THE STUDY OF THE RELATIONSHIP BETWEEN ODORANT CONCENTRATION AND ODOR INTENSITY

TEWAN CHAWANGWONGSANUKUN

A THESIS SUBMITTED IN PARTIAL FULFILLMENT
OF THE REQUIREMENTS FOR
THE DEGREE OF MASTER OF SCIENCE
(TECHNOLOGY OF ENVIRONMENTAL MANAGEMENT)
FACULTY OF GRADUATE STUDIES
MAHIDOL UNIVERSITY
2007

Thesis
Entitled

THE STUDY OF THE RELATIONSHIP BETWEEN ODORANT CONCENTRATION AND ODOR INTENSITY

....
Mr. Tewan Chawangwongsanukun
Candidate

....
Asst. Prof. Dr. Winai Nutmagul,
Ph.D. (Engineering Science)
Major-Advisor

....
Assoc. Prof. Usanee Uyasatian,
M.Eng. (Sanitary Engineering)
Co-Advisor

....
Asst. Prof. Dr. Kraichat Tantrakarnapa,
Ph.D. (Environmental Engineering)
Co-Advisor

....
Prof. Banchong Mahaisavariya,
M.D.
Dean
Faculty of Graduate Studies

....
Dr. Kulvadee Kansuntisukmongkol,
Ph.D. (Ecology)
Chair
Master of Science Programme in
Technology of Environmental Management
Faculty of Environment and Resource Studies

Thesis
Entitled

THE STUDY OF THE RELATIONSHIP BETWEEN ODORANT CONCENTRATION AND ODOR INTENSITY

was submitted to the Faculty of Graduate Studies, Mahidol University
For the degree of Master of Science
(Technology of Environmental Management)
On
December 28, 2007

....
Mr. Tewan Chawangwongsanukun
Candidate

....
Dr. Decha Pimpisut,
Ph.D. (Environmental Management)
Chair

....
Asst. Prof. Dr. Winai Nutmagul,
Ph.D. (Engineering Science)
Member

....
Assoc. Prof. Usanee Uyasatian,
M.Eng. (Sanitary Engineering)
Member

....
Asst. Prof. Dr. Kraichat Tantrakarnapa,
Ph.D. (Environmental Engineering)
Member

....
Prof. Banchong Mahaisavariya,
M.D.
Dean
Faculty of Graduate Studies
Mahidol University

....
Asst. Prof. Dr. Sittipong Dilokwanich,
Ph.D. (Human Geography)
Dean
Faculty of Environment and Resource Studies
Mahidol University

ACKNOWLEDGEMENTS

This research work is supported by the grant from the Post-Graduate Education, Training and Research Program in Environmental Science, Technology and Management under Higher Education Development Project of the Commission on Higher Education, Ministry of Education. Special thanks to Department of Industrial Works and Japan External Trade Organization (JETRO) for materials, apparatus, odorous substances and research grant in this research.

The success of this thesis can be attributed to the extensive support and assistance from my major advisor, Asst. Prof. Dr. Winai Nutmagul and my co-advisors, Assoc. Prof. Usanee Uyasatian, and Asst. Prof. Dr. Kraichat Tantrakarnapa. I deeply thank them for their valuable advice, guidance and comments in this research. Especially kindness and also sacrifice their time for me, including many suggestions that are useful to make my thesis more comprehensive.

I wish to thank Dr. Decha Pimpisut, Bureau of Water Technology and Industrial Pollution Management, Department of Industrial Works, for his kindness in providing suggestions for improvement, and who was the external examiner of the thesis defense. Pollution Control Department, for complaint statistics of environmental pollution in 2000-2005. Dr. Kessinee Unapumnuk, Pollution Control Department, for valuable advice in establishing standards for individual nuisance odorous substances. Scientists (especially to Khun Tai) and the odor measurement laboratory, Faculty of Environment and Resource Studies, Mahidol University, for their huge support in allowing me to use the odor measurement laboratory, facilitate, and advice in this research. Kittiphong Chaimanuskul, Nisa Rattanadilok na Phuket, and all friends in Technology of Environmental Management Program (ET' 32) that cannot be announced to here for their friendship, helpful, and encouragement.

Finally, I would like to express the sincere thanks to my family (father, mother, and older brother) for their financial support, entirely care, and love.

Tewan Chawangwongsanukun

THE STUDY OF THE RELATIONSHIP BETWEEN ODORANT CONCENTRATION AND ODOR INTENSITY

TEWAN CHAWANGWONGSANUKUN 4837301 ENTM/M

M.Sc. (TECHNOLOGY OF ENVIRONMENTAL MANAGEMENT)

THESIS ADVISORS: WINAI NUTMAGUL, Ph.D. (ENGINEERING SCIENCE); USANEE UYASATIAN, M.Eng. (SANITARY ENGINEERING); KRAICHAT TANTRAKARNAPA, Ph.D. (ENVIRONMENTAL ENGINEERING)

ABSTRACT

The purpose of this research was to study the relationship between odorant concentrations and odor intensities using a sensory test. Nine odorous substances, common odor nuisances of various industries, were selected for this study: ammonia, n-butyl acetate, hydrogen sulfide, methanol, methyl mercaptan, propionic acid, styrene, toluene, and xylene. About 4-6 concentration levels of each odorous substance inside odor bags, corresponding to the odor intensities in the range of 2 to 4, were prepared at random and presented to six panelists (who passed the sensory screening test according to the Japanese Industrial Standard) for assessing the odor intensities (in the range of 0 to 5) of diluted odorant samples.

Simple regression analysis was conducted and found that the relationship between odorant concentrations and odor intensities for all nine odorous substances obeyed the Weber-Fechner equation with significant differences at p-value ≤ 0.01. The range of correlation coefficients (r) and mean square errors (MSE) were 0.75-0.97 and 0.19-0.49, respectively.

Results from this study can be used to determine the odorant concentration range for each odorous substance corresponding to the odor intensities between 2.5 and 3.5 which is an indication of a nuisance. The concentration range for ammonia, n-butyl acetate, hydrogen sulfide, methanol, methyl mercaptan, propionic acid, styrene, toluene, and xylene are 3.3-25 ppm, 0.9-4 ppm, 0.02-0.09 ppm, 171-200 ppm, 0.006-0.02 ppm, 0.63-2.71 ppm, 0.2-0.6 ppm, 8.7-26.6 ppm, and 0.4-1.0 ppm, respectively. These concentration ranges may be used by the concerned agencies for establishing ambient air standards at ground level along the boundary line of the factory of the individual nuisance odorous substances.

KEY WORDS: ODORANT CONCENTRATION / OLFACTORY PERCEPTION / ODOR INTENSITY

138 pp.

การศึกษาความสัมพันธ์ระหว่างความเข้มข้นของสารที่มีกลิ่นกับความแรงของกลิ่น (THE STUDY OF THE RELATIONSHIP BETWEEN ODORANT CONCENTRATION AND ODOR INTENSITY)

เทวัญ ฉวางวงศานุกูล 4837301 ENTM/M

วท.ม. (เทคโนโลยีการบริหารสิ่งแวดล้อม)

คณะกรรมการควบคุมวิทยานิพนธ์: วินัย นุตมากุล, Ph.D. (ENGINEERING SCIENCE); อุษณีย์ อุยะเสถียร, วศ.ม. (วิศวกรรมสุขาภิบาล); ไกรชาติ ตันตระการอาภา, วศ.ด. (วิศวกรรมสิ่งแวดล้อม)

บทคัดย่อ

งานวิจัยนี้มีวัตถุประสงค์เพื่อศึกษาความสัมพันธ์ระหว่างความเข้มข้นของสารที่มีกลิ่นกับความแรงของกลิ่นด้วยวิธีการดม สารที่มีกลิ่นรวม 9 ชนิด ได้แก่ แอมโมเนีย นอร์มอลบิวทิลอะซีเตท ไฮโดรเจนซัลไฟด์ เมทานอล เมทิลเมอร์แคปเทน กรดพรอพิโอนิก สไตรีน โทลูอีน และไซลีน โดยสารที่ถูกเลือกมาศึกษาเหล่านี้เป็นสารที่มักจะก่อให้เกิดปัญหากลิ่นรบกวนแก่ชุมชนรอบๆโรงงานอุตสาหกรรมและมีการร้องเรียนมายังหน่วยงานที่เกี่ยวข้องอยู่เสมอๆ โดยสารที่มีกลิ่นแต่ละตัวจะถูกเตรียมที่ระดับความเข้มข้น 4-6 ระดับภายในถุงทดสอบกลิ่น โดยใช้วิธีการสุ่ม (ซึ่งอยู่ในช่วงความแรงของกลิ่นประมาณ 2-4) แล้วให้ผู้ตรวจวัดกลิ่นจำนวน 6 คนทำการประเมินความแรงของกลิ่นที่ระดับความเข้มข้นต่างๆ (ผู้ทดสอบกลิ่นได้ผ่านการทดสอบความไวในการดมกลิ่นตามวิธีการของ Japanese Industrial Standard) เพื่อประเมินความแรงของกลิ่นในช่วงสเกล 0-5

ทำการวิเคราะห์ข้อมูลด้วยสมการถดถอยอย่างง่าย (Simple regression analysis) พบว่าความสัมพันธ์ระหว่างความเข้มข้นของสารที่มีกลิ่นกับความแรงของกลิ่นของสารที่มีกลิ่นทั้ง 9 ชนิดสอดคล้องตามสมการล็อกการิทึมของเวเบอร์เฟชเนอร์ (Weber-Fechner logarithmic equation) ที่ระดับนัยสำคัญน้อยกว่า 0.01 โดยมีสัมประสิทธิ์สหสัมพันธ์ (r), และค่าเฉลี่ยความผิดพลาดยกกำลังสอง (MSE) อยู่ในช่วง 0.75-0.97 และ 0.19-0.49 ตามลำดับ

ผลจากการศึกษานี้สามารถนำไปใช้หาช่วงของความเข้มข้นของสารแต่ละชนิดที่สัมพันธ์กับช่วงของความแรงของกลิ่นในระดับที่ก่อให้เกิดปัญหากลิ่นรบกวน (คือช่วงความแรงของกลิ่นเท่ากับ 2.5-3.5) โดยช่วงความเข้มข้นที่ก่อให้เกิดปัญหากลิ่นรบกวนของแอมโมเนีย นอร์มอลบิวทิลอะซีเตท ไฮโดรเจนซัลไฟด์ เมทานอล เมทิลเมอร์แคปเทน กรดพรอพิโอนิก สไตรีน โทลูอีน และไซลีน ได้แก่ 3.3-25 พีพีเอ็ม 0.9-4 พีพีเอ็ม 0.02-0.09 พีพีเอ็ม 171-200 พีพีเอ็ม 0.006-0.02 พีพีเอ็ม 0.63-2.71 พีพีเอ็ม 0.2-0.6 พีพีเอ็ม 8.7-26.6 พีพีเอ็ม และ 0.4-1.0 พีพีเอ็ม ตามลำดับ ซึ่งช่วงของความเข้มข้นนี้อาจนำไปใช้ในการกำหนดค่ามาตรฐานความเข้มข้นของสารที่มีกลิ่นที่บริเวณรั้วหรือขอบเขตภายในโรงงาน เพื่อควบคุมสารที่มีกลิ่นเป็นรายตัวโดยหน่วยงานที่เกี่ยวข้อง

138 หน้า

CONTENTS

CHAPTER

I INTRODUCTION

II LITERATURE REVIEW

CONTENTS (Continued)

LIST OF TABLES

LIST OF TABLES (Continued)

LIST OF TABLES (Continued)

LIST OF TABLES (Continued)

LIST OF TABLES (Continued)

LIST OF FIGURES

LIST OF FIGURES (Continued)

LIST OF ABBREVIATION

a	Simple regression slope
ACGIH	American Conference of Governmental Industrial Hygienists
ANOVA	Analysis of variance
A.R. Grade	Analytical Reagent Grade
AS/NZS	Australian and New Zealand Standard
ASTM	American Society for Testing and Materials
b	Y intercept
B.E.	Buddhist Era
BET	Best-estimate threshold
C	Odorant concentration
°C	Degree Celsius
cc	Cubic centimeter
cm	Centimeter
D	Density
D/T	Dilution to threshold
GC/MS	Gas Chromatography/Mass Spectrometry
gm	Gram
hr	Hour
I	Odor intensity
JIS	Japanese Industrial Standard
L	Liter
L/min	Liter per minute
L/s	Liter per second
Log	Logarithm
M	Mass
m^3/h	Cubic meter per hour
µg/m^3	Microgram per cubic meter

LIST OF ABBREVIATION (Continued)

µl	Micro liter
ml	Milliliter
mm	Millimeter
mmHg	Millimeter of mercury
mPa.sec	Millipascal second
MSE	Mean Square Error
MW	Molecular weight
No.	Number
OC	Odor concentration
OU	Odor unit
OU/m^3	Odor unit per cubic meter
PCD	Pollution Control Department
ppbv	Parts per billion (by volume)
ppm	Parts per Million
p-value	Significance of F-test
r	Correlation coefficient
TLV	Threshold Limit Values
TLV – C	Threshold Limit Values – Ceiling
TLV – STEL	Threshold Limit Values – Short Term Exposure Limit
TLV – TWA	Threshold Limit Values – Time Weight Average
U.S.A.	United States of America
V	Volume
VDI	Verein Deutscher Ingenieure
w/w	Weight by weight
WWTP	Wastewater Treatment Plant

CHAPTER I
INTRODUCTION

1.1 Background and importance of the problem

By definition, odor means a quantity of something that stimulates the olfactory organ (Thai Royal Institute, 2003). Mostly odors are volatile organic compounds but some odors might be volatile inorganic compounds, for example ammonia and hydrogen sulfide (Glindemann et al., 2006). The great majority of odors come from three sources, (1) industry (2) wastewater treatment plants and (3) other businesses such as garages; repair shops; livestock farms, etc (PCD, 2004) which may cause a nuisance to local communities and lead to complaints.

The complaint data of communities regarding environmental pollution from industries in Thailand obtained from the Pollution Control Department (2007) during 2000-2005 showed that odor received the most of complaints (144 cases/year). Other environmental problems such as, dust, wastewater, noise, hazardous waste, vibration, solid waste and night soil were 98, 64, 36, 7, 3 and 2 cases/year, respectively (Figure 1-1). Odor appears to be a severe problem and need more attention than any other environmental pollution.

According to information obtained from a government official of the Department of Industrial Works, nine commonly known odorous substances are ammonia, n-butyl acetate, hydrogen sulfide, methanol, methyl mercaptan, propionic acid, styrene, toluene and xylene. Considering the quantity of these chemical substances imported since 2002-2005 each year, over 200,000 tons of ammonia and methanol, over 50,000 tons of styrene, and over 10,000 tons of n-butyl acetate, were imported. In 2002-2003, about 100-200 tons of toluene was imported, but since 2003 over 20,000 tons was imported; nearly 200-500 tons of propionic acid was imported. Hydrogen sulfide and methyl mercaptan were seldom imported each year (Customs

Department, 2006). Although propionic acid, hydrogen sulfide and methyl mercaptan were seldom imported each year, considering the odor threshold of those three odorous substances compared to other odorous substances, it was found that humans can sense propionic acid, hydrogen sulfide and methyl mercaptan at very low concentrations, i.e., 0.0057 ppm, 0.00041 ppm, and 0.00007 ppm, respectively when compared with other odorous substances as shown in Figure 1-2.

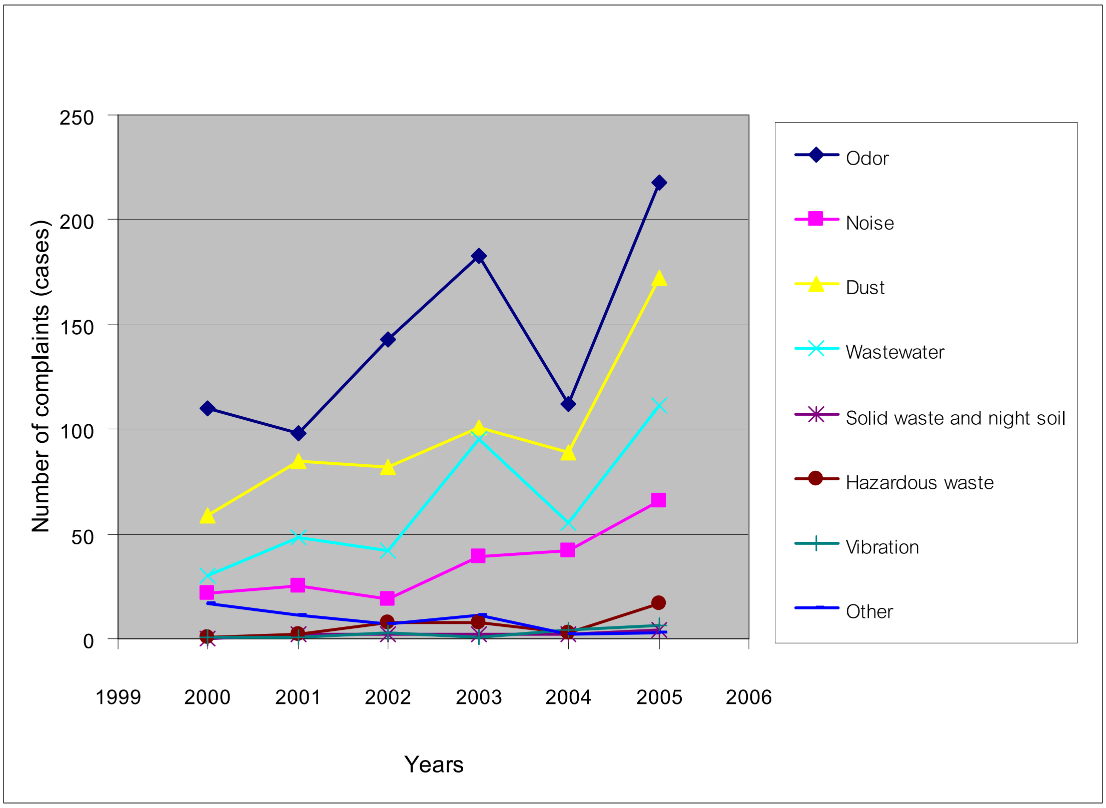
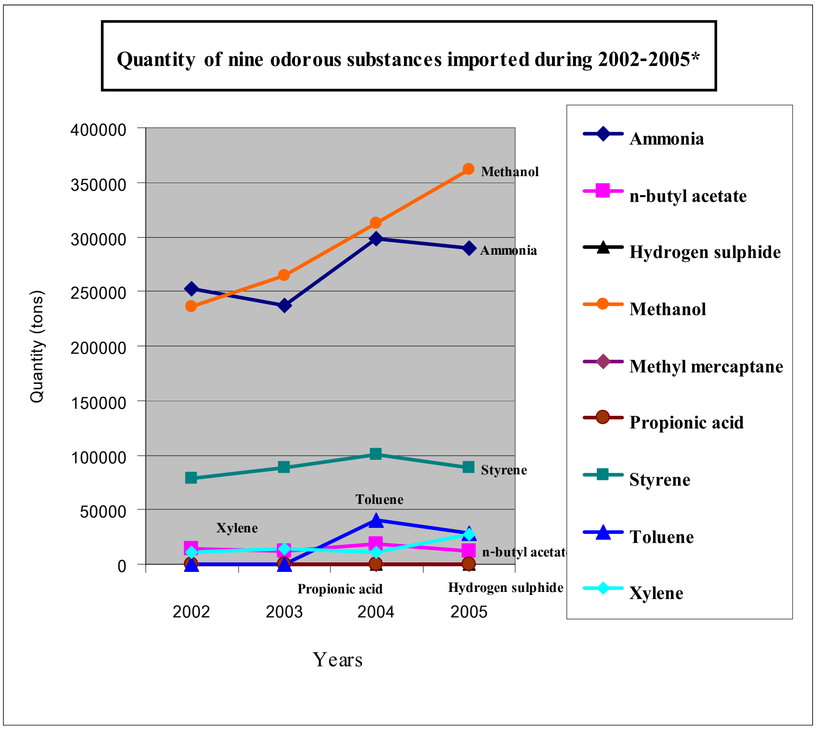


Figure 1-1: Complaints about environmental pollution during 2000-2005

Source: PCD, 2007



Odor threshold of nine odorous substances**

Chemical substances	Odor Threshold (ppm)
Ammonia	1.5
n-Butyl acetate	0.016
Hydrogen sulfide	0.00041
Methanol	33
Methyl mercaptan	0.000070
Propionic acid	0.0057
Styrene	0.035
Toluene	0.33
Xylene	-

Figure 1-2: Quantity of nine odorous substances imported during 2002-2005 and odor threshold of nine odorous substances

Source: Customs Department, 2006*

Nagata, 2002**

Various methods of odor control and odor nuisance improvements exist such as odor treatment system, material substitution, etc. However, an effective method to control odor is by establishing laws or standards. At present, the existing laws and standards concerning the control of odor in Thailand are as follow: (1) The Enhancement and Conservation of the National Environmental Quality Act, B.E. 2535 (1992)-Chapter 4: “Environmental Pollution,” (2) The Public Health Act, B.E. 2535 (1992)-Chapter 5: “Nuisance,” (3) The Factory Act, B.E. 2535(1992): “Standards and control methods of waste or pollutant emission,” (4) Notification of Ministry of Industry (No. 4) “The odor removal from industry,” and (5) Ministerial Regulation of Industry: “Standards and measurements of odor in air from factory B.E. 2548 (2005).” These laws and standards are used to control odor from a mixture of many odorous substances.

In foreign countries, for example, Japan and Korea, laws and standards for odor control were established, for both a mixture of many odorous substances and an individual odorous substance, which is more effective to control odor in their countries.

Therefore, the study of the relationship between odorant concentration and odor intensity of nine odorous substances: ammonia, n-butyl acetate, hydrogen sulfide, methanol, methyl mercaptan, propionic acid, styrene, toluene, and xylene to determine suitable concentrations will be very useful to concerned government agencies for establishing standards for individual common odorants.

1.2 Objectives of the study

1) To test the odor perception of panelists according to the Japanese Industrial Standard (JIS) Method (Panel screening method).

2) To study the relationship between odorant concentration and odor intensity of nine odorous substances.

1.3 Expected outcomes

1) Odor perception of Thai panelists according to Japanese Industrial Standard (JIS) Method is known.

2) The relationship between odorant concentration and odor intensity of nine odorous substances can be established.

3) A suitable concentration to control odor nuisance from nine odorous substances can be obtained.

1.4 Scope of the study

1.4.1 General data collection

Basic data and information related to odor such as, odor definitions; odor characteristics; odor measurements; odor control laws and standards in Thailand and foreign countries such as Japan, Korea and the United States of America will be collected.

1.4.2 Study method and data analysis

1) Sensory tests should be conducted in a place which fulfills the following requirements such as air ventilation system in the sensory test room is suitable; the temperature in the sample preparation room and sensory test room is maintained at 28±1°C; the lighting system has enough light intensity, etc.

2) Screening sensory test of panelists using five standard odor solutions according to the Japanese Industrial Standard (JIS) Method will be employed.

3) Odor intensity to be measured by olfactory test, divided into six levels.

4) Data analysis will be based on simple regression analysis with scatter diagram and suitable equations selected using the maximum value of correlation coefficient (r), the minimum value of mean square error (MSE), and p-value by ANOVA test (F-test) at significant level less than 0.01 for each equation.

1.4.3 Conclusion and recommendations

1) Present the relationship between odorant concentration and odor intensity in formation of linear regression, correlation coefficient (r), and mean square error (MSE)

2) Offer the concentration of individual odorous substance for nine common odorants to control odor in Thailand.

1.5 Conceptual framework

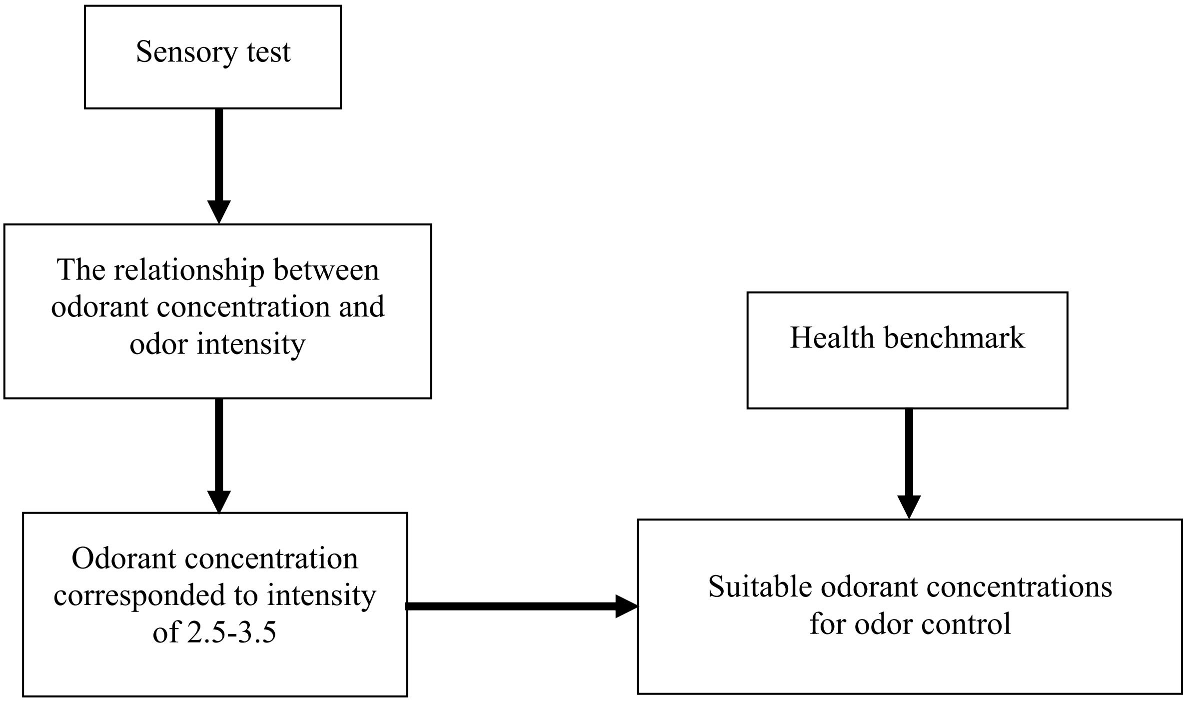


Figure 1-3: Conceptual framework

1.6 Definition of terms

1) Odorant concentration is the concentration of odorous substance in units of parts per million (ppm).

