื้อเพลิงในกรุงเทพมหานคร

นางสาวมิ่งขวัญ กิจวัฒนาวงศ์

วิทยานิพนธ์นี้เป็นส่วนหนึ่งของการศึกษาตามหลักสูตรปริญญาวิทยาศาสตรมหาบัณฑิต
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INHALATION EXPOSURE TO CARBONYL COMPOUNDS AND BTEX AND HEALTH RISK ASSESSMENT OF GAS STATION WORKERS IN BANGKOK METROPOLITAN

Miss Mingkwan Kitwattanavong

A Thesis Submitted in Partial Fulfillment of the Requirements
for the Degree of Master of Science Program in Environmental Management
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Thesis Title	INHALATION EXPOSURE TO CARBONYL COMPOUNDS AND BTEX AND HEALTH RISK ASSESSMENT OF GAS STATION WORKERS IN BANGKOK METROPOLITAN
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มิ่งขวัญ กิจวัฒนาวงศ์ : การรับสัมผัสสารประกอบคาร์บอนิลและบีเทคผ่านการหายใจและการประเมินความเสี่ยงสุขภาพของพนักงานในสถานีบริการน้ำมันเชื้อเพลิงในกรุงเทพมหานคร. (INHALATION EXPOSURE TO CARBONYL COMPOUNDS AND BTEX AND HEALTH RISK ASSESSMENT OF GAS STATION WORKERS IN BANGKOK METROPOLITAN) อ. ที่ปรึกษาวิทยานิพนธ์หลัก : อ.ดร. ทรรศนีย์ พฤกษาสิทธิ์, อ. ที่ปรึกษาวิทยานิพนธ์ร่วม : ดร. เดชี่ หมอกน้อย, 181 หน้า.

งานวิจัยนี้มีจุดประสงค์เพื่อประเมินการรับสัมผัสสารประกอบคาร์บอนิลและบีเทคของพนักงานในสถานีบริการน้ำมันเชื้อเพลิงที่เกิดขึ้นผ่านทางการหายใจ พร้อมทั้งประเมินความเสี่ยงต่อสุขภาพ การเก็บตัวอย่างได้แบ่งออกเป็น 2 ช่วง ตามลักษณะของพื้นที่ การศึกษาช่วงแรกทำการเก็บตัวอย่างในสถานีบริการน้ำมันเชื้อเพลิงจำนวน 6 แห่งในเขตปทุมวัน ซึ่งเป็นตัวแทนพื้นที่เขตกรุงเทพมหานครชั้นใน ระหว่างเดือนพฤษภาคม - มิถุนายน 2553 สำหรับการศึกษาช่วงที่สองทำการเก็บตัวอย่างในสถานีบริการน้ำมันเชื้อเพลิงจำนวน 6 แห่งในเขตต่างๆของพื้นที่กรุงเทพมหานครโดยรวม ในเดือนพฤศจิกายน 2553 การเก็บตัวอย่างโดยใช้ 2,4 dinitrophenylhydrazine (DNPH) cartridge และ charcoal glass tube เพื่อเก็บสารประกอบคาร์บอนิลและสารบีเทค ตามลำดับ โดยต่อเข้ากับเครื่องปั๊มดูดอากาศสำหรับบุคคลที่อัตราการไหลของอากาศเท่ากับ 100 มิลลิลิตรต่อนาที อุปกรณ์ดังกล่าวได้ติดไว้บริเวณหน้าอกของพนักงานเพื่อเก็บตัวอย่างการรับสัมผัสของบุคคล และอีกชุดนำไปวางกลางสถานีบริการน้ำมันเชื้อเพลิงที่ระดับความสูงประมาณ 1.5 เมตรเหนือพื้นดิน ดำเนินการเก็บระหว่างเวลาการทำงาน 8 ชั่วโมง (6.00 – 14.00 น.) นำ 2,4 DNPH cartridge และ charcoal glass tube มาสกัดด้วยสารละลายอะซีโตไนไตรล์และคาร์บอนไดซัลไฟด์และนำไปวิเคราะห์ด้วยเครื่อง HPLC/UV และ GC/FID ตามลำดับ พนักงานในสถานีบริการน้ำมันเชื้อเพลิงได้รับสัมผัสสาร benzene, toluene, ethylbenzene, m,p-xylene และ o-xylene (BTEX) ในการศึกษาทั้งสองครั้งในช่วงความเข้มข้นเท่ากับ 36.93 – 292.52, 69.21 – 490.38, 7.86 – 52.42, 22.33 – 154.14 และ 5.28 – 49.90 ไมโครกรัมต่อลูกบาศก์เมตร ตามลำดับ และได้รับสัมผัสสารประกอบคาร์บอนิลหลักจำนวน 9 ชนิด ได้แก่ formaldehyde, acetaldehyde, acetone, propionaldehyde, crotonaldehyde, butylraldehyde, benzaldehyde, valeraldehyde และ hexanaldehydeในช่วงความเข้มข้นเท่ากับ 3.40 – 39.76, 1.59 – 35.33, 3.49 – 104.90, 0.27 – 4.78, 0.34 – 19.11, 0.12 – 7.57, 0.13 – 4.57, 0.04 – 3.09 และ 0.18 – 3.96 ไมโครกรัมต่อลูกบาศก์เมตร ตามลำดับ การประเมินความเสี่ยงต่อสุขภาพพนักงานสามารถประเมินได้เฉพาะสารประกอบ 8 ชนิดได้แก่ benzene, ethylbenzene, formaldehyde, acetaldehyde, toluene, m,p-xylene, o-xylene และ propionaldehyde ผลการศึกษาแสดงให้เห็นว่าพนักงานในสถานีบริการน้ำมันเชื้อเพลิงมีค่า lifetime cancer risks จากการรับสัมผัส benzene, formaldehyde, ethylbenzene and acetaldehyde อยู่ในช่วง 4.14×10^{-5} - 4.99×10^{-4}, 4.28×10^{-6} - 5.72×10^{-5}, 1.47×10^{-6} - 1.26×10^{-5} และ 8.46×10^{-7} - 2.03×10^{-5} ตามลำดับ สำหรับสารที่ไม่ก่อให้เกิดมะเร็ง ค่า hazard quotients ของการรับสัมผัส toluene, m,p-xylene, o-xylene และ propionaldehyde อยู่ในช่วง 0.0044 - 0.0313, 0.0714 - 0.4927, 0.0169 - 0.1595 and 0.0106 - 0.1910 ตามลำดับ ค่าความเสี่ยงต่อการเกิดมะเร็งของพนักงานในสถานีบริการน้ำมันเชื้อเพลิงมีค่าสูงโดยเฉพาะอย่างยิ่งสารเบนซีนที่ประเมินพบค่ามากกว่า 10^{-6} ซึ่งอาจเหนี่ยวนำให้เกิดโรคมะเร็งในเม็ดเลือดขาว (leukemia) ได้ นอกจากนี้ พบว่า การรับสัมผัสสารกลุ่มที่ไม่ก่อมะเร็งอาจไม่เพิ่มความเสี่ยงของการเกิดโรคอื่นๆที่เกี่ยวข้อง เนื่องจากค่า hazard quotients มีค่าน้อยกว่า 1

สาขาวิชา การจัดการสิ่งแวดล้อม ลายมือชื่อนิสิต มิ่งขวัญ กิจวัฒนาวงศ์
ปีการศึกษา 2553 ลายมือชื่อ อ. ที่ปรึกษาวิทยานิพนธ์หลัก
ลายมือชื่อ อ.ที่ปรึกษาวิทยานิพนธ์ร่วม

5287594420 : MAJOR ENVIRONMENTAL MANAGEMENT
KEYWORDS : INHALATION EXPOSURE / CARBONYL COMPOUNDS / BTEX / RISK ASSESSMENT / GAS STATION WORKERS / PERSONAL EXPOSURE / AMBIENT AIR

MINGKWAN KITWATTANAVONG : INHALATION EXPOSURE TO CARBONYL COMPOUNDS AND BTEX AND HEALTH RISK ASSESSMENT OF GAS STATION WORKERS IN BANGKOK METROPOLITAN. ADVISOR : TASSANEE PRUEKSASIT, Ph.D., CO-ADVISOR : DAISY MORKNOY, Ph.D., 181 pp.

The study aimed to evaluate potential occupational exposure of gas station workers to carbonyl compounds and BTEX via inhalation pathway and to estimate their health risk. The sampling was divided into 2 parts based on area focusing. The first sampling was performed in 6 gas stations located in Pathumwan district representing the inner city of Bangkok during May – June 2010, and the second sampling was performed in 6 gas stations located in different districts representing the widespread area of Bangkok in November 2010. 2, 4 DNPH active cartridge and a charcoal glass tube connected to a personal air pump with the air flow rate of 100 ml/min was used for collecting the carbonyl compounds and BTEX, respectively. This device was attached within the breathing zone of the workers to collect the personal exposure and was taken place inside in the center of gas station at the height of approximately 1.5 m during 8 work hours (6.00 am–2.00 pm). The 2,4 dinitrophenylhydrazine (DNPH) cartridge and charcoal glass tube were extracted by acetonitrile and carbondisulfide, and the samples were analyzed by HPLC/UV and GC/FID, respectively. The gas station workers exposure to benzene, toluene, ethylbenzene, m,p-xylene and o-xylene (BTEX) from both samplings were in range of 36.93 – 292.52, 69.21 – 490.38, 7.86 – 52.42, 22.33 – 154.14 and 5.28 – 49.90 $\mu g/m^3$, respectively, and their exposure to nine major species of carbonyl compounds namely formaldehyde, acetaldehyde, acetone, propionaldehyde, crotonaldehyde, butylraldehyde, benzaldehyde, valeraldehyde and hexanaldehyde were in range of 3.40 – 39.76, 1.59 – 35.33, 3.49 – 104.90, 0.27 – 4.78, 0.34 – 19.11, 0.12 – 7.57, 0.13 – 4.57, 0.04 – 3.09 and 0.18 – 3.96 $\mu g/m^3$, respectively. Only eight compounds including benzene, ethylbenzene, formaldehyde, acetaldehyde, toluene, m,p-xylene, o-xylene and propionaldehyde can be estimated the health risks. The results show that the lifetime cancer risks of gas station workers exposure to benzene, formaldehyde, ethylbenzene and acetaldehyde were in the range of 4.14×10^{-5} - 4.99×10^{-4}, 4.28×10^{-6} - 5.72×10^{-5}, 1.47×10^{-6} - 1.26×10^{-5} and 8.46×10^{-7} - 2.03×10^{-5}, respectively. The hazard quotients for non-carcinogenic compounds of gas station workers exposure to toluene, m,p-xylene, o-xylene and propionaldehyde were found in range of 0.0044 - 0.0313, 0.0714 - 0.4927, 0.0169 - 0.1595 and 0.0106 - 0.1910, respectively. The high cancer risk of the gas station workers especially exposure to benzene leading to leukemia was determined greater than 10^{-6}. Otherwise, the overall workers were not posed to increase risk of some adverse health effects from exposure to non-carcinogenic compounds due to hazard quotients were less than 1.

Field of Study : Environmental Management Student's Signature Mingkwan
Academic Year : 2010 Advisor's Signature T. Prueksasit
Co-advisor's Signature

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LIST OF ABBREVIATIONS

ACGIH	The American Conference of Governmental Industrial Hygienists
ACN	Acetonitrile
ADD	Average daily dose
AIHA	American Industrial Hygiene Association
AML	Acute myelogenous leukemia
ANOVA	The analysis of variance
AT	Averaging time
ATSDR	The Agency for Toxic Substances and Disease Registry
BAC	Blood ethanol concentration
BP	Barometric pressure
BTEX	Benzene, Toluene, Ethylbenzene and Xylenes
BW	Body weight
C	Ceiling values
CA	Contaminant concentration in air
CDI	Chronic daily intake
CNS	Central nervous system
CO	Carbonmonoxide
NGV	Natural gas vehicles
CO_2	Carbondioxide
CS_2	Carbondisulfide
CSF_i	Inhalation cancer slope factor
DHHS	The Department of Health and Human Services
DNPH	Dinitrophenylhydrazine
E10	A mixture of 10% ethanol and 90% gasoline
E85	A mixture of 85% ethanol and 15% gasoline
EC	Exposure concentration
ED	Exposure duration
EF	Exposure frequency
ERTC	Environmental Research and Training Centre
ET	Exposure time

GC/FID	Gas Chromatography with Flame Ionize Detector
HEC	Human equivalent concentration
HO_2	Hydroperoxyl radicals
HPLC/UV	High Performance Liquid Chromatography with UV Detector
HQ	Hazard quotient
IARC	The International Agency for Research on Cancer
IDHL	Immediately Dangerous to Life and Health concentration
IDL	The instrument detection limits
ILTCR	Integrated life time cancer risk
IQL	The instrument quantification limit
IR	Inhalation rate
IRIS	Integrated Risk Information System
IUR	Inhalation unit risk
LOD	The limit of detection
LOQ	The limit of quantification
LPG	Liquid petroleum gas
MTBE	Methyl tertiary butyl ether
n	The number of samples
NCEA	National Center for Environmental Assessment
ND	Not detected
NIOSH	The National Institute for Occupational Safety and Health
NO	Nitric oxide
NO_X	Oxides of nitrogen
OAQPS	The Office of Air Quality Planning and Standards
OEHHA	The Office of Environmental Health Hazard Assessment
OPEC	The Organization of the Petroleum Exporting Countries
ORD	The Office of Research and Development
OSHA	The Occupational Safety & Health Administration
PAN	Peroxyacetyl nitrate
PCD	The Pollution Control Department
PEL	Permissible exposure limit
r	Pearson’s correlation

R^2	A symbol for the coefficient of determination of a linear regression
RAGS	The original Risk Assessment Guidance for Superfund
RAIS	The Risk Assessment Information System
REL	Recommended exposure limit
RfC	Reference concentration
RfD_i	Inhalation reference dose
RH	Relative humidity
RSD	Relative standard deviation
SD	Standard deviation
SR	Solar radiation
STEL	Short term exposure limit
Temp	Temperature
TLV	Threshold limit value
TWA	Time weighted average
UF	Uncertainty factor
US EPA	The United States Environmental Protection Agency
USA	The United States of America
VOCs	Volatile organic compounds
WD	Wind direction
WEEL	Workplace environmental exposure level
WS	Wind speed
λ	Wave length

CHAPTER I
INTRODUCTION

1.1 Rationale background and problem addressed

Thailand is one of the developing countries in the Southeast Asia which energy fuel is demanded to generate the national economic growth. Energy consumption in Thailand is increasing rapidly in a decade especially petrol. The Department of Alternative Energy Development and Efficiency reported that the highest final energy consumption was the sector of manufacturing. It consumed energy as 36.0 % of the total energy in the country as well as the sector of transportation which consumed energy as 35.8 % of the total energy in the country in 2009 (Ministry of Energy, 2010). However, the occurrence of fuel crisis in 1997 and decreasing of energy fuel in each year are inevitable problems. To solve these problems, Thai's government needed to find an alternative energy which was lower price than petrol. Due to Thailand is also an agriculture country, the agricultural waste can be produced ethanol which is added to gasoline as an oxygenate. The mixed product of ethanol and gasoline is called gasohol which was supported by Thai's government to be the alternative fuel for the vehicles in 2000.

Presently, gasohol is the most popular fuel in Thailand because it is lower price than gasoline and lower emission of some toxic pollutants such as carbon monoxide and non-burning hydrocarbon in vehicle exhausts (Brown, 2008). In the second quarter 2010, Department of Energy Business reported the number of gas stations in Thailand as the total of 19,068 stations in which gasohol is 4,323 stations. In Bangkok and suburb that was found 875 gas stations and 637 gas stations, respectively (Ministry of Energy, 2010). A number of gas station being supported the fuel demand for transportation in our country is increasing. The Ministry of Energy in Thailand reported that the situation of gasohol was the highest consumed, 9.2 million liters per day in 2008 and increased to 12.2 million liters per day in this year (or increasing about 32.5 %) (Ministry of Energy, 2009). Nevertheless, some previous studies found that higher consumption of ethanol fuels was considerable to increase carbonyl compounds in atmosphere especially acetaldehyde and formaldehyde. The atmospheric levels of formaldehyde and acetaldehyde measured at vehicular fleet in the city of Rio de Janeiro, Brazil, were in range of 1.52 to 54.31 ppb and 2.36 to 45.60 ppb, respectively. The evidence of high concentrations of formaldehyde and acetaldehyde in Brazil could be suggested that they came from alcohol-based fuel for vehicles which resulted in increase of ozone formation (Corrêa, Martins, and Arbilla, 2003). The ambient concentrations of carbonyl compounds in Bangkok, Thailand were also estimated at the roadside for 24 hours. The levels of formaldehyde and acetaldehyde were in range of 5.14 to 17.2 µg/m³ and 1.59 to 7.95 µg/m³, respectively. This study indicated that the increasing formaldehyde and acetaldehyde emission in atmosphere related to increasing of gasohol consumption (Morknoy, 2008). Typically, acetaldehyde is generated from ethanol oxidation, whilst formaldehyde is generated from methanol oxidation. Both compounds are considered as the secondary pollutants, precursors to produce ozone (O_3) and peroxyacetyl nitrate (PAN). In addition, exposure to low level of acetaldehyde and formaldehyde can cause irritation of eyes, throat, and respiratory tract in human. There are some evidences that these substances also cause nasal squamous cell carcinoma (or adenocarcinoma) from acetaldehyde and squamous cell carcinoma from formaldehyde in higher concentrations (RAIS, 2009; U.S. EPA, 2010).

Gas station is likely to be an important point source of carbonyl compounds and VOCs especially benzene, toluene, ethylbenzene, and xylene (BTEX) emission. People who work in gas station without health protection might directly expose to high concentrations of these compounds through inhalation route. Inhalation exposure to these compounds cause serious health effects in human depending on types and concentration of chemicals as well as exposure duration. Many researches revealed that the gas station workers had been affected from exposure to aldehydes and BTEX (Periago, Zambudio, and Prado, 1997; Jo and Song, 2001; de Oliveira *et al.*, 2007; Majumdar *et al.*, 2008; Byeon, Lee, and Afanayev, 2008; and Thaveevongs, 2008). Currently, mono-aromatic hydrocarbon and carbonyl compounds such as benzene, toluene and formaldehyde were already measured at gas stations in Kolkata, India. The means of occupational exposure to formaldehyde and acetaldehyde were 27.8 µg/m³ (in range of 11.6 to 55.5 µg/m³) and 18.3 µg/m³, respectively. The study found that the mean personal exposure concentrations of benzene, toluene, ethylbenzene, m,p-xylene and o-xylene were 137.5, 643.6, 118.0, 209.7 and 68.2 µg/m³, respectively. In addition, the individual lifetime cancer risks (40 years of occupational exposure) of carcinogenic compounds were assessed. The cancer risk resulted 9.66×10^{-5} for benzene, 1.18×10^{-5} for ethylbenzene, 3.52×10^{-5} for formaldehyde, and 4.03×10^{-6} for acetaldehyde which indicated the workers had the probability of cancer (Majumdar *et al.*, 2008). In Thailand, Thaveevongs (2008) studied on the inhalation exposure to VOCs of gas station worker in Bangkok measuring by passive sampling technique and investigation of their possible health risk assessment. The result of risk assessment show that the gas station worker might be at cancer risk from exposure to MTBE and benzene, resulting in the range of 2.41×10^{-5} to 1.18×10^{-4} and 3.42×10^{-4} to 1.23×10^{-3}, respectively.

As mentioned above, the risk information of occupational health related to carbonyl compounds and BTEX in Thailand is still limited. Therefore, this study intentionally determined ambient air concentrations of carbonyl compounds and of BTEX in the gas stations of Bangkok, and also estimated the potential risk of the workers exposure to these substances via inhalation route.

1.2 Objectives of the study

This research aims to estimate occupational exposure of carbonyl compounds and BTEX and health risk assessment of the gas station workers in Bangkok, Thailand. Inhalation exposure of such volatile chemicals is considerably to be the predominant pathway of the gas station workers. The target compounds of carbonyl group in this study were formaldehyde, acetaldehyde, propionaldehyde, crotonaldehyde, butyraldehyde, benzaldehyde, valeraldehyde and hexanaldehyde. Benzene, toluene, ethylbenzene, m,p-xylene and o-xylene were assigned to be the target compounds for VOCs. To know how these toxic pollutants are able to impact either on natural ambient air or workers' health situation in their workplaces. The specific objectives of the study are then designed as follows:

1) To determine ambient air concentrations of carbonyl compounds and of BTEX in the gas stations in Bangkok,

2) To evaluate potential occupational exposure to carbonyl compounds and BTEX of the gas station workers via inhalation pathway, and

3) To estimate their health risk in their workplaces.

1.3 Hypothesis

Gas station workers in Bangkok, Thailand pose to have risks from exposure to carbonyl compounds and BTEX in their workplaces through inhalation.

1.4 Scopes of the study

1.4.1 Study area

Considering on area based purposes, the study was divided into two parts: (1) the study in the same district where representing an inner city of Bangkok (six gas stations with difference companies), and (2) the study in different districts representing widespread areas of Bangkok (six gas stations with the same company).

The first part, six gas stations in Pathumwan district, Bangkok belonging to three different companies which are located on Rama IV Road (Hua Lamphong), Charumuang Road, Rongmuang Road, Rama IV Road (Lumphini), Banthad Thong Road, and Phetchaburi Road were selected.

The second part, the same company of six gas stations locating in five districts of Bangkok, i.e. Don Mueang district, Phayathai district, Saphan Sung district, Bang Khun Thian district, and Pathumwan district, were chosen.

1.4.2 Sampling technique for ambient air

Active sampling was performed in this study using 2,4 dinitrophenylhydrazine (DNPH) cartridges and charcoal glass tubes connected to personal air pump, and also taken place inside the gas stations at the height of approximately 1.5 m during 8 work hours.

1.4.3 Sampling technique for occupational exposure

Personal sampling device was the same as that of ambient air sampling. The sample collecting equipment was hold by two workers and the cartridges and charcoal glass tubes were attached within the breathing zone of the workers which is good for representing the air mass of their inhalation exposure.

1.4.4 Sampling duration

The sampling of the first part was carried out during May to June 2010. All samples in each gas station were collected twice within two weeks; the second day was after the first day for a week. For second sampling, the samples in each gas station were collected for four days per week (i.e. Friday, Saturday, Sunday, and Monday) in November 2010.

1.4.5 Analytical techniques

Analytical techniques for carbonyl compounds and BTEX are different. Carbonyl compounds collected by 2,4 dinitrophenylhydrazine (DNPH) cartridges were extracted by acetonitrile, and analyzed by HPLC/UV. While carbon disulfide was used as extracting solvent for BTEX absorbed on activated charcoal, and analyzed by GC/FID.

1.5 Expected outcomes

The four main desired outcomes are as follows:

1) The investigation of ambient air concentrations of carbonyl compounds and BTEX in the gas stations in Bangkok,

2) The essential baseline of inhalation exposure to carbonyl compounds and BTEX of the gas station workers in Bangkok,

3) The health risk information of the workers and the owners in the gas station which can be utilized for further risk management and risk communication to prevent

or reduce the risk from inhalation exposure to carbonyl compounds and BTEX of the workers, and

4) The background knowledge which can be applied to further studies on the exposure to these compounds in other careers and general population in Bangkok or other cities in Thailand.

CHAPTER II

LITERATURE REVIEWS

2.1 Fuel crisis in Thailand

Currently, many countries in the world face environmental problems such as waste pollution, water pollution, and air pollution, which derive from the progress of manufacture, tourism, and transportation to generate the economic growth in the countries. Thailand is a developing country which locates in South-East of Asia. Especially, Bangkok is the capital city which demands the energy consumption for manufacture and transportation more than the other provinces in a decade. According to the Department of Alternative Energy Development and Efficiency (2010), Ministry of Energy in Thailand indicated the energy situation on data energy production, import, export, transformation, and consumption in 2009. The sectors including transportation, commercial, residential, construction, manufacturing, mining and agriculture demand the energy in their processes. It reported that the manufacturing was the highest final energy consumption which consumed as 36.0 % of the total energy in the country, and the transportation consumed as 35.8 % of the total energy in the country in 2009. The trends of all the sectors have increased since 2005 as shown in Figure 2.1.

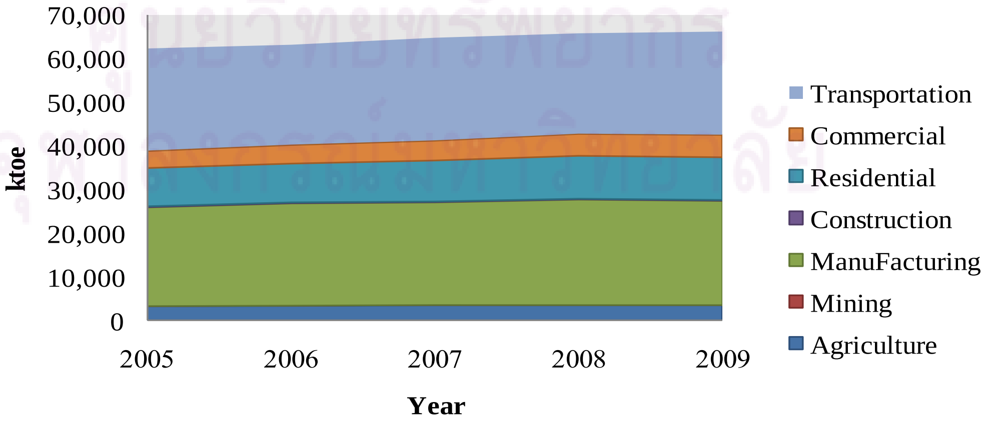


Figure 2.1 Trends of energy consumption by economic sector

Source: Thailand Energy Statistic 2009 (Ministry of Energy, 2010)

Nevertheless, the occurrence of economy crashed from unstable exchange rate in Thailand and OPEC decreased their oil production in 1997, which mostly effected to the fuels prize especially oil. This problem was solved by the strategy of Thai government which was finding of the renewable fuel in the country in place of oil importation (Morknoy, 2008). Natural gas and gasohol were promoted and supported to the country by Ministry of Energy using as the alternative fuels for cars and other vehicles in 2000. Especially, gasohol is placed importance due to ethanol, a component of gasohol, is lower price and some toxic pollutants emission than petrol and it can be produced in our country from agricultural product. In fact, gasohol production in Thailand had originated by the Royal Project of King Bhumibol in 1985, in the Study Project on Gasohol Production for an Alternative Energy by producing ethanol from cane (Bhandhubanyong, n.d.). Gasohol is a mixture of gasoline and alcohol, sometimes called E10 due to 10% ethanol or 3% methanol is typically mixed with petrol. In USA, a mixture of 85% ethanol and 15% petrol which called E85 can be used in some cars.

2.2 Ethanol and air pollution

Ethanol is an alcohol, a group of chemical compounds whose molecules contain a hydroxyl group which is volatile, flammable, clear, colorless liquid. Ethanol is miscible with water and with many organic solvents, including acetic acid, acetone, benzene, carbon tetrachloride, chloroform, diethyl ether, ethylene glycol, glycerol, nitromethane, pyridine, and toluene. It is produced by fermentation of agricultural crops or crop residues such as cane, cassava and other grains.

The occupational standard limit of inhalation exposure to ethanol is 1,000 ppm for 8 hour per day. The human health effects at this level or higher is temporary irritation of the eyes and respiratory tract. At high concentration, the ethanol’s vapor also induces headaches, fatigue, and sleepiness, and effect to the central nervous system (CNS). Since their toxic effect is absorbed into the bloodstream, airborne exposure can be evaluated by measuring blood ethanol concentrations (BAC) or breath alcohol. Endogenous level of ethanol in blood usually range from 0.02 – 0.15

mg % in normal subjects and the general rate of ethanol metabolism in human is about 83 mg/kg/h (Nadeau *et al*., 2003).

Ethanol is commonly added to gasoline as an oxygenate. The oxygen content of ethanol is believed to promote easier and more complete combustion, leading to generally lower emission of carbon monoxide and unburnt hydrocarbon in vehicle exhausts (Brown, 2008). Ethanol in blends may be expected to reduce some of the harmful pollutant through dilution. The essential fuel properties of ethanol and compared with gasoline and diesel are shown in Table 2.1. However, the ethanol can damage certain engine components such as rubber seals if the ethanol is present in higher concentrations. Likewise, methanol in blends is more toxic and corrosive, and emit aldehydes especially formaldehyde which is potentially to aggravate ozone pollution in warm weather. Many research suggested that the use of ethanol as fuel or fuel additive, leads to increase the atmospheric level of acetaldehyde and formaldehyde. The chemical products of ethanol oxidation are acetaldehyde (a precursor to PAN) and ozone and those of methanol are formaldehyde and ozone (Jacobson, 2002; Grosjean, 1997). According to the report of Pereira *et al*. (2004), the reaction of ethanol, which leads to ozone formation and carbonyl compounds, can be described below:

$$\mathrm{CH_3CH_2OH + {}^{\bullet}OH \rightarrow CH_3{}^{\bullet}CHOH + H_2O} \qquad (1)$$

$$\mathrm{CH_3{}^{\bullet}CHOH + O_2 \rightarrow CH_3CHO + {}^{\bullet}OOH} \qquad (2)$$

$$\mathrm{{}^{\bullet}OOH + NO \rightarrow NO_2 + {}^{\bullet}OH} \qquad (3)$$

$$\mathrm{NO_2} + h\nu \rightarrow \mathrm{NO + O} \qquad (4)$$

$$\mathrm{O + O_2 + M \rightarrow O_3 + M} \qquad (5)$$

Table 2.1 The essential fuel properties of ethanol compared with gasoline and diesel (Brown, 2008)

Property	**Ethanol**	**Gasoline**	**Diesel**
Composition, weight %			
C	52.2	85-88	84-87
H	13.1	12-15	13-16
O	34.7	0	0
Density, kg/m^3	794	750	825
Lower heating value, MJ/kg	26.7	42.9	43
Octane number	100	86-94	-
Cetane number	8	5-20	40-55
Reid vapour pressure (kPa)	15.6	55-103	1.4
Stoichiometric air/fuel ratio, weight	9:1	14.7:1	14.7:1
Boiling temperature, ^{O}C	78	80-225	188-343
Flash point, closed cup, ^{O}C	13	-42	74

The studies of International Energy Agency (2004) reviewed the impact of gasohol (E10) and found that E10 reduced emission of carbon monoxide, exhaust VOCs, particulate matter and some unregulated pollutants, but increased evaporative and total VOCs, NO_x and some unregulated pollutants as resulted in Table 2.2. In Thailand, the Pollution Control Department (PCD) introduced a project to measure air pollutants such as BTEX and carbonyl compounds released from the vehicles using gasohol as fuel. The PCD directly collected the pollutants in the exhaust pipe of the vehicles and also in Bangkok's ambient air in 2006. It was found that the emission of air pollutants from cars using gasohol compared to gasoline indicated that carbon monoxide, benzene and 1,3 butadiene had decreased and hydrocarbons, NO_x, carbon dioxide, ethylbenzene, xylene, toluene, formaldehyde, and acetaldehyde increased as seen in Table 2.3.

Table 2.2 Changes in Emission when ethanol is blended with gasoline (Brown, 2008)

Pollutant	**Effect of ethanol on emission**
Commonly regulated air pollutants	
CO	decrease
NO_X	increase
Tailpipe VOC	decrease
Evaporative VOC	increase
Total VOC	increase
Particulate matters	decrease
Toxic/ other air pollutants	
Acetaldehyde	increase
Benzene	decrease
1,3 Butadiene	decrease
Formaldehyde	increase
Peroxyacetyl nitrates	increase
Isobutene	decrease
Toluene	decrease
Xylene	decrease

Table 2.3 Emission of toxic air pollutants from cars using gasohol in Thailand by Pollution Control Department (Morknoy, 2008)

Air Toxic Pollutants	**Emission changes**
Hydrocarbon	5.73%
Carbon Monoxide (CO)	-14.97%
Oxide of Nitrogen (NO_x)	12.20%
Carbon Dioxide (CO_2)	3.93%
Benzene	-12.86%
1,3 Butadiene	-55.71%
Ethylbenzene	122.34%
Xylene	177.07%
Toluene	6.20%
Formaldehyde	20.72%
Acetaldehyde	127.27%

As a present, gasohol is widely used in the country which is substitution of gasoline as the transportation fuel. The report of Ministry of Energy indicates the situation of gasohol, NGV, gasoline, and diesel in recent year. It reports that gasohol is the highest consumed, 9.2 million liters per day in 2008 and increased to 12.2 million liters per day in this year (or increasing about 32.5 %). High consumption happened because it is the strategy of the government to support the alternative fuel for reducing fuel importation. The average gasohol 95 consumption is 8.1 million liters per day, but the gasoline consumption is constant due to the types of gasohol are presently available in gasohol 95 for gasoline 95 substitution, and in gasohol 91 for replacing of gasoline 91 (Ministry of Energy, 2009).

The second quarter in 2010, Department of Energy Business, Ministry of Energy (2010) reports the number of gas stations in the entire nation is 19,068; gasohol is 4,323 stations; NGV is 402 stations; and LPG is 810 stations. In Bangkok, there are 875 gas stations while 637 gas stations are located in suburb. An expansion of gas stations in Thailand implies the number of vehicles and transportation fuels demand are increasing.

Even though gas station is an important source of energy for vehicles, it can be considerable as an emission source of some toxic pollutants such as carbon monoxide, hydrocarbon, nitrogen oxide, particular matter, and VOCs. These compounds can be found during refueling into the vehicles and fuels combustion of the vehicles. These toxic pollutants in the fuel highly react to other compounds and are commonly released in the gas stations.

2.3 Chemical properties of the pollutants

2.3.1 Carbonyl compounds

A carbonyl group is a functional group composed of a carbon atom double-bonded to an oxygen atom: C=O. Carbonyls which include aldehydes and ketones, have a functional group in their chemical structure (see Figure 2.2). The carbonyl is in a terminal position in aldehydes and is placed between two carbons in ketones. The double bond in the carbonyl group highly reacts to chemicals. Carbonyl groups can be decreased by reaction with hydride reagents such as $NaBH_4$ and $LiAlH_4$, or catalytically by hydrogen and a catalyst such as copper chromite, Raney nickel, rhenium, ruthenium or even rhodium. Ketones give secondary alcohols; aldehydes, esters and carboxylic acids give primary alcohols. Carbonyls can be alkylated by nucleophilic attack by organometallic reagents such as organolithium reagents and Grignard reagents. Carbonyls also be alkylated by enolates as in aldol reactions. Carbonyls are also the prototypical groups with vinylogous reactivity, e.g. the Michael reaction where an unsaturated carbon in conjugation with the carbonyl is alkylated instead of the carbonyl itself (Morknoy, 2008).

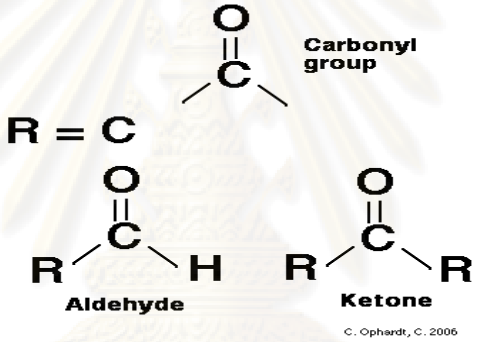


Figure 2.2 Chemical structures of carbonyl group, aldehyde and ketone
Source: Ophardt, 2006

Tanner *et al*. (1988) indicated that formaldehyde and acetaldehyde levels are important since these compounds substantially influence photochemical smog processes in complex ways, including accelerating the formation of secondary products and increasing ozone maxima. For example, gas-phase photochemistry of HCHO in the atmosphere can lead via reaction with OH (reaction 1) or via photolysis (reaction 2) to the net formation of one or two hydroperoxyl (HO_2) radicals:

$$HCHO + OH + O_2 \rightarrow HO_2 + CO + H_2O \qquad (1)$$

$$HCHO + h\nu\ (\lambda < 360\ \text{nm}) \rightarrow HCO + H \qquad (2)$$

$$HCO + O_2 \rightarrow HO_2 + CO \qquad (2a)$$

$$H + O_2 \rightarrow HO_2 \qquad (2b)$$

These hydroperoxyl radicals may oxidize nitric oxide (NO) molecules to NO_2 and OH or recombine by reaction 3. This reaction produces increased levels of gas-phase hydrogen peroxide, an important oxidant of dissolved sulfur dioxide in cloudwater and precipitation.

$$\mathrm{2HO_2 \rightarrow H_2O_2 + O_2} \tag{3}$$

Photolysis of acetaldehyde in the atmosphere leads to the formation of HO_2 radicals, CO, and methylperoxyl radicals (reaction 4) and by reaction with OH to the peroxyacetyl radical and peroxyacetyl nitrate (PAN) via reactions 5-7. In the presence of high concentrations of NO, the formation of PAN is suppressed, since acetylperoxyl radicals formed in reaction 6 can also oxidize NO to NO_2.

$$\mathrm{CH_3CHO \rightarrow CH_3 + CHO + 2O_2 \rightarrow CH_3O_2 + HO_2 + CO} \tag{4}$$

$$\mathrm{CH_3CHO + OH \rightarrow CH_3CO^{\bullet} + H_2O} \tag{5}$$

$$\mathrm{CH_3CO^{\bullet} + O_2 \rightarrow CH_3C(O)O_2^{\bullet}} \tag{6}$$

$$\mathrm{CH_3C(O)O_2^{\bullet} + NO_2 \leftrightarrow CH_3C(O)OONO_2\ (PAN)} \tag{7}$$

However, in polluted urban air daytime decomposition of CH_3CHO via reaction with OH is expected to be a major route of PAN formation, especially away from the immediate vicinity of NO emission sources. This process, of course, also contributes to elevated ozone levels downwind in an urban plume. The formation of peroxyacetyl nitrates has substantive health implications since PAN and higher alkyl homologues are known to be potent phytotoxins and along with their aromatic homologues (e.g., peroxybenzoyl nitrate) are strong lachrymators. The reasonably long lifetime of PAN, particularly at colder temperatures, has also made it an important agent for transporting NO, on regional and global scales. Accordingly, this study mainly focuses on aldehydes such as formaldehyde, acetaldehyde and propionaldehyde which are the secondary pollutants and their characteristics, properties, potential sources and health effect can be summarized as the following:

1) Formaldehyde

Formaldehyde is also known as formic aldehyde, methanal, methyl aldehyde, methylene oxide, oxomethane, or oxymethylene. At room temperature, formaldehyde is a colorless gas with a strong, pungent, suffocating, and highly irritating odor. Its molecular structure is depicted in Figure 2.3. It is readily soluble in water, alcohols, ether, and other polar solvents. Naturally, it can be produced in small amounts in our bodies. A synopsis of its physicochemical properties is given in Table 2.4.

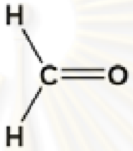


Figure 2.3 Chemical structure of formaldehyde

Source: U.S. EPA, 2010

Table 2.4 Physicochemical properties of formaldehyde

Property	Information	Reference
Formula	CH_2O	ATSDR, 1999
CAS registry no.	50-00-0	ATSDR, 1999
Molecular weight	30.03	ATSDR, 1999
Density	0.815 g/cm^3 at -20 ^{o}C	U.S. EPA, 2010
Vapor density	1.067 (air= 1)	U.S. EPA, 2010
Vapor pressure	3,883 mmHg at 25°C	U.S. EPA, 2010
Log K_{ow}	0.35	ATSDR, 1999
Henry's law constant at 25°C	3.27×10^{-7} atm-m^3/mol	ATSDR, 1999
Conversion factors in air (25^{o}C, 760 mm Hg)	1 ppm = 1.23 mg/m^3 (v/v) 1 mg/m^3 = 0.81 ppm (v/v)	U.S. EPA, 2010
Boiling point	-19.5^{o}C	U.S. EPA, 2010
Melting point	-92 ^{o}C	U.S. EPA, 2010
Solubility in water	400 mg/mL at 20 ^{o}C	HSDB, 2006

Formaldehyde is widely used in the production of plywood adhesives, abrasive materials, insulation, insecticides and embalming fluids. It is mainly produced from anthropogenic sources such as motor vehicle exhaust, and power plants. In the lower atmosphere, formaldehyde is mostly formed by photochemical oxidation of hydrocarbon such as methane and isoprene that is released from combustion processes. It can also be formed by various natural processes such as decomposition of plant residues in the soil and forest fires. Some pathways can remove formaldehyde in the environment such as direct photolysis and oxidation which produced hydroxyl and nitrate radicals. The half-life of formaldehyde in the atmosphere is measured in range from 1.6 to 19 hours depending on radiant energy, the presence and concentrations of other pollutants, and other factors.

Low concentrations of formaldehyde can cause irritation of the eyes, nose, throat, and skin. People with asthma may be more susceptible to formaldehyde through inhalation. Large amounts of formaldehyde in drinking water can cause severe pain, vomiting, coma, and possible death. Some studies indicated that people who exposed to formaldehyde in their workplace found more cases of cancer of the nose and throat than expected. In animal studies, rats inhaled high concentrations of formaldehyde and developed nose cancer. The Department of Health and Human Services (DHHS) and the National Toxicology Program noted that formaldehyde is reasonably anticipated to be a human carcinogen. The International Agency for Research on Cancer (IARC) has classified formaldehyde as 2A, probably carcinogenic to humans. The EPA has classified formaldehyde as a B1 compound, probable human carcinogen. (ATSDR, 1999; U.S. EPA, 2010)

2) Acetaldehyde

Acetaldehyde is also known as acetic aldehyde, ethanal, or ethyl aldehyde. At room temperature, acetaldehyde is a volatile, colorless liquid with a pungent, fruity odor. The chemical structure of acetaldehyde is shown in Figure 2.4. Acetaldehyde is miscible in water, alcohol, ether, benzene, gasoline, solvent naphtha, toluene, xylene, turpentine, acetone, and other common organic solvents. A synopsis of its physicochemical properties is given in Table 2.5.

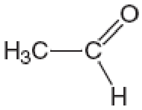


Figure 2.4 Chemical structure of acetaldehyde

Source: U.S. EPA, 1999

Table 2.5 Physicochemical properties of acetaldehyde

Property	**Information**	**Reference**
Formula	C_2H_4O	U.S. EPA, 1999
CAS registry no.	75-07-0	U.S. EPA, 1999
Molecular weight	44.06	U.S. EPA, 1999
Density	0.7834 g/cm^3 at 18 ^{o}C	HSDB, 2006
Vapor density	1.52 (air= 1)	HSDB, 2006
Vapor pressure	755 mmHg at 20°C	U.S. EPA, 1999
Log K_{ow}	-0.34	HSDB, 2006
Henry's law constant at 25°C	6.67×10^{-5} atm-m^3/mol	HSDB, 2006
Conversion factors in air (25^{o}C, 760 mm Hg)	1 ppm = 1.8 mg/m^3 (v/v) 1 mg/m^3 = 0.555 ppm (v/v)	U.S. EPA, 1999
Boiling point	20.1^{o}C	HSDB, 2006
Melting point	-123.37 ^{o}C	HSDB, 2006
Solubility in water	0.1-1.0 mg/mL at 19 ^{o}C	U.S. EPA, 1999

Acetaldehyde is usually used as a component in the chemical synthesis of acetic acid, pyridine and pyridine bases, and peracetic acid. Small amounts of acetaldehyde are used as a food additive in such foods as milk products, baked goods, fruit juices, candies, and soft drinks. Acetaldehyde is ubiquitous in the environment, and is produced from the atmospheric oxidation of terpenes. In urban areas, the oxidation of olefins such as propene (C_3H_6), and paraffins such as propane (C_3H_8) and ethanol (C_2H_5OH) produces acetaldehyde. Acetaldehyde in the atmosphere is commonly released from industrial emission or motor vehicle exhaust.

Acetaldehyde is a high chemical reactivity which can cause irritation of the eyes, skin, mucous membranes, throat, and respiratory tract. Both in animals and in humans highly expose to acetaldehyde through oral and inhalation pathways.

Observed effects of oral exposure to acetaldehyde in animals lead to be hyperplasia of the tongue, epiglottis, and fore stomach. The health effects from inhalation in humans result in substantial toxic effects in the nasal epithelium, including hyperplastic and metaplastic changes. It is possible that the carcinogenic effects seen following acetaldehyde inhalation are a result of this enhanced proliferation, a response to the substantial cytotoxic effects in chronic studies. The EPA has classified acetaldehyde as a B2 compound, probable human carcinogen (U.S. EPA, 1999; 1994).

3) Propionaldehyde

Propionaldehyde is also known as propanal, propionic aldehyde, methylacetaldehyde, propyl aldehyde, propaldehyde, and propylic aldehyde. Propionaldehyde is a colorless liquid with a suffocating, fruity odor. The chemical structure of propionaldehyde is shown in Figure 2.5. It is used in the manufacturing of propionic acid and polyvinyl and other plastics, in the synthesis of rubber chemicals, and as a disinfectant and preservative. It is prepared by treating propyl alcohol with a bichromate oxidizing mixture or by passing propyl alcohol vapor over copper at a high temperature. Some relevant chemical and physical properties are listed in Table 2.6.

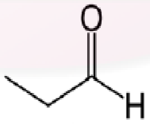


Figure 2.5 Chemical structure of propionaldehyde

Source: U.S. EPA, 2008

Propionaldehyde is primarily released to the environment through the combustion of wood, gasoline, diesel fuel, and polyethylene. Propionaldehyde is also a component of both mainstream and sidestream cigarette smoke. In air, propionaldehyde is expected to exist solely as a vapor; it may be degraded in the atmosphere by reaction with photochemically produced hydroxyl radicals with a half-life of 19.6 hours for this reaction in air. Propionaldehyde has been detected in ambient and indoor air in several studies. Báez *et al*. (2003) measured the concentrations of propionaldehyde in indoor and outdoor air in Mexico and found in the range of 0.0002–0.018 mg/m^3 and 0.0002–0.016 mg/m^3, respectively.

Table 2.6 Physicochemical properties of propionaldehyde

Property	Information	Reference
Formula	C_3H_6O	U.S. EPA, 2008
CAS registry no.	123-38-6	U.S. EPA, 2008
Molecular weight	58.08	U.S. EPA, 2008
Density	0.8657 g/cm^3 at 25 ^{o}C	U.S. EPA, 2008
Vapor density	1.8 (air= 1)	U.S. EPA, 2008
Vapor pressure	317 mmHg at 25°C	U.S. EPA, 2008
Log K_{ow}	0.59	U.S. EPA, 2008
Henry's law constant at 25°C	7.34 × 10^{-5} atm-m^3/mol	HSDB, 2006
Conversion factors in air (25^{o}C, 760 mm Hg)	1 ppm = 2.38 mg/m^3 (v/v) 1 mg/m^3 = 0.42 ppm (v/v)	U.S. EPA, 2008
Boiling point	49^{o}C	U.S. EPA, 2008
Melting point	-81 ^{o}C	U.S. EPA, 2008
Solubility in water	306 mg/mL at 25 ^{o}C	U.S. EPA, 2008

Eye contact with propionaldehyde causes severe irritation, experienced as discomfort or pain, with excessive blinking and tear production. Redness and swelling of the eye may occur along with temporary, superficial injury of the cornea. Prolonged skin contact causes mild to moderate local redness and swelling. Inhalation of propionaldehyde may cause irritation of the upper respiratory tract, nose and throat, possibly accompanied by chest pain. Excessive inhalation of high concentrations may cause nausea, vomiting, headache, and dizziness, progressing to difficulty in breathing, even death. Repeated skin contact may cause dermatitis. Prolonged or repeated overexposure to vapor may result in damage to the tissues of the nose and upper respiratory tract (U.S. EPA, 2008).

2.3.2 BTEX

BTEX is an acronym that stands for benzene, toluene, ethylbenzene, and xylenes. These compounds are some of the volatile organic compounds (VOCs) which are generated mostly from anthropogenic sources, point, area and mobile sources. These hydrocarbons are used extensively as solvent and raw materials in a petroleum industry and found in fuel for transportation. BTEX released in to 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 downwind 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 workplaces and residential areas.

Volatile organic compounds, mainly released through fugitive emission, benzene, toluene, and xylenes in the lower atmosphere will react with other atmospheric components, which plays significant role as the primary pollutant contributing to the formation of ground level ozone and other air pollutants (Pimpisut, 2004). For example, the atmospheric oxidant production of toluene is described by the Figure 2.6.

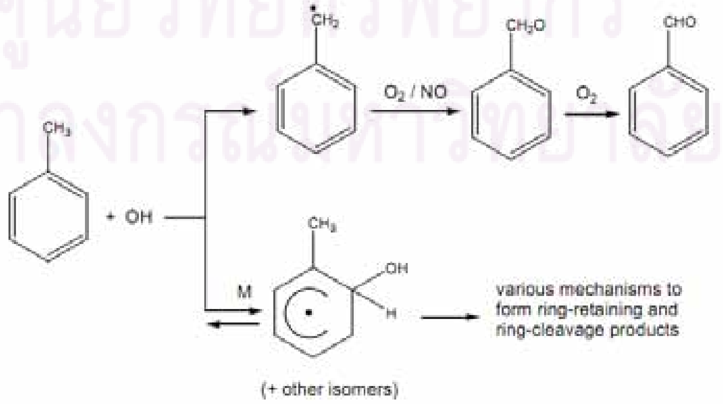


Figure 2.6 The oxidation of toluene in atmospheric air

Source: Barnes, 2011

The characteristics, properties, potential sources and health effect of BTEX can be summarized as the following:

1) Benzene

Benzene is a colorless liquid with a sweet odor. It evaporates into the air very quickly and dissolves slightly in water. It is highly flammable and is formed from both natural processes and human activities. Its chemical structure is shown in Figure 2.7 and some relevant chemical and physical properties are listed in Table 2.7. Some industries use benzene to make other chemicals which are used to make plastics, resins, rubbers, lubricants, dyes, detergents, drugs, and pesticides. Natural sources of benzene include emissions from volcanoes and forest fires. Benzene is also a natural part of crude oil, gasoline, and cigarette smoke.

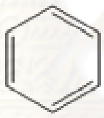


Figure 2.7 Chemical structure of benzene

Source: NIST/TRC Web Thermo Tables (WTT): Critically Evaluated Thermophysical Property Data, 2010

Breathing very high levels of benzene can result in death, while high levels can cause drowsiness, dizziness, rapid heart rate, headaches, tremors, confusion, and unconsciousness. Eating or drinking foods containing high levels of benzene can cause vomiting, irritation of the stomach, dizziness, sleepiness, convulsions, rapid heart rate, and death. The major effect of benzene from long-term exposure is on the blood. Benzene causes harmful effects on the bone marrow and can cause a decrease in red blood cells leading to anemia. Long-term exposure to high levels of benzene in the air can cause leukemia, particularly acute myelogenous leukemia, often referred to as AML. This is a cancer of the bloodforming organs. The Department of Health and Human Services (DHHS) has determined that benzene is a known carcinogen. The International Agency for Research on Cancer (IARC) and the EPA have determined that benzene is carcinogenic to humans (ATSDR, 2007; U.S. EPA, 2002).

Table 2.7 Physicochemical properties of benzene

Property	**Information**	**Reference**
Formula	C_6H_6	U.S. EPA, 2002
CAS registry no.	71-43-2	U.S. EPA, 2002
Molecular weight	78.11	U.S. EPA, 2002
Density	0.8787 g/cm^3 at 15 ^{o}C	ATSDR, 2007
Vapor density	2.8 (air= 1)	HSDB, 2006
Vapor pressure	94.8 mmHg at 25°C	HSDB, 2006
Log K_{ow}	2.13	U.S. EPA, 2002
Henry's law constant at 25°C	5.56 × 10^{-3} atm-m^3/mol	HSDB, 2006
Conversion factors in air (25^{o}C, 760 mm Hg)	1 ppm = 3.26 mg/m^3 (v/v) 1 mg/m^3 = 0.31 ppm (v/v)	ATSDR, 2007
Boiling point	80.1^{o}C	ATSDR, 2007
Melting point	5.5 ^{o}C	ATSDR, 2007
Solubility in water	1750 mg/mL at 25 ^{o}C	U.S. EPA, 2002

2) Toluene

Toluene is also known as toluol, phenylmethane, methylbenzol, methylbenzene, monomethyl benzene, and methacide. Some relevant physical and chemical properties of toluene are shown in Figure 2.8 and Table 2.8, respectively. Toluene is a clear, colorless liquid with a distinctive smell. Toluene occurs naturally in crude oil and in the tolu tree. Toluene is used as an additive in gasoline mixtures to increase octane ratings, in benzene production, and as a solvent in paints, coatings, inks, adhesives, and cleaners. Additionally, toluene is used in the production of nylon, plastics, and polyurethanes.

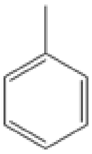


Figure 2.8 Chemical structure of toluene

Source: NIST/TRC Web Thermo Tables (WTT): Critically Evaluated Thermophysical Property Data, 2010

Table 2.8 Physicochemical properties of toluene

Property	**Information**	**Reference**
Formula	C_7H_8	U.S. EPA, 2005
CAS registry no.	108-88-3	U.S. EPA, 2005
Molecular weight	92.14	U.S. EPA, 2005
Density	0.8636 g/cm^3 at 20 ^oC	HSDB, 2006
Vapor density	3.2 (air=1)	ATSDR, 2000
Vapor pressure	28.4 mmHg at 25°C	U.S. EPA, 2005
Log K_{ow}	2.72	U.S. EPA, 2005
Henry’s law constant at 25°C	5.94× 10^{-3} atm-m^3/mol	ATSDR, 2000
Conversion factors in air (25^{o}C, 760 mm Hg)	1 ppm = 3.77 mg/m^3 (v/v) 1 mg/m^3 = 0.265 ppm (v/v)	U.S. EPA, 2005
Boiling point	110.6^{o}C	HSDB, 2006
Melting point	-94.9 ^{o}C	HSDB, 2006
Solubility in water	0.59 mg/mL at 25 ^{o}C	U.S. EPA, 2005

Toluene may affect the nervous system. Low to moderate levels can cause tiredness, confusion, weakness, drunkentype actions, memory loss, nausea, loss of appetite, and hearing and color vision loss. These symptoms usually disappear when exposure is stopped. Inhalation of high levels of toluene in a short time can make light-headed, dizzy, or sleepy. It can also cause unconsciousness, and even death. High levels of toluene may affect the kidneys (ATSDR, 2000; U.S. EPA, 2005).

3) Ethylbenzene

Ethylbenzene is known as ethylbenzol or phenylethane which is a colorless, flammable liquid that smells like gasoline. It is naturally found in coal tar and petroleum and is also found in manufactured products such as inks, pesticides, and paints. Ethylbenzene is used primarily to make another chemical, styrene. Other uses include as a solvent, in fuels, and to make other chemicals. Its chemical structure is shown in Figure 2.9 and some relevant chemical and physical properties are listed in Table 2.9.

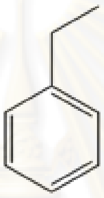


Figure 2.9 Chemical structure of ethylbenzene

Source: NIST/TRC Web Thermo Tables (WTT): Critically Evaluated Thermophysical Property Data, 2010

Table 2.9 Physicochemical properties of ethylbenzene

Property	**Information**	**Reference**
Formula	C_8H_{10}	ATSDR, 2007
CAS registry no.	100-41-4	ATSDR, 2007
Molecular weight	106.17	ATSDR, 2007
Density	0.867 g/cm^3 at 20 ^oC	ATSDR, 2007
Vapor density	3.66 (Air= 1)	HSDB, 2006
Vapor pressure	9.6 mmHg at 25°C	HSDB, 2006
Log K_{ow}	3.13	HSDB, 2006
Henry’s law constant at 25°C	7.88×10^{-3} atm-m^3/mol	HSDB, 2006
Conversion factors in air (25^{o}C, 760 mm Hg)	1 ppm = 4.35 mg/m^3 (v/v) 1 mg/m^3 = 0.23 ppm (v/v)	ATSDR, 2007
Boiling point	136.1 ^oC	HSDB, 2006
Melting point	-94.9 ^oC	HSDB, 2006
Solubility in water	177 mg/L at 25 ^oC	ATSDR, 2007

Exposure to high levels of ethylbenzene in air for short periods can cause eye and throat irritation. Exposure to higher levels can result in dizziness. Irreversible damage to the inner ear and hearing has been observed in animals exposed to relatively low concentrations of ethylbenzene for several days to weeks. Exposure to relatively low concentrations of ethylbenzene in air for several months to years causes kidney damage in animals. The International Agency for Research on Cancer (IARC) has determined that ethylbenzene is a possible human carcinogen (ATSDR, 2007).

4) Xylene

There are three forms of xylene in which the methyl groups vary on the benzene ring: meta-xylene, ortho-xylene, and para-xylene (m-, o-, and p-xylene). These different forms are referred to as isomers. Xylene is a colorless, sweet-smelling liquid that catches on fire easily. Some relevant physical and chemical properties of toluene are shown in Figure 2.10 and Table 2.10, respectively. It occurs naturally in petroleum and coal tar. Chemical industries produce xylene from petroleum. It is one of the top 30 chemicals produced in the United States in terms of volume. Xylene is used as a solvent and in the printing, rubber, and leather industries. It is also used as a cleaning agent, a thinner for paint, and in paints and varnishes. It is found in small amounts in airplane fuel and gasoline.

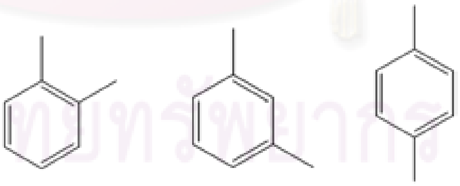


Figure 2.10 Chemical structure of xylene

Source: NIST/TRC Web Thermo Tables (WTT): Critically Evaluated Thermophysical Property Data, 2010

Table 2.10 Physicochemical properties of xylene

Property	Mixed xylene	m-Xylene	o-Xylene	p-Xylene
Formula	C_8H_{10}[a]			
CAS registry no.	1330-20-7[a]	108-38-3[a]	95-47-6[a]	106-42-3[a]
Molecular weight	106.16[b]			
Density	0.864 g/cm^3[b]	0.864 g/cm^3[b]	0.860 g/cm^3[b]	0.8611 g/cm^3[b]
Vapor density	No data			
Vapor pressure	6.72 mmHg at 21°C[b]	8.29 mmHg at 25 °C[b]	6.61 mmHg at 25 °C[b]	8.84 mm Hg at 25 °C[b]
Log K_{ow}	No data	3.2[b]	3.12[b]	3.15[b]
Henry's law constant at 25°C	No data	7.34×10^{-3} atm-m^3/mol[a]	5.19×10^{-3} atm-m^3/mol[a]	7.66×10^{-3} atm-m^3/mol[a]
Conversion factors in air (25°C, 760 mm Hg)	1 ppm = 4.34 mg/m^3 (v/v)[a] 1 mg/m^3 = 0.23 ppm (v/v)[a]			
Boiling point	137–140 °C[a]	139.1 °C[a]	144.5 °C[a]	138.4 °C[a]
Melting point	No data	-47.8 °C[a]	-25.2 °C[a]	13.2 °C[a]
Solubility in water (at 25 °C)	106 mg/L[a]	161 mg/L[a]	178 mg/L[a]	162 mg/L[a]

[a] U.S. EPA, 2003; [b] ATSDR,2007

High levels of exposure for short or long periods can cause headaches, lack of muscle coordination, dizziness, confusion, and changes in one's sense of balance. Exposure of people to high levels of xylene for short periods can also cause irritation of the skin, eyes, nose, and throat; difficulty in breathing; problems with the lungs; delayed reaction time; memory difficulties; stomach discomfort; and possibly changes in the liver and kidneys. It can cause unconsciousness and even death at very high levels (ATSDR, 2007; U.S. EPA, 2003).

2.4 Air quality standards related to carbonyl compounds and BTEX in workplaces

People in the workplace are extremely exposed amount and concentration of pollutants more than general population, depending on the chemicals being used, the process design and operation, the control to reduce the pollutants emission, and personal protection provided. Air monitoring in workplace often collects the sample at the breathing zone of the worker. Generally, passive samplers are used for gases and vapors or personal pump (with battery-powered) extraction samplers are used for gases and particles. These operate over periods of 1-8 hours. Analysis of the collected samples can provide accurate measure of individual exposure to specific pollutants in air.