2) Odor intensity is the perceived strength of the odor sensation increasing with higher concentrations by a panel comprising six levels including the following information:

Odor intensity 0 means no odor.
Odor intensity 1 means barely traceable.
Odor intensity 2 means faint but identifiable.
Odor intensity 3 means easily detectable.
Odor intensity 4 means strong odor.
Odor intensity 5 means repulsive.

3) A panel is a group of persons recognized to have normal olfaction by the panel screening method using the standard odor solutions based on the Japanese Industrial Standard (JIS) Method.

4) The panel screening method is a procedure to determine whether the performance of panel members is in compliance with the requirement by using five standard odor solutions that are (1) β-Phenylethyl alcohol (floral smell); (2) Methyl cyclopentenolone (sweet burning smell); (3) Isovaleric acid (smell of stuffy socks); (4) γ-Undecalactone (smell of ripe fruit); and (5) 3-Methyl indole (smell of feces).

5) Odorous substances are chemical substances which stimulate the human olfactory system. In this study, it refers to nine odorous substances: ammonia, n-butyl acetate, hydrogen sulfide, methanol, methyl mercaptan, propionic acid, styrene, toluene and xylene.

6) The sensory test is the determination of odor intensities of odorous substances by sniffing in an odor test sample bag at various concentration levels by six panelists assessing the odor intensities in the range of 0 to 5.

CHAPTER II
LITERATURE REVIEW

In the study of the relationship between odorant concentration and odor intensity, the researcher has collected documents and related research works including the following information:

2.1 Odor definitions and characteristics
2.2 Human olfaction
2.3 Odorous substances
2.4 The principle of odor measurements
2.5 Odor control standards and odor measurements in Thailand and foreign countries
2.6 Related research works on the relationship between odorant concentration and odor intensity

2.1 Odor definitions and characteristics

"Odor" is a term, with many definitions for example "a quantity of something that stimulates the olfactory organ" (Thai Royal Institute, 2003), "the property of a substance affecting the sense of smell" (University of New South Wales, 2006), "that perceived by our brains in response to chemicals present in the air we breathe" (Ministry for the Environment New Zealand, 2003), "organoleptic attributes perceptible by the olfactory organ on sniffing certain volatile substances" (CEN, 1999 and AS/NZS, 2001), etc. In this study, odor is defined as the olfactory perception of odorous chemical substances by the nose.

Also known as, odors are volatilized chemical compounds, generally at a very low concentration (Glindemann et al., 2006). Humans can perceive many different odors, thereby; the physiologic collection of information on odor characteristics has resulted in a nine categories of odor characteristics system (Zwaardemaker, 1925) as shown in Table 2-1.

Table 2-1: Nine categories of odor characteristics system

Class	Subclass	Example of odor
1. Etherial	-	acetone, chloroform, ethyl ether, ethyl acetate
2. Aromatic	a. Camphorous b. Spicy c. Anisic d. Citric e. Amygdalate f. Others	camphor, pinene, eucalyptol eugenol anisole, thymol, menthol citral, geraniol benzaldehyde, nitrobenzene laurel, resins, lemon, rose, cinnamon, mint, lavender, marjoram
3. Amber-musk	-	-
4. Balsamic	a. Flower perfumes b. Lily c. Vanilla	jasmine, orange blossom ionone, violet root -
5. Alliaceous	a. Garlic b. Cacodyl c. Halogen	acetylene, mercaptan, hydrogen sulfide, ethyl sulfide trimethylamine bromine, iodine
6. Empyreumatic	-	roasted coffee, toasted bread, tobaccosmoke, tar, benzol, phenyl xylol, toluol, cresol, guiacol, naphthalene, aniline
7. Hircine	-	caproic acid, other fatty acids, cheese, sweat, bilberry, cat's urine; perhaps also vaginal and sperm odor, chestnut and barberry
8. Repulsive suffocating	-	odors of the solanaceae and of coriander, some orchids, some bugs; narcotic odors
9. Nauseous	-	rotten meat, indole, skatole, carrion flower

Source: Zwaardemaker, 1925

2.2 Human olfaction

Sniffing air includes odor in nasal cavity leading to human olfaction. Air in nasal cavities will change into turbulence, where odorous molecules interact with olfactory receptor cells in a region of 5 cm^2 of the nasal epithelium (Vetchapas, 1997). The olfactory receptor cells are activated and send electronics signals. The signals are relayed in glomeruli which are amplified and transmitted to the brain in the regions of the olfactory cortex, where can consciously experience the smell of odorant substances and recall this olfactory memory at other times.

In 2004, the Nobel Prize in Physiology or Medicine was awarded to Richard Axel and Linda Buck who discovered a large gene family, comprising some 1,000 different genes (three per cent of our genes) that give rise to an equivalent number of olfactory receptor types. Each olfactory receptor cell possesses only one type of odorant receptor and each receptor can detect a limited number of odorant substances. Our olfactory receptor cells are therefore highly specialized for a few odors. The cells send thin nerve processes directly to distinct micro domains, glomeruli, in the olfactory bulb, the primary olfactory area of the brain. Receptor cells carrying the same type of receptor send their nerve processes to the same glomerulus. From these micro domains in the olfactory bulb the information is relayed further to other parts of the brain, where the information from several olfactory receptors is combined, forming a pattern. Therefore, we can recognize and remember about 10,000 different odors (Axel and Buck, 2004) as shown in Figure 2-1.

In conclusion, the olfactory system of humans and mammalians consist of three parts as follows: (1) olfactory receptors, which include cells and genes, (2) signal transduction system which includes transmitting and amplifier, and (3) recognition system (Gerdjaroen, 2005).

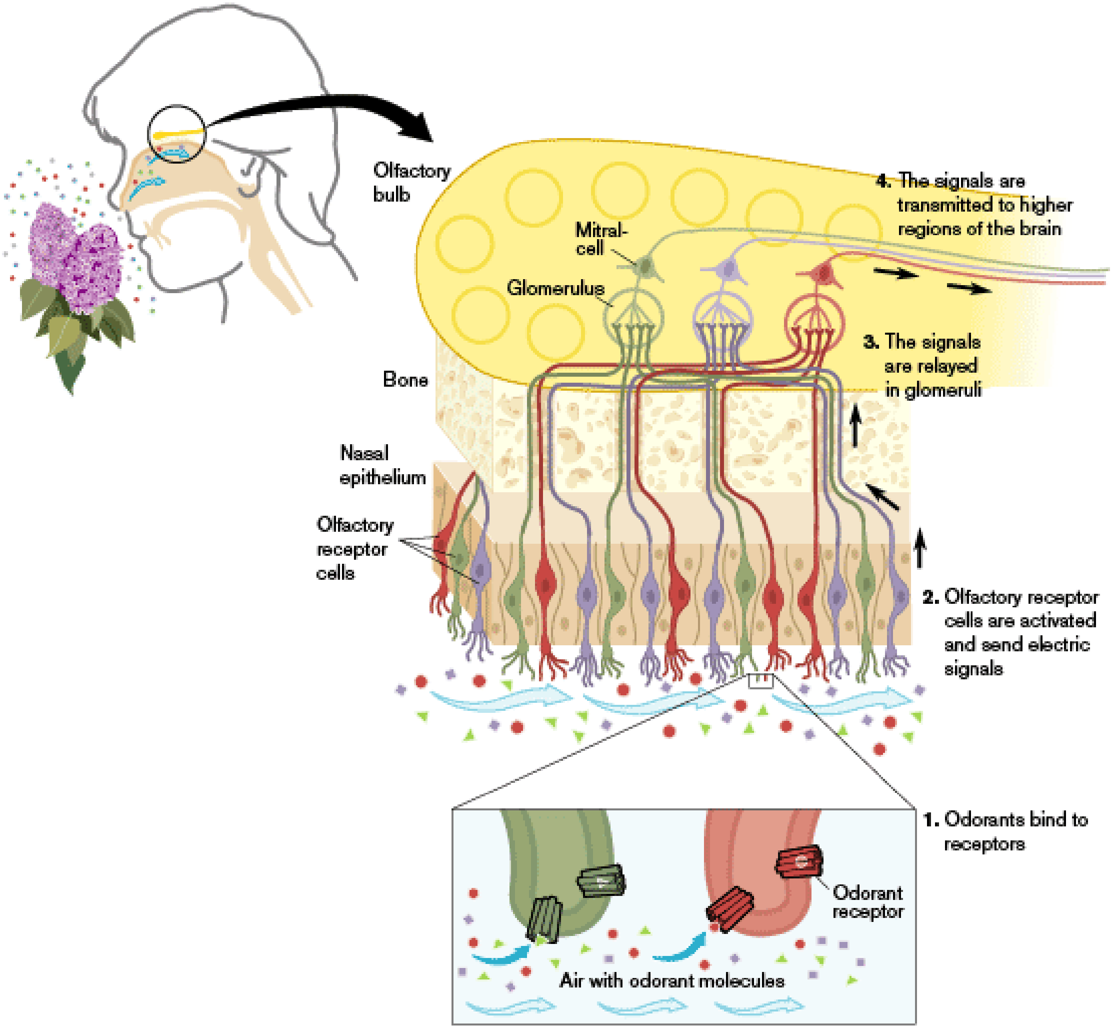


Figure 2-1: The olfactory system of humans

Source: Axel and Buck, 2004

2.3 Odorous substances

Odor is a sensation caused by odorant molecules dissolved in air. The widest ranges of odors consist of organic substances although some are inorganic substances (Glindemann et al., 2006). Generally, organic substances are chemical compounds based on carbon chains or rings and containing hydrogen (with or without oxygen; nitrogen; or other elements), whereas inorganic substances are chemical compounds that do not contain carbon as the principal element (except carbonates; cyanides; and cyanates) that is, matter other than plant or animal (Spencer et al., 2004).

In this study, data of nine chemical substances were collected, consisting of seven organic substances, i.e., n-butyl acetate, methanol, methyl mercaptan, propionic acid, styrene, toluene, xylene, and two inorganic substances, i.e., ammonia, and hydrogen sulfide. The details of these nine chemical substances (except IUPAC, chemical name, synonyms, molecular formula, structural formula, family and toxicity to human see Appendix A) are as follows:

2.3.1 Ammonia

2.3.1.1 Chemical identification

Ammonia is an alkaline and colorless gas, with a pungent odor (PCD, 2001) with the chemical and physical properties as shown in Table 2-2.

Table 2-2: Chemical and physical properties of ammonia

Properties	Information
Physical state	Gas
Color	Colorless
Odor	Pungent
Molecular weight	17.031
Boiling point (°C)	-33.35
Melting point/Freezing point (°C)	-77.7
Flash point (°C)	26.1
Autoignition temperature (°C)	527
Specific gravity (water = 1)	0.6819
Vapor density (air = 1)	0.579
Viscosity (mPa.sec)	-
Vapor pressure (mmHg)	5,900 at 20°C
Solubility in water (gm./100 ml)	-
pH	11.6

Source: PCD, 2001

2.3.1.2 Productions and trade

Ammonia gas is produced industrially by reacting hydrogen and nitrogen at high temperature and pressure. This reaction is known as the Haber-Bosch process (Pritchard, 2006a). The quantity of anhydrous ammonia imported from foreign countries during 2002-2005 is shown in Table 2-3.

Table 2-3: Quantity of anhydrous ammonia imports during 2002-2005

Year	Quantity (Tons)
2002	252,334.90
2003	236,766.30
2004	298,022.40
2005	289,385.30

Source: Customs Department, 2006

2.3.1.3 Uses

The primary use of ammonia gas in industry is as a direct application in fertilizers, plastics and the manufacture of explosives (ATSDR, 1990), and refrigerants (CARB, 1999).

2.3.2 n-Butyl acetate

2.3.2.1 Chemical identification

The chemical, n-Butyl acetate is an ester compound, liquid, colorless, with a pungent ester-like or fruity odor (PCD, 2001) with the chemical and physical properties as shown in Table 2-4.

Table 2-4: Chemical and physical properties of n-butyl acetate

Properties	Information
Physical state	Liquid
Color	Odorless
Odor	Pungent ester-like or fruity odor
Molecular weight	116.18
Boiling point (°C)	126
Melting point/Freezing point (°C)	-77
Flash point (°C)	26
Autoignition temperature (°C)	425
Specific gravity (water = 1)	0.88
Vapor density (air = 1)	4
Viscosity (mPa.sec)	0.69
Vapor pressure (mmHg)	15 at 25°C
Solubility in water (gm./100 ml)	0.7 at 20°C
pH	-

Source: PCD, 2001

2.3.2.2 Production and trade

The compound, n-Butyl acetate, is produced by a nucleophilic addition reaction during slow distillation of acetic acid and the corresponding butyl alcohol in the presence of sulphuric acid as a catalyst (Zaleski, 1992). The quantity of n-butyl acetate imported from foreign countries during 2002-2005 is shown in Table 2-5.

Table 2-5: Quantity of n-butyl acetate imports during 2002-2005

Year	Quantity (Tons)
2002	14,011.40
2003	12,468.30
2004	18,502.40
2005	12,505.60

Source: Customs Department, 2006

2.3.2.3 Uses

The chemical, n-Butyl acetate, is used in the cosmetics industry as a solvent in nail polish, base coats, nail polish removers and other preparations for manicuring (Toy, 1989); in the food industry as a component in synthetic flavors, as a component used in articles used for food packaging, and also as a diluents for dyes in inks for marking vegetables and fruits; in the production of artificial leather, shoes and leather glues, photographic films, plastics, and safety glass; and in the pharmaceutical industry as an extracting (Zaleski, 1992).

2.3.3 Hydrogen sulphide

2.3.3.1 Chemical identification

Hydrogen sulphide is a, colorless gas, with a rotten egg odor (PCD, 2001) with the chemical and physical properties as shown in Table 2-6

Table 2-6: Chemical and physical properties of hydrogen sulphide

Properties	Information
Physical state	Gas
Color	Colorless
Odor	Rotten eggs
Molecular weight	34.04

Table 2-6: Chemical and physical properties of hydrogen sulphide (continued)

Properties	Information
Boiling point (°C)	-60.2
Melting point/Freezing point (°C)	-85.7
Flash point (°C)	-
Autoignition temperature (°C)	290
Specific gravity (water = 1)	1.45
Vapor density (air = 1)	1.21
Viscosity (mPa.sec)	-
Vapor pressure (mmHg)	-
Solubility in water (gm./100 ml)	Soluble
pH	4.5 at 20°C

Source: PCD, 2001

2.3.3.2 Production and trade

Hydrogen sulfide is produced as a by-product in petroleum industries, and can be produced by reacting dilute sulfuric acid with iron sulfite; heating hydrogen and sulfur in the vapor phase; heating sulfur with paraffin; etc (Beauchamp et al., 1984). Hydrogen sulfide was not imported from foreign countries during 2002-2005 except in 2004, which about 0.9 tons was imported.

2.3.3.3 Uses

Hydrogen sulfide is used as an intermediate in the manufacture of sulfuric acid and inorganic sulfides, (such as; thiophenes; thiols; thioaldehydes and thioketone) and also used in leather processing (World Health Organization, 1981). It can be used as a disinfectant in agriculture (NICNAS, 1995).

2.3.4 Methanol

2.3.4.1 Chemical identification

Methanol is aliphatic alcohol, liquid, colorless and with a faint alcohol-like odor (PCD, 2001) with the chemical and physical properties as shown in Table 2-7.

Table 2-7: Chemical and physical properties of methanol

Properties	Information
Physical state	Liquid
Color	Colorless
Odor	Faint alcohol-like odor
Molecular weight	32
Boiling point (°C)	64.6
Melting point/Freezing point (°C)	-97.8
Flash point (°C)	12.2
Autoignition temperature (°C)	464
Specific gravity (water = 1)	0.79
Vapor density (air = 1)	1.1
Viscosity (mPa.sec)	-
Vapor pressure (mmHg)	96 at 20°C
Solubility in water (gm./100 ml)	Soluble at 20°C
pH	-

Source: PCD, 2001

2.3.4.2 Production and trade

Originally distilled from wood, methanol is now manufactured synthetically from carbon oxides and hydrogen (OEHHA, 1999). The quantity of methanol imported from foreign countries during 2002-2005 is shown in Table 2-8.

Table 2-8: Quantity of methanol imports during 2002-2005

Years	Quantity (Tons)
2002	236,382.70
2003	264,388.70
2004	312,671.40
2005	361,999.80

Source: Customs Department, 2006

2.3.4.3 Uses

Methanol is used in a variety of industrial applications. Its largest use is as a raw material for the production of methyl t-butyl ether (MTBE), a gasoline additive. It is also used in the production of formaldehyde, acetic acid, chloromethanes, methyl methacrylate, methylamines, dimethyl terephthalate, and as a solvent or antifreeze in paint strippers, aerosol spray paints, wall paints, carburetor cleaners, and car windshield washer compounds (U.S. EPA, 1994).

2.3.5 Methyl mercaptan

2.3.5.1 Chemical identification

Methyl mercaptan is a colorless gas, with a distinct odor (PCD, 2001) which has chemical and physical properties as shown in Table 2-9.

Table 2-9: Chemical and physical properties of methyl mercaptan

Properties	Information
Physical state	Gas
Color	Colorless
Odor	Special odor
Molecular weight	48.11
Boiling point (°C)	6
Melting point/Freezing point (°C)	0
Flash point (°C)	-50
Autoignition temperature (°C)	-
Specific gravity (water = 1)	0.9
Vapor density (air = 1)	1.7
Viscosity (mPa.sec)	-
Vapor pressure (mmHg)	1,292 at 20°C
Solubility in water (gm./100 ml)	2.3 at 20°C
pH	1.7

Source: PCD, 2001

2.3.5.2 Production and trade

Methyl mercaptan is produced commercially by the reaction of hydrogen sulfide with methanol (ATSDR, 1992). Methyl mercaptan was not imported during 2002-2005.

2.3.5.3 Uses

Methyl mercaptan is used as an intermediate chemical in the production of jet fuel, certain pesticides, plastics, the synthesis of the amino acid methionine, and to add odor to certain odorless hazardous gases (ATSDR, 1992).

2.3.6 Propionic acid

2.3.6.1 Chemical identification

Propionic acid is carboxylic acid, liquid, colorless, and with a pungent odor (PCD, 2001) with the chemical and physical properties as shown in Table 2-10.

Table 2-10: Chemical and physical properties of propionic acid

Properties	Information
Physical state	Liquid
Color	Colorless
Odor	Pungent
Molecular weight	74.08
Boiling point (°C)	141
Melting point/Freezing point (°C)	-21
Flash point (°C)	52
Autoignition temperature (°C)	495
Specific gravity (water = 1)	0.99
Vapor density (air = 1)	2.56
Viscosity (mPa.sec)	-
Vapor pressure (mmHg)	2.4 at 20°C
Solubility in water (gm./100 ml)	100
pH	2.5 at 20°C

Source: PCD, 2001

2.3.6.2 Production and trade

Propionic acid is produced as a by-product in acetic acid processes. Industrially, propionic acid is usually made from the air oxidation of propionaldehyde. In the presence of cobalt or manganese ions, this reaction proceeds rapidly even at mild temperatures. Usually, the industrial process is carried out at 40-50°C (Wikipedia, 2007). The quantity of propionic acid imported from foreign countries during 2002-2005 is shown in Table 2-11.

Table 2-11: Quantity of propionic acid imports during 2002-2005

Year	Quantity (Tons)
2002	408.8
2003	268.1
2004	502.2
2005	367.4

Source: Customs Department, 2006

2.3.6.3 Uses

Propionic acid inhibits the growth of mold and some bacteria. Accordingly, most propionic acid produced is used as a preservative for both animal feed and food for human consumption, and it can be used as a preservative for Ballistics Gel. For animal feed, it is used either directly or as ammonium salt. In human foods, especially bread and other baked goods, it is used as sodium or calcium salt. Similarly, in the U.S.A., it is found in some of the older anti-fungal foot powders (Wikipedia, 2007).

2.3.7 Styrene

2.3.7.1 Chemical identification

Styrene is aromatic hydrocarbon, liquid, colorless, and with a special odor (PCD, 1998b) with the chemical and physical properties as shown in Table 2-12.

Table 2-12: Chemical and physical properties of styrene

Properties	Information
Physical state	Liquid
Color	Colorless
Odor	Special odor
Molecular weight	104.15
Boiling point (°C)	145
Melting point/Freezing point (°C)	-31
Flash point (°C)	31
Autoignition temperature (°C)	489
Specific gravity (water = 1)	0.91
Vapor density (air = 1)	3.6
Viscosity (mPa.sec)	-
Vapor pressure (mmHg)	5 at 20°C
Solubility in water (gm./100 ml)	< 0.1%
pH	-

Source: PCD, 2001

2.3.7.2 Production and trade

Styrene is produced commercially by the reaction of benzene and ethylene in petroleum processes (PCD, 1998b). The quantity of styrene imported from foreign countries during 2002-2005 is shown in Table 2-13.

Table 2-13: Quantity of styrene imports during 2002-2005

Years	Quantity (Tons)
2002	78,565.6
2003	88,785.6
2004	100,918.0
2005	89,062.2

Source: Customs Department, 2006

2.3.7.3 Uses

Styrene is used as a monomer for polystyrene, synthetic rubber, and styrofoam. It is used in food packaging, intermediate of chemical substances such as; butadiene-styrene rubber and acrylonitrile-butadiene-styrene (ABS), and used as a solvent (PCD, 1998b).

2.3.8 Toluene

2.3.8.1 Chemical identification

Toluene is an aromatic hydrocarbon, liquid, with a sweet-smell or benzene like-odor but toxicity less than benzene (PCD, 1998a) with the chemical and physical properties as shown in Table 2-14.

Table 2-14: Chemical and physical properties of toluene

Properties	Information
Physical state	Liquid
Color	Colorless
Odor	Benzene like-odor or sweet-smell
Molecular weight	92.13
Boiling point (°C)	110.6
Melting point/Freezing point (°C)	-126
Flash point (°C)	6
Autoignition temperature (°C)	535

Table 2-14: Chemical and physical properties of toluene (continued)

Properties	Information
Specific gravity (water = 1)	0.87
Vapor density (air = 1)	3.2
Viscosity (mPa.sec)	0.59
Vapor pressure (mmHg)	22 at 20°C
Solubility in water (gm./100 ml)	0.054 - 0.058
pH	-

Source: PCD, 2001

2.3.8.2 Production and trade

Toluene is produced as a by-product in petrochemical and coal processes (PCD, 1998a). The quantity of toluene imported from foreign countries during 2002-2005 is shown in Table 2-15.

Table 2-15: Quantity of toluene imports during 2002-2005

Years	Quantity (Tons)
2002	207.00
2003	78.90
2004	40,091.30
2005	28,616.30

Source: Customs Department, 2006

2.3.8.3 Uses

Toluene is used as a solvent in various industries such as, medicine, chemical substances, synthetic rubber, and plastics. It is used as an intermediate of synthetic chemical processes, as a cleaning agent, a thinner for paint, and found in paints, varnishes, and small amounts in airplane fuel and gasoline (PCD, 1998a).

2.3.9 Xylene

2.3.9.1 Chemical identification

Xylene is an aromatic hydrocarbon, liquid, colorless, with a sweet-smell. Commercially, xylene is a mixture of three isomers, o-xylene about 30 %; m-xylene about 60-70 %; and p-xylene about 5 % (PCD, 1998a). The chemical and physical properties of xylene are shown in Table 2-16.

Table 2-16: Chemical and physical properties of xylene

Properties	Information
Physical state	Liquid
Color	Colorless
Odor	Sweet-smelling
Molecular weight	106.16
Boiling point (°C)	138.3
Melting point/Freezing point (°C)	30
Flash point (°C)	26.1
Autoignition temperature (°C)	527
Specific gravity (water = 1)	0.87
Vapor density (air = 1)	3.7
Viscosity (mPa.sec)	0.62 - 0.81
Vapor pressure (mmHg)	6.72 at 21°C
Physical state	0.13
pH	-

Source: PCD, 2001

2.3.9.2 Production and trade

Xylene is produced in the process of refining coal tar and petroleum (PCD, 1998c). The quantity of xylene imported from foreign countries during 2002-2005 is shown in Table 2-17.

Table 2-17: Quantity of xylene imports during 2002-2005

Years	Quantity (Tons)
2002	11,431.30
2003	13,764.00
2004	11,270.20
2005	27,241.70

Source: Customs Department, 2006

2.3.9.3 Uses

Xylene is used as an intermediate in plastics and synthetic fiber industries. It is used as a thinner for paint, a solvent and in rubber, solvents, emulsifiers, and pesticides. It is used as raw material in the production of benzoic acid, phthalic anhydride, and isophthalic and terephthalic acids. It is found in small amounts in airplane fuel and gasoline (PCD, 1998c).

2.3.10 Standards for toxicity control of nine odorous substances

In this study, standards for toxicity control of nine odorous substances were collected: ammonia, n-butyl acetate, hydrogen sulfide, methanol, methyl mercaptane, propionic acid, styrene, toluene and xylene. The standards for toxicity control in Thailand and foreign country are as follows.

1) Notification of the Ministry of Interior: safety in airborne workplaces (chemical substances) on 30 May B.E. 2520 (1977) determining the airborne chemical concentration in workplace should not exceed limit of concentration. If airborne chemical concentration is over the limit of concentration, those workplaces should reduce the airborne chemical concentration below limit of concentration.

2) Occupational safety standards called the Threshold Limit Values (TLVs) were created by the American Conference of Governmental Industrial Hygienists (ACGIH) and used as guidelines or recommendations to control airborne chemical concentrations in the workplace, which may or may not control directly.

The details of two standards for toxicity control of nine odorous substances are shown in Table 2-18.

Table 2-18: Airborne workplace exposure limits for nine chemical substances

Chemical substances	Notification of Ministry of Interior B.E. 2520 (1977) [g]					ACGIH [h]		
	Concentration of chemical substances in Table 1 [a] (ppm)	Concentration of chemical substances in Table 2 [b] (ppm)	Concentration of chemical substances in Table 3 [c] (ppm)			TLV – STEL[d] (ppm)	TLV – TWA[e] (ppm)	TLV – C[f] (ppm)
			concentration during a normal work	concentration during a short period of time	concentration maybe allowed			
Ammonia	50	-	-	-	-	35	25	-
n-Butyl acetate	-	-	-	-	-	200	150	-
Hydrogen sulfide	-	-	-	50 (10 min)	20	15	10	-
Methanol	200	-	-	-	-	250	200	-
Methyl mercaptan	-	10	-	-	-	-	0.5	-
Propionic acid	-	-	-	-	-	15	10	-
Styrene	-	-	100	600 (5 min / 3 hrs)	200	100	50	-
Toluene	-	-	200	500 (10 min)	-	150	50	-
Xylene	100	-	-	-	-	150	100	-

Notes:

a) Table 1 means an arithmetical mean value of concentration of the chemical substances in the airborne workplace during a normal work that should not exceed the limit of concentration.

b) Table 2 means the concentration of chemical substances in the airborne workplace during any part of the work shift that should not exceed the limit of concentration.

c) Table 3 means the concentration of chemical substances in the airborne workplace (concentration during a normal work, maximum concentration during a short period of time, and concentration maybe allowed) that should not exceed the limit of concentration.

d) TLV – STEL means the maximum concentration to which workers can be exposed for a short period of time (15 minutes) for only four times throughout the day with at least one hour between exposures.

e) TLV – TWA means the time weighted average airborne chemical concentration for a normal eight hour work day and a 40 hour work week to which nearly all workers may be repeatedly exposed, day after day, without adverse effect.

f) TLV – C means The Ceiling exposure limit; the concentration that should not be exceeded during any part of the work shift.

g) Notification of Ministry of Interior: safety in airborne workplace (chemical substances) on 30 May B.E.2520 (1977)

h) ACGIH, 2003

2.4 The principle of odor measurements

Odor can be measured by two methods, i.e., (1) analysis of odor-causing substances (measuring odorant concentration) and (2) sensory test method (using sensory abilities of humans in odor measurement) (TIAER, 1994). Details of the two methods are summarized below:

2.4.1 Analysis of odor-causing substances

Sweeten (1995) summarized the research on a number of techniques for the measurement of specific odorous gases such as ammonia, including gas chromatography (differential adsorption), mass spectrometry (light spectrum differentiation), packed bed chemical-specific syringe tubes, ammonia absorption traps, and electronic sensors, etc. These techniques can provide concentrations of specific odorous gases relative to their threshold limit value (TLV) in parts per million (ppm) and odor threshold in parts per million (ppm).

2.4.2 Sensory test method

An odor is defined as a sensation resulting from the reception of a stimulus by the olfactory sensory system. The way the human response to an odor is evaluated depends on the particular sensory property that is being measured, including detectability, intensity, character, and hedonic tone of the odor (DEC, 2002). The details of the particular sensory properties all of four types are as follows:

2.4.2.1 Odor detectability or odor threshold

Odor detectability or threshold is a sensory property referring to the minimum concentration that produces an olfactory response or sensation. This threshold is usually determined by an odor panel consisting of a specified number of people. The numerical result is typically expressed as occurring when 50 percent of the panel correctly detects the odor (DEC, 2002). It can be divided into two types as follows (Panitch, 2004):

1) Detection threshold is defined as the lowest concentration of odorant substance that 50 percent of the panel correctly detects the odor. This

threshold relates to detection of the odor but might not necessary relate to a recognized odor.

2) Recognition threshold is defined as the minimum concentration that 50 percent of the panel recognizes as having a characteristic odor quality.

2.4.2.2 Odor intensity

Odor intensity is the strength of the perceived odor sensation. It is related to the odorant concentration. If the odorant substance has a high concentration, the perceived intensity is high as well. The relationship between odorant concentration and odor intensity can be explained by Weber-Fechner Law and Stevens' Power Law (VDI 3882 BL. 1, 1992 and AS/NZS, 2001).

1) Weber-Fechner Law

$$\Delta I = \frac{k.\ \Delta S}{S}$$

If integration

$$dI = \frac{k.\ dS}{S}$$

$$I = k \int \frac{1}{S} ds$$

$$I = k \log (S) + \text{constant}$$

Where:
I = Odor intensity
k = Constant
S = Perceived intensity of sensation

2) Stevens' Power Law

$$I = k_s (S)^n$$

$$\text{Log } I = n\text{Log}(S) + \text{Log } K_s \text{ [Logarithmic transformation]}$$

Where:
I = Odor intensity
k_s = Constant
S = Perceived intensity of sensation
n = the exponent

2.4.2.3 Odor character

Odor character or quality is that property that identifies an odor and differentiates it from another odor of equal intensity. The odor character is described by a method known as multidimensional scaling or profiling. In this method, the odor is characterized by either the degree of its similarity to a set of reference odors or the degree to which it matches a scale of various descriptor terms. The result is an odor profile. (DEC, 2002)

2.4.2.4 Hedonic tone

Hedonic tone is a property of an odor relating to its pleasantness or unpleasantness. A distinction should be made between the acceptability and the hedonic tone of an odor. When an odor is evaluated in the laboratory for its hedonic tone in the neutral context of an olfactometric presentation, the panelist is exposed to a controlled stimulus in terms of intensity and duration. The degree of pleasantness or unpleasantness is determined by each panelist's experience and emotional associations (DEC, 2002).

2.5 Odor control standards and odor measurements in Thailand and foreign countries

2.5.1 Odor measurements in Thailand

The determination of odor concentration in Thailand is stated in the Ministerial regulation of the Ministry of Industry: Standard and measurement of odor in air from the factory B.E. 2548 (2005) which complies with the methods of the American Society for Testing and Materials (ASTM) or Japanese Industrial Standard (JIS). Details are summarized as follows:

2.5.1.1 Determination of Odor Thresholds by a Forced Choice Ascending Concentration Series Method of Limits of American Society for Testing and Materials (ASTM) (ASTM, 1997)

1. Summary practice

1.1 A series of test odor samples is prepared by dispersing the substance whose threshold is to be determined in clean air. This concentration scale should increase in geometric increments so that any two adjacent concentration steps are separated by a constant factor. At each concentration step, two blank samples consisting of clean air only are made available to the panelist. The blank and test samples are encoded so that there is no visual, audible, tactile, or thermal difference between the samples other than code designators.

1.2 The panelist starts at the lowest concentration step, which should be two or three concentration steps below the estimated threshold. Each sample within the set of three is compared with the other two.

1.3 The panelist indicates which of the three samples is different from the other two. A choice must be made, even if no difference is noted, so that all data can be utilized.

1.4 Individual best-estimate values of threshold are derived from the pattern of correct/incorrect responses produced separately by each panelist. Group thresholds are derived by geometrical averaging of the individual best-estimate thresholds.

2. Significance and Use

2.1 Odor thresholds are used to determine the potential of substances at low concentrations to impart odor to some matter.

2.2 Odor thresholds are used, for example, in setting limits for air pollution, in water treatment, and in food science and technology.

2.3 Odor thresholds are used to characterize and compare the sensitivity of individuals or groups to a given stimuli.

3. Preparation of concentration scale

3.1 The concentration levels of the test substance in clean air should begin well below the level at which the most sensitive panelist is able to detect or recognize the added substance, and end at (or above) the concentration at which all panelists give a correct response.

3.2 The increase in concentration of the test substance per scale step should be by a constant factor. It is desirable to obtain a scale step factor that will allow the correct responses of a group of nines panelists to distribute over three to four concentration steps (see 8). This will allow more accuracy in determining the odor threshold valued base on the geometric mean of the individual panelists.

3.3 Good judgment is required by the person in charge in order to determine the appropriate scale step range for a particular substance. This might involve the preparation of an approximate threshold concentration of the odorous substance in clean air of choice. The concentration of the substance may be increased two to three times for odorants depending on how the perceived intensity of odor varies with the concentration of the substance providing the sensory response. Thus, if x represents an approximate odor threshold concentration, then a series of concentration steps would appear as follows if a step factor of “3” were used:

…x/27, x/9, x/3, x, 3x, 9x, 27x,…

3.4 In actual practice, the various concentrations are obtained by starting at the highest concentration and diluting three times per step, thus providing a series of dilution factors, “Vi” being the initial volume:

…729Vi, 243Vi, 81Vi, 27Vi, 9Vi, 3Vi, Vi,...

3.5 At each selected concentration or dilution, a 3-AFC sample set, consisting of one test and two blank samples, is presented to panelists in indistinguishable fashion. It is desirable to have all samples prepared and ready for judging before the evaluation session begins.

3.6 If the samples are arranged in a left-center-right, or an above-center-below order, care must be taken that the test sample is presented in one third of the presentations in the left (top) position, one third in the center position, and one third in the right (bottom) position to eliminate positional bias.

3.7 If only one sample at a time is available, the test and blank samples may be presented one after another in units of three presentations, with the test sample being randomized to be the first, the second, and the third, and requesting the response after all three samples in the set have been presented. Better results, however, are obtained if the test and the two blank samples are available for a direct comparison, so that the panelist may sniff back and forth at ease until a decision is reached.

4. Judgment procedure

4.1 The panelist begins judging with that set, which contains the test sample with the lowest concentration (highest dilution) of the odorous substance, taking the time needed to make a selection, and proceeds systematically toward the higher concentrations.

4.2 Within each set, the panelist indicates that sample which is different from the two others (detection threshold) or which exhibits a recognizable odor of the substance (recognition threshold). If the panelist cannot readily discriminate, a guess must be made so that all data may be utilized.

4.3 The judgments are completed when the panelist either (1) completes the evaluation of all sets of the scale, or (2) reaches a set wherein the test sample is correctly identified, then continues to choose correctly in higher concentration test sample sets.

5. Data evaluation

5.1 The series of each panelist's judgments may be expressed by writing a sequence containing (0) for an incorrect choice or (+) for a correct choice arranged in the order of judgments of ascending concentrations of the added substance.

5.2 If the concentration range has been correctly selected, all panelists should judge correctly within the range of concentration steps provided. Thus, the representation of the panelists' judgments as in 5.1 should terminate with two or more consecutive plusses (+).

5.3 Because there is a finite probability that a correct answer will occur by chance alone, it is important that a panelist continues to take the test until there is no doubt by that person of the correctness of the choice.

5.4 The best-estimate threshold concentration for the panelist is then the geometric mean of that concentration at which the last miss (0) occurred and the next higher concentration designated by a (+).

5.5 The panel threshold is the geometric mean of the best-estimate threshold of the individual panelist is desired, it may be obtained by calculating the geometric mean of the best-estimate threshold of all series administered to that person.

6. Report

6.1 Successful completion of the foregoing procedure provides either detection or recognition threshold of the substance in clean air in accordance with this practice.

6.2 The threshold value is in concentration or dilution units appropriate for the substance tests.

6.3 For enhanced understanding of the threshold results, the following information is recommended:

Threshold of:
Procedure: ASTM Practice E 679 (Rapid Method)
Presentation:
Number of scale steps:
Dilution factor per step:
Temperature of samples:
Panelist selection:
Number of times test given:
Type of threshold (detection or recognition):
Best-estimate threshold:
  Individual:
  Panel:

6.4 Refer to 8 for an example of the calculation required and reporting.

7. Precision and Bias

7.1 Because odor threshold values are functions of odor sample presentation variables and of individual sensitivities, interlaboratory tests cannot be interpreted statistically in the usual way, and a general statement regarding precision and bias of thresholds obtained by this practice cannot be made. However, certain comparisons made under particular circumstances are of interest and are detailed below.

7.2 When four panels of 23-35 members evaluated butanol in air, the ratio of the highest to the lowest panel threshold was 2.7 to 1; when the same panel repeated the determination on four days, the ratio was 2.4 to 1. For 10 panels of 9 members evaluating hexylamine in air, the ratio was 2.1 to 1.

7.3 When 14 laboratories determined the threshold of purified hydrogen sulfide in odorless air, the ratio of the highest to the lowest laboratory threshold was 20 to 1. Interlaboratory tests with dibutylamine, isoamyl alcohol, methyl acrylate and a spray thinner for automobile paint gave somewhat similar results from this practice, the results are comparable.

7.4 A discussion of the likely bias of results by this practice compared to a true threshold can be found in references.

8. Example

8.1 The odor threshold of an odorous air sample was to be determined.

8.2 Six difference concentrations of the odorous sample in air were prepared. Each of these was presented in conjunction with two samples of non odorous air. The concentrations were increased by a factor of three per concentration step. Nine randomly selected panelists participated. Each proceeded from the lower to higher concentrations. At each concentration level, panelists compared the three samples—two blanks and one diluted odorous sample—and indicated which sample was different from the other two.

8.3 The following results were obtained (see Table 2-19).

8.4 Details of calculation are as follow:

8.4.1 For panelist 1, the best-estimate threshold is $\sqrt{135 \text{ x } 45}$ = 78, or at a dilution by a factor of 78 (one volume of the odorous air sample diluted with non odorous air to occupy 78 volumes in total). For panelist 2, the threshold is at $\sqrt{125 \text{ x } 405}$ = 701.

8.4.2 Panelist 4 missed at the highest concentration, where the dilution is only by a factor of 15. It is assumed that he would have been correct at a higher concentrations level, where the dilution would have been a factor 15/3 = 5.

Table 2-19: Example of ASTM odor threshold determination

Panelists [1]	Judgments [A]							
	Dilution Factors						Best-estimate threshold (BET)	
	(Concentrations increase—>)						Value	Log$_{10}$ of Value
	3,645	1,215	405	135	45	15		
1	0	+	+	0	+	+	78	1.89
2	+	0	+	+	+	+	701	2.85
3	0	+	0	0	+	+	78	1.89
4	0	0	0	0	+	0	9	0.94
5	+	0	0	+	+	+	234	2.37
6	+	+	+	+	+	+	6,313	3.80
7	0	+	+	0	+	+	78	1.89
8	+	0	0	+	+	+	234	2.37
9	+	0	+	+	+	+	701	2.85
Group BET geometric mean							∑log10 →	20.85
							209 ←	2.32
Standard deviation								0.81

Notes: [A] “0” indicates that the panelist selected the wrong sample of the set of the set of three.

“+” indicates that the panelist selected the correct sample.

[1] This example has been selected to represent both extremes. Panelist 4 missed even at the highest concentration. Panelist 6 was correct even at the lowest concentration and continued to be correct at all subsequent higher concentrations.

8.4.3 Consequently, an estimate of his threshold is $\sqrt{15 \text{ x } 5} = 9$. The underlying assumption is that since the thresholds of the other panelists were within the presented scale range, his threshold should not be far away from the range if he belongs to the same statistical population. If the test were to establish the sensitivity of the panelists, this panelist would have been retested, with a scale range extended to the right of the results in Table 2-19.

8.4.4 Panelist 6 represents the opposite extreme. The estimate is based on the assumption that a miss would have occurred at a dilution of 3 x 3,645 = 10,935; the best-estimate thresholds from two adjacent valued in the table.

8.4.5 In Table 2-19, dilutions change exactly by a factor of three per scale step. Experimentally, small deviations from such equal spacing occur, and the actual dilutions or concentrations should be used in calculating the best-estimate thresholds from two adjacent values in the table.

8.5 Report—The report shall include the following information:

Odor threshold: Odorous Air Sample XX
Procedure: ASTM Practice E 679
Presentation: at 500 ml/min (dynamic dilution olfactometer)
Number of scale steps: 6
Dilution factor per step: 3
Temperature: 25°C (room and samples)

Panelist selection: random
Number of panelists: 9
Type of threshold: detection
Best-estimate threshold:
$Z_{OL} = 209$
$\mathrm{Log}_{10} Z_{OL} = 2.32$
Standard log deviation = 0.81

Note. 8.1—The symbol Z represents a dilution factor proposed to designate a dimensionless measure of sample dilution needed to reach some target effect (10)[5]. For threshold work, the subscript “OL” represents the dilution at which the odor reaches a limit that corresponds to the best-estimate threshold.

2.5.1.2 Olfactory measurement method of Japanese Industrial Standard (JIS) (Ministry of the Environment (MOE), 2002c)

1) Requirements for location and environment of sensory test room are as follow:

1.1) The room with a ventilation system, no odor, and a quiet location with little human traffic.

1.2) The room should not be a location that has odors which would affect the sensory test.

1.3) The room where panelists cannot see the sample preparation.

1.4) The temperature and humidity of the test room be adequately maintained. The temperature should be 17-25°C. It would also be preferable to maintain the relative humidity of the room at a range between 40 to 70%.

2) Qualification of panelists

2.1) Panelists are 18-60 years old and in good health.

2.2) Panelists must pass the sensory screening test and it must confirm that a person maintains normal olfaction by carrying out the above test every five years (every three years for people over 40 years old).

2.3) Panelists must not drink and smoke.

2.4) Panelists must not be persons who live near where the samples to be tested were collected because he may not sense the odor.

3) Screening panelist

3.1) Equipment, apparatus, and chemical substance

3.1.1) Smelling strip (14 cm long x 7 mm wide)

3.1.2) Holders for smell strip

3.1.3) Five standard odor solutions and liquid paraffin, shown in Table 2-20

Table 2-20: The details of five standard odor solutions

No.	Standard odor solutions	Standard Concentration for Panel Selection (w/w)	Odor characteristic
A	β-Phenylethyl alcohol ($C_9H_{10}O$)	$10^{-4.0}$	Floral smell
B	Methyl cyclopentenolone ($C_6H_1O_2$)	$10^{-4.5}$	Sweet burning smell
C	Isovaleric acid ($C_5H_{10}O_2$)	$10^{-5.0}$	Smell of stuffy socks
D	γ-Undecalactone ($C_{11}H_{20}O_2$)	$10^{-4.5}$	Smell of ripe fruit
E	Skatole (3-Methyl indole) (C_9H_8N)	$10^{-5.0}$	Smell of feces

Note: five standard odor solutions must be kept below 10°C and before use must be kept in normal temperature about 1-2 hours.

Sources: Ministry of the Environment (MOE) of Japan, 2002c

3.2) Olfactory test procedures

3.2.1) a set of five strips of test paper, marked with the numbers 1 to 5 (14 cm long x 7 mm wide, hereinafter called the "smelling strip"), are prepared. These smelling strips are clipped to or inserted into holders for the test.

3.2.2) the top 1 cm of any two smelling strips out of the above five smelling strips are soaked in one standard odor solution. The remaining three smelling strips are soaked in the odor-free liquid paraffin (commercially available odor-free liquid) in order to avoid being distinguished by sight. Be careful that any liquids do not drip in doing so.

3.2.3) a set of five smelling strips are handed to the subjects, who then sniff these smelling strips. Subjects are to sniff the smelling strips one by one, and check for the presence of odor. Subjects sniff an odor by putting their nose close to, but not touching, the tip of a smelling strip. After sniffing the odor of all the smelling strips, subjects answer by giving the numbers of the two smelling strips with odor. If they cannot distinguish the odors, they can sniff the smelling strips a second time. Subjects are not to give answers verbally, but are to write their answers on the answer sheet.

3.2.4) Smelling strips are to be discarded after each test. Since discarded smelling strips may leave some odors in the test room, they should be thrown away in a lidded wastebasket, or placed in a plastic bag and sealed before being thrown away in a wastebasket.

3.2.5) a person who answers correctly for all of the five standard odors has successfully passed the olfactory test.

4) Sensory Test

4.1) Equipment, apparatus, and chemical substance

4.1.1) Pump for supplying air has a flow rate 30 L/min. It is necessary for this pump to be odor-free, such as a diaphragm pump or carbon plate pump.

4.1.2) Odor-free air distributor with nine cocks consisting of an activated carbon tank, filter, and distributor.

4.1.3) Glass syringes, which are used to inject a sample from the sampling bag to odor bag.

4.1.4) Odor bags equipped with a glass tube with an inner diameter of about 10 mm, an external diameter of about 12 mm, and length of 6 cm should be odor free and have low adsorption and low permeability. Its inner volume should be 3 L.

4.1.5) A sniffing mask should be connected to the glass tube of an odor bag and should be structured to cover the nose. Sniffing masks made of rigid polyvinyl chloride are commercially available.

4.1.6) Silicone plug no. 03 is used as a stopper for the odor bag.

4.2) Procedures for the Sensory Test

Taking the fatigue of the panel into account, the maximum number of samples which can be measured in one day is 10 to 14 (4 to 6 samples in the morning, 6 to 8 samples in the afternoon).

4.2.1) Preparation of the odor bag

4.2.1.1) Fill the activated carbon in odor-free air distributor with nine cocks and connect it with pump by silicone tube.

4.2.1.2) Using the pump for supplying odor-free air, inject odor-free air into the odor bag until it is almost full, and seal the bag by using a silicone rubber stopper (No. 03). At this point, approximately 3 L of air is in the bag. It is also necessary to thoroughly replace air that has lingered in the bag previously with the odor-free air.

4.2.1.3) To make one of the odor bags of the fixed dilution ratio, take one of the odor bags filled with odor-free air (three bags per person), and use a syringe to inject a fixed amount of the undiluted odor from the sampling bag through the top of the label. If a syringe with a large-holed needle is used for the injection, seal off the hole of the injection needle with adhesive tape to prevent the sample air from escaping.

4.2.1.4) For the other two odor bags filled with only odor-free air, open a hole from the top of the label in the same way, using only a needle. If a large-holed needle is used, seal off the hole of the injection needle with adhesive tape. This is to avoid the panel from realizing that only the odor bag injected with the undiluted odor has a needle hole, and thus, being able to identify the bag with odor.

4.2.1.5) Give one set, consisting of a total of three bags — one odor bag with odor and two odor bags without odor — as prepared in this way, to the panel. In the sample preparation room, the operator must correctly record the numbers of the odor bags with odor that is given to the panel.

4.3) Sensory test

The first dilution ratio of the exhaust port sample should be high enough so that the panel can adequately determine the presence of odor. The panel gets three odor bags and puts a sniffing mask on the odor bags given to them (4.2.1.5), removes the silicone rubber stoppers, and sniffs the odor. The fundamentals of sniffing is to press one's face against the sniffing mask tightly so that there is no space, and sniff the odor inside the bag in line with one's own breathing. The panel must fully understand that air that has been inhaled is not to be exhaled into the bag again and gives the number of one bag out of the three that has an odor. Answers are not submitted verbally but are always written down on the answer sheet. In this selection operation, for the panel members who are able to correctly select the odor bag with odor, another selection operation is conducted, with the dilution ratio at about threefold the first dilution ratio (30-fold, 100-fold, 1,000-fold, etc.) as shown in Table 2-21. For the panel members who are successful in this selection operation, another selection operation is conducted, with a set of odor bags further diluted about threefold. In this manner, selection is performed with odor bags gradually diluted approximately threefold. The dilution ratio at which an individual panel member's answer is incorrect or unclear is the point at which the sensory test is complete for that person. The test is conducted in this manner until all of the panel member answer incorrectly (or answer "unclear"). In addition, if the test is continuing when only one panel member has answered correctly, it is acceptable to finish testing at this point.

Table 2-21: Dilution ratio to be prepared and the amount of sample to be injected

Injected amount	Dilution ratio
300 ml	10
100 ml	30
30 ml	100
10 ml	300
3 ml	1,000
1 ml	3,000
300 µl	10,000
100 µl	30,000
30 µl	100,000

4.4) Calculation of odor concentration

4.3.1) Exhaust port samples have very high concentrations, so samples from this place must be diluted with the dilution ratio at about threefold the first dilution ratio (30-fold, 100-fold, 1,000-fold, 3,000-fold, etc.). Calculating the odor concentration of the exhaust port sample as follow:

First, calculate the threshold value of each panel member in the following equation.

$$Xa = \frac{\log(a1) + \log(a2)}{2}$$

Xa = Threshold value of panel member a

a1 = The largest dilution ratio at which panel member a answered correctly

a2 = The dilution ratio at which panel member a answered incorrectly, or was not able to give a clear answer.

1) From Xa, eliminate the largest and smallest values and the mean of the values for the other four persons is the threshold value X (common logarithm indication) of the overall panel.