Some agencies recommend the acceptable limits for occupational exposure to hazardous substances such as the National Institute for Occupational Safety and Health (NIOSH), the Occupational Safety & Health Administration (OSHA), the American Conference of Governmental Industrial Hygienists (ACGIH) and American Industrial Hygiene Association (AIHA). The exposure limits in the workplaces of these agencies can be described below (European Agency for Safety and Health at Work, 2011).

Recommended Exposure Levels (RELs) are identified by NIOSH which is the statutory responsibility for recommending exposure levels that are protective to workers. These limits have no legal force and were recommended via criteria documents to OSHA and other OEL setting institutions.

Permissible Exposure Limits (PELs) are published by OSHA of the U.S. Department of Labour (USDOL). PELs are regulatory limits on the amount or concentration of a substance in the air, and they are enforceable. The initial set of limits from 1971 was based on the ACGIH TLVs. An attempt to extend the number of TLV to other widely used chemicals was proposed by OSHA in 1989. Existing PELs are contained in a document called "29 CFR 1910.1000", the air contaminants standard.

Threshold Limit Values (TLVs) are guidelines prepared by ACGIH. The definition of TLVs is an exposure limit which is believed nearly all workers can be exposed day after day for a working lifetime without ill effect. TLVs reflect the level of exposure that the typical worker can experience without an unreasonable risk of disease or injury.

Threshold Limit Values (TLVs) are guidelines prepared by ACGIH to assist industrial hygienists in making decisions regarding safe levels of exposure to various hazards found in the workplace. A TLV reflects the level of exposure that the typical worker can experience without an unreasonable risk of disease or injury. TLVs are not quantitative estimates of risk at different exposure levels or by different routes of exposure.

Workplace Environmental Exposure Levels (WEELs) are defined by ALHA as the air concentrations of agents in a healthy worker's breathing zone. The WEELs was developed to guide on exposure levels for chemical and physical agents and stresses when no legal or authorative limits exist which are used to assess the potential for adverse health effects following healthy worker exposure to agents that may occur day after day for a working lifetime (AIHA, 2011).

These acceptable limits are established to protect safety and health of the workers from exposure to the substance in their workplace. Some agencies define the acceptable limits in the following and the acceptable limits for occupational exposure to the chemicals in this study are shown in Table 2.11.

In Thailand, the occupational exposure limits in the workplace were found in the declaration of Ministry of Interior (1972) for some compounds in this study. Some of these values were derived from the international agencies and used as a guideline in order to protect the workers’ health in the workplaces as shown in Table 2.12.

Table 2.11 Acceptable limits for occupational exposure to BTEX and carbonyl compounds

Compound	Agency	Exposure Limit	Concentration	
			ppm	µg/m^3
Benzene	NIOSH (REL)	TWA (8-hr)	0.1	320
		C (15-min)	1	3,200
	OSHA (PEL)	TWA (8-hr)	10	30,000
		AccepTable C (10-min)	25	75,000
		Maximun C (10-min)	50	150,000
	ACGIH (TLV)	TWA (8-hr)	10	30,000
		STEL (15-min)	25	75,000
Toluene	NIOSH (REL)	TWA (8-hr)	100	375,000
		C (10-min)	200	750,000
	OSHA (PEL)	TWA (8-hr)	200	750,000
		AccepTable C (10-min)	300	1,125,000
		Maximun C (10-min)	500	1,875,000
	ACGIH (TLV)	TWA (8-hr)	100	375,000
		STEL (15-min)	150	560,000
Ethylbenzene	NIOSH (REL)	TWA (8-hr)	100	435,000
		STEL (15-min)	125	545,000
	OSHA (PEL)	TWA (8-hr)	100	435,000
	ACGIH (TLV)	TWA (8-hr)	100	435,000
		STEL (15-min)	125	545,000
Xylenes	NIOSH (REL)	TWA (8-hr)	100	434,000
		C (10-min)	200	868,000
	OSHA (PEL)	TWA (8-hr)	100	435,000
	ACGIH (TLV)	TWA (8-hr)	100	435,000
		STEL (15-min)	150	655,000
Formaldehyde	NIOSH (REL)	TWA (8-hr)	0.016	20
		C (15-min)	0.1	130
	OSHA (PEL)	TWA (8-hr)	0.75	930
		STEL (15-min)	2	2,460
	ACGIH (TLV)	TWA (8-hr)	0.30	390
Acetaldehyde	NIOSH (REL)	none established	-	-
	OSHA (PEL)	TWA (8-hr)	200	360,000
	ACGIH (TLV)	C (15-min)	25	45,000
Acetone	NIOSH (REL)	TWA (10-hr)	250	590,000
	OSHA (PEL)	TWA (8-hr)	1,000	2,400,000
	ACGIH (TLV)	TWA (8-hr)	500	1,200,000
		STEL (15-min)	750	1,800,000
Propionaldehyde	ACGIH (TLV)	TWA (8-hr)	20	47,600
	AIHA (WEEL)	TWA (8-hr)	20	47,600
Crotonaldehyde	NIOSH (REL)	TWA (10-hr), supplementary exposure limit	2	6,000
	OSHA (PEL)	TWA (8-hr)	2	6,000
Benzaldehyde	AIHA (WEEL)	TWA (8-hr)	2	8,680
		STEL (15-min)	4	17,400
Valeraldehyde	NIOSH (REL)	TWA (10-hr), supplementary exposure limit	50	175,000
	ACGIH (TLV)	TWA (8-hr)	50	175,000

TWA=Time-weighted average; TLV=Threshold Limit Value; STEL=Short-term Exposure Limit; C=Ceiling limit; PEL=Personal Exposure Limit; REL=Recommended Exposure Limit; and WEEL=Workplace Environmental Exposure Level

Table 2.12 Occupational exposure limit of BTEX and carbonyl compounds in Thailand

Compound	Exposure Limit	Concentration	
		ppm	$\mu g/m^3$
Benzene	TWA (8-hr) STEL (10-min) AccepTable C (10-min)	10 50 25	30,000 75,000 150,000
Toluene	TWA (8-hr) STEL (10-min) AccepTable C (10-min)	200 500 300	750,000 1,875,000 1,125,000
Xylenes	TWA (8-hr)	100	435,000
Formaldehyde	TWA (8-hr) STEL (30-min) AccepTable C (10-min)	3 10 5	1,300 13,000 6,500

2.5 Human health risk assessment

EPA's Integrated Risk Information System (IRIS) is a human health assessment program that evaluates risk information on effects that may result from exposure to environmental contaminants. IRIS is prepared and maintained by the EPA’s National Center for Environmental Assessment (NCEA) within the Office of Research and Development (ORD). The IRIS database provides information on human health effects for at least 540 chemical substances that may result from exposure to various substances in the environment. According to EPA’s human risk assessment (2010), a human health risk assessment is the process to estimate the nature and probability of adverse health effects in humans who may be exposed to chemicals in contaminated environmental media, now or in the future. The process of risk assessment consists of four steps (See Figure 2.11):

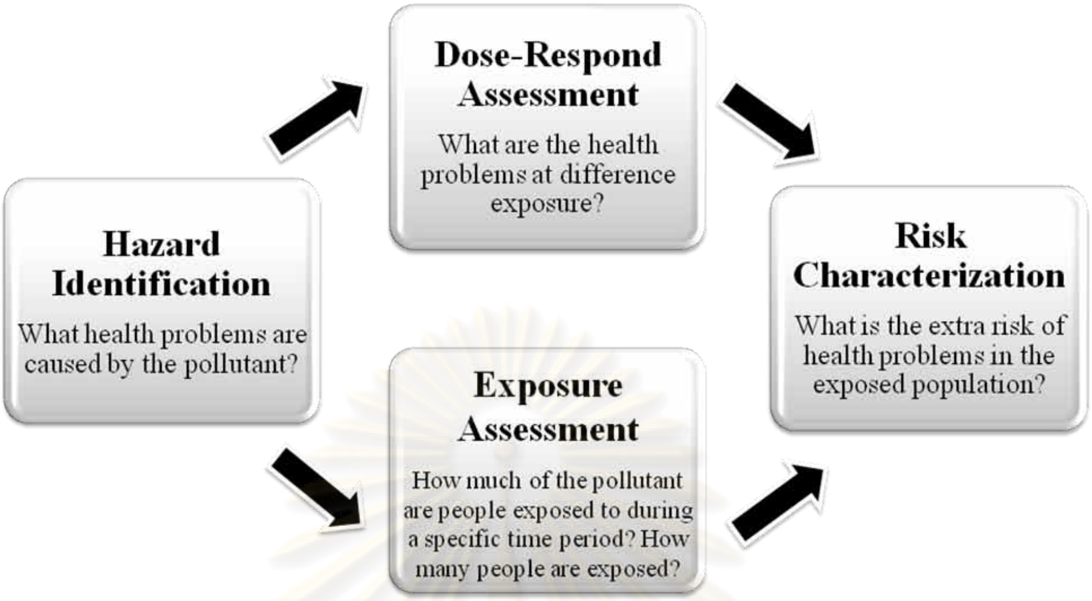


Figure 2.11 Four steps of risk assessment

2.5.1 Hazard identification

Hazard Identification is the first step of identification and quantification of risk. This step aims to identify potentially harmful substances which may be exposed by human, regardless of the level exposure. The clinical and epidemiological evidence is found for the trust. Most of toxic substances cannot be evaluated from the human studies that the limited data in humans will be tested by animal such as mice, rabbits, and monkeys. The approaches to predict the toxicity in humans have been developed, but the different between the species and the complex mechanism in the body are limited of the approaches. The key of this step is supported by the studies and described by toxicokinetics and toxicodynamics of the chemicals.

2.5.2 Dose-response assessment

The second step is dose-response assessment which characterizes the relationship between the dose of the interested chemical and any adverse health effect. Some factors are considered in this step which influences dose-response relationships such as age, gender, diet, lifestyle, histories of smoking, and other variables that could directly affect to susceptible groups. To assess the risk of such substances, it needs an appropriate dose-response model for human safe with uncertainty factor to extrapolate the responses from high dose to low dose, and from animal to human.

2.5.3 Exposure assessment

The third step, exposure assessment that is the determination of the intensity, frequency, and duration of actual or hypothetical exposure of humans to the substances. Nonvalidated exposure models or the monitoring of the regulated exposure media such as air, water, soil, and food is used to assess the exposure. Recently, the development of biomarker is analyzed to present the actual exposure.

2.5.4 Risk characterization

In the forth step, risk characterization, the information generated in the first three steps is integrated to estimate the number of persons who may be affected and the severities of their effect. The information derives from the preceding steps which are limited by uncertainty, assumptions, and scientific judgments. Risk characterization is a tool which synthesizes an overall conclusion about risk using for decision makers.

2.6 Related research articles

Periago *et al*. (1997) evaluated the levels of benzene, toluene and xylenes in gasoline service station by personal exposure sampling. The personal diffusive samplers were used to collect the compounds from the breathing zones of the workers (n=21) in morning and afternoon for two periods at quite different temperature (March and July). The significant relationship between the volume of gasoline sold during the shift and the ambient concentration of BTX was found in this study. They also found the effect of climate conditions of countries with high temperature can increase the risk of exposure to these compounds.

Bono *et al*. (2003), the occupational exposure of three employees (petrol pump attendants, traffic policemen and municipal employees) were determined for benzene, toluene and xylenes in Biella and Torino, Italy. A good correlation between ambient and personal exposure were found in this study (r = 0.97089). The petrol pump attendants' exposures of BTX were higher than the other employees in both winter and summer samplings. The higher concentration of BTX was found in winter (October - March) at all sampling site. The season and type of weekday were found as the factors in ambient air contaminant levels.

Corrêa *et al*. (2003) measured the atmospheric levels of formaldehyde and acetaldehyde at vehicular fleet in the city of Rio de Janeiro, Brazil, were in range of 1.52 to 54.31 ppb (1.87 to 66.70 µg/m^3) and 2.36 to 45.60 ppb (4.25 to 82.17 µg/m^3) , respectively. The evidence of high concentrations of formaldehyde and acetaldehyde in Brazil could be suggested that they came from alcohol-based fuel for vehicles which resulted in increase of ozone formation.

Lin, Chiang, and Lu (2005) determined the air quality impact of MTBE, measurements were made of ambient MTBE, benzene and toluene at a service station in Taiwan. The ambient concentrations of benzene and toluene were in range of 10.2 – 52 ppb and 44.8 – 270.2 ppb, respectively. In addition, environmental conditions (wind speed, wind direction, and temperature, etc.) were the factors that could affect the distribution of VOCs, but the effect of temperature was not found in this study. The VOCs concentrations at the service stations may be influenced by refueling throughput.

Periago and Prado (2005) aimed to evaluate the occupational exposure of service station attendants to BTX compounds in 2000 and 2003. The volume of gasoline sold in refuelling operations and the ambient temperature can significantly increase the environmental level of benzene, toluene and xylene (BTX) vapours and the occupational risk of service station attendants. The mean time-weighted average concentrations of benzene for 8 h was 736 mg/m^3 (range 272–1603) in 1995, 241 mg/m^3 (range 115–453) in 2000 and 163 mg/m^3 (range 36–564) in 2003. The season and the volume of gasoline sold were identified as the factors in different concentrations of BTX.

Byeon *et al*. (2008) studied fine particulate ($PM_{2.5}$), heavy metals and aldehydes concentrations in an auto-mobile repair shop and a gas station in Ulsan, an industrial city of Korea. The researchers used a 2,4-DNPH cartridge tube attached with an ozone scrubber and personal air sampling pump with an average flow rate of 0.5 L/min to collect samples of aldehydes over 8 hours in four seasons of a year. The samples were taken in no rain days from April 2007 to January 2008. The result was found the average exposure to aldehydes concentrations of the autorepair shop mechanic and the gas station worker to total aldehyde during the summer period were much higher than those during other seasons. The conclusion was the average exposure concentrations of the workers in the gas station and autorepair shop during the summer period were 751 and 1,255 ppb (992 and 1541 µg/m^3) which significantly exceeded the WHO’s ambient or indoor standard of formaldehyde (100 µg/m^3).

Huang *et al*. (2008) measured the atmospheric levels of carbonyl compounds in Shanghai, China during January 2007 to October 2007. A number of 114 samples were collected and eighteen carbonyls were identified. The concentrations of formaldehyde and acetaldehyde in Shanghai were higher than Beijing and Guangzhou which were 19.40 ± 12.00 and 15.92 ± 12.07 µg/ m^3, respectively. The conclusion was primary emissions including vehicle exhaust and industrial emissions were important local sources of carbonyls.

Majumdar *et al*. (2008) measured concentrations of mono-aromatic hydrocarbon and carbonyl compounds such as benzene, toluene and formaldehyde at gas stations in Kolkata, India. The means of occupational exposure to formaldehyde and acetaldehyde were 27.8 µg/m^3 (in range of 11.6 to 55.5 µg/m^3) and 18.3 µg/m^3, respectively. The study found that the mean personal exposure concentrations of benzene, toluene, ethylbenzene, m,p-xylene and o-xylene were 137.5, 643.6 , 118.0 , 209.7 and 68.2 µg/m^3 , respectively. The correlation among the aldehydes in all the pumps was generally fair; 0.69 between formaldehyde and acetaldehyde, 0.69 between formaldehyde and propanal, and 0.90 between acetaldehyde and acetone suggesting a common source. In addition, the individual lifetime cancer risks (40 years of occupational exposure) of carcinogenic compounds were assessed. The cancer risk resulted 9.66E-5 for benzene, 1.18E-5 for ethylbenzene, 3.52E-5 for formaldehyde, and 4.03E-6 for acetaldehyde which indicated the workers had the probability of cancer For individual hazard quotients were lower than 1 which indicated the levels of these chemicals for chronic health effects were accepTable.

Morknoy (2008) focused on airborne carbonyl compounds in Bangkok associated with gasohol. Active cartridge sampler containing 2,4 DNPH was used in this study to collect ambient air samples at 10 sites in Bangkok during 2007 to 2008. The results of the study indicated that 10 carbonyl compounds including formaldehyde, acetaldehyde, acetone, butyraldehyde, propionaldehyde, crotonaldehyde, benzaldehyde, isovaleraldehyde, valeraldehyde, and hexanaldehyde that were found both at the roadside and residential areas in Bangkok. Formaldehyde concentration in the roadside areas ranged from 5.14 to 17.2 µg/m^3 (average 11.53 µg/m^3) while, in the residential areas ranged from 3.06 to 19.9 µg/m^3 (average 9.65 µg/m^3). The concentration of acetaldehyde in roadside areas ranged from 1.59 to 7.95 µg/m^3 (average 3.51 µg/m^3) while at the residential areas ranged from 1.07 to 8.05 µg/m^3 (average 3.11 µg/m^3). Other carbonyl compounds were found low concentration. In conclusions, the concentration of carbonyl compounds in Bangkok increased significantly due to rapid increase in gasohol consumption. It was also found that the concentration level of carbonyl compounds at the roadside and residential areas in Bangkok were high due to the high density of vehicles especially gasohol fuelled cars and motorcycles, which are the major sources of carbonyl compounds.

Thaveevongs (2008) studied the exposure to VOCs of the gas stations worker in 11 gas stations in Bangkok. Passive charcoal gas tube was used in this study to collect VOCs which occurred in the gas station for 8 work hours. Ten compounds of thirty-nine VOCs, such as methyl-tertiary-butyl-ether (MTBE), benzene, isooctane, n-heptane, toluene, ethylbenzene, m,p-xylene, o-xylene, stylene, 3-ethylbenzene and decanal were mainly observed in 11 gas stations with the ranges of 638 - 1628, 308 - 852, 20 - 49, 140 - 401, 270 - 682, 10 - 27 , 22 - 58 , 11 - 20 , 13 - 26 and 1.8 – 9.8 µg/m^3, respectively. The gas station workers were assessed health risk of cancer to these compounds that found only MTBE and benzene were in the range of 2.41×10^{-5} - 1.18×10^{-4} and 3.42×10^{-4} - 1.23×10^{-3}, respectively. The conclusion was the gas station workers may be at risk of MTBE and benzene and no increase risk from ethylbenzene exposure. Also, there were no increase the adverse health effect from toluene and xylene exposure in case of non-cancer.

Dutta *et al*. (2009) measured 15 carbonyls and BTEX in ambient air of Kolkata, India at three sites for 24 hours from March to June 2006, and also evaluated the photochemical reactivity of these compounds. The results presented formaldehyde was the most abundant carbonyl (mean concentration ranging between 14.07 µg/m³ to 26.12 µg/m³ over the three sites) followed by acetaldehyde (7.60–18.67 µg/m³) and acetone (4.43–10.34 µg/m³). Among the mono-aromatic VOCs, mean concentration of toluene (27.65–103.31 µg/m³) was maximum, closely followed by benzene (24.97–79.18 µg/m³). An assessment was done for both cancer risk and non-cancer hazard. Integrated life time cancer risk (ILTCR) of benzene, ethyl benzene, formaldehyde and acetaldehyde were estimated to be 1.42×10^{-4} and non-cancer hazard index for the VOCs was 5.6. The conclusion was found that the general population had the probability of cancer as well as the chronic health effects due to the level of BTEX in Kolkata was also very high compared to other cities. Using of gasoline which contained relatively higher concentrations of aromatics mainly leaded to increase the higher concentration of carbonyl compounds and BTEX that these compounds reacted to OH radical and produced primary and secondary pollutants by photochemical reaction.

CHAPTER III
RESEARCH METHODOLOGY

3.1 Study area

Bangkok Metropolitan was chosen for this study due to this city is an urban area where the number of vehicles and gas stations, also fuels consumption for transportation are much higher than the other cities in Thailand. Bangkok covers large area, 1568.74 km^2, and consists of 50 districts that have its specific environment. Two sampling campaigns considering on area-based were then assigned for this study. First sampling campaign was performed at six gas stations located in Pathumwan district, representing an inner-urban environment during May – June 2010 (see Figure 3.1). Details of the sampling sites are given in Table 3.1, and the location of each point is shown in Figure 3.2. This sampling was focused on workers exposure to the target substances in different stations of fuel manufacturers.

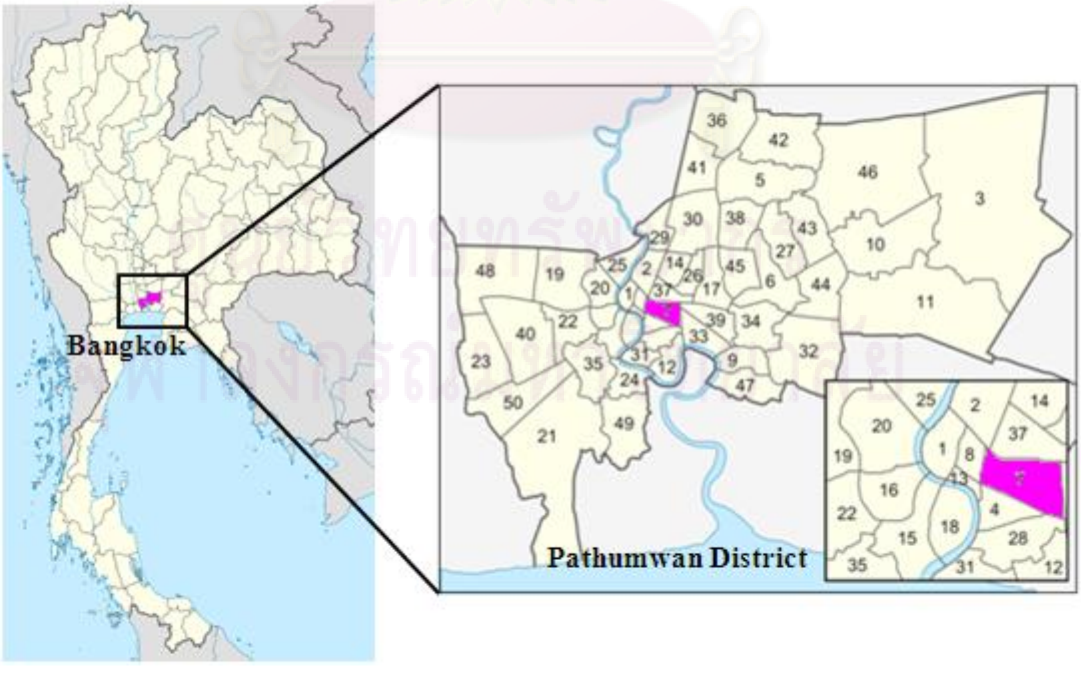


Figure 3.1 Map of Pathumwan district in Bangkok, Thailand

Table 3.1 Details of the gas stations for the first sampling

Station	Fuel circulation[*] (L/month)	Area description
TRO	416,785	Small size; closed to Rama IV Rd. (8 lanes road) near express way entrance
PCC	207,426	Small size; closed to Charumuang Rd. (4 lanes road) under express way; little air movement
NW	303,903	Extra small size; closed to Rongmuang Rd. (2 lanes road) behind Hua Lamphong Main Railway Station
TP	826,000	Medium size; closed to Rama IV Rd. (8 lanes road) and near Lumphini's community
BK	305,790	Small size; closed to Banthad Thong Rd. (4 lanes road)
SBS	171,347	Small size; closed to Phetcha Buri Rd. (8 lanes road); near workers dormitory

[*] The data of April 2010

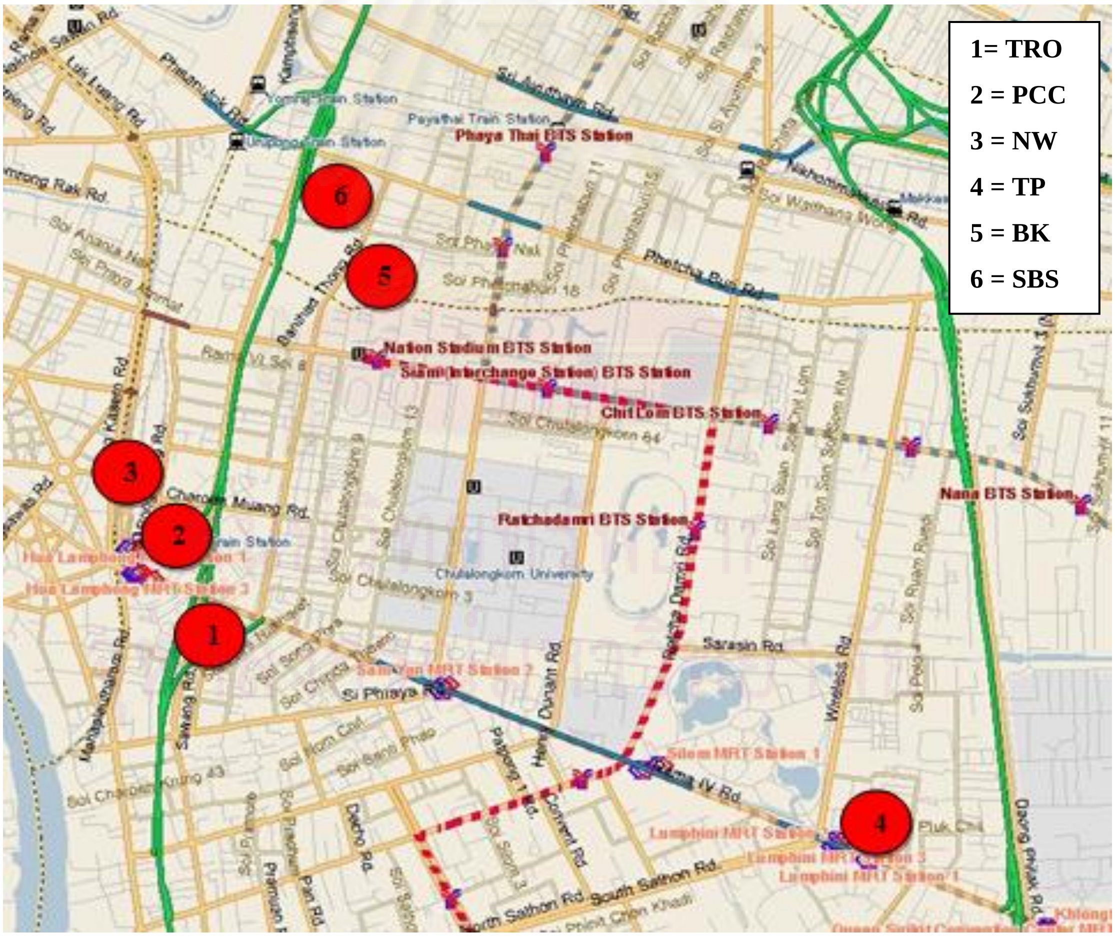


Figure 3.2 The location of gas stations in the first sampling

For the second campaign, the sampling was carried out in different districts of Bangkok in November 2010 and studied at the same fuel products stations in order to control specificity of the product. From the previous study of Thaveevongs (2008), a good correlation between fuels circulation (L/day) and the total VOCs at ten gas stations located in seven districts covering the Bangkok area could be obtained, $R^2 = 0.827$ (Thaveevongs et al., 2010). The same six gas stations as the previous study where located in the five districts of Bangkok were selected for this study as follows:

Gas station 1: Bang Khun Thian Branch (BT)
Gas station 2: Express Way (Dao Kanong) Branch (DKN)
Gas station 3: Don Muang International Airport 2 Branch (J)
Gas station 4: The First Infantry Regiment, The King's Bodyguard Branch (RO)
Gas station 5: Sukhaphibal 3 Branch (TL)
Gas station 6: Thanit Petroleum Ltd. (TP) (The same as in the first sampling)

Actually, the gas station at Nimit Mai was proposed to be one of the sites for this study, but this station was being reconstructed. TP gas station was then selected to sampling instead. TP gas station is the same manufacture as the other gas stations in the second sampling. In addition, the effects of seasonal variation at the same gas station, TP, would be studied in summer and winter. Each sampling site detail is shown in Table 3.2. These six gas stations are considerable to represent different ranges of fuel circulation, i.e. high, medium, and low, resulting in different exposure levels for the workers. All sampling sites location is illustrated in Figure 3.3.

Table 3.2 Details of the gas stations for the second sampling

Station	Fuel Circulation* (L/month)	Fuel Circulation** (L/month)	Area description
BT	510,714	614,583	Small size; located on boundary of Bangkok in Bang Khun Thian district; closed to 6 lanes road
DKN	1,048,351	1,039,416	Medium size; located in Bang Khun Thian district, closed to express way entrance and 6 lanes road
J	1,331,373	1,133,068	Small size; located in Don Mueang district, closed to 4 lanes road, national airport and department store; near car park
RO	1,665,730	1,636,624	Large size; located in Phayathai district, closed to main street (10 lanes road)
TL	1,026,557	783,435	Large size; located on boundary of Bangkok in Saphan Sung district; closed to 6 lanes road
TP	-	900,000	Medium size; located in Pathumwan district, closed to main street (10 lanes road)

*The data were derived from Thaveevongs (2008). ** The data of October 2010

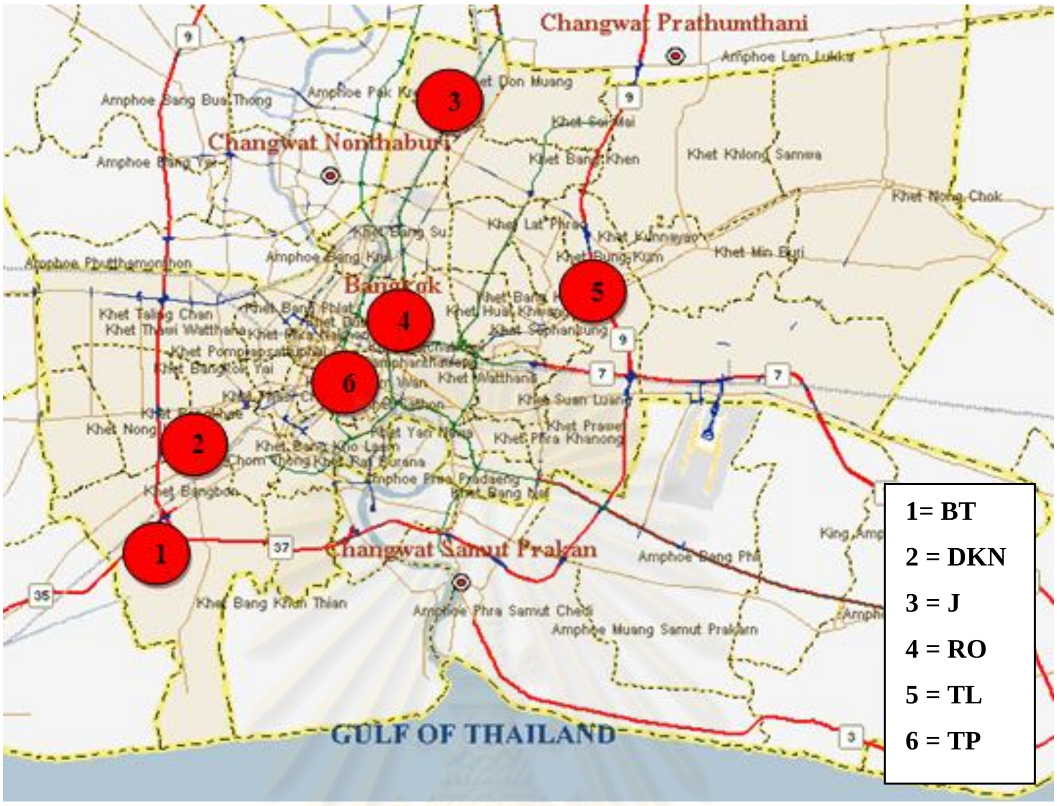


Figure 3.3 The location of gas stations in the second sampling

3.2 Analysis instruments

3.2.1 High Performance Liquid Chromatography (HPLC)

In this study, a High Performance Liquid Chromatography with UV-VIS detector, model Shimadzu SPD 20A, and the integrator of Shimadzu CBM 20A, at Environmental Research and Training Centre (ERTC) was used for qualitatively and quantitatively analysis of carbonyl compounds. Both acetonitrile (HPLC grade) and water (HPLC grade) manufactured by Fisher Company, Canada, were used as the mobile phases and pumped into the system by Shimadzu LC pumps AB20. Before using, these mobile phases were prepared and filtered with nylon filters (Advantec, USA), 0.22 µm pore size. The temperature in the oven was set at 40 ^{o}C during analysis. A column RP Amide Discovery C16 250 cm x 4.6 mm i.d. with 0.5 µm packing from SUPELCO Company, USA, was used to separate carbonyl compounds. The schematic diagram of the HPLC system is shown in Figure 3.4. The samples will be pumped into the system with a linear gradient program. The standard solution of T011/IP-6A Aldehyde/Ketone-DNPH Mix (Supelco, USA) containing 15 carbonyl compounds i.e. formaldehyde, acetaldehyde, acetone, acrolein, propionaldehyde, crotonaldehyde, butyraldehyde, benzaldehyde, isovaleraldehyde, valeraldehyde, o-tolualdehyde, m,p-tolualdehyde, hexanaldehyde and 2,5-dimethylbenzaldehyde was already analyzed. The optimum condition for analysis of carbonyl compounds, following the study of Morknoy (2008), is given in Table 3.3.

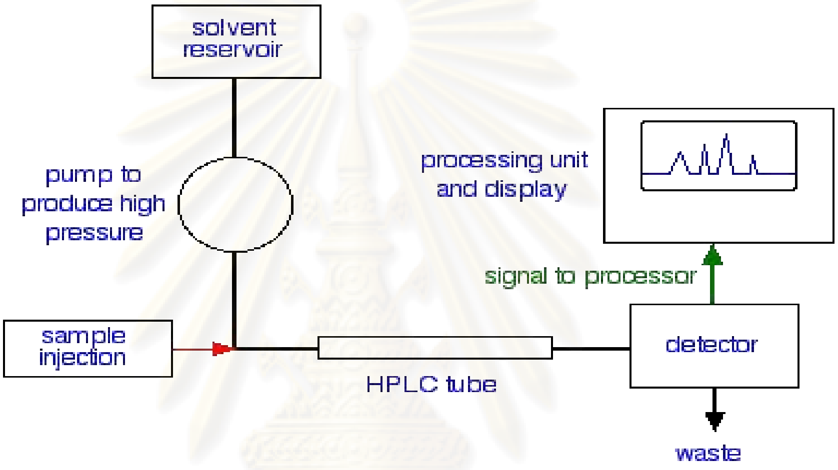


Figure 3.4 Schematic diagram of HPLC

Table 3.3 The condition for analysis of carbonyl compounds (Morknoy, 2008)

Main Column	RP Amide Discovery C16 250 cm x 4.6 mm i.d. with 0.5 µm packing
Pre- Column	RP Amide C16 2 cm x 4.0 mm i.d. with 0.5 µm packing
Mobile Phase	A: Water HPLC grade (45%) B: Acetonitrile HPLC grade (55%)
Column Temperature	40ºC
Flow rate	1.0 ml/min
Detector	UV detector
Wavelength	360 nm
Injection volume	25 µL
Gradient Program	Time (min)
Acetonitrile : 55%	20
Acetonitrile 65%	5
Acetonitrile 55%	5

3.2.2 Gas Chromatography (GC)

For analysis of benzene, toluene, ethylbenzene, m,p-xylene and o-xylene (or BTEX), Gas Chromatography, model HP 6890N, connected with Flame Ionization Detector (GC/FID) at Petrochemical Building 11th floor, Chulalongkorn University, will be used. The schematic diagram of the GC system is shown in Figure 3.5.

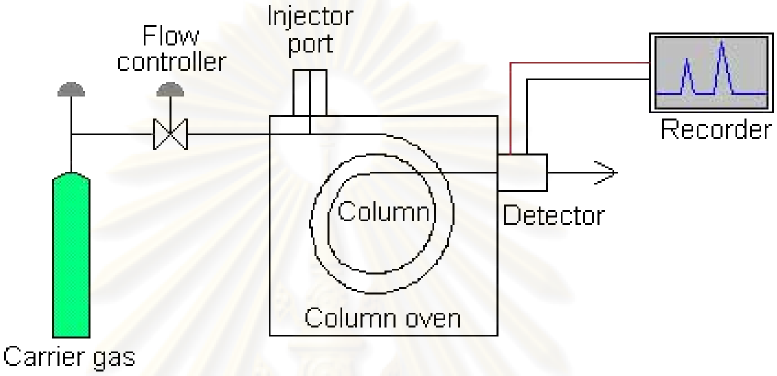


Figure 3.5 Schematic diagram of GC

Table 3.4 The condition for analysis of BTEX

Capillary Column	HP-5 size 30 m × 0.32 mm × 0.25 µm (19091J-413)			
Carrier Gas	Nitrogen (N_2) Helium (He) Hydrogen (H_2) Air zero			
Flow rate of He	1.5 ml/min			
Type of Injection	Spiltless			
Injection volume	1 µL			
Injector Temperature	300 ^oC			
Detector	Flame Ionization Detector (FID)			
Detector Temperature	300 ^oC			
Oven Ramp	^oC/min	Next ^oC	Hold (min)	Run Time (min)
Initial		35	0.00	0.00
Ramp 1	5.00	120	0.00	17.00
Ramp 2	20.00	230	5.00	27.50

The capillary column, HP-5 size 30 m × 0.32 mm × 0.25 µm (19091J-413) produced by Agilent, will be used for separating BTEX. Carrier gases are Nitrogen (N_2), Helium (He), Hydrogen (H_2) and Air zero. The initial oven temperature was set at 35^oC, temperature was programmed to increase thereafter from

35^oC to 120^oC at 5^oC/min as the ramp 1, and then continually increase from 120^oC to 230^oC at 20^oC/min as the ramp 2, with temperature hold for 5 min at 230^oC, FID temperature 300^oC. To find an optimum condition, standard solution of BTEX (Cerilliant, USA) was analyzed. The optimum condition could be obtained as, shown in Table 3.4.

3.3 Preliminary experiments

3.3.1 Standard curves

The calibration curves were made by using mixed standard solution of 15 carbonyl compounds, which consists of formaldehyde, acetaldehyde, acetone, acrolein, propionaldehyde, crotonaldehyde, butyraldehyde, benzaldehyde, isovaleraldehyde, valeraldehyde, o-tolualdehyde, m,p-tolualdehyde, hexanaldehyde and 2,5-dimethylbenzaldehyde. Five difference concentrations, i.e. 0.010, 0.050, 0.100, 0.600 and 1.000 µg/ml (1 µg/ml = 1 ppm), were prepared. The reliability of the carbonyl compounds calibration curve is needed to clarify; $R^2 \geq 0.999$ for all compounds, and the %RSD for each compound should be within 10%.

For the calibration curves of BTEX, the mixed standard of benzene, toluene, ethylbenzene, m,p-xylene, and o-xylene were prepared at seven concentrations of 125, 250, 500, 1,000, 2,000, 4,000 and 8,000 ng/ml (1,000 ng/ml = 1 ppm). In each standard BTEX concentration, Toluene-d8 (Supelco, USA) with the concentration 8,115 ng/ml was added as an internal standard. Likewise the calibration curve of carbonyl compounds, the reliability of BTEX calibration curve should have $R^2 \geq 0.99$, and the %RSD for each compound should be within 10%.

3.3.2 Limits of instruments

The instrument detection limit (IDL) and instrument quantification limit (IQL) were determined for HPLC-UV. The mix standard carbonyl compounds at the lowest concentration calibration standards (0.05 mg/l) were prepared and injected into the instrument for 7 times. The average value, standard deviation (SD), and %RSD were calculated. The IDL and IQL were calculated by multiplication of standard deviation (see equation 3.1 and 3.2).

$$\text{IDL} = 3\text{SD} \qquad \text{(Eq. 3.1)}$$

$$\text{IQL} = 10\text{SD} \qquad \text{(Eq. 3.2)}$$

The Limit of Detection (LOD) and Limit of Quantification (LOQ) for GC/FID were examined by the measurable lowest concentration of the mix standard BTEX. The signal compared with noise was mostly found as a signal to noise ratio of 3:1 for LOD and 10:1 for LOQ. The concentration of sample lower than LOQ was reported as not detected (ND). The calculation for determining the LOD and LOQ are shown in equation 3.3 and 3.4.

$$\text{LOD} = \frac{3 \times \text{the lowest concentration used} \times \delta}{\bar{x}} \qquad \text{(Eq.3.3)}$$

$$\text{LOQ} = \frac{10 \times \text{the lowest concentration used} \times \delta}{\bar{x}} \qquad \text{(Eq.3.4)}$$

$$\delta = \sqrt{\sum_{i=1}^{n} (x_i - \bar{x})^2 / (n - 1)}$$

where;

δ = Standard deviation

x_i = Peak area of target compound observed

$\bar{x}$ = Average peak area of these observations

n = Number of observations

3.3.3 Recovery test

Recovery test is used to evaluate the capacity of a certain collection medium to collect and retain the analyte collected. The recovery test of carbonyl compounds using 2,4-dinitrophenyl hydrazine cartridge had been performed in the previous study (Morknoy, 2008). It was performed by injecting 100 µL of 0.5 ppm mix standard solution of carbonyl compounds into active 2, 4-dinitrophenyl hydrazine cartridges produced from Wako and then extracted the same procedure as the samples. The result of recovery test of 15 carbonyl compounds were found in range of 69 – 103% as shown in Table 3.5.

For the recovery test of BTEX mentioned in the study of Thaveevong (2008), the mix standard of Japanese 50 component indoor air at the concentration 1,000 ng/ml was injected into active activated charcoal glass tubes produced by Sibata. The result of the recovery test of BTEX was found in range of 86.4 – 120.4% as shown in Table 3.6.

Table 3.5 The result of % recovery of Carbonyl compounds (Morknoy, 2008)

Compounds	% Recovery
Formaldehyde	101
Acetaldehyde	80
Acetone	103
Acrolein	84
Propionaldehyde	85
Crotonaldehyde	69
Butyraldehyde	72
Benzaldehyde	89
Isovaleraldehyde	90
Valeraldehyde	73
o-Tolualdehyde	84
m,p-Tolualdehyde	84
Hexaldehyde	78
2,5-Dimethylbenzaldehyde	83

Table 3.6 The result of % recovery of BTEX (Thaveevong, 2008)

Compounds	% Recovery
Benzene	120.4
Toluene	96.0
Ethybenzene	92.4
m,p-Xylene	89.5
o-Xylene	86.4

3.3.4 Air sampling train design

Generally, most atmospheric sampling techniques make use of a sampling train that can be seen in Figure 3.6. Air containing the interested pollutant enters the sampling train and passes through a sample collection device that controls the rate and duration of sampling. This collection device either physically or chemically removes the pollutant from the air stream for later analysis. Air sampling is becoming more important in recent years due to research that demonstrates the health effects associated with even small quantities of pollutants in the air, promulgation of air toxic regulations by state air pollution agencies, and improvements in analytical techniques which increased smaller quantities of pollutants to be detected at a reasonable cost (U.S. EPA, 1983).

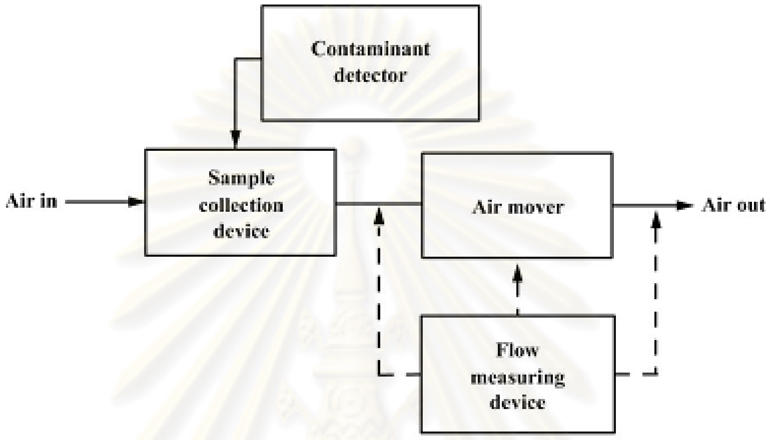


Figure 3.6 Schematic diagram of typical sampling train (U.S. EPA, 1983)

Due to two main groups of target compounds, carbonyl compounds and BTEX, would be investigated, two different sample collecting devices were needed. Following the Method TO -11A for the Determination of Formaldehyde in Ambient Air Using Adsorbent Cartridge Followed by High Performance Liquid Chromatography (HPLC) (Active Sampling Methodology), 2,4-Dinitrophenylhydrazine (2,4-DNPH) active cartridge (Wako Pure. Chemicals, Japan) (See Figure 3.7) was used for collecting carbonyl compounds. Carbonyl compounds are removed from the air stream and react with the acidified 2,4 Dinitrophenylhydrazine (2,4-DNPH) containing in the cartridge as a collection device to form the corresponding hydrazones derivative according to the reaction shown in Figure 3.8.

Figure 3.7 2,4 Dinitrophenylhydrazine active cartridge

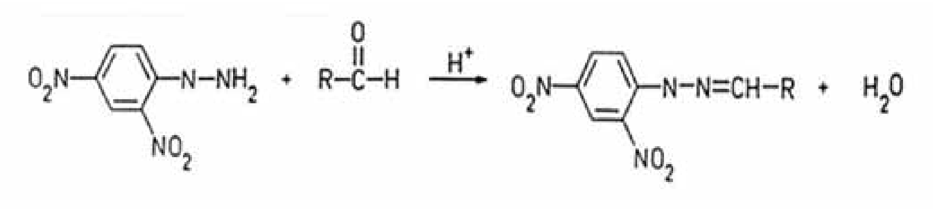
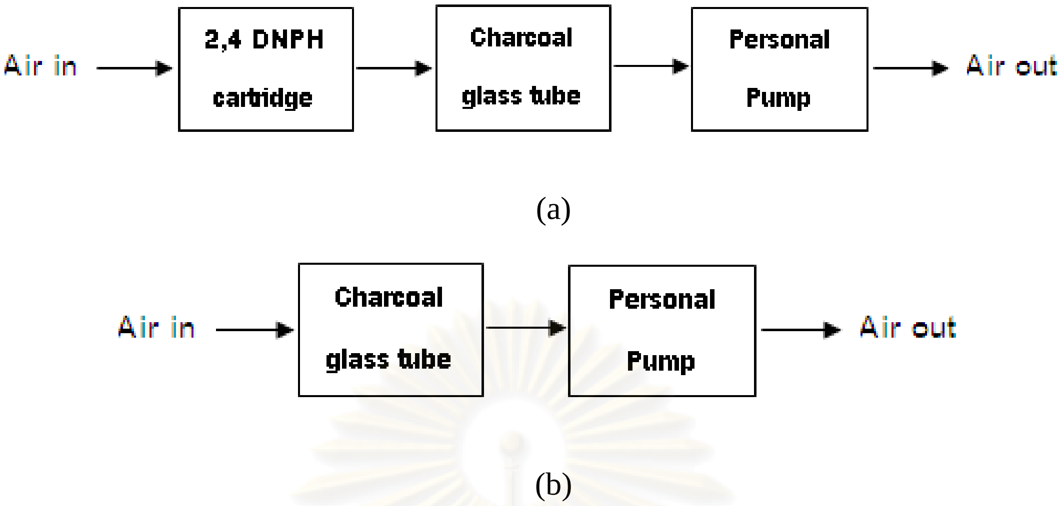


Figure 3.8 Reaction of aldehydes with DNPH

For collecting BTEX, these pollutants are removed from the air stream and physically adsorbed into activated charcoal. The activated charcoal with the size of 20-40 mesh is contained in glass tube, or called a charcoal glass tube (see Figure 3.9). The charcoal tube is divided into two sorbent parts; the upper part contains 400 mg of activated charcoals, and the lower contains 200 mg.

Figure 3.9 Charcoal tube

In order to get all target substances from the same air stream, both 2, 4 DNPH active cartridge and a charcoal glass tube connected to a personal air pump (Sibata mini pump MP E30, Japan) as a sampling train, was set up. However, to know whether 2, 4 DNPH active cartridge would affect an adsorption of BTEX on activated charcoal in the tube, two sample collecting systems were then be designed to compare, (a) 2, 4 DNPH active cartridge and a charcoal glass tube connected to a personal air pump and (b) only a charcoal glass tube connected to a personal air pump, as shown in Figure 3.10. Two sets of this experiment were studied at different locations, gas station and parking area in the department store. The result of BTEX comparing between two sampling systems had been examined as given in chapter 4. The concentrations of BTEX determined by collecting with different sampling train systems were almost the same. Consequently, sampling train consists of both 2, 4 DNPH active cartridge and a charcoal glass tube could be properly used for the actual sampling as seen in the Figure 3.11.



(a)

(b)

Figure 3.10 Schematic diagrams of two different sample collecting systems

Figure 3.11 The sampling train for the actual sampling

3.4 Study on ambient air concentration and personal exposure of carbonyl compounds and BTEX

3.4.1 Ambient air sampling and personal exposure

Active sampling using the sampling train of 2,4 DNPH cartridge and charcoal glass tube connected to low flow personal air pump was performed during 8-hr working period of the workers and installed in the center of the gas station, at 1.5 m height above the ground. The air was drawn through the sampling train at the flow rate of 100 ml/min. The sampling was started at the work shift for 8 hours in the morning (6.00 AM – 2.00 PM). After finishing each sampling, cartridge and charcoal tube would be kept at cold condition and transferred to refrigerator (<-4 ^{o}C) at the laboratory. The cartridge was extracted immediately. The flow rate of all pumps was calibrated using Primary Standard Airflow Calibrator (SIS Inc., USA) before and after each sampling.

Likewise ambient air sampling, the sampling train of 2, 4 DNPH cartridge and charcoal glass tube was used and clipped to the personal breathing zone of the worker. Two workers who are non-smoking at each gas station were asked to collect their inhalation exposure to carbonyl compounds and BTEX in order to avoid other possible sources of exposure to such compounds. Personal sampling was held during the same period as ambient air sampling.

The selected gas station workers were asked to interview as well. The questionnaires were designed to collect their general information and some factors which would be utilized for calculating their exposure to carbonyl compounds and BTEX. The information about gender, body weight, age, activities data and health situation were included in the questionnaire (Appendix A). In addition, some factors such as area, fuel circulation and numbers of fuel nozzles were noted for data analysis.

3.4.2 Installation of metrological monitoring instrument

The metrological monitoring instrument in this study is known as Met-One, produce by Met One Instruments, Inc., as seen in Figure 3.12. The installation was done in the second sampling in November 2010. The instrument can measure some of atmospheric variables such as barometric pressure (BP), relative humidity (RH), solar radiation (SR), temperature (Temp), wind direction (WD) and wind speed (WS), and these data can be displayed by using a complete package of Met One Instruments Micro Met Plus Software for Windows. These variables were used to find the relationship between affecting factors of atmospheric condition and the ambient concentrations of pollutants in gas stations. Met-One was installed in 3 gas stations in the second sampling i.e. BT, RO and TL.

Figure 3.12 Metrological monitoring instrument, Met-One

3.4.3 Sample preparation

3.4.3.1 Carbonyl compounds

The extraction procedure for DNPH active cartridge is illustrated in Figure 3.13. The extraction was carefully taken for short time in order to prevent the sample contamination, acetonitrile, HPLC grade, produced by J.T. Baker, Inc., USA was used as extracting solvent.

3.4.3.2 BTEX

The extraction procedure for charcoal gas tube is illustrated in Figure 3.14. Due to the pollutants in this procedure are volatile organic compounds, a cap of the glass tube was closed immediately after sampling to avoid the loss of the sample. The upper and lower activated charcoal of the tube was analyzed separately. The BTEX analyzed from upper part would be represented as the actual amount for the sampling, while those of the lower would be used for breakthrough checking. 100 µl of internal standard, Toluene-d8, at the concentration of 162,300 ng/ml was spiked in each sample. The solvent for extracting was carbon disulfide (CS_2).

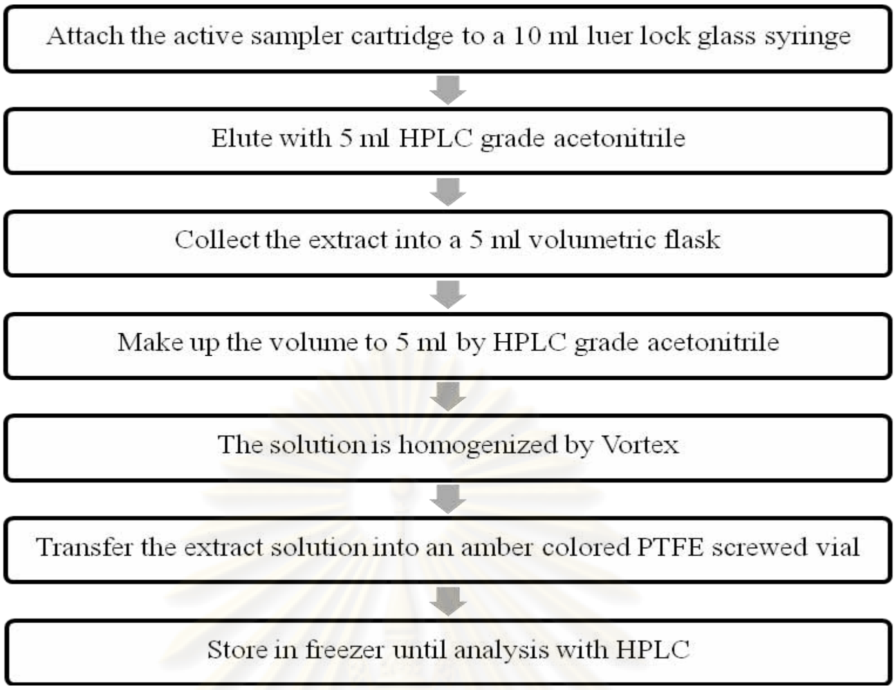


Figure 3.13 Extraction Procedures for DNPH active sampler

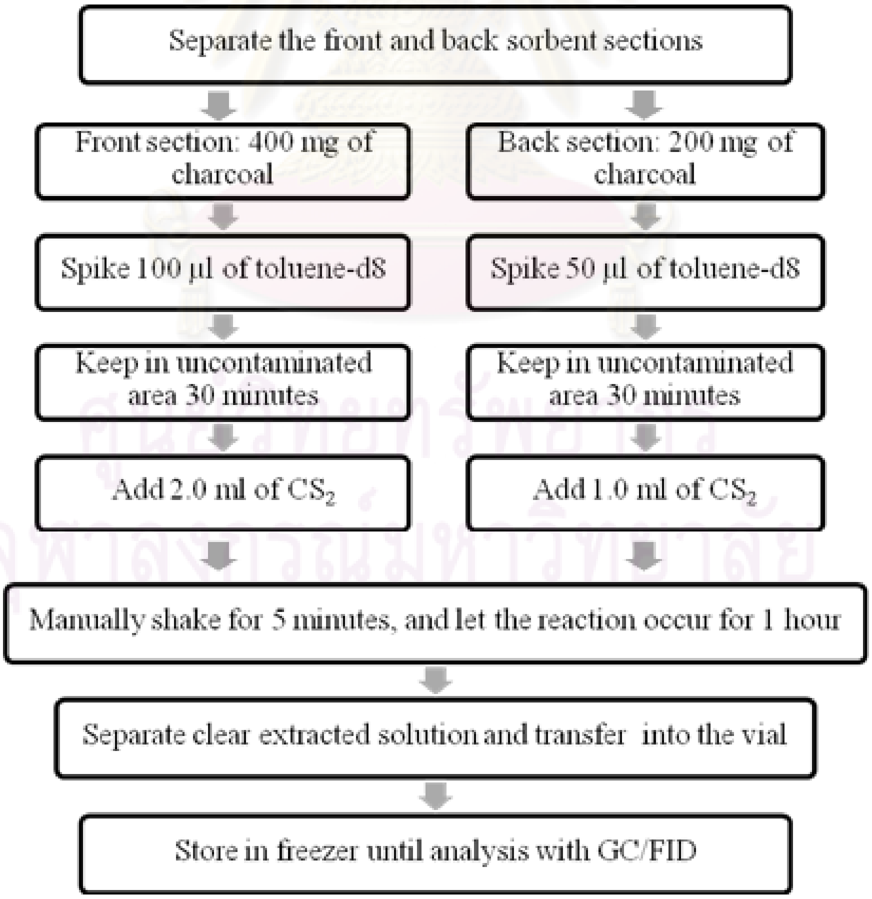


Figure 3.14 Extraction Procedures for charcoal gas tube

3.4.4 Calculation of carbonyl compounds and BTEX concentrations

3.4.4.1 Carbonyl compounds

Quantitative of carbonyl compounds in the samples could be done by daily calibration curve to check the stability of the HPLC instrument. The concentration of the daily calibration was 0.1 mg/l which was the middle concentration of the real calibration curve. The concentration difference of the daily calibration and the real calibration curve should not exceed 10% difference. Therefore, the detected concentrations of carbonyl compounds (ppm = µg/ml) from HPLC analysis were available to use for calculation of the mass of carbonyl compounds (see Equation 3.5).

$$M_S = (X_A - X_B) \times V_S \qquad \text{(Eq. 3.5)}$$

where;

M_S (µg/sample) = Mass of carbonyl compounds
X_A (µg/ml) = Concentration of carbonyl compounds in sample
X_B (µg/ml) = Concentration of carbonyl compounds in blank
V_S (ml) = Sample volume 5 ml

$$\text{Concentration of carbonyls } (\mu g/\ m^3) = \frac{\text{Mass of Carbonyls } (\mu g)}{\text{Volume of air } (m^3)} \qquad \text{(Eq. 3.6)}$$

3.4.4.2 BTEX

Quantitative of BTEX in the samples could be done by comparing with the mixed standard solution containing internal standard Toluene-d8 at the concentration of 162,300 ng/ml. The mass of BTEX is calculated by the following equation;

$$M_S = \frac{P_A - P_B}{P_S} \times C_S \times \frac{V_S}{V_I} \qquad \text{(Eq. 3.7)}$$

where;

M_S (µg/sample) = Mass of BTEX
C_S (µg/ml) = Concentration of the mixed standard solution
P_A (unitless) = Peak area of BTEX per peak area of Toluene d-8 in sample
P_B (unitless) = Peak area of BTEX per peak area of Toluene d-8 in blank
P_S (unitless) = Peak area of BTEX per peak area of Toluene d-8 in mixed standard solution
V_S (µl) = Sample volume 2 ml
V_I (µl) = Injection volume 1 µl

$$\text{Concentration of BTEX } (\mu g/\ m^3) = \frac{\text{Mass of BTEX } (\mu g)}{\text{Volume of air } (m^3)} \qquad \text{(Eq. 3.8)}$$

3.4.5 Data Analysis

All observed data were analyzed as follows:

1) Relationship between some factors affecting the concentrations of carbonyl compounds and BTEX was examined using Bivariate correlation.

2) The difference of the pollutants among gas stations was statistically analyzed by T-Test and ANOVA using *SPSS 17.0 for Windows.*

3.5 Health Risk Assessment of the gas station workers

This study focused on occupational exposure to carbonyl compounds and BTEX of gas station worker which the chemicals would be predominantly exposed by inhalation route. In this study, the risk assessment for inhalation exposure was then used to estimate the nature and possibility of adverse health effects in gas station worker. According to Environmental Protection Agency (EPA) approach, four steps: (1) Hazard Identification; (2) Dose-Respond Assessment; (3) Exposure Assessment; and (4) Risk Characterization were conducted to obtain the risk level. EPA published Risk Assessment Guidance for Superfund (RAGS) Volume I: Human Health Evaluation Manual that consists of many parts. Two parts were referred in this study including part A, the Baseline Risk Assessment (U.S. EPA, 1989) and part F, Supplemental Guidance for Inhalation Risk Assessment (U.S. EPA, 2009). Some steps of risk assessment between part A and F are different that can be illustrated in Table 3.7.

Table 3.7 The four steps of risk assessment in RAGS part A and part F

RAGS Volume I: Human Health Evaluation Manual	Part A The Baseline Risk Assessment		Part F Supplemental Guidance for Inhalation Risk Assessment	
Step 1: Hazard Identification	Cancer	Non-cancer	Cancer	Non-cancer
Step 2: Dose-Respond Assessment	Inhalation Cancer Slope Factor (CSF_i)	Inhalation Reference Dose (RfD_i)	Inhalation Unit Risk (IUR)	Reference Concentration (RfC)
Step 3: Exposure Assessment	Chronic Daily Intake (CDI)	Average Daily Dose (ADD)	Exposure Concentration (EC)	Exposure Concentration (EC)
Step 4: Risk Characterization	CDI x CSF_i	ADD/RfD_i	EC x IUR	EC/RfC

The difference between RAGS part A and part F was found in the step of exposure assessment which the body weight and inhalation rate were regarded for the RAGS part F. To estimate the individual risks of gas station workers, the RAGS part A was principally performed for this study.

3.5.1 Hazard identification

The first step of risk assessment, the hazard identification provides the target organ and serious health effects of the chemicals. In this study, carbonyl compounds and BTEX were classified as air toxic pollutants that cause adverse health effect in gas station workers. Available toxicity data for human can be found for BTEX and some chemicals of the total carbonyl compounds as shown in Table 3.8.

3.5.2 Dose-respond assessment

Dose-Respond assessment is the second step of risk assessment which characterizes the relationship between levels of chemical and effect occurrences. To perform the dose-respond assessment after identifying the substances as carcinogenic and non-carcinogenic compounds, the reference values for inhalation exposure were prepared for calculating the risk level in further step.

Table 3.8 The critical health effects of the chemicals

Compounds	EPA Cancer Classification*	Target Organ	Precursor Effect/ Tumor Type	Critical Effects
Formaldehyde	B1	Nasal cavity^2	Squamous cell carcinoma^1	-
Acetaldehyde	B2	Nasal^2	Nasal squamous cell carcinoma or adenocarcinoma^{1,2}	Degeneration of olfactory epithelium^{1,2}
Acetone	D		-	Nephropathy^1
Propionaldehyde			-	Atrophy of olfactory epithelium^1
Benzene	A	Blood^2	Leukemia^1	Decreased lymphocyte count^{1,2}
Toluene	D		-	Neurological effects in occupationally-exposed workers ^{1,2}
Ethylbenzene	B2	Kidney^2	Tumors^2	Developmental toxicity^{1,2}
Xylene	D		-	Impaired motor coordination (decreased rotarod performance)^{1,2}

^{1} Integrated Risk Information System (IRIS), 2010

^{2} The Risk Assessment Information System (RAIS), 2009

*EPA cancer classification: A - Human Carcinogen; B1 - Probable Human Carcinogen; B2 - Probable Human Carcinogen; C - Possible Human Carcinogen; D - Not Classifiable as to Human Carcinogenicity; E - Evidence of Non-Carcinogenicity for Humans

As mentioned above, the risk assessment the RAGS part A (1989) which originally used to estimate the risk the Inhalation Cancer Slope Factor ($\mathrm{CSF_i}$) and the Inhalation Reference Dose ($\mathrm{RfD_i}$) were the toxicity values which would be prepared for carcinogenic and non-carcinogenic compounds, respectively. The Inhalation Cancer Slope Factors ($\mathrm{CSF_i}$) of carcinogenic compounds were found for benzene, ethylbenzene, formaldehyde and acetaldehyde which were provided by The Risk Assessment Information System (RAIS) and Office of Environmental Health Hazard Assessment (OEHHA) as shown in Table 3.9. For non-carcinogenic compounds, the Inhalation Reference Doses ($\mathrm{RfD_i}$) were not found for the RAGS part A. The

Reference Concentrations (RfC) were found as the toxicity values of non-carcinogenic compounds as shown in Table 3.10. Theses RfCs were provided by Integrated Risk Information System (IRIS), The Risk Assessment Information System (RAIS) and Agency for Toxic Substances and Disease Registry (ATSDR) which would be used in the RAGS part F (2009).

Table 3.9 Toxicity values for carcinogenic compounds

Compounds	RAIS's CSF_i $(mg/kg\text{-}day)^{-1}$	OEHHA's CSF_i $(mg/kg\text{-}day)^{-1}$
Formaldehyde	-	2.1×10^{-2}
Acetaldehyde	-	1.0×10^{-2}
Benzene	2.73×10^{-2}	1.0×10^{-1}
Ethylbenzene	3.85×10^{-3}	8.7×10^{-3}

The Risk Assessment Information System (RAIS)

Office of Environmental Health Hazard Assessment (OEHHA)

Table 3.10 Toxicity values for non-carcinogenic compounds

Compounds	IRIS's RfC (mg/m^3)	RAIS's RfC (mg/m^3)	ATSDR's RfC (mg/m^3)
Acetone	-	-	3.09×10^{1}
Propionaldehyde	8×10^{-3}	8×10^{-3}	-
Toluene	5	5	-
Xylene	0.1	0.1	-

Integrated Risk Information System (IRIS)

The Risk Assessment Information System (RAIS)

Agency for Toxic Substances and Disease Registry (ATSDR)

3.5.3 Exposure assessment

According to the original RAGS Part A (1989), the inhalation exposure estimation was typically derived in terms of a chronic daily intake (CDI) using the following general approach. The intake of the chemical was estimated as a function of the concentration of the chemical in air (CA), inhalation rate (IR), body weight (BW), and the exposure scenario. Age-specific values for BW and IR were used when evaluating childhood exposures (U.S. EPA, 1989). This study used the RAGS Part A for carcinogenic compounds which the CDI was calculated by Equation 3.9 below.

$$\mathrm{CDI} = \frac{\mathrm{CA \times IR \times ET \times EF \times ED}}{\mathrm{BW \times AT}} \qquad \text{(Eq. 3.9)}$$

where;

CDI (mg/kg·day) = Chronic daily intake
CA (mg/m^3) = Contaminant concentration in air
IR (m^3/hr) = Inhalation rate (0.875 m^3/hr assumed for adult)
BW (kg) = Body weight (derived from questionnaires)
ET (hours/day) = Exposure time (8 hours/day for occupation)
EF (days/year) = Exposure frequency (350 days/year assumed for occupation)
ED (years) = Exposure duration (30 years assumed for occupation)
AT (days) = Averaging time (70 × 365 = 25,550 days)

Currently, the RAGS Part F approach is recommended for estimating exposures to inhaled contaminants. The generic equation described above is not consistent due to the amount of the chemical that reaches the target site is not a simple function of IR and BW. This approach involves the estimation of exposure concentrations (ECs) for each receptor exposed to contaminants via inhalation in the risk assessment. ECs are time-weighted average concentrations derived from measured or modeled contaminant concentrations in air at a site, adjusted based on the characteristics of the exposure scenario being evaluated (U.S. EPA, 2009). This study used the RAGS Part F for non-carcinogenic compounds which the EC was calculated by Equation 3.10 below.

$$\mathrm{EC} = \frac{\mathrm{CA \times ET \times EF \times ED}}{\mathrm{AT}} \qquad \text{(Eq. 3.10)}$$

where;

EC (µg/m^3) = Exposure concentration
CA (µg/m^3) = Contaminant concentration in air
ET (hours/day) = Exposure time (8 hours/day for occupation)
EF (days/year) = Exposure frequency (350 days/year assumed for occupation)
ED (years) = Exposure duration (30 years assumed for occupation)
AT (hours) = Averaging time (30 × 365 × 24 = 262,800 hours)

3.5.4 Risk characterization and interpretation

The approach outlined in RAGS Part A for carcinogenic compounds in this study was developed before EPA issued the Inhalation Domistry Methodology, which described the Agency's refined recommended approach for interpreting inhalation toxicity studies in laboratory animals or studies of occupational exposures of humans to airborne chemicals. Inhalation toxicity values were converted into similar units for the risk quantification step. Cancer risk was estimated by multiplying the chronic daily intake (CDI) of the chemical from the air by the inhalation cancer slope factor (CSF_i). The risk level can be calculated as follows:

$$\text{Cancer risk} = CDI \times CSF_i \qquad \text{(Eq. 3.11)}$$

where;

Cancer risk $> 10^{-6}$ means Carcinogenic effects of concern

Cancer risk $\leq 10^{-6}$ means Acceptable level

Under the RAGS part F for non-carcinogenic compounds in this study, the experimental exposures are typically extrapolated to a Human Equivalent Concentration (HEC), and a reference concentration (RfC) is typically calculated by dividing the HEC by uncertainty factors (UFs). The excess hazard quotient (HQ) for a receptor exposed via the inhalation pathway was estimated by dividing exposure concentration (EC) of the chemical by the reference concentration (RfC) which can be estimated with Equation 3.12.

$$HQ = EC/(RfC \times 1000\ \mu g/mg) \qquad \text{(Eq. 3.12)}$$

where;

$HQ > 1$ means Adverse non-carcinogenic effects of concern

$HQ \leq 1$ means Acceptable level (of no concern)

CHAPTER IV

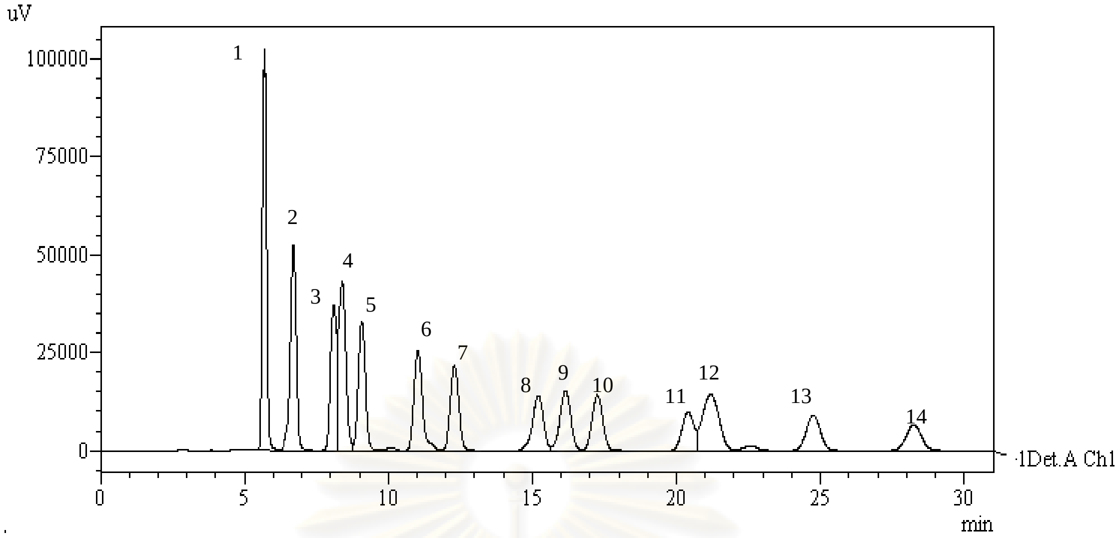
RESULTS AND DISCUSSION

4.1 Preliminary study

4.1.1 Optimum condition of instruments for determining carbonyl compounds and BTEX

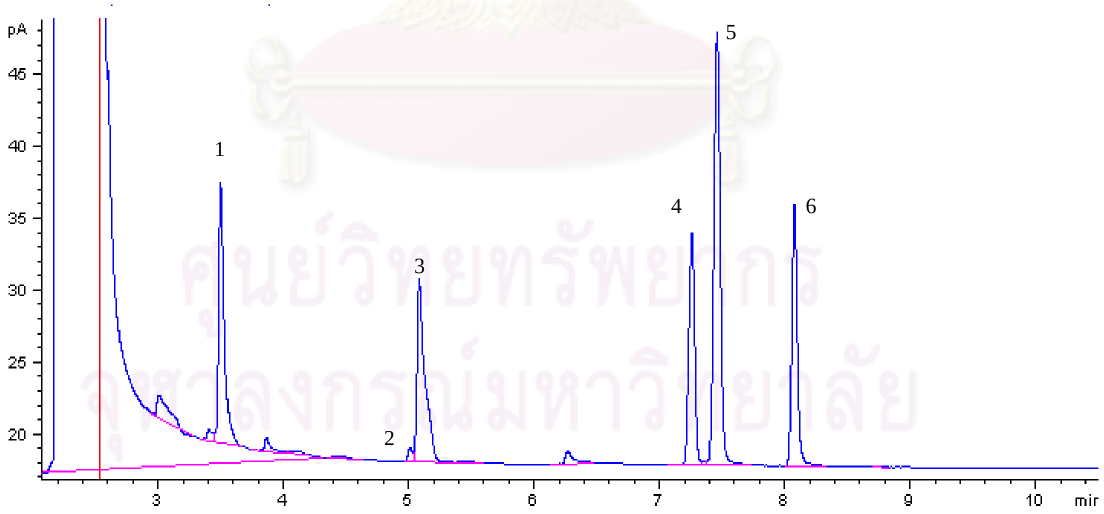
The condition of high performance liquid chromatography with ultra violet detector (HPLC-UV) was set up following Compendium Method TO-11A using mixed fifteen standard carbonyl compounds and the optimum condition had been revealed in the study of Morknoy (2008). The RP Amide Discovery C16 250 cm x 4.6 mm i.d. with 0.5 µm packing was used as a main column of this instrument which the temperature was set at 40^{o}C. Water and acetonitrile were used as mobile phases with the ratio 45/55% at the flow rate of 1.0 ml/min. The UV detector was performed at wavelength 360 nm. Total runtime for the standard was 30.00 min and retention time of each substance could be found in the chromatogram as shown in Figure 4.1. Fourteen peaks of standard carbonyl compounds could be identified including formaldehyde, acetaldehyde, acetone, acrolein, propionaldehyde, crotonaldehyde, butyraldehyde, benzaldehyde, isovaleraldehyde, valeraldehyde, o-tolualdehyde, m,p-tolualdehyde, hexanaldehyde and 2,5-dimethylbenzaldehyde

For BTEX, the optimum condition of gas chromatography with flame ionization detector (GC-FID) was set up by using standard solution of BTEX and Toluene d-8 as an internal standard. The capillary column, HP-5 30 m × 0.32 mm × 0.25 µm (19091J-413) produced by Agilent was used for analyzes. The oven temperature was programmed as follows: an initial temperature started at 35^{o}C, increase at 5^{o}C/min to 120^{o}C and continually increase at 20^{o}C/min to 230^{o}C, and hold for 5 min. FID temperature was set at 300^{o}C. Total runtime was 27.50 min and the retention times of BTEX and Toluene d-8 were presented in the chromatogram as seen in the Figure 4.2.



1. Formaldehyde (6.55)
2. Acetaldehyde (7.83)
3. Acetone (9.35)
4. Acrolein (9.71)
5. Propionaldehyde (10.41)
6. Crotonaldehyde (12.48)
7. Butyraldehyde (13.81)
8. Benzaldehyde (16.89)
9. Isovaleraldehyde (17.80)
10. Valeraldehyde (18.88)
11. o-Tolualdehyde (21.91)
12. m,p-Tolualdehyde (22.55)
13. Hexanaldehyde (25.35)
14. 2,5-Dimethylbenzaldehyde (27.93)

Figure 4.1 Chromatogram of standard 14 carbonyl compound at the concentration of 0.100 ppm (The number in bracket represented retention time)



1. Benzene (3.51)
2. Toluene d-8* (5.02)
3. Toluene (5.09)
4. Ethylbenzene (7.25)
5. m,p-Xylene (7.45)
6. o-Xylene (8.07)

The number in the blanket is retention time of the compounds and * means internal standard

Figure 4.2 Chromatogram of standard BTEX at the concentration of 16,000 ng/ml with Toluene d-8 as the internal standard (The number in bracket represented retention time)

4.1.2 Calibration curves

The calibration curves of the mix carbonyl compounds standard were prepared at five concentrations including 0.010, 0.050, 0.100, 0.600 and 1.000 mg/l. The peak areas of all compounds were plotted against with their concentrations as the calibration curves, as in Appendix A. The R^2 of the calibration curves of 15 carbonyl compounds were found in range of 0.999810 - 0.999988.

For BTEX, the calibration curves of BTEX standard were prepared at seven concentrations including 125, 250, 500, 1,000, 2,000, 4,000 and 8,000 ng/ml. The calibration curves BTEX were illustrated in Appendix A. The R^2 of the calibration curves of BTEX were found in range of 0.99828 - 0.99959.

The standard concentrations in the unit of mg/l could be converted to the unit of mass per air volume, µg/m^3, as given in Table 4.1

Table 4.1 Concentrations of carbonyl compounds and BTEX standards in calibration curves

Standard Solution	Concentration of Standard Solution	Concentration in air (µg/m^3)
Standard 14 Carbonyls	0.010 mg/l	0.21
	0.050 mg/l	1.04
	0.100 mg/l	2.08
	0.600 mg/l	12.50
	1.000 mg/l	20.83
Standard BTEX	125 ng/ml	2.60
	250 ng/ml	5.21
	500 ng/ml	10.42
	1,000 ng/ml	20.83
	2,000 ng/ml	41.67
	4,000 ng/ml	83.33
	8,000 ng/ml	166.67

4.1.3 Determination limits of HPLC and GC

4.1.3.1 IDL and IQL of High Performance Liquid Chromatography

The Instrument Quantification Limit (IQL) and Instrument Detection Limit (IDL) were determined by preparing 0.05 mg/l of mix standard carbonyl compounds. This standard was injected into the HPLC with UV detector for 7 times. The average value, standard deviation (SD), and %RSD were calculated. The IDL of each compound were determined from 3SD, and the IQL were obtained from 10SD. The value of IQL was used as the Not Detected (ND) for each compound quantified. The results of IDL and IQL are shown in Table 4.2.

Table 4.2 Results of IDL and IQL for carbonyl compounds analysis

Compound	**IDL**		**IQL**	
	mg/l	**µg/m^{3*}**	**mg/l**	**µg/m^{3*}**
Formaldehyde	0.002	0.04	0.008	0.17
Acetaldehyde	0.003	0.06	0.010	0.21
Acetone	0.002	0.04	0.008	0.17
Acrolein	0.002	0.04	0.008	0.17
Propionaldehyde	0.002	0.04	0.008	0.17
Crotonaldehyde	0.004	0.08	0.012	0.25
Butyraldehyde	0.004	0.08	0.013	0.27
Benzaldehyde	0.004	0.08	0.012	0.25
Isovaleraldehyde	0.005	0.10	0.018	0.38
Valeraldehyde	0.005	0.10	0.016	0.33
o-Tolualdehyde	0.006	0.13	0.019	0.40
m,p-Tolualdehyde	0.004	0.08	0.013	0.27
Hexanaldehyde	0.004	0.08	0.014	0.29
2,5-Dimethylbenzaldehyde	0.005	0.10	0.018	0.38

[*] Based on volume of sample in environment

4.1.3.2 LOD and LOQ of Gas Chromatography

The Limit of Detection (LOD) and Limit of Quantification (LOQ) were determined by preparing the lowest concentration of mix standard BTEX. The standard was injected into the GC-FID for 3 times. The average value and standard deviation (SD) were calculated. The LOD was usually defined as a signal to noise ratio of 3:1, and LOQ was 10:1. The LOD and LOQ of each compound were calculated from the equation 3.3 and 3.4 in Chapter 3. The results of LOD and LOQ as the unit of µg/m^3 based on volume of sample in air were in the range of 0.05 – 0.79 and of 0.17 – 2.62 µg/m^3, respectively, as shown in Table 4.3. The highest LOD and LOQ were toluene and the lowest LOD and LOQ were m,p-xylene.

The previous studies were found the LOD of BTEX determined by GC/FID preparing from 18 organohalogens as 0.92 – 1.93 µg/m^3 (Edward *et al.*, 2001), preparing from Japanese 52 component indoor air as 0.03 – 0.20 µg/m^3 (Poolma, 2005) and as 0.12 – 0.50 µg/m^3 (Thaveevongs, 2008) and preparing from standard BTEX as 0.06 – 1.04 µg/m^3 (Esplugues *et al.*, 2010). The LOD of BTEX in this study found in Table 4.3 reveals that the results were better than the studies of Edward *et al.* (2001) and Esplugues *et al.* (2010).

Table 4.3 Results of LOD and LOQ for BTEX analysis

Compound	**LOD**		**LOQ**	
	ng/ml	**µg/m^{3*}**	**ng/ml**	**µg/m^{3*}**
Benzene	2.40	0.05	7.99	0.17
Toluene	27.14	0.57	90.48	1.88
Ethylbenzene	22.38	0.47	74.59	1.55
m,p-Xylene	3.80	0.08	12.65	0.26
o-Xylene	37.70	0.79	125.66	2.62

[*] Based on volume of sample in environment

4.1.4 Sampling train design

To collect the carbonyl compounds and BTEX in the same air stream, two sampling trains were tested and then compared these substances amount. The 2, 4 DNPH cartridge and charcoal glass tube connected with the personal air pump was defined as the sampling train Type A, while only charcoal glass tube connected with the personal air pump was defined as the sampling train Type B. Both types were tested in the same place and same time in the gas station and parking area. The result in Table 4.4 shows that the collected BTEX concentration of the sampling train Type A was similar to that collected by the sampling train Type B, and this implied that 2, 4 DNPH cartridges did not much affect to an efficiency of charcoal glass tube when they were used together. Consequently, the sampling train Type A was chosen to collect carbonyl compounds and BTEX for personal exposure and ambient in this study.

Table 4.4 BTEX concentration collected by two sampling trains

Compounds	Conc. in gas station (µg/m^3)		% Difference (A to B)	Conc. in parking area (µg/m^3)		% Difference (A to B)	Average of % Difference
	Type A	Type B		Type A	Type B		
Benzene	271.56	273.13	-0.58	286.40	287.19	+0.28	-0.15
Toluene	221.46	225.84	-1.96	287.58	298.52	+3.73	+0.89
Ethylbenzene	12.22	12.34	-1.01	43.48	50.73	+15.39	+7.19
m,p-Xylene	13.00	12.59	+3.23	42.02	48.90	+15.14	+9.19
o-Xylene	5.16	5.53	-6.95	12.79	9.46	-29.91	-18.43

4.2 Detectable carbonyl compounds and BTEX at gas stations in Bangkok

This study area was divided into two phases focusing on area-based. The first sampling was performed in six gas stations belonging to three different companies where located in Pathumwan district, an inner city of Bangkok, and the samples were collected twice within two weeks in May to June 2010. While the second phase was performed in six gas stations with the same company located in widespread area of

Bangkok, and the samples were collected four days per week (i.e. Friday, Saturday, Sunday and Monday) in November 2010.

All samples were collected to examine concentrations of carbonyl compounds and BTEX during 6.00 am – 2.00 pm (8 work hours). Daily personal exposure and ambient concentration at each gas station was carried out in both sampling campaigns. The concentration of these target compounds at roadside was additionally investigated in the second sampling in order to find whether traffic was relative source or not.

From both samplings, 19 target compounds could be detected at the gas stations including 5 compounds of BTEX and 14 carbonyl compounds, as presented in Table 4.5. The result indicated that the target compounds detected from personal exposure sample were more varied than those found from ambient and roadside. The predominant target compounds found in personal exposure, ambient and roadside air concentrations at all gas stations were formaldehyde, acetaldehyde, acetone, propionaldehyde, crotonaldehyde, butyraldehyde, valeraldehyde, hexanaldehyde, benzene, toluene, ethylbenzene, m,p-xylene and o-xylene. Hence, these predominant compounds will be selected to report and discuss only in the next sessions.

The types of compounds in this study were similar to those found in some previous studies (as in Table 4.6). All previous studies at gas stations in Taiwan, Rio de Janeiro (Brazil), India, and also Thailand had also found BTEX. (Lin *et al.*, 2005; De Oliveira *et al.*, 2007; Majumdar *et al.*, 2008 and Thaveevongs, 2008). For carbonyls compounds, predominant species such as formaldehyde, acetaldehyde, acetone, propionaldehyde, crotonaldehyde, butylraldehyde, benzaldehyde and hexanaldehyde were also detectable in the previous studies in India (Majumdar *et al.*, 2008).

Table 4.5 Detectable carbonyl compounds and BTEX at the gas stations in Bangkok

Compound Name	**Part I**						**Part II**					
	TRO	**PCC**	**NW**	**TP**	**BK**	**SBS**	**BT**	**DKN**	**J**	**RO**	**TL**	**TP**
Benzene	PA	PA	PA	PA	PA	PA	PAR	PAR	PAR	PAR	PAR	PAR
Toluene	PA	PA	PA	PA	PA	PA	PAR	PAR	PAR	PAR	PAR	PAR
Ethylbenzene	PA	PA	PA	PA	PA	PA	PAR	PAR	PAR	PAR	PAR	PAR
m,p-Xylene	PA	PA	PA	PA	PA	PA	PAR	PAR	PAR	PAR	PAR	PAR
o-Xylene	PA	PA	PA	PA	PA	PA	PAR	PAR	PAR	PAR	PAR	PAR
Formaldehyde	PA	PA	PA	PA	PA	PA	PAR	PAR	PAR	PAR	PAR	PAR
Acetaldehyde	PA	PA	PA	PA	PA	PA	PAR	PAR	PAR	PAR	PAR	PAR
Acetone	PA	PA	PA	PA	PA	PA	PAR	PAR	PAR	PAR	PAR	PAR
Propionaldehyde	PA	PA	PA	PA	PA	PA	PAR	PAR	PAR	PAR	PAR	PAR
Crotonaldehyde	PA	PA	PA	PA	PA	PA	PAR	PAR	PAR	PAR	PAR	PAR
Butyraldehyde	PA	PA	PA	PA	PA	PA	PAR	PAR	PAR	PAR	PAR	PAR
Benzaldehyde	PA	PA	PA	PA	PA	PA	PR	PAR	PAR	PAR	PA	PAR
Isovaleraldehyde	PA	P	P	PA	PA	P	PR	PAR	PAR	AR	P	PR
Valeraldehyde	PA	PA	PA	PA	PA	PA	PAR	PAR	PAR	PAR	PAR	PAR
o-Tolualdehyde	PA	P	P	PA	P	PA	PAR	PAR	-	P	P	P
m,p-Tolualdehyde	-	-	P	PA	P	P	PAR	P	-	P	-	-
Hexanaldehyde	PA	PA	PA	PA	PA	PA	PAR	PAR	PAR	PAR	PAR	PAR
2,5-Dimethylbenzaldehyde	P	P	P	PA	PA	PA	-	P	P	-	P	P

P means Detectable compounds in personal exposure

A means Detectable compounds in ambient

R means Detectable compounds in roadside

- means Non-detectable Compounds

Table 4.6 Comparison of carbonyl compounds and BTEX found in ambient gas stations in some other cities

Location	Carbonyl compounds	BTEX	Reference
Bangkok, Thailand	Formaldehyde, Acetaldehyde, Acetone, Propionaldehyde, Crotanaldehyde, Butylraldehyde, Benzaldehyde, Valeraldehyde, Hexanaldehyde,	Benzene Toluene Ethylbenzene m,p-Xylene o-Xylene	This study
Bangkok, Thailand	NS	Benzene Toluene Ethylbenzene m,p-Xylene o-Xylene	Thaveevongs, 2008
Kolkata, India	Formaldehyde, Acetaldehyde, Acetone, Propionaldehyde, Crotanaldehyde, Butylraldehyde, Benzaldehyde, Hexanaldehyde, Methylethylketone	Benzene Toluene Ethylbenzene m,p-Xylene o-Xylene	Majumdar *et al.*, 2008
Rio de Janeiro, Brazil	NS	Benzene Toluene Ethylbenzene m,p-Xylene o-Xylene	De Oliveira *et al.*, 2007
Changhua, Taiwan	NS	Benzene Toluene	Lin *et al.*, 2005

Remark: NS = Not study

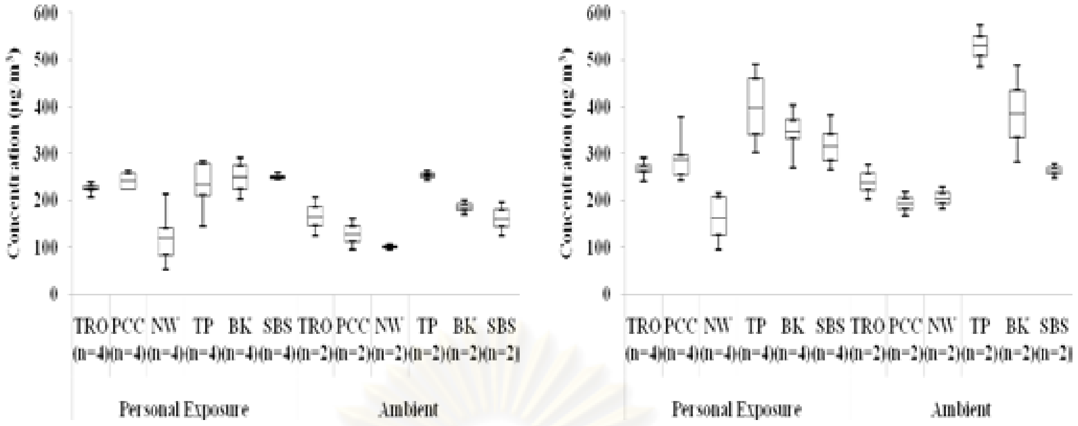
4.3 BTEX and carbonyl compounds concentrations at the gas stations locating in the inner city of Bangkok

The first sampling was conducted at six gas stations to compare the distribution of BTEX and carbonyl compounds from different fuel productions. Six gas stations were TRO, PCC, NW, TP, BK and SBS where located in Pathumwan district, an inner city of Bangkok, the description of each station was explained in Table 3.1. Three different types of fuel were produced by company A, B and C. TRO and SBS stations sell the production of the company A, PCC and BK stations are the agency of company B, and NW and TP stations are belonging to the company C. At each gas station, two samples were collected from two gas station workers to represent their personal exposure, and one sample was collected from ambient inside the station. . This sampling was carried out twice within two weeks during May – June 2010.

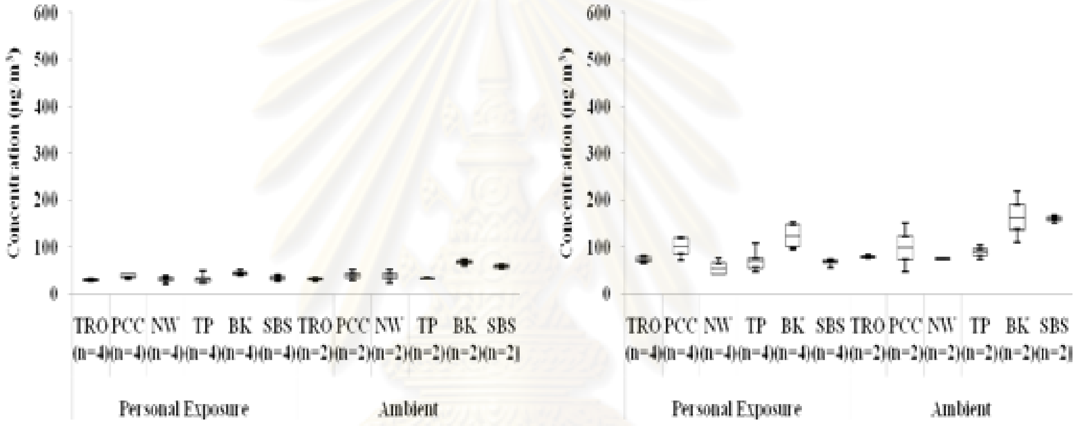
4.3.1 Comparison on BTEX at the gas stations

BTEX consists of five aromatic compounds which are benzene, toluene, ethylbenzene, m-xylene, p-xylene and o-xylene. They are identified as the primary pollutants which are released directly from gasoline. The gas station workers can expose to these pollutants through inhalation as a main route. Before calculating the average 8-hr personal exposure of two gas station workers at each station, the mean of two days sampling was compared using Paired-sample T test, *SPSS 17.0 for Window*.

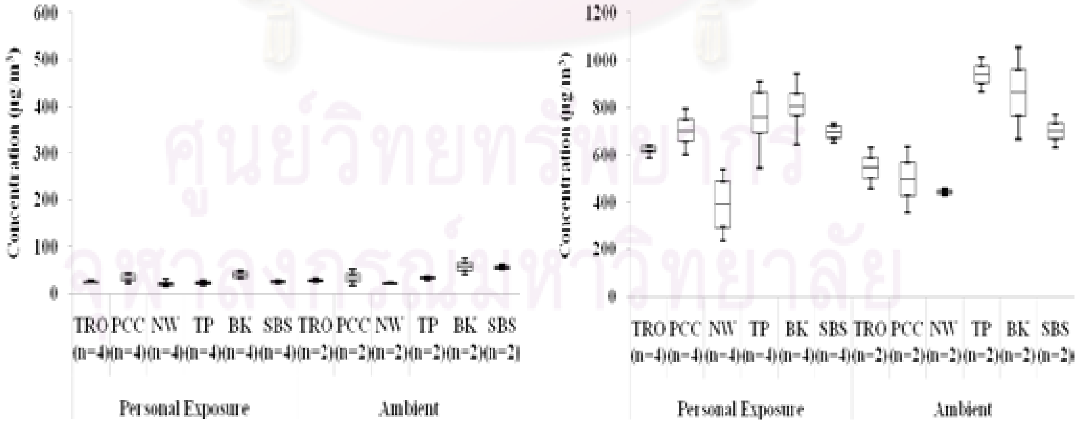
Considering personal exposure to BTEX between two workers at all gas stations, there was significant difference for the workers at some stations at the confidence interval of 95% including exposure of toluene and m,p-xylene at TRO, ethylbenzene and total BTEX at NW, and benzene at BK (Appendix E). These different personal exposures between two workers might be come from the different individual activities during working period. The average 8-hr personal exposure to BTEX (n=4) and those of average 8-hr ambient concentrations (n=2) were calculated All average personal exposure and ambient concentration of BTEX and of total BTEX at six gas stations , i.e. TRO, PCC, NW, TP, BK and SBS, were plotted as shown in Figure 4.3.



(a) Benzene (b) Toluene



(c) Ethylbenzene (d) m,p-Xylene



(e) o-Xylene (f) Total BTEX*

Figure 4.3 The personal exposure and ambient concentrations of BTEX at the six gas stations in the first sampling (*The scale is in range of 0 – 1200 µg/m^3)

The mean difference between the BTEX of all stations was statistically analyzed using Compared mean one way ANOVA, *SPSS 17.0 for Window*. The result was summarized in Table 4.7 and the detail of statistical analysis was shown in Appendix E.

From Figure 4.4 and Table 4.7, the 8-hr averages of personal exposure and of ambient concentrations of toluene were found the highest concentration at all stations which were 297.03 (94.77 – 490.38) and 302.64 (167.74 – 574.17) µg/m^3, respectively. The concentration of toluene was more than benzene, m,p-xylene, ethylbenzene and o-xylene, respectively. The average concentrations of benzene were 220.29 (55.22 – 292.52) µg/m^3 for personal exposure and 166.23 (95.47 – 262.90) µg/m^3 for ambient. The average concentrations of m,p-xylene were 81.67 (40.79 – 154.14) µg/m^3 for personal exposure and 111.27 (46.71 – 218.40) µg/m^3 for ambient. The average concentrations of ethylbenzene were 34.96 (22.64 – 52.42) µg/m^3 for personal exposure and 44.72 (24.61 – 73.48) µg/m^3 for ambient. The average concentrations of o-xylene were 28.22 (15.64 – 49.90) µg/m^3 for personal exposure and 38.83 (17.59 – 75.13) µg/m^3 for ambient. For total BTEX, the summation of benzene, toluene, ethylbenzene, m,p-xylene and o-xylene, the average concentrations were 662.17 (239.01 – 940.39) µg/m^3 for personal exposure and 663.68 (355.55 – 1054.66) µg/m^3 for ambient.

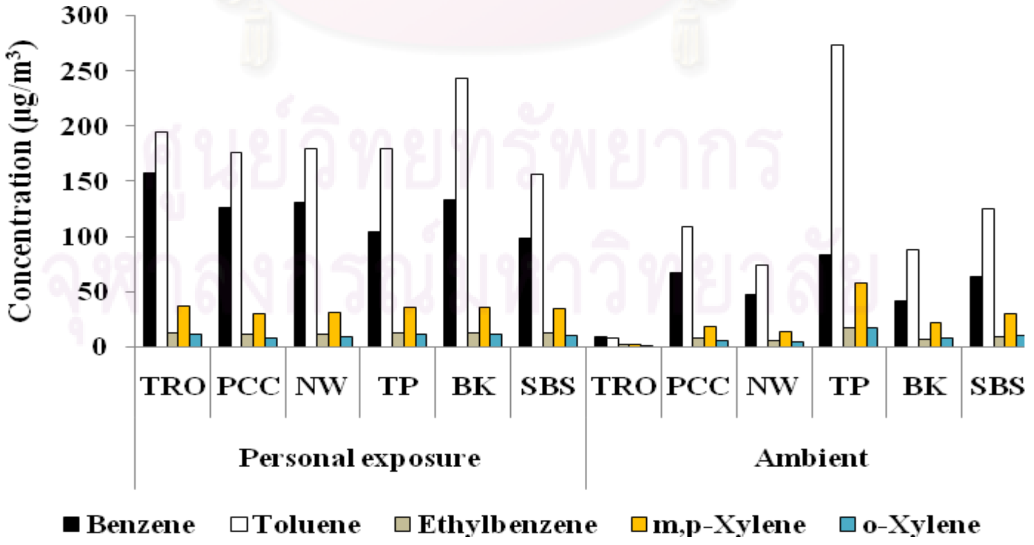


Figure 4.4 The 8-hr average BTEX concentration of personal exposure and ambient concentrations between all gas stations

Table 4.7 Comparison of BTEX at all gas stations

Compound	Average conc. (µg/m^3)	Conc. Range (µg/m^3)	Concentration Ranking (High → Low)
Benzene			
- Personal exposure	220.29	55.22 – 292.52	$SBS^{b} = BK^{b} = PCC^{b} = TP^{b} = TRO^{b} > NW^{a}$
- Ambient	166.23	95.47 – 262.90	$TP^{b} > BK^{ab} = TRO^{ab} = SBS^{ab} > PCC^{a} = NW^{a}$
Toluene			
- Personal exposure	297.03	94.77 – 490.38	$TP^{c} > BK^{bc} = SBS^{bc} > PCC^{b} = TRO^{b} > NW^{a}$
- Ambient	302.64	167.74 – 574.17	$TP^{c} > BK^{bc} > SBS^{ab} = TRO^{ab} > NW^{a} = PCC^{a}$
Ethylbenzene			
- Personal exposure	34.96	22.64 – 52.42	$BK^{b} > PCC^{ab} = SBS^{ab} > TP^{a} = NW^{a} = TRO^{a}$
- Ambient	44.72	24.61 – 73.48	$BK^{b} > SBS^{ab} = PCC^{ab} > NW^{a} = TP^{a} = TRO^{a}$
m,p-Xylene			
- Personal exposure	81.67	40.79 – 154.14	$BK^{c} > PCC^{bc} > TRO^{ab} = TP^{ab} > SBS^{a} = NW^{a}$
- Ambient	111.27	46.71 – 218.40	$BK^{a} = SBS^{a} = PCC^{a} = TRO^{a} = TP^{a} = NW^{a}$
o-Xylene			
- Personal exposure	28.22	15.64 – 49.90	$BK^{c} > PCC^{bc} > SBS^{ab} = TRO^{ab} > TP^{a} = NW^{a}$
- Ambient	38.83	17.59 – 75.13	$BK^{b} > SBS^{ab} = PCC^{ab} = TP^{ab} = TRO^{ab} > NW^{a}$
Total BTEX			
- Personal exposure	662.17	239.01 – 940.39	$BK^{c} > TP^{bc} = PCC^{bc} = SBS^{bc} > TRO^{b} > NW^{a}$
- Ambient	663.68	355.55 – 1054.66	$TP^{c} > BK^{bc} > SBS^{abc} > TRO^{ab} = PCC^{ab} > NW^{a}$

Remark: The characters on the right of gas station name show the comparable mean difference among gas stations

The personal exposure of BTEX in this study were compared with the previous studies which performed in India (Majumdar *et al.*, 2008), in Spain (Periago and Prado, 2005), in Italy (Bono *et al.*, 2003) and in Bangkok (Thaveevongs *et al.*, 2010) and in Chonburi province (Yimrungruang *et al.*, 2008). The personal exposure of benzene was less than those found in the previous studies excepting the studies in India and in Italy (only winter) which the average personal exposure concentrations of benzene were 137.5 (58.2 – 253.3) and 160.9 µg/m^3, respectively. For toluene, the personal exposure was less than those of all previous studies. The personal exposure of ethylbenzene was reported only in India and Thailand which the average of this study was less than 118.0 µg/m^3 in India; 44.0 µg/m^3 in Chonburi province, but more than 10 – 27 µg/m^3 in the previous study of Bangkok. The average personal exposure of m,p-xylene and o-xylene were less than the study in India (209.7 and 68.2 µg/m^3, respectively) but these compounds' ranges were higher than those of the previous study in Bangkok (22 – 58 and 11 – 20 µg/m^3, respectively). The summation of m,p-xylene and o-xylene was resulted as the personal exposure concentration of xylenes and the average was found less than 316 (125 – 871) µg/m^3 in Spain and 285.2 µg/m^3 in Italy, but higher than 208.6 µg/m^3 in Chonburi province. For the ambient concentrations of predominant species, benzene and toluene were relatively higher than the previous study in India which found the ranges of 17.4 – 81.6 and 49.3 – 236.8 µg/m^3, respectively.

Comparing the personal exposure measured from all gas stations, the workers' exposure to total BTEX at BK (Banthad Thong Rd.) was the highest level, and followed by the exposure at TP (Rama IV Rd., near Lumphini's community), PCC (Charumuang Rd.), SBS (Phetcha Buri Rd.), TRO (Rama IV Rd.), and NW (Rongmuang Rd.), respectively. The sequence of ambient concentration was almost similar to the personal exposure. The highest concentration was observed at TP and followed by BK, SBS, TRO, PCC, and NW, respectively.

The analysis of correlation between personal exposure and ambient concentrations of BTEX which performed for 12 sampling days (n=12) was found the significant relationships for toluene, ethylbenzene, m,p-xylene and o-xylene and not significantly found for benzene. The Pearson's correlations coefficients of these compounds were 0.744 (p=0.01), 0.753 (p=0.01), 0.657 (p=0.05) and 0.720 (p=0.01), respectively. In addition, Total BTEX was also found significant correlation between personal exposure and ambient concentrations which the Pearson's correlation coefficient was 0.695 (p=0.05). This result can be explained that the exposure of the workers would be directly related to the working environment. This correlation in this study is agree with the study in residential area (non-roadside) of Bangkok which found the significant Pearson's correlations between outdoor and personal exposure of 0.325 (p=0.01) for ethylbenzene, of 0.681 (p=0.01) for m-xylene, of 0.729 (p=0.01) for p-xylene and of 0.831 (p=0.01) for o-xylene (Poolma, 2005). Another was studies at three sites in Italy, there was found the consistent overlapping between ambient and personal air measurements which r was 0.97089 ($p < 0.05$) (Bono *et al.*, 2003).

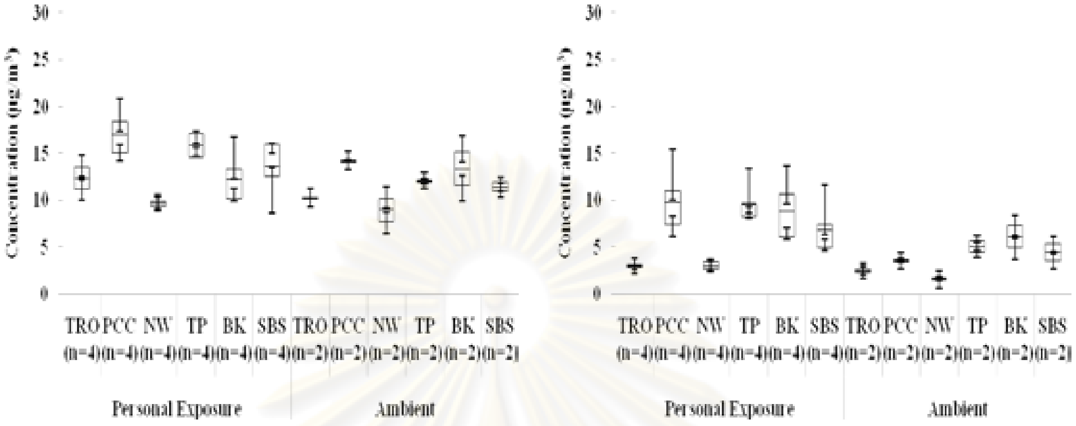
As above results, these reveal that the workers at different gas stations as well as different fuel productions in the inner city of Bangkok could exposure to different levels of BTEX. This might be influenced by some factors such as an individual activity of the workers during working period, an atmospheric condition and fuel circulations in each gas station. The detail of some available factors affecting on the contribution of BTEX will be discussed later on.

4.3.2 Comparison on carbonyl compounds at the gas stations

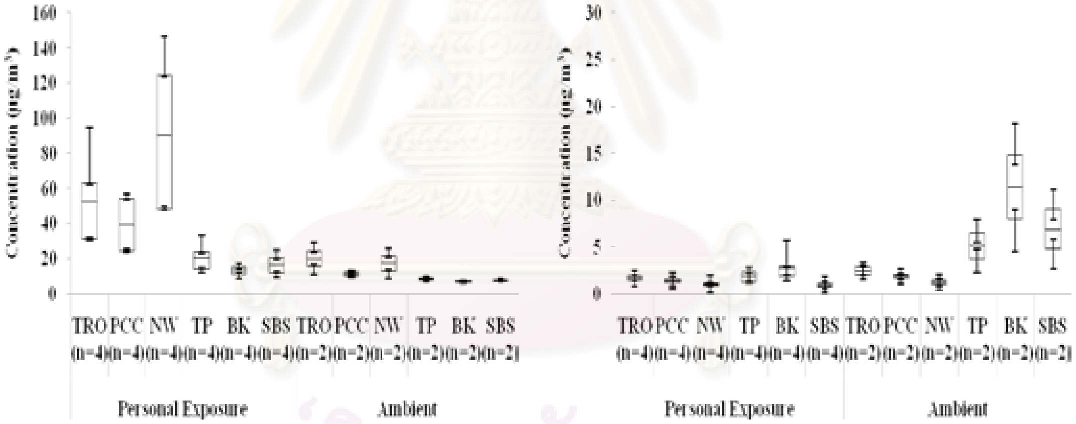
Even thought carbonyl compounds are classified as the secondary pollutants, the gas station workers can also have an opportunity to expose to this pollutants through inhalation as a main route as same as BTEX. As already mentioned in 4.2, the types of carbonyl compounds found in all gas stations were formaldehyde, acetaldehyde, acetone, propionaldehyde, crotonaldehyde, butylraldehyde, benzaldehyde, valeraldehyde and hexanaldehyde. Formaldehyde, acetaldehyde, acetone and propionaldehyde were the major species of the nine carbonyl compounds which their concentrations were much more than the others species.

Before calculating, the average personal exposure concentration of two gas station workers in two days, the paired mean difference between the gas station worker#1 (n=2) and the gas station worker#2 (n=2) in each gas station was tested using *SPSS 17.0 for Window*. From statistical tests, the personal exposure concentrations of formaldehyde, acetaldehyde, acetone and propionaldehyde between two workers were not significantly difference at the confidence interval of 95% (Appendix E), while the personal exposure concentrations of crotonaldehyde, butylraldehyde, benzaldehyde, valeraldehyde and hexanaldehyde, which classified as the minor species, could not be computed due to some data were non-detectable ($n \neq 2$) and theirs averages could not be calculated.

At each station four samples collected from the workers and two samples from ambient were calculated as the 8-hr average personal exposure and ambient concentrations of the major carbonyl compounds, respectively. The concentrations of nine carbonyl compounds including formaldehyde, acetaldehyde, acetone, propionaldehyde, crotonaldehyde, butylraldehdye, benzaldehyde, valeraldehyde and hexanaldehyde at all gas stations including TRO, PCC, NW, TP, BK and SBS were separately reported into 2 groups, personal exposure and ambient, as shown in Figure 4.5.

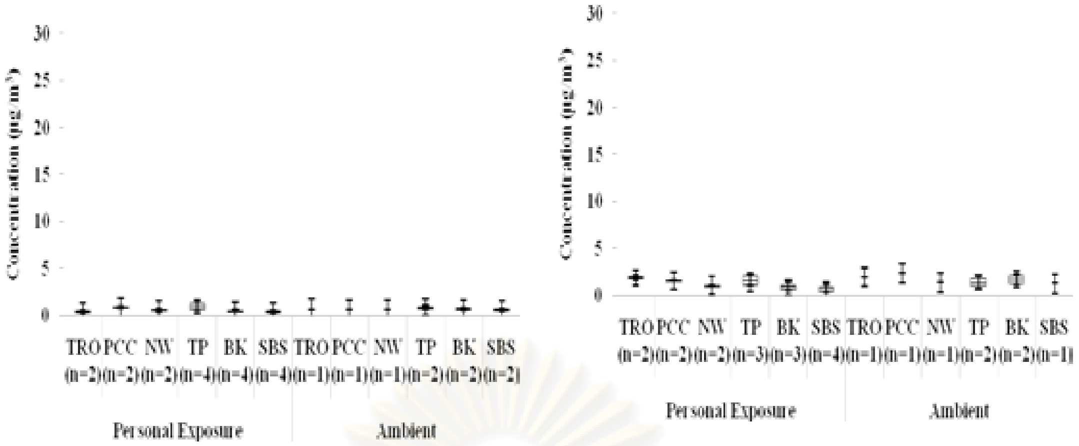


(a) Formaldehyde (b) Acetaldehyde

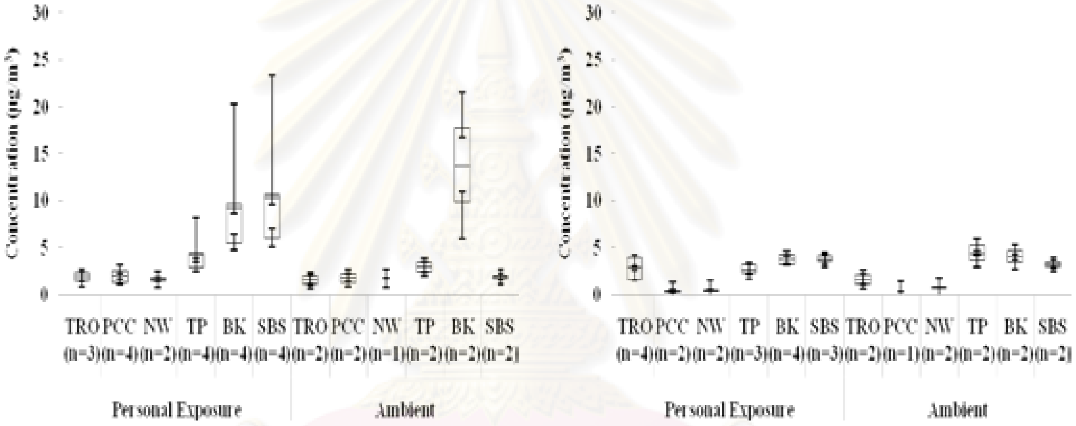


(c) Acetone* (d) Propionaldehyde

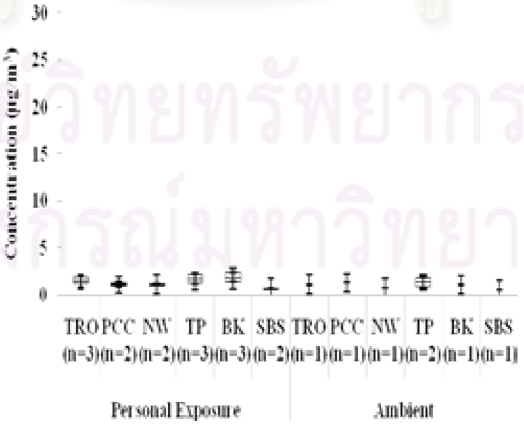
Figure 4.5 The average personal exposure and average ambient concentrations of nine carbonyl compounds in the six gas stations in the first sampling (*The scale is in range of 0 – 160 µg/m^3)



(e) Crotonaldehyde (f) Butylraldehyde



(g) Benzaldehyde (h) Valeraldehyde



(i) Hexanaldehyde

Figure 4.5 The average personal exposure and average ambient concentrations of nine carbonyl compounds at the six gas stations in the first sampling. (cont.)

From Figure 4.5, some compounds levels were less than the detectable limit resulting in the number of samples was not equal to 4 for personal exposure and to 2 for ambient concentration. The high levels of personal exposure to formaldehyde and acetaldehyde could be found and theirs levels were higher than those of the other carbonyl compounds excluding acetone at TRO, PCC and NW. The higher personal exposure concentrations of acetone at these 3 gas stations were approximately 2 – 5 times higher than the concentrations at others. This might be caused by contamination of acetone in the 2, 4-Dinitrotrophenylhydrazine active cartridges which had been kept for long time. The acetone concentrations of the blank test for the cartridges from the same package were also found at the quite high level. Therefore, these samples would not be included for data analysis.

The mean difference between nine carbonyl compounds of all stations was statistically analyzed using Compared mean one way ANOVA, *SPSS 17.0 for Window*. The result was summarized in Table 4.8 and the detail of statistical analysis was shown in Appendix E.

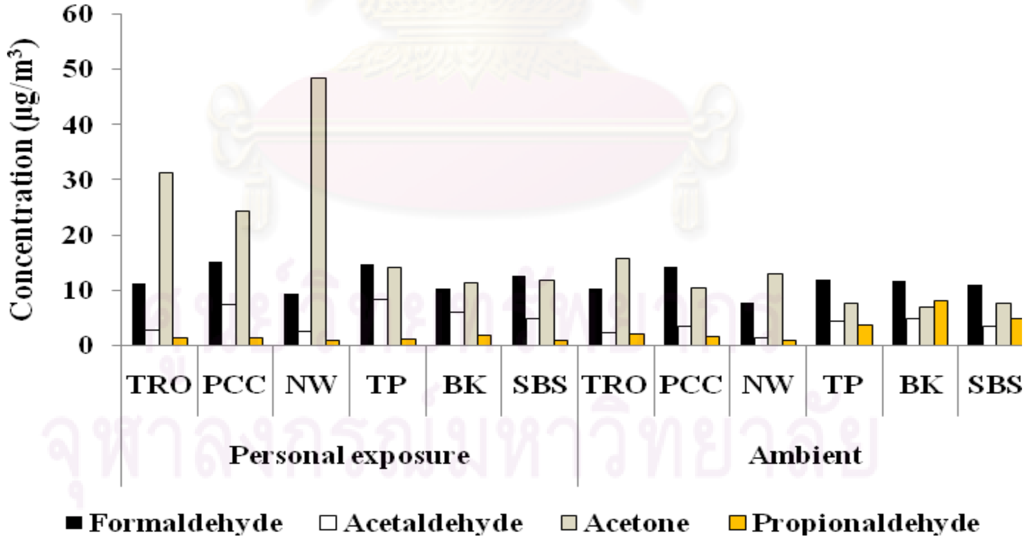


Figure 4.6 The 8-hr average carbonyl compounds (major species) concentration of personal exposure and ambient concentrations between all gas stations

Table 4.8 Comparison of nine carbonyl compounds at all gas stations

Compound	Average conc. (µg/m^{3})	Conc. Range (µg/m^{3})	Concentration Ranking (High → Low)
Formaldehyde			
- Personal exposure	12.17	7.56 – 18.83	PCC^{c} > TP^{bc} > SBS^{abc} > TRO^{ab} > BK^{a} = NW^{a}
- Ambient	11.12	5.31 – 15.12	PCC^{b} > TP^{ab} = BK^{ab} = SBS^{ab} = TRO^{ab} > NW^{a}
Acetaldehyde			
- Personal exposure	5.34	2.15 – 13.11	TP^{b} = PCC^{b} > BK^{ab} = SBS^{ab} > TRO^{a} = NW^{a}
- Ambient	3.36	1.27 – 7.29	BK^{a} = TP^{a} = SBS^{a} = PCC^{a} = TRO^{a} = NW^{a}
Acetone*			
- Personal exposure	12.46	4.82 – 26.99	TP^{a} = SBS^{a} = BK^{a}
- Ambient	7.36	6.26 – 9.07	TP^{a} = SBS^{a} = BK^{a}
Propionaldehyde			
- Personal exposure	1.28	0.45 – 4.78	BK^{a} = TRO^{a} = PCC^{a} = TP^{a} = NW^{a} = SBS^{a}
- Ambient	3.55	0.59 – 14.86	BK^{a} = SBS^{a} = TP^{a} = TRO^{a} = PCC^{a} = NW^{a}
Crotonaldehyde			
- Personal exposure	3.32	0.34 – 19.11	SBS^{a} = BK^{a} = TP^{a} = NW^{a} = TRO^{a} = PCC^{a}
- Ambient	3.16	0.26 – 17.72	Non comparable
Butylraldehyde			
- Personal exposure	2.12	0.12 – 4.06	SBS^{c} = BK^{c} > TP^{bc} > TRO^{ab} = NW^{ab} > PCC^{a}
- Ambient	2.21	0.21 – 5.21	Non comparable
Benzaldehyde			
- Personal exposure	0.49	0.13 – 1.16	PCC^{b} > TP^{ab} = NW^{ab} = BK^{ab} = TRO^{ab} > SBS^{a}
- Ambient	0.63	0.32 – 0.97	Non comparable
Valeraldehyde			
- Personal exposure	0.97	0.04 – 2.05	TRO^{b} = PCC^{b} > TP^{ab} = NW^{ab} = BK^{ab} > SBS^{a}
- Ambient	1.45	0.36 – 2.34	Non comparable
Hexanaldehyde			
- Personal exposure	1.15	0.18 – 2.33	BK^{a} = TP^{a} = TRO^{a} = NW^{a} = PCC^{a} = SBS^{a}
- Ambient	0.96	0.12 – 1.80	Non comparable

Remark: The characters on the gas stations show the comparable mean difference among gas stations and Non comparable means at least one gas station has the number of samples fewer than two.

From Figure 4.6 and Table 4.8, the 8-hr averages of personal exposure and of ambient concentrations could be divided to the major and minor species of carbonyl compounds. The major species were composed of formaldehyde, acetaldehyde, acetone and propionaldehyde, while the minor species were composed of crotonaldehyde, butylraldehyde, benzaldehyde, valeraldehyde and hexanaldehyde. For the major species, the average concentrations of formaldehyde were 12.17 (7.56 – 18.83) µg/m^3 for personal exposure and 11.12 (5.31 – 15.12) µg/m^3 for ambient. The average concentrations of acetaldehyde were 5.34 (2.15 – 13.11) µg/m^3 for personal exposure and 3.36 (1.27 – 7.28) µg/m^3 for ambient. The average concentrations of acetone were 12.46 (4.82 – 26.99) µg/m^3 for personal exposure and 7.36 (6.26 – 9.07) µg/m^3 for ambient. The average concentrations of propionaldehyde were 1.28 (0.45 – 4.78) µg/m^3 for personal exposure and 3.55 (0.59 – 14.86) µg/m^3 for ambient. For minor species, the average concentrations of crotonaldehyde were 3.32 (0.34 – 19.11) µg/m^3 for personal exposure and 3.16 (0.26 – 17.72) µg/m^3 for ambient. The average concentrations of butylraldehyde were 2.12 (0.12 – 4.06) µg/m^3 for personal exposure and 2.21 (0.21 – 5.21) µg/m^3 for ambient. The average concentrations of benzaldehyde were 0.49 (0.13 – 1.16) µg/m^3 for personal exposure and 0.63 (0.32 – 0.97) µg/m^3 for ambient. The average concentrations of valeraldehyde were 0.97 (0.04 – 2.05) µg/m^3 for personal exposure and 1.45 (0.36 – 2.34) µg/m^3 for ambient. The average concentrations of hexanaldehyde were 1.15 (0.18 – 2.33) µg/m^3 for personal exposure and 0.96 (0.12 – 1.80) µg/m^3 for ambient.

As the previous study in India reported the ambient concentrations of abundant carbonyl compounds in gas station, the averages of formaldehyde, acetaldehyde and acetone were found as 27.8 (11.6 – 55.5), 18.3 and 12.2 µg/m^3, respectively (Majumdar *et al.*, 2008). The results showed that the ambient concentrations of these compounds were higher than the results of this study approximately 2.5 times for formaldehyde, 5 times for acetaldehyde and 1.5 times for acetone.