2) Odor concentration = 10^x

Table 2-22: Example of JIS odor threshold determination

Panelists	**Dilution ratio**							**Threshold of every panelist**	**Omitted Largest & smallest**
	Dilution ratio	**30**	**100**	**300**	**1,000**	**3,000**	**10,000**		
	log	**1.48**	**2.00**	**2.48**	**3.00**	**3.48**	**4.00**		
A		O	O	X				2.24	X
B		O	O	O	X			2.74	
C		O	O	O	X			2.74	
D		O	O	O	O	O	X	3.74	X
E		O	O	X				2.24	
F		O	O	O	O	X		3.24	

Notes: 1) O = Correct

2) X = Incorrect

3) ^ = Unable to select or guess

$$\text{Threshold of Panelist A} = X_a = \frac{\log(a1) + \log(a2)}{2}$$

$$= \frac{\log 300 + \log 200}{2}$$

$$= \frac{2.48 + 2.00}{2}$$

$$= 2.24$$

After calculating the threshold value for each panel member, eliminate the largest and smallest values, and calculate the mean value for the rest of the values. In other words, in this figure, panel member D has the largest value, and panel members A and E have the smallest value. When these values are eliminated, the mean value of the four remaining panel members is calculated as

$$X = \frac{2.74 + 2.74 + 2.24 + 3.24}{4} = 2.74$$

$$\text{Odor concentration} = 10^{x} = 10^{2.74} = 550$$

2.5.2 Odor control standards in Thailand

In the past, laws and standards for odor control in Thailand have not been established directly but are hidden in laws and regulations of emission control standards and nuisance control laws. Examples of laws and standards for odor control in Thailand are summarized as follows: (Panitch et al., 2004).

2.5.2.1 The Factory Act, B.E. 2535 (1992) with the Ministry of Industry has the power to control air pollution.

1) Adopt the standards and methods of controlling the discharge of waste, pollutants or anything that effects the environment as a result of the engagement in a factory business.

2) Adopt the required information relating to the engagement in a factory business of which a person engaging in a factory business must inform, from time to time or in a specified period.

Furthermore, Notification of the Ministry of Industry (No.4) enforces the factory business to remove odor, noise, vibration, dust, smoke, and ash as a result of the engagement in a factory business to the level that should not damage or cause harm to the nearby community.

2.5.2.2 The Enhancement and Conservation of the National Environmental Quality Act, B.E. 2535 (1992) with the Pollution Control official has the authority to set environmental quality standards, ambient air quality standards, standards set by the Provincial Governor in special case for the pollution control area, and can be fined for compensation from polluter.

2.5.2.3 The Public Health Act, B.E. 2535 (1992), which has air pollution laws related to the nuisance, include three sections as follows:

Section 25 (4) determine any action, which causes odor, light, ray, noise, heat, toxic substance, and thereby causing impairment or likely being harmful to health.

Sections 26 and 27, local official shall have powers to forbid to cause of a nuisance in a public place or way or private place and also to abate nuisance. In this connection, the local official shall have powers to issue written orders to abate, eliminate, and control sources of nuisance.

2.5.2.4 The Labour Protection Act, B.E.2541 (1998) is the Act set to protect labourers who work in the area, in which a person engaging in a factory must maintain air quality in the working area, to be safe to the worker.

2.5.2.5 Ministerial regulation of Industry: Standard and measurement of odor in air from factory B.E. 2548 (2005). This Ministerial regulation is the first standard for controlling odor in industry. Table 2-23 shows details of odor control standards.

Table 2-23: Standards for odor concentration in air from factory in Thailand

Location of factory	**Odor concentration at ground level along the boundary line of the factory**	**Odor concentration in stack**
Inside industrial area	30	1,000
Outside industrial area	15	300

Notes:

a) Odor concentration means the dilution ratio of odorant air sample with odor-free air until becoming odorless. Higher odor intensity yields higher odor concentration because it must be diluted with a higher volume of odor-free air. Sensory test is used for analysis.

b) Inside industrial area means the areas that are established to land utilization for industrial areas according to the city plan law, or the Thailand industrial estate law, or industrial area of the Industry law.

c) Outside industrial area means other areas excluding the industrial area.

2.5.3 Odor control standards and odor measurements in foreign countries

The documents for odor standards and odor measurements in foreign countries will emphasize odor control from production processes within industries. Standards will include both the odorant concentration and odor concentration. Furthermore, odor controls in foreign countries include odor control at source and boundaries of companies as follows:

2.5.3.1 Odor control standards and odor measurements in Japan

1) Odor measurements in Japan

In Japan, a typical of odor measurement consists of the analysis method of chemical compounds (instrumental method) and sensory methods, which are summarized as follows:

1.1) Analysis method of chemical compounds (instrumental method), analysing the odorant concentration with instruments including gas chromatograph, UV/Vis-Spectrophotometer, gas chromatography/mass spectrometer (GC/MS), detection tube, etc., which use control odorant concentration according to the standard of offensive odor substances.

1.2) Sensory method measures odor concentration with olfactory perception to control odor concentration according to the standard of odor index. An example of this method is the triangular odor bag method, dynamic olfactometer, subjective direct indication, etc. Table 2-24 shows the procedure for the triangular odor bag method in Japan.

Table 2-24: Procedure for triangular odor bag method in Japan

Procedure	Details
Selection of panel	- Test is conducted using five standard odorants to choose a group of persons without olfaction abnormalities as the panel.
Sampling	- Measurement of the odor index is conducted indoors, using samples from the site in question. - Sampling from the location where the smell is most intense.
Performance of sensory test	- Conducted by at least six members of the panel. - Each panel is given three bags (with a sample in it and two odor-free air). - Panel chooses the correct bag (bag with odor).
Calculation	- The odor index is calculated using the statistics equation, and disregarding the extraneous data.

Source: Ministry of Environment (MOE) of Japan, 2002b

2) Odor control standards in Japan

In the present, Japan establishes laws to control odor nuisance and improve odor nuisance having two types as follows:

2.1) Standard of offensive odorous substances of all 22 compounds substances, the range of this established standard is determined to be equivalent to 2.5-3.5 of odor intensity as shown in Table 2-25.

Table 2-25: National ambient air standards of offensive odorous substances in Japan

Odorous substances	Chemical formula	Range of concentration (ppm)
Ammonia	NH_3	1-5
Methyl mercaptan	CH_3SH	0.002-0.01
Hydrogen sulfide	H_2S	0.02-0.2
Dimethyl sulfide	$(CH_3)_2S$	0.01-0.2
Dimethyl disulfide	$(CH_3)_2S_2$	0.009-0.1
Trimethylamine	$(CH_3)_3N$	0.005-0.07
Propionic acid	C_2H_5COOH	0.03-0.2
Normalbutyric acid	$CH_3CH_2CH_2COOH$	0.001-0.006
Normalvaleric acid	$(CH_3)_2CHCH_2COOH$	0.0009-0.004
Isovaleric acid	$CH_3(CH_2)_3COOH$	0.001-0.01
Acetaldehyde	CH_3CHO	0.05-0.5
Propionaldehyde	CH_3CH_2CHO	0.05-0.5
Butyraldehyde	$CH_3(CH_2)_2CHO$	0.009-0.08
Isobutyraldehyde	$(CH_3)_2CHCHO$	0.02-0.2
Valericaldehyde	$C_5H_{10}O$	0.009-0.05
Isovaleraldehyde	$(CH_3)_2CHCH_2OH$	0.003-0.01
Isobutyl alcohol	$(CH_3)_2CHCH_2OH$	0.9-20
Ethyl acetate	$C_4H_8O_2$	3-20
Methyl isobutyl ketone	$C_6H_{12}O$	1-6
Toluene	C_7H_8	10-60
Styrene	C_8H_8	0.4-2
Xylene	$C_{24}H_{30}$	1-5

Note: Concentrations of the specified offensive odorous substances are measured at the ground surface on the boundary line of a place of business.

Source: Ministry of Environment (MOE) of Japan, 2002a

2.2) The standard of odor index, the range of the regulation standard for odor index, is determined to be equivalent to 2.5-3.5 of odor intensity, the same as the standard of offensive odorous substances. The range of odor index has been found to be 10-21 as shown in Table 2-26.

Table 2-26: The relationship between odor intensity and odor index

Odor intensity	Range of odor index
2.5	10-15
3.0	12-18
3.5	14-21

Note: the survey of the relation between odor intensity and odor index for almost all types of industry

Source: Ministry of Environment (MOE) of Japan, 2002a

2.5.3.2 Odor control standards and odor measurements in the U.S.A.

1) Odor measurements in the U.S.A.

Odor measurements in U.S.A. will refer to the standard method of the American Society for Testing and Materials (ASTM) including ASTM E 679-91 Standard Practice for Determination of Odor Taste Thresholds and ASTM E 544-75 Standard Practices for Referencing Suprathreshold Odor Intensity.

2) Odor control standards in the U.S.A.

Generally, a number of different approaches are commonly used in the U.S.A. to regulate odors.

2.1) General regulatory language prohibits off-site nuisance or annoyance conditions as determined by field inspectors in response to complaints from the public. Some agencies have implemented procedures whereby inspectors rate the intensity of the odor in the field, based on an intensity scale (as Table 2-27). The advantage to this approach is its simplicity and the fact that it is not a theoretical value predicted by a model. One disadvantage for both this approach and the hydrogen sulfide hand-held meter approach is that odor nuisance conditions occur much more frequently in the evening and early morning when regulatory staff are usually not working.

Table 2-27: Intensity scale

Intensity (degree)	**Status**
1	very weak
2	weak
3	distinct
4	strong
5	very strong
6	extremely strong

Source: Mahin, 2002

2.2) Off-site limits are based on levels predicted by dispersion modeling and using the dynamic olfactometry approach with the criteria reported as odor units (OU), OU/m^3 or dilutions/threshold (D/T). The terms D/T, OU/m^3 and OU will be used interchangeably in this paper since they all represent the same concept as Table 2-28.

Table 2-28: Examples of ambient air standards or guideline for odor concentration

Location	**Off-site standard or guideline**	**Average times**
Allegheny County Wastewater Treatment Plant (WWTP)	4 D/T (design goal)	2-minutes
San Francisco Bay Area Air Quality District	5 D/T	Applied after at least 10 complaints within 90-days
State of Colorado	7 D/T (Scentometer)	
State of Connecticut	7 D/T	
State of Massachusetts	5 D/T*	
State of New Jersey	5 D/T **	5-minutes or less
State of North Dakota	2 D/T (Scentometer)	
State of Oregon	1 to 2 D/T	15-minutes
City of Oakland, CA	50 D/T	3-minute
City of San Diego WWTP	5 D/T	5-minutes
City of Seattle WWTP	5 D/T	5-minutes

Note: * draft policy and guidance for composting facilities

** for biosolids/sludge handling and treatment facilities

Source: Mahin, 2002

2.3) Establishing the standard for control emission of odorous substances from industries stack such as Bay Area Pollution Control District, California as Table 2-29.

Table 2-29: Maximum allowable emission of odorous substances

Substance	Maximum allowable emission (ppm)	
	Type A[a] Emission point	**Type B[b] Emission point**
Trimethylamine [$(CH_3)_3N$]	0.02	0.01
Phenolic compounds calculated as phenol [C_6H_5OH]	5.0	2.5
Mercaptans calculated as Methyl mercaptan [CH_3SH]	0.2	0.1
Ammonia [NH_3]	5,000	2,500
Dimethylsulfide [$(CH_3)_2S$]	0.1	0.005

Note: [a] A well-defined emission point such as a stack or vent or a diffuse source

[b] B ground level emission

Source: Leonardos, 1974

2.4) Best available control technology (BACT) or similar approaches that specify required levels of odor treatment controls for new or upgraded large facilities.

2.5) The American Society of Agricultural Engineering (ASAE) document Engineering Practice 379.1 “Control of Manure Odors” recommends setbacks from livestock facilities of 0.4 to 0.8 km for neighboring residences and 1.6 km to residential development.

2.6) The use of ambient air limits for individual compounds such as hydrogen sulfide as used in the state of Minnesota (see Table 2-30). The existence of so many different odorous compounds associated with waste water treatment plants (WWTPs) and particularly most livestock operations creates serious potential problems when using individual compounds as the basis for assessing odors. In addition, detection and odor annoyance thresholds cited in the literature and in regulations vary widely for compounds such as hydrogen sulfide.

Table 2-30: Examples of ambient air standards for odor causing compounds

Location	Compounds	Ambient Odor Standards
California	Hydrogen sulfide	30 ppbv* (1-hour average)
Connecticut	Hydrogen sulfide	6.3 µg/m^3
	Methyl mercaptan	2.2 µg/m^3
Idaho	Hydrogen sulfide	10 ppbv (24 hour average) 30 ppbv (30 minutes average)
Minnesota	Hydrogen sulfide	30 ppbv (30 minutes average)** 50 ppbv (30 minutes average)***
Nebraska	Total reduced sulfur	100 ppb (30 minutes average)
New Mexico	Hydrogen sulfide	10 ppbv (1 hour average) or 30 - 100 ppbv (30 minutes average)
New York State	Hydrogen sulfide	10 ppbv (14 µg/m3) 1-hour average
New York City	Hydrogen sulfide	1 ppbv (for wastewater plants)
North Dakota	Hydrogen sulfide	50 ppbv (instantaneous, two readings 15 min. apart)
Pennsylvania	Hydrogen sulfide	100 ppbv (1 hour average) 5 ppbv (24 hour average)
Texas	Hydrogen sulfide	80 ppbv (30 minutes avg.) - residential/commercial & 120 ppbv - industrial, vacant or range lands

Notes: * - parts per billion by volume

** - not to be exceeded more than 2 days in a 5-day period

*** - not to be exceeded more than twice per year

Source: Mahin, 2002

2.5.3.3 Odor control standards and odor measurements in Korea

1) Odor measurements in Korea

In Korea, three major methods of odor analysis include direct sensory test, air dilution method, and chemical compound of analysis, which are summarized below.

1.1) The direct sensory test has been major measurements and uses measurement at the boundary of companies including the enclosures (the details of this method are shown in Table 2-31). The direct sensory test was not effective in analyzing the cause of odor in wide-open spaces of industrial complexes and outlets, which cause highly-intensified odor.

Table 2-31: Direct sensory test method

Intensity (degree)	Status
0	None
1	Threshold
2	Moderate
3	Strong
4	Very strong
5	Excessively strong

Source: Park, 2002

1.2) Air dilution sensory test method should be measured at the boundary of companies including the enclosures, same as the direct sensory test, but this method was effective in analyzing the cause of the odor. Table 2-32 shows details of air dilution sensory test method.

Table 2-32: Procedure for air dilution sensory test method in Korea

Procedure	Details
Sampling	- 3 ~ 20 Liter/ less than 5 minutes. - use the teflon sampling bag.
Prepare odor free air	- Prepare odor free air.
Panelist screening test	- test the olfactory sensibility using four standard odors. - more than five persons. - wait for the test for ten minutes. - stop the negative effective activity of the test.
Perform the sensory test	- prepare diluted odor samples using odor free air (dilution ratio 3, 10, 30, 100, 300 times, etc …) by the method of descending series. - prepare odor samples which consisting of two bags filled with odor-free air and one odor-injected bag and keep the break period to maintain the olfactory sensibility after the first phase of the test.
Calculation of odor using the sensory test results	- calculate the odor concentration using the statistical equation, and disregard the extraneous data.

Source: Park, 2002

1.3) The analysis method of chemical compounds (instrumental method) analyses the odorant concentration with instruments following on Table 2-33.

Table 2-33: Instruments for analysis of odor-containing compounds

Compounds	Instruments
Ammonia	UV-Spectrophotometer
Hydrogen sulfides, Methyl mercaptan Dimethyl sulfide, Dimethyl disulfide	GC-FPD
Trimethyl amine	GC-FID
Acetaldehyde	GC-FID
Styrene	GC-FID

Source: Park, 2002

2) Odor control standards in Korea

Odor control standards in Korea are established in atmospheric and environmental protection laws, which have three odor control standards. The details of odor control standards are summarized in Table 2-34.

Table 2-34: Analysis and permission level of odor in Korea

Methods of odor analysis	Criteria for permission level of odor release		
Direct sensory test	Odor Intensity : less than 2 degrees		
Air dilution sensory test	A. Outlets including stack (a) Companies in industrial area: less than 1,000 OC (b) Companies in other areas: less than 500 OC B. Boundaries of companies including enclosures (a) companies in industrial areas: less than 20 OC (b) companies in other areas: less than 15 OC		
Chemical compound analysis using GC or UV	**Compounds**	**in industrial areas**	**in other areas**
	Ammonia	less than 2 ppm	less than 1 ppm
	methyl mercaptane	less than 0.004 ppm	less than 0.002 ppm
	Hydrogen sulfide	less than 0.06 ppm	less than 0.02 ppm
	Dimethyl sulfide	less than 0.05 ppm	less than 0.01 ppm
	Dimethyl disulfide	less than 0.03 ppm	less than 0.009 ppm
	Trimethyl amine	less than 0.02 ppm	less than 0.005 ppm
	Acetaldehyde	less than 0.1 ppm	less than 0.05 ppm
	Styrene	less than 0.8 ppm	less than 0.4 ppm
	propionaldehyde	less than 0.1 ppm	less than 0.05 ppm
	n -butyl aldehyde	less than 0.03 ppm	less than 0.009 ppm
	i-butyl aldehyde	less than 0.07 ppm	less than 0.02 ppm
	n -valeric aldehyde	less than 0.02 ppm	less than 0.009 ppm
	i -valeric aldehyde	less than 0.006 ppm	less than 0.003 ppm

Source: Park, 2002

2.6 Related research works on the relationship between odorant concentration and odor intensity

2.6.1 The study of relationships between odorant concentration and odor intensity in Japan (Nagata et al., 2006)

Nagata et al. (2006) studied the relationship between odorant concentration and odor intensity within an odorless chamber, which was built from stainless steel. It encased 4 m^3 of volume and had sniffing windows as shown in Figure 2-2.

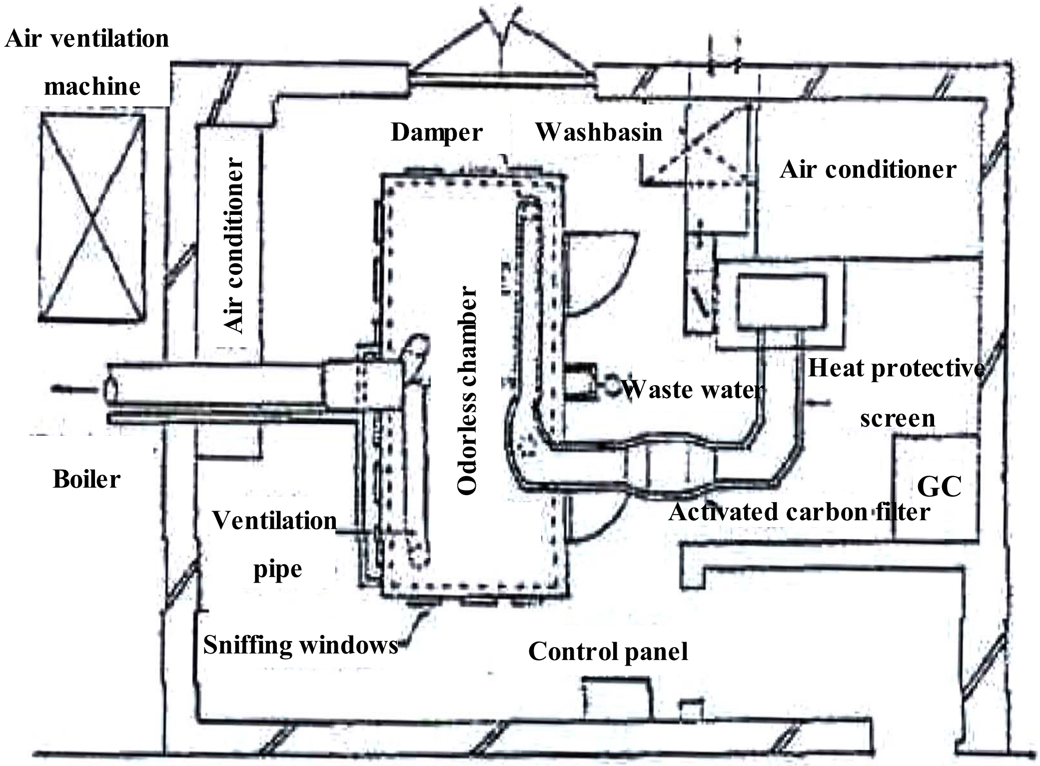


Figure 2-2: Design of odorless chamber

Source: Nagata et al., 2006

Odorant substances are measured with panelists, who include mainly perfumers and staff of this laboratory. After the gas sample is prepared in the odorless chamber with fix a concentration, all six panelists shall assess odor intensity (following Table 2-35) at the sniffing windows. For each assessment, panelists will inhale about 1-4 times, which demands about 2-8 seconds. The result of the assessment of each panelist is written on the answer sheet. After finishing each assessment, panelists move to a waiting room until a new test starts.

Table 2-35: Definitions of odor intensity in Japan

Odor intensity	Odor definitions
0	No odor
1	Barely traceable
2	Faint but identifiable
3	Easily detectable
4	Strong odor
5	Repulsive

Source: Nagata et al., 2006

Analysis of variance (ANOVA) was conducted to determine the study relationship between odorant concentration and odor intensity in Japan. The results showed that the relationship between odorant concentration and odor intensity of each odorous substance can be displayed by logarithm linear regression of concentration (with significant differences at p-value $\leq$ 1%) corresponding to the Weber-Fechner logarithmic equation as follows.

$$I = K_1 \log(C) + K_2$$

Whereas: I = Odor intensity

C = Odorant concentration

K_1, K_2 = Constant

The details of the relationship equation of all chemical substances are studied and examples of the relationship between odorant concentration and odor intensity in Japan are shown in Table 2-36 and 2-37, respectively.

Table 2-36: Constants of the relationship equation between odorant concentration and odor intensity for each odorant

Odorous compounds	**Relation I = a log (C) + b**		**Odorous compounds**	**Relation I = a log (C) + b**	
	a	**b**		**a**	**b**
Methyl mercaptan	1.25	5.99	Methyl acetate	2.17	-0.864
Ethyl mercaptan	0.808	4.86	Isovaleric acid	1.09	5.65
Ethyl sulfide	1.08	4.69	Isobutyric acid	1.43	5.08
Dimethyl disulfide	0.985	4.51	n-Butyric acid	1.16	5.66
Dimethyl sulfide	0.784	4.06	Propionic acid	1.46	5.03
Hydrogen sulfide	0.950	4.14	m-Cresol	0.792	4.08
n-Valeric aldehyde	1.36	5.28	o-Cresol	0.826	3.83
n-Butyraldehyde	0.90	4.18	Phenol	1.42	3.74
Propionaldehyde	1.01	3.86	p-Cresol	0.604	3.64
Acetaldehyde	1.01	3.85	Trimethyl amine	0.901	4.56
Acrolein	1.51	3.30	Methyl amine	1.03	4.10
Formaldehyde	1.53	1.59	Dimethyl amine	0.811	3.52
Methyl isobutyl ketone	1.65	2.27	Ammonia	1.67	2.38
Isobutyl alcohol	0.90	2.53	Diethyl amine	1.00	2.52
Methyl ethyl ketone	1.85	0.15	Styrene	1.42	3.10
Ethyl alcohol	0.818	1.36	Isopropyl benzene	1.16	3.12
Acetone	1.01	-1.64	p-Xylene	1.57	2.44
Methanol	1.84	-2.23	o-Xylene	1.66	2.24
Ethyl acrylate	1.26	2.65	m-Xylene	1.46	2.37
n-Butyl acrylate	1.00	4.56	1,2,4-Trimethyl benzene	1.13	2.75
Methyl acrylate	1.30	4.30	1,3,5-Trimethyl benzene	1.11	2.60
Methyl methacrylate	2.05	2.68	Toluene	1.40	1.05
n-Butyl acetate	1.14	2.34	Isobutene	2.04	-0.657
Ethyl acetate	1.36	1.82	Tetrachloro ethylene	1.57	0.583

Source: Nagata et al., 2006

Table 2-37: Examples of the relationship between odorant concentration and odor intensity in Japan

Odorous compounds (ppm)	Odor Intensity						
	1	2	2.5	3	3.5	4	5
Ammonia	0.15	0.59	1.18	2.35	4.68	9.33	37.06
n-Butyl acetate	0.067	0.50	1.38	3.79	10.41	28.58	215.44
Hydrogen sulfide	0.0005	0.0056	0.019	0.063	0.21	0.71	8.04
Methanol	56.94	199.03	372.09	695.65	1,300.56	2,431.47	8,498.61
Methyl mercaptan	0.0001	0.00064	0.0016	0.0041	0.010	0.026	0.16
Propionic acid	0.0024	0.013	0.03	0.069	0.16	0.37	1.90
Styrene	0.033	0.17	0.38	0.84	1.90	4.30	22
Toluene	0.92	4.80	11	25	56	130	660
Xylene	0.11	0.52	1.10	2.30	4.90	10	47

Source: Nagata et al., 2006

2.6.2 Olfactometry: Determination of odor intensity in Germany (VDI 3882 BL. 1, 1992)

The determination of odor intensity is obtained using olfactometry according to Guideline VDI 3882 BL. 1 assigned to panelists who pass screening and not less than eight panelists are employed. The dynamically diluting olfactometer is used for this test which has air supply at the olfactometer outlet (nose mask or sniffing tube) not less than 1.2 m^3/h (0.33 l/s) for breathing at rest and 2.0 m^3/h (0.56 l/s) for sniffing. The instrument shall be so designed that it can easily be cleaned in the event of any contamination due to the odorant-laden gas. Panelists shall assess the odor intensity of the inhaled sample as shown in Table 2-38.

Table 2-38: Definitions of odor intensity in Germany

Odor definitions	Intensity level
Extremely strong	6
Very strong	5
Strong	4
Distinct	3
Weak	2
Very weak	1
Not perceptible	0

Source: VDI 3882 BL. 1, 1992

The results of determination of odor intensity of butanol, menthone, hydrogen sulphide, and guaiacol showed that the relationship between odorant concentration and odor intensity of four odorous substances corresponded to the Weber-Fechner logarithmic equation ($I = K_1 \log(C) + K_2$). The details of relationship equations of each odorous substance and relationship between odorant concentration and odor intensity of four odorous substances are shown in Table 2-39.