Comparing the personal exposure measured from all gas stations, the workers' exposure to the major species of carbonyl compounds excluding acetone (due to the contaminated acetone in the blank test) was found the highest level at TP (Rama IV Rd., near Lumphini's community), and followed by the exposure at PCC (Charumuang Rd.), SBS (Phetcha Buri Rd.), BK (Banthad Thong Rd.), TRO (Rama IV Rd.), and NW (Rongmuang Rd.), respectively. The sequence of ambient concentration was almost similar to the personal exposure. The highest concentration was observed at BK and followed by TP, PCC, SBS, TRO, and NW, respectively

The analysis of correlation between personal exposure and ambient concentrations of the major species of carbonyl compounds which performed for 12 sampling days (n=12) excepting acetone that was analyzed for 6 days (n=6) was found the significant relationships for formaldehyde, acetaldehyde, acetone and propionaldehyde. The Pearson's correlations coefficient of these compounds were 0.631 (p=0.05), 0.622 (p=0.05), 0.887 (p=0.05) and 0.808 (p=0.01), respectively. Similarly to BTEX, the exposure of the workers could be found to relate with the working environment.

Likewise the result of BTEX, the workers' exposure to carbonyl compounds especially formaldehyde and acetaldehyde at different gas stations as well as different fuel productions in the inner city of Bangkok was different. These compounds are classified as the secondary pollutant in such environment, theirs level might be influenced by the contribution of primary pollutants and also some intermediate radical occurred in the air. In addition, some factors such as an individual activity of the workers during working period, an atmospheric condition, and fuel circulations in each gas station might have some effects on distribution of the carbonyl compounds. The detail of some available factors affecting on the contribution of Formaldehyde, Acetaldehyde and others compounds will be discussed in the later part.

4.4 BTEX and carbonyl compounds concentrations at the gas stations locating in different areas of Bangkok

In the second sampling, the samples were collected from six gas stations where belonging to the same company. Six gas stations were BT, DKN, J, RO, TL and TP where located in different districts representing widespread area of Bangkok. BT and DKN were located in Bangkhuntian district, J was located in Don Mueang district, RO was located in Payathai district, TL was located in Saphansung district and TP (as the same gas station in the first sampling) was located in Pathumwan district. Two gas stations were selected to perform the sampling in the same day, the samplings at BT and DKN, J and RO, and TL and TP were held during 5 – 8 November 2010, 12 – 15 November 2010, and 19 – 22 November 2010, respectively. At each gas station on a sampling day, four samples were collected which could be classified as personal exposure from two gas station workers, one sample from ambient in their workplace , and another sample from the position closed to the main road (or defined as roadside sample). Each sampling at each station was conducted four days in a week, Friday, Saturday, Sunday and Monday. Regarding to the study of Thaveevong (2008), Friday and Monday were selected to sampling and to represent as the high concentration of Total VOCs on workdays, while Saturday and Sunday were selected to represent the low concentration of Total VOCs. The result of the second sampling can be described as follows.

4.4.1 Comparison on BTEX at the gas stations

The concentrations of BTEX and total BTEX collected from personal exposure, ambient and roadside for four days in the second sampling were presented in Figures 4.7 – 4.12. At some stations, BT and J stations, there was a problem on operation of the personal air pump. Then, complete data could not be obtained.

The statistical analysis of the data in the second sampling was also performed as the same method as explained in 4.3. Before calculating of the average personal exposure concentration of two gas station workers in four days, the paired mean difference between the gas station worker#1 (n=4) and the gas station worker#2 (n=4) in each gas station was tested using *SPSS 17.0 for Window*, as the description summarized in Appendix E. The statistical results show that most of personal exposure concentrations of BTEX between two workers was not different at the confidence interval of 95% excepting theirs exposure to benzene and total BTEX at DKN and theirs exposure to benzene at RO. These different personal exposure concentrations between two workers might come from the different individual activities.

At each station, the 8-hr average concentrations of BTEX for personal exposure, ambient, and roadside were derived from 8 samples of the workers (n=8), 4 samples of ambient (n=4) and 4 samples of roadside (n=4), respectively. The concentrations of BTEX and Total BTEX were presented by dividing into 3 groups including personal exposure, ambient and roadside as shown in Figure 4.7 – 4.12.

For benzene as in Figure 4.7, the figure shows that the personal exposure concentrations of benzene at all gas stations were higher than those of ambient and of roadside concentrations, respectively. The 8-hr average concentrations of personal exposure, ambient, and roadside were 123.70 (36.93 – 259.73, n=44), 52.00 (5.98 – 109.19, n=24), and 16.23 (4.80 – 37.38, n=21) µg/m^3, respectively.

From Figure 4.8, the personal exposure concentrations of toluene at all gas stations were higher than those of ambient and of roadside concentrations, excepting for RO where the ambient concentrations were found higher than those of personal exposure and of roadside. From all gas stations, the 8-hr average concentrations of personal exposure, ambient, and roadside were 188.39 (69.21 – 404.29, n=44), 112.95 (3.47 – 290.47, n=24), and 27.45 (8.56 – 67.20, n=21) µg/m^3, respectively.

From Figure 4.9, the personal exposure concentrations of ethylbenzene at all gas stations were higher than those of ambient and of roadside concentrations, excepting for RO as same as the result of toluene. From all gas stations, the 8-hr average concentrations of personal exposure, ambient, and roadside were 12.20 (7.86 – 22.08, n=44), 9.23 (2.24 – 18.83, n=21), and 3.48 (1.33 – 6.94, n=21) µg/m^3, respectively.

From Figure 4.10, the personal exposure concentrations of m,p-xylene at all gas stations were higher than those of ambient and of roadside concentrations, excepting for RO as same as the result of toluene and ethylbenzene. From all gas stations, the 8-hr average concentrations of personal exposure, ambient, and roadside were 34.16 (22.33 – 59.03, n=44), 26.41 (1.52 – 63.40, n=22), and 7.14 (3.01 – 17.11, n=21) µg/m^3 , respectively.

From Figure 4.11, the personal exposure concentrations of o-xylene at all gas stations were higher than those of ambient and of roadside concentrations, excepting for RO as same as the result of toluene, ethylbenzene and m,p-xylene. From all gas stations, the 8-hr average concentrations of personal exposure, ambient, and roadside were 10.42 (5.28 – 23.55, n=44), 8.89 (1.39 – 18.96, n=21), and 3.11 (0.91 – 6.11, n=21) µg/m^3, respectively.

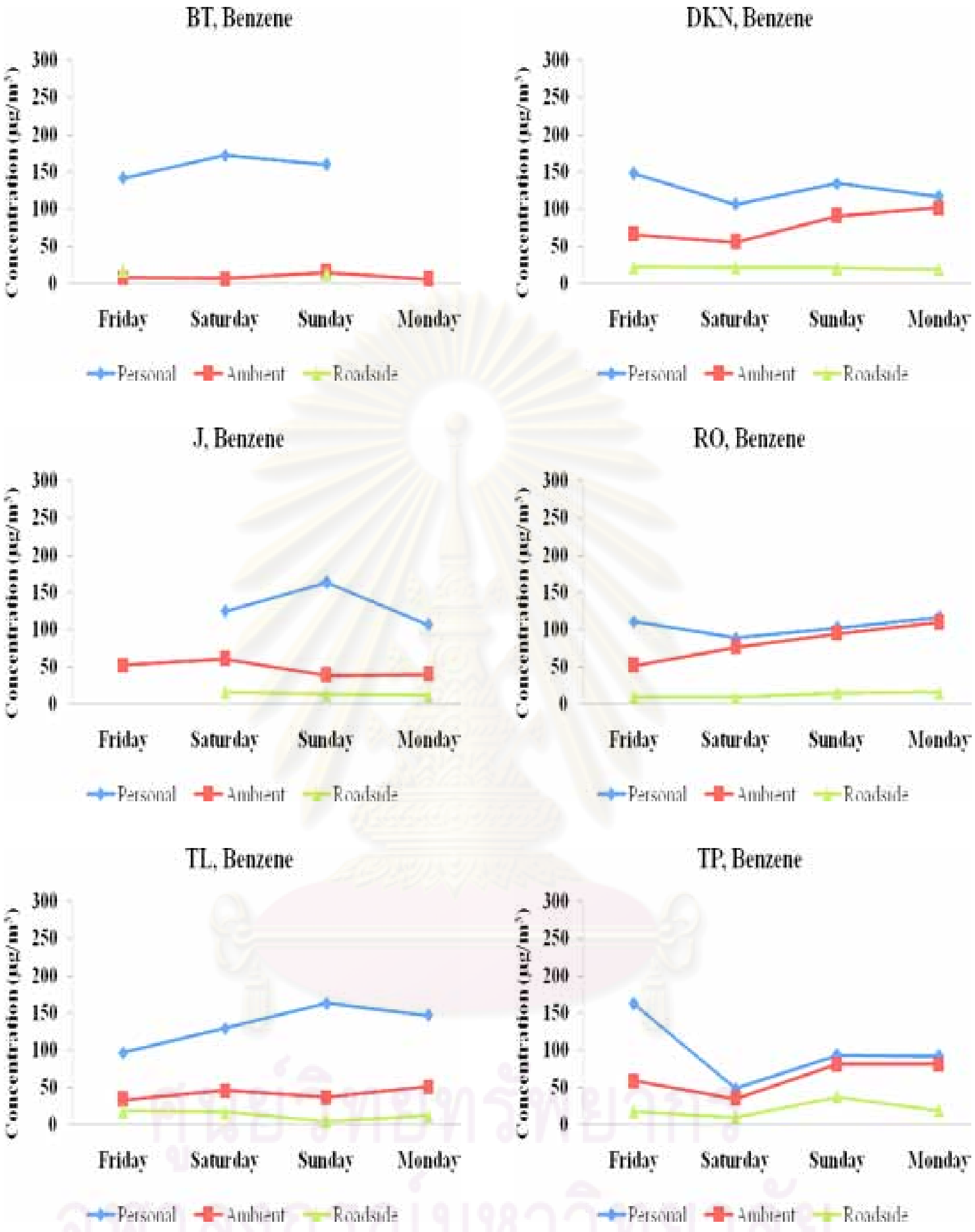


Figure 4.7 The average personal exposure, ambient and roadside concentrations of Benzene at the six gas stations in the second sampling

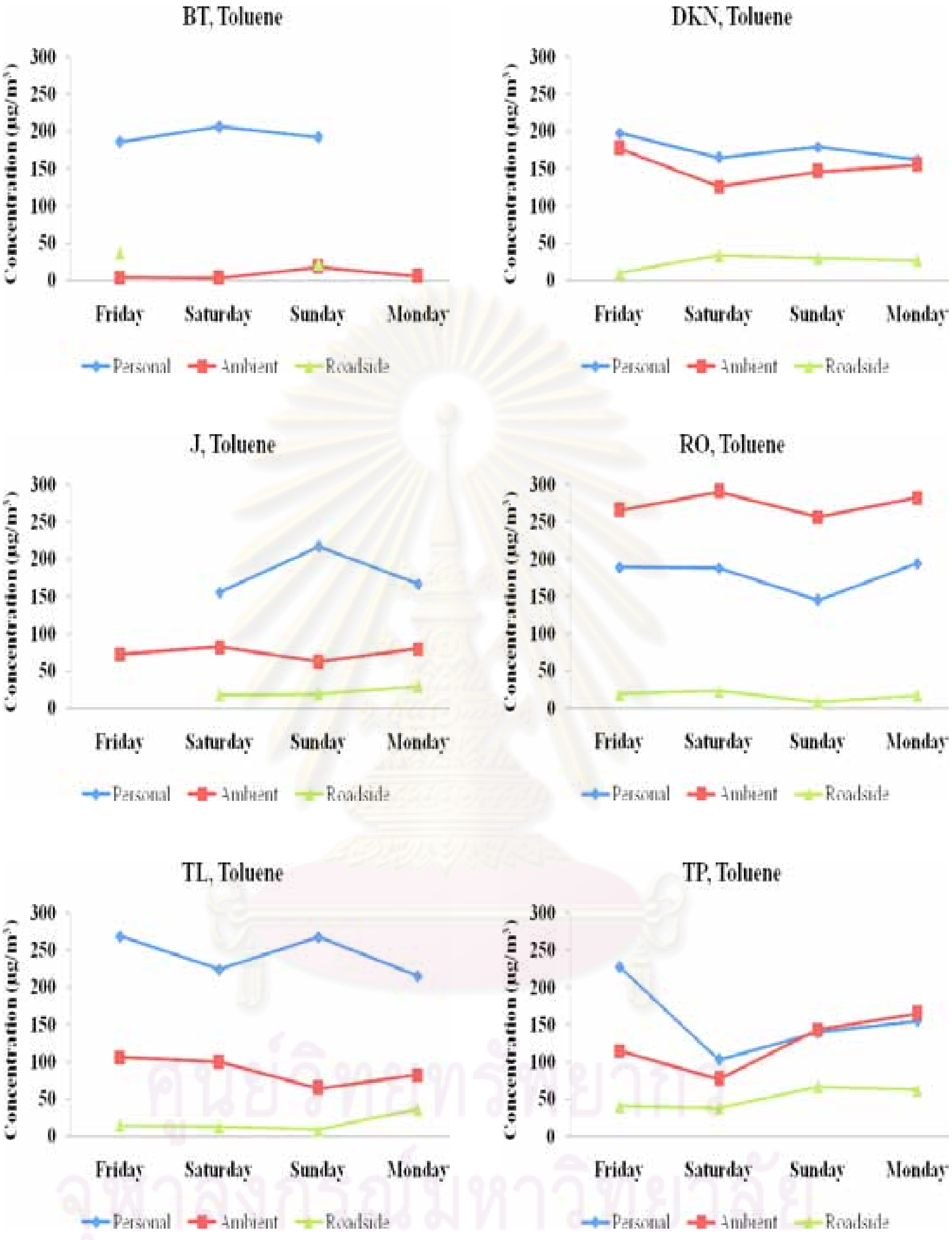


Figure 4.8 The average personal exposure, ambient and roadside concentrations of Toluene at the six gas stations in the second sampling

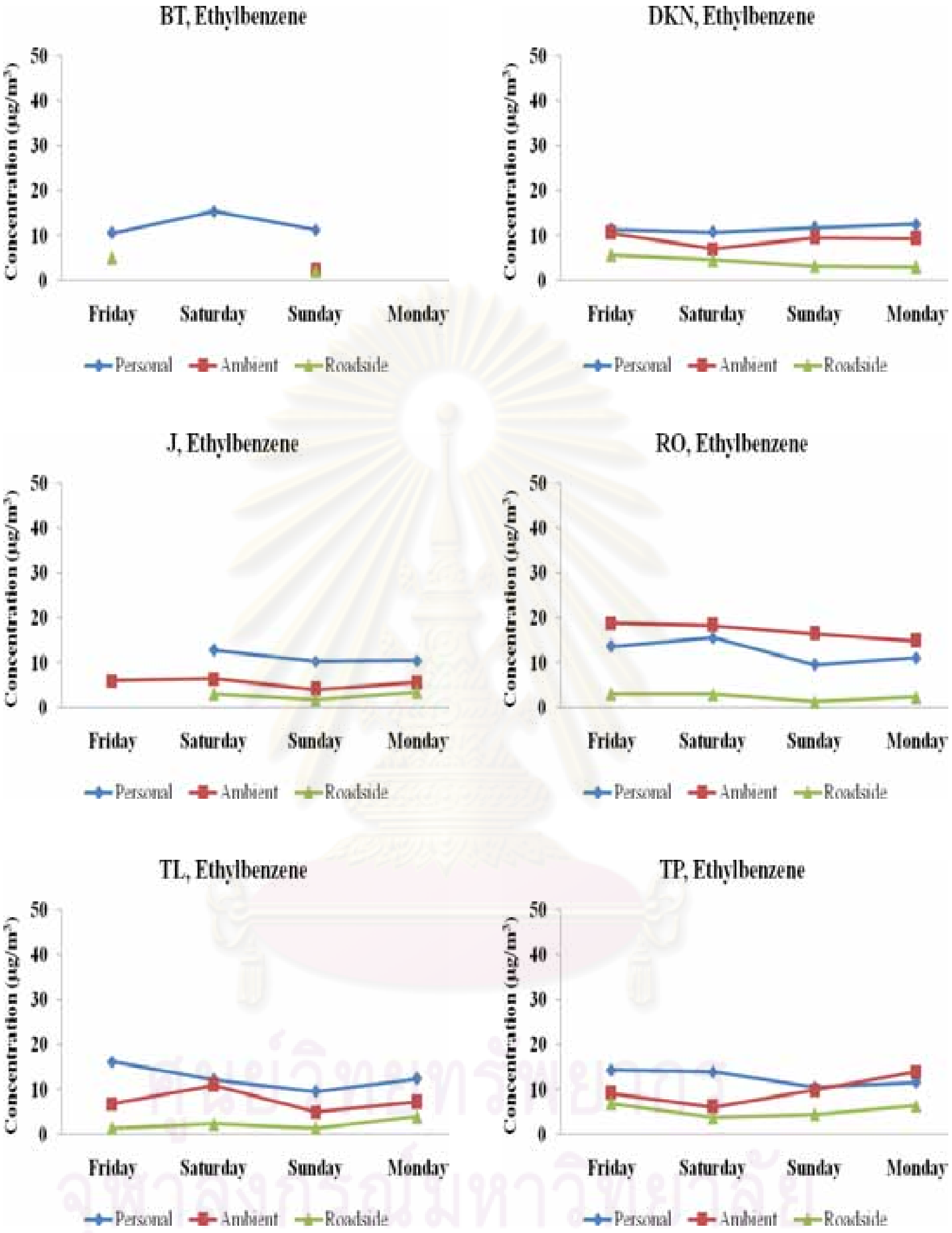


Figure 4.9 The average personal exposure, ambient and roadside concentrations of Ethylbenzene at the six gas stations in the second sampling

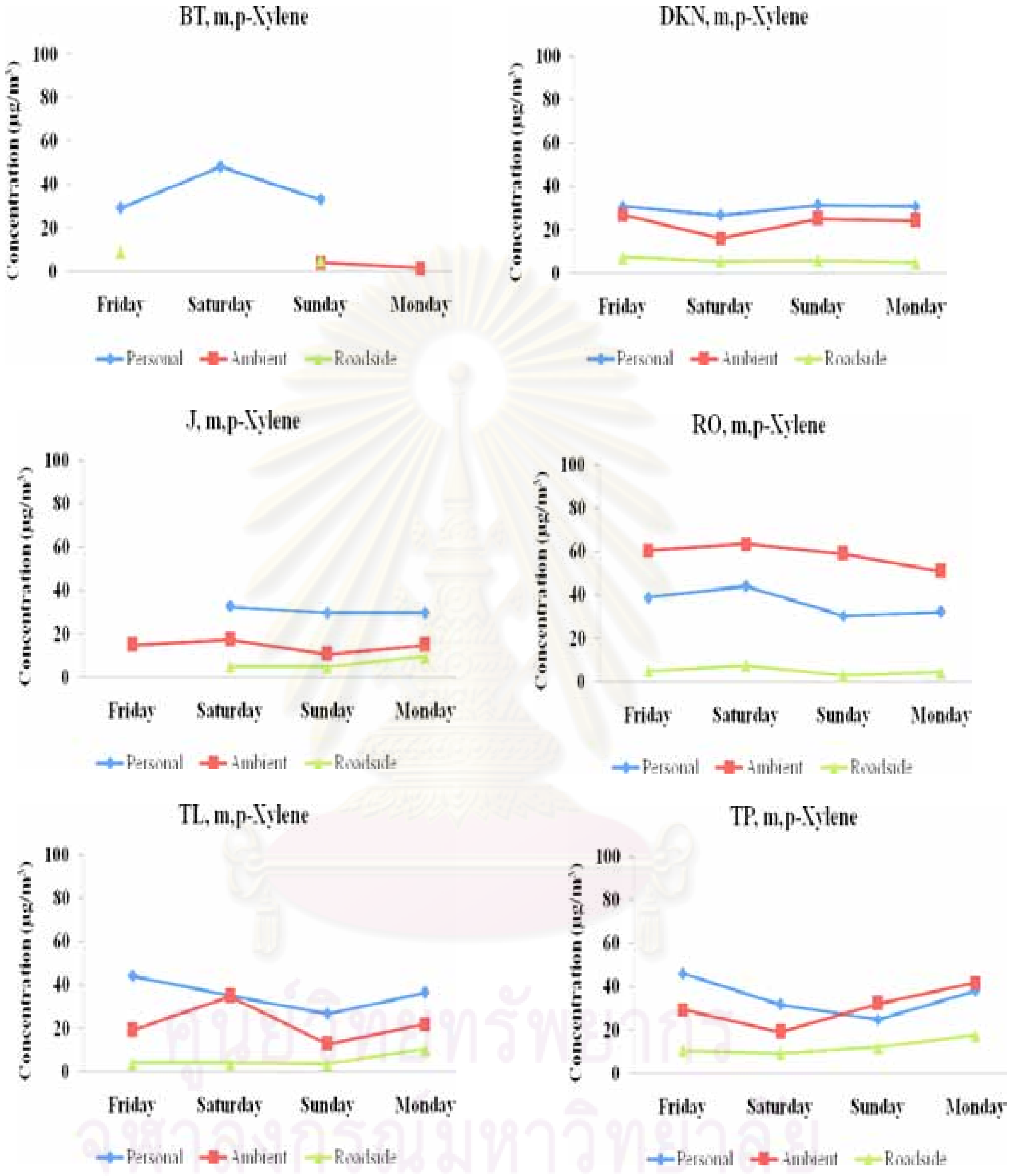


Figure 4.10 The average personal exposure, ambient and roadside concentrations of m,p-Xylene at the six gas stations in the second sampling

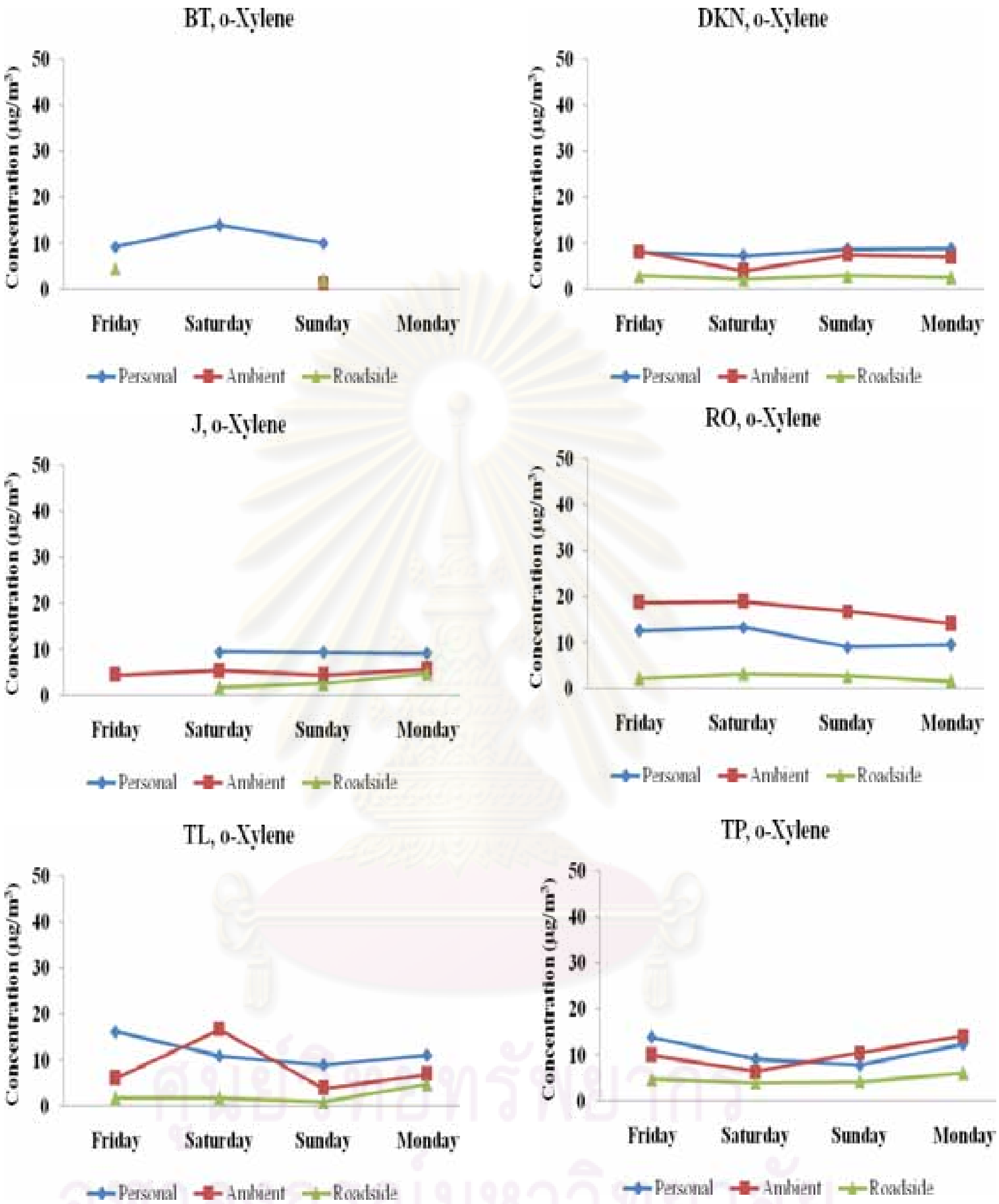


Figure 4.11 The average personal exposure, ambient and roadside concentrations of o-Xylene at the six gas stations in the second sampling

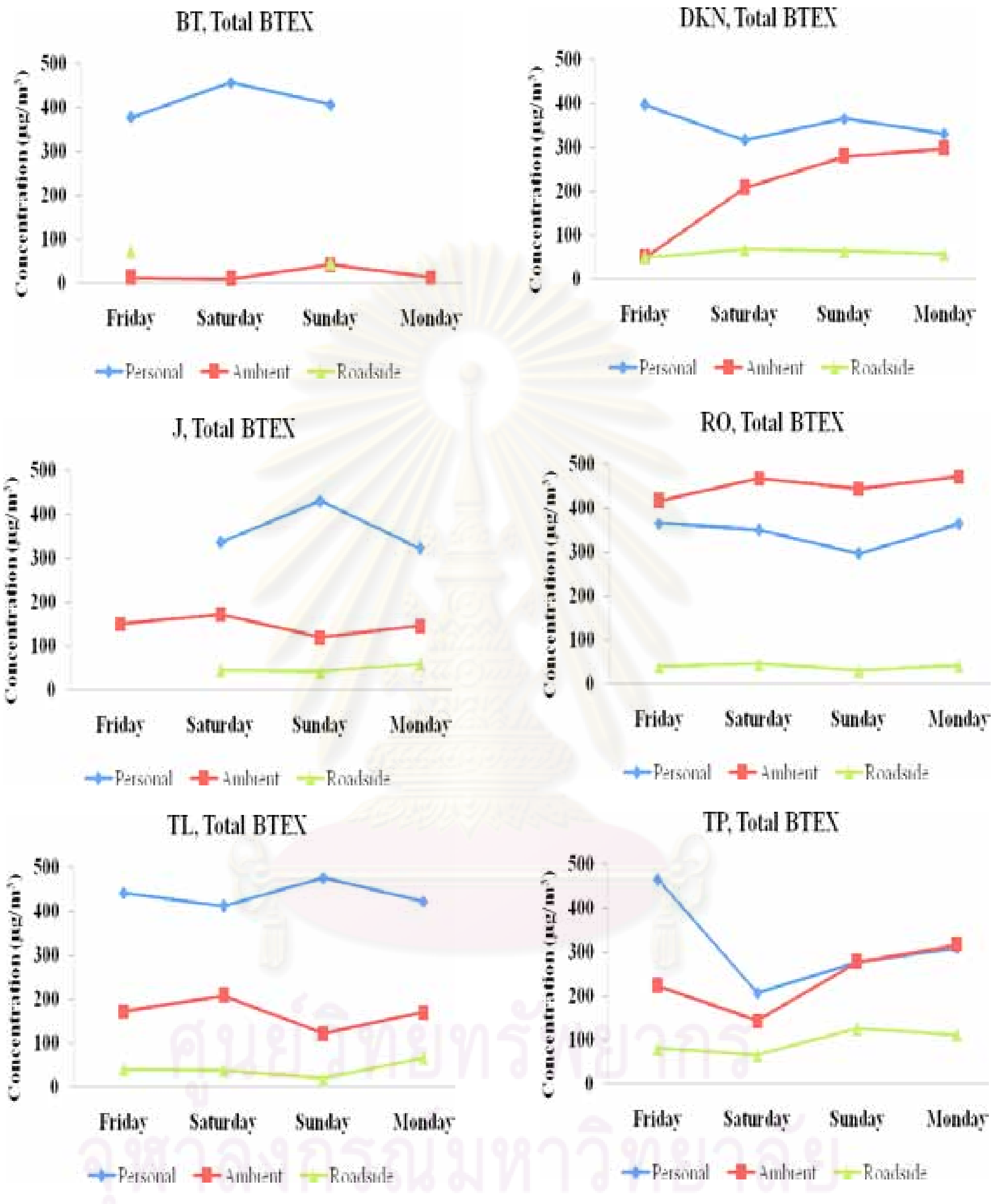


Figure 4.12 The average personal exposure, ambient and roadside concentrations of Total BTEX at the six gas stations in the second sampling

For total BTEX, Figure 4.12, the personal exposure concentrations of total BTEX at all gas stations were higher than those of ambient and of roadside concentrations, excepting for RO where the ambient concentrations were found higher than those of personal exposure and of roadside. From all gas stations, the 8-hr average concentrations of personal exposure, ambient, and roadside were 368.87 (159.40 – 715.71, n=44), 205.02 (9.86 – 471.63, n=24), and 57.41 (20.06 – 125.53, n=21) µg/m^3, respectively.

As a whole result above, most of the observed results including personal exposure, ambient and roadside concentrations, among gas stations in different four days based on weekdays (Friday and Monday) and weekends (Saturday and Sunday) was found that the concentrations on weekdays were higher than those on weekend. These should relate to the fuel circulations at each station. However, the concentrations of total BTEX at some stations on weekends tended to be slightly higher than those concentrations on weekdays especially at BT, J and TL. The point of how much difference between the concentrations observed on weekends and weekdays might depend on customer behavior and community surrounding gas station. This result was found the same trend as the previous study which of most concentrations of total VOCs at gas stations was not much different between on weekdays, and those concentrations were higher than weekends at some gas stations (Thaveevongs, 2008).

From summary results of this study and of some previous studies in Table 4.9, comparing BTEX measured in the widespread area of Bangkok to the result studies in the inner city of Bangkok, there were lower concentrations of BTEX for both ambient and personal exposure in the second sampling. For the other studies, the ambient concentrations of benzene and toluene were found in the same range as those concentration of study in India (Majumdar *et al.*, 2008), but the personal exposure concentrations of BTEX were found lower than some previous studies results (Majumdar *et al.*, 2008; Thaveevongs *et al.*, 2010; Yimrungruang *et al.*, 2008; Periago and Prado, 2005; Bono *et al.*, 2003). The roadside concentrations in this study were lower than those measured 12-hr in the daytime at the roadside in India where the traffic density was high (Dutta *et al.*, 2009).

Table 4.9 Comparison of BTEX measured in the second sampling with the result of the first sampling and other studies

Location	Comp.	Ambient conc.	Personal conc.	Roadside Conc.	Reference
Bangkok, Thailand	B^1	166.23(95.47–262.90)	220.29(55.22–292.52)	-	This study
	T^1	302.64(167.74–574.17)	297.03(94.77–490.38)	-	
	E^1	44.72(24.61–73.48)	34.96(22.64–52.42)	-	
	m,p-X^1	111.27(46.71–218.40)	81.67(40.79–154.14)	-	
	o-X^1	38.83(17.59–75.13)	28.22(15.64–49.90)	-	
	B^2	52.00(5.98–109.19)	123.70(36.93–259.73)	16.23(4.80–37.38)	
	T^2	112.45(3.47–290.47)	188.39(69.21–404.29)	27.45(8.56–67.20)	
	E^2	9.23(2.24–18.83)	12.20(7.86–22.08)	3.48(1.33–6.94)	
	m,p-X^2	26.41(1.52–63.40)	34.16(22.33–59.03)	7.14(3.01–17.71)	
	o-X^2	8.89(1.39–18.96)	10.42(5.28–23.55)	3.11 (0.91–6.11)	
Kolkata, India	B	-	-	79.18	Dutta *et al.*, 2009[a]
	T	-	-	86.22	
	E	-	-	16.41	
	m,p-X	-	-	29.58	
	o-X	-	-	22.60	
Kolkata, India	B	(17.4–81.6)	137.5(58.2–253.3)	-	Majumdar *et al.*, 2008
	T	(49.3–236.8)	643.6(210.4–1536.0)	-	
	E	-	118.0	-	
	m,p-X	-	209.7	-	
	o-X	-	68.2	-	
Bangkok, Thailand	B	-	(308–852)	-	Thaveevongs *et al.*, 2010
	T	-	(270–682)	-	
	E	-	(10–27)	-	
	m,p-X	-	(22–58)	-	
	o-X	-	(11–20)	-	
Chonburi, Thailand	B	-	876.4	-	Yimrungruang *et al.*, 2008
	T	-	1305.8	-	
	E	-	44.0	-	
	X	-	208.6	-	
Spain	B^1	-	241 (114–452)	-	Periago and Prado, 2005
	T^1	-	580 (194–1141)	-	
	X^1	-	216 (91–411)	-	
	B^2	-	163 (35–554)	-	
	T^2	-	753 (172–2142)	-	
	X^2	-	316 (125–871)	-	
Torino, Italy	B^1	-	502.7	-	Bono *et al.*, 2003
	T^1	-	711.6	-	
	X^1	-	379.4	-	
	B^2	-	160.9	-	
	T^2	-	567.5	-	
	X^2	-	285.2	-	

Remark: The concentrations result is presented as the average (range) with the unit of $\mu g/m^3$

^{1} means the 1st sampling, ^{2} means the 2nd sampling

[a] A study was focused especially on roadside in the northern part of Kolkata (high traffic volume) for 12-hr daytime.

When considered the 8-hr average concentration of personal exposure, ambient and roadside between all gas stations, the result can be displayed as Figure 4.13. In addition, the mean difference between BTEX of all stations was statistically analyzed using Compared mean one way ANOVA, *SPSS 17.0 for Window*. The result was summarized in Table 4.10 and the detail of statistical analysis was shown in Appendix E.

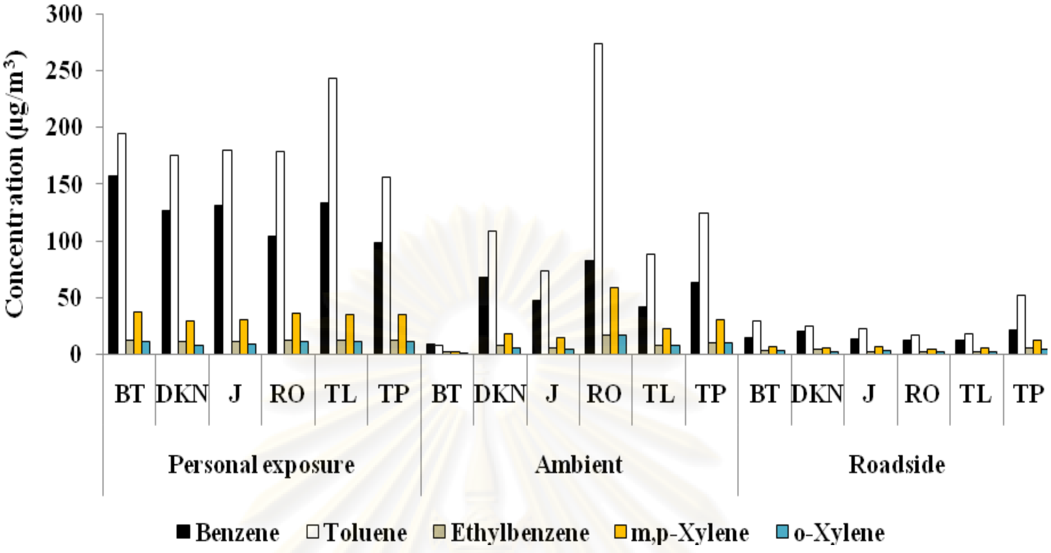


Figure 4.13 The 8-hr average BTEX concentration of personal exposure, ambient and roadside between all gas stations

Table 4.10 The mean difference between BTEX of all gas stations

Comp-ound	Compared mean of BTEX		
	Personal exposure	Ambient	Roadside
B	BT^{b}> TL^{ab}= J^{ab}= DKN^{ab}> RO^{a}= TP^{a}	RO^{c}> DKN^{bc}= TP^{bc}> J^{b}= TL^{b} > BT^{a}	TP^{a} = DKN^{a} = BT^{a} = J^{a} = TL^{a} = RO^{a}
T	TL^{b}> BT^{ab}> J^{a} = RO^{a} = DKN^{a} = TP^{a}	RO^{d}> TP^{c} > DKN^{bc} = TL^{bc} > J^{b} > BT^{a}	TP^{b} > BT^{a} = DKN^{a} = J^{a} = TL^{a} = RO^{a}
E	TL^{a}= TP^{a} = RO^{a} = BT^{a} = DKN^{a} = J^{a}	RO^{c} > TP^{b} > DKN^{ab} = TL^{ab} > J^{a} *	TP^{b} > DKN^{ab} = BT^{ab} > J^{a} = RO^{a}= TL^{a}
m,p-X	BT^{a}= RO^{a} = TL^{a} = TP^{a} = J^{a} = DKN^{a}	RO^{d} > TP^{c} > TL^{bc} > DKN^{b} > J^{ab}> BT^{a}	TP^{b} > BT^{a} = J^{a} = DKN^{a} = TL^{a} = RO^{a}
o-X	TL^{b}= RO^{ab}= BT^{ab}= TP^{ab}= J^{ab}>DKN^{a}	RO^{c} > TP^{b} > TL^{ab} > DKN^{a} = J^{a} *	TP^{b}> BT^{ab} = J^{ab} > DKN^{a} = RO^{a} = TL^{a}
TBTEX	TL^{b}> BT^{ab}= J^{ab}= DKN^{ab}= RO^{ab}>TP^{a}	RO^{d}> TP^{c} > DKN^{bc} = TL^{bc} > J^{b} > BT^{a}	TP^{b} > BT^{a} = DKN^{a} = J^{a} = TL^{a} = RO^{a}

Remark: B = Benzene, T = Toluene, E = Ethylbenzene, m,p-X = m,p-Xylene, o-X = o-Xylene and TBTEX = Total BTEX

*The result at BT was not taken to compare due to the number of samples was less than two.

The characters on the right of each gas station show the comparable mean difference among gas stations

Considering the result of personal exposure to BTEX of the workers at all gas stations. From Figure 4.13 and Table 4.10, the exposure to benzene was found the highest at BT (Bang Khun Thian district) as well as those found for m,p-xylene.

While, theirs exposure to toluene, ethylbenzene, o-xylene and total BTEX were found the highest level at TL station (Saphan Sung district). However, almost the workers' exposure to ethylbenzene, m,p-xylene and o-xylene was not significant different even they worked at different places. This reveals that ethylbenzene, m,p-xylene and o-xylene might not be the major substances directly emitted from the fuel.

For the result of ambient concentration from Figure 4.13 and Table 4.10, all substances measured at RO (Phayathai district) were found significantly higher than those found at other stations. Otherwise, BT was the station where all substances found at the lowest level. This distribution of all substances might relate directly to the fuel circulation as given in Table 3.2 (chapter 3).

When compared the concentrations at roadside of all gas stations, Figure 4.13 and Table 4.10 show that the highest concentration of all substances was observed at TP (Pathumwan district), while the lowest concentration was found at RO or TL station. This result of roadside was not the same trend found for personal exposure and ambient. This can be explained that the concentration of BTEX at roadside might be strongly affected from the traffic condition on the road where the station located. TP station is located on Rama IV Rd. and near an express way entrance, traffic at this position is always congested, whereas, the traffic flow nearby the RO (locating on Viphawadee Road) and TL (locating on Ramkhamhaeng Road) is quite good and not always congested like at TP station.

As above results, the workers worked at gas stations with the same fuel productions in different areas of Bangkok could expose to different levels of BTEX. Workers' activities, location configuration and local conditions surrounding the sampling station would have some effects on the distribution of BTEX at such microenvironment. More explicit relationship between some available factors affecting on the contribution of BTEX will be discussed later on.

4.4.2 Comparison on carbonyl compounds at the gas stations

The concentrations of the major and minor species of carbonyl compounds collected from personal exposure, ambient and roadside for four days in the second sampling were presented in Figures 4.14 – 4.22. As mentioned in 4.4.1, there was a problem on operation of the personal air pump at BT and J stations. Then, complete data could not be obtained.

The statistical analysis of the data in the second sampling was also performed as the same method as explained in 4.3. Before calculating the average personal exposure concentration of two gas station workers in four days, the paired mean difference between the gas station worker#1 (n=4) and the gas station worker#2 (n=4) in each gas station was tested using *SPSS 17.0 for Window*, as the description summarized in Appendix E. The statistical results show that all of personal exposure concentrations of carbonyl compounds between two workers were not different at the confidence interval of 95%.

At each station, the 8-hr average concentrations of carbonyl compounds (the major and minor species) for personal exposure, ambient, and roadside were derived from 8 samples of the workers (n=8), 4 samples of ambient (n=4) and 4 samples of roadside (n=4), respectively. The concentrations of carbonyl compounds were presented with 3 groups including personal exposure, ambient and roadside as shown in Figure 4.14 – 4.22.

From Figure 4.14, the personal exposure concentrations of formaldehyde at all gas stations were mostly in the range of ambient and roadside concentrations, excepting for BT where most of ambient concentrations in four days were lower than those of the other stations and for TL where the personal exposure concentration on Friday was found higher than those of personal exposure and of roadside approximately 2 times. From all gas stations, the 8-hr average concentrations of personal exposure, ambient, and roadside were 10.95 (3.40 – 39.76, n=44), 7.83 (0.95 – 15.60, n=24), and 7.81 (3.27 – 14.82, n=21) µg/m^3, respectively.

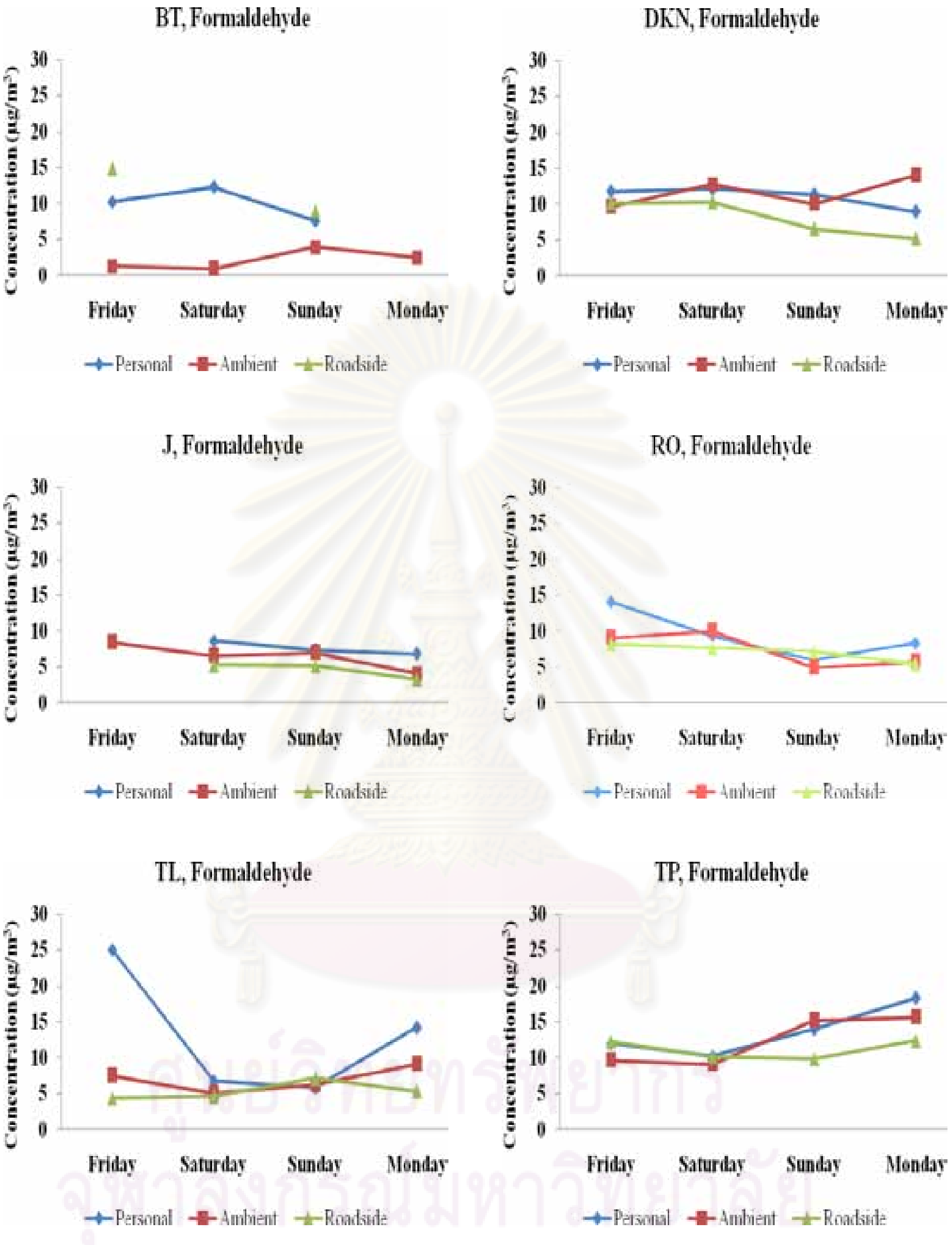


Figure 4.14 The average personal exposure, ambient and roadside concentrations of Formaldehyde at the six gas stations in the second sampling

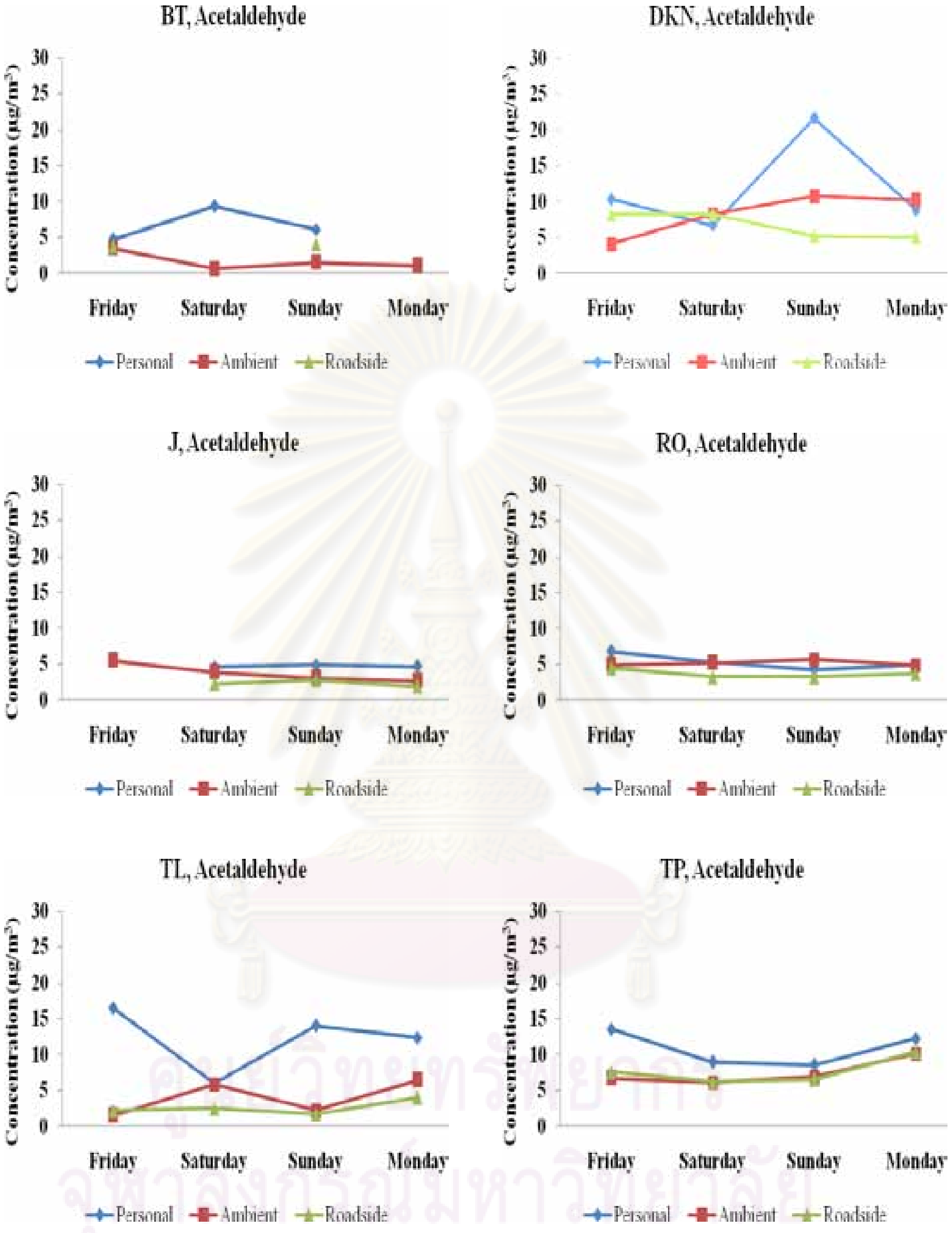


Figure 4.15 The average personal exposure, ambient and roadside concentrations of Acetaldehyde at the six gas stations in the second sampling

From Figure 4.15, the personal exposure concentrations of acetaldehyde at all gas stations were mostly in the range of ambient and of roadside concentrations, excepting for BT where most of ambient concentrations in four days were lower than those of the other stations and for DKN and TL where the personal exposure concentrations in some days were found higher than those of personal exposure and of roadside approximately 1 - 2 times. This was the same trend as found for formaldehyde. From all gas stations, the 8-hr average concentrations of personal exposure, ambient, and roadside were 8.87 (1.59 – 35.33, n=44), 5.05 (0.57 – 10.74, n=24), and 4.62 (1.65 – 10.36, n=21) µg/m^3, respectively.

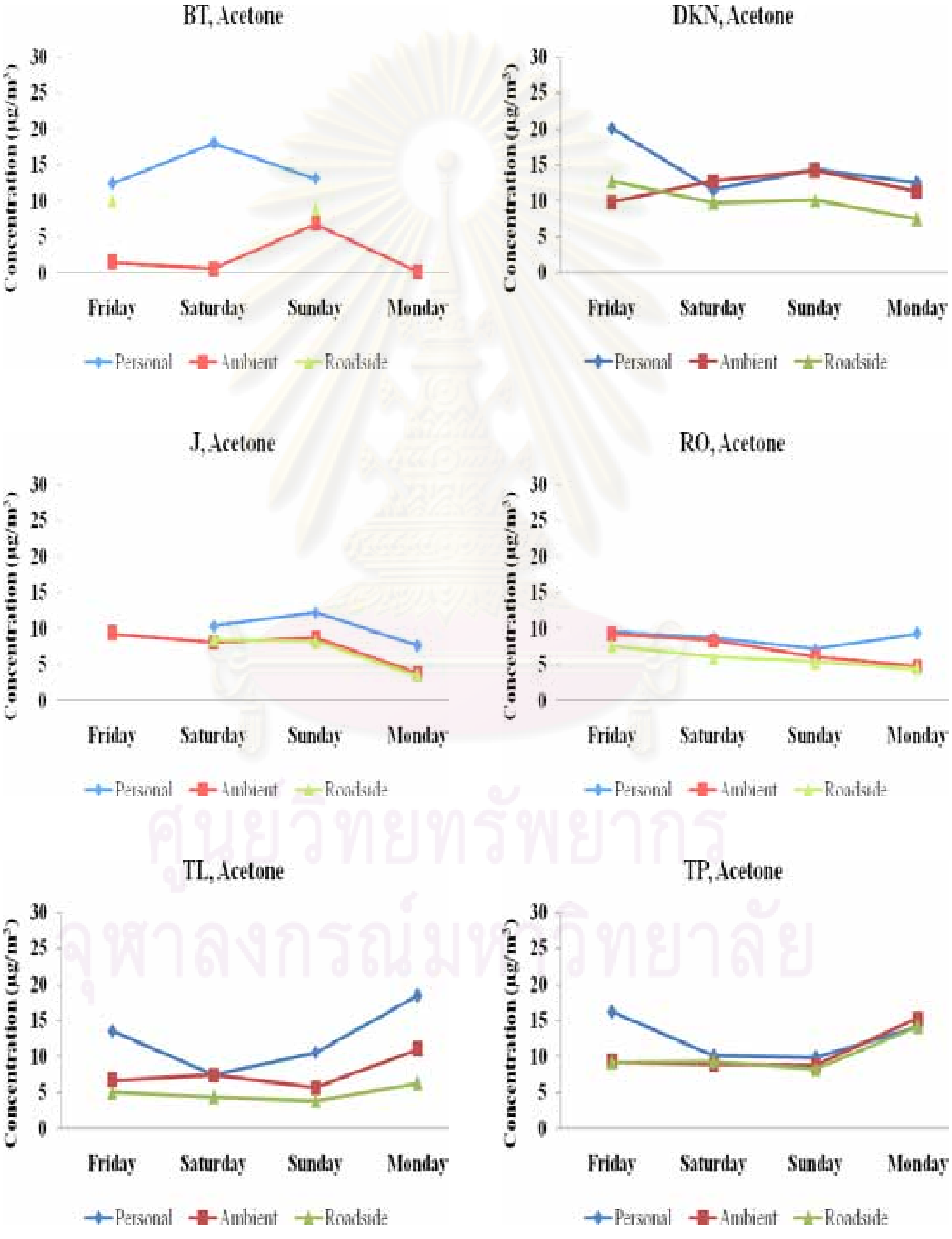


Figure 4.16 The average personal exposure, ambient and roadside concentrations of Acetone at the six gas stations in the second sampling

From Figure 4.16, the personal exposure concentrations of acetone at all gas stations were mostly in the range of ambient and of roadside concentrations, excepting for BT where most of ambient concentrations in four days were lower than those of the other stations and for DKN, J, TL and TP where the personal exposure concentrations in some days were found higher than those of personal exposure and of roadside approximately 2 times. From all gas stations, the 8-hr average concentrations of personal exposure, ambient, and roadside were 12.15 (3.49 – 23.22, n=44), 7.85 (0.21 – 15.29, n=24), and 7.78 (3.46 – 14.18, n=21) µg/m^3, respectively.

From Figure 4.17, the personal exposure concentrations of propionaldehyde at all gas stations were mostly in the range of ambient and of roadside concentrations, excepting for BT where the ambient concentrations in four days were lower than those of the other stations and for TL where the personal exposure concentrations in some days were found higher than those of personal exposure and of roadside approximately 2 times. From all gas stations, the 8-hr average concentrations of personal exposure, ambient, and roadside were 1.03 (0.27 – 2.37, n=44), 0.89 (0.20 – 1.99, n=22), and 0.73 (0.25 – 1.42, n=21) µg/m^3, respectively.

From Figure 4.18, the personal exposure concentrations of crotonaldehyde at all gas stations were mostly in the range of ambient and of roadside concentrations, excepting for BT where the ambient concentration on Monday was found higher than those of personal exposure and of roadside approximately 2 times and for TL where the personal exposure concentration on Friday was found higher than those of personal exposure and of roadside approximately 2 - 3 times. From all gas stations, the 8-hr average concentrations of personal exposure, ambient, and roadside were 3.47 (0.94 – 17.07, n=43), 3.08 (0.92 – 12.88, n=23), and 2.53 (0.68 – 8.79, n=21) µg/m^3, respectively.

From Figure 4.19, the personal exposure concentrations of butylraldehyde at all gas stations were mostly in the range of ambient and of roadside concentrations. From all gas stations, the 8-hr average concentrations of personal exposure, ambient, and roadside were 4.30 (1.51 – 7.57, n=42), 3.83 (0.97 – 9.54, n=24), and 3.20 (0.78 – 7.77, n=21) µg/m^3, respectively.

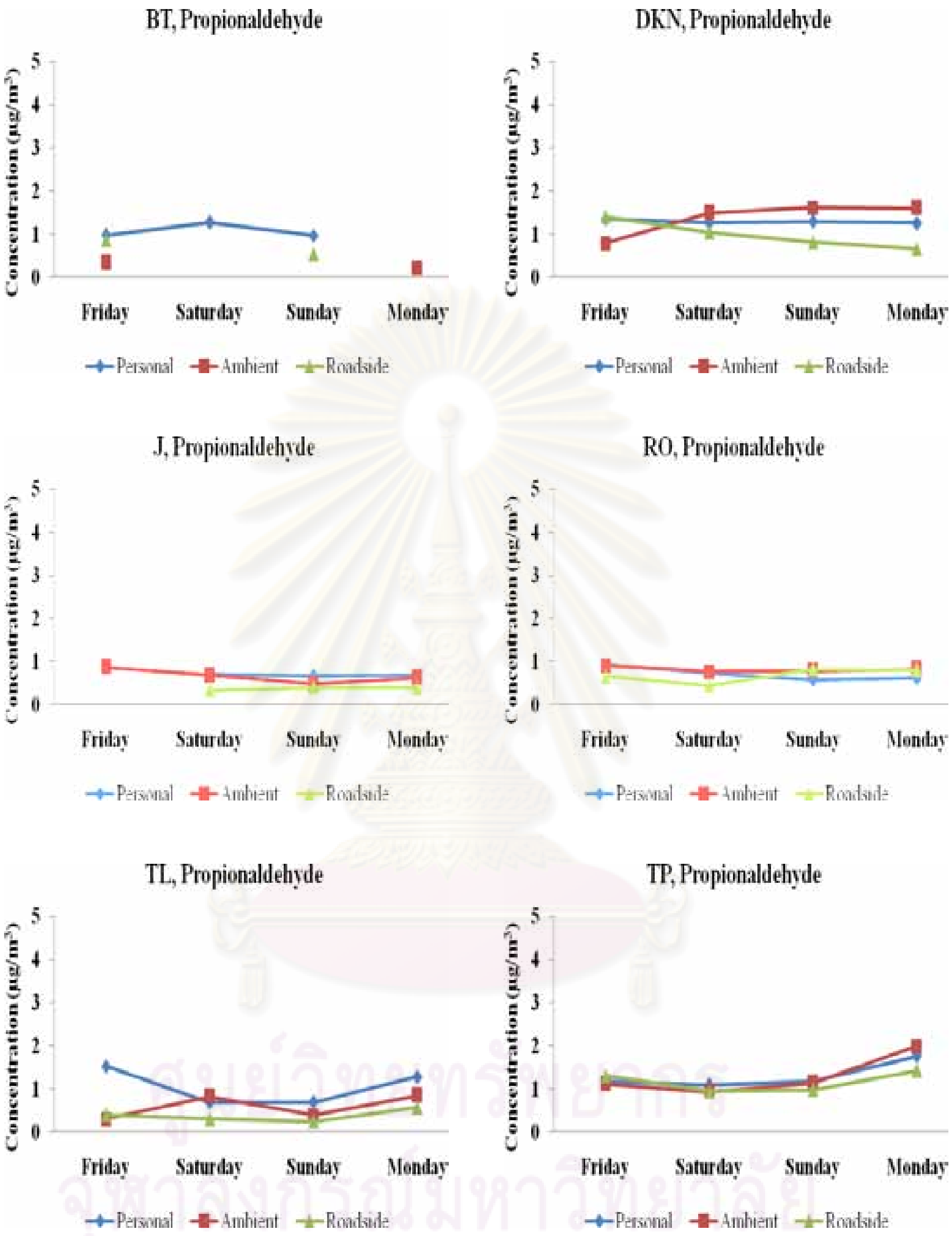


Figure 4.17 The average personal exposure, ambient and roadside concentrations of Propionaldehyde at the six gas stations in the second sampling

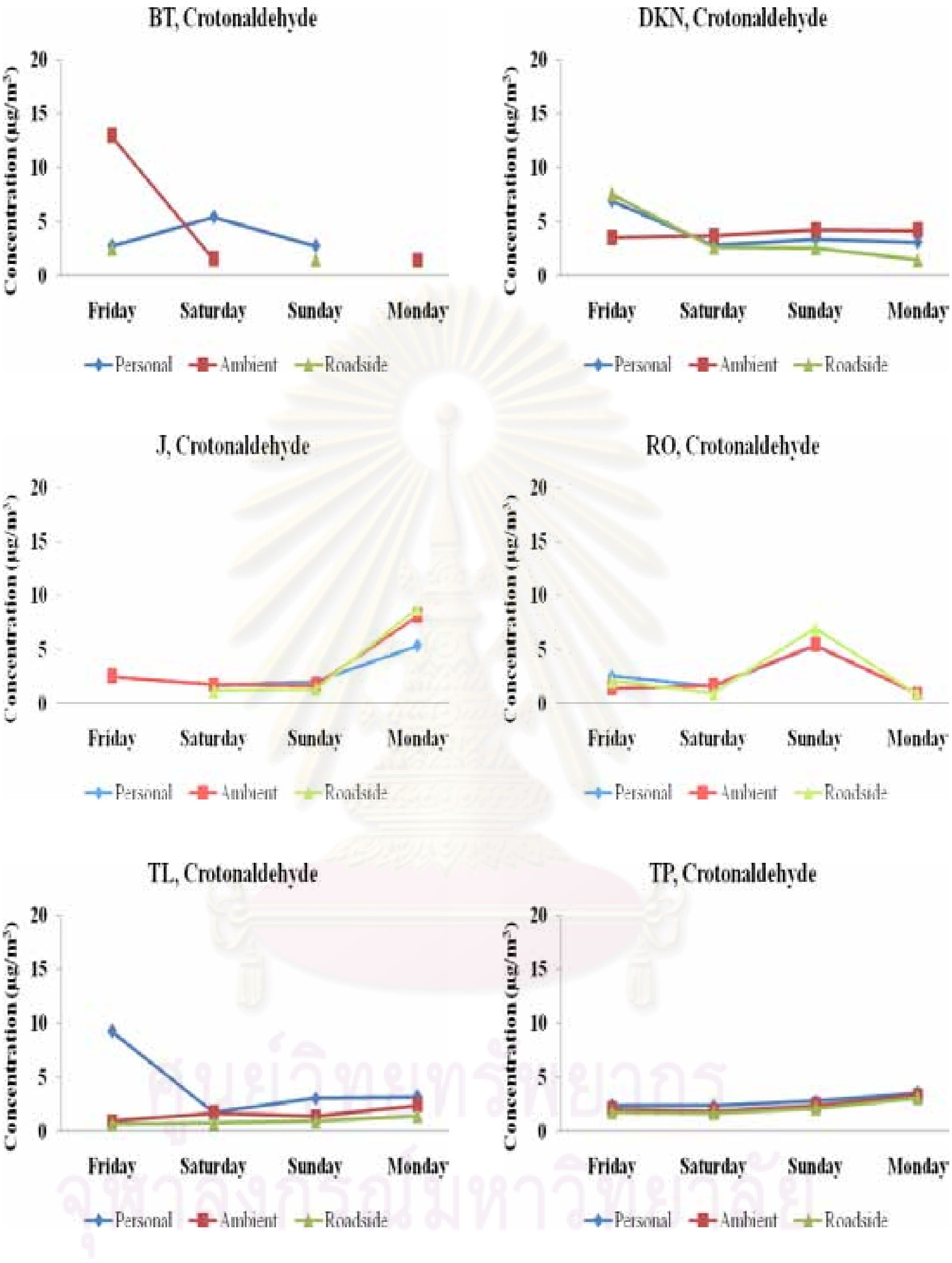


Figure 4.18 The average personal exposure, ambient and roadside concentrations of Crotonaldehyde at the six gas stations in the second sampling

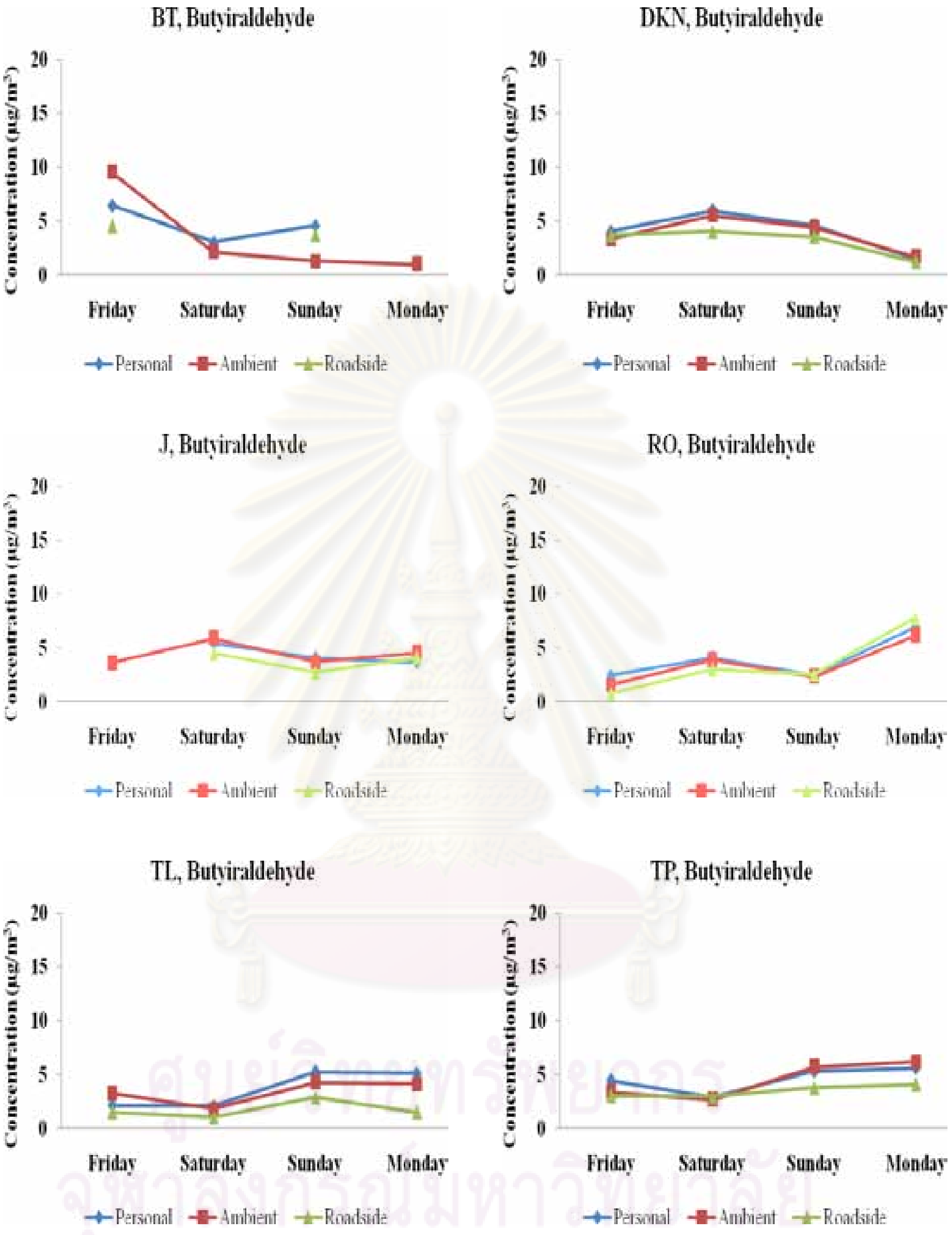


Figure 4.19 The average personal exposure, ambient and roadside concentrations of Butylraldehyde at the six gas stations in the second sampling

From Figure 4.20, the personal exposure concentrations of benzaldehyde at all gas stations were mostly in the range of ambient and of roadside concentrations, excepting for BT and RO where the roadside concentrations in some days were found higher than those of personal exposure and of ambient approximately 2 - 3 times. From all gas stations, the 8-hr average concentrations of personal exposure, ambient, and roadside were 1.05 (0.32 – 4.57, n=31), 0.84 (0.29 – 3.71, n=12), and 1.57 (0.31 – 5.35, n=11) µg/m^3, respectively.

From Figure 4.21, the personal exposure concentrations of valeraldehyde at all gas stations were mostly in the range of ambient and of roadside concentrations, excepting for J where the ambient concentration on Friday was found higher than those of personal exposure and of ambient approximately 2 - 3 times. From all gas stations, the 8-hr average concentrations of personal exposure, ambient, and roadside were 1.30 (0.33 – 3.09, n=41), 1.84 (0.33 – 5.87, n=22), and 1.49 (0.33 – 3.22, n=19) µg/m^3, respectively.

Form Figure 4.22, the personal exposure concentrations of hexanaldehyde at all gas stations were mostly in the range of ambient and of roadside concentrations. From all gas stations, the 8-hr average concentrations of personal exposure, ambient, and roadside were 1.99 (0.83 – 3.96, n=43), 1.81 (0.71 – 3.44, n=21), and 1.54 (0.49 – 3.00, n=21) µg/m^3, respectively.

As a whole result above, most of the observed results including personal exposure, ambient and roadside concentrations, among gas stations in different four days based on weekdays (Friday and Monday) and weekends (Saturday and Sunday) was found that the concentrations on weekdays were higher than those on weekend as same as the trend of BTEX. The distribution of carbonyl compounds was probably resulting from an existing of BTEX.

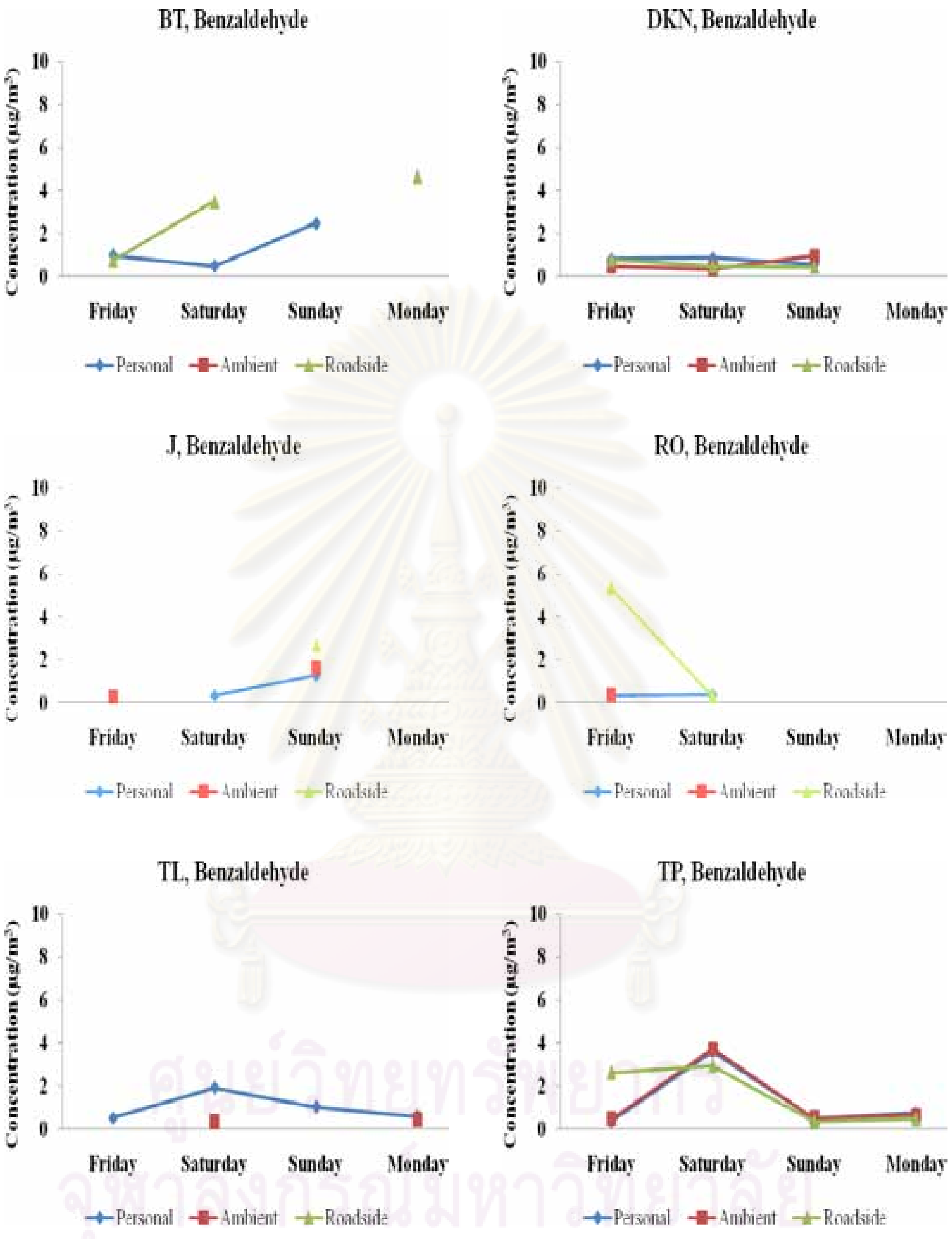


Figure 4.20 The average personal exposure, ambient and roadside concentrations of Benzaldehyde at the six gas stations in the second sampling

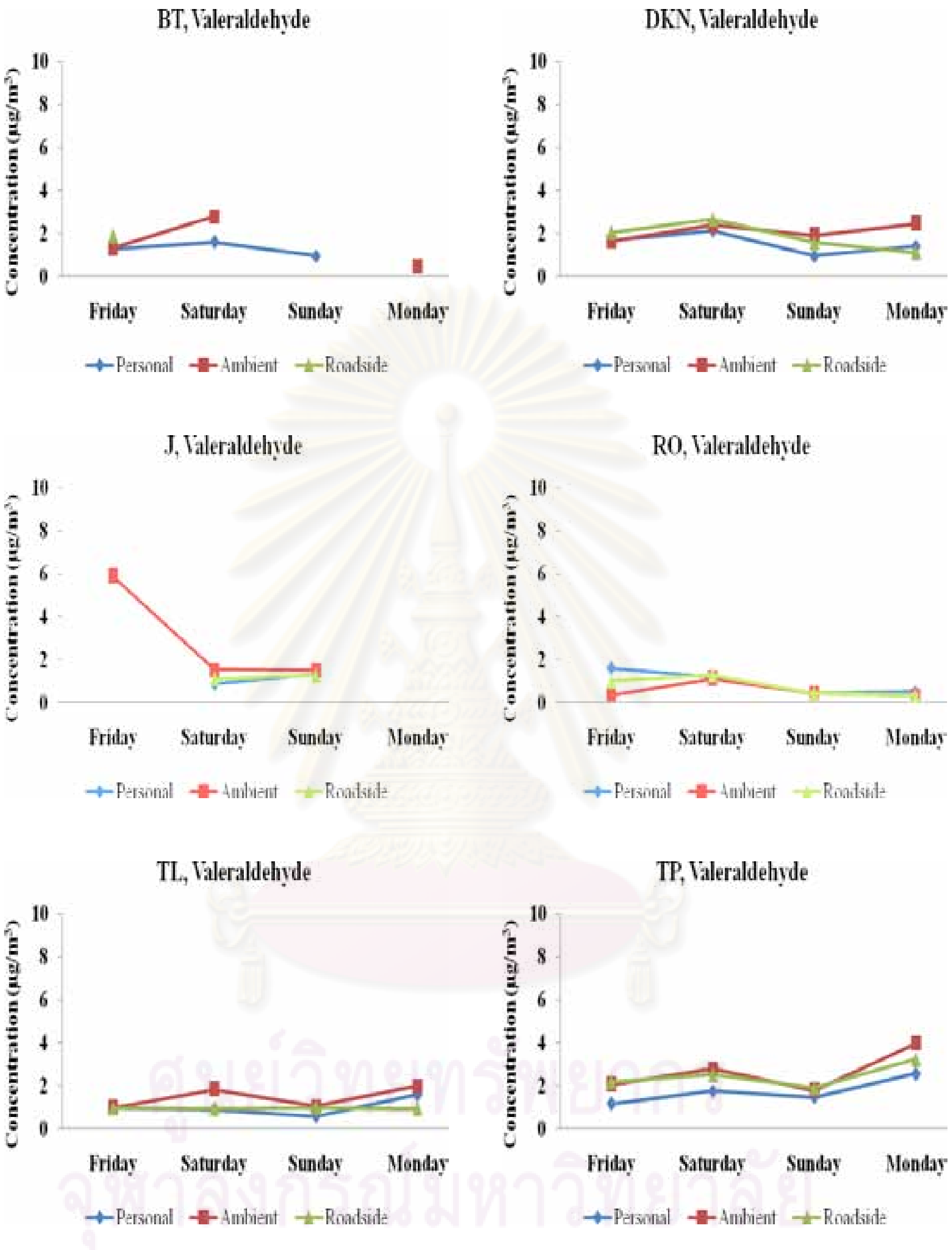


Figure 4.21 The average personal exposure, ambient and roadside concentrations of Varleraldehyde at the six gas stations in the second sampling

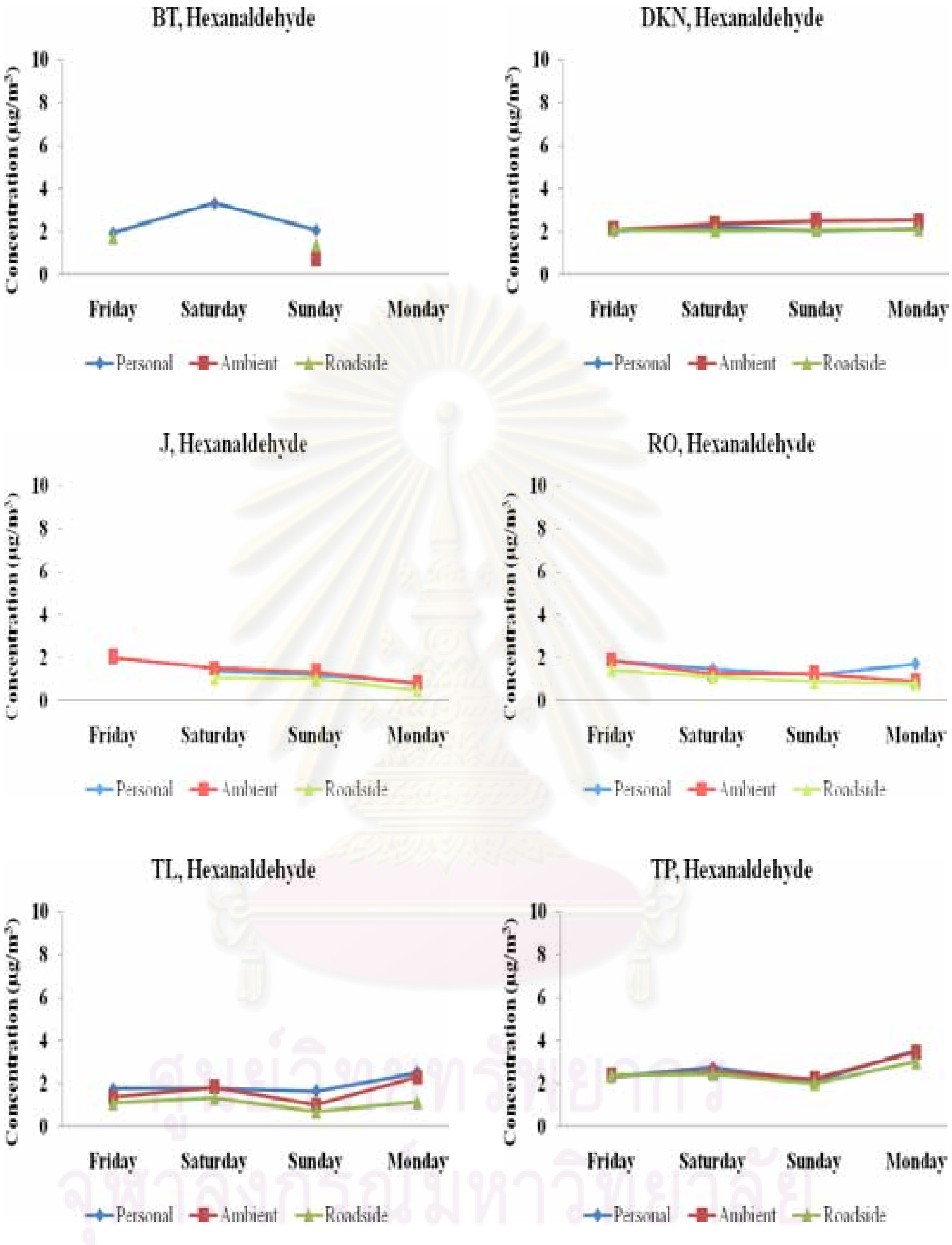


Figure 4.22 The average personal exposure, ambient and roadside concentrations of Hexanaldehyde at the six gas stations in the second sampling

From summary results of this study and of some previous studies in Table 4.11, comparing major carbonyl compounds species measured in the widespread area of Bangkok to the result studies in the inner city of Bangkok, there were lower concentrations of formaldehyde and propionaldehyde for both ambient and personal exposure in the second sampling. While, the concentration of acetaldehyde in the second sampling was higher than that of the first sampling, and acetone was found the same range. For the other studies, the ambient concentrations of formaldehyde, acetaldehyde and acetone were lower than those found in India (Majumdar *et al.*, 2008). The roadside concentrations in this study were lower than those measured 12-hr in the daytime at the roadside in India as well as the BTEX (Dutta *et al.*, 2009).

Table 4.11 Comparison of the major species of carbonyl compounds measured in the second sampling with the result of first sampling and other studies

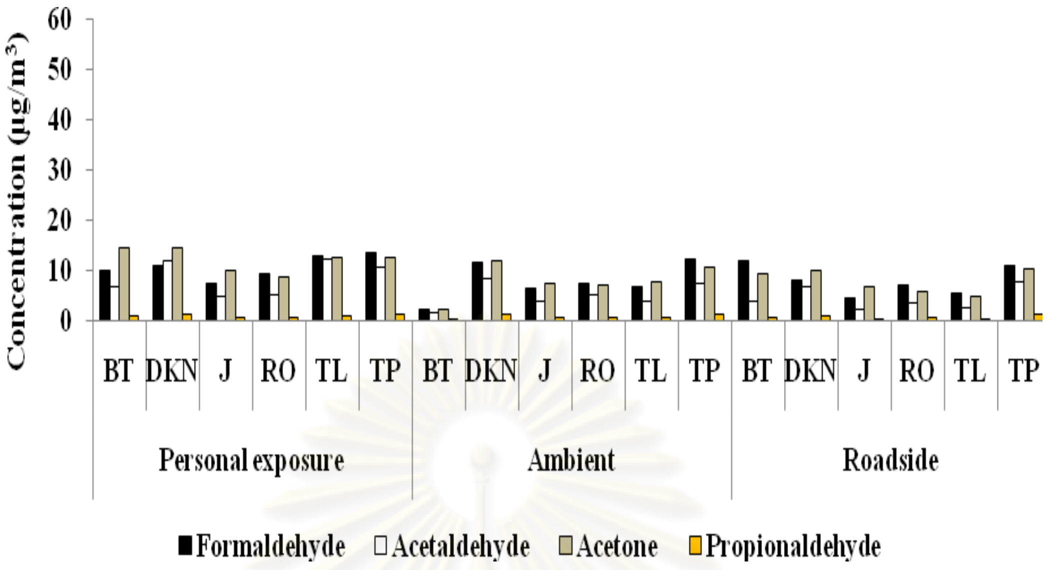
Location	Comp.	Ambient conc.	Personal conc.	Roadside Conc.	Reference
Bangkok, Thailand	Formald[1]	11.12(5.31–15.12)	12.17(7.56–18.83)	-	This study
	Acetald[1]	3.36(1.27–7.29)	5.34(2.15–13.11)	-	
	Acetone[1]	7.36(6.26–9.07)	12.46(4.82–26.99)	-	
	Propionald[1]	1.28(0.45–4.78)	3.55(0.59–14.86)	-	
	Formald[2]	7.83(0.95–15.60)	10.95(3.40–39.76)	7.81(3.27–14.82)	
	Acetald[2]	5.05(0.57–10.74)	8.87(1.59–35.33)	4.62(1.65–10.36)	
	Acetone[2]	7.85(0.21–15.29)	12.15(3.49–23.22)	7.78(3.46–14.18)	
	Propional[2]	0.89(0.20–1.99)	1.03(0.27–2.37)	0.73(0.25–1.42)	
Kolkata, India	Formald	27.8(11.6–55.5)	-	-	Majumdar *et al.*, 2008
	Acetald	18.3	-	-	
	Acetone	12.2	-	-	
Kolkata, India	Formald	-	-	26.12	Dutta *et al.*, 2009[a]
	Acetald	-	-	16.46	
	Acetone	-	-	10.34	
	Propionald	-	-	3.27	

Remark: The concentrations result is present as the average (range) with the unit of µg/m^3

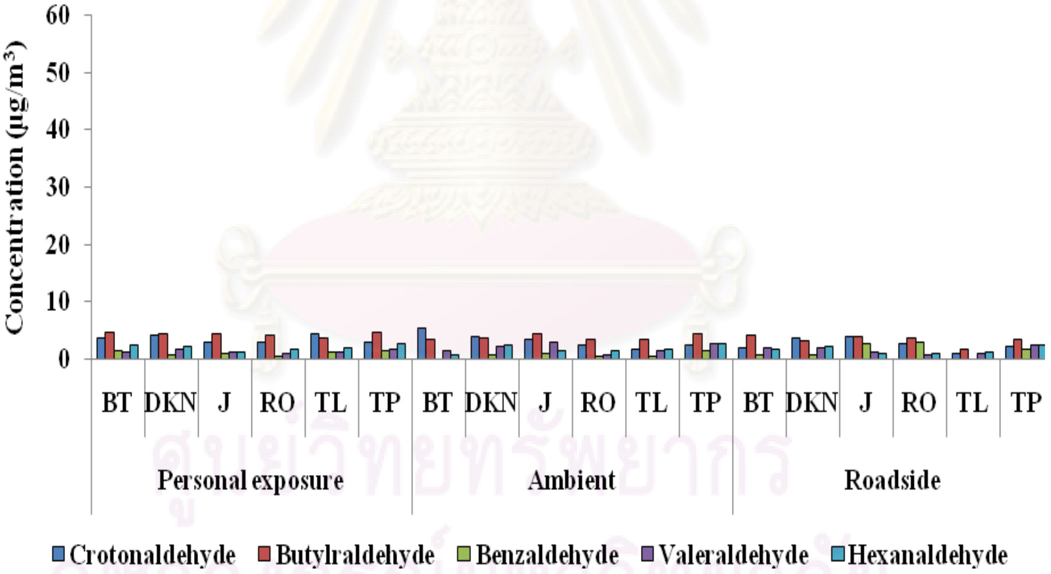
[1] means the 1st sampling, [2] means the 2nd sampling

[a] The study was focused especially on roadside in the northern part of Kolkata (the high traffic volume) for 12-hr daytime.

When considered the 8-hr average concentration of personal exposure, ambient and roadside between all gas stations, the result can be displayed as Figure 4.23. In addition, the mean difference between carbonyl compounds of all stations was statistically analyzed using Compared mean one way ANOVA, *SPSS 17.0 for Window*. The result was summarized in Table 4.12 and the detail of statistical analysis was shown in Appendix E.



(a) Major species



(b) Minor species

Figure 4.23 The 8-hr average carbonyl compounds concentration of personal exposure, ambient and roadside between all gas stations

Table 4.12 The mean difference between carbonyl compounds of all gas stations

Comp-ound	Compared mean of BTEX		
	Personal exposure	Ambient	Roadside
Formald	$TP^{a}=TL^{a}=DKN^{a}=BT^{a}=RO^{a}=J^{a}$	$TP^{c}=DKN^{c}>RO^{b}=TL^{b}=J^{b}>BT^{a}$	$BT^{c}=TP^{c}>DKN^{b}>RO^{ab}=TL^{ab}>J^{a}$
Acetald	$TL^{b}=DKN^{b}>TP^{ab}=BT^{ab}>RO^{a}=J^{a}$	$DKN^{d}>TP^{cd}>RO^{bc}>TL^{ab}=J^{ab}>BT^{a}$	$TP^{b}=DKN^{b}>BT^{a}>RO^{a}=TL^{a}=J^{a}$
Acetone	$DKN^{c}>BT^{bc}>TP^{abc}=TL^{abc}>J^{ab}>RO^{a}$	$DKN^{c}>TP^{bc}>TL^{b}=J^{b}=RO^{b}>BT^{a}$	$TP^{d}>DKN^{cd}>BT^{bcd}>J^{abc}>RO^{ab}>TL^{a}$
Propionald	$TP^{b}=DKN^{b}>BT^{ab}=TL^{ab}>RO^{a}=J^{a}$	$DKN^{b}=TP^{b}>RO^{a}=J^{a}=TL^{a}=BT^{a}$	$TP^{c}>DKN^{bc}>BT^{ab}=RO^{ab}>TL^{a}=J^{a}$
Crotonald	$TL^{a}=DKN^{a}=BT^{a}=J^{a}=RO^{a}=TP^{a}$	$BT^{a}=DKN^{a}=J^{a}=TP^{a}=RO^{a}=TL^{a}$	$J^{a}=DKN^{a}=RO^{a}=TP^{a}=BT^{a}=TL^{a}$
Butylrald	$BT^{a}=TP^{a}=J^{a}=DKN^{a}=RO^{a}=TL^{a}$	$TP^{a}=J^{a}=DKN^{a}=BT^{a}=RO^{a}=TL^{a}$	$BT^{a}=J^{a}=RO^{a}=TP^{a}=DKN^{a}=TL^{a}$
Benzald	$BT^{a}=TP^{a}=TL^{a}=J^{a}=DKN^{a}=RO^{a}$	$TP^{a}=J^{a}=DKN^{a}=TL^{a}$ **	Non comparable
Valerald	$TP^{c}>DKN^{bc}>BT^{abc}=J^{abc}>TL^{ab}>RO^{a}$	$J^{b}=TP^{b}>DKN^{ab}=BT^{ab}=TL^{ab}>RO^{a}$	$TP^{c}>DKN^{bc}>J^{ab}>TL^{a}=RO^{a}$ *
Hexanald	$TP^{d}>BT^{cd}>DKN^{c}>TL^{bc}>TL^{ab}>J^{a}$	$TP^{b}=DKN^{b}>TL^{a}=J^{a}=RO^{a}$ *	$TP^{c}=DKN^{c}>BT^{b}>TL^{ab}=RO^{ab}>J^{a}$

Remark: *The result at BT was not taken to compare due to the number of samples was less than two.
**The result at BT and RO were not taken to compare due to the number of samples was less than two.
The characters on the right of each gas station show the comparable mean difference among gas stations

Considering the result of personal exposure to carbonyl compounds of the workers at all gas stations From Figure 4.23 and Table 4.12, the exposure to formaldehyde was found the highest at TP (Pathumwan district) as well as those found for propionaldehyde, valeraldehyde and hexanaldehyde. Theirs exposure to acetaldehyde and crotonaldehyde were found the highest level at TL station (Saphan Sung district). Theirs exposure to Acetone were found the highest level at DKN station (Bang Khun Thian district). While, theirs exposure to butylraldehyde and benzaldehyde were found the highest level at BT station (Bang Khun Thian district). However, almost the workers' exposure to formaldehyde, acetaldehyde, propionaldehyde, crotonaldehyde, butylraldehyde and benzaldehyde was not significant different even they worked at different places. This reveals that formaldehyde, acetaldehyde, propionaldehyde, crotonaldehyde, butylraldehyde and benzaldehyde might not be the major substances directly emitted from the fuel, but they might be changed in accordance with some reactions of air pollutants in the surrounding atmosphere.

For the result of ambient concentration from Figure 4.23 and Table 4.12, the concentration of formaldehyde was found the highest at TP (like the personal exposure) as well as those found for butylraldehyde, benzaldehyde and hexanaldehyde. The concentration of acetaldehyde, acetone and propionaldehyde were found the highest level at DKN station. While, crotonaldehyde and valeraldehyde were found at the highest level at BT and J (Don Muang district), respectively. Otherwise, BT was the station where all major species substances found at the lowest level as same as the BTEX that also found at the lowest ambient concentration. The distribution of all substances might directly relate to primary air pollutants especially BTEX and fuel circulations.

When compared the concentrations at roadside of all gas stations, Figure 4.23 and Table 4.12 show that the highest concentration of almost substances was observed at TP, while the lowest concentration was found at J or TL station. The concentration of carbonyl compounds at roadside was likely to change in accordance with the traffic condition on the road nearby. As mentioned for BTEX, TP station is located on Rama IV Rd. and near an express way entrance, traffic at this position is always congested, whereas, the traffic flow on the roads (narrow road) closed to J and BT is quite good and there is no congestion like at TP station. However, interestingly for the Figure 4.23, the concentrations of either major or minor species at roadside were in the same range of personal exposure and ambient and differed from the pattern of BTEX. This would support the point that variation of carbonyl compound is likely to relate with the reactions of air pollutants in the atmosphere rather than direct emission from the sources.

As above results, even the workers worked at gas stations in different areas of Bangkok, theirs exposure to carbonyl compounds could be observed at different levels. Therefore, workers' activities, location configuration and local conditions surrounding the sampling station would have some effects on the distribution of carbonyl compounds at such microenvironment as same as BTEX. This matter is needed to verify how strong in relationship between some factors affecting on carbonyl compounds distribution.

To compare the 8-hr average personal exposure concentrations of BTEX and carbonyl compounds with the available occupational limits in workplace which were mentioned in Chapter 2. The 8-hr average personal exposure concentrations of benzene, toluene, ethylbenzene, xylenes, formaldehyde, acetaldehyde, acetone and propionaldehyde in this study were found less than the occupational limits (TWA 8-hr) of NIOSH, OSHA, ACGIH and those found in Thailand as shown in Table 4.13.

Table 4.13 Comparison of the 8-hr average personal exposure in the study with the occupational limits

Compound	Average personal exposure in the first sampling (μg/m^3)	Average personal exposure in the second sampling (μg/m^3)	NIOSH TWA (8-hr) (μg/m^3)	OSHA TWA (8-hr) (μg/m^3)	ACGIH TWA (8-hr) (μg/m^3)	Occupational limits in Thailand (μg/m^3)
Benzene	220.29	123.70	320	30,000	30,000	30,000
Toluene	297.03	188.39	375,000	750,000	375,000	750,000
Ethylbenzene	34.96	12.20	435,000	435,000	435,000	-
Xylenes	109.89	44.58	434,000	435,000	435,000	435,000
Formaldehyde	12.17	10.95	20	930	390	1,300
Acetaldehyde	5.34	8.87	-	360,000	-	-
Acetone	12.46	12.15	590,000 (10-hr)	2,400,000	1,200,000	-
Propionaldehyde	3.55	1.03	-	-	47,600	-

4.5 Analysis of affecting factors on ambient concentrations of BTEX and carbonyl compounds

At each gas station, an ambient sample was collected approximately at 1.5 m height above the ground in the center of the gas station using the sampling train as described in Chapter 3. The concentrations of BTEX and carbonyl compounds from ambient sample were then selected to investigate the relationship with some available the affecting factors during the sampling such as the amount of fuel circulations, the number of customer cars, the number of fuel nozzles and the atmospheric conditions.

The correlations between affecting factors and ambient concentrations of BTEX and carbonyl compounds were represented by Pearson’s correlation coefficient (*r*) with the p value of 0.01 or 0.05. In this study, the data of fuel circulations and a number of customer cars during 8-hr working period was obtained from the gas office. About information of atmospheric conditions, on site atmospheric monitoring instrument, as known as Met-One, was installed inside the gas station. Because of limitation of Met-One, only one gas station was selected to observe atmospheric conditions during each four days sampling. Met-One was then placed at three gas stations including BT, TL and RO.

4.5.1 Correlations between fuel circulations and ambient concentrations of BTEX and carbonyl compounds

In the first sampling, fuel circulation of one month (in April) at each gas station was used for calculating fuel circulation per day instead of an actual data of fuel circulation in the sampling day. The significant relationship between the average fuel circulations and the average ambient concentrations of benzene and toluene of six gas stations namely TRO, PCC, NW, TP, BK and SBS (n = 6) were only found with the Pearson's correlations coefficient (*r*) of 0.867 and of 0.851, respectively (*p* = 0.05), as shown in Figure 4.24.

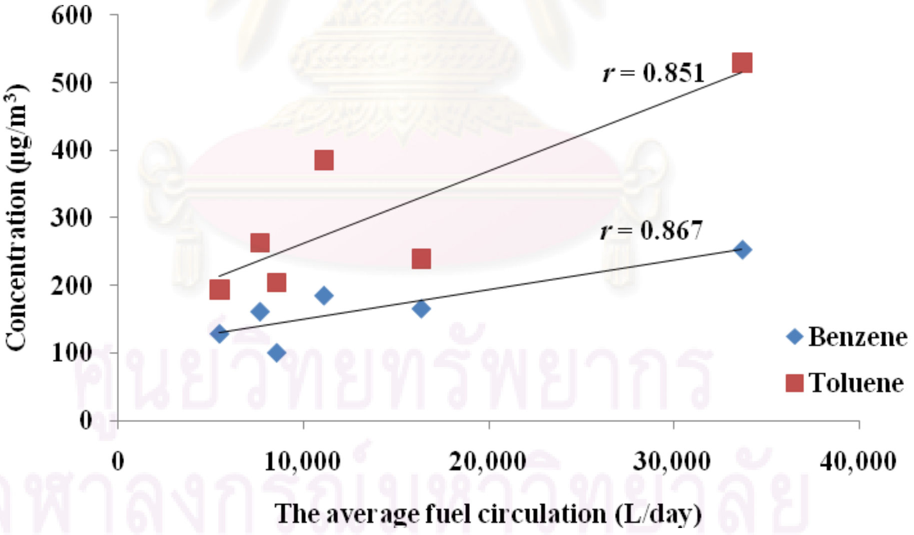


Figure 4.24 The correlation between average fuel circulation and ambient concentration of benzene and of toluene in the first sampling

In the second sampling, only the fuel circulations during 8-hr working period (6.00 am – 2.00 pm) of BT, DKN, J, RO, and TL were available, while such data at TP was not available due to the data system had not been updated. The detail of fuel circulations on Friday, Saturday, Sunday and Monday of all gas stations was presented in Appendix D. The significant relationship between the daily 8-hr fuel circulations and the ambient concentrations of Benzene, Toluene, Ethylbenzene, m,p-Xylene, o-Xylene, and total BTEX (n = 20) could be obtained with the good Pearson's correlations coefficient (r) of 0.651 ($p = 0.01$), 0.770 ($p = 0.01$), 0.696 ($p = 0.01$), 0.687 ($p = 0.01$), 0.570 ($p = 0.05$), and 0.768 ($p = 0.01$), respectively, as shown in Figure 4.25. The result of correlation in the first sampling was not as good as that of the second sampling because the number of samples in the first sampling was much less than that of the second sampling. From above result, these correlations observed can be implied that the concentrations of BTEX in the ambient were significant proportion to fuel circulation, and also implied that fuel was a major source of these pollutants. This result agrees with the study in Taiwan (Lin *et. al.*, 2005) which reported that the concentration of MTBE, benzene and xylenes at a gas station may be influenced by the refueling throughout. The previous study in Thailand was also found the good correlation between the concentration of total VOCs and the fuel circulation ($R^2 = 0.827$) among nine gas stations in Bangkok (Thaveevongs *et. al.*, 2010). Another study also suggested the significant relationship between aromatic compounds levels in air and the volume of gasoline sold during the shift in 2000, the r calculated from statistical tests were found as 0.65, 0.64 and 0.76 ($p < 0.001$) and in 2003 as 0.88, 0.74 and 0.81 ($p < 0.001$) for benzene, toluene and xylenes, respectively (Periago and Prado, 2005).

For carbonyl compounds, the ambient concentration of especially nine predominant carbonyl compounds namely formaldehyde, acetaldehyde, acetone, propionaldehyde, crotonaldehdye, butylraldehyde, banzaldehyde, valeraldehyde and hexanaldehyde among 5 gas stations as above mentioned were taken to test the correlations with the fuel circulations. The Pearson's correlation coefficient (n = 20) could be found only for formaldehyde with the value of 0.493 ($p = 0.05$) as seen in Figure 4.26. This evidence reveals that carbonyl compounds did not directly release from the fuel. As the theoretical background, formaldehyde and acetaldehyde are not the components of evaporative emission of fuel. The ambient levels of primary and secondary formaldehyde and acetaldehyde are formed by the photooxidation of VOC, though the rate of photooxidation of acetaldehyde is much less than that of formaldehyde. The oxidation of methanol (CH_3OH) produces formaldehyde while the oxidation of ethanol (C_2H_5OH) also produces acetaldehyde. The photolysis of acetaldehyde produces the CH_3O_2 radical, which reacts with NO to form formaldehyde (U.S. EPA, 1993).

From the results above, this can be considerable that the primary pollutants like BTEX are directly released from the gas stations. To get more explicit relationship, the ambient concentrations were plotted with the fuel circulations as shown in Figure 4.27. From this figure, the highest ambient concentrations of BTEX was found at RO station where was classified as a large size gas station with the largest amount of daily fuel circulations. On contradiction, the lowest concentrations of BTEX were observed at BT station where focusing the lowest amount of daily fuel circulations. This might be classified as a background gas station. For DKN, J and TP stations, there was the medium range of the BTEX concentrations. These stations were classified as the medium size gas stations. The small size gas station was TL, and relative low concentrations could be measured.

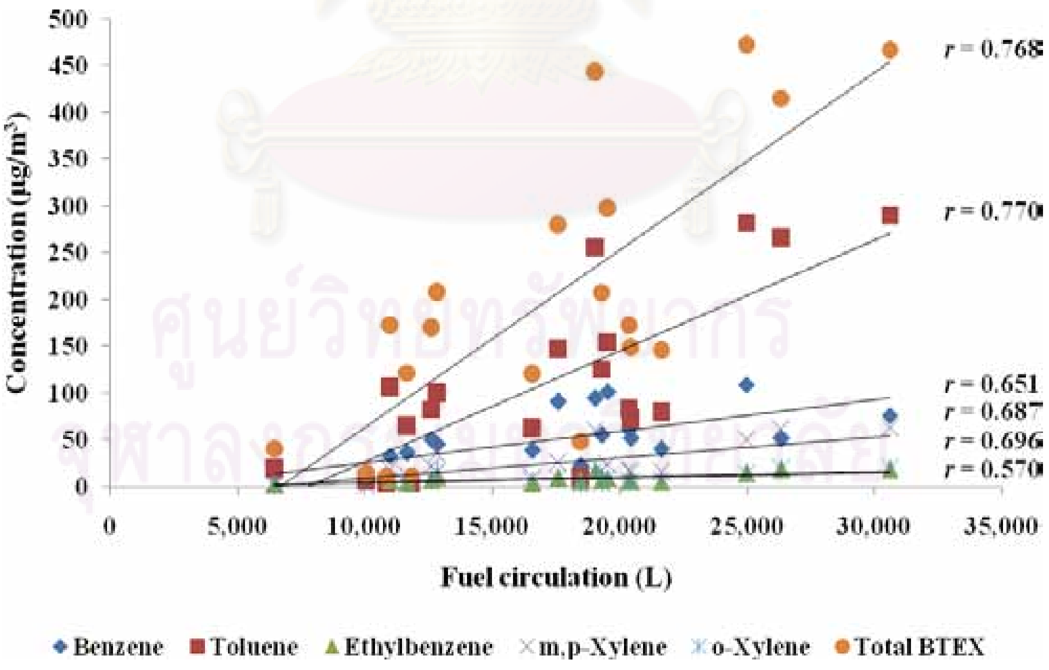


Figure 4.25 The correlation between 8-hr fuel circulation and ambient concentration of BTEX in the second sampling

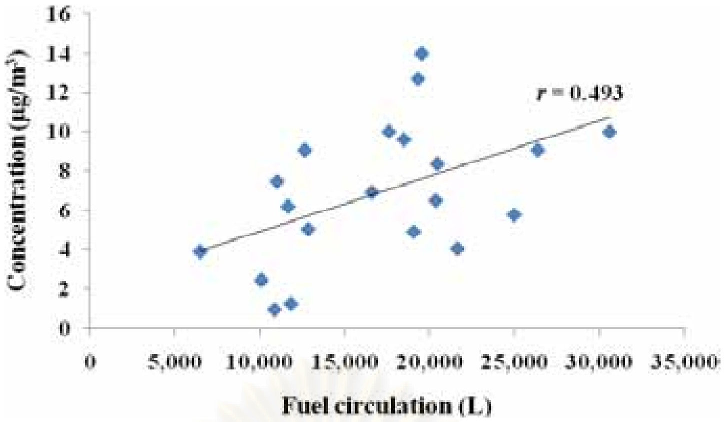


Figure 4.26 The correlation between 8-hr fuel circulation and ambient concentration of formaldehyde in the second sampling

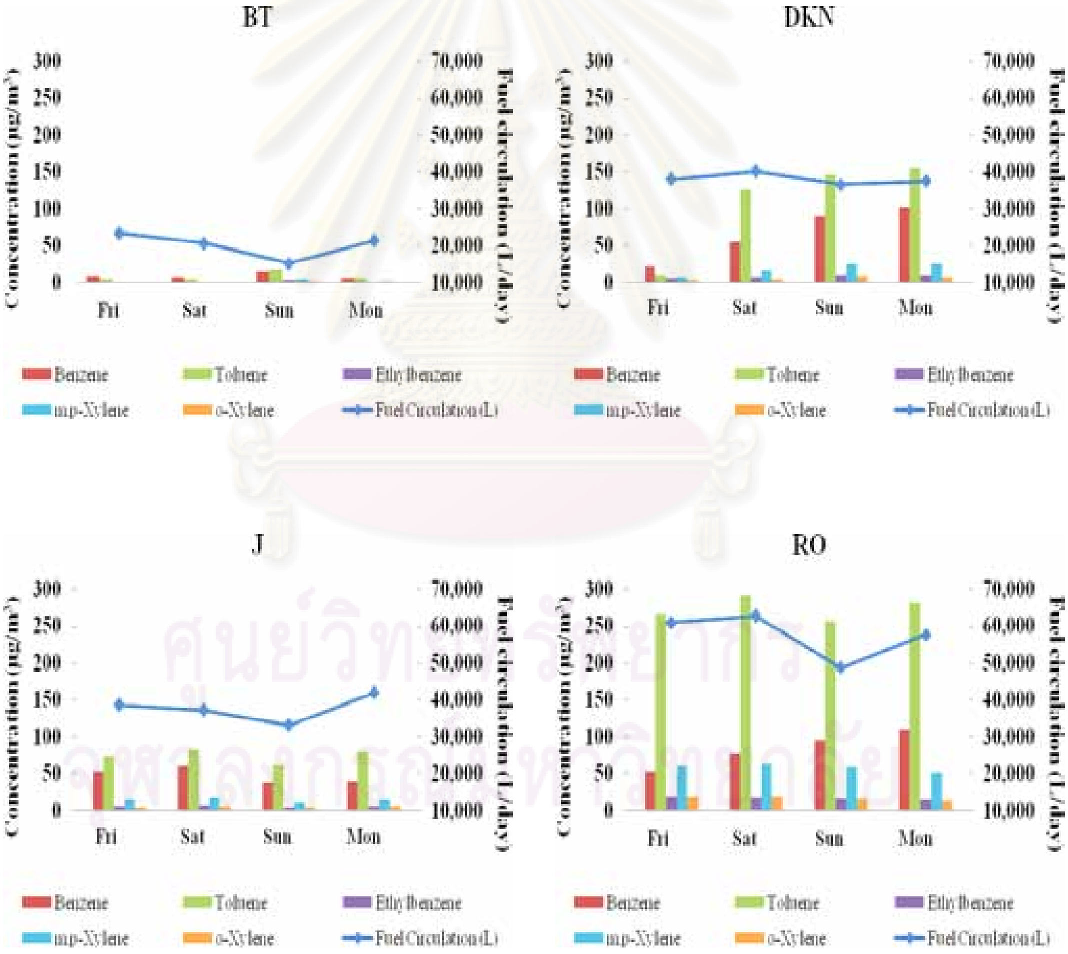


Figure 4.27 The relationship between ambient concentrations of BTEX and the daily fuel circulations in six gas stations in the second sampling

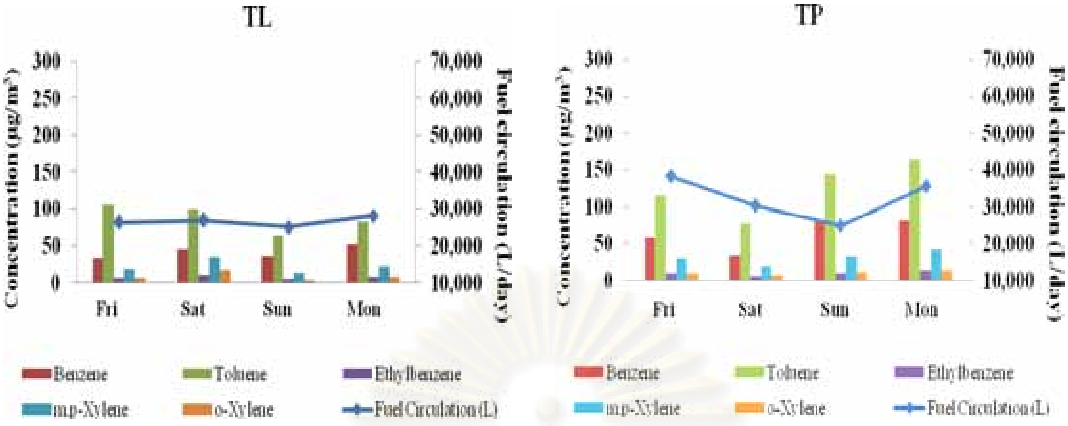


Figure 4.27 The relationship between ambient concentrations of BTEX and the daily fuel circulations in six gas stations in the second sampling (cont.)

4.5.2 Correlations between a number of customer cars and ambient concentrations of BTEX and carbonyl compounds

The number of customer cars during 8-hr working period for four sampling days in only five gas stations in the second sampling was available. The correlation between the number of customer cars and ambient concentration of BTEX in the second sampling were shown in Figure 4.28. Exhaust gas from cars contains the air pollutants which can be classified as the additional source in the gas station while refueling. The number of cars was used to investigate the relationship with the ambient concentrations of BTEX and carbonyl compound (n = 20). There are the significant Pearson’s correlations coefficient (*r*) at *p* = 0.01 only for toluene, ethylbenzene and m,p-xylene with the value of 0.681, 0.661 and 0.661, respectively. While the Pearson’s correlations coefficients at *p* = 0.05 could be obtained for benzene and o-xylene, as 0.449 and 0.579, respectively. For Total BTEX, there was significant correlation with *r* of 0.654 (*p* = 0.01). These correlations can be suggested that the exhaust gas from the cars was additional significant source of BTEX especially toluene, ethylbenzene and m,p-xylene as shown the significant at the 99% confidence level (2-tailed).

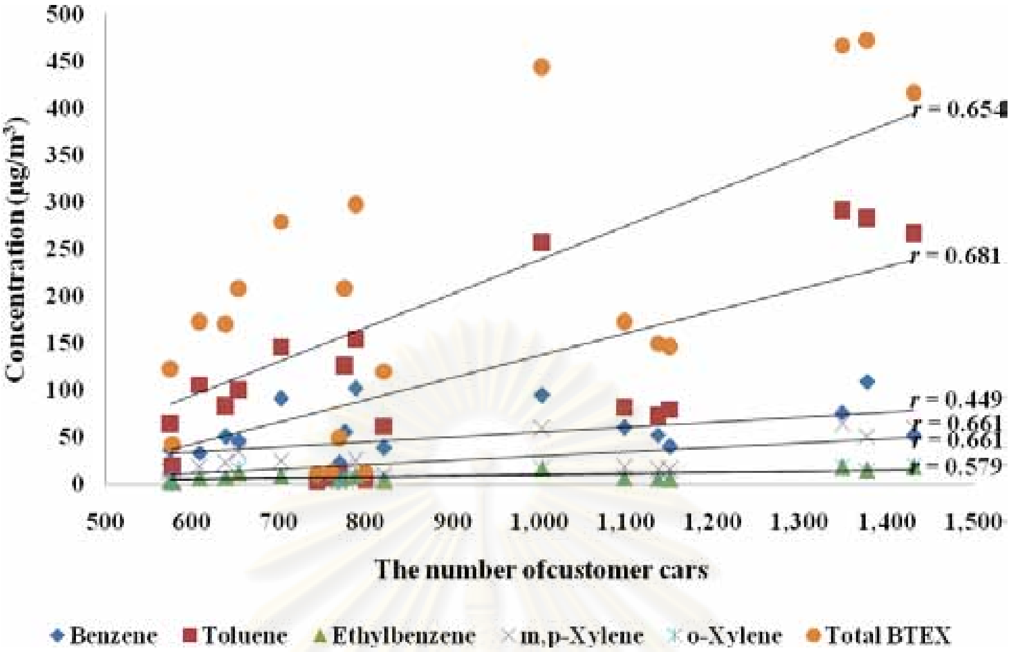


Figure 4.28 The correlation between the number of customer cars and ambient concentration of BTEX in the second sampling

4.5.3 Effect of meteorological conditions on ambient concentrations of BTEX and carbonyl compounds

As already mentioned, Met-One was installed in the three gas stations namely BT, RO and TL in the second sampling. Meteorological conditions monitoring by Met-One were wind speed, wind direction, temperature, relative humidity, solar radiation and barometric pressure. These data were collected during 8-hr working period for four sampling days. The position of Met-One installed at each gas station is illustrated in Figure 4.29. Wind speed and wind direction were plotted by wind roses as shown in Appendix D. The detail of all meteorological data is summarized in Appendix D. The average meteorological data during four days sampling was reported in Table 4.14. These meteorological data was considered how can affect on the distribution of the compounds in this study. When compared only ambient concentration measuring at BT, RO and TL stations, their sequence of total BTEX, and four major species of carbonyl compound can be seen in Table 4.15.

Table 4.14 The average meteorological data during four days sampling at BT, RO and TL stations

Station	Sampling date in Nov. 2011	WS (m/s)	Temp (Deg C)	RH (%)	SR (W/m^2)	BP (mmHg)	Main wind direction
BT	5 - 8	0.4 (30 – 80% calm)*	30.2	65.9	245.7	665.1	ENE, E
RO	12 – 15	0.5 (4 – 20% calm) *	30.9	67.1	277.3	665.2	NNW,N, ENE, E SE, S
TL	19 – 22	0.5 (9 – 30% calm) *	31.7	71.0	366.1	664.8	ESE, SE SSE, NNW

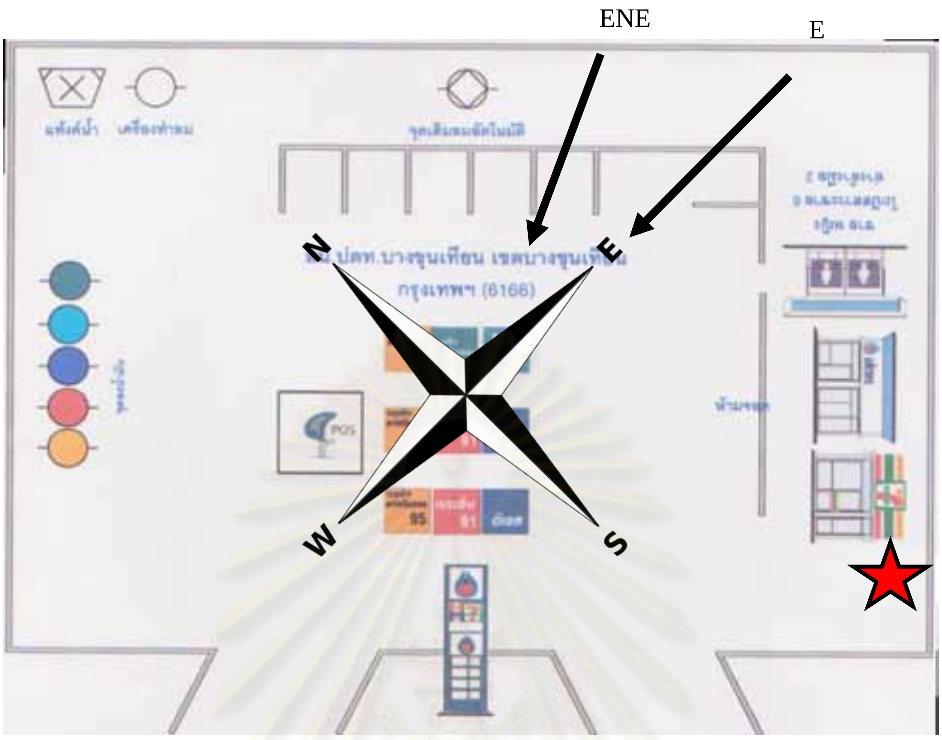
Remark : * calm condition means wind speed was less than 0.5 m/s

Table 4.15 Comparison on ambient and roadside concentration of total BTEX and four major carbonyl compound species between BT, RO and TL stations

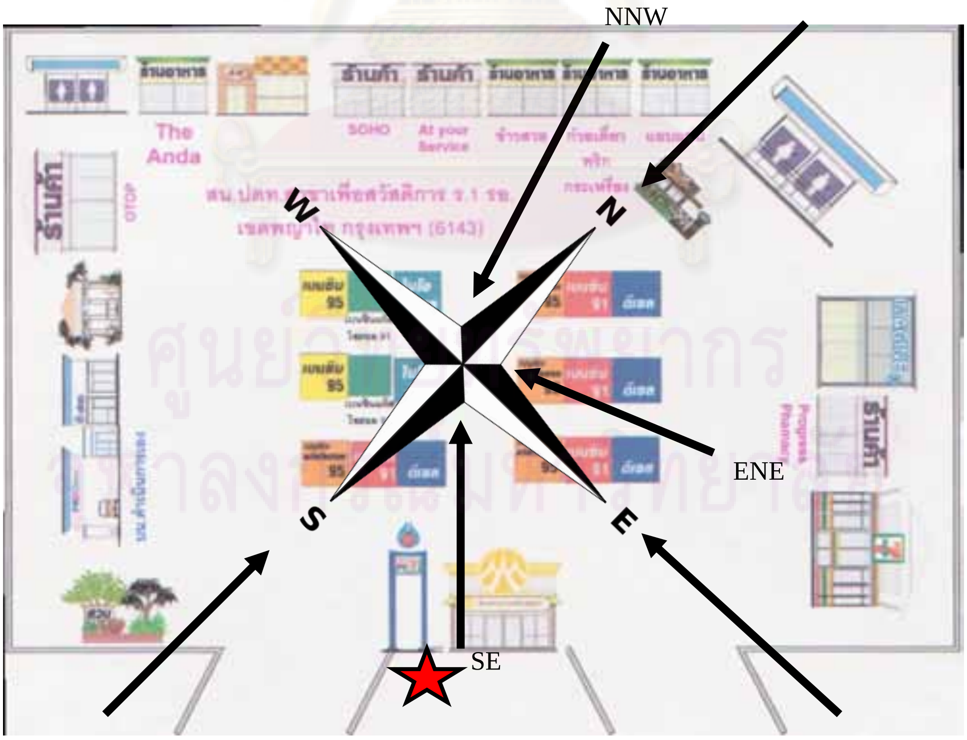
Compound	Sequence of ambient concentration	Sequence of roadside concentration
Total BTEX	$RO^{d} > TL^{bc} > BT^{a}$	$BT^{a} = TL^{a} = RO^{a}$
Formaldehyde	$RO^{b} = TL^{b} > BT^{a}$	$BT^{c} > RO^{ab} = TL^{ab}$
Acetaldehyde	$RO^{bc} > TL^{ab} > BT^{a}$	$BT^{a} > RO^{a} = TL^{a}$
Acetone	$TL^{b} = RO^{b} > BT^{a}$	$BT^{bcd} > RO^{ab} > TL^{a}$
Propionaldehyde	$RO^{a} = TL^{a} = BT^{a}$	$BT^{ab} = RO^{ab} > TL^{a}$

From Table 4.14, the meteorological conditions, i.e. wind speed, temperature, relative humidity, solar radiation and barometric pressure, at three stations were not much different since the monitoring was held in the same month. Solar radiation measured at TL was slightly higher than those at other sites, and this resulted in a bit higher temperature at this station as well. These meteorological conditions, therefore, would not strongly influent on the variation of either BTEX or carbonyl compounds in the microenvironment like a gas station, as no relation with the sequence of these compounds found at three stations. Generally, wind speed is an important factor for distribution of air pollutants. High wind speed condition can dilute pollutants very well. The wind speed observed in this study was quite low and not strong wind. Even the wind speeds at RO and TL were seem to be stronger than that of BT, the level of most compounds at RO and TL were still higher than that of BT. This reveals that meteorological conditions as above mentioned at the gas station might not play an important role on the contribution of BTEX and carbonyl compounds like the sources, e.g. fuel circulation and number of customer cars.