Table 2-39: The results of investigations on the odor intensity variations of pure substances in Germany

Odorous substances	Relation I = a log (C) + b		r
	a	b	
Butanol	1.65	-2.24	0.97
Menthone	2.35	-2.24	0.98
Hydrogen sulphide	2.41	0.78	0.90
Guaiacol	2.66	-1.81	0.99

Source: VDI 3882 BL. 1, 1992

CHAPTER III

RESEARCH METHODOLOGY

Procedures of the study on the relationship between odorant concentration and odor intensity of odorous substances in this research study can be described as Figure 3-1.

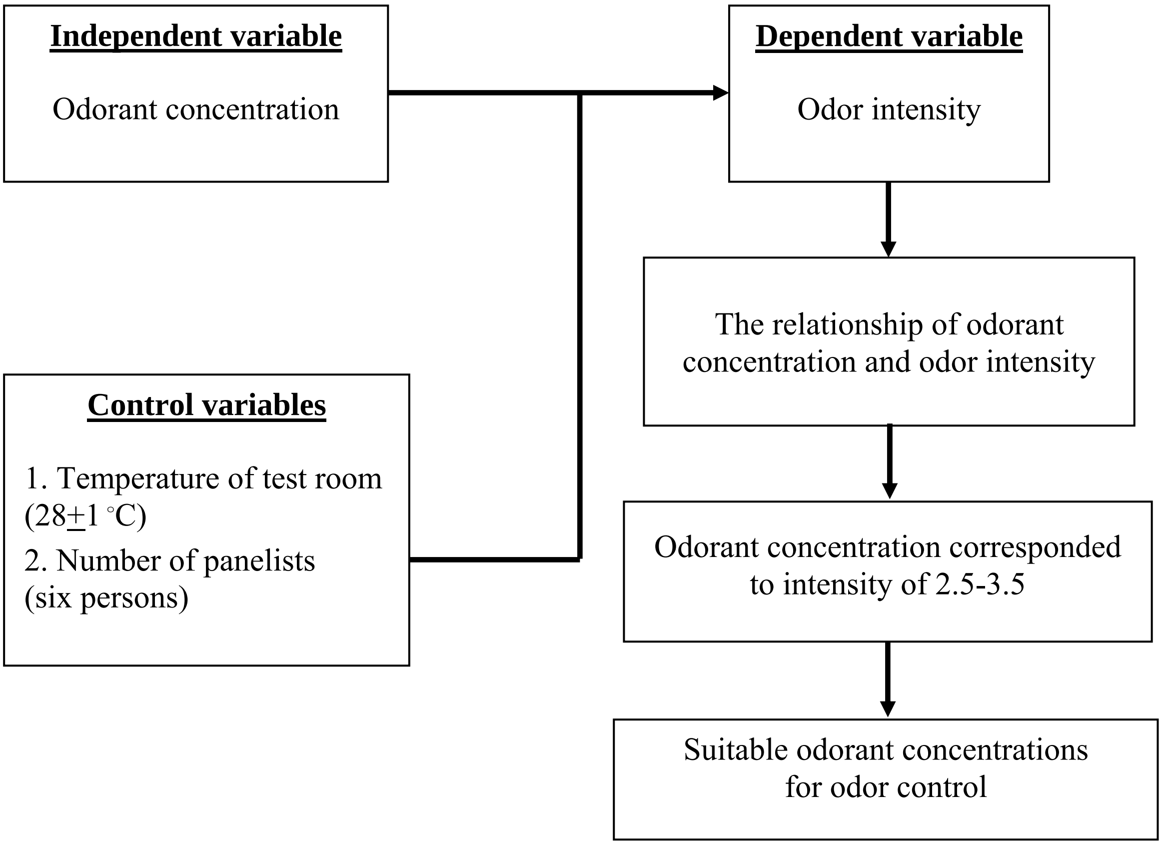


Figure 3-1: Procedures of the study on the relationship between odorant concentration and odor intensity

3.1 Location and environment of the test rooms

3.1.1 Layout of the test rooms

Test rooms in this study consist of three rooms, i.e., Rooms A, B, and C (Figure 3-2) which can be described as follows:

1) Room A was the room where the operator prepared standard odors for panel screening.

2) Room B was the room where panelists sniffed standard odors for panel screening and determination of odor intensity.

3) Room C was the room where operators prepared odorous substance for determination of odor intensity.

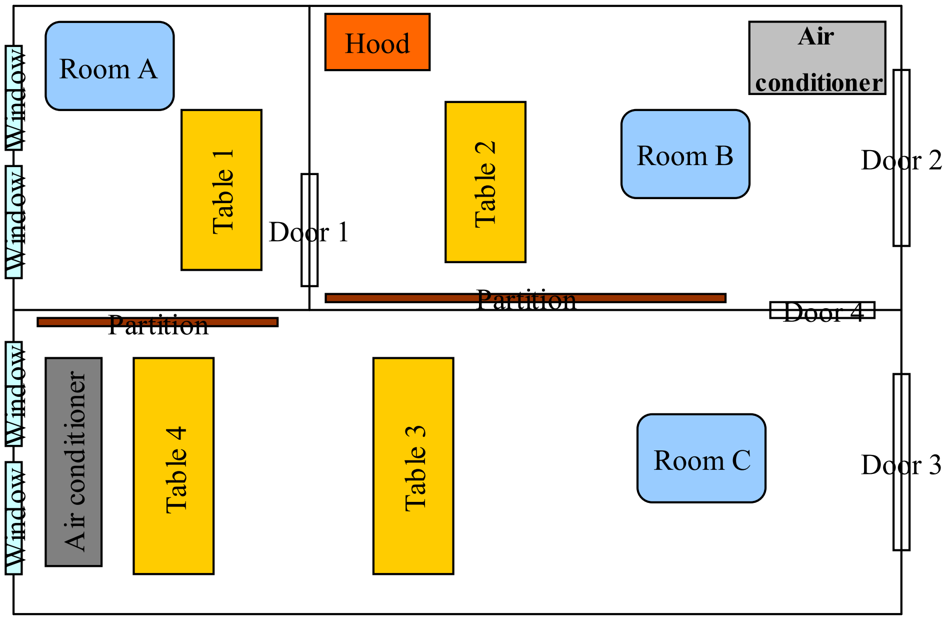


Figure 3-2: Layout of the test rooms

3.1.2 Location and conditions of test rooms

Location and conditions of sensory test rooms can be explained as follows:

1) Location of sensory test room

Test rooms located upstairs and at the edge of the building, accordingly, this area was located far away from human travel, nuisance noise, odor source, etc.

2) Facilities in the sensory test rooms

2.1) had a ventilation system consisting of hood and ventilation windows for air ventilation.

2.2) had an air conditioner, which can control temperature. The temperature in the preparation room and sensory test room was maintained at 28±1°C during sensory test.

2.3) had partitions for preventing the sample preparation from being seen.

2.4) had enough water supplies during sensory test.

2.5) had enough lighting so panelists are not stressed.

2.6) floors and walls of test rooms were constructed of cement and were not tiled with odorant materials (i.e., floor wax, new linoleum, etc.) to maintain free odor during sensory test.

3) Maintenance of test rooms

3.1) cleaning the floor and facilities within test rooms once every two days without odorant detergent.

3.2) no smoking within test rooms, and no strong food or drink odor in the test room although the sensory test had not yet started.

3.3) residual odor must be ventilated after the sensory test was finished each day by opening doors and windows for about 2-3 hours.

3.2 Olfactory test of panelists (Panel screening)

3.2.1 Design of olfactory test room

Olfactory panelists test (Panel screening), rooms include Rooms A and B, in which Room A was the room where the operator prepared standard odors for panel screening and Room B was the room where panelists sniffed standard odors for panel screening as shown in Figure 3-3.

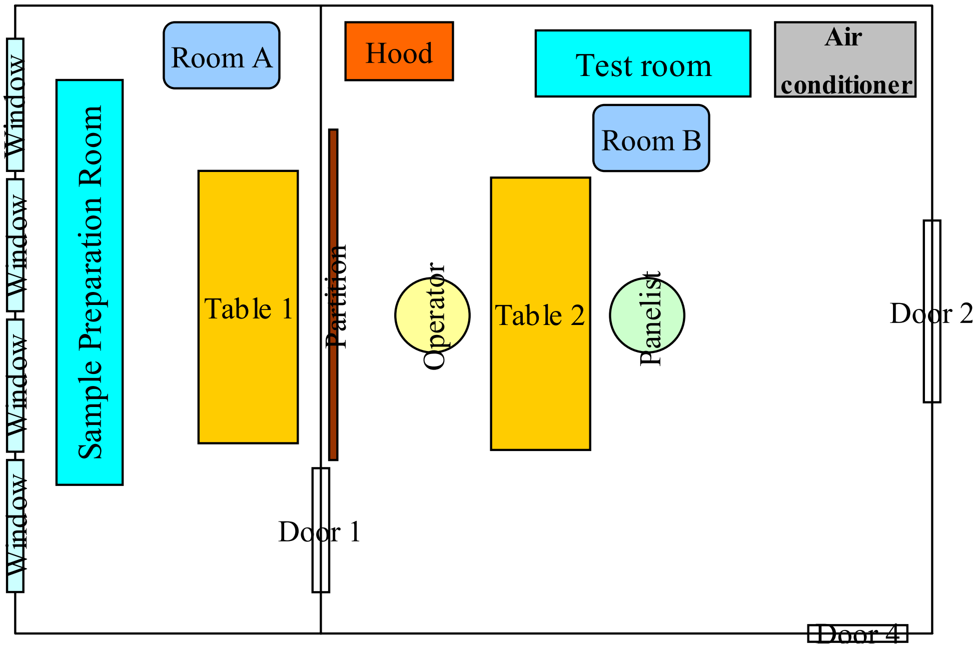


Figure 3-3: Design of the panel screening rooms

3.2.2 Equipment, apparatus, and odorant substance used for screening panelists

1) Smelling strip (14 cm long x 7 mm wide)

2) Holders for smelling strips

3) Five standard odor solutions and liquid paraffin

3.2.3 Procedure of olfactory test of panelists (Panel screening)

The person who assesses standard odors must passed the olfactory test was a panelist. The olfactory test used five standard odor solutions for the test. Details of five standard odor solutions are shown in Table 3-1. The olfactory test procedures are explained as follows:

Table 3-1: Details of five standard odor solutions

No.	Standard Test Odor	Standard Concentration for Panel Selection (w/w)	Odor characteristic
A	β-Phenylethyl alcohol	$10^{-4.0}$	Floral smell
B	Methyl cyclopentenolone	$10^{-4.5}$	Sweet burning smell
C	Isovaleric acid	$10^{-5.0}$	Smell of stuffy socks
D	γ-Undecalactone	$10^{-4.5}$	Smell of ripe fruit
E	Skatole (3-Methyl indole)	$10^{-5.0}$	Smell of feces

Source: Ministry of Environment (MOE) of Japan, 2002c

1) A set of five strips of test paper, marked with the numbers 1 to 5 (14 cm long x 7 mm wide, hereinafter called the "smelling strips"), were prepared. These smelling strips were clipped to or inserted into holders for the test.

2) The top 1 cm of any two smelling strips out of the above five smelling strips was soaked in one standard odor solution. The remaining three smelling strips were soaked in the odor-free liquid paraffin (commercially available odor-free liquid) in order to avoided being distinguished by sight, being careful that any liquid did not drip in doing so.

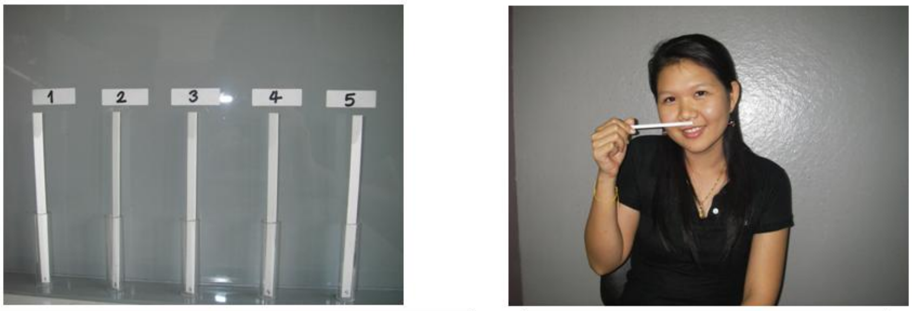
3) A set of five smelling strips were handed to the subjects, who then sniffed these smelling strips. Subjects were to sniff the smelling strips one by one, and checked for the presence of odor. Subjects sniffed an odor by putting their nose close to, but not touching, the tip of a smelling strip. After sniffing the odor of all the smelling strips, subjects answered by giving the numbers of the two smelling strips with odor. If they could not distinguish the odors, they sniffed the smelling strips a second time. Subjects were not to give answers verbally, but were to write their answers on the answer sheet.

4) Smelling strips were to be discarded after each test. Since discarded smelling strips may leave some odors in the test room, they should be thrown away in a lidded wastebasket, or placed in a plastic bag and sealed before being thrown away in a waste bin.

5) A person who answered correctly all of the five standard odors successfully passed the olfactory test. The details of olfactory test procedures are shown in Figure 3-4.

1. Materials for screening panelist

2. Marked smelling strip numbers 1 to 5 in



3. Smelling strip soaked in standard odor solution

4. Panelists sniff smelling strips

Figure 3-4: Steps in olfactory test

3.2.4 Odor panel practices

A person who passed the olfactory test (called "panelist") must obey the odor panel practices (or the assessor's agreement to participate in odor testing) as follows:

1) Performance of panelist prior to sensory test

a) Panelist must be free of colds or physical conditions that may affect the sense of smell

b) Panelist must avoid other fragrances cosmetics, soaps, etc. the day of the odor panel and must have clean hands free of odors the day of the odor panel.

c) Panelist must not wear perfume, cologne, or after shave the day of the odor panel.

d) Panelist must refrain from eating spicy foods prior to the odor panel.

e) Panelist must have their clothes odor free the day of the sensory test.

2) Performance of panelist during sensory test

a) Panelist does not smoke.

b) Panelist must not drink coffee, tea, or soda.

c) Panelist must not chew gum or eat at least one hour prior to the odor panel.

3.3 Determination of odor intensity (Sensory test)

3.3.1 Layout of sensory test

The rooms for the determination of odor intensity included Rooms B and C in which Room B was the room where panelists sniffed odor for the determination of odor intensity and Room C was the room where operators prepared odorous substances for the determination of odor intensity, as shown in Figure 3-5.

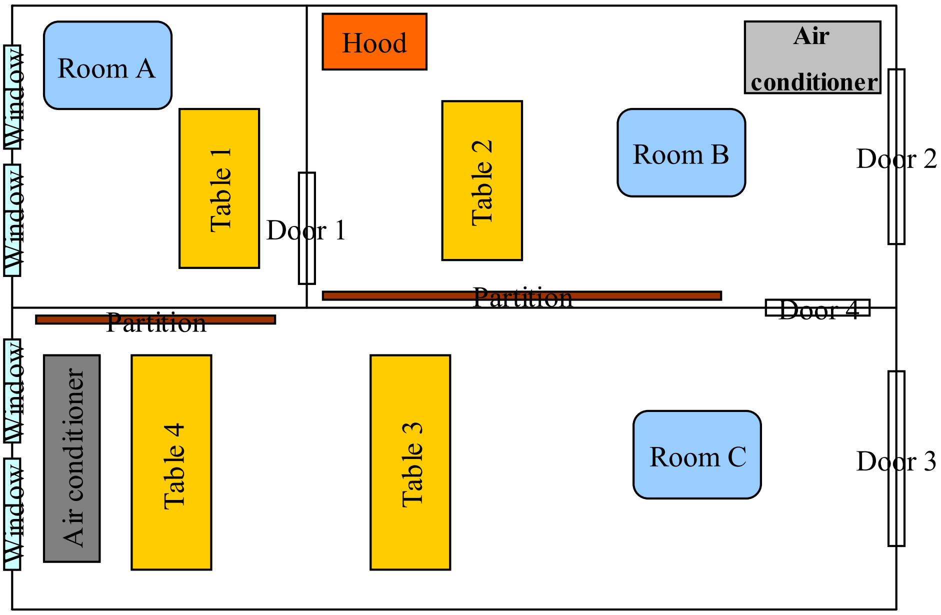


Figure 3-5: Design of the sensory test rooms

3.3.2 Materials, apparatus, and odorous substances

1) Pure odorous substances

1.1) Liquid odorous substances

A. n-Butyl acetate (A.R. Grade)

B. Methanol (A.R. Grade)

C. Propionic acid (A.R. Grade)

D. Styrene (A.R. Grade)

E. Toluene (A.R. Grade)

F. Xylene (A.R. Grade)

1.2) Standard gases

A. Ammonia gas (48.9 ± 1.0 ppm) including pressure regulator and certificate of analysis report from BOC Canada Limited

B. Hydrogen sulphide gas (48.2 ± 4.1 ppm) including pressure regulator and certificate of analysis report from Thai Industrial Gases Public Company Limited

C. Methyl mercaptan gas (47.2 ± 4.1 ppm) including pressure regulator and certificate of analysis report from Thai Industrial Gases Public Company Limited

2) Materials and apparatus for preparation of odor sample

2.1) Odor bag

A. Odor sample bag, volume 20 liters, include rubber stopper

B. Odor test bag, volume 20 liters, include silicone plug no. 03

2.2) Airtight glass syringe

A. Airtight glass syringe volume 200 cc

B. Airtight glass syringe volume 100 cc

C. Airtight glass syringe volume 50 cc

D. Airtight glass syringe volume 20 cc

E. Airtight glass syringe volume 10 cc

F. Airtight glass syringe volume 5 cc

G. Airtight glass syringe volume 1 cc

2.3) Syringe for liquid

A. Syringe for liquid, volume 100 μl

B. Syringe for liquid, volume 10 μl

C. Syringe for liquid, volume 1 μl

2.4) Syringe needles

2.5) Odor-free air distributor with nine cocks consisting of an activated carbon tank, filter, and distributor

2.6) Diaphragm vacuum pump

2.7) Dry test gas meter (Model: DC-1), an apparatus for calibration of air flow rate

2.8) Rotameter (air flow rate at 0-5 liters/minute)

3.3.3 Procedure for the determination of the odor intensity (Sensory test)

Six panelists were used for determination of odor intensity and the concentration of odor samples in odor bag was obtained from calculation. The procedures for the determination of odor intensity are as follows:

3.3.3.1 System for preparation of odorless air

Procedures of odorless air preparation are as follows:

1) Connected the diaphragm vacuum pump and odor-free air distributor (with nine exits) with teflon tube.

2) Connected the odor-free air distributor (with, nine exits) and rotameter with teflon tube.

3) Opened the diaphragm vacuum pump for about 30 minutes before the determination of odor intensity to clear the odorless air system. Figure 3-6 shows the odorless air system.

Figure 3-6: odorless air system

3.3.3.2 Calibration of Air Flow Rate

Procedures for air flow rate calibration are as follows:

1) Connected the diaphragm vacuum pump and odor-free air distributor (with nine exits) with teflon tube.

2) Connected the odor-free air distributor (with nine exits) and dry test gas meter (Model: DC-1) with teflon tube.

3) Connected the dry test gas meter (Model: DC-1) and rotameter with teflon tube.

4) Opened the diaphragm vacuum pump, afterwards, recorded air flow rate from dry test gas meter (Model: DC-1) and rotameter at varied steps of air flow rate. Figure 3-7 shows apparatuses of the air flow rate calibration.

5) Assessed relationship between dry test gas meter (Model: DC-1) and rotameter.

In this research, the air flow rate was calibrated twice (before and after the determination of odor intensity). Actual air flow rate can be obtained from the calibration error plot between the dry test gas meter and the rotameter reading.

Figure 3-7: Apparatuses for calibration of air flow rate

The result of calibrating the air flow rate twice displays the actual air flow rate as show in Table 3-2. Details of calibrating the air flow rate are shown in Appendix B.

Table 3-2: Air flow rate from rotameter compared with the dry test gas meter

Air flow rate (l/min) from rotameter reading	Actual air flow rate (l/min) from dry test gas meter
5.0	5.04
4.9	4.94
4.8	4.84
4.7	4.74
4.6	4.64
4.5	4.53
4.4	4.43
4.3	4.43
4.2	4.23
4.1	4.13
4.0	4.03

3.3.3.3 Preparation for stock concentrations of odor Samples

1) Stock concentrations of odorant samples was prepared in odor sample bags, volume 20 liters (1st dilution), from liquid odorous substances.

1.1) the odor sample bags were washed by filling with odorless air and afterwards deflating the odorless air from the odor sample bag. Repeated 3-4 times and then sniffed the air inside the odor sample bag to confirm that it is odorless.

1.2) filled with odorless air to the volume shown in Table 3-3 and then closed with rubber stopper.

1.3) injected a specified volume of liquid odorous substance as shown in Table 3-3 into the odor sample bag filled with odorless air (1.2). Afterwards, seal off the hole of the injection needle with adhesive tape to prevent the sample air from escaping. Wait for about 45 minutes to allow the whole liquid odorous substance to evaporate into vapor.

1.4) Repeated the above steps (1.1-1.3), but changed the liquid odorous substance to other substances as shown in Table 3-3 (in this research study, six liquid odorous substances were used). Figure 3-8 displays the procedure of stock concentration preparation of odorant sample in the odor sample bag (1st dilution) from liquid odorous substances.

Table 3-3: The details of stock concentration of odor sample prepared in odor bag, volume 20 liters (1st dilution), from liquid odorous substances

No.	**Odorous substances**	**First dilution (odor bag 20 L)**		
		Volume of odorless air (L)	**Volume of liquid (µl)**	**Calculated odorant concentration (ppm) [a]**
1	n-Butyl acetate	20.33	93	858.135
2	Methanol	20.33	826	24,816.932
3	Propionic acid	24.20	8	109.385
4	Styrene	20.33	12	126.878
5	Toluene	20.33	113	1,293.249
6	Xylene	20.33	1	9.926

Note: [a] Calculation method of odorant concentration displayed in Appendix C

1. Injecting the liquid reagent into odor bag, volume 20 liters

2. Wait about 45 minutes or until all liquid chemical reagent evaporates to vapor.

Figure 3-8: Steps in preparation of stock concentration of odorant sample in odor bag, volume 20 liters (1st dilution), from liquid odorous substances

2) Transfer of gaseous odorant standard into an odor sample bag, volume 20 liters

2.1) washed the odor sample bag by filling with odorless air. Afterwards, deflate the odorless air from the odor sample bag. Repeated 3-4 times and then sniffed the air inside the odor sample bag to confirm that it is odorless.

2.2) opened valve of gas cylinder (while the valve of pressure regulator was closed), later on, closed valve of gas cylinder and opened valve of pressure regulator slowly to eliminate residual air in pressure regulator. Then close valve of pressure regulator.

2.3) filled standard gas (as shown in Table 3-4) into an empty odor sample bag by inserting odor bag into pressure regulator outlet. Opened the gas cylinder valve and slowly opened the pressure regulator valve to allow standard gas from the gas cylinder to transfer into the odor sample bag as shown in Figure 3-8. When the odor bag had enough volume, closed the valve of gas cylinder. Wait for the standard gas to empty from the pressure regulator, and then closed valve of the pressure regulator. Take off the odor bag from the pressure regulator and closed the bag with rubber stopper.

2.4) repeated the above steps (2.1-2.3) but changed the standard gas to the next gas as shown in Table 3-4 (in this research study, three standard gases were used). Figure 3-9 displays the transfer of gaseous odorant standard into an odor sample bag, volume 20 liters.

Table 3-4: Concentrations of the three gaseous odorant standards used in this study

No.	Odorous substances	Concentration (ppm)[a]
1	Ammonia	48.9 ± 1.0
2	Hydrogen sulphide	48.2 ± 4.1
3	Methyl mercaptan	47.2 ± 4.1

Note: [a] Certificate of analysis report from BOC Canada Limited and Thai Industrial Gases Public Company Limited (see Appendix D)

1. A cylinder of gaseous odorant standard connected with an odor bag, volume 20 liters

2. Fill odorant standard gas into odor sample bag at a volume of 20 liters

Figure 3-9: Transfer of gaseous odorant standard into an odor sample bag

3) Preparation of odor test sample bag, volume 3 liters

Various concentration levels in the odor test bag (volume 3 liters) were prepared with a range of concentrations (equivalent to 2-4 of odor intensity in the study of relationship between concentration of odorants and odor intensity in Japan) (Nakata et al., 2006). In this study, the Threshold Limit Value - Short Term Exposure Limit (TLV-STEL) or "the maximum concentration to which workers can be exposed for a short period of time (15 minutes) for only four times throughout the day with at least one hour between exposures" was used to justify the suitable concentration range of the nine odorous substances as shown in Table 3-5.

Table 3-5: The range of concentrations of odorous substances to be prepared in odor test bag, volume 3 liters

Odorous substances	Odor intensity [a]		TLV-STEL (ppm) [b]	Range of concentration for test (ppm)
	2 (ppm)	4 (ppm)		
Ammonia	0.59	9.33	35	0.59-9.33
n-Butyl acetate	1.40	29	200	1.40-29.00
Hydrogen sulfide	0.0056	0.71	15	0.0056-0.71
Methanol [c]	200	2,500	250	200-2,500
Methyl mercaptan [d]	0.00064	0.026	-	0.00064-0.026
Propionic acid	0.013	0.37	15	0.013-0.37
Styrene	0.17	4.30	100	0.17-4.30
Toluene	4.8	130	150	4.80-130
Xylene	0.52	10	150	0.52-10

Notes: [a] Nakata et al., 2006

[b] ACGIH, 2003

[c] Although methanol had concentration steps higher than TLV-STEL, because the demanding times in sniffing were very short (about 2-8 seconds per once of sniffing) and extra be careful in determination of odor intensity (Sensory test) of methanol safety was ensured.