Wind direction as presented in wind rose consisting of 18 directions was taken to investigate possibility of dispersion of the target compounds from other sources. Predominant wind directions observed at BT during the sampling period were ENE and E (see Figure 4.29(a) which these directions are not represented the wind flow from the road. Moreover, high % calm condition (about 30-80%) was existed at this station. This is considerable that dispersion from other sources (traffic and surrounding activities) would be minor. When considered at RO, more varied of wind direction occurred (Figure 4.29(b)) and relative low % calm condition was found with the range of about 4 – 20, as shown in Table 4.14. This might relate to configuration of the gas station where here is the largest station in this study and also there is not high building closed to the station. All main wind directions observed at this station included the wind blew from the main road, and this would have some effects on dispersion of the compounds in the gas station area. At TL stations, the wind mainly blew from the road (Figure 4.29(c)) and low % calm condition was found with the range of about 9 – 30, see in Table 4.14. The ambient concentration of the compounds would be increased by their dispersion from the road. In addition, these might also explain why the roadside concentrations measured at RO and TL stations were slightly lower than that observed at BT since more dispersion occurred at these points. Similarly, a study in Taiwan suggested that VOCs concentrations in gas stations showed some dependence on wind direction and were not found the effect of temperature in the same season (Lin *et. al.*, 2005). The higher concentrations of pollutants would be found in downwind zone due to the wind would carry VOCs from the other sources such as roads and car parks.

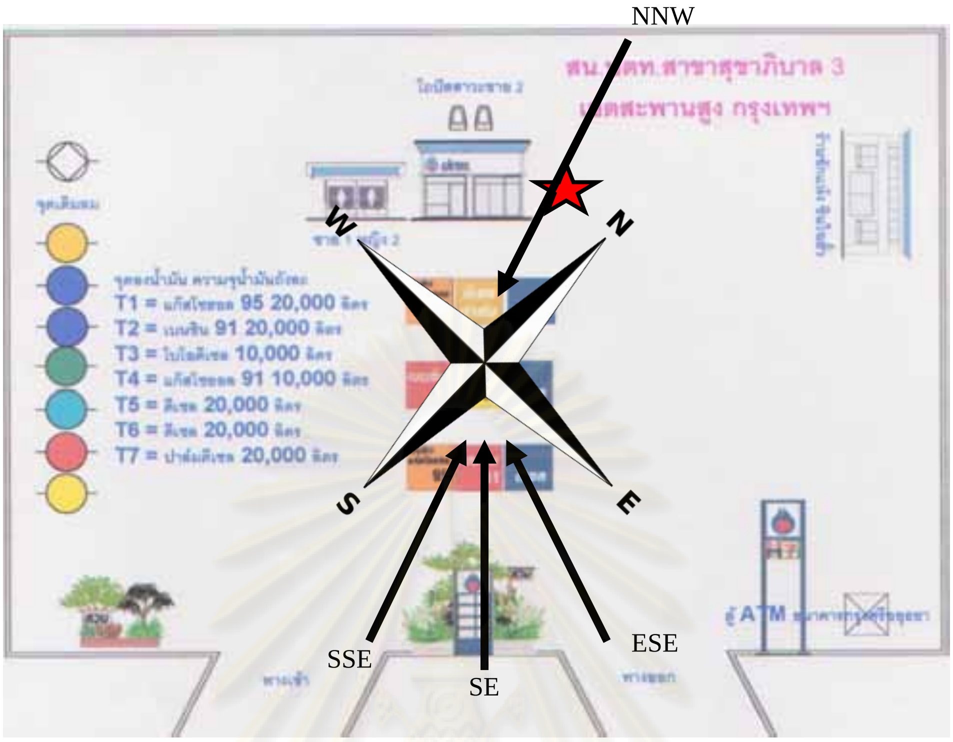


(a) BT



(b) RO

Figure 4.29 The locations of Met-One and physical characteristics of three gas stations (★ represents the position of Met-One)

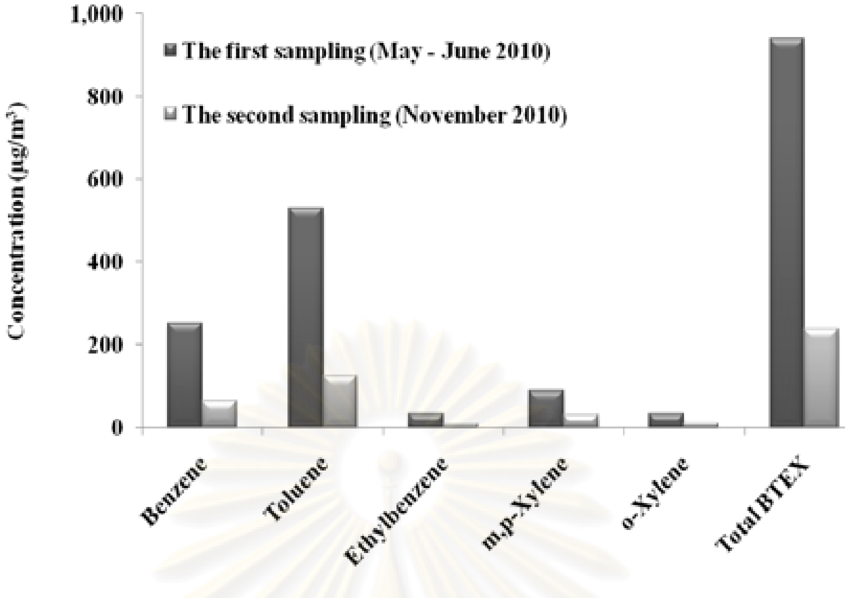


(c) TL

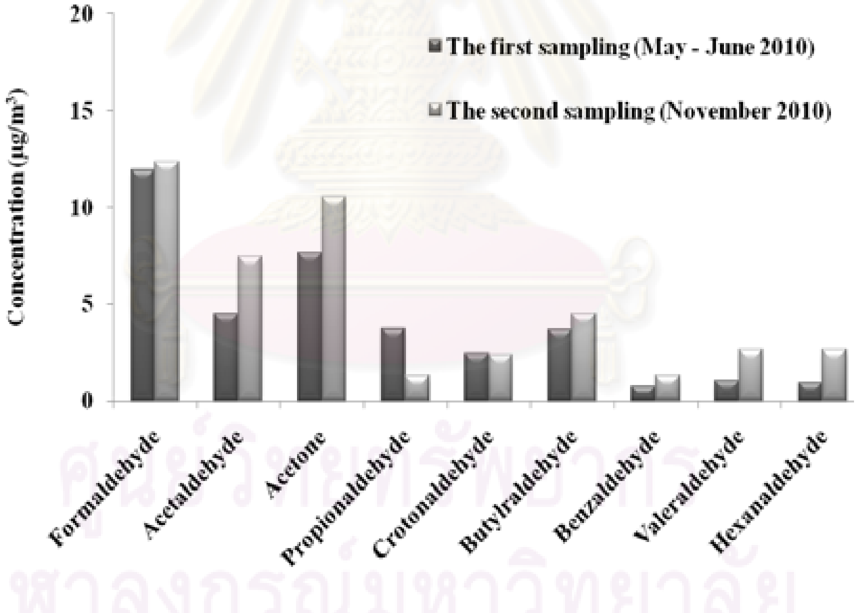
Figure 4.29 The locations of Met-One and physical characteristics of three gas stations (cont.) (★ represents the position of Met-One)

4.5.4 Seasonal variation of BTEX and carbonyl compounds in the ambient air inside the gas station

Due to the ambient samples in TP were collected either in the first or second sampling during May – June 2010 representing wet season and in November 2010 representing dry season (dry deposition). The 8-hr average ambient concentrations of BTEX and carbonyl compounds in the first sampling (n=2) and those in the second sampling (n=4) were calculated to compare in different seasons, as illustrated in Figure 4.30. The 8-hr average ambient concentrations of BTEX during wet season were significantly higher than those found in dry season as seen in Figure 4.30(a), while the 8-hr average ambient concentrations of carbonyl compounds were slightly different between wet and dry seasons as seen in Figure 4.30(b).



(a) BTEX



(b) Carbonyl compounds

Figure 4.30 The average ambient concentration of BTEX and carbonyl compounds in TP in the first and the second sampling

These results suggested that the different temperature, humidity and solar radiation could influent the ambient concentrations of pollutants. This can be supported by the other studies report that the concentration of carbonyl compounds was higher in the morning hour than at night time (the effect of solar radiation); moreover, dry deposition was importantly found as the night time sink for formaldehyde (Dutta *et. al.*, 2009). The higher concentration of carbonyl compounds collected in November (dry season) in this study was similar to the previous study in Bangkok, Thailand that the concentrations of carbonyl compounds were high during the cold season due to the stable condition in winter (dry season), while the concentrations were low in summer (wet season) due to the photolysis under higher temperature. In addition, lower concentrations of formaldehyde and acetaldehyde in the night time were observed (Morknoy *et. al.*, 2011). Another study in Spain for BTEX was also found that the high temperature in the summer could increase the concentration exposure to benzene, toluene and xylenes (Periago *et. al.*, 1997).

As the theoretical information reported by U.S. EPA (1997), dry deposition is a minor removal mechanism of acetaldehyde (slow process), but the process under winter, nighttime conditions are slower. For BTEX, cloud to solar radiation at ground level (slowing photolysis rates and decreasing radical concentrations) can cause effects and may be effect to increasing of the atmospheric reactions due to clouds are themselves a reactive medium.

As a whole results above, these can be suggested that the important factors on BTEX and carbonyl compounds distribution were: (1) fuel circulation directly effect on BTEX and probably indirectly affect to some carbonyl compounds, (2) a number of customer cars significantly relating to increase of BTEX, (3) metrological conditions especially wind direction influencing the distribution of all substance, and (4) atmospheric chemical reactions of all substances considerably depending on seasonal variation (wet or dry seasons). Therefore, affecting factors as above mentioned could cause the different concentrations at gas stations in the sampling day and shift.

4.6 Relationship between BTEX and carbonyl compounds in the ambient air

In order to find the relationship between BTEX and carbonyl compounds in the ambient air at gas station, the analysis of Pearson’s correlations were then conducted from both the first and the second sampling results. For the first sampling which the number of samples was only 6 (n=6), there was only the significant correlation between the ambient concentrations of total BTEX and the ambient concentrations of acetaldehyde with the r of 0.873 (p = 0.05) as seen in Figure 4.31.

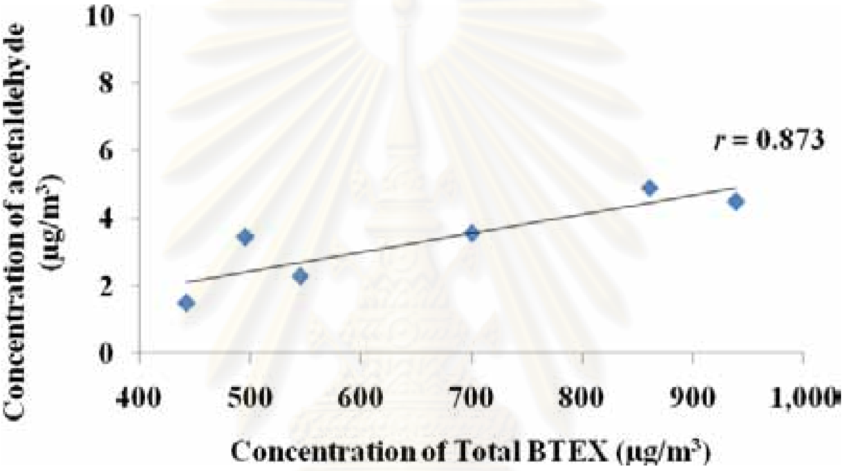


Figure 4.31 The correlation between the average ambient concentration of Total BTEX and the average ambient concentration of acetaldehyde in the first sampling

In the second sampling, the number of samples was much more than those of the first sampling. The significant Pearson’s correlation coefficients between the ambient concentrations of Total BTEX and the ambient concentrations of formaldehyde (n = 24), acetaldehyde (n = 24) and propionaldehyde (n = 22) could be obtained with the value of 0.464, 0.534 and 0.429 (p = 0.05), respectively, as seen in Figure 4.32. If considering more specific correlation of each substance, the good Pearson’s correlations were found between the ambient concentration of benzene and the ambient concentrations of formaldehyde (n = 24), acetaldehyde (n = 24), acetone (n = 24) and propionaldehyde (n = 22) with the r of 0.601, 0.736, 0.543 and 0.645 (p = 0.01), respectively. Further, the satisfactory Pearson’s correlations between the ambient concentration of toluene and the ambient concentrations of formaldehyde (n

= 24) and acetaldehyde (n = 24) were also found with the *r* of 0.406 and 0.457 (*p* = 0.05), respectively. The relationships of these compounds were presented in Figure 4.33 and 4.34.

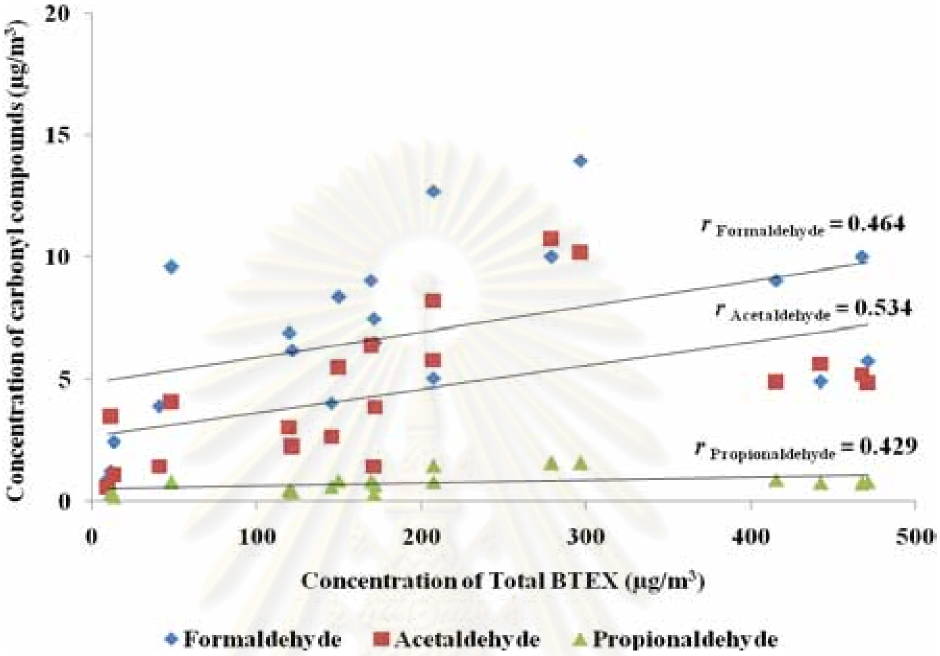


Figure 4.32 The correlations between the ambient concentration of Total BTEX and the ambient concentration of carbonyl compounds in the second sampling

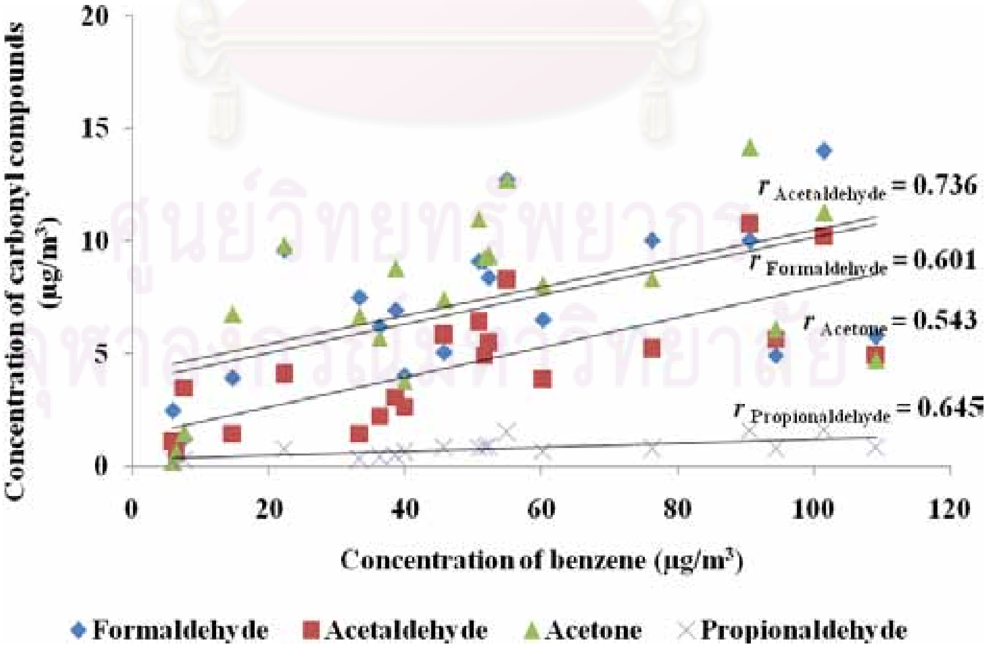


Figure 4.33 The correlations between the ambient concentration of benzene and the ambient concentration of carbonyl compounds in the second sampling

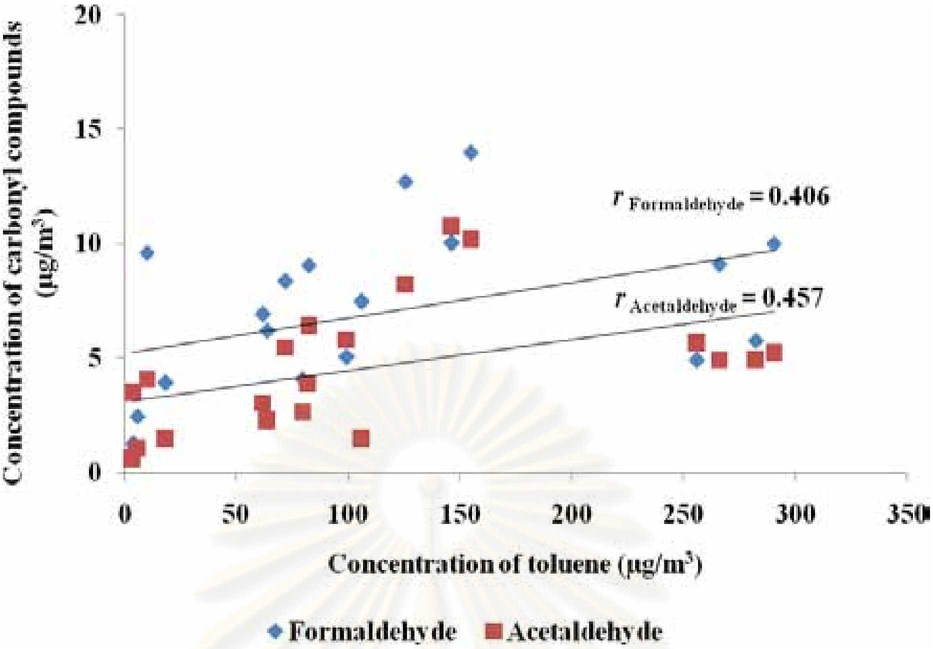


Figure 4.34 The correlations between the ambient concentration of toluene and the ambient concentration of carbonyl compounds in the second sampling

As above correlations, according to BTEX are typically emitted direct from the fuel at gas station as the primary pollutant, these compounds can be transformed to be the secondary pollutants including production of carbonyl compounds. Some reactions can give explanation of transformation between BTEX and carbonyl compounds as the following:

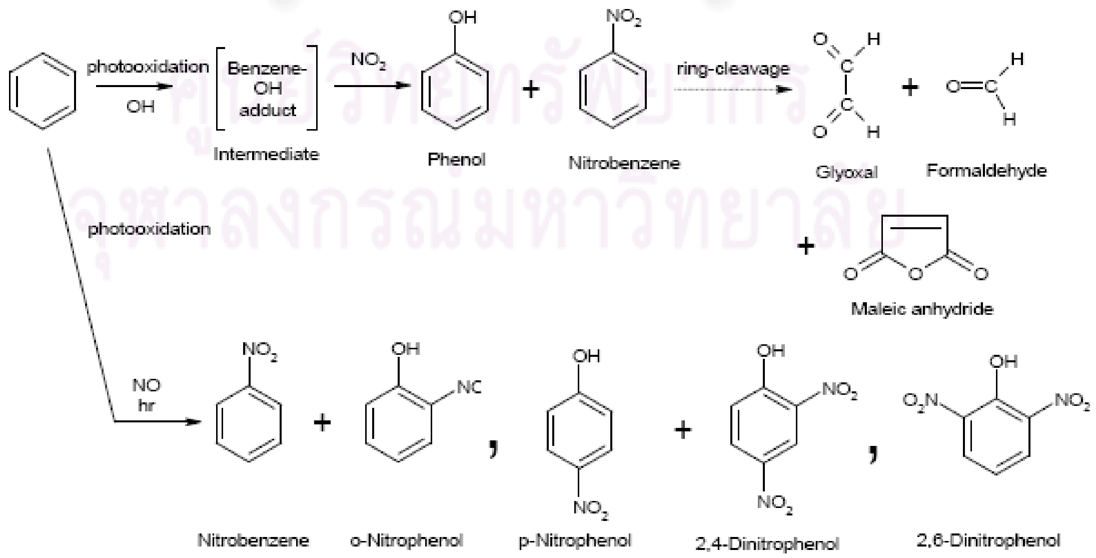


Figure 4.35 Photooxidation of benzene (ATSDR, 2007)

Form Figure 4.35, benzene in the atmosphere is rapidly degraded by reaction with hydroxyl radicals to yield phenol and nitrobenzene, which in turn undergo ring cleavage to yield glycol, formaldehyde and maleic anhydride. Otherwise, the degradation of benzene with nitrogenmonoxide produces some toxic gas (e.g., nitrobenzene, *o*- and *p*-nitrophenol, and 2,4- and 2,6-dinitrophenol). Therefore, this supports the finding of significant correlation between BTEX and carbonyl compound in this study.

4.7 Inhalation exposure and health risk assessment of gas station workers

Regarding to availability of toxicological data at present, only some target compounds are able to estimate health risk of the gas station workers. The data of inhalation personal exposure of the worker was used to calculate their chemical intake, defined as Average Daily Intake or Chronic Daily Intake (CDI). Before starting risk assessment process, critical endpoint of each substance should be verified. According to risk assessment method, the critical endpoint can be classified as cancer and non-cancer endpoints. From all available data, some of the target compounds are concerned as the carcinogenic compounds including Benzene, Ethylbenzene, Formaldehyde and Acetaldehdye, while non-carcinogenic compounds are Toluene, m,p-Xylene, o-Xylene and Propionaldehyde.

In the process of exposure assessment in this study, according to the Risk Assessment Guidance for Superfund Part A, the personal exposure concentrations of carcinogenic compounds were used to calculate the Chronic Daily Intake (CDI), and body weight of the gas station worker received from questionnaire was also involved in CDI calculation. For non-carcinogenic compounds, the personal exposure concentrations and body weight of the workers were used to calculate the Exposure Concentration (EC) following the Risk Assessment Guidance for Superfund Part F as already described in Chapter 3. The equations that were used to calculate CDI for carcinogenic compounds and EC for non-carcinogenic compounds are as follows:

$$\text{CDI} = \frac{\text{CA x IR x ET x EF x ED}}{\text{BW x AT}}$$

where:

CDI (mg/kg.day) = Chronic daily intake

CA (µg/m^3) = Contaminant concentration in air

IR (m^3/hr) = Inhalation rate (0.875 m^3/hr)

BW (kg) = Body weight (base on questionnaires*)

ET (hours/day) = Exposure time (8 hours/day)

EF (days/year) = Exposure frequency (350 days/year)

ED (years) = Exposure duration (30 years)

AT (days) = Averaging time (25,550 days for cancer)

* The average body weight of gas station worker was 58.8 (39.0 – 90.0) kg

$$EC = \frac{CA \times ET \times EF \times ED}{AT}$$

where:

EC (µg/m^3) = Exposure concentration

CA (µg/m^3) = Contaminant concentration in air

ET (hours/day) = Exposure time (8 hours/day)

EF (days/year) = Exposure frequency (350 days/year)

ED (years) = Exposure duration (30 years)

AT (hours) = Averaging time (262,800 hours for non-cancer)

For step of dose-response assessment, the toxicity values such as Inhalation Cancer Slope Factors (CSF$_i$) for carcinogenic compounds and Inhalation Reference Concentrations (RfC$_i$) for non-carcinogenic compounds of the compounds mentioned above were used for estimating Cancer Risk and Hazard Quotient (HQ), respectively.

From the major target compounds that found in all gas station workers, the toxicity values of only 8 compounds are available. Inhalation Cancer Slope Factors (CSF$_i$) of Benzene, Ethylbenzene, Formaldehyde and Acetaldehyde and Inhalation Reference Concentrations (RfC$_i$) of Toluene, m,p-xylene, o-xylene and propionaldehyde are published by Integrated Risk Information System (IRIS), The Risk Assessment Information System (RAIS) and Office of Environmental Health Hazard Assessment (OEHHA) as seen in Table 4.16.

Table 4.16 Inhalation Cancer Slope Factors (CSF_i) and Inhalation Reference Concentrations (RfC_i)

Compounds	Inhalation Cancer Slope Factors (mg/kg-day)$^{-1}$	Inhalation Reference Concentrations (mg/m^3)
Benzene	2.73×10^{-2} [b]	-
Ethylbenzene	3.85×10^{-3} [b]	-
Formaldehyde	2.10×10^{-2} [c]	-
Acetaldehyde	1.00×10^{-2} [c]	-
Toluene	-	5 [a]
m,p-Xylene	-	0.1[a]
o-Xylene	-	0.1[a]
Propionaldehyde	-	8.00×10^{-3} [b]

[a] Integrated Risk Information System (IRIS), 2010
[b] The Risk Assessment Information System (RAIS), 2009
[c] Office of Environmental Health Hazard Assessment (OEHHA), 2003

Final step in risk assessment is risk characterization which is the combination of the data from exposure assessment and dose-response assessment. The equations for estimating the cancer risks and the hazard quotients are as follows:

$$\text{Cancer risk} = \text{CDI} \times CSF_i$$

where:

CDI (mg/kg·day) = Chronic daily intake
CSF_i (mg/kg-day)$^{-1}$ = Inhalation Cancer Slope Factor

If a number of cancer risk higher than 10^{-6}, this means carcinogenic effects of concern. Otherwise, if cancer risk level less than or equal to 10^{-6}, this means the risk in an acceptable level.

$$\text{Hazard Quotient (HQ)} = \text{EC} / (RfC_i \times 1000\ \mu g/mg)$$

where:

EC (µg/m^3) = Exposure concentration
RfC (mg/m^3) = Reference concentration

If a number of HQ higher than 1, this means non-carcinogenic effects of concern. Otherwise, if HQ less than or equal to 1, this means the risk in an acceptable level.

The calculated CDI, as mg/kg.day, of benzene, ethylbenzene, formaldehyde, and acetaldehyde were found in range of 1.52×10^{-3} - 1.83×10^{-2}, 3.82×10^{-4} – 3.28×10^{-3}, 2.04×10^{-4} – 2.72×10^{-3}, and 8.46×10^{-5} – 2.03×10^{-3} mg/kg.day, respectively. The lifetime cancer risks of gas station workers exposure to BTEX and carbonyl compounds especially benzene, ethylbenzene, formaldehyde and acetaldehyde were summarized in Table 4.17 and illustrated in Figure 4.34. The cancer risk of benzene was found in range 4.14×10^{-5} - 4.99×10^{-4} which showed the highest 100.0% unacceptable risk of total workers. The cancer risk of formaldehyde was in the second order, 64.7% unacceptable risk of total workers, which was in range of 4.28×10^{-6} - 5.72×10^{-5}. For ethylbenzene and acetaldehyde, those cancer risks were in the same range, 2.9% unacceptable risk of total workers, their cancer risks were in range of 1.47×10^{-6} - 1.26×10^{-5} and 8.46×10^{-7} - 2.03×10^{-5}, respectively.

Table 4.17 The cancer risks of gas station workers exposure to BTEX and carbonyl compounds in this study

Compounds	Cancer risks		Number of the worker at unacceptable risk/Total workers (% Unacceptable risk)	Disease/symptom
	MIN	MAX		
Benzene	4.14×10^{-5}	4.99×10^{-4}	24+44/24+44 (100.0%)	Leukemia/drowsiness, dizziness, rapid heart rate, headaches, tremors, confusion, and unconsciousness
Ethylbenzene	1.47×10^{-6}	1.26×10^{-5}	2+0/24+44 (2.9%)	Kidney Tumors/eye and throat irritation, dizziness, Irreversible damage to the inner ear and hearing
Formaldehyde	4.28×10^{-6}	5.72×10^{-5}	18+26/24+44 (64.7%)	Squamous cell carcinoma/ irritation of the eyes, nose, throat
Acetaldehyde	8.46×10^{-7}	2.03×10^{-5}	0+2/24+44 (2.9%)	Nasal squamous cell carcinoma or adenocarcinoma/ irritation nose and throat, dizziness, drowsiness, weakness, fatigue, nausea, headache, unconsciousness

Remark: n = 24 for the first sampling and n = 44 for the second sampling

The calculated EC was in range of 22.12 – 156.74 µg/m^3 for toluene, 7.14 – 49.27 µg/m^3 for m,p-xylene, 1.69 – 15.95 µg/m^3 for o-xylene, and 0.08 – 1.53 µg/m^3 for propionaldehyde. The hazard quotients for non-carcinogenic compounds of gas station workers exposure to BTEX and carbonyl compounds were summarized in Table 4.18 and presented in Figure 4.34. The hazard quotients of toluene, m,p-xylene, o-xylene and propionaldehyde were found in range 0.0044 - 0.0313, 0.0714 - 0.4927, 0.0169 - 0.1595 and 0.0106 - 0.1910, respectively. All of them were in acceptable level; hazard quotients were less than 1, for all non-carcinogenic compounds in this study.

Table 4.18 The non-cancer risks of gas station workers exposure to BTEX and carbonyl compounds in this study

Compounds	Hazard quotients		Number of the worker at unacceptable risk/Total workers (% Unacceptable risk)	Disease/symptom
	MIN	MAX		
Toluene	0.0044	0.0313	0+0/24+44 (0%)	Tiredness, confusion, weakness, memory loss, nausea, loss of appetite, and hearing and color vision loss
m,p-Xylene	0.0714	0.4927	0+0/24+44 (0%)	Headaches, lack of muscle coordination, dizziness, confusion, irritation of eyes, nose, and throat, difficulty in breathing, unconsciousness
o-Xylene	0.0169	0.1595	0+0/24+44 (0%)	
Propionaldehyde	0.0106	0.1910	0+0/24+44 (0%)	Irritation of the upper respiratory tract, nose and throat, chest pain, nausea, vomiting, headache, and dizziness

Remark: n = 24 for the first sampling and n = 44 for the second sampling

From the symptoms of gas station workers observed by questionnaire (n=28) summarized in Appendix A. There was found 35.7% of total workers had headache and drowsiness, 50% of total workers had irritations of eyes, nose, throat and skin, 67.9% of total workers had tried and fatigued, 28.6% of total workers had chest pain and suffocation and 14.3% of total workers had bored with food and temporary hearing and/or vision loss. While the symptoms of faint and unconscious was not found. These results from questionnaires were found corresponding to the symptoms of exposure to BTEX and carbonyl compounds as presented in Table 4.17 and 4.18. The observable symptoms were then suggested that daily exposure to these compounds can cause the occurrence of some diseases in the gas station workers.

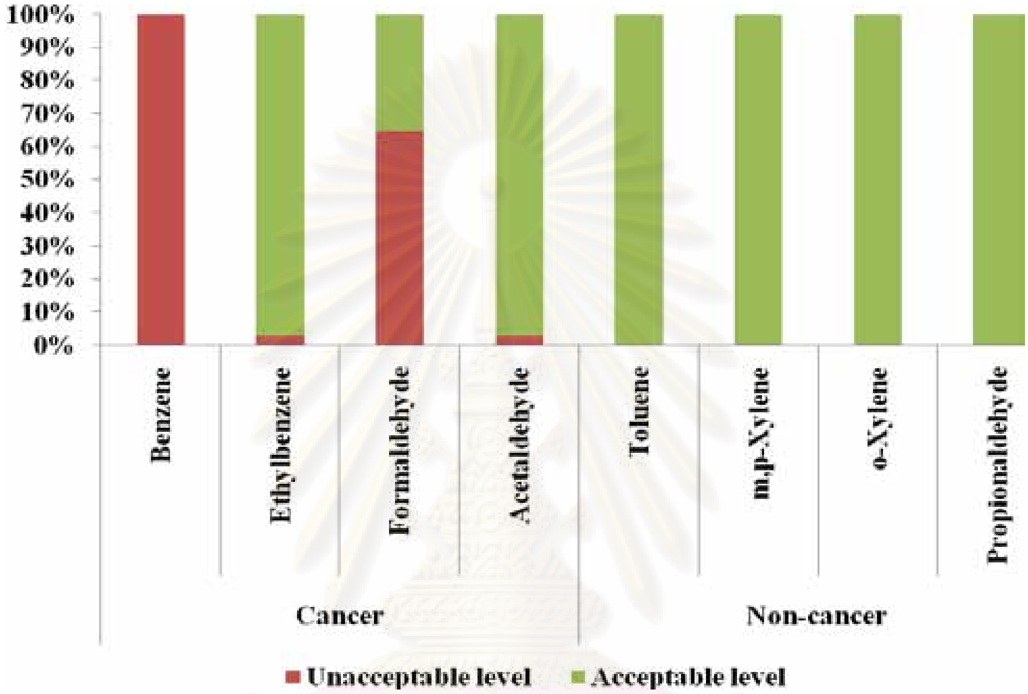


Figure 4.36 Unacceptable risk and acceptable risk (%) compared to overall worker population

Figure 4.36 presents the overall proportion of the workers pose to have risk of exposure to the substances concerned in this study. For carcinogenic compounds, the overall workers (100%) were at risk of cancer especially leukemia from inhalation exposure to benzene which was found relatively higher than formaldehyde (64.7%) causing squamous cell carcinoma, ethylbenzene (2.9%) causing kidney tumors, and acetaldehyde (2.9%) causing nasal squamous cell carcinoma or adenocarcinoma, respectively. For non-carcinogenic compounds, the overall workers (100%) were not pose to increase risk of some adverse health effects from exposure to toluene, m,p-xylene, o-xylene and propionaldehyde, since the risk levels were still be at the acceptable level of HQ < 1.

Table 4.19 Comparison of gas station workers' risk estimated in this study with other studies

Location	Pollutant	Cancer risk	HQ	Reference
Bangkok, Thailand	Benzene	2.18×10^{-4} $(4.14\times10^{-5} - 4.99\times10^{-4})$	-	This study[a]
	Toluene	-	0.0145 (0.0044 - 0.0313)	
	Ethylbenzene	3.94×10^{-6} $(1.47\times10^{-6} - 1.26\times10^{-5})$	-	
	m,p-Xylene	-	0.1628 (0.0714 - 0.4927)	
	o-Xylene	-	0.0534 (0.0169 - 0.1595)	
	Formald	1.23×10^{-5} $(4.28\times10^{-6} - 5.72\times10^{-5})$	-	
	Acetald	3.85×10^{-6} $(8.46\times10^{-7} - 2.03\times10^{-5})$	-	
	Propionald	-	0.0447 (0.0106 - 0.1910)	
Bangkok, Thailand	Benzene	$3.42\times10^{-4} – 1.23\times10^{-3}$	-	Thaveevongs *et al.*, 2010[a]
	Toluene	-	0.0077 – 0.0376	
	Ethylbenzene	$1.55\times10^{-6} – 5.83\times10^{-6}$	-	
	Xylenes	-	0.0309 – 0.0990	
Kolkata, India	Benzene	9.66×10^{-5}	0.7740	Majumdar *et al.*, 2008[b]
	Toluene	-	0.0217	
	Ethylbenzene	1.18×10^{-5}	0.0201	
	m,p-Xylene	-	0.4720	
	o-Xylene	-	0.4720	
	Formald	3.52×10^{-5}	0.5070	
	Acetald	4.03×10^{-6}	0.3810	
Chonburi, Thailand	Benzene	2.00×10^{-5}	0.114	Yimrungruang *et al.*, 2008[c]
	Toluene	-	0.034	
	Ethylbenzene	-	0.000	
	Xylene	-	0.002	

Remark: [a] Exposure durations (ED) of occupational exposure is 30 years
[b] Exposure durations (ED) of occupational exposure is 40 years
[c] Exposure durations (ED) of occupational exposure is 2 years (Questionaires)

These results are within the range of some previous studies as seen in Table 4.19. Thaveevongs *et al.* (2010), reported that the average cancer risks of the gas station workers in Bangkok exposure to benzene and ethylbenzene in the range of $3.42\times10^{-4} – 1.23\times10^{-3}$ and $1.55\times10^{-6} – 5.83\times10^{-6}$, respectively. The average hazard quotient of toluene was in the range of 0.0077 – 0.0376. While the HQs of xylenes (summation of m,p-xylene and o-xylene) in this study was found higher than that of the previous study. Further, they also reported that the gas station workers in Bangkok might be at risk of exposure to benzene. The study in India reported that the gas station workers might be at risk of exposure to benzene, ethylbenzene and formaldehyde excepting for acetaldehyde which the average cancer risk found as 4.03×10^{-6} (Majumdar *et al.*, 2008). The another study in Chonburi province of

Thailand reported that the gas station workers might be at risk of exposure to benzene as well (Yimrungruang *et al.*, 2008).

Considering from actual information of the workers, they would not work in this career as long as 30 years like the risk scenario mentioned above. The expected time to work of gas station workers was in range of 1 – 20 years, which was asked by questionnaires. The unacceptable risks (cancer risk > 10^{-6}) of some workers estimated from 30 years exposure duration (ED) were compared with those cancer risks estimated from their available actual information of ED as seen in Table 4.20. The result reveals that almost of the cancer risk of the workers were in an acceptable level (cancer risk ≤ 10^{-6}) and decreased about one to two magnitude of order. Their cancer risk estimated from actual ED (derived from questionnaire) were in range of 3.64×10^{-6} - 7.97×10^{-5} for benzene, 3.52×10^{-7} - 7.16×10^{-6} for formaldehyde, and 4.44×10^{-7} - 6.77×10^{-7} for acetaldehyde. Therefore, the cancer risk levels of workers exposure to benzene, formaldehyde and acetaldehyde might be reduced by decreasing their exposure duration.

Table 4.20 Comparison of individual cancer risk of gas station worker estimated from 30 years exposure duration with those estimated from actual information

Sample	ED* (years)	Cancer risk (ED=30)			Cancer risk (ED derived from questionnaire)		
		Benzene	Formald	Acetald	Benzene	Formald	Acetald
DKN P1/3	5	1.45×10^{-4}	-	-	2.42×10^{-5}	-	-
DKN P2/3	1	2.42×10^{-4}	1.52×10^{-5}	2.03×10^{-5}	8.07×10^{-6}	5.08×10^{-7}	6.77×10^{-7}
DKN P2/4	2	2.48×10^{-4}	1.25×10^{-5}	-	1.66×10^{-5}	8.32×10^{-7}	-
J P1/2	1	2.61×10^{-4}	-	-	8.71×10^{-6}	-	-
J P1/3	10	2.25×10^{-4}	-	-	7.50×10^{-5}	-	-
J P1/4	3	1.25×10^{-4}	-	-	1.25×10^{-5}	-	-
RO P1/1	5	2.17×10^{-4}	2.25×10^{-5}	-	3.62×10^{-5}	3.74×10^{-6}	-
RO P2/1	20	1.20×10^{-4}	1.07×10^{-5}	-	7.97×10^{-5}	7.16×10^{-6}	-
RO P1/2	2	1.70×10^{-4}	1.22×10^{-5}	-	1.13×10^{-5}	8.10×10^{-7}	-
TL P1/1	2	2.84×10^{-4}	5.72×10^{-5}	-	9.45×10^{-6}	3.81×10^{-6}	-
TL P2/1	1	5.47×10^{-5}	1.06×10^{-5}	1.33×10^{-5}	3.64×10^{-6}	3.52×10^{-7}	4.44×10^{-7}
TL P1/3	3	1.09×10^{-4}	-	-	1.09×10^{-5}	-	-
TL P2/3	1	2.40×10^{-4}	-	-	8.00×10^{-6}	-	-
TP P2/1	3	2.26×10^{-4}	1.46×10^{-5}	-	2.26×10^{-5}	1.46×10^{-6}	-

Remark: * The actual information of each gas station worker which was derived from questionnaire, and – means the cancer risk was in acceptable level (cancer risk ≤ 10^{-6}).

According to the higher cancer risk of the gas station workers at gas stations in Bangkok, Thailand was determined, the owner should concern more how to protect their health while they are working. The gasoline vapor recovery system should be installed and also frequently carried on maintenance program to reduce emission of such substances to ambient air. For the workers, they should minimally wear protective equipment like masks or vapor respirators during working time in order to reduce their exposure to the pollutants through inhalation. A half-mask respirator with cartridge was recommended by OSHA (Appendix E - OSHA Respirator Requirements for Selected Chemicals) for less than 10 ppm (30,000 $\mu g/m^3$) of benzene and less than 7.5 ppm (9,300 $\mu g/m^3$) of formaldehyde. For cooperating with customers, the owner should ask customers to turn off car engines when refueling in order to reduce the pollutants emitted from car exhaust. Finally, the concentration of pollutants in workplace should be monitored regularly and compared with the concentrations contaminated in human given as the biomarker of the workers.

CHAPTER V

CONCLUSION AND RECOMMENDATIONS

5.1 Conclusions

This study aimed to determine the concentrations of carbonyl compounds and BTEX in gas stations of Bangkok. Personal exposure and ambient air concentrations at the six gas stations locating in the inner city of Bangkok were measured for the first sampling. For the second sampling, personal exposure, ambient air and roadside concentrations at the six gas stations locating in the widespread area of Bangkok were investigated. The correlations between some available affecting factors and the ambient concentrations of the pollutants were examined. Further, the personal exposure concentrations were used to calculate their inhalation exposure and theirs possible health risk. All results can be concluded as follows:

1) From both samplings, the predominant target compounds found in personal exposure, ambient and roadside air concentrations at all gas stations were formaldehyde, acetaldehyde, acetone, propionaldehyde, crotonaldehyde, butyraldehyde, valeraldehyde, hexanaldehyde, benzene, toluene, ethylbenzene, m,p-xylene and o-xylene.

2) For the study in the inner city of Bangkok, the 8-hr averages of personal exposure and of ambient concentrations of toluene were found the highest concentration at all stations which were 297.03 (94.77 – 490.38) and 302.64 (167.74 – 574.17) µg/m^3, respectively. The concentration of toluene was more than benzene, m,p-xylene, ethylbenzene and o-xylene, respectively. The average concentrations of benzene were 220.29 (55.22 – 292.52) µg/m^3 for personal exposure and 166.23 (95.47 – 262.90) µg/m^3 for ambient. The average concentrations of m,p-xylene were 81.67 (40.79 – 154.14) µg/m^3 for personal exposure and 111.27 (46.71 – 218.40) µg/m^3 for ambient. The average concentrations of ethylbenzene were 34.96 (22.64 – 52.42) µg/m^3 for personal exposure and 44.72 (24.61 – 73.48) µg/m^3 for ambient. The average concentrations of o-xylene were 28.22 (15.64 – 49.90) µg/m^3 for personal exposure and 38.83 (17.59 – 75.13) µg/m^3 for ambient.

3) For the result of carbonyl compounds in the inner city of Bangkok, the 8-hr averages of major species including formaldehyde, acetaldehyde, acetone and propionaldehyde were as follows; the average concentrations of formaldehyde were 12.17 (7.56 – 18.83) µg/m^3 for personal exposure and 11.12 (5.31 – 15.12) µg/m^3 for ambient; the average concentrations of acetaldehyde were 5.34 (2.15 – 13.11) µg/m^3 for personal exposure and 3.36 (1.27 – 7.28) µg/m^3 for ambient; the average concentrations of acetone were 12.46 (4.82 – 26.99) µg/m^3 for personal exposure and 7.36 (6.26 – 9.07) µg/m^3 for ambient; and the average concentrations of propionaldehyde were 1.28 (0.45 – 4.78) µg/m^3 for personal exposure and 3.55 (0.59 – 14.86) µg/m^3 for ambient.

4) Comparing BTEX measured in the widespread area of Bangkok to the result studies in the inner city of Bangkok, there were lower concentrations of BTEX for both ambient and personal exposure in the second sampling. The roadside concentration was additionally measured in the second sampling. The 8-hr average concentrations of personal exposure, ambient, and roadside for benzene were 123.70 (36.93 – 259.73), 52.00 (5.98 – 109.19), and 16.23 (4.80 – 37.38) µg/m^3, respectively. Those concentrations of toluene were 188.39 (69.21 – 404.29), 112.95 (3.47 – 290.47), and 27.45 (8.56 – 67.20) µg/m^3, respectively, and of ethylbenzene were 34.16 (22.33 – 59.03), 26.41 (1.52 – 63.40), and 7.14 (3.01 – 17.11) µg/m^3, respectively, and of m,p-xylene were 34.16 (22.33 – 59.03), 26.41 (1.52 – 63.40), and 7.14 (3.01 – 17.11) µg/m^3 , respectively, and of o-xylene were 10.42 (5.28 – 23.55), 8.89 (1.39 – 18.96), and 3.11 (0.91 – 6.11) µg/m^3, respectively.

5) Comparing major carbonyl compounds species measured in the widespread area of Bangkok to the result studies in the inner city of Bangkok, there were lower concentrations of formaldehyde and propionaldehyde for both ambient and personal exposure in the second sampling. While, the concentration of acetaldehyde in the second sampling was higher than that of the first sampling, and acetone was found the same range. From all gas stations studied in the second sampling, the 8-hr average concentrations of major species including formaldehyde, acetaldehyde, acetone and propionaldehyde for personal exposure, ambient, and roadside are as follows; the average concentrations of formaldehyde were 10.95 (3.40 – 39.76), 7.83 (0.95 – 15.60, n=24), and 7.81 (3.27 – 14.82) µg/m^3, respectively; those

of acetaldehyde were 8.87 (1.59 – 35.33), 5.05 (0.57 – 10.74), and 4.62 (1.65 – 10.36) $\mu g/m^3$, respectively; those of acetone were 12.15 (3.49 – 23.22), 7.85 (0.21 – 15.29), and 7.78 (3.46 – 14.18) $\mu g/m^3$, respectively; those of propionaldehyde were 1.03 (0.27 – 2.37), 0.89 (0.20 – 1.99), and 0.73 (0.25 – 1.42) $\mu g/m^3$, respectively

6) The 8-hr average personal exposure concentrations of BTEX and of carbonyl compounds were found to be not exceeding the occupational limits of NIOSH, OSHA, ACGIH and in Thailand.

7) The affecting factors on ambient concentrations of BTEX and carbonyl compounds were fuel circulations, a number of customer cars, meteorological conditions especially wind direction and seasonal variation (related to atmospheric chemical reactions).

8) The good relationship between BTEX and carbonyl compounds in the ambient air was found in this study due to BTEX are typically emitted direct from the fuel at gas station as the primary pollutant, these compounds can be transformed to be the secondary pollutants including production of carbonyl compounds.

9) The lifetime cancer risk of benzene was found in range 4.14×10^{-5} - 4.99×10^{-4} which showed the highest 100.0% unacceptable risk of total workers. The cancer risk of formaldehyde was in the second order, 64.7% unacceptable risk of total workers, which was in range of 4.28×10^{-6} - 5.72×10^{-5}. For ethylbenzene and acetaldehyde, those cancer risks were in the same range, 2.9% unacceptable risk of total workers, their cancer risks were in range of 1.47×10^{-6} - 1.26×10^{-5} and 8.46×10^{-7} - 2.03×10^{-5}, respectively. For carcinogenic compounds, the overall workers (100%) were at risk of cancer especially leukemia from inhalation exposure to benzene which was found relatively higher than formaldehyde (64.7%), ethylbenzene (2.9%), and acetaldehyde (2.9%), respectively.

10) For non cancer risk, the hazard quotients of toluene, m,p-xylene, o-xylene and propionaldehyde were found in range 0.0044 - 0.0313, 0.0714 - 0.4927, 0.0169 - 0.1595 and 0.0106 - 0.1910, respectively. All of them were in acceptable level; hazard quotients were less than 1. The overall workers (100%) were not posed to increase risk of some adverse health effects from exposure to these compounds.

5.2 Recommendations and suggestions

1) The personal exposure concentrations of these compounds should be compared with some biomarkers of the workers.

2) The concentrations of ozone and the other by-products should be determined for the further study.

3) This study should be applied for the other occupational workers which also exposure to these compounds in their workplace.

4) Some information relating to possibility of the worker exposure to these pollutants from other sources should be added in the questionnaire such as location of their houses, part time jobs and travelling to work.

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APPENDICES

APPENDIX A

Questionnaires

A.1 Questionnaire for gas station workers (English version)

Questionnaires for gas station workers

Date ………/………/………

Gas station code ……………………………………… District ………………………

Gender ☐ Male ☐ Female

Age ……………………… years

Body weight ……………… kg

Work experience in gas station ……………………… years

Responsibilities ……………………………………………………………………………

Number of working days …………… days/week

Working duration ………………… hours/day

Working period ……………… to ………………………

Break time ………………… to ………………………

Activities during break time ……………………………………………………………

Annual health check ☐ Yes ☐ No

Last health check ☐ Less than 3 months ☐ 3 months – 6 months
☐ 6 months – 1 year ☐ More than 1 year

Smoking before working ☐ Yes ☐ No

Drinking before working ☐ Yes ☐ No

Using perfume/cologne before working ☐ Yes ☐ No

Route of exposure to petrol ☐ Skin ☐ Inhalation

Headache /drowsiness during working ☐ No ☐ Yes

Irritations of eyes/ nose/ throat/ skin during working ☐ No ☐ Yes

Tired/ fatigued during working ☐ No ☐ Yes

Chest pain/ suffocation during working ☐ No ☐ Yes

Bored with food/ temporary hearing and/or vision loss during working
☐ No ☐ Yes

Faint/ unconscious during working ☐ No ☐ Yes

Cleaning contaminated body after exposure to petrol ☐ No ☐ Yes

Protecting health during working
☐ No ☐ Yes, using mask ☐ Yes, wearing cloth entirely ☐ Yes, using gloves

Atmospheric conditions during working ……………………………………………

Expected time to work at gas station ………… years

A.2 Questionnaire for gas station workers (Thai version)

แบบสอบถามข้อมูลพนักงานในสถานีบริการน้ำมันเชื้อเพลิง

วัน................/........./..........

ชื่อสถานีบริการน้ำมันเชื้อเพลิง..เขต.........................

เพศ ☐ ชาย ☐ หญิง

อายุ..............................ปี

น้ำหนัก..........................กิโลกรัม

ระยะเวลาที่ทำงานในสถานีบริการน้ำมันเชื้อเพลิง..............................ปี

งานที่รับผิดชอบ..

จำนวนวันที่ทำงานต่อสัปดาห์.....................วัน/สัปดาห์

ระยะเวลาในการทำงานต่อวัน..............................ชั่วโมง/วัน

ช่วงเวลาทำงาน........................น. ถึง........................น.

ช่วงเวลาพัก............................น. ถึง........................น.

กิจกรรมระหว่างพัก คือ...

การตรวจสุขภาพประจำปี ☐ เคย ☐ ไม่เคย

ตรวจสุขภาพครั้งล่าสุด ☐ ต่ำกว่า 3 เดือน ☐ 3 เดือน – 6 เดือน
☐ 6 เดือน – 1 ปี ☐ มากกว่า 1 ปี

ท่านสูบบุหรี่หรือไม่ ☐ ใช่ ☐ ไม่ใช่

ท่านดื่มสุราก่อนมาทำงานหรือไม่ ☐ ใช่ ☐ ไม่ใช่

ท่านมีการใช้น้ำหอม/โคโลญจน์ก่อนมาทำงานหรือไม่ ☐ ใช่ ☐ ไม่ใช่

ในขณะทำงานมีการสัมผัสกับน้ำมันเชื้อเพลิงทางใดบ้าง ☐ ทางผิวหนัง ☐ ทางการหายใจ

ในระหว่างการทำงานท่านมีอาการปวดศีรษะ/มึนงง หรือไม่ ☐ ไม่มี ☐ มี

ในระหว่างการทำงานท่านมีอาการระคายเคืองตา/จมูก/คอ/ผิวหนัง หรือไม่ ☐ ไม่มี ☐ มี

ในระหว่างการทำงานท่านมีอาการอ่อนเพลีย/เมื่อยล้า หรือไม่ ☐ ไม่มี ☐ มี

ในระหว่างการทำงานท่านมีอาการเจ็บหน้าอก/หายใจติดขัด หรือไม่ ☐ ไม่มี ☐ มี

ในระหว่างการทำงานท่านรู้สึกเบื่ออาหาร/สูญเสียการได้ยินหรือการมองเห็นชั่วขณะ หรือไม่ ☐ไม่มี ☐มี

ในระหว่างการทำงานท่านเคยเป็นลม/หมดสติ หรือไม่ ☐ ไม่มี ☐ มี

ท่านมีการทำความสะอาดบริเวณที่สัมผัสกับน้ำมันเชื้อเพลิง หรือไม่ ☐ ไม่มี ☐ มี

ในระหว่างการทำงานท่านมีการป้องกันการสัมผัสกับน้ำมันเชื้อเพลิงหรือไม่

☐ ไม่มี ☐ มี ใส่ผ้าปิดจมูก/หน้ากากป้องกัน ☐ มี ใส่เสื้อผ้ามิดชิด ☐ มี ใส่ถุงมือ

สภาพอากาศระหว่างเวลาทำงาน..

ท่านคาดว่าจะทำงานในสถานีบริการน้ำมันเชื้อเพลิงอีก..............ปี

Table A.1 General information of gas station workers (n=28)

General information	**n**	**%**
Gender		
• Male	15	53.6
• Female	13	46.4
Age (years)		
• less than 20	12	42.9
• 20-25	9	34.1
• 26-30	3	10.7
• more than 30	2	7.1
• n/a	2	7.1
Body weight (kg)		
• less than 50	8	28.6
• 50-55	6	21.4
• 56-60	5	17.9
• more than 60	9	32.1
Symptom		
• Headache /drowsiness		
○ Yes	10	35.7
○ No	18	64.3
• Irritations of eyes/ nose/ throat/ skin		
○ Yes	14	50.0
○ No	14	50.0
• Tired/ fatigued		
○ Yes	19	67.9
○ No	9	32.1
• Chest pain/ suffocation		
○ Yes	8	28.6
○ No	20	71.4
• Bored with food/ temporary hearing and/or vision loss		
○ Yes	4	14.3
○ No	24	85.7
• Faint/ unconscious		
○ Yes	0	0.0
○ No	28	100.0
Health protection		
• No	23	82.1
• Yes, using mask	1	3.6
• Yes, wearing cloth entirely	3	37.5
• Yes, using gloves	1	3.6
Expected time to work at gas station (years)		
• 1-5	14	50.0
• 6-10	1	3.6
• more than 10	1	3.6
• not expected	12	42.9

APPEXDIX B

Preliminary Study

B.1 Calibration curves

Table B.1 Peak area of standard BTEX of calibration curve

Compounds	Peak Area Ratio									
	125 ng/ml	250 ng/ml	500 ng/ml	1,000 ng/ml	2,000 ng/ml	4,000 ng/ml	8,000 ng/ml	16,000 ng/ml	Average	SD
Benzene	1.13	1.41	1.81	2.58	3.91	7.10	12.83	-	4.40	4.25
Toluene	0.61	0.85	1.37	2.37	4.13	7.38	13.10	-	4.26	4.56
Ethylbenzene	0.17	0.35	0.83	1.75	3.32	6.63	12.58	-	3.66	4.53
m,p-Xylene	-	0.49	0.83	1.81	3.70	7.23	13.94	25.90	7.70	9.31
o-Xylene	0.27	0.51	0.98	1.99	3.57	6.98	13.01	-	3.90	4.64

Table B.2 Peak area of 14 standard carbonyl compounds of calibration curve

Compounds	Peak Area						
	0.010 ppm	0.050 ppm	0.100 ppm	0.600 ppm	1.000 ppm	Average	SD
Formaldehyde	10185	49747	101789	581811	971926	343092	420572
Acetaldehyde	6991	36003	75360	429251	720036	253528	311589
Acetone	5371	27424	55172	319283	530735	187597	229936
Acrolein	6459	34439	71108	408807	684490	241061	296388
Propionaldehyde	4959	26432	54681	318654	531256	187196	230366
Crotonaldehyde	4028	21756	44420	295524	494429	172031	215803
Butyraldehyde	3888	20702	43524	249655	419345	147423	181555
Benzaldehyde	2643	15938	36070	209222	348506	122476	151485
Isovaleraldehyde	3053	18524	38672	225103	375331	132137	162859
Valeraldehyde	2992	17015	35521	203639	338880	119609	146916
o-Tolualdehyde	1731	12678	28055	161026	269238	94546	116913
m,p-Tolualdehyde	4713	26431	58910	341652	568671	200075	247059
Hexanaldehyde	2443	13526	29133	170237	285374	100143	123808
2,5-Dimethylbenzaldehyde	1749	11337	23359	136759	228519	80345	99153

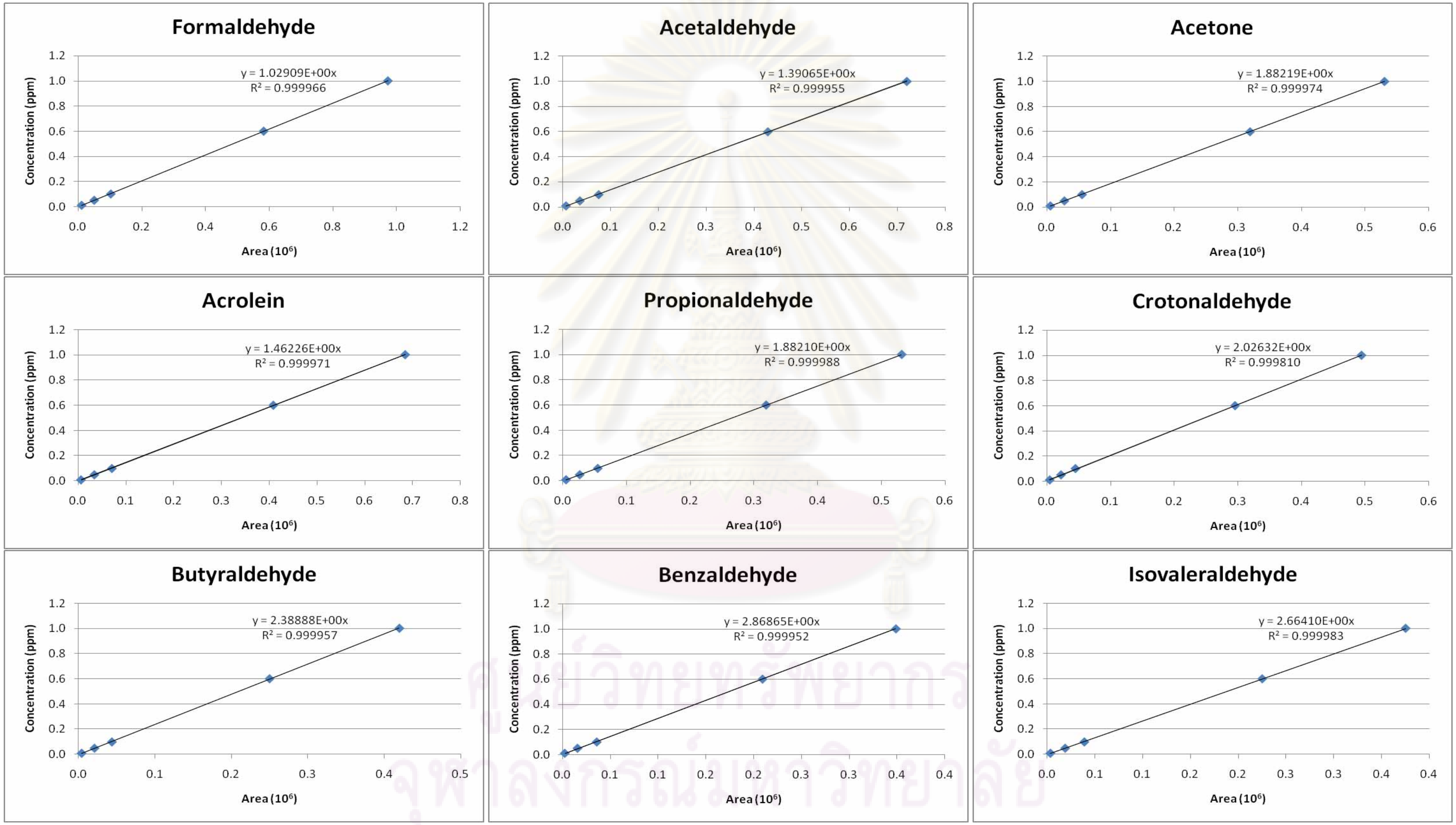


Figure B.1 Calibration Curve of Standard 14 Carbonyl Compounds

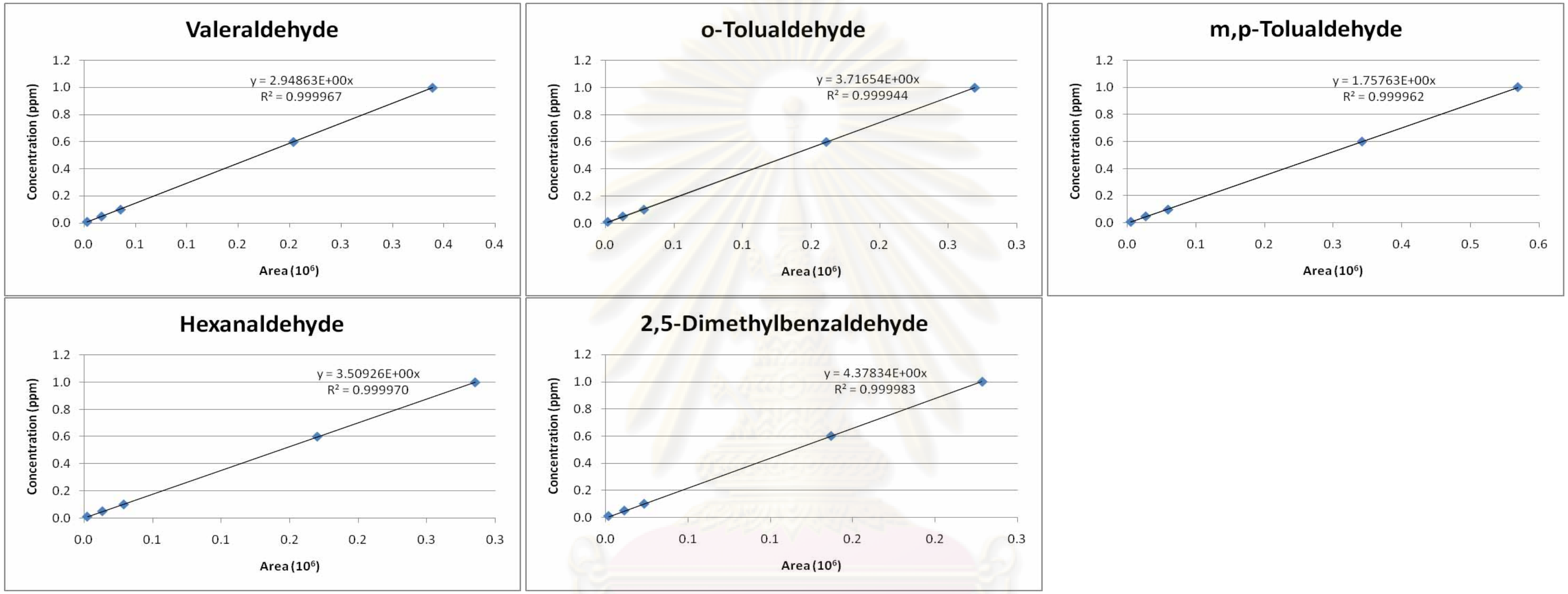


Figure B.1 Calibration Curve of Standard 14 Carbonyl Compounds (continue)

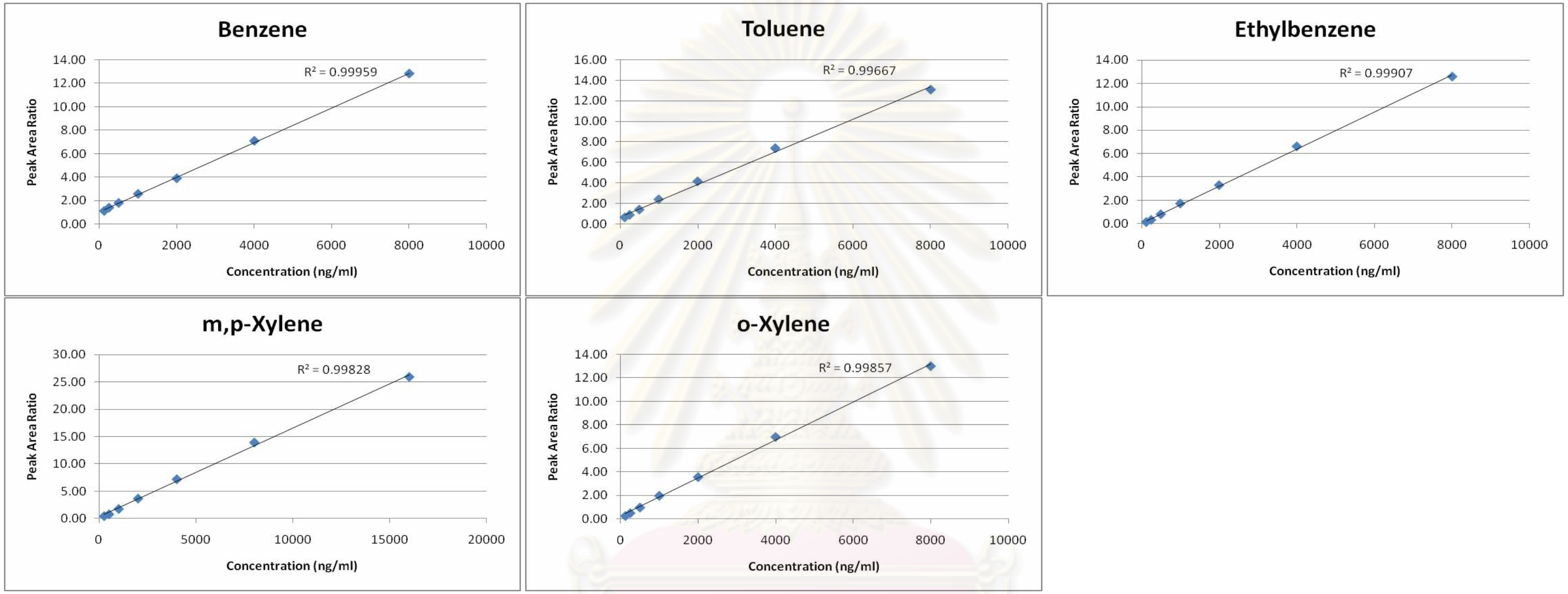


Figure B.2 Calibration Curve of Standard BTEX

B.2 Limit of instruments

Table B.3 LOD and LOQ of GC for BTEX

Compounds	Peak area (25 ng/ml)			Average	SD	LOD (ng/ml)	LOQ (ng/ml)
	(1)	(2)	(3)				
Benzene	0.138998	0.141281	0.132775	0.137685	0.004402	2.40	7.99
Toluene	0.188823	0.409634	0.355467	0.317975	0.115081	27.14	90.48
Ethylbenzene	0.168403	0.10597	0.101553	0.125309	0.037386	22.38	74.59
m,p-Xylene	0.251056	0.270513	0.245987	0.255852	0.012947	3.80	12.65
o-Xylene	0.135222	0.117356	0.280088	0.177555	0.089244	37.70	125.66

Table B.3 IDL and IQL of HPLC for carbonyl compounds

Compounds	Concentration (0.050 mg/l)							Average	SD	IDL (mg/l)	IQL (mg/l)	%RSD
	(1)	(2)	(3)	(4)	(5)	(6)	(7)					
Formaldehyde	0.052	0.050	0.051	0.051	0.050	0.050	0.050	0.051	0.001	0.002	0.008	1.556
Acetaldehyde	0.052	0.050	0.050	0.050	0.050	0.049	0.049	0.050	0.001	0.003	0.010	2.000
Acetone	0.051	0.051	0.051	0.051	0.050	0.050	0.049	0.050	0.001	0.002	0.008	1.560
Acrolein	0.051	0.050	0.050	0.050	0.049	0.049	0.049	0.050	0.001	0.002	0.008	1.521
Propionaldehyde	0.051	0.050	0.050	0.049	0.049	0.050	0.049	0.050	0.001	0.002	0.008	1.521
Crotonaldehyde	0.049	0.051	0.048	0.049	0.049	0.049	0.047	0.049	0.001	0.004	0.012	2.487
Butyraldehyde	0.052	0.051	0.050	0.052	0.049	0.050	0.049	0.050	0.001	0.004	0.013	2.523
Benzaldaldehyde	0.052	0.051	0.048	0.050	0.050	0.050	0.050	0.050	0.001	0.004	0.012	2.423
Isovaleraldehyde	0.053	0.051	0.048	0.048	0.051	0.049	0.050	0.050	0.002	0.005	0.018	3.651
Valeraldehyde	0.053	0.048	0.051	0.050	0.052	0.050	0.050	0.051	0.002	0.005	0.016	3.200
o-Tolualdehyde	0.054	0.050	0.050	0.048	0.050	0.049	0.049	0.050	0.002	0.006	0.019	3.830
m,p Tolualdehyde	0.048	0.046	0.047	0.047	0.047	0.047	0.044	0.047	0.001	0.004	0.013	2.732
Hexanaldehyde	0.052	0.050	0.048	0.049	0.051	0.051	0.051	0.050	0.001	0.004	0.014	2.745
2,5 Dimethylbenzaldehyde	0.053	0.050	0.048	0.048	0.051	0.049	0.049	0.050	0.002	0.005	0.018	3.620

APPENDIX C

BTEX and carbonyl compounds in the first sampling

C.1 Personal exposure concentrations of BTEX

Table C.1 Personal exposure concentration of BTEX at TRO

Compounds	Personal exposure concentration (µg/m^3)				Average ± SD (µg/m^3)
	D1 P1	D1 P2	D2 P1	D2 P2	
Benzene	208.36	228.78	238.95	227.29	225.84 ± 12.76
Toluene	242.12	268.53	267.44	292.24	267.58 ± 20.47
Ethylbenzene	33.68	32.16	26.17	27.34	29.84 ± 3.64
m,p-Xylene	78.12	81.35	65.54	69.15	73.54 ± 7.42
o-Xylene	25.06	27.50	24.00	23.34	24.98 ± 1.83
Total BTEX	587.34	638.31	622.10	639.36	621.78 ± 24.28

Table C.2 Personal exposure concentration of BTEX at PCC

Compounds	Personal exposure concentration (µg/m^3)				Average ± SD (µg/m^3)
	D1 P1	D1 P2	D2 P1	D2 P2	
Benzene	223.98	263.78	257.27	224.16	242.30 ±21.21
Toluene	256.97	377.04	271.44	243.90	287.34 ± 60.85
Ethylbenzene	29.76	34.05	43.17	44.41	37.85 ± 7.10
m,p-Xylene	71.15	90.14	118.53	120.89	100.17 ± 23.87
o-Xylene	22.65	28.83	43.31	42.20	34.25 ± 10.15
Total BTEX	604.50	793.84	733.71	675.56	701.90 ± 80.92

Table C.3 Personal exposure concentration of BTEX at NW

Compounds	Personal exposure concentration (µg/m^3)				Average ± SD (µg/m^3)
	D1 P1	D1 P2	D2 P1	D2 P2	
Benzene	55.22	92.26	117.24	212.94	119.42 ± 67.35
Toluene	94.77	137.75	207.18	215.25	163.74 ± 57.66
Ethylbenzene	27.56	22.64	38.62	33.95	30.70 ± 7.03
m,p-Xylene	41.51	40.79	75.11	62.11	54.88 ± 16.72
o-Xylene	19.95	15.64	29.82	18.05	20.86 ± 6.22
Total BTEX	239.01	309.09	467.97	542.31	389.59 ± 139.79

Table C.4 Personal exposure concentration of BTEX at TP

Compounds	Personal exposure concentration (µg/m^3)				Average ± SD (µg/m^3)
	D1 P1	D1 P2	D2 P1	D2 P2	
Benzene	144.19	278.09	233.65	285.59	235.38 ± 64.97
Toluene	301.27	451.91	490.38	353.08	399.16 ± 87.20
Ethylbenzene	29.07	26.32	50.71	23.87	32.49 ± 12.33
m,p-Xylene	46.71	66.08	108.67	57.35	69.71 ± 27.16
o-Xylene	23.19	21.32	28.85	18.46	22.95 ± 4.39
Total BTEX	544.43	843.73	912.26	738.34	759.69 ± 160.35

Table C.5 Personal exposure concentration of BTEX at BK

Compounds	Personal exposure concentration (µg/m^3)				Average ± SD (µg/m^3)
	D1 P1	D1 P2	D2 P1	D2 P2	
Benzene	202.99	270.02	229.94	292.52	248.87 ± 40.07
Toluene	270.41	363.25	353.15	403.03	347.46 ± 55.70
Ethylbenzene	42.17	38.63	45.29	52.42	44.63 ± 5.86
m,p-Xylene	95.53	100.90	154.14	145.59	124.04 ± 30.10
o-Xylene	32.32	34.29	49.90	46.84	40.84 ± 8.83
Total BTEX	643.42	807.09	832.43	940.39	805.83 ± 122.74

Table C.6 Personal exposure concentration of BTEX at SBS

Compounds	Personal exposure concentration (µg/m^3)				Average ± SD (µg/m^3)
	D1 P1	D1 P2	D2 P1	D2 P2	
Benzene	246.27	246.85	258.12	248.38	249.91 ± 5.55
Toluene	381.24	265.09	328.13	293.21	316.92 ± 50.04
Ethylbenzene	26.36	41.77	31.84	37.11	34.27 ± 6.66
m,p-Xylene	57.30	73.42	71.89	68.10	67.68 ± 7.27
o-Xylene	22.35	27.20	24.16	27.98	25.42 ± 2.63
Total BTEX	733.51	654.33	714.15	674.77	694.19 ± 36.11

C.2 Ambient concentrations of BTEX

Table C.7 Ambient concentration of BTEX at TRO

Compounds	Ambient concentration (μg/m³)		Average ± SD (μg/m³)
	D1	D2	
Benzene	126.20	206.50	166.35 ± 56.77
Toluene	203.14	276.24	239.69 ± 51.69
Ethylbenzene	26.31	35.12	30.72 ± 6.24
m,p-Xylene	75.26	84.23	79.75 ± 6.34
o-Xylene	24.84	31.70	28.27 ± 4.85
Total BTEX	455.75	633.78	544.77 ± 125.89

Table C.8 Ambient concentration of BTEX at PCC

Compounds	Ambient concentration (μg/m³)		Average ± SD (μg/m³)
	D1	D2	
Benzene	95.47	162.68	129.08 ±47.53
Toluene	167.74	219.13	193.44 ±36.34
Ethylbenzene	28.05	51.30	39.67 ±16.44
m,p-Xylene	46.71	151.05	98.88 ±73.78
o-Xylene	17.59	51.25	34.42 ±23.80
Total BTEX	355.55	635.41	495.48 ±197.89

Table C.9 Ambient concentration of BTEX at NW

Compounds	Ambient concentration (μg/m³)		Average ± SD (μg/m³)
	D1	D2	
Benzene	106.21	95.77	100.99 ± 7.38
Toluene	228.19	180.68	204.43 ± 33.60
Ethylbenzene	24.61	52.27	38.44 ± 19.56
m,p-Xylene	76.31	74.70	75.50 ± 1.13
o-Xylene	21.62	24.41	23.01 ± 1.97
Total BTEX	456.93	427.82	442.38 ± 63.64

Table C.10 Ambient concentration of BTEX at TP

Compounds	Ambient concentration (μg/m³)		Average ± SD (μg/m³)
	D1	D2	
Benzene	244.18	262.90	253.54 ± 13.24
Toluene	486.15	574.17	530.16 ± 62.24
Ethylbenzene	32.68	33.42	33.05 ± 0.52
m,p-Xylene	73.88	104.19	89.03 ± 21.43
o-Xylene	28.61	37.43	33.02 ± 6.23
Total BTEX	865.50	1012.10	938.80 ± 103.66

Table C.11 Ambient concentration of BTEX at BK

Compounds	Ambient concentration (μg/m³)		Average ± SD (μg/m³)
	D1	D2	
Benzene	170.50	200.78	185.64 ± 21.41
Toluene	283.52	486.87	385.19 ± 143.79
Ethylbenzene	61.76	73.48	67.62 ± 8.29
m,p-Xylene	109.71	218.40	164.06 ± 76.86
o-Xylene	41.54	75.13	58.34 ± 23.75
Total BTEX	667.03	1054.66	860.85 ± 274.10

Table C.12 Ambient concentration of BTEX at SBS

Compounds	Ambient concentration (μg/m³)		Average ± SD (μg/m³)
	D1	D2	
Benzene	197.18	126.35	161.76 ± 50.08
Toluene	277.66	248.22	262.94 ± 20.82
Ethylbenzene	63.79	53.83	58.81 ± 7.04
m,p-Xylene	169.51	151.24	160.38 ± 12.92
o-Xylene	60.70	51.14	55.92 ± 6.76
Total BTEX	768.83	630.78	699.80 ± 97.62

C.3 Personal exposure concentrations of carbonyl compounds

Table C.13 Personal exposure concentration of carbonyl compounds at TRO

Compounds	**Personal exposure concentration (μg/m^3)**				**Average ± SD (μg/m^3)**
	D1 P1	**D1 P2**	**D2 P1**	**D2 P2**	
Formaldehyde	10.43	8.86	11.97	13.64	11.22 ± 2.05
Acetaldehyde	3.55	2.69	2.65	2.41	2.82 ± 0.50
Acetone	31.52	73.97	10.35	9.43	31.32 ± 30.21
Propionaldehyde	1.77	1.67	1.18	1.29	1.48 ± 0.29
Crotonaldehyde	1.56	2.30	nd	0.41	1.42 ± 0.95
Butyraldehyde	0.34	0.42	3.04	2.68	1.62 ± 1.44
Benzaldehyde	0.17	0.52	nd	nd	0.34 ± 0.25
Isovaleraldehyde	0.05	0.07	nd	nd	0.06 ± 0.01
Valeraldehyde	1.45	2.05	nd	nd	1.75 ± 0.42
o-Tolualdehyde	0.35	0.44	nd	nd	0.40 ± 0.07
m,p-Tolualdehyde	nd	nd	nd	nd	> 0.01
Hexanaldehyde	0.40	nd	1.54	1.70	1.21 ± 0.71
2,5-Dimethylbenzaldehyde	1.14	nd	nd	nd	1.14

Table C.14 Personal exposure concentration of carbonyl compounds at PCC

Compounds	**Personal exposure concentration (μg/m^3)**				**Average ± SD (μg/m^3)**
	D1 P1	**D1 P2**	**D2 P1**	**D2 P2**	
Formaldehyde	18.83	15.59	12.34	13.28	15.01 ± 2.89
Acetaldehyde	13.11	7.15	3.78	5.38	7.35 ± 4.08
Acetone	41.84	37.95	8.28	9.04	24.27 ± 18.11
Propionaldehyde	0.77	1.71	1.28	1.34	1.27 ± 0.39
Crotonaldehyde	2.37	1.67	0.54	0.34	1.23 ± 0.96
Butyraldehyde	0.44	0.12	nd	nd	0.28 ± 0.23
Benzaldehyde	0.92	0.78	nd	nd	0.85 ± 0.10
Isovaleraldehyde	0.47	0.11	nd	nd	0.29 ± 0.25
Valeraldehyde	1.43	1.62	nd	nd	1.53 ± 0.13
o-Tolualdehyde	0.18	nd	nd	nd	0.18
m,p-Tolualdehyde	nd	nd	nd	nd	> 0.01
Hexanaldehyde	nd	nd	0.76	1.25	1.00 ± 0.34
2,5-Dimethylbenzaldehyde	0.49	0.15	nd	nd	0.32 ± 0.24

Table C.15 Personal exposure concentration of carbonyl compounds at NW

Compounds	**Personal exposure concentration (μg/m^3)**				**Average ± SD (μg/m^3)**
	D1 P1	**D1 P2**	**D2 P1**	**D2 P2**	
Formaldehyde	8.75	10.26	9.28	9.09	9.34 ± 0.65
Acetaldehyde	3.01	3.08	2.31	2.15	2.64 ± 0.47
Acetone	75.56	104.90	7.04	6.11	48.40 ± 49.76
Propionaldehyde	1.00	1.08	0.81	0.83	0.93 ± 0.13
Crotonaldehyde	1.75	1.24	nd	nd	1.50 ± 0.36
Butyraldehyde	0.45	0.52	nd	nd	0.48 ± 0.05
Benzaldehyde	0.30	0.65	nd	nd	0.48 ± 0.25
Isovaleraldehyde	0.13	0.08	nd	nd	0.11 ± 0.04
Valeraldehyde	0.95	1.08	nd	nd	1.01 ± 0.09
o-Tolualdehyde	0.17	nd	nd	nd	0.17
m,p-Tolualdehyde	nd	0.05	nd	nd	0.05
Hexanaldehyde	nd	nd	1.14	1.10	1.12 ± 0.03
2,5-Dimethylbenzaldehyde	0.63	nd	nd	nd	0.63

Table C.16 Personal exposure concentration of carbonyl compounds at TP

Compounds	**Personal exposure concentration (μg/m^3)**				**Average ± SD (μg/m^3)**
	D1 P1	**D1 P2**	**D2 P1**	**D2 P2**	
Formaldehyde	15.78	16.12	13.40	13.38	14.67 ± 1.49
Acetaldehyde	12.12	7.09	6.79	7.11	8.28 ± 2.57
Acetone	14.54	26.99	8.35	6.22	14.03 ± 9.34
Propionaldehyde	2.24	1.55	0.68	0.57	1.26 ± 0.79
Crotonaldehyde	1.89	6.89	1.14	1.68	2.90 ± 2.68
Butyraldehyde	nd	1.29	2.98	2.72	2.33 ± 0.91
Benzaldehyde	1.16	0.82	0.24	0.33	0.64 ± 0.43
Isovaleraldehyde	nd	0.05	0.06	nd	0.05 ± 0.00
Valeraldehyde	1.41	1.98	0.07	nd	1.15 ± 0.98
o-Tolualdehyde	0.73	0.79	nd	0.12	0.55 ± 0.37
m,p-Tolualdehyde	nd	0.20	0.03	0.04	0.09 ± 0.10
Hexanaldehyde	2.04	1.61	0.18	nd	1.28 ± 0.97
2,5-Dimethylbenzaldehyde	0.12	0.42	0.34	0.14	0.25 ± 0.15

Table C.17 Personal exposure concentration of carbonyl compounds at BK

Compounds	Personal exposure concentration ($\mu g/m^3$)				Average ± SD ($\mu g/m^3$)
	D1 P1	**D1 P2**	**D2 P1**	**D2 P2**	
Formaldehyde	7.89	10.07	14.70	8.27	10.23 ± 3.12
Acetaldehyde	3.38	6.86	10.94	3.12	6.08 ± 3.66
Acetone	15.59	12.79	10.36	7.05	11.45 ± 3.63
Propionaldehyde	1.13	4.78	1.02	0.48	1.85 ± 1.97
Crotonaldehyde	1.98	2.41	16.53	1.04	5.49 ± 7.38
Butyraldehyde	3.56	4.01	2.50	2.58	3.16 ± 0.74
Benzaldehyde	0.60	0.44	0.41	0.34	0.44 ± 0.11
Isovaleraldehyde	nd	nd	0.08	nd	0.08
Valeraldehyde	1.14	0.50	0.34	nd	0.66 ± 0.42
o-Tolualdehyde	nd	nd	0.03	0.17	0.10 ± 0.10
m,p-Tolualdehyde	nd	nd	0.07	0.03	0.05 ± 0.03
Hexanaldehyde	1.48	2.33	0.22	nd	1.34 ± 1.06
2,5-Dimethylbenzaldehyde	0.30	1.50	0.10	0.15	0.51 ± 0.66

Table C.18 Personal exposure concentration of carbonyl compounds at SBS

Compounds	Personal exposure concentration ($\mu g/m^3$)				Average ± SD ($\mu g/m^3$)
	D1 P1	**D1 P2**	**D2 P1**	**D2 P2**	
Formaldehyde	14.88	12.74	7.56	14.97	12.54 ± 3.47
Acetaldehyde	3.04	2.71	4.08	9.71	4.88 ± 3.27
Acetone	20.23	14.64	4.82	7.92	11.90 ± 6.90
Propionaldehyde	1.20	0.85	0.45	0.96	0.86 ± 0.32
Crotonaldehyde	2.04	2.10	0.75	19.11	6.00 ± 8.76
Butyraldehyde	4.06	3.81	2.62	nd	3.50 ± 0.77
Benzaldehyde	0.39	0.18	0.13	0.40	0.27 ± 0.14
Isovaleraldehyde	nd	nd	nd	0.11	0.11
Valeraldehyde	0.90	0.10	0.04	0.49	0.38 ± 0.40
o-Tolualdehyde	nd	nd	0.05	0.12	0.09 ± 0.05
m,p-Tolualdehyde	nd	nd	0.04	nd	0.04
Hexanaldehyde	0.73	0.72	nd	nd	0.72 ± 0.01
2,5-Dimethylbenzaldehyde	0.29	0.91	0.16	0.04	0.35 ± 0.39

C.4 Ambient concentration of carbonyl compounds

Table C.19 Ambient concentration of carbonyl compounds at TRO

Compounds	Ambient concentration ($\mu g/m^3$)		Average ± SD ($\mu g/m^3$)
	D1	**D2**	
Formaldehyde	10.25	10.30	10.28 ± 0.04
Acetaldehyde	2.68	1.89	2.28 ± 0.56
Acetone	24.70	6.70	15.70 ± 12.73
Propionaldehyde	2.91	1.11	2.01 ± 1.28
Crotonaldehyde	1.99	0.26	1.12 ± 1.23
Butyraldehyde	0.21	2.10	1.16 ± 1.33
Benzaldehyde	0.70	nd	0.70
Isovaleraldehyde	0.06	nd	0.06
Valeraldehyde	1.94	nd	1.94
o-Tolualdehyde	0.56	nd	0.56
m,p-Tolualdehyde	nd	nd	> 0.01
Hexanaldehyde	nd	1.14	1.14
2,5-Dimethylbenzaldehyde	nd	nd	> 0.02

Table C.20 Ambient concentration of carbonyl compounds at PCC

Compounds	Ambient concentration ($\mu g/m^3$)		Average ± SD ($\mu g/m^3$)
	D1	**D2**	
Formaldehyde	14.07	14.28	14.17 ± 0.15
Acetaldehyde	3.68	3.21	3.44 ± 0.33
Acetone	12.21	8.65	10.43 ± 2.52
Propionaldehyde	2.05	1.39	1.72 ± 0.47
Crotonaldehyde	2.26	0.36	1.31 ± 1.35
Butyraldehyde	0.39	nd	0.39
Benzaldehyde	0.66	nd	0.66
Isovaleraldehyde	nd	nd	> 0.02
Valeraldehyde	2.34	nd	2.34
o-Tolualdehyde	nd	nd	> 0.02
m,p-Tolualdehyde	nd	nd	> 0.01
Hexanaldehyde	nd	1.29	1.29
2,5-Dimethylbenzaldehyde	nd	nd	> 0.02

Table C.21 Ambient concentration of carbonyl compounds at NW

Compounds	Ambient concentration (μg/m^3)		Average ± SD (μg/m^3)
	D1	D2	
Formaldehyde	10.21	5.31	7.76 ± 3.46
Acetaldehyde	1.71	1.27	1.49 ± 0.31
Acetone	21.83	4.29	13.06 ± 12.40
Propionaldehyde	1.44	0.64	1.04 ± 0.57
Crotonaldehyde	1.73	nd	1.73
Butyraldehyde	0.76	0.80	0.78 ± 0.03
Benzaldehyde	0.63	nd	0.63
Isovaleraldehyde	nd	nd	> 0.02
Valeraldehyde	1.38	nd	1.38
o-Tolualdehyde	nd	nd	> 0.02
m,p-Tolualdehyde	nd	nd	> 0.01
Hexanaldehyde	nd	0.76	0.76
2,5-Dimethylbenzaldehyde	nd	nd	> 0.02

Table C.22 Ambient concentration of carbonyl compounds at TP

Compounds	Ambient concentration (μg/m^3)		Average ± SD (μg/m^3)
	D1	D2	
Formaldehyde	11.69	12.18	11.93 ± 0.34
Acetaldehyde	3.32	5.66	4.49 ± 1.65
Acetone	9.07	6.26	7.66 ± 1.99
Propionaldehyde	6.56	0.89	3.73 ± 4.01
Crotonaldehyde	3.42	1.52	2.47 ± 1.34
Butyraldehyde	5.21	2.12	3.66 ± 2.18
Benzaldehyde	0.97	0.49	0.73 ± 0.34
Isovaleraldehyde	nd	0.06	0.06
Valeraldehyde	1.77	0.36	1.07 ± 1.00
o-Tolualdehyde	0.77	0.03	0.40 ± 0.52
m,p-Tolualdehyde	nd	0.04	0.04
Hexanaldehyde	1.80	0.12	0.96 ± 1.19
2,5-Dimethylbenzaldehyde	nd	0.08	0.08

Table C.23 Ambient concentration of carbonyl compounds at BK

Compounds	Ambient concentration (μg/m^3)		Average ± SD (μg/m^3)
	D1	D2	
Formaldehyde	8.14	15.12	11.63 ± 4.94
Acetaldehyde	2.53	7.29	4.91 ± 3.36
Acetone	7.38	6.32	6.85 ± 0.75
Propionaldehyde	14.86	1.14	8.00 ± 9.70
Crotonaldehyde	2.04	17.72	9.88 ± 11.08
Butyraldehyde	4.67	2.09	3.38 ± 1.82
Benzaldehyde	0.81	0.42	0.62 ± 0.27
Isovaleraldehyde	nd	0.07	0.07
Valeraldehyde	2.17	0.40	1.28 ± 1.25
o-Tolualdehyde	nd	nd	> 0.02
m,p-Tolualdehyde	nd	nd	> 0.01
Hexanaldehyde	1.11	nd	1.11
2,5-Dimethylbenzaldehyde	0.58	0.18	0.38 ± 0.29

Table C.24 Ambient concentration of carbonyl compounds at SBS

Compounds	Ambient concentration (μg/m^3)		Average ± SD (μg/m^3)
	D1	D2	
Formaldehyde	11.93	9.92	10.92 ± 1.42
Acetaldehyde	1.78	5.33	3.55 ± 2.52
Acetone	7.92	7.19	7.56 ± 0.51
Propionaldehyde	9.01	0.59	4.80 ± 5.95
Crotonaldehyde	2.06	1.35	1.70 ± 0.51
Butyraldehyde	3.45	2.55	3.00 ± 0.64
Benzaldehyde	0.68	0.32	0.50 ± 0.26
Isovaleraldehyde	nd	nd	> 0.02
Valeraldehyde	1.26	nd	1.26
o-Tolualdehyde	nd	0.06	0.06
m,p-Tolualdehyde	nd	nd	> 0.01
Hexanaldehyde	0.52	nd	0.52
2,5-Dimethylbenzaldehyde	0.56	0.16	0.36 ± 0.28

APPENDIX D
BTEX and carbonyl compounds in the second sampling

D.1 Personal exposure concentrations of BTEX

Table D.1 Personal exposure concentration of BTEX at BT

Compounds	Personal exposure concentration (µg/m^3)								Average ± SD (µg/m^3)
	Fri P1	Fri P2	Sat P1	Sat P2	Sun P1	Sun P2	Mon P1	Mon P2	
Benzene	156.10	126.78	168.95	175.61	156.34	162.98	n/a	n/a	157.80 ± 16.95
Toluene	206.97	165.55	216.00	196.50	199.26	184.65	n/a	n/a	194.82 ± 17.77
Ethylbenzene	10.99	10.29	16.72	14.13	11.98	10.74	n/a	n/a	12.47 ± 2.49
m,p-Xylene	29.93	28.76	59.03	37.66	35.49	30.64	n/a	n/a	36.92 ± 11.37
o-Xylene	9.35	9.17	17.03	10.81	10.57	9.59	n/a	n/a	11.09 ± 2.99
Total BTEX	413.34	340.54	477.73	434.72	413.64	398.60	n/a	n/a	413.09 ± 44.99

Table D.2 Personal exposure concentration of BTEX at DKN

Compounds	Personal exposure concentration (µg/m^3)								Average ± SD (µg/m^3)
	Fri P1	Fri P2	Sat P1	Sat P2	Sun P1	Sun P2	Mon P1	Mon P2	
Benzene	123.53	172.78	91.37	121.05	114.46	154.19	109.55	123.36	126.29 ± 25.70
Toluene	184.38	211.83	168.28	161.81	175.54	182.48	145.66	177.58	175.95± 19.20
Ethylbenzene	11.14	11.63	10.65	10.93	11.19	12.43	10.41	14.60	11.62± 1.35
m,p-Xylene	30.06	31.55	24.77	28.60	27.14	35.55	30.56	30.87	29.89± 3.20
o-Xylene	8.27	7.91	6.85	7.78	7.53	9.96	8.65	9.02	8.25± 0.96
Total BTEX	357.38	435.69	301.92	330.16	335.86	394.61	304.82	355.43	351.99± 45.25

Table D.3 Personal exposure concentration of BTEX at J

Compounds	Personal exposure concentration (µg/m^3)								Average ± SD (µg/m^3)
	Fri P1	Fri P2	Sat P1	Sat P2	Sun P1	Sun P2	Mon P1	Mon P2	
Benzene	n/a	n/a	199.55	49.91	173.37	153.24	90.85	121.87	131.47 ± 55.24
Toluene	n/a	n/a	242.35	69.21	206.49	227.32	146.06	187.81	179.87 ± 63.74
Ethylbenzene	n/a	n/a	13.08	12.67	10.65	9.91	10.12	10.88	11.22 ± 1.34
m,p-Xylene	n/a	n/a	43.22	22.33	32.20	27.31	26.39	33.21	30.78 ± 7.29
o-Xylene	n/a	n/a	13.70	5.28	9.97	8.72	8.07	10.19	9.32 ± 2.78
Total BTEX	n/a	n/a	511.91	159.40	432.68	426.49	281.49	363.96	271.99 ± 198.72

Table D.4 Personal exposure concentration of BTEX at RO

Compounds	Personal exposure concentration (µg/m^3)								Average ± SD (µg/m^3)
	Fri P1	Fri P2	Sat P1	Sat P2	Sun P1	Sun P2	Mon P1	Mon P2	
Benzene	132.87	88.26	97.43	79.86	112.14	91.89	128.13	105.50	104.51 ± 18.91
Toluene	209.85	168.49	200.38	175.37	157.74	133.08	166.02	222.02	179.12 ± 29.55
Ethylbenzene	14.71	12.59	18.02	13.23	10.60	8.51	10.01	12.26	12.49 ± 2.97
m,p-Xylene	39.87	37.66	48.46	39.76	34.40	26.31	30.40	33.95	36.35 ± 6.74
o-Xylene	13.03	12.17	14.28	12.48	10.33	7.83	8.93	10.19	11.15 ± 2.19
Total BTEX	410.33	319.17	378.56	320.70	325.21	267.62	343.48	383.92	343.62 ± 45.57

Table D.5 Personal exposure concentration of BTEX at TL

Compounds	Personal exposure concentration (µg/m^3)								Average ± SD (µg/m^3)
	Fri P1	Fri P2	Sat P1	Sat P2	Sun P1	Sun P2	Mon P1	Mon P2	
Benzene	151.62	41.06	116.17	142.18	66.50	259.73	134.06	158.73	133.76 ± 65.80
Toluene	211.42	325.45	206.80	240.94	130.91	404.29	198.24	231.91	243.74 ± 84.36
Ethylbenzene	10.40	22.08	12.45	12.00	7.86	11.30	11.75	13.15	12.62 ± 4.15
m,p-Xylene	30.02	58.06	36.36	34.13	22.94	30.54	34.27	38.56	35.61 ± 10.25
o-Xylene	8.76	23.55	11.60	10.24	8.11	9.85	10.75	11.48	11.79 ± 4.91
Total BTEX	412.22	470.21	383.39	439.48	236.33	715.70	389.06	453.84	437.53 ±133.70

Table D.6 Personal exposure concentration of BTEX at TP

Compounds	Personal exposure concentration (µg/m^3)								Average ± SD (µg/m^3)
	Fri P1	Fri P2	Sat P1	Sat P2	Sun P1	Sun P2	Mon P1	Mon P2	
Benzene	189.28	135.44	36.93	59.13	83.35	102.73	125.56	58.45	98.86 ± 50.04
Toluene	252.94	202.97	80.06	126.30	141.42	137.21	198.82	110.79	156.31 ± 56.94
Ethylbenzene	15.21	13.61	16.22	11.63	8.46	12.45	14.14	9.06	12.60 ± 2.77
m,p-Xylene	47.83	44.30	32.71	30.82	25.25	24.46	48.72	27.76	35.23 ± 10.14
o-Xylene	14.27	13.47	9.22	9.12	8.57	7.04	15.08	9.72	10.81 ± 3.00
Total BTEX	519.52	409.78	175.14	237.00	267.06	283.89	402.32	215.77	313.81 ±117.83

D.2 Ambient concentrations of BTEX

Table C.7 Ambient concentration of BTEX at BT

Compounds	**Ambient concentration (µg/m^3)**				**Average ± SD (µg/m^3)**
	Friday	**Saturday**	**Sunday**	**Monday**	
Benzene	7.67	6.40	14.73	5.98	8.69 ± 4.09
Toluene	3.91	3.47	18.30	5.75	7.86 ± 7.03
Ethylbenzene	nd	nd	2.24	nd	2.24
m,p-Xylene	nd	nd	4.08	1.52	2.80 ± 1.81
o-Xylene	nd	nd	1.39	nd	1.39
Total BTEX	11.58	9.87	40.74	13.25	18.86 ± 14.65

Table C.8 Ambient concentration of BTEX at DKN

Compounds	**Ambient concentration (µg/m^3)**				**Average ± SD (µg/m^3)**
	Friday	**Saturday**	**Sunday**	**Monday**	
Benzene	65.83	55.06	90.67	101.57	78.28 ± 21.52
Toluene	177.59	125.62	146.23	154.73	151.04 ± 21.51
Ethylbenzene	10.57	7.04	9.63	9.36	9.15 ± 1.50
m,p-Xylene	26.96	15.87	25.12	24.23	23.04 ± 4.92
o-Xylene	8.31	4.14	7.54	7.04	6.76 ± 1.82
Total BTEX	289.26	207.73	279.19	296.92	268.27 ± 41.01

Table C.9 Ambient concentration of BTEX at J

Compounds	**Ambient concentration (µg/m^3)**				**Average ± SD (µg/m^3)**
	Friday	**Saturday**	**Sunday**	**Monday**	
Benzene	52.36	60.27	38.71	39.93	47.82 ± 10.34
Toluene	72.17	82.09	62.04	79.56	73.96 ± 9.00
Ethylbenzene	5.99	6.46	4.13	5.57	5.54 ± 1.00
m,p-Xylene	14.81	17.52	10.55	14.82	14.42 ± 2.88
o-Xylene	4.55	5.38	4.52	5.67	5.03 ± 0.58
Total BTEX	149.88	171.71	119.95	145.55	146.77 ± 21.23

Table C.10 Ambient concentration of BTEX at RO

Compounds	**Ambient concentration (µg/m^3)**				**Average ± SD (µg/m^3)**
	Friday	**Saturday**	**Sunday**	**Monday**	
Benzene	51.62	76.20	94.35	109.19	82.84 ± 24.80
Toluene	265.86	290.47	256.19	282.57	273.77 ± 15.58
Ethylbenzene	18.83	18.33	16.47	14.83	17.12 ± 1.83
m,p-Xylene	60.56	63.40	58.94	50.92	58.45 ± 5.35
o-Xylene	18.74	18.96	16.79	14.12	17.15 ± 2.25
Total BTEX	415.61	467.35	442.75	471.62	449.33 ± 25.84

Table C.11 Ambient concentration of BTEX at TL

Compounds	**Ambient concentration (µg/m^3)**				**Average ± SD (µg/m^3)**
	Friday	**Saturday**	**Sunday**	**Monday**	
Benzene	33.35	45.73	36.29	50.83	41.55 ± 8.13
Toluene	106.07	99.34	63.91	82.38	87.93 ± 18.86
Ethylbenzene	6.83	11.02	5.02	7.20	7.52 ± 2.52
m,p-Xylene	19.11	34.73	12.71	21.86	22.10 ± 9.25
o-Xylene	6.17	16.65	3.86	6.97	8.41 ± 5.65
Total BTEX	171.54	207.47	121.79	169.24	167.51 ± 35.15

Table C.12 Ambient concentration of BTEX at TP

Compounds	**Ambient concentration (µg/m^3)**				**Average ± SD (µg/m^3)**
	Friday	**Saturday**	**Sunday**	**Monday**	
Benzene	58.93	34.39	80.91	80.64	63.71 ± 22.10
Toluene	114.83	76.93	143.33	165.05	125.04 ± 38.10
Ethylbenzene	9.21	6.13	9.87	14.00	9.80 ± 3.24
m,p-Xylene	29.53	19.07	32.34	41.83	30.70 ± 9.37
o-Xylene	10.00	6.48	10.53	14.21	10.30 ± 3.16
Total BTEX	222.50	143.00	276.98	315.74	239.55 ± 74.87

D.3 Roadside concentrations of BTEX

Table C.13 Roadside concentration of BTEX at BT

Compounds	Roadside concentration (μg/m^3)				Average ± SD (μg/m^3)
	Friday	Saturday	Sunday	Monday	
Benzene	17.29	n/a	13.14	n/a	10.81 ± 5.61
Toluene	36.87	n/a	22.63	n/a	16.30 ± 16.58
Ethylbenzene	5.16	n/a	2.19	n/a	1.84 ± 2.45
m,p-Xylene	8.95	n/a	5.34	n/a	3.57 ± 4.38
o-Xylene	4.64	n/a	2.12	n/a	1.69 ± 2.21
Total BTEX	72.92	n/a	45.42	n/a	34.22 ± 30.97

Table C.14 Roadside concentration of BTEX at DKN

Compounds	Roadside concentration (μg/m^3)				Average ± SD (μg/m^3)
	Friday	Saturday	Sunday	Monday	
Benzene	22.27	21.57	20.83	18.63	20.83 ± 1.58
Toluene	10.02	33.53	30.18	26.87	25.15 ± 10.45
Ethylbenzene	5.68	4.56	3.30	3.12	4.16 ± 1.19
m,p-Xylene	7.49	5.65	5.93	5.01	6.02 ± 1.05
o-Xylene	3.00	2.14	3.00	2.62	2.69 ± 0.41
Total BTEX	48.47	67.45	63.25	56.25	58.85 ± 8.32

Table C.15 Roadside concentration of BTEX at J

Compounds	Roadside concentration (μg/m^3)				Average ± SD (μg/m^3)
	Friday	Saturday	Sunday	Monday	
Benzene	n/a	16.41	13.07	11.77	13.75 ± 2.39
Toluene	n/a	18.34	19.21	29.43	22.33 ± 6.17
Ethylbenzene	n/a	3.04	1.87	3.51	2.80 ± 0.84
m,p-Xylene	n/a	5.04	4.88	9.51	6.47 ± 2.63
o-Xylene	n/a	1.82	2.58	4.82	3.07 ± 1.56
Total BTEX	n/a	44.64	41.60	59.04	48.43 ± 9.31

Table C.16 Roadside concentration of BTEX at RO

Compounds	Roadside concentration (μg/m^3)				Average ± SD (μg/m^3)
	Friday	Saturday	Sunday	Monday	
Benzene	9.76	9.20	15.05	15.76	12.44 ± 3.44
Toluene	18.99	22.90	8.56	17.36	16.95 ± 6.06
Ethylbenzene	3.08	3.00	1.33	2.41	2.45 ± 0.81
m,p-Xylene	5.05	7.60	3.01	4.53	5.05 ± 1.91
o-Xylene	2.22	3.26	2.78	1.70	2.49 ± 0.67
Total BTEX	39.10	45.96	30.72	41.76	39.39 ± 6.43

Table C.17 Roadside concentration of BTEX at TL

Compounds	Roadside concentration (μg/m^3)				Average ± SD (μg/m^3)
	Friday	Saturday	Sunday	Monday	
Benzene	18.36	17.23	4.80	11.68	13.02 ± 6.21
Toluene	14.73	12.92	9.16	35.93	18.18 ± 12.06
Ethylbenzene	1.47	2.41	1.46	3.95	2.32 ± 1.17
m,p-Xylene	4.03	4.09	3.73	10.39	5.56 ± 3.22
o-Xylene	1.86	1.83	0.91	4.82	2.35 ± 1.70
Total BTEX	40.44	38.47	20.06	66.76	41.43 ± 19.22

Table C.18 Roadside concentration of BTEX at TP

Compounds	Roadside concentration (μg/m^3)				Average ± SD (μg/m^3)
	Friday	Saturday	Sunday	Monday	
Benzene	17.76	9.78	37.38	19.13	21.01 ± 11.66
Toluene	40.37	38.66	67.20	62.53	52.19 ± 14.78
Ethylbenzene	6.94	3.78	4.46	6.46	5.41 ± 1.53
m,p-Xylene	10.55	9.32	12.18	17.71	12.44 ± 3.71
o-Xylene	4.79	3.97	4.31	6.11	4.79 ± 0.94
Total BTEX	80.41	65.51	125.52	111.93	95.84 ± 27.67

D.4 Personal exposure concentrations of carbonyl compounds

Table D.19 Personal exposure concentration of Carbonyl Compounds at BT

Compounds	Personal exposure concentration (μg/m^3)								Average ± SD (μg/m^3)
	Fri P1	Fri P2	Sat P1	Sat P2	Sun P1	Sun P2	Mon P1	Mon P2	
Formald	10.60	9.84	10.59	14.02	8.07	7.05	n/a	n/a	10.03 ±2.42
Acetald	5.37	3.95	8.42	10.26	7.08	5.09	n/a	n/a	6.69 ± 2.36
Acetone	13.15	11.65	13.44	22.65	13.81	12.43	n/a	n/a	14.52 ±4.06
Propionald	1.20	0.77	1.06	1.49	1.05	0.88	n/a	n/a	1.08 ± 0.25
Crotonald	2.86	2.62	4.72	6.13	3.22	2.31	n/a	n/a	3.64 ± 1.48
Butyrald	6.73	6.14	2.59	3.57	4.66	4.49	n/a	n/a	4.70 ± 1.55
Benzald	1.07	0.89	0.46	0.52	0.35	4.57	n/a	n/a	1.31 ± 1.62
Isovalerald	nd	nd	nd	1.07	2.12	0.35	n/a	n/a	1.18 ± 0.89
Valerald	1.66	0.88	0.88	2.34	1.38	0.52	n/a	n/a	1.28 ± 0.66
o-Toluald	nd	1.74	0.93	0.71	nd	nd	n/a	n/a	1.13 ± 0.54
m,p-Toluald	0.76	0.54	nd	0.47	nd	nd	n/a	n/a	0.59 ± 0.15
Hexanald	1.99	1.90	3.96	2.67	2.49	1.66	n/a	n/a	2.44 ± 0.83
2,5-Dimethyl benzald	nd	nd	nd	nd	nd	nd	n/a	n/a	> 0.02

Table D.20 Personal exposure concentration of Carbonyl Compounds at DKN

Compounds	Personal exposure concentration (μg/m^3)								Average ± SD (μg/m^3)
	Fri P1	Fri P2	Sat P1	Sat P2	Sun P1	Sun P2	Mon P1	Mon P2	
Formald	9.98	13.43	10.97	13.18	10.02	12.62	9.73	8.06	11.00 ±1.91
Acetald	7.29	13.47	5.82	7.59	7.96	35.33	8.34	9.48	11.91 ±9.72
Acetone	23.22	16.87	11.37	11.63	13.46	15.34	11.65	13.42	14.62 ±3.98
Propionald	1.22	1.47	1.00	1.52	1.17	1.41	1.24	1.26	1.29 ± 0.17
Crotonald	7.26	6.67	3.15	2.47	3.27	3.48	2.57	3.66	4.07 ± 1.84
Butyrald	4.72	3.35	6.40	5.51	4.35	4.89	nd	1.51	4.39 ± 1.58
Benzald	0.78	0.86	1.19	0.55	0.57	0.55	nd	nd	0.75 ± 0.25
Isovalerald	nd	nd	0.87	1.12	0.83	3.85	0.50	3.65	1.80 ± 1.52
Valerald	1.39	1.97	1.18	3.09	0.78	1.14	1.38	1.44	1.55 ± 0.71
o-Toluald	1.37	2.31	1.26	2.34	nd	nd	nd	nd	1.82 ± 0.58
m,p-Toluald	nd	nd	0.30	0.31	nd	nd	nd	nd	0.30 ± 0.01
Hexanald	2.02	2.03	2.15	2.27	1.98	2.10	2.05	2.17	2.10 ± 0.10
2,5-Dimethyl benzald	nd	nd	nd	nd	nd	nd	nd	0.53	0.53

Table D.21 Personal exposure concentration of Carbonyl Compounds at J

Compounds	Personal exposure concentration (μg/m^3)								Average ± SD (μg/m^3)
	Fri P1	Fri P2	Sat P1	Sat P2	Sun P1	Sun P2	Mon P1	Mon P2	
Formald	n/a	n/a	8.26	8.98	8.37	6.37	4.88	8.68	7.59 ± 1.61
Acetald	n/a	n/a	4.57	4.63	4.20	5.51	3.98	5.32	4.70 ± 0.61
Acetone	n/a	n/a	10.84	9.83	10.11	14.35	7.22	8.10	10.07 ±2.49
Propionald	n/a	n/a	0.70	0.72	0.59	0.76	0.66	0.70	0.69 ± 0.06
Crotonald	n/a	n/a	1.71	1.64	1.80	2.19	6.49	4.22	3.01 ± 1.96
Butyrald	n/a	n/a	5.17	5.71	4.34	3.88	3.46	3.85	4.40 ± 0.87
Benzald	n/a	n/a	0.37	0.32	0.79	1.74	nd	nd	0.80 ± 0.66
Isovalerald	n/a	n/a	0.57	0.47	nd	nd	nd	nd	0.52 ± 0.07
Valerald	n/a	n/a	0.73	0.99	1.25	1.38	nd	nd	1.09 ± 0.29
o-Toluald	n/a	n/a	nd	nd	nd	nd	nd	nd	> 0.02
m,p-Toluald	n/a	n/a	nd	nd	nd	nd	nd	nd	> 0.01
Hexanald	n/a	n/a	1.35	1.43	1.09	1.27	0.83	0.84	1.13 ± 0.26
2,5-Dimethyl benzald	n/a	n/a	0.59	nd	nd	nd	nd	nd	0.59

Table D.22 Personal exposure concentration of Carbonyl Compounds at RO

Compounds	Personal exposure concentration (μg/m^3)								Average ± SD (μg/m^3)
	Fri P1	Fri P2	Sat P1	Sat P2	Sun P1	Sun P2	Mon P1	Mon P2	
Formald	17.85	10.31	9.05	9.69	6.33	5.68	9.05	7.66	9.45 ± 3.76
Acetald	6.41	7.22	5.53	5.03	5.04	3.51	4.80	4.96	5.31 ± 1.11
Acetone	9.94	9.20	9.04	8.40	8.08	6.24	5.30	13.36	8.69 ± 2.44
Propionald	0.97	0.88	0.76	0.71	0.65	0.48	0.60	0.63	0.71 ± 0.16
Crotonald	2.62	2.43	1.63	1.51	5.61	5.03	nd	0.94	2.82 ± 1.81
Butyrald	2.46	nd	4.26	3.94	1.98	3.05	7.57	6.36	4.23 ± 2.06
Benzald	0.36	nd	nd	0.37	nd	nd	nd	nd	0.37 ± 0.01
Isovalerald	nd	nd	nd	nd	nd	nd	nd	nd	> 0.02
Valerald	1.45	1.74	1.02	1.40	0.52	0.33	0.59	0.43	0.93 ± 0.54
o-Toluald	0.55	nd	nd	nd	nd	nd	nd	nd	0.55
m,p-Toluald	nd	nd	nd	nd	nd	nd	nd	nd	> 0.01
Hexanald	1.93	1.82	1.49	1.47	1.33	1.01	1.92	1.46	1.55 ± 0.32
2,5-Dimethyl benzald	nd	nd	nd	nd	nd	nd	nd	nd	> 0.02

Table D.23 Personal exposure concentration of Carbonyl Compounds at TL

Compounds	Personal exposure concentration (μg/m^3)								Average ± SD (μg/m^3)
	Fri P1	Fri P2	Sat P1	Sat P2	Sun P1	Sun P2	Mon P1	Mon P2	
Formald	39.76	10.32	5.90	7.56	3.40	8.24	12.79	15.59	12.94±11.49
Acetald	5.61	27.34	4.43	7.46	1.59	26.39	13.01	11.67	12.19 ± 9.79
Acetone	8.43	18.68	5.57	9.20	3.49	17.56	21.14	15.71	12.47 ± 6.60
Propionald	0.67	2.37	0.55	0.84	0.27	1.11	1.30	1.26	1.05 ± 0.64
Crotonald	1.42	17.07	1.43	2.11	1.02	5.11	3.30	3.08	4.32 ± 5.32
Butyrald	2.67	1.64	1.88	2.30	4.00	6.54	3.94	6.29	3.66 ± 1.91
Benzald	nd	0.51	1.31	2.53	nd	1.03	nd	0.59	1.19 ± 0.81
Isovalerald	nd	6.84	nd	nd	nd	nd	nd	nd	6.84
Valerald	1.08	0.89	0.73	1.04	nd	0.59	1.20	1.98	1.07 ± 0.45
o-Toluald	nd	0.62	nd	nd	nd	nd	0.60	nd	0.61 ± 0.01
m,p-Toluald	nd	0.87	nd	nd	nd	nd	nd	nd	0.87
Hexanald	1.72	1.80	1.61	1.94	nd	1.65	2.34	2.66	1.96 ± 0.39
2,5-Dimethyl benzald	nd	0.55	nd	nd	nd	nd	1.70	nd	1.13 ± 0.82

Table D.24 Personal exposure concentration of Carbonyl Compounds at TP

Compounds	Personal exposure concentration (μg/m^3)								Average ± SD (μg/m^3)
	Fri P1	Fri P2	Sat P1	Sat P2	Sun P1	Sun P2	Mon P1	Mon P2	
Formald	12.57	11.33	10.40	9.99	15.57	12.40	20.83	15.80	13.61 ±3.62
Acetald	15.17	11.94	9.83	8.09	9.18	7.86	11.52	12.95	10.82 ±2.54
Acetone	17.37	15.05	11.28	9.07	9.90	9.91	13.93	14.25	12.60 ±2.98
Propionald	1.09	1.29	1.15	1.03	1.24	1.10	1.76	1.77	1.30 ± 0.29
Crotonald	2.25	2.57	2.01	2.74	3.45	2.15	3.62	3.51	2.79 ± 0.65
Butyrald	5.04	3.85	3.96	1.86	4.75	5.88	6.28	4.90	4.56 ± 1.37
Benzald	0.33	0.37	3.87	3.34	0.53	0.46	0.87	0.58	1.29 ± 1.44
Isovalerald	0.37	nd	nd	nd	nd	nd	nd	nd	0.37
Valerald	1.14	1.19	1.79	1.73	1.64	1.31	2.77	2.34	1.74 ± 0.57
o-Toluald	nd	0.82	nd	nd	nd	nd	nd	nd	0.82
m,p-Toluald	nd	nd	nd	nd	nd	nd	nd	nd	> 0.01
Hexanald	2.28	2.36	2.85	2.63	2.07	2.06	3.42	3.64	2.66 ± 0.60
2,5-Dimethyl benzald	nd	nd	nd	nd	nd	0.51	nd	nd	0.51

D.5 Ambient concentrations of BTEX of carbonyl compounds

Table C.25 Ambient concentration of BTEX at BT

Compounds	Ambient concentration (μg/m^3)				Average ± SD (μg/m^3)
	Fri	Sat	Sun	Mon	
Formaldehyde	1.26	0.95	3.92	2.46	2.15 ± 1.35
Acetaldehyde	3.48	0.57	1.46	1.08	1.65 ± 1.27
Acetone	1.49	0.61	6.79	0.21	2.27 ± 3.05
Propionaldehyde	0.33	nd	nd	0.20	0.27 ± 0.09
Crotonaldehyde	12.88	1.51	nd	1.46	5.28 ± 6.58
Butyraldehyde	9.54	2.14	1.31	0.97	3.49 ± 4.06
Benzaldehyde	nd	nd	nd	nd	> 0.01
Isovaleraldehyde	nd	nd	nd	nd	> 0.02
Valeraldehyde	1.31	2.78	nd	0.45	1.51 ± 1.18
o-Tolualdehyde	0.60	nd	nd	nd	0.60
m,p-Tolualdehyde	0.44	nd	nd	nd	0.44
Hexanaldehyde	nd	nd	0.71	nd	0.71
2,5-Dimethylbenzaldehyde	nd	nd	nd	nd	> 0.02

Table C.26 Ambient concentration of BTEX at DKN

Compounds	Ambient concentration (μg/m^3)				Average ± SD (μg/m^3)
	Fri	Sat	Sun	Mon	
Formaldehyde	9.62	12.72	10.03	14.00	11.59 ± 2.11
Acetaldehyde	4.09	8.25	10.74	10.18	8.32 ± 3.01
Acetone	9.81	12.73	14.17	11.25	11.99 ± 1.88
Propionaldehyde	0.80	1.49	1.61	1.60	1.38 ± 0.39
Crotonaldehyde	3.50	3.68	4.21	4.19	3.89 ± 0.36
Butyraldehyde	3.33	5.50	4.39	1.68	3.73 ± 1.63
Benzaldehyde	0.48	0.36	0.97	nd	0.60 ± 0.32
Isovaleraldehyde	nd	0.99	4.02	0.64	1.88 ± 1.86
Valeraldehyde	1.63	2.39	1.91	2.45	2.09 ± 0.39
o-Tolualdehyde	0.77	nd	nd	nd	0.77
m,p-Tolualdehyde	nd	nd	nd	nd	> 0.01
Hexanaldehyde	2.10	2.37	2.50	2.52	2.37 ± 0.19
2,5-Dimethylbenzaldehyde	nd	nd	nd	nd	> 0.02

Table C.27 Ambient concentration of BTEX at J

Compounds	Ambient concentration (µg/m^3)				Average ± SD (µg/m^3)
	Fri	Sat	Sun	Mon	
Formaldehyde	8.39	6.52	6.94	4.06	6.48 ± 1.80
Acetaldehyde	5.47	3.90	3.06	2.66	3.77 ± 1.24
Acetone	9.36	8.06	8.78	3.80	7.50 ± 2.52
Propionaldehyde	0.86	0.68	0.47	0.62	0.66 ± 0.16
Crotonaldehyde	2.49	1.74	1.70	8.10	3.51 ± 3.08
Butyraldehyde	3.59	5.87	3.71	4.54	4.43 ± 1.05
Benzaldehyde	0.29	nd	1.62	nd	0.96 ± 0.94
Isovaleraldehyde	0.57	0.66	nd	nd	0.61 ± 0.06
Valeraldehyde	5.87	1.54	1.48	nd	2.96 ± 2.52
o-Tolualdehyde	nd	nd	nd	nd	> 0.02
m,p-Tolualdehyde	nd	nd	nd	nd	> 0.01
Hexanaldehyde	1.99	1.49	1.33	0.81	1.41 ± 0.49
2,5-Dimethylbenzaldehyde	nd	nd	nd	nd	> 0.02