[d] Methyl mercaptan had no TLV-STEL and reference to toxicity control of standards of offensive odor substances in Japan as shown in Table 2-26, 0.002-0.01 ppm when compared with the range of concentration for testing slightly higher than toxicity control.

Odorant concentrations in the odor test bags were prepared at random in each set of tests using a random number table and each concentration step was diluted in three-fold in series. Details of odorants in the preparation of the odor test bag (volume 3 liters) in each set are described as follows:

3.1) washed the odor test bag by filling with odorless air. Afterwards, deflate the odorless air from the odor bag. Repeated 3-4 times and then sniffed the air inside the odor test bag to confirm that it is odorless.

3.2) filled test bag with the odorless air up to the volume shown in Table 3-6 and then plugged the bag with silicone plug no. 03.

3.3) withdrawn a certain volume of odorant from the stock concentration of odorant in air sample using an airtight glass syringe with volume shown in Table 3-6. Afterwards, injected into the odor test bag from (3.2), and then sealed off the hole of the injection needle with adhesive tape to prevent the air in the bag from escaping. Figure 3-10 shows the preparation of the odor bag, volume 3 liters.

3.4) prepared another five odor bags for six panelists (one test set) by repeating the above steps (3.1-3.3). After that, brought the six panelists to sniff and assessed the odor intensity in this test set.

3.5) repeated the above steps (3.1-3.4), but change to the next concentration set as shown in Table 3-6 by a random set of concentrations until completing all sets of concentrations (one test series). Table 3-7 displays the actual data of the preparation of concentrations of the nine odorous substances in the odor test bag, volume 3 liters.

Table 3-6: Series of concentrations of the nine odorous substances in the odor test bag, volume 3 liters

No.	Odorous substances	List	Second dilution (odor test bag 3 L)						
			Set 1	**Set 2**	**Set 3**	**Set 4**	**Set 5**	**Set 6**	**unit**
1	Ammonia	Volume[a]	1.5	2	2	2	2	-	L
		Inject[b]	850	376	125	42	14	-	ml
		Tot. Vol.[c]	2,350	2,376	2,125	2,042	2,014	-	ml
		Conc.[d]	17.687	7.738	2.876	1.006	0.340	-	ppm
2	n-Butyl acetate	Volume[a]	3	3	3	3	3	3	L
		Inject[b]	100	30	10	3	1	0.3	ml
		Tot. Vol.[c]	3,100	3,030	3,010	3,000	3,000	3,000	ml
		Conc.[d]	27.682	8.496	2.851	0.857	0.286	0.086	ppm
3	Hydrogen sulphide	Volume[a]	3	3	3	3	3	3	L
		Inject[b]	45	15	5	2	0.6	0.2	ml
		Tot. Vol.[c]	3,045	3,015	3,000	3,000	3,000	3,000	ml
		Conc.[d]	0.712	0.240	0.080	0.032	0.0096	0.0032	ppm
4	Methanol	Volume[a]	2.7	3	3	3	3	-	L
		Inject[b]	300	100	30	10	3	-	ml
		Tot. Vol.[c]	3,000	3,100	3,030	3,010	3,000	-	ml
		Conc.[d]	2,481.693	800.546	245.712	82.448	24.792	-	ppm
5	Methyl mercaptan	Volume[a]	3	3	3	3	3	-	L
		Inject[b]	2	0.6	0.2	0.07	0.02	-	ml
		Tot. Vol.[c]	3,000	3,000	3,000	3,000	3,000	-	ml
		Conc.[d]	0.0314	0.0094	0.0031	0.0011	0.0003	-	ppm
6	Propionic acid	Volume[a]	3	3	3	3	3	3	L
		Inject[b]	100	30	10	3	1	0.3	ml
		Tot. Vol.[c]	3,100	3,030	3,010	3,000	3,000	3,000	ml
		Conc.[d]	3.528	1.083	0.363	0.109	0.036	0.011	ppm

Table 3-6: Series of concentrations of the nine odorous substances in the odor test bag, volume 3 liters (continued)

No.	Odorous substances	List	Second dilution (odor test bag 3 L)						
			Set 1	**Set 2**	**Set 3**	**Set 4**	**Set 5**	**Set 6**	**unit**
7	Styrene	Volume[a]	3	3	3	3	3	-	L
		Inject[b]	100	30	10	3	1	-	ml
		Tot. Vol.[c]	3,100	3,030	3,010	3,000	3,000	-	ml
		Conc.[d]	4.093	1.256	0.421	0.127	0.042	-	ppm
8	Toluene	Volume[a]	2.7	3	3	3	3	-	L
		Inject[b]	300	100	30	10	3	-	ml
		Tot. Vol.[c]	3,000	3,100	3,030	3,010	3,000	-	ml
		Conc.[d]	129.325	41.718	12.804	4.296	1.292	-	ppm
9	Xylene	Volume[a]	2.7	3	3	3	-	-	L
		Inject[b]	300	100	30	10	-	-	ml
		Tot. Vol.[c]	3,000	3,100	3,030	3,010	-	-	ml
		Conc.[d]	0.993	0.320	0.098	0.033	-	-	ppm

Notes: [a] Volume means volume of odorless air need to fill odor test bag.

[b] Inject means volume of air sample which is sucked from odor sample bag to inject in odor test bag.

[c] Tot. Vol. means total volume of air inside odor test bag (calculated from Volume + Inject).

[d] Conc. means odorant concentration inside odor test bag which is injected with air sample from odor sample bag. The calculation method is displayed in Appendix C.

1. Withdraw the stock odorant air sample from the odor bag, volume 20 liters

2. Inject the stock odorant air sample into the odor bag, volume 3 liters

Figure 3-10: Steps in preparation of the odor bag, volume 3 liters

Table 3-7: Actual data of preparation of concentrations at random of the nine odorous substances in the odor test bag, volume 3 liters

No.	**Odorous substances**	**Series**	**Second dilution or odor test bag 3 L (ppm)**							
			Set 1	**Set 2**	**Set 3**	**Set 4**	**Set 5**	**Set 6**	**Set 7**	**Set 8**
1	Ammonia	1	0.340	7.738	Blank	1.006	Blank	2.876	17.69	-
		2	1.006	Blank	7.738	17.687	2.876	Blank	0.34	-
		3	17.687	Blank	7.738	Blank	2.876	1.006	0.34	-
2	n-Butyl acetate	1	2.851	0.857	Blank	27.682	0.286	Blank	8.496	0.086
		2	Blank	2.851	Blank	0.857	27.682	8.496	0.086	0.286
		3	8.496	Blank	27.682	Blank	2.851	0.086	0.857	0.286
3	Hydrogen sulphide	1	0.240	0.0096	Blank	0.0032	0.712	0.080	0.032	Blank
		2	Blank	0.0096	0.240	0.0032	0.080	0.712	0.032	Blank
		3	Blank	0.080	0.712	0.032	0.0096	Blank	0.240	0.0032
4	Methanol	1	Blank	2,481.69	82.448	Blank	245.71	800.546	24.79	-
		2	245.71	82.45	2,481.69	Blank	800.55	24.792	Blank	-
		3	Blank	82.448	800.546	245.712	2,481.69	Blank	24.792	-
5	Methyl mercaptan	1	0.0003	0.0011	Blank	0.0032	0.0094	0.0313	Blank	-
		2	0.0313	0.0032	0.0094	Blank	0.0003	Blank	0.0011	-
		3	0.0032	0.0094	Blank	0.0003	Blank	0.0011	0.0313	-
6	Propionic acid	1	Blank	0.363	3.528	0.011	0.109	0.036	1.083	Blank
		2	0.109	Blank	0.011	Blank	3.528	0.036	0.363	1.083
		3	0.036	1.083	0.363	0.109	3.528	Blank	0.011	Blank
7	Styrene	1	0.421	1.256	Blank	4.093	Blank	0.127	0.042	-
		2	0.421	Blank	4.093	Blank	0.042	0.127	1.256	-
		3	0.421	Blank	4.093	0.042	1.256	Blank	0.127	-
8	Toluene	1	129.325	Blank	12.804	Blank	4.296	1.292	41.72	-
		2	Blank	12.804	4.296	Blank	41.718	1.292	129.32	-
		3	Blank	129.325	4.296	41.718	Blank	1.292	12.80	-
9	Xylene	1	Blank	0.320	0.993	0.033	0.098	Blank	-	-
		2	0.033	0.993	Blank	0.320	0.098	Blank	-	-
		3	0.320	Blank	0.033	0.993	0.098	Blank	-	-

3.3.3.4 Odor assessment

Each panelist (total six persons) received an odor test bag, volume 3 liters, at the same odorant concentration. All six panelists must sniffed and assessed for odor intensity of air sample in the odor test sample bag. The fundamentals of sniffing were to softly press the odor bag and sniffed the odor inside in line with one’s own breathing, as shown in Figure 3-11. The panelists must fully understand that the air that had been inhaled is not to be exhaled into the odor bag again. The odor intensity of the odorant sample inside the odor bag was assessed on a scale from 0-5 (Table 3-8) by sniffing 1-4 times and spending about 2-8 seconds per sniff. Then, panelists wrote the answer down on the answer sheet.

After all six panelists assessed the odor intensity in the first set, ten minutes, was allowed to release any stress from olfactory perception and then the next odorant sample start was sniffed and assessed as given in Table 3-7 until all sets of concentrations were completed (which is one series of the test). After 30 minutes, the next series was repeated until all three series of the test were completed. In determining of odor intensity (Sensory test), two blank samples were inserted in each series of the test and it took one day for each odorous substance.

Figure 3-11: Sniffing odor in odor bag

Table 3-8: Definitions of odor intensity

Odor intensity	Odor definitions
0	No odor
1	Barely traceable
2	Faint but identifiable
3	Easily detectable
4	Strong odor
5	Repulsive

Source: Nakata et al., 2006

3.3.3.5 Calculation of odor intensity

Determine the arithmetic mean of odor intensity for each concentration set from only four panelists (excluding both maximum and minimum values) using the following equation:

$$\boxed{\overline{I} = \frac{I_1 + I_2 + I_3 + I_4}{4}}$$

Whereas:

$\overline{I}$ = the average odor intensity for each level of concentration
I_1 = odor intensity at each level of concentration from panelist no.1
I_2 = odor intensity at each level of concentration from panelist no.2
I_3 = odor intensity at each level of concentration from panelist no.3
I_4 = odor intensity at each level of concentration from panelist no.4

3.3.3.6 Determination of suitable linear equations

The relationship between odorant concentration and the average of odor intensity was calculated by using simple regression analysis and drew scatter diagram with selected suitable equations among odorant concentration and odor intensity, odorant concentration and logarithm of odor intensity, logarithm of odorant concentration and odor intensity, and logarithm of odorant concentration and logarithm of odor intensity. The maximum value of correlation coefficient (r), the minimum value of the mean square error (MSE), and p-value by ANOVA test (F-test) at significant level less than 0.01 were used to justify the selection of an appropriate equation. For hypothesis of ANOVA (F-test) was H_0: $ß_1 = 0$ and H_1: $ß_1 \neq 0$.

CHAPTER IV
RESULTS AND DISCUSSIONS

4.1 Determination of olfactory perceptions of panelists using the Japanese Industrial Standard (JIS)

From the olfactory test of panelists (Panel screening) using Japanese Industrial Standard (JIS), students with master degrees, 16 persons, (male 2 persons, female 14 persons) 20-35 years of age were used. The result of panelist screening test indicated that 12 panelists had passed the test for which all panelists having passed were female. Table 4-1 shows the result of the olfactory test of panelists (Panel screening).

Table 4-1: The results of panel screening test using the Japanese Industrial Standard (JIS)

Panelists number	**Sex**	**Age**	**Education**	**Standard solutions***					**Result of test**
				A	**B**	**C**	**D**	**E**	
1	female	24	graduate student	/	/	/	/	/	pass
2	female	24	graduate student	/	/	/	/	/	pass
3	female	24	graduate student	/	/	/	/	/	pass
4	female	24	graduate student	X	X	X	/	/	fail
5	male	32	graduate student	/	X	X	/	/	fail
6	female	23	graduate student	X	X	/	X	/	fail
7	female	24	graduate student	/	/	/	/	/	pass
8	female	24	graduate student	/	/	/	/	/	pass
9	female	28	graduate student	/	/	/	/	/	pass
10	female	23	graduate student	/	/	/	/	/	pass
11	male	24	graduate student	/	X	/	/	/	fail
12	female	24	graduate student	/	/	/	/	/	pass
13	female	24	graduate student	/	/	/	/	/	pass
14	female	24	graduate student	/	/	/	/	/	pass
15	female	24	graduate student	/	/	/	/	/	pass
16	female	27	graduate student	/	/	/	/	/	pass

Notes: * A is standard solution which has a floral smell (β-Phenylethyl alcohol).
B is standard solution which has a sweet burning smell (Methyl cyclopentenolone).
C is standard solution which has a smell of stuffy socks (Isovaleric acid).
D is standard solution which has a smell of ripe fruit (γ-Undecalactone).
E is standard solution which has a smell of feces (Skatole or 3-Methyl indole).

4.2 The relationship between odorant concentration and odor intensity of nine odorous substances

This research used six panelists to sniff and assess odor intensity of nine odorants at various concentration levels inside the odor test bag (volume three liters) at random as shown in Table 3-6, and the results have been arranged in order from minimum to maximum odor concentrations as shown in Tables 4-2 to 4-10. The averages of odor intensity in each set of sensory test of each series (three series) was calculated (see Appendix E) and analyzed using simple regression analysis to determine the relationship between odorant concentration and odor intensity. The results of linear equations with significant differences at $p\text{-value} \leq 0.01$ (by ANOVA-test) for each odorous substance are shown in Table 4-11, suitable linear equations were selected from the maximum value of correlation coefficient (r), and the minimum value of mean square error (MSE). Results showed that the relationship between odorant concentration and odor intensity for seven odorous substances, i.e., n-butyl acetate, hydrogen sulphide, methanol, methyl mercaptan, styrene, toluene, and xylene corresponded to the Weber-Fechner logarithmic equation ($I = a\log(C) + b$), that is, odor intensity will relate to logarithmic of odorant concentration. For propionic acid and ammonia, if consider from the maximum value of the correlation coefficient (r) and the minimum value of mean square error (MSE), Stevens' Power Law ($\log I = a\log(C) + b$) and simple linear ($I = a(C) + b$) fit better than Weber-Fechner logarithmic equation, respectively. However, the value of correlation coefficient (r) and mean square error (MSE) from Weber-Fechner logarithmic equation for propionic acid and ammonia were also not much different from Stevens' Power Law and simple linear, respectively. Therefore, in this study, the nine odorous substances based on the Weber-Fechner logarithmic equation were selected.

The Weber-Fechner logarithmic equation, correlation coefficient (r), and mean square error (MSE) of the nine odorous substances are shown in Figures 4-1 to 4-9 and the relationship between odorant concentration and odor intensity of all nine odorous substances are shown in Figure 4-10.

Table 4-2: Odor intensity of ammonia at various concentration levels

Panelist number	Blank	Concentration (ppm)				
		0.340	1.006	2.876	7.738	17.687
9	11	0	0	1	1	3
	00	3	1	3	2	3
	00	1	0	1	2	4
7	11	0	1	1	2	3
	32	3	0	4	2	1
	10	1	0	1	1	2
2	00	0	0	0	1	2
	00	0	0	0	1	2
	00	1	0	1	0	3
10	00	0	0	0	1	4
	10	1	1	1	3	4
	01	1	0	1	4	5
3	10	1	0	1	2	3
	12	1	1	2	1	2
	00	0	0	1	3	2
15	10	0	1	0	1	3
	10	1	1	1	1	1
	10	0	0	1	1	3

Table 4-3: Odor intensity of n-butyl acetate at various concentration levels

Panelist number	Blank	Concentration (ppm)					
		0.086	0.286	0.857	2.851	8.496	27.682
9	00	1	2	3	3	4	4
	00	1	2	2	2	3	5
	00	1	2	2	3	3	5
10	00	1	2	4	4	5	5
	01	1	3	4	3	5	5
	00	1	2	3	3	4	5
2	00	1	1	5	5	5	5
	00	1	1	2	4	5	5
	00	0	1	1	4	5	5
1	00	1	1	3	3	5	5
	00	1	1	3	3	4	5
	00	0	1	1	3	4	5
8	00	2	2	4	4	4	5
	00	2	1	3	3	4	5
	00	2	0	3	3	4	5
3	10	0	2	2	3	3	4
	11	2	2	3	2	3	5
	01	1	2	2	3	4	5

Table 4-4: Odor intensity of hydrogen sulfide at various concentration levels

Panelist number	Blank	Concentration (ppm)					
		0.0032	**0.0096**	**0.032**	**0.080**	**0.240**	**0.712**
9	00	1	3	3	4	5	5
	00	3	4	3	4	5	5
	00	1	2	3	4	5	5
7	10	2	4	3	4	5	5
	00	2	0	2	4	5	4
	00	0	0	3	3	4	5
2	00	1	3	2	4	4	5
	00	2	1	5	5	5	5
	00	3	3	5	5	5	5
10	00	0	2	3	4	5	5
	00	0	3	1	4	5	5
	00	0	1	1	4	4	5
3	01	0	1	2	3	2	5
	01	1	1	2	3	3	4
	00	0	1	2	4	4	5
15	01	1	1	1	3	4	5
	00	1	1	2	4	4	4
	00	1	1	3	4	4	4

Table 4-5: Odor intensity of methanol at various concentration levels

Panelist number	Blank	Concentration (ppm)				
		24.792	**82.448**	**245.712**	**800.546**	**2,481.693**
9	00	0	0	1	2	2
	10	0	0	1	2	3
	00	1	0	2	3	3
7	02	0	1	0	1	2
	10	0	0	1	1	2
	00	0	1	1	2	3
2	01	1	0	1	4	3
	00	0	0	0	0	2
	00	0	1	1	3	5
16	00	0	0	2	4	1
	00	0	1	0	1	3
	00	2	1	1	4	4
8	01	0	0	1	3	3
	20	0	0	0	2	3
	00	0	1	1	3	3
12	01	0	1	1	3	3
	00	0	0	0	0	1
	01	2	1	1	3	4

Table 4-6: Odor intensity of methyl mercaptan at various concentration levels

Panelist number	Blank	Concentration (ppm)				
		0.0003	**0.0011**	**0.0031**	**0.0094**	**0.0314**
9	00	0	0	1	3	4
	00	0	0	0	2	4
	01	0	0	0	4	3
7	23	0	1	2	3	3
	10	0	1	0	1	4
	11	0	0	0	3	4
2	00	1	3	4	4	4
	00	1	2	4	4	5
	00	1	2	2	3	4
10	00	1	3	4	4	2
	00	0	1	3	3	4
	00	0	4	2	3	5
17	01	1	1	1	3	4
	50	0	0	0	3	4
	10	0	1	2	1	3
15	00	1	2	3	4	4
	00	0	1	2	3	4
	00	0	1	1	1	4

Table 4-7: Odor intensity of propionic acid at various concentration levels

Panelist number	Blank	Concentration (ppm)					
		0.011	**0.036**	**0.109**	**0.363**	**1.083**	**3.528**
9	01	1	0	1	1	3	4
	01	0	0	1	0	4	4
	00	0	0	1	1	5	5
2	11	0	0	1	2	3	4
	10	0	0	1	3	3	4
	00	0	0	0	3	3	5
7	10	0	2	1	3	3	3
	00	1	0	1	0	3	1
	00	1	0	1	1	3	4
1	00	0	0	1	1	3	4
	00	0	1	1	4	3	5
	00	0	0	1	3	4	5
8	11	0	2	1	1	3	3
	01	0	0	2	3	3	3
	00	1	1	0	1	3	2
3	11	1	0	1	1	4	4
	10	1	1	0	2	3	3
	10	0	0	0	2	3	5

Table 4-8: Odor intensity of styrene at various concentration levels

Panelist number	Blank	Concentration (ppm)				
		0.042	0.127	0.421	1.256	4.093
9	00	0	4	5	5	5
	00	2	3	4	4	5
	00	0	2	4	4	5
10	10	2	3	5	4	5
	00	1	3	3	4	5
	00	1	2	4	4	5
2	00	1	1	0	4	5
	00	0	0	4	5	5
	10	1	1	5	4	5
1	00	0	1	4	3	5
	00	1	1	3	4	5
	00	0	1	3	4	4
8	00	0	3	4	5	5
	00	1	2	3	5	5
	00	1	2	3	5	5
15	00	1	3	4	4	5
	00	1	3	3	5	5
	00	1	2	4	4	5

Table 4-9: Odor intensity of toluene at various concentration levels

Panelist number	Blank	Concentration (ppm)				
		1.292	4.296	12.804	41.718	129.325
9	01	0	2	2	4	4
	00	0	1	2	4	5
	00	1	1	3	4	5
7	01	1	3	4	4	3
	01	0	2	4	5	5
	00	1	1	4	3	4
2	00	0	1	2	5	5
	00	1	1	3	5	4
	00	1	1	3	4	5
16	20	1	3	3	4	4
	01	0	0	1	4	5
	00	1	1	4	3	4
8	10	1	2	3	4	4
	00	3	2	4	5	5
	00	3	0	4	4	5
3	01	2	2	3	4	5
	02	1	2	3	5	5
	10	2	3	3	4	5

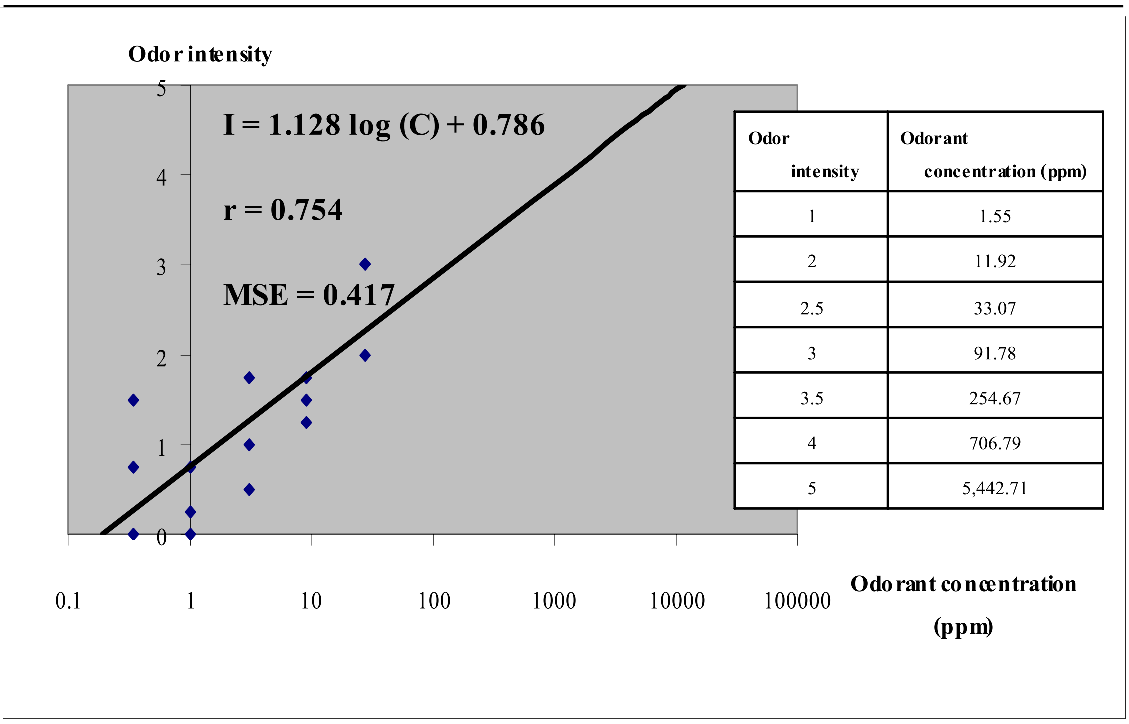
Table 4-10: Odor intensity of xylene at various concentration levels

Panelist number	Blank	Concentration (ppm)			
		0.033	**0.098**	**0.320**	**0.993**
9	12	1	1	1	4
	00	0	2	0	4
	00	0	1	0	4
10	10	0	2	1	3
	00	0	2	2	4
	20	0	3	2	4
16	00	0	1	1	1
	10	1	3	4	4
	02	0	2	2	4
1	00	0	0	4	3
	00	0	0	3	3
	00	0	0	5	4
8	11	1	2	2	1
	01	0	0	2	4
	02	0	0	4	3
15	01	0	1	2	3
	00	0	1	3	4
	00	1	1	4	4

Table 4-11: Linear equations with significant differences at p-value ≤ 0.01, correlation of coefficient (r), and mean square error (MSE) of the nine odorous substances

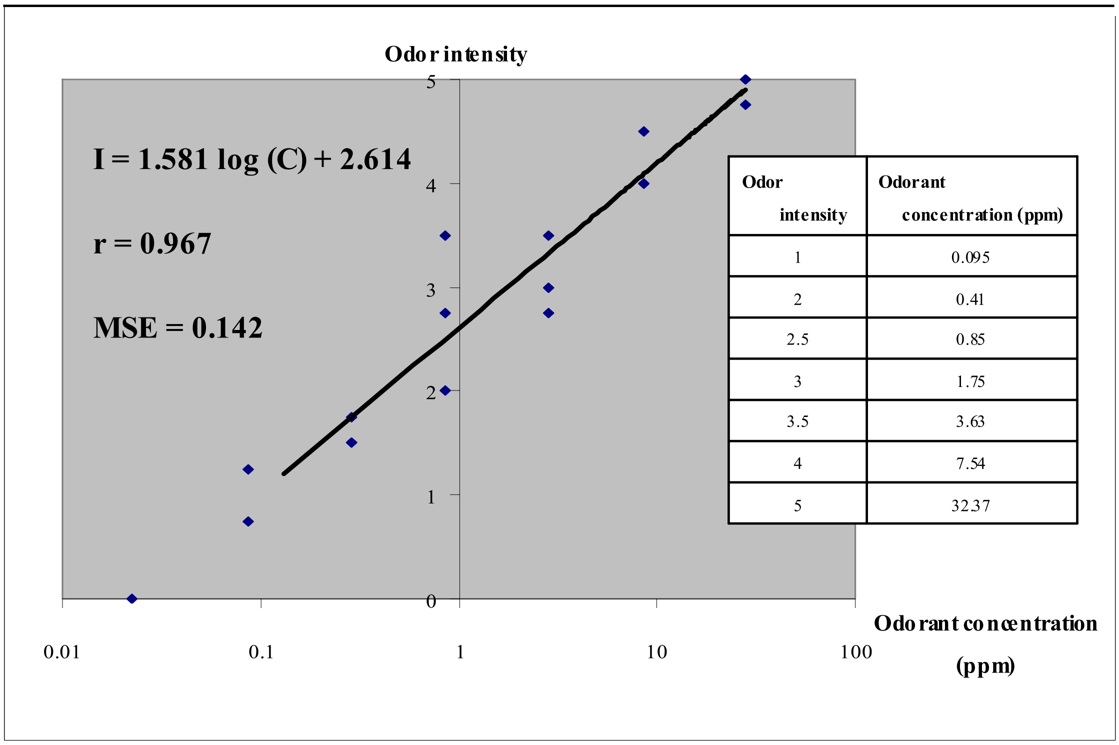
Odorous substance	Linear equation	r	MSE	p-value[*]
Ammonia	$I = 0.121C + 0.550$	0.848	0.271	0.000
	$I = 1.128\log C + 0.786$	0.754	0.417	0.001
n-Butyl acetate	$I = 0.114C + 2.152$	0.801	0.783	0.000
	$I = 1.581\log C + 2.614$	0.967	0.142	0.000
	$\mathrm{Log}\ I = 0.017C + 0.286$	0.684	1.122	0.002
	$\mathrm{Log}\ I = 0.276\log C + 0.349$	0.946	0.275	0.000
Hydrogen sulfide	$I = 4.338C + 2.277$	0.732	1.160	0.001
	$I = 1.801\log C + 5.419$	0.964	0.177	0.000
	$\mathrm{Log}\ I = 0.701C + 0.283$	0.608	1.714	0.007
	$\mathrm{Log}\ I = 0.329\log C + 0.840$	0.905	0.621	0.000
Methanol	$I = 0.001C + 0.570$	0.790	0.621	0.000
	$I = 1.420\log C - 2.091$	0.838	0.490	0.000
	$\mathrm{Log}\ I = 0.434\log C -1.051$	0.714	0.504	0.009
Methyl mercaptan	$I = 96.647C + 1.091$	0.841	0.602	0.000
	$I = 1.793\log C + 6.456$	0.945	0.221	0.000
	$\mathrm{Log}\ I = 16.882C + 0.110$	0.776	0.795	0.002
	$\mathrm{Log}\ I = 0.378\log C + 1.173$	0.906	0.281	0.000
Propionic acid	$I = 1.017C + 0.811$	0.875	0.555	0.000
	$I = 1.573\log C + 2.818$	0.941	0.266	0.000
	$\mathrm{Log}\ I = 0.265C -0.187$	0.737	1.396	0.001
	$\mathrm{Log}\ I = 0.516\log C + 0.393$	0.971	0.261	0.000
Styrene	$I = 0.766C + 2.274$	0.747	1.232	0.001
	$I = 2.129\log C + 4.008$	0.964	0.196	0.000
	$\mathrm{Log}\ I = 0.397\log C + 0.572$	0.893	0.993	0.000
Toluene	$I = 0.025C + 1.936$	0.776	1.057	0.001
	$I = 2.053\log C + 0.574$	0.955	0.232	0.000
	$\mathrm{Log}\ I = 0.004C + 0.205$	0.663	1.666	0.007
	$\mathrm{Log}\ I = 0.400\log C -0.079$	0.908	0.674	0.000
Xylene	$I = 3.084C + 0.657$	0.860	0.582	0.000
	$I = 2.307\log C + 3.494$	0.936	0.275	0.000
	$\mathrm{Log}\ I = 0.637\log C + 0.607$	0.907	0.462	0.000

Note: [*] p-value was tested by ANOVA-test (F-test) with statistical analysis program (see Appendix F).



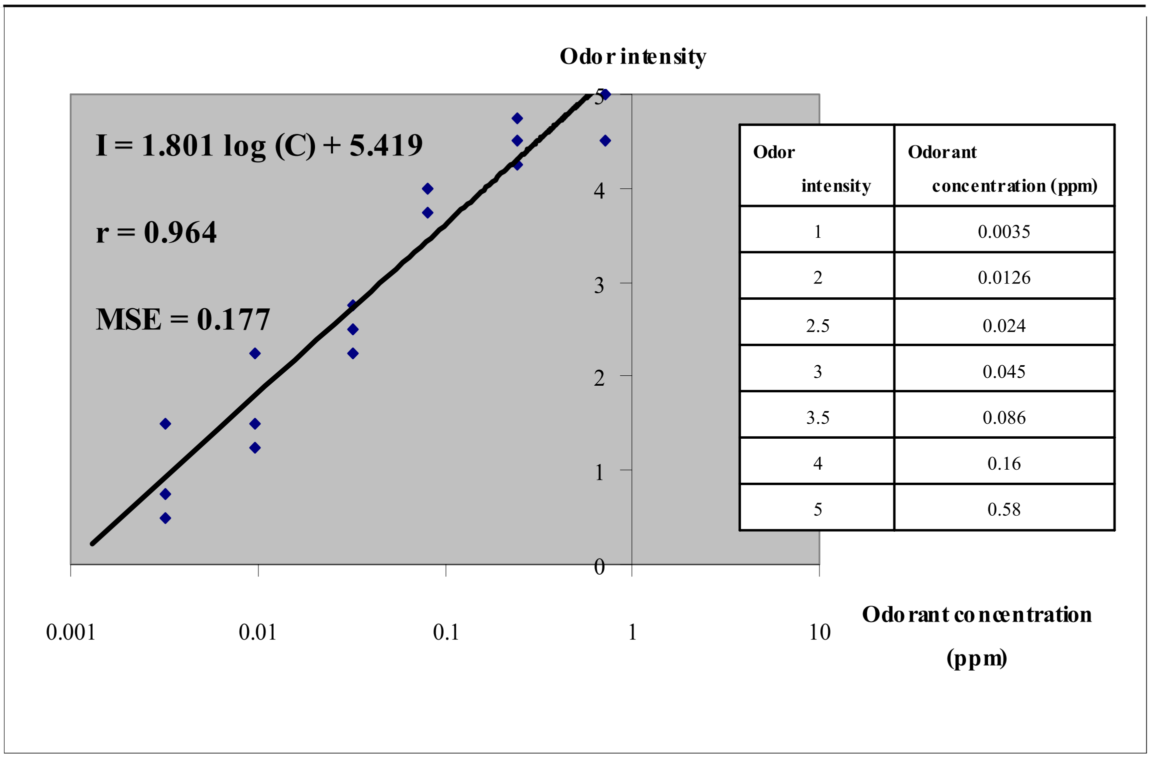
Odor intensity	Odorant concentration (ppm)
1	1.55
2	11.92
2.5	33.07
3	91.78
3.5	254.67
4	706.79
5	5,442.71

Figure 4-1: The relationship between odorant concentration and odor intensity of ammonia



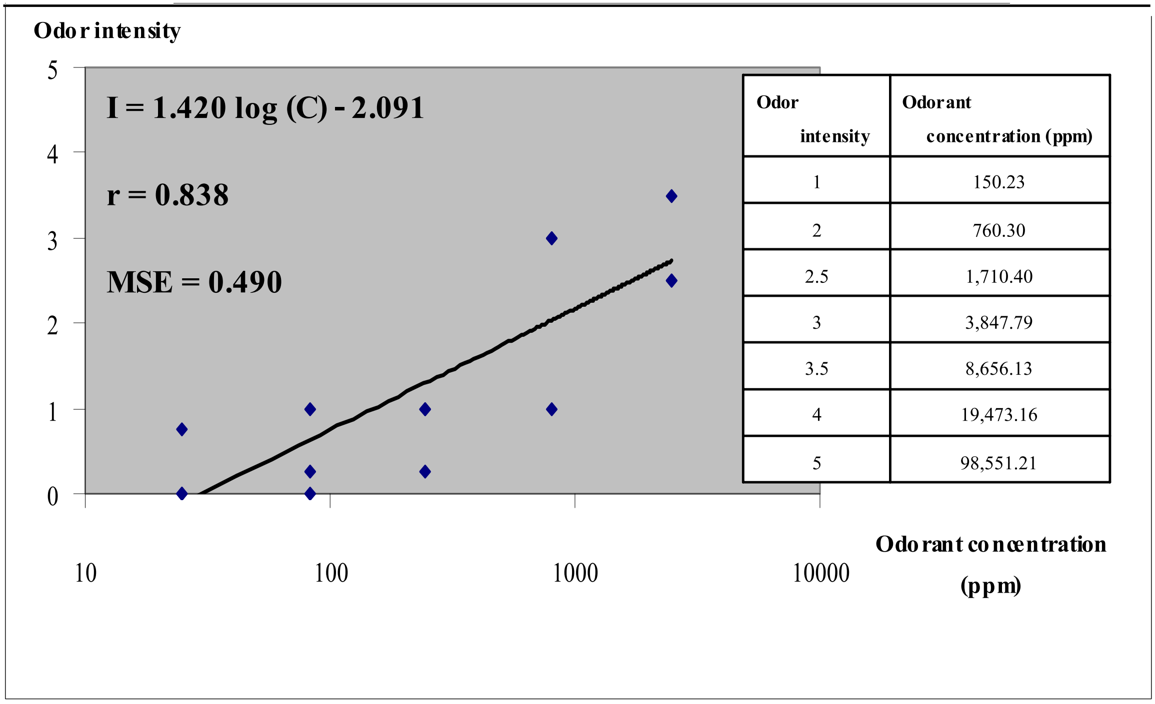
Odor intensity	Odorant concentration (ppm)
1	0.095
2	0.41
2.5	0.85
3	1.75
3.5	3.63
4	7.54
5	32.37

Figure 4-2: The relationship between odorant concentration and odor intensity of n-butyl acetate



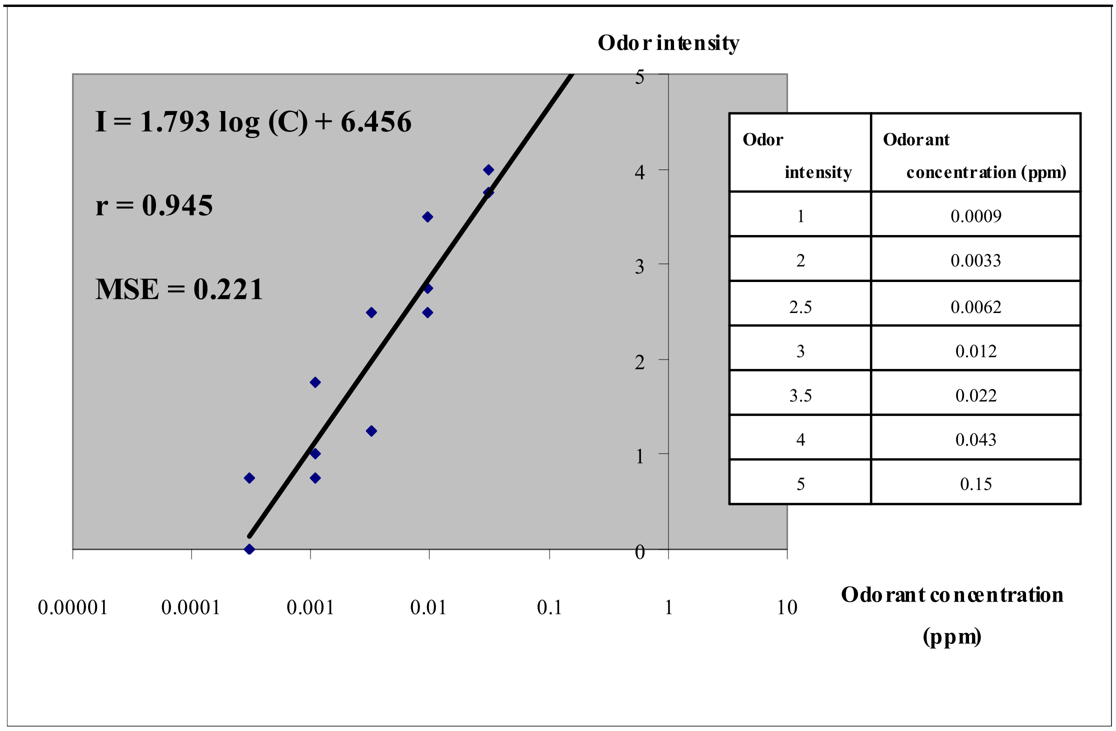
Odor intensity	Odorant concentration (ppm)
1	0.0035
2	0.0126
2.5	0.024
3	0.045
3.5	0.086
4	0.16
5	0.58

Figure 4-3: The relationship between odorant concentration and odor intensity of hydrogen sulphide



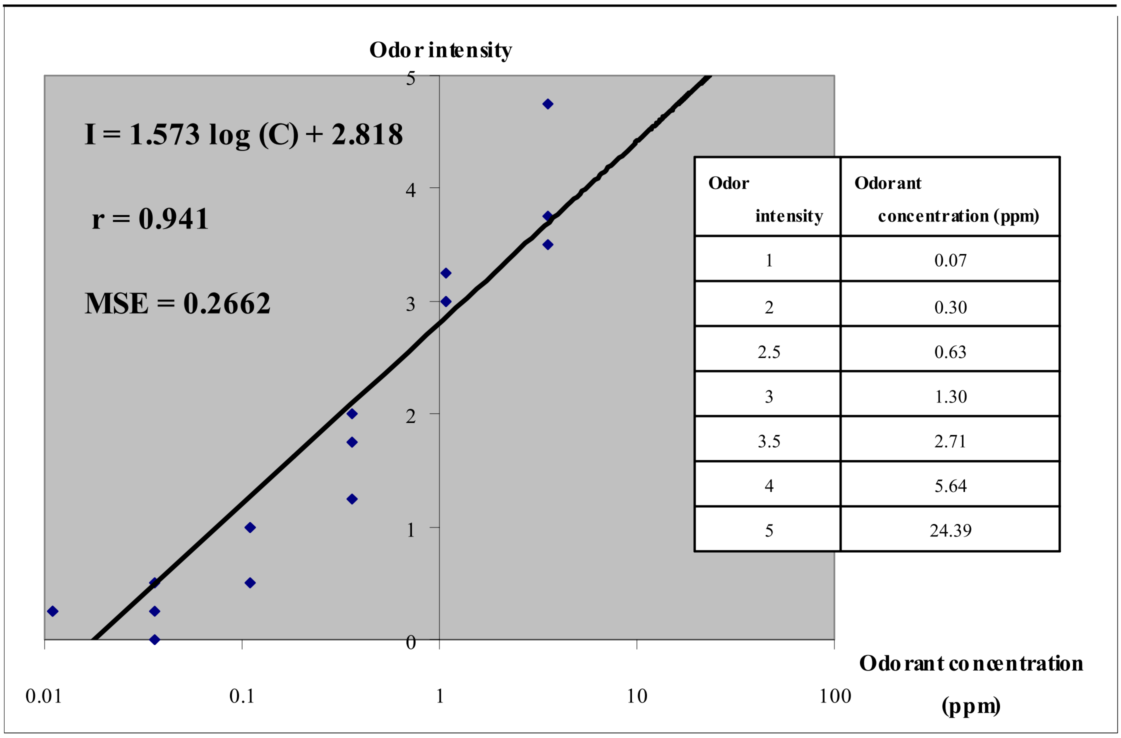
Odor intensity	Odorant concentration (ppm)
1	150.23
2	760.30
2.5	1,710.40
3	3,847.79
3.5	8,656.13
4	19,473.16
5	98,551.21

Figure 4-4: The relationship between odorant concentration and odor intensity of methanol



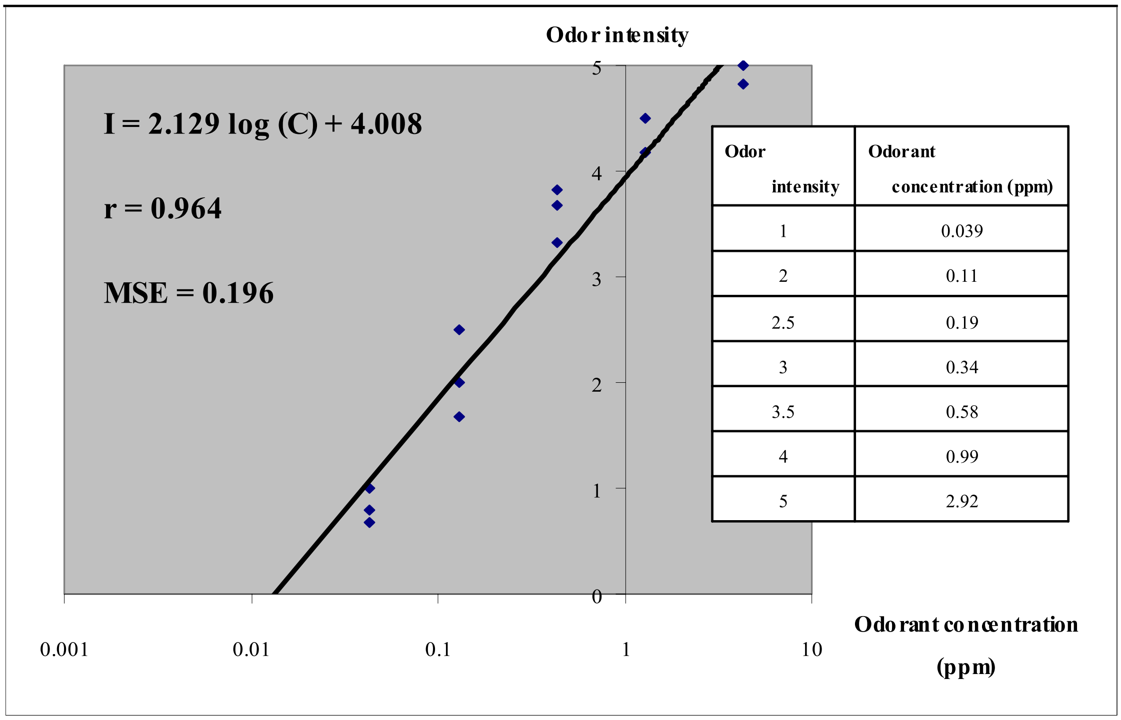
Odor intensity	Odorant concentration (ppm)
1	0.0009
2	0.0033
2.5	0.0062
3	0.012
3.5	0.022
4	0.043
5	0.15

Figure 4-5: The relationship between odorant concentration and odor intensity of methyl mercaptan



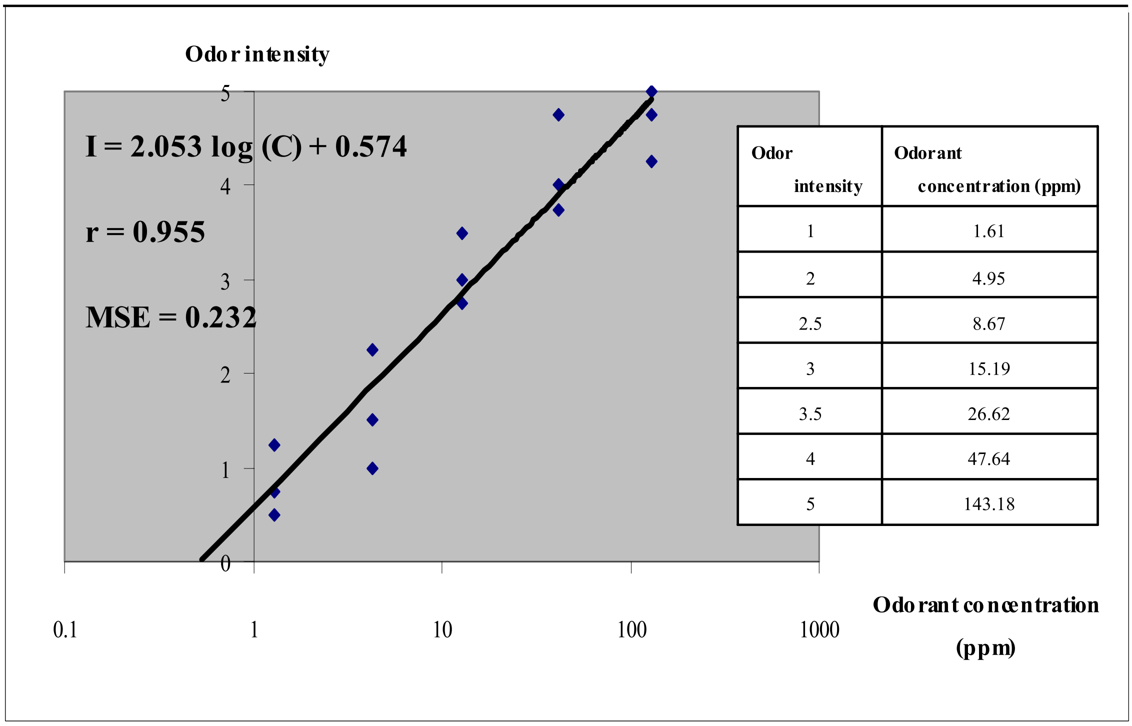
Odor intensity	Odorant concentration (ppm)
1	0.07
2	0.30
2.5	0.63
3	1.30
3.5	2.71
4	5.64
5	24.39

Figure 4-6: The relationship between odorant concentration and odor intensity of propionic acid



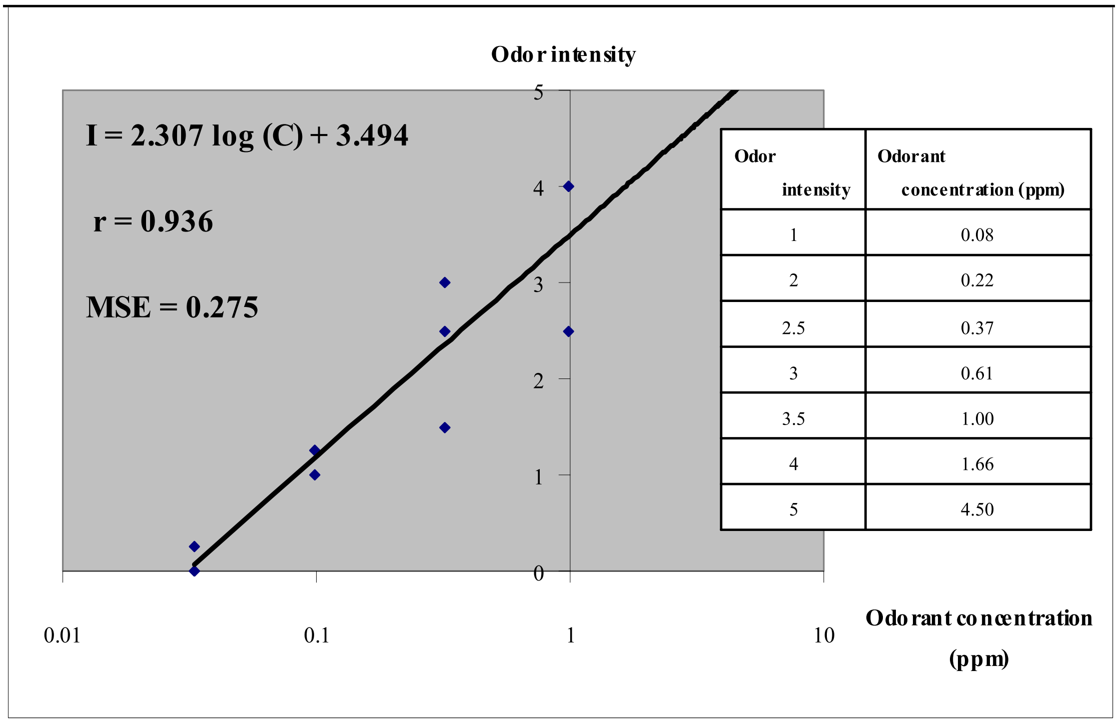
Odor intensity	Odorant concentration (ppm)
1	0.039
2	0.11
2.5	0.19
3	0.34
3.5	0.58
4	0.99
5	2.92

Figure 4-7: The relationship between odorant concentration and odor intensity of styrene



Odor intensity	Odorant concentration (ppm)
1	1.61
2	4.95
2.5	8.67
3	15.19
3.5	26.62
4	47.64
5	143.18

Figure 4-8: The relationship between odorant concentration and odor intensity of toluene



Odor intensity	Odorant concentration (ppm)
1	0.08
2	0.22
2.5	0.37
3	0.61
3.5	1.00
4	1.66
5	4.50

Figure 4-9: The relationship between odorant concentration and odor intensity of xylene

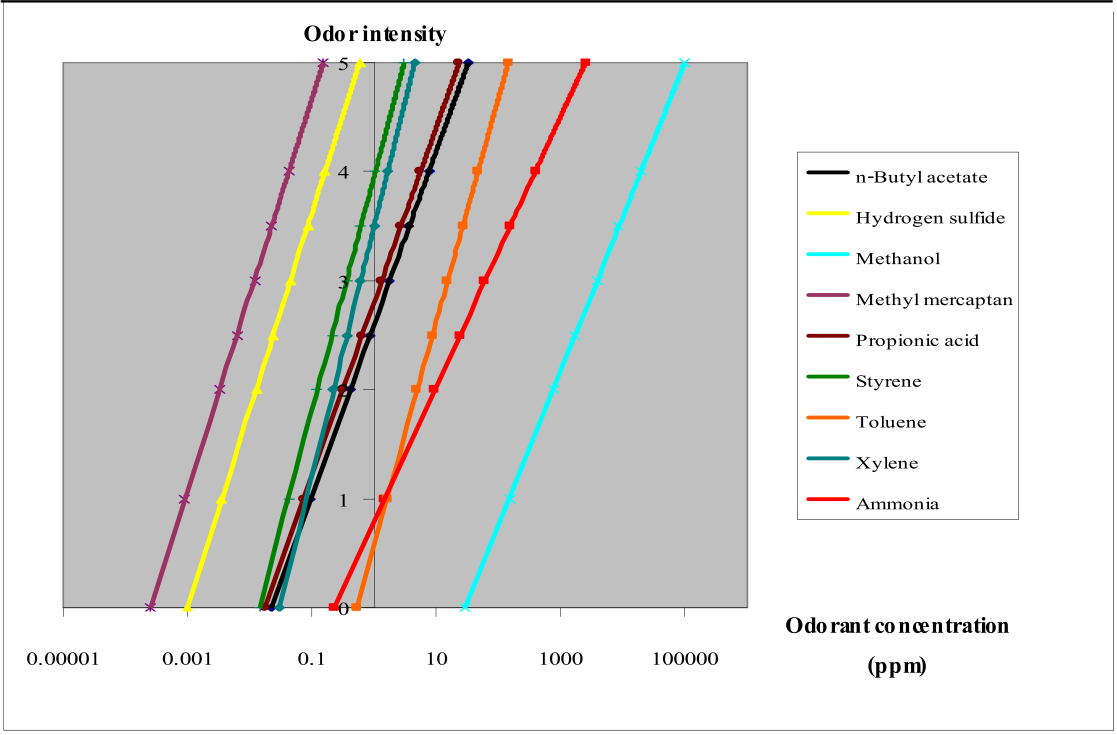


Figure 4-10: The relationship between odorant concentration and odor intensity of the nine odorous substances

Figures 4-1 to 4-9 summarize the odorant concentrations that were equivalent to the odor intensity of 1-5 for all nine odorous substances as shown in Table 4-12.