Table C.28 Ambient concentration of BTEX at RO

Compounds	Ambient concentration (µg/m^3)				Average ± SD (µg/m^3)
	Fri	Sat	Sun	Mon	
Formaldehyde	9.09	10.02	4.92	5.78	7.45 ± 2.48
Acetaldehyde	4.94	5.21	5.66	4.90	5.18 ± 0.35
Acetone	9.27	8.35	6.10	4.73	7.11 ± 2.07
Propionaldehyde	0.90	0.77	0.78	0.82	0.82 ± 0.06
Crotonaldehyde	1.42	1.63	5.41	0.92	2.34 ± 2.07
Butyraldehyde	1.58	3.86	2.33	6.12	3.47 ± 2.00
Benzaldehyde	0.31	nd	nd	nd	0.31
Isovaleraldehyde	6.35	nd	nd	nd	6.35
Valeraldehyde	0.36	1.11	0.42	0.33	0.55 ± 0.37
o-Tolualdehyde	nd	nd	nd	nd	> 0.02
m,p-Tolualdehyde	nd	nd	nd	nd	> 0.01
Hexanaldehyde	1.86	1.22	1.24	0.88	1.30 ± 0.41
2,5-Dimethylbenzaldehyde	nd	nd	nd	nd	> 0.02

Table C.29 Ambient concentration of BTEX at TL

Compounds	Ambient concentration (µg/m^3)				Average ± SD (µg/m^3)
	Fri	Sat	Sun	Mon	
Formaldehyde	7.49	5.05	6.21	9.08	6.96 ± 1.73
Acetaldehyde	1.47	5.82	2.24	6.39	3.98 ± 2.49
Acetone	6.65	7.40	5.70	10.97	7.68 ± 2.30
Propionaldehyde	0.30	0.82	0.39	0.85	0.59 ± 0.28
Crotonaldehyde	0.93	1.71	1.37	2.40	1.60 ± 0.62
Butyraldehyde	3.23	1.81	4.29	4.14	3.37 ± 1.14
Benzaldehyde	nd	0.32	nd	0.40	0.36 ± 0.05
Isovaleraldehyde	nd	nd	nd	nd	> 0.02
Valeraldehyde	0.98	1.82	1.05	1.98	1.45 ± 0.52
o-Tolualdehyde	nd	nd	nd	nd	> 0.02
m,p-Tolualdehyde	nd	nd	nd	nd	> 0.01
Hexanaldehyde	1.36	1.83	1.00	2.29	1.62 ± 0.56
2,5-Dimethylbenzaldehyde	nd	nd	nd	nd	> 0.02

Table C.30 Ambient concentration of BTEX at TP

Compounds	Ambient concentration (µg/m^3)				Average ± SD (µg/m^3)
	Fri	Sat	Sun	Mon	
Formaldehyde	9.61	9.05	15.22	15.60	12.37 ± 3.52
Acetaldehyde	6.70	6.06	6.91	10.06	7.43 ± 1.79
Acetone	9.19	8.88	8.74	15.29	10.52 ± 3.18
Propionaldehyde	1.11	0.94	1.14	1.99	1.29 ± 0.47
Crotonaldehyde	2.07	1.81	2.42	3.33	2.41 ± 0.66
Butyraldehyde	3.39	2.67	5.71	6.18	4.49 ± 1.72
Benzaldehyde	0.44	3.71	0.50	0.65	1.33 ± 1.60
Isovaleraldehyde	nd	nd	nd	nd	> 0.02
Valeraldehyde	2.06	2.79	1.79	3.97	2.65 ± 0.97
o-Tolualdehyde	nd	nd	nd	nd	> 0.02
m,p-Tolualdehyde	nd	nd	nd	nd	> 0.01
Hexanaldehyde	2.36	2.52	2.20	3.44	2.63 ± 0.56
2,5-Dimethylbenzaldehyde	nd	nd	nd	nd	> 0.02

D.6 Roadside concentrations of BTEX of carbonyl compounds

Table C.31 Roadside concentration of BTEX at BT

Compounds	Roadside concentration ($\mu g/m^3$)				Average ± SD ($\mu g/m^3$)
	Fri	Sat	Sun	Mon	
Formaldehyde	14.82	n/a	9.03	n/a	11.92 ± 4.10
Acetaldehyde	3.76	n/a	4.06	n/a	3.91 ± 0.21
Acetone	10.10	n/a	8.93	n/a	9.52 ± 0.82
Propionaldehyde	0.86	n/a	0.55	n/a	0.71 ± 0.22
Crotonaldehyde	2.49	n/a	1.54	n/a	2.01 ± 0.67
Butyraldehyde	4.52	n/a	3.76	n/a	4.14 ± 0.54
Benzaldehyde	0.76	n/a	nd	n/a	0.76
Isovaleraldehyde	nd	n/a	0.32	n/a	0.32
Valeraldehyde	1.87	n/a	nd	n/a	1.87
o-Tolualdehyde	3.63	n/a	nd	n/a	3.63
m,p-Tolualdehyde	0.58	n/a	nd	n/a	0.58
Hexanaldehyde	1.73	n/a	1.39	n/a	1.56 ± 0.23
2,5-Dimethylbenzaldehyde	nd	n/a	nd	n/a	> 0.02

Table C.32 Roadside concentration of BTEX at DKN

Compounds	Roadside concentration ($\mu g/m^3$)				Average ± SD ($\mu g/m^3$)
	Fri	Sat	Sun	Mon	
Formaldehyde	10.14	10.27	6.55	5.18	8.04 ± 2.57
Acetaldehyde	8.22	8.19	5.21	5.04	6.67 ± 1.78
Acetone	12.72	9.72	10.07	7.46	9.99 ± 2.15
Propionaldehyde	1.40	1.05	0.81	0.66	0.98 ± 0.32
Crotonaldehyde	7.55	2.62	2.60	1.49	3.56 ± 2.71
Butyraldehyde	3.69	4.05	3.56	1.26	3.14 ± 1.27
Benzaldehyde	0.80	0.49	0.45	nd	0.58 ± 0.19
Isovaleraldehyde	nd	0.87	3.92	0.69	1.83 ± 1.81
Valeraldehyde	2.06	2.66	1.59	1.12	1.86 ± 0.66
o-Tolualdehyde	0.45	nd	nd	nd	0.45
m,p-Tolualdehyde	nd	nd	nd	nd	> 0.01
Hexanaldehyde	2.10	2.05	2.07	2.10	2.08 ± 0.02
2,5-Dimethylbenzaldehyde	nd	nd	nd	nd	> 0.02

Table C.33 Roadside concentration of BTEX at J

Compounds	Roadside concentration ($\mu g/m^3$)				Average ± SD ($\mu g/m^3$)
	Fri	Sat	Sun	Mon	
Formaldehyde	n/a	5.25	5.14	3.27	4.55 ± 1.11
Acetaldehyde	n/a	2.28	2.78	1.86	2.31 ± 0.46
Acetone	n/a	8.57	8.23	3.46	6.75 ± 2.86
Propionaldehyde	n/a	0.33	0.40	0.39	0.37 ± 0.03
Crotonaldehyde	n/a	1.21	1.32	8.79	3.77 ± 4.34
Butyraldehyde	n/a	4.50	2.72	4.08	3.77 ± 0.93
Benzaldehyde	n/a	nd	2.67	nd	2.67
Isovaleraldehyde	n/a	0.37	nd	nd	0.37
Valeraldehyde	n/a	1.11	1.27	nd	1.19 ± 0.11
o-Tolualdehyde	n/a	nd	nd	nd	> 0.02
m,p-Tolualdehyde	n/a	nd	nd	nd	> 0.01
Hexanaldehyde	n/a	1.04	1.00	0.49	0.85 ± 0.31
2,5-Dimethylbenzaldehyde	n/a	nd	nd	nd	> 0.02

Table C.34 Roadside concentration of BTEX at RO

Compounds	Roadside concentration ($\mu g/m^3$)				Average ± SD ($\mu g/m^3$)
	Fri	Sat	Sun	Mon	
Formaldehyde	8.18	7.70	7.13	5.38	7.10 ± 1.22
Acetaldehyde	4.45	3.25	3.25	3.71	3.66 ± 0.57
Acetone	7.60	6.08	5.43	4.41	5.88 ± 1.34
Propionaldehyde	0.66	0.44	0.83	0.80	0.68 ± 0.18
Crotonaldehyde	2.10	0.95	6.98	0.87	2.73 ± 2.89
Butyraldehyde	0.78	3.03	2.53	7.77	3.53 ± 2.99
Benzaldehyde	5.35	0.31	nd	nd	2.83 ± 3.56
Isovaleraldehyde	3.22	nd	nd	nd	3.22
Valeraldehyde	0.99	1.29	0.44	0.33	0.76 ± 0.45
o-Tolualdehyde	nd	nd	nd	nd	> 0.02
m,p-Tolualdehyde	nd	nd	nd	nd	> 0.01
Hexanaldehyde	1.42	1.10	0.87	0.79	1.04 ± 0.28
2,5-Dimethylbenzaldehyde	nd	nd	nd	nd	> 0.02

Table C.35 Roadside concentration of BTEX at TL

Compounds	**Roadside concentration (μg/m^3)**				**Average ± SD (μg/m^3)**
	Fri	**Sat**	**Sun**	**Mon**	
Formaldehyde	4.36	4.58	7.12	5.33	5.35 ± 1.25
Acetaldehyde	2.20	2.48	1.65	4.00	2.58 ± 1.01
Acetone	5.04	4.41	3.87	6.28	4.90 ± 1.04
Propionaldehyde	0.40	0.30	0.25	0.57	0.38 ± 0.14
Crotonaldehyde	0.68	0.75	0.92	1.41	0.94 ± 0.33
Butyraldehyde	1.53	1.05	2.89	1.52	1.75 ± 0.80
Benzaldehyde	nd	nd	nd	nd	> 0.01
Isovaleraldehyde	nd	nd	nd	nd	> 0.02
Valeraldehyde	0.96	0.93	0.97	0.94	0.95 ± 0.02
o-Tolualdehyde	nd	nd	nd	nd	> 0.02
m,p-Tolualdehyde	nd	nd	nd	nd	> 0.01
Hexanaldehyde	1.09	1.34	0.70	1.13	1.07 ± 0.27
2,5-Dimethylbenzaldehyde	nd	nd	nd	nd	> 0.02

Table C.36 Roadside concentration of BTEX at TP

Compounds	**Roadside concentration (μg/m^3)**				**Average ± SD (μg/m^3)**
	Fri	**Sat**	**Sun**	**Mon**	
Formaldehyde	12.20	10.08	9.85	12.37	11.12 ± 1.35
Acetaldehyde	7.55	6.23	6.56	10.36	7.67 ± 1.88
Acetone	9.20	9.37	8.23	14.18	10.24 ± 2.67
Propionaldehyde	1.31	0.95	0.97	1.42	1.16 ± 0.24
Crotonaldehyde	1.80	1.69	2.16	3.13	2.19 ± 0.65
Butyraldehyde	3.05	2.97	3.81	4.11	3.48 ± 0.56
Benzaldehyde	2.62	2.93	0.36	0.46	1.59 ± 1.37
Isovaleraldehyde	nd	0.36	nd	nd	0.36
Valeraldehyde	2.19	2.51	1.90	3.22	2.45 ± 0.57
o-Tolualdehyde	nd	nd	nd	nd	> 0.02
m,p-Tolualdehyde	nd	nd	nd	nd	> 0.01
Hexanaldehyde	2.37	2.44	2.01	3.00	2.46 ± 0.41
2,5-Dimethylbenzaldehyde	nd	nd	nd	nd	> 0.02

D.7 Fuel circulations and the number of customer cars

Table D.25 Fuel Circulation and the number of customer cars at BT

Types of Petrol	Number of Nozzles	11/5/2010		11/6/2010		11/7/2010		11/8/2010	
		Circulation (L)	Number of Cars	Circulation (L)	Number of Cars	Circulation (L)	Number of Cars	Circulation (L)	Number of Cars
HSD-B3	4	4,612.57	430	8,581.27	366	2,313.83	283	8,704.21	406
BIO B5+	4	10,144.80	206	4,003.99	189	5,458.24	119	3,861.52	181
GAS95-E20	2	1,542.69	81	1,399.87	72	1,730.37	80	1,703.06	77
GASOHOL91	2	2,886.27	420	3,449.90	474	2,245.92	377	3,099.99	491
GASOHOL95	6	4,214.49	472	3,136.11	381	3,428.51	376	3,891.89	473
Total	**18**	**23,400.82**	**1,609**	**20,571.14**	**1,482**	**15,176.87**	**1,235**	**21,260.67**	**1,628**

Table D.26 Fuel Circulation and the number of customer cars at DKN

Types of Petrol	Number of Nozzles	11/5/2010		11/6/2010		11/7/2010		11/8/2010	
		Circulation (L)	Number of Cars	Circulation (L)	Number of Cars	Circulation (L)	Number of Cars	Circulation (L)	Number of Cars
HSD-B3	8	15,264.34	635	15,806.88	634	13,666.89	546	15,114.39	587
BIO B5+	8	5,596.40	255	5,949.18	277	5,327.76	218	6,133.43	258
GAS95-E20	4	1,979.26	74	2,109.65	73	1,948.57	69	2,203.73	83
GASOHOL91	4	5,200.53	249	5,084.53	245	4,985.49	234	5,383.47	256
GASOHOL95	8	9,930.54	395	11,199.99	427	10,537.23	420	8,622.89	353
Total	**32**	**37,971.07**	**1,608**	**40,150.23**	**1,656**	**36,465.94**	**1,487**	**37,457.91**	**1,537**

Table D.27 Fuel Circulation and the number of customer cars at J

Types of Petrol	Number of Nozzles	11/12/2010		11/13/2010		11/14/2010		11/15/2010	
		Circulation (L)	Number of Cars	Circulation (L)	Number of Cars	Circulation (L)	Number of Cars	Circulation (L)	Number of Cars
HSD-B3	6	11,841.34	394	9,634.35	361	9,092.50	319	12,647.91	416
BIO B5+	4	3,820.37	157	4,225.78	167	3,733.82	154	4,339.24	173
GAS95-E20	2	3,673.45	161	3,240.64	152	3,703.95	149	3,586.96	149
GASOHOL91	4	7,834.97	575	7,985.20	527	6,268.26	421	8,663.41	580
GASOHOL95	4	8,815.14	507	8,951.27	443	7,248.90	366	9,751.25	498
ULR91	2	2,626.67	289	3,094.22	264	3,048.03	234	2,826.24	319
Total	**22**	**38,611.94**	**2,083**	**37,131.46**	**1,914**	**33,095.46**	**1,643**	**41,815.01**	**2,135**

Table D.28 Fuel Circulation and the number of customer cars at RO

Types of Petrol	Number of Nozzles	11/12/2010		11/13/2010		11/14/2010		11/15/2010	
		Circulation (L)	Number of Cars	Circulation (L)	Number of Cars	Circulation (L)	Number of Cars	Circulation (L)	Number of Cars
HSD-B3	8	15,324.98	509	20,922.10	641	13,353.48	485	14,732.71	498
BIO B5+	4	6,837.29	253	6,690.85	247	3,996.76	162	6,063.69	222
GAS95-E20	4	4,615.35	204	4,397.17	190	3,842.06	167	5,244.77	212
GASOHOL91	8	11,059.17	826	9,744.61	616	9,058.98	562	10,296.02	755
GASOHOL95	8	16,923.07	875	14,755.59	758	14,052.37	669	16,348.92	848
ULR91	4	6,185.12	632	6,159.80	522	4,354.39	444	4,922.93	606
Total	**36**	**60,944.98**	**3,299**	**62,670.12**	**2,974**	**48,658.04**	**2,489**	**57,609.04**	**3,141**

Table D.29 Fuel Circulation and the number of customer cars at TL

Types of Petrol	Number of Nozzles	11/19/2010		11/20/2010		11/21/2010		11/22/2010	
		Circulation (L)	Number of Cars	Circulation (L)	Number of Cars	Circulation (L)	Number of Cars	Circulation (L)	Number of Cars
HSD-B3	8	7,340.06	306	7,564.97	306	6,423.06	267	7,314.86	285
BIO B5+	8	4,443.20	213	4,271.03	230	3,235.51	171	4,138.78	199
GAS95-E20	4	3,214.85	128	2,988.62	116	3,467.48	135	2,891.43	126
GASOHOL91	12	5,379.01	486	5,483.45	435	5,699.89	421	6,432.84	512
GASOHOL95	4	5,911.08	354	6,654.65	358	6,251.87	345	7,311.26	393
Total	**36**	**26,288.20**	**1,487**	**26,962.72**	**1,445**	**25,077.81**	**1,339**	**28,089.17**	**1,515**

Table D.30 Fuel Circulation and the number of customer cars at TP

Types of Petrol	Number of Nozzles	11/19/2010		11/20/2010		11/21/2010		11/22/2010	
		Circulation (L)	Number of Cars	Circulation (L)	Number of Cars	Circulation (L)	Number of Cars	Circulation (L)	Number of Cars
HSD-B3	6	10,189.06	n/a	9,902.26	n/a	7,147.93	n/a	10,680.34	n/a
GASOHOL95	6	22,327.01	n/a	16,160.95	n/a	14,014.23	n/a	19,329.27	n/a
ULR91	6	5,754.16	n/a	4,238.35	n/a	3,696.20	n/a	5,528.55	n/a
Total	**18**	**38,270.23**	-	**30,301.56**	-	**24,858.36**	-	**35,538.16**	-

n/a means not available

D.8 Atmospheric conditions

Table D.31 The atmospheric conditions during 6:00am-2:00pm at BT

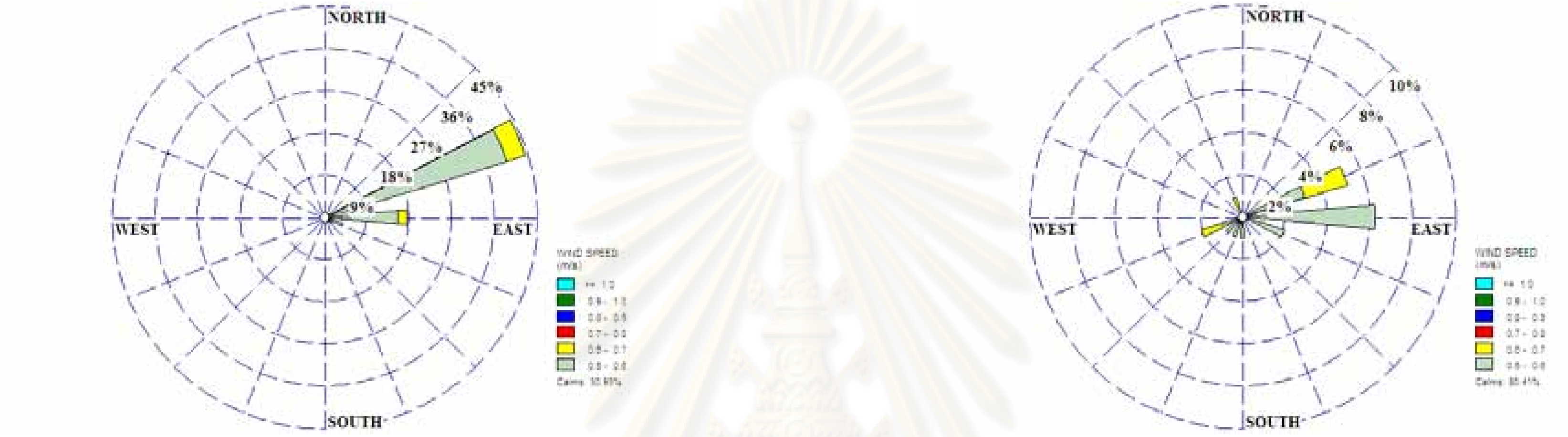
Date	Day	Station	Time	WS (m/s)	Temp (Deg C)	RH (%)	SR (W/m^2)	BP (mmHg)
11/5/2010	FRI	BT	6:00-14:00	0.5	29.2	64.0	278.1	665.2
11/6/2010	SAT	BT	6:00-14:00	0.4	29.9	65.2	230.2	665.1
11/7/2010	SUN	BT	6:00-14:00	0.4	29.8	68.9	199.8	665.0
11/8/2010	MON	BT	6:00-14:00	0.4	31.9	65.4	274.9	664.9
Average				**0.4**	**30.2**	**65.9**	**245.7**	**665.1**
SD				**0.0**	**1.2**	**2.1**	**37.6**	**0.1**

Table D.32 The atmospheric conditions during 6:00am-2:00pm at RO

Date	Day	Station	Time	WS (m/s)	Temp (Deg C)	RH (%)	SR (W/m^2)	BP (mmHg)
11/12/2010	FRI	RO	6:00-14:00	0.5	29.4	68.3	172.3	665.5
11/13/2010	SAT	RO	6:00-14:00	0.5	30.8	65.3	257.5	665.4
11/14/2010	SUN	RO	6:00-14:00	0.6	31.6	66.2	371.1	665.1
11/15/2010	MON	RO	6:00-14:00	0.5	31.9	68.5	308.2	664.7
Average				**0.5**	**30.9**	**67.1**	**277.3**	**665.2**
SD				**0.0**	**1.1**	**1.6**	**84.0**	**0.3**

Table D.33 The atmospheric conditions during 6:00am-2:00pm at TL

Date	Day	Station	Time	WS (m/s)	Temp (Deg C)	RH (%)	SR (W/m^2)	BP (mmHg)
11/19/2010	FRI	TL	6:00-14:00	0.6	31.5	69.3	370.1	665.0
11/20/2010	SAT	TL	6:00-14:00	0.5	31.4	68.5	351.3	664.7
11/21/2010	SUN	TL	6:00-14:00	0.5	31.5	72.9	287.9	664.8
11/22/2010	MON	TL	6:00-14:00	0.5	32.4	73.2	335.2	664.7
Average				**0.5**	**31.7**	**71.0**	**336.1**	**664.8**
SD				**0.0**	**0.5**	**2.4**	**35.1**	**0.2**



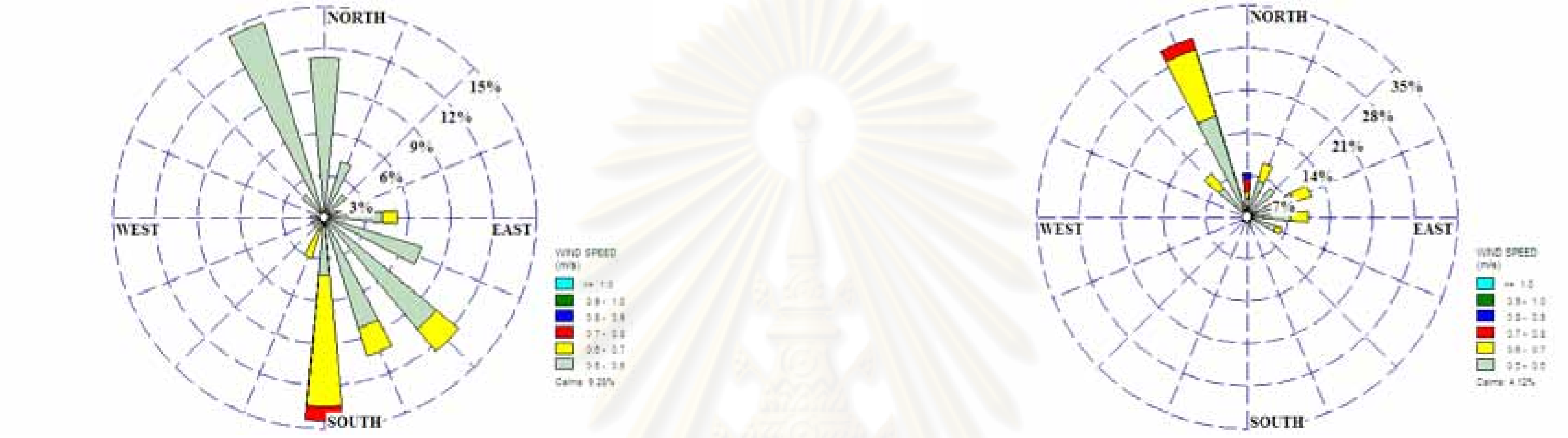
(a) Friday, November 5, 2010

(b) Saturday, November 6, 2010

(c) Sunday, November 7, 2010

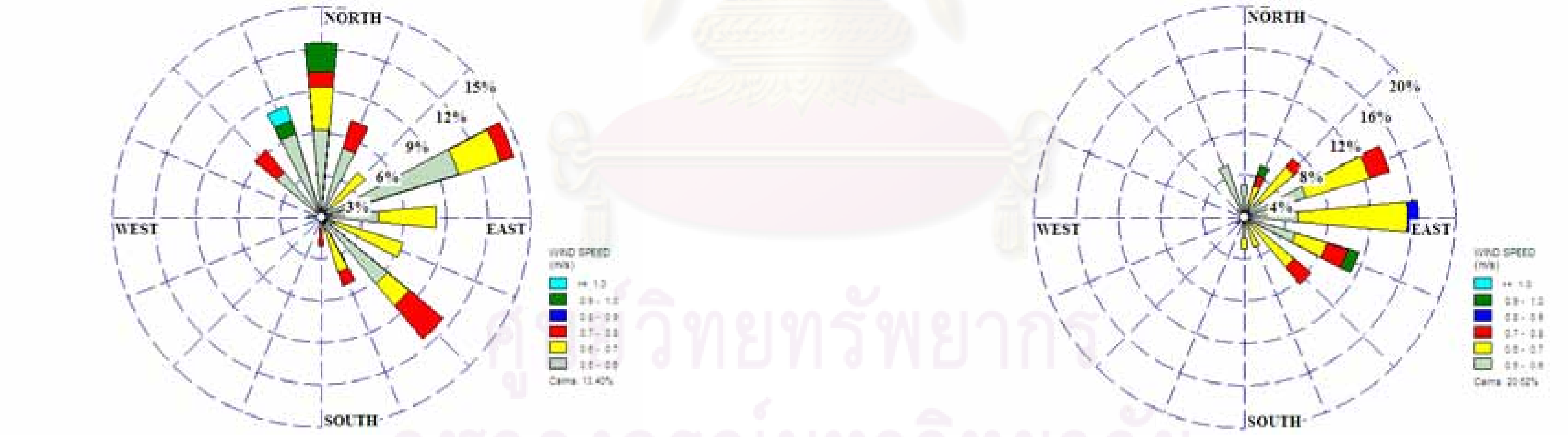
(d) Monday, November 8, 2010

Figure D.1 Wind roses at BT during 6.00 am – 2.00 pm



(a) Friday, November 12, 2010

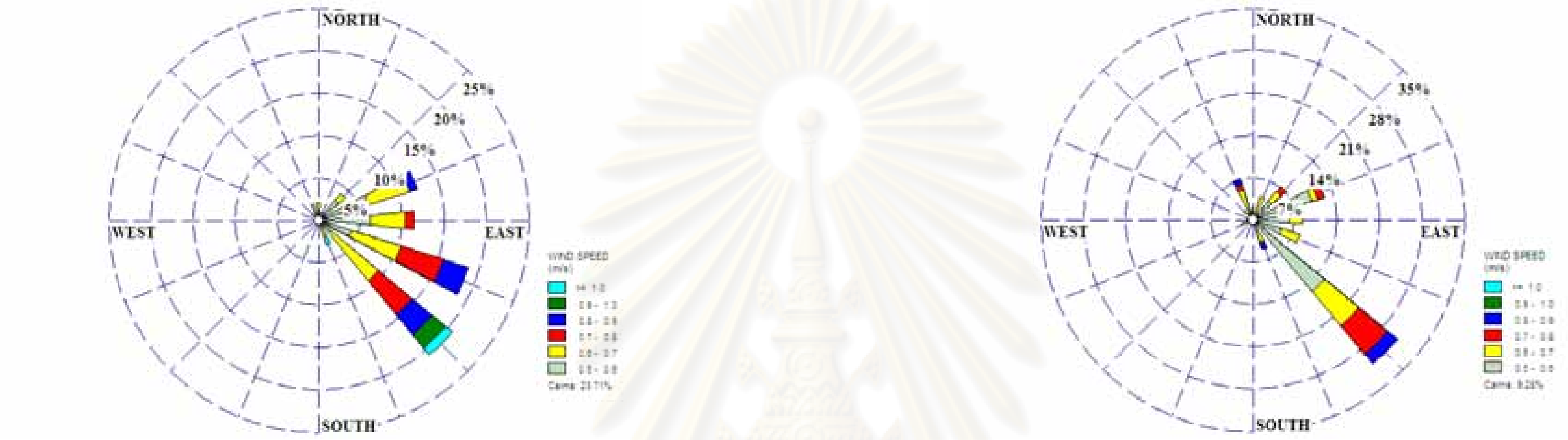
(b) Saturday, November 13, 2010



(c) Sunday, November 14, 2010

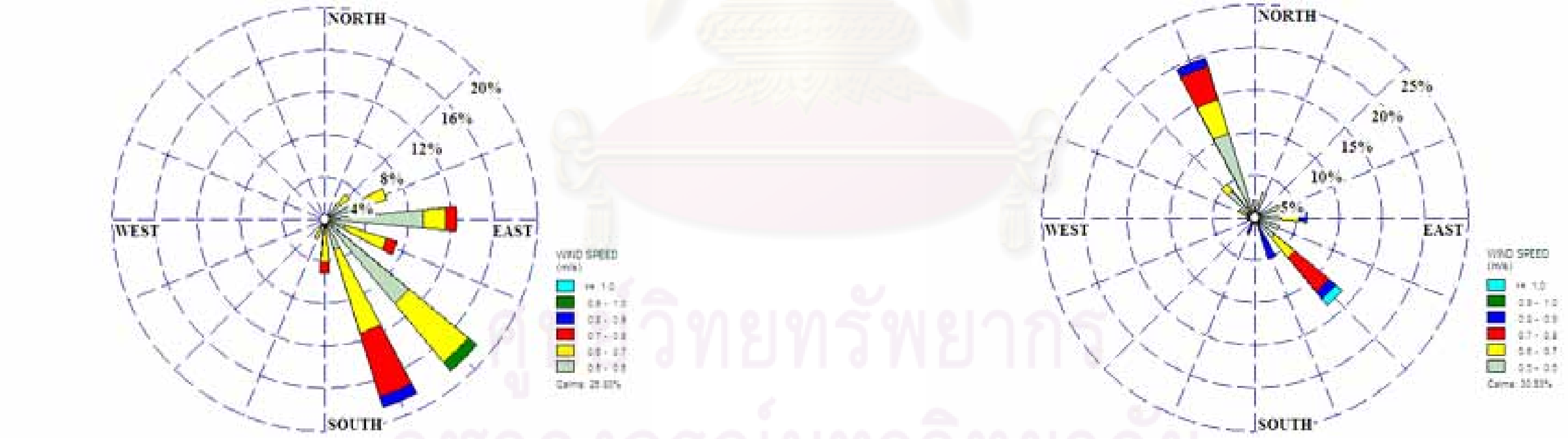
(d) Monday, November 15, 2010

Figure D.2 Wind roses at RO during 6.00 am – 2.00 pm



(a) Friday, November 19, 2010

(b) Saturday, November 20, 2010



(c) Sunday, November 21, 2010

(d) Monday, November 22, 2010

Figure D.3 Wind roses at TL during 6.00 am – 2.00 pm

APPENDIX E

Examples of Statistical Tests

Table E.1 Paired sample T-test of personal exposure concentrations of Benzene between worker 1 and worker 2

Paired Samples Statistics

		Mean	N	Std. Deviation	Std. Error Mean
Pair 1	P1S1	160.4633	3	7.35065	4.24390
	P2S1	155.1233	3	25.34537	14.63315
Pair 2	P1S2	109.7275	4	13.53926	6.76963
	P2S2	142.8450	4	25.02999	12.51499
Pair 3	P1S3	154.5900	3	56.73129	32.75382
	P2S3	108.3400	3	52.97705	30.58631
Pair 4	P1S4	117.6400	4	16.12945	8.06472
	P2S4	91.3775	4	10.67832	5.33916
Pair 5	P1S5	117.0875	4	36.69921	18.34961
	P2S5	150.4250	4	89.52698	44.76349
Pair 6	P1S6	108.7800	4	64.73259	32.36630
	P2S6	88.9325	4	37.28728	18.64364

Paired Samples Correlations

		N	Correlation	Sig.
Pair 1	P1S1 & P2S1	3	.712	.496
Pair 2	P1S2 & P2S2	4	.856	.144
Pair 3	P1S3 & P2S3	3	-.440	.710
Pair 4	P1S4 & P2S4	4	.640	.360
Pair 5	P1S5 & P2S5	4	-.929	.071
Pair 6	P1S6 & P2S6	4	.694	.306

Paired Samples Test

		Paired Differences							
					95% Confidence Interval of the Difference				
		Mean	Std. Deviation	Std. Error Mean	Lower	Upper	t	df	Sig. (2-tailed)
Pair 1	P1S1 - P2S1	5.34000	20.76729	11.99000	-46.24881	56.92881	.445	2	.700
Pair 2	P1S2 - P2S2	-33.11750	15.15012	7.57506	-57.22473	-9.01027	-4.372	3	.022
Pair 3	P1S3 - P2S3	46.25000	93.11928	53.76244	-185.07111	277.57111	.860	2	.480
Pair 4	P1S4 - P2S4	26.26250	12.40441	6.20221	6.52431	46.00069	4.234	3	.024
Pair 5	P1S5 - P2S5	-33.33750	124.36629	62.18314	-231.23201	164.55701	-.536	3	.629
Pair 6	P1S6 - P2S6	19.84750	47.24470	23.62235	-55.32935	95.02435	.840	3	.462

Table E.2 One way ANOVA of ambient concentrations of toluene among gas stations

ANOVA

		Sum of Squares	df	Mean Square	F	Sig.
Benzene	Between Groups	27312.973	5	5462.595	3.776	.068
	Within Groups	8679.237	6	1446.539		
	Total	35992.209	11			

Multiple Comparisons

LSD

Dependent Variable	(I) Station	(J) Station	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
						Lower Bound	Upper Bound
Benzene	TRO	PCC	37.27500	38.03340	.365	-55.7894	130.3394
		NW	65.36000	38.03340	.137	-27.7044	158.4244
		TP	-87.19000	38.03340	.062	-180.2544	5.8744
		BK	-19.29000	38.03340	.630	-112.3544	73.7744
		SBS	4.58500	38.03340	.908	-88.4794	97.6494
	PCC	TRO	-37.27500	38.03340	.365	-130.3394	55.7894
		NW	28.08500	38.03340	.488	-64.9794	121.1494
		TP	-124.46500*	38.03340	.017	-217.5294	-31.4006
		BK	-56.56500	38.03340	.188	-149.6294	36.4994
		SBS	-32.69000	38.03340	.423	-125.7544	60.3744
	NW	TRO	-65.36000	38.03340	.137	-158.4244	27.7044
		PCC	-28.08500	38.03340	.488	-121.1494	64.9794
		TP	-152.55000*	38.03340	.007	-245.6144	-59.4856
		BK	-84.65000	38.03340	.068	-177.7144	8.4144
		SBS	-60.77500	38.03340	.161	-153.8394	32.2894
	TP	TRO	87.19000	38.03340	.062	-5.8744	180.2544
		PCC	124.46500*	38.03340	.017	31.4006	217.5294
		NW	152.55000*	38.03340	.007	59.4856	245.6144
		BK	67.90000	38.03340	.124	-25.1644	160.9644
		SBS	91.77500	38.03340	.052	-1.2894	184.8394
	BK	TRO	19.29000	38.03340	.630	-73.7744	112.3544
		PCC	56.56500	38.03340	.188	-36.4994	149.6294
		NW	84.65000	38.03340	.068	-8.4144	177.7144
		TP	-67.90000	38.03340	.124	-160.9644	25.1644
		SBS	23.87500	38.03340	.553	-69.1894	116.9394
	SBS	TRO	-4.58500	38.03340	.908	-97.6494	88.4794
		PCC	32.69000	38.03340	.423	-60.3744	125.7544
		NW	60.77500	38.03340	.161	-32.2894	153.8394
		TP	-91.77500	38.03340	.052	-184.8394	1.2894
		BK	-23.87500	38.03340	.553	-116.9394	69.1894

*. The mean difference is significant at the 0.05 level.

Table E.3 Correlation between ambient concentration of BTEX and affecting factors

Correlations

		Fuel circulation (L)	Number of Cars	Temperature	% RH	SR	BP
Fuel circulation (L)	Pearson Correlation	1	.879**	-.013	-.187	-.134	.476
	Sig. (2-tailed)		.000	.969	.561	.679	.118
	N	20	20	12	12	12	12
Number of Cars	Pearson Correlation	.879**	1	-.158	-.332	-.294	.525
	Sig. (2-tailed)	.000		.625	.292	.354	.079
	N	20	20	12	12	12	12
Temperature	Pearson Correlation	-.013	-.158	1	.478	.731**	-.712**
	Sig. (2-tailed)	.969	.625		.116	.007	.009
	N	12	12	12	12	12	12
% RH	Pearson Correlation	-.187	-.332	.478	1	.214	-.550
	Sig. (2-tailed)	.561	.292	.116		.505	.064
	N	12	12	12	12	12	12
SR	Pearson Correlation	-.134	-.294	.731**	.214	1	-.563
	Sig. (2-tailed)	.679	.354	.007	.505		.057
	N	12	12	12	12	12	12
BP	Pearson Correlation	.476	.525	-.712**	-.550	-.563	1
	Sig. (2-tailed)	.118	.079	.009	.064	.057	
	N	12	12	12	12	12	12
Benzene	Pearson Correlation	.651**	.449*	.433	.148	.359	-.060
	Sig. (2-tailed)	.002	.047	.160	.647	.252	.853
	N	20	20	12	12	12	12
Toluene	Pearson Correlation	.770**	.681**	.159	-.022	.081	.321
	Sig. (2-tailed)	.000	.001	.621	.947	.803	.308
	N	20	20	12	12	12	12
Ethylbenzene	Pearson Correlation	.696**	.661**	-.154	-.690*	-.100	.578
	Sig. (2-tailed)	.002	.004	.693	.040	.798	.103
	N	17	17	9	9	9	9
m,p-Xylene	Pearson Correlation	.687**	.661**	-.211	-.386	-.012	.534
	Sig. (2-tailed)	.002	.003	.558	.271	.974	.112
	N	18	18	10	10	10	10
o-Xylene	Pearson Correlation	.570*	.579*	-.115	-.695*	-.002	.463
	Sig. (2-tailed)	.017	.015	.768	.038	.997	.210
	N	17	17	9	9	9	9
Total BTEX	Pearson Correlation	.768**	.654**	.212	.016	.141	.254
	Sig. (2-tailed)	.000	.002	.508	.961	.662	.425
	N	20	20	12	12	12	12

**. Correlation is significant at the 0.01 level (2-tailed).

*. Correlation is significant at the 0.05 level (2-tailed).

Table E.4 Correlation between BTEX and BTEX

Correlations

		Benzene	Toluene	Ethylbenzene	m,p-Xylene	o-Xylene	Total BTEX
Benzene	Pearson Correlation	1	.812**	.649**	.678**	.540*	.870**
	Sig. (2-tailed)		.000	.001	.001	.012	.000
	N	24	24	21	22	21	24
Toluene	Pearson Correlation	.812**	1	.939**	.950**	.849**	.992**
	Sig. (2-tailed)	.000		.000	.000	.000	.000
	N	24	24	21	22	21	24
Ethylbenzene	Pearson Correlation	.649**	.939**	1	.986**	.951**	.944**
	Sig. (2-tailed)	.001	.000		.000	.000	.000
	N	21	21	21	21	21	21
m,p-Xylene	Pearson Correlation	.678**	.950**	.986**	1	.963**	.952**
	Sig. (2-tailed)	.001	.000	.000		.000	.000
	N	22	22	21	22	21	22
o-Xylene	Pearson Correlation	.540*	.849**	.951**	.963**	1	.861**
	Sig. (2-tailed)	.012	.000	.000	.000		.000
	N	21	21	21	21	21	21
Total BTEX	Pearson Correlation	.870**	.992**	.944**	.952**	.861**	1
	Sig. (2-tailed)	.000	.000	.000	.000	.000	
	N	24	24	21	22	21	24

**. Correlation is significant at the 0.01 level (2-tailed).

*. Correlation is significant at the 0.05 level (2-tailed).

Table E.5 Correlation between carbonyl compounds and carbonyl compounds

Correlations

		Formaldehyde	Acetaldehyde	Acetone	Propionaldehyde	Crotonaldehyde	Butylraldehyde	Benzaldehyde	Valeraldehyde	Hexanaldehyde
Formaldehyde	Pearson Correlation	1	.786**	.857**	.816**	-.232	.117	-.139	.343	.813**
	Sig. (2-tailed)		.000	.000	.000	.287	.585	.667	.119	.000
	N	24	24	24	22	23	24	12	22	21
Acetaldehyde	Pearson Correlation	.786**	1	.820**	.957**	.078	.193	-.102	.358	.821**
	Sig. (2-tailed)	.000		.000	.000	.724	.367	.753	.102	.000
	N	24	24	24	22	23	24	12	22	21
Acetone	Pearson Correlation	.857**	.820**	1	.845**	-.187	.070	-.132	.406	.879**
	Sig. (2-tailed)	.000	.000		.000	.393	.747	.683	.061	.000
	N	24	24	24	22	23	24	12	22	21
Propionaldehyde	Pearson Correlation	.816**	.957**	.845**	1	-.029	.067	-.145	.486*	.826**
	Sig. (2-tailed)	.000	.000	.000		.897	.767	.652	.026	.000
	N	22	22	22	22	22	22	12	21	20
Crotonaldehyde	Pearson Correlation	-.232	.078	-.187	-.029	1	.541**	-.229	.012	.021
	Sig. (2-tailed)	.287	.724	.393	.897		.008	.474	.959	.929
	N	23	23	23	22	23	23	12	22	20
Butylraldehyde	Pearson Correlation	.117	.193	.070	.067	.541**	1	-.169	.066	.146
	Sig. (2-tailed)	.585	.367	.747	.767	.008		.599	.772	.528
	N	24	24	24	22	23	24	12	22	21
Benzaldehyde	Pearson Correlation	-.139	-.102	-.132	-.145	-.229	-.169	1	.021	.069
	Sig. (2-tailed)	.667	.753	.683	.652	.474	.599		.948	.830
	N	12	12	12	12	12	12	12	12	12
Valeraldehyde	Pearson Correlation	.343	.358	.406	.486*	.012	.066	.021	1	.614**
	Sig. (2-tailed)	.119	.102	.061	.026	.959	.772	.948		.005
	N	22	22	22	21	22	22	12	22	19
Hexanaldehyde	Pearson Correlation	.813**	.821**	.879**	.826**	.021	.146	.069	.614**	1
	Sig. (2-tailed)	.000	.000	.000	.000	.929	.528	.830	.005	
	N	21	21	21	20	20	21	12	19	21

**. Correlation is significant at the 0.01 level (2-tailed).

*. Correlation is significant at the 0.05 level (2-tailed).

Table E.6 Correlation between BTEX and carbonyl compounds

Correlations

		Benzene	Toluene	Ethyl-benzene	m,p-Xylene	o-Xylene	Total BTEX
Formaldehyde	Pearson Correlation	.601**	.406*	.215	.228	.100	.464*
	Sig. (2-tailed)	.002	.049	.350	.306	.666	.022
	N	24	24	21	22	21	24
Acetaldehyde	Pearson Correlation	.736**	.457*	.355	.352	.270	.534**
	Sig. (2-tailed)	.000	.025	.115	.108	.236	.007
	N	24	24	21	22	21	24
Acetone	Pearson Correlation	.543**	.330	.084	.148	-.020	.395
	Sig. (2-tailed)	.006	.115	.718	.510	.931	.056
	N	24	24	21	22	21	24
Propionaldehyde	Pearson Correlation	.645**	.353	.248	.254	.141	.429*
	Sig. (2-tailed)	.001	.107	.293	.267	.554	.047
	N	22	22	20	21	20	22
Crotonaldehyde	Pearson Correlation	-.131	-.207	-.092	-.059	-.145	-.207
	Sig. (2-tailed)	.552	.344	.700	.798	.541	.344
	N	23	23	20	21	20	23
Butylraldehyde	Pearson Correlation	.158	.023	.005	.109	-.068	.037
	Sig. (2-tailed)	.460	.914	.983	.629	.768	.863
	N	24	24	21	22	21	24
Benzaldehyde	Pearson Correlation	-.279	-.240	-.336	-.260	-.251	-.280
	Sig. (2-tailed)	.379	.453	.286	.415	.431	.377
	N	12	12	12	12	12	12
Valeraldehyde	Pearson Correlation	-.002	-.284	-.357	-.272	-.343	-.228
	Sig. (2-tailed)	.994	.201	.134	.246	.150	.307
	N	22	22	19	20	19	22
Hexanaldehyde	Pearson Correlation	.236	-.036	.109	.021	.066	.035
	Sig. (2-tailed)	.303	.877	.638	.927	.776	.880
	N	21	21	21	21	21	21

**. Correlation is significant at the 0.01 level (2-tailed).

*. Correlation is significant at the 0.05 level (2-tailed).

APPENDIX F
Risk Assessment

F.1 Risk assessment in the first sampling representing the inner city of Bangkok

Table F.1 Cancer risk of workers exposed to benzene

Stations	**Gas station worker 1**		**Gas station worker 2**	
	Day 1	**Day 2**	**Day 1**	**Day 2**
TRO	6.66×10^{-4}	1.29×10^{-3}	7.64×10^{-4}	1.28×10^{-3}
PCC	1.26×10^{-3}	1.36×10^{-3}	9.25×10^{-4}	1.54×10^{-3}
NW	2.12×10^{-4}	5.31×10^{-4}	6.13×10^{-4}	1.46×10^{-3}
TP	6.38×10^{-4}	1.67×10^{-3}	1.03×10^{-3}	1.71×10^{-3}
BK	9.73×10^{-4}	1.69×10^{-3}	1.10×10^{-3}	1.83×10^{-3}
SBS	1.01×10^{-3}	1.00×10^{-3}	1.06×10^{-3}	1.01×10^{-3}

Table F.2 Cancer risk of workers exposed to ethylbenzene

Stations	**Gas station worker 1**		**Gas station worker 2**	
	Day 1	**Day 2**	**Day 1**	**Day 2**
TRO	9.37×10^{-6}	1.58×10^{-5}	7.28×10^{-6}	1.34×10^{-5}
PCC	1.46×10^{-5}	1.52×10^{-5}	1.35×10^{-5}	2.65×10^{-5}
NW	9.20×10^{-6}	1.13×10^{-5}	1.76×10^{-5}	2.02×10^{-5}
TP	1.12×10^{-5}	1.37×10^{-5}	1.95×10^{-5}	1.24×10^{-5}
BK	1.76×10^{-5}	2.10×10^{-5}	1.89×10^{-5}	2.85×10^{-5}
SBS	9.42×10^{-6}	1.47×10^{-5}	1.14×10^{-5}	1.31×10^{-5}

Table F.3 Cancer risk of workers exposed to formaldehyde

Stations	**Gas station worker 1**		**Gas station worker 2**	
	Day 1	**Day 2**	**Day 1**	**Day 2**
TRO	7.00×10^{-6}	1.05×10^{-5}	8.03×10^{-6}	1.62×10^{-5}
PCC	2.23×10^{-5}	1.68×10^{-5}	9.32×10^{-6}	1.91×10^{-5}
NW	7.05×10^{-6}	1.24×10^{-5}	1.02×10^{-5}	1.31×10^{-5}
TP	1.47×10^{-5}	2.03×10^{-5}	1.25×10^{-5}	1.68×10^{-5}
BK	7.94×10^{-6}	1.32×10^{-5}	1.48×10^{-5}	1.09×10^{-5}
SBS	1.28×10^{-5}	1.08×10^{-5}	6.53×10^{-6}	1.27×10^{-5}

Table F.4 Cancer risk of workers exposed to acetaldehyde

Stations	**Gas station worker 1**		**Gas station worker 2**	
	Day 1	**Day 2**	**Day 1**	**Day 2**
TRO	1.14×10^{-6}	1.51×10^{-6}	8.46×10-7	1.36×10^{-6}
PCC	7.39×10^{-6}	3.67×10^{-6}	1.36×10^{-6}	3.68×10^{-6}
NW	1.16×10^{-6}	1.77×10^{-6}	1.21×10^{-6}	1.48×10^{-6}
TP	5.36×10^{-6}	4.25×10^{-6}	3.00×10^{-6}	4.26×10^{-6}
BK	1.62×10^{-6}	4.29×10^{-6}	5.24×10^{-6}	1.95×10^{-6}
SBS	1.25×10^{-6}	1.10×10^{-6}	1.68×10^{-6}	3.93×10^{-6}

Table F.5 Hazard quotient of workers exposed to toluene

Stations	**Gas station worker 1**		**Gas station worker 2**	
	Day 1	**Day 2**	**Day 1**	**Day 2**
TRO	0.0155	0.0172	0.0171	0.0187
PCC	0.0164	0.0241	0.0174	0.0156
NW	0.0061	0.0088	0.0132	0.0138
TP	0.0193	0.0289	0.0313	0.0226
BK	0.0173	0.0232	0.0226	0.0258
SBS	0.0244	0.0169	0.0210	0.0187

Table F.6 Hazard quotient of workers exposed to m,p-xylene

Stations	**Gas station worker 1**		**Gas station worker 2**	
	Day 1	**Day 2**	**Day 1**	**Day 2**
TRO	0.2497	0.2600	0.2095	0.2210
PCC	0.2274	0.2881	0.3788	0.3864
NW	0.1327	0.1304	0.2401	0.1985
TP	0.1493	0.2112	0.3474	0.1833
BK	0.3053	0.3225	0.4927	0.4654
SBS	0.1831	0.2347	0.2298	0.2177

Table F.7 Hazard quotient of workers exposed to o-xylene

Stations	**Gas station worker 1**		**Gas station worker 2**	
	Day 1	**Day 2**	**Day 1**	**Day 2**
TRO	0.0801	0.0879	0.0767	0.0746
PCC	0.0724	0.0921	0.1384	0.1349
NW	0.0638	0.0500	0.0953	0.0577
TP	0.0741	0.0681	0.0922	0.0590
BK	0.1033	0.1096	0.1595	0.1497
SBS	0.0714	0.0869	0.0772	0.0894

Table F.8 Hazard quotient of workers exposed to propionaldehyde

Stations	**Gas station worker 1**		**Gas station worker 2**	
	Day 1	**Day 2**	**Day 1**	**Day 2**
TRO	0.0707	0.0667	0.0471	0.0515
PCC	0.0308	0.0683	0.0511	0.0535
NW	0.0400	0.0432	0.0324	0.0332
TP	0.0895	0.0619	0.0272	0.0228
BK	0.0451	0.1910	0.0408	0.0192
SBS	0.0479	0.0340	0.0180	0.0384

F.2 Risk assessment in the second sampling representing the widespread area of Bangkok

Table F.9 Cancer risk of workers exposed to benzene

Stations	**Gas station worker 1**				**Gas station worker 2**			
	Fri	**Sat**	**Sun**	**Mon**	**Fri**	**Sat**	**Sun**	**Mon**
BT	1.53×10^{-4}	1.99×10^{-4}	1.66×10^{-4}	2.76×10^{-4}	1.53×10^{-4}	2.56×10^{-4}	n/a	n/a
DKN	1.83×10^{-4}	2.06×10^{-4}	1.35×10^{-4}	2.00×10^{-4}	1.45×10^{-4}	2.42×10^{-4}	1.39×10^{-4}	2.48×10^{-4}
J	n/a	n/a	2.61×10^{-4}	7.26×10^{-5}	2.25×10^{-4}	2.46×10^{-4}	1.25×10^{-4}	1.95×10^{-4}
RO	2.17×10^{-4}	1.20×10^{-4}	1.70×10^{-4}	1.08×10^{-4}	1.96×10^{-4}	1.24×10^{-4}	2.24×10^{-4}	1.43×10^{-4}
TL	2.84×10^{-4}	5.47×10^{-5}	1.63×10^{-4}	1.89×10^{-4}	1.09×10^{-4}	2.40×10^{-4}	2.19×10^{-4}	1.47×10^{-4}
TP	2.12×10^{-4}	2.26×10^{-4}	4.14×10^{-5}	9.88×10^{-5}	1.04×10^{-4}	1.12×10^{-4}	1.41×10^{-4}	9.77×10^{-5}

Table F.10 Cancer risk of workers exposed to ethylbenzene

Stations	**Gas station worker 1**				**Gas station worker 2**			
	Fri	**Sat**	**Sun**	**Mon**	**Fri**	**Sat**	**Sun**	**Mon**
BT	1.52×10^{-6}	2.28×10^{-6}	2.31×10^{-6}	3.13×10^{-6}	1.66×10^{-6}	2.38×10^{-6}	n/a	n/a
DKN	2.33×10^{-6}	1.95×10^{-6}	2.23×10^{-6}	2.54×10^{-6}	2.00×10^{-6}	2.75×10^{-6}	1.86×10^{-6}	4.15×10^{-6}
J	n/a	n/a	2.41×10^{-6}	2.60×10^{-6}	1.95×10^{-6}	2.24×10^{-6}	1.97×10^{-6}	2.46×10^{-6}
RO	3.39×10^{-6}	2.40×10^{-6}	4.43×10^{-6}	2.53×10^{-6}	2.61×10^{-6}	1.62×10^{-6}	2.46×10^{-6}	2.34×10^{-6}
TL	2.74×10^{-6}	4.15×10^{-6}	2.46×10^{-6}	2.25×10^{-6}	1.81×10^{-6}	1.47×10^{-6}	2.71×10^{-6}	1.71×10^{-6}
TP	2.41×10^{-6}	3.21×10^{-6}	2.57×10^{-6}	2.74×10^{-6}	1.49×10^{-6}	1.92×10^{-6}	2.24×10^{-6}	2.13×10^{-6}

Table F.11 Cancer risk of workers exposed to formaldehyde

Stations	**Gas station worker 1**				**Gas station worker 2**			
	Fri	**Sat**	**Sun**	**Mon**	**Fri**	**Sat**	**Sun**	**Mon**
BT	8.01×10^{-6}	1.19×10^{-5}	8.00×10^{-6}	1.69×10^{-5}	6.10×10^{-6}	8.52×10^{-6}	n/a	n/a
DKN	1.14×10^{-5}	1.23×10^{-5}	1.25×10^{-5}	1.67×10^{-5}	9.77×10^{-6}	1.52×10^{-5}	9.48×10^{-6}	1.25×10^{-5}
J	n/a	n/a	8.32×10^{-6}	1.00×10^{-5}	8.36×10^{-6}	7.86×10^{-6}	5.17×10^{-6}	1.07×10^{-5}
RO	2.25×10^{-5}	1.07×10^{-5}	1.22×10^{-5}	1.01×10^{-5}	8.50×10^{-6}	5.92×10^{-6}	1.21×10^{-5}	7.97×10^{-6}
TL	5.72×10^{-5}	1.06×10^{-5}	6.36×10^{-6}	7.74×10^{-6}	4.28×10^{-6}	5.86×10^{-6}	1.61×10^{-5}	1.11×10^{-5}
TP	1.09×10^{-5}	1.46×10^{-5}	8.98×10^{-6}	1.28×10^{-5}	1.49×10^{-5}	1.04×10^{-5}	1.80×10^{-5}	2.03×10^{-5}

Table F.12 Cancer risk of workers exposed to acetaldehyde

Stations	**Gas station worker 1**				**Gas station worker 2**			
	Fri	**Sat**	**Sun**	**Mon**	**Fri**	**Sat**	**Sun**	**Mon**
BT	1.93×10^{-6}	2.27×10^{-6}	3.03×10^{-6}	5.90×10^{-6}	2.55×10^{-6}	2.93×10^{-6}	n/a	n/a
DKN	3.96×10^{-6}	5.87×10^{-6}	3.16×10^{-6}	4.59×10^{-6}	3.69×10^{-6}	2.03×10^{-5}	3.87×10^{-6}	6.99×10^{-6}
J	n/a	n/a	2.19×10^{-6}	2.46×10^{-6}	1.99×10^{-6}	3.24×10^{-6}	2.01×10^{-6}	3.12×10^{-6}
RO	3.84×10^{-6}	3.58×10^{-6}	3.53×10^{-6}	2.49×10^{-6}	3.22×10^{-6}	1.74×10^{-6}	3.07×10^{-6}	2.46×10^{-6}
TL	3.84×10^{-6}	1.33×10^{-5}	2.27×10^{-6}	3.64×10^{-6}	9.53×10-7	8.93×10^{-6}	7.80×10^{-6}	3.95×10^{-6}
TP	6.23×10^{-6}	7.31×10^{-6}	4.04×10^{-6}	4.95×10^{-6}	4.19×10^{-6}	3.14×10^{-6}	4.74×10^{-6}	7.92×10^{-6}

Table F.13 Hazard quotient of workers exposed to toluene

Stations	**Gas station worker 1**				**Gas station worker 2**			
	Fri	**Sat**	**Sun**	**Mon**	**Fri**	**Sat**	**Sun**	**Mon**
BT	0.0132	0.0106	0.0138	0.0126	0.0127	0.0118	n/a	n/a
DKN	0.0118	0.0135	0.0108	0.0103	0.0112	0.0117	0.0093	0.0114
J	n/a	n/a	0.0155	0.0044	0.0132	0.0145	0.0093	0.0120
RO	0.0134	0.0108	0.0128	0.0112	0.0101	0.0085	0.0106	0.0142
TL	0.0135	0.0208	0.0132	0.0154	0.0084	0.0258	0.0127	0.0148
TP	0.0162	0.0130	0.0051	0.0081	0.0090	0.0088	0.0127	0.0071

Table F.14 Hazard quotient of workers exposed to m,p-xylene

Stations	**Gas station worker 1**				**Gas station worker 2**			
	Fri	**Sat**	**Sun**	**Mon**	**Fri**	**Sat**	**Sun**	**Mon**
BT	0.0957	0.0919	0.1887	0.1204	0.1134	0.0979	n/a	n/a
DKN	0.0961	0.1008	0.0792	0.0914	0.0868	0.1136	0.0977	0.0987
J	n/a	n/a	0.1382	0.0714	0.1029	0.0873	0.0843	0.1061
RO	0.1274	0.1204	0.1549	0.1271	0.1100	0.0841	0.0972	0.1085
TL	0.0959	0.1856	0.1162	0.1091	0.0733	0.0976	0.1095	0.1233
TP	0.1529	0.1416	0.1045	0.0985	0.0807	0.0782	0.1557	0.0887

Table F.15 Hazard quotient of workers exposed to o-xylene

Stations	**Gas station worker 1**				**Gas station worker 2**			
	Fri	**Sat**	**Sun**	**Mon**	**Fri**	**Sat**	**Sun**	**Mon**
BT	0.0299	0.0293	0.0544	0.0346	0.0338	0.0307	n/a	n/a
DKN	0.0264	0.0253	0.0219	0.0249	0.0241	0.0318	0.0277	0.0288
J	n/a	n/a	0.0438	0.0169	0.0319	0.0279	0.0258	0.0326
RO	0.0417	0.0389	0.0456	0.0399	0.0330	0.0250	0.0286	0.0326
TL	0.0280	0.0753	0.0371	0.0327	0.0259	0.0315	0.0344	0.0367
TP	0.0456	0.0430	0.0295	0.0292	0.0274	0.0225	0.0482	0.0311

Table F.16 Hazard quotient of workers exposed to propionaldehyde

Stations	**Gas station worker 1**				**Gas station worker 2**			
	Fri	**Sat**	**Sun**	**Mon**	**Fri**	**Sat**	**Sun**	**Mon**
BT	0.0478	0.0309	0.0423	0.0595	0.0421	0.0353	n/a	n/a
DKN	0.0489	0.0588	0.0401	0.0605	0.0467	0.0562	0.0496	0.0505
J	n/a	n/a	0.0281	0.0287	0.0235	0.0302	0.0265	0.0280
RO	0.0389	0.0353	0.0304	0.0285	0.0261	0.0190	0.0240	0.0252
TL	0.0269	0.0945	0.0219	0.0334	0.0106	0.0444	0.0521	0.0505
TP	0.0434	0.0514	0.0461	0.0413	0.0497	0.0438	0.0702	0.0706

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