Table 4-12: The odorant concentration (ppm) equivalent to odor intensity of 1-5 for the nine odorous substances

Odorous substances	**Odor intensity**						
	1	**2**	**2.5**	**3**	**3.5**	**4**	**5**
Ammonia	1.55	11.92	33.07	91.78	254.67	706.79	5,442.71
n-Butyl acetate	0.095	0.41	0.85	1.75	3.63	7.54	32.37
Hydrogen sulfide	0.0035	0.0126	0.024	0.045	0.086	0.16	0.58
Methanol	150.23	760.30	1,710.40	3,847.79	8,656.13	19,473.16	98,551.21
Methyl mercaptan	0.0009	0.0033	0.0062	0.012	0.022	0.043	0.15
Propionic acid	0.07	0.30	0.63	1.30	2.71	5.64	24.39
Styrene	0.039	0.11	0.20	0.34	0.58	0.99	2.92
Toluene	1.61	4.95	8.67	15.19	26.62	46.64	143.18
Xylene	0.08	0.22	0.37	0.61	1.00	1.66	4.50

The results of odorant concentration corresponded to odor intensity of 2.5-3.5 are shown in Table 4-13. Comparison of the results obtained from this study and Nagata et al. (2006), it was found that five odorous substances (n-butyl acetate, hydrogen sulphide, styrene, toluene, and xylene) in this study were perceived by the Thai panelists at concentrations lower than Japanese panelists. Whereas the remaining four odorous substances (ammonia, methanol, methyl mercaptan, and propionic acid) were perceived by the Thai panelists at concentration higher than Japanese panelists. These differences in sensitivity may be due to different sensitizations to the different odors between Thai panelists and Japanese panelists.

Table 4-13: Comparison of the concentration ranges of the nine odorous substances corresponding to odor intensity of 2.5-3.5 between this study and the study in Japan

Odorous substances	The range of concentrations from this study (ppm)	The range of concentrations from Japanese study (ppm)*
Ammonia	33-255	1-5
n-Butyl acetate	0.9-4	1.4-10
Hydrogen sulfide	0.02-0.09	0.02-0.2
Methanol	1,710-8,656	374-1,300
Methyl mercaptan	0.006-0.02	0.002-0.01
Propionic acid	0.63-2.70	0.03-0.2
Styrene	0.2-0.6	0.4-2
Toluene	8.7-26.7	10-60
Xylene	0.4-1.0	1-5

Note: * Nagata et al., 2006

When comparing of the results between this study and the threshold limit value-time weighted average (TLV-TWA) of each odorous substance, it was found that ammonia and methanol had higher concentrations of TLV-TWA (the TLV-TWA of ammonia was 25 ppm and the TLV-TWA of methanol was 200 ppm), which not only caused odor nuisances, but posed a harm to health, as shown in Table 4-14.

Table 4-14: Comparison between the concentration ranges of the nine odorous substances corresponding to odor intensity of 2.5-3.5 in this study and the TLV-TWA values

Odorous substances	The range of concentrations from this study (ppm)	TLV – TWA* (ppm)
Ammonia	33-255	25
n-Butyl acetate	0.9-4	150
Hydrogen sulfide	0.02-0.09	10
Methanol	1,710-8,656	200
Methyl mercaptan	0.006-0.02	0.5
Propionic acid	0.63-2.70	10
Styrene	0.2-0.6	50
Toluene	8.7-26.7	50
Xylene	0.4-1.0	100

Note: * ACGIH, 2003

CHAPTER V

CONCLUSION AND RECOMMENDATIONS

5.1 Conclusion

5.1.1 Determination of olfactory perceptions of panelists using the Japanese Industrial Standard (JIS)

The results of the Thai panelist screening test (20-35 years of age) indicated that 75% of all Thai panelists passed the test. All Thai panelists who passed were female.

5.1.2 The relationship between odorant concentration and odor intensity of nine odorous substances

The relationship between odorant concentration and odor intensity of nine odorous substances corresponded to the Weber-Fechner logarithmic equation with significant differences at p-value ≤ 0.01 (by ANOVA-test) for which the Weber-Fechner logarithmic equation, correlation coefficient (r), and mean square error (MSE) of the nine odorous substances are shown in Table 5-1.

Table 5-1: Weber-Fechner logarithmic equation with significant differences at p-value ≤ 0.01, correlation coefficient (r), and mean square error (MSE) of the nine odorous substances

Odorous substances	Suitable equations	r	MSE	p-value
Ammonia	$I = 1.128\log C + 0.786$	0.754	0.417	0.001
n-Butyl acetate	$I = 1.581\log C + 2.614$	0.967	0.142	0.000
Hydrogen sulfide	$I = 1.801\log C + 5.419$	0.964	0.177	0.000
Methanol	$I = 1.420\log C - 2.091$	0.838	0.490	0.000
Methyl mercaptan	$I = 1.793\log C + 6.456$	0.945	0.221	0.000
Propionic acid	$I = 1.573\log C + 2.818$	0.941	0.266	0.000
Styrene	$I = 2.129\log C + 4.008$	0.964	0.196	0.000
Toluene	$I = 2.053\log C + 0.574$	0.955	0.232	0.000
Xylene	$I = 2.307\log C + 3.494$	0.936	0.275	0.000

5.1.3 The concentration ranges of nine odorous substances may be used to establish ambient air standards at ground level along the boundary line of the factory for the individual nuisance odorous substances

The results from Table 4-14, may be used as recommending ambient air standards at ground level along the boundary line of the factory for individual nuisance odorous substances which are the concentration ranges corresponding to odor intensity of 2.5-3.5. The concentration ranges of nine odorous substances are as follow: 33-255 ppm ammonia, 0.9-4 ppm n-butyl acetate, 0.02-0.09 ppm hydrogen sulfide, 1710-8656 ppm methanol, 0.006-0.02 ppm methyl mercaptan, 0.63-2.70 ppm propionic acid, 0.2-0.6 ppm styrene, 8.7-26.7 ppm toluene, and 0.4-1.0 ppm xylene. For ammonia and methanol, according to human variability and human safety, a 10-fold safety factor (Dornel and Renwick, 2005) and TLV-TWA (ACGIH, 2003), were used to adjust the concentration ranges for ammonia and methanol i.e. 3.3-25 ppm and 171-200 ppm, respectively. The concentration ranges of the nine odorous substances which may be used to establish ambient air standards at ground level along the boundary line of the factory for individual nuisance odorous substance are shown in Table 5-2.

Table 5-2: The recommended concentration ranges of nine odorous substances for ambient air standards at ground level along the boundary line of the factory

Odorous substances	Ambient air standards at ground level along the boundary line of the factory for the individual nuisance odorous substances (ppm)
Ammonia	3.3-25
n-Butyl acetate	0.9-4
Hydrogen sulfide	0.02-0.09
Methanol	171-200
Methyl mercaptan	0.006-0.02
Propionic acid	0.63-2.70
Styrene	0.2-0.6
Toluene	8.7-26.7
Xylene	0.4-1.0

5.2 Recommendations

1) Because this study used only six panelists to assess odor intensity, it may not be sufficient to represent typical Thai people; therefore, further testing of olfactory perceptions of Thai people covering all areas in Thailand by using panel screening test which would not require much time and expense should be done in order to obtain valid and reliable information of olfactory perceptions that accurately represent the Thai population.

2) It is recommended that more studies and testing should be performed (especially ammonia, propionic acid, and methanol), and instead of using odorant concentration in the odor test bag from calculation; the actual concentration from analysis should be used.

REFERENCES

ACGIH (American Conference of Governmental Industrial Hygienists). (1986). Documentation of the Threshold Limit Values and Biological Exposure Indices. (5th ed). Cincinnati, H: American Conference of Governmental Industrial Hygienists.

ACGIH (American Conference of Governmental Industrial Hygienists). (2003). TLVs and BEIs Threshold Limit Values for Chemical Substances and Physical Agents, and Biological Exposure Indices. Ohio.

AS/NZS (Australian and New Zealand Standard) 4323.3. (2001). Stationary source emissions: Part 3: Determination of odour concentration by dynamic olfactometry**.**

ASTM, Standard E679-04. (2006). Standard Practice for Determination of Odor and Taste Thresholds by a Forced-Choice Ascending Concentration Series Method of Limits. Philadelphia, PA: American Society for Testing and Materials.

ATSDR (Agency for Toxic Substances and Disease Registry). (1992). Toxicological profile for methyl mercaptan. Atlanta, GA: U.S. Department of Health and Human Services, Public Health Service.

ATSDR (Agency for Toxic Substances and Disease Registry). (1999). Managing Hazardous Materials Incidents, Volume III – Medical Management Guidelines for Acute Chemical exposures: Methyl Mercaptan. Atlanta, GA: U.S. Department of Health and Human services, Public Health Service.

ATSDR (Agency for Toxic Substances and Disease Registry). (2004). Toxicological Profile for Ammonia. Atlanta, GA: U.S. Department of Health and Human Services, Public Health Service.

ATSDR (Agency for Toxic Substances and Disease Registry). (1990). Toxicological Profile for Ammonia. Atlanta, GA: ATSDR, U.S. Public Health Service.

Axel, R., and Buck, B.L. (2004). Odorant receptors and the organization of the olfactory system [online]. Available: http://nobelprize.org/medicine/laureates/2004/press.html. [2007, February 20].

Baker, D.E. (1993). Using Agricultural Anhydrous Ammonia Safely. Columbia: University Extension and University of Missouri-Columbia.

Beauchamp, R.O., Bus, J.S., Popp, J.A., Boreiko, C.J., and Andjelkovich, D.A. (1984). A critical review of the literature on hydrogen sulfide toxicity. Critical Reviews in Toxicology.

CARB. (1999). Air toxics emissions data collected in the Air Toxics Hot Spots Program. CEIDARS.

CEN. (1999). Air quality - Determination of odour concentration by dynamic olfactometry. Brussels: CEN European Committee for Standardization.

Copestake, P., and Heath, M. (2005). Butyl acetates**.** Illus: World Health Organization.

Customs Department. (2006). Foreign Trade Statistic [online]. Available: http://www.customs.go.th/Statistic/Index.jsp [2007, May 8]. (in Thai)

DEC (Department of Environment and Conservation). (2002). Odor control [online]. Available:http://www.environment.nsw.gov.au/mao/odourcontrol.html. [2006, April 30].

Dornel, J. L., and Renwick, A. G. (2005). The Refinement of Uncertainty/Safety Factors in Risk Assessment by the Incorporation of Data on Toxicokinetic Variability in Humans [online]. Available: http://toxsci.oxfordjournals.org/cgi/reprint/86/1/20. [2007, November 8].

Gerdjaroen, T. (2005). Electronic Nose (Part 1): Nanoscience of olfaction [online]. Available: http://nanotech.sc.mahidol.ac.th. [2007, March 18]. (in Thai)

Glindemann, D., Dietrich, A., Staerk, H.J., and Angewandte, P.K. (2006). Communication The Two Odors of Iron when Touched or Pickled: (Skin) Carbonyl Compounds and Organophosphines. Chemie.

Guest, D., Katz, G.V., and Astill, B.D. (1982). Aliphatic carboxylic acids. In Clayton GD and Clayton FE (eds): Patty's Industrial Hygiene and Toxicology. (3rd ed). New York: Wiley Interscience.

Health Council of the Netherlands: Dutch Expert Committee on Occupational Standards. (2001). n-, iso-, sec-, and tert-Butyl acetate; Health-based recommended occupational exposure limit. Hague: Health Council of the Netherlands.

Hunter. (1969). The diseases of occupations. (3rd ed). Boston: Little Brown.

Jacobson, L.D., Moon, R., Bicudo, J., Janni, K., Noll, S., Shurson, G., Zhu, J., Schmidt, D., McGinley, C., Goodrich, P., Nicolai, R., Clanton, C., Davis, K., Brosseau, L., Bruns, J., Pijoan, C., Blaha, T., Durgan, B. and Draeger, K. (2001). Generic Environmental Impact Statement on Animal Agriculture: A Summary of the Literature Related to Air Quality and Odor (H). Minnesota: Department of Agriculture and Minnesota Environmental Quality Board.

Kaley, K.B., and Salocks, C. (2003). Ammonia [online]. Available: www.oehha.ca.gov. [2006, October 27].

Key, M.M., Henschel, J., and Butler, R.N. (1977). Occupational diseases: A guide to their recognition. Washington DC: National Institute for Occupation Safety and Health.

Leonardos, G. A. (1974). A critical review of regulations for the control of odors. JAPCA.

Mahin, T.D. (2002). Measurement and Regulation of Odors in the USA [online]. Available: www.env.go.jp/en/air/odor/measure/02_1_4.pdf. [2006, October 14].

Ministry for the Environment New Zealand. (2003). Good Practice Guide for Assessing and Managing Odour in New Zealand. Wellington.

Ministry of environment (MOE) of Japan. (2002a). Control of Offensive Odor [online]. Available: www.env.go.jp/en/air/odor/odor.html. [2006, October 14].

Ministry of the Environment (MOE) of Japan. (2002b). Odor Measurement Review [online]. Available: www.env.go.jp/en/air/odor/measure. [2006, October 14].

Ministry of the Environment (MOE) of Japan. (2002c). Olfactory Measurement Method in Japan [online]. Available: www.env.go.jp/en/air/odor/olfactory_mm. [2006, October 14].

Ministry of the Environment (MOE) of Japan. (2002d). Olfactory Measurement Method Safety Management Manual [online]. Available: www.env.go.jp/en/air/odor/olfactory_mm/03safety.pdf. [2006, October 14].

Nagata, Y. (2002), Measurement of odor threshold by triangle odor bag method [online]. Available: www.env.go.jp/en/air/odor/measure/02_3_2.pdf. [2006, October 14].

Nagata, Y., Takeuchi N., Ishiguro, T., Hasegawa, T., Furukawa, O., Nakayama, S., and Shigeta, Y. (2006). Relationship between concentration of odorants and odor intensity. Japan Environmental Sanitation Center.

New Jersey Department of Health and Senior Services, (2001). n-Butyl Acetate [online]. Available: http://nj.gov/health/eoh/rtkweb/documents/fs/1329.pdf. [2007, February 19].

NICNAS. (1995). Full public report: Sodium ethyl xanthate. Canberra: Australian Government Printing Services.

NTIS. (1974). Hydrogen sulfide health effects and recommended air quality standard. Chicago: Illinois.

OEHHA (Office of Environmental Health Hazard Assessment). (1999). Determination of Acute Reference Exposure Levels for Airborne Toxicants, Acute Toxicity Summery: Methanol [online]. Available: www.oehha.ca.gov. [2007, March 4].

Panitch, N., Panitch, S., Limpasanee, W., Jongwisal, V., and Seardee, V. (2004). Air Pollution Treatment System Textbook. Bangkok: Department of Industrial Works. (in Thai)

Park, S.J. (2002)**.** The Regulation and Measurement of Odor in Korea [online]. Available: www.env.go.jp/en/air/odor/measure/02_1_5.pdf. [2006, October 14].

PCD (Pollution Control Department). (1998a). Monograph: Toluene. (2nd ed). Bangkok: Intergrated Promotion Technology. (in Thai)

PCD (Pollution Control Department). (1998b). Monograph: Styrene. (2nd ed). Bangkok: Intergrated Promotion Technology. (in Thai)

PCD (Pollution Control Department). (1998c). Monograph: Xylene. (2nd ed). Bangkok: Intergrated Promotion Technology. (in Thai)

PCD (Pollution Control Department). (2001). Material Safety Data Sheet (MSDS) [online]. Available: http://msds.pcd.go.th. [2007, February 19]. (in Thai)

PCD (Pollution Control Department). (2004). Project of odor treatment technology from wastewater treatment system and industry**.** Bangkok. (in Thai)

PCD (Pollution Control Department). (2007). Complaint statistics of environmental pollution during 2000-2005 [Excel file]. Bangkok. (Data from Inspection and Enforcement Division, Pollution Control Department on March 20, 2007).

Pritchard. J.D. (2006a). Ammonia General information [online]. Available: http://www.camr.org.uk. [2007, March 3].

Pritchard. J.D. (2006b). Methanol Toxicological overview [online]. Available: http://www.hpa.org.uk. [2007, March 3].

Rumack, B.H. (2007). POISINDEX**.** Information System Micromedex (Inc.).

Shults, W.T. (1970). Fountain EN and Lynch EC: Methanethiol poisoning. JAMA.

Spencer, L., Seager, Michael R., and Slabaugh. (2004). Chemistry for Today: general, organic, and biochemistry. Thomson Brooks/Cole.

Stuetz, R.M., and Frechen, F.B. (2001). Odour in Wastewater Treatment: Measurement, Modelling and Control. Cornwall: TJ International (Ltd).

Sweeten, J.M. (1995). Odor measurement technology and applications: A state-of-the-art review. Chicago: Illinois.

Thai Royal Institute. (2003). Royal Institute Dictionary B.E. 2542. Bangkok: Siriwattana Interprint. (in Thai)

Theodore, L., and Buonicore, A.J. (1988). Air pollution control equipment: gases. CRC Press.

TIAER. (1994). Final Report: Preliminary research concerning the character, sources and intensity of odors from diary operations in Erath County, Texas. Texas: Austin.

Toy, N.J. (1989). Final report on the safety assessment of ethyl acetate and butyl acetate. In: Health Council of the Netherlands: Dutch Expert Committee on Occupational Standards. (2001). n-, iso-, sec-, and tert-Butyl acetate; Health-based recommended occupational exposure limit. Hague: Health Council of the Netherlands.

U.S. EPA. (U.S. Environmental Protection Agency). (1994). Chemical summary for methanol. Office of Pollution Prevention and Toxics.

Vetchapas, C. (1997). Physiology of human 2. (3rd ed). Bangkok: Bunsiri. (in Thai)

VDI 3882 Part 1. (1992). Olfactometry, Determination of odour Intensity. Berlin: Verein Deutscher Ingenieure.

Wikipedia, the free encyclopedia. (2007). Propionic acid [online]. Available: http://en.wikipedia.org/wiki/Propionic_acid. [2007, October 26].

World Health Organization. (1981). Hydrogen sulfide. Geneva.

Zaleski, J. (1992). Butyl acetates. In: Health Council of the Netherlands: Dutch Expert Committee on Occupational Standards. (2001). n-, iso-, sec-, and tert-Butyl acetate; Health-based recommended occupational exposure limit. Hague: Health Council of the Netherlands.

Zwaardemaker, H. (1925). L 'Odorant. In Laing D.G., Doty R.L., and Breipohl, w. (1992). The Human Sense of Smell. Berlin: Springer-Verlag.

APPENDIX

APPENDIX A

CHEMICAL IDENTIFICATION AND TOXICITY TO HUMAN OF NINE ODOROUS SUBSTANCES

1. Ammonia

1.1 Chemical identification

Chemical identification of ammonia is summarized in Table A-1.

Table A-1: Chemical identification of ammonia

Properties	Information
IUPAC	Ammonia
Chemical name	Ammonia; Anhydrous
Synonyms	N-H; Ammonia, aqueous~Ammonia, solution
Molecular formula	NH_3
Structural formula	
Family	Alkaline Gas

Source: PCD, 2001

1.2 Toxicity of ammonia to human

1) Acute exposure

Anhydrous ammonia reacts with moisture in mucosal surfaces (eyes, skin, and respiratory tract) to produce ammonium hydroxide, which may cause caustic injury. Exposure to high levels of ammonia in air may be irritating to your skin, eyes, throat, and lungs and cause coughing and burns. Lung damage and death may occur after exposure to very high concentrations of ammonia (ATSDR, 2004). Table A-2 display concentration of ammonia and acute effects to human.

Table A-2: Acute effects of ammonia to human

Concentration (ppm)	Exposure time	Acute effects
5	5 minutes	Detectable by almost all persons. Some people complain of nose irritation
134	-	Most people experience dryness and irritation of nose, throat and eyes.
700	-	Coughing. Severe eye irritation, if not treated, may lead to partial or total loss of sight.
1,700	-	Serious lung damage, death unless treated.
2,000	-	Burns and blisters skin after a few seconds of exposure.
5,000	1 minute	Death by suffocation within minutes.

Source: Baker, 1993

2) Chronic exposure

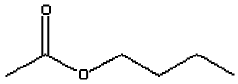
Repeated exposure may cause chronic skin, eye, and respiratory irritation. Chronic cough, asthma, and lung fibrosis may occur (Kaley and Salocks, 2003).

2. n-Butyl acetate

2.1 Chemical identification

Chemical identification of n-butyl acetate is summarized in Table A-3.

Table A-3: Chemical identification of n-butyl acetate

Properties	Information
IUPAC	Butyl ethanoate
Chemical name	Butyl acetate
Synonyms	1-Butyl Acetate; n-Butyl acetate; Acetic acid n-butyl ester
Molecular formula	$C_6H_{12}O_2$
Structural formula	
Family	Ester

Source: PCD, 2001

2.2 Toxicity of n-butyl acetate to human

1) Acute exposure

Human studies indicate that inhalation exposure to n-butyl acetate may cause slight irritation to the eyes, nose and throat; sensitivity to odor occurs at much lower concentrations than those at which irritation is reported (Copestake and Heath, 2005) as Table A-4.

The following acute (short-term) health effects may occur immediately or shortly after exposure to n-Butyl Acetate:

1.1) Skin and eye contact can cause severe irritation and burns.

1.2) Breathing n-Butyl Acetate can irritate the nose, throat and lungs causing coughing and/or shortness of breath (New Jersey Department of Health and Senior Services, 2001).

2) Chronic exposure

The following chronic (long-term) health effects can occur at some time after exposure to n-Butyl Acetate and can last for months or years: Prolonged exposure can cause rash, dryness and cracking of the skin. n-Butyl Acetate may cause an acne-like rash following skin contact. Repeated exposure may affect the nervous system causing headache, nausea, dizziness, muscle weakness, confusion and even passing out (New Jersey Department of Health and Senior Services, 2001).

Table A-4: Acute exposure of n-butyl acetate to human

Concentration (ppm)	Exposure time	Acute effects
145 ppm (700 mg/m^3)	4 hours	to be minimal irritation
200 ppm (970 mg/m^3)	3-5 minutes	to be irritating to the throat
300 ppm (1,450 mg/m^3)	-	to be irritating to the nose and the eyes (and severely to the throat)

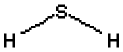
Source: Health Council of the Netherlands, 2001

3. Hydrogen sulphide

3.1 Chemical identification

Chemical identification of hydrogen sulphide is summarized in Table A-5.

Table A-5: Chemical identification of hydrogen sulphide

Properties	Information
IUPAC	Hydrogen sulphide
Chemical name	-
Synonyms	Hepatic acid; Stink Damp; Sulfureted Hydrogen; Hydrosulfuric acid; Sulfur hydride; Sewer gas; Sour gas; Sulfuretted hydrogen; H_2S
Molecular formula	H_2S
Structural formula	
Family	Nonmetal hydride

Source: PCD, 2001

3.2 Toxicity of hydrogen sulphide to human

1) Acute exposure

Hydrogen sulfide is a toxic and irritant gas whose major effects are experted on the nervous system, the eyes and the respiratory tract (Hunter, 1969). Table A-6 show acute exposure of hydrogen sulfide to human.

Table A-6: Acute exposure of hydrogen sulfide to human

Concentration	Exposure times	Acute effects
0.008 ppm (0.015 mg/m^3)	-	Undefined.
0.06 ppm (0.12 mg/m^3)	-	Increased incidence of mental depression, dizziness and blurred vision.
0.23 ppm (0.45 mg/m^3)	-	Increased incidence of nausea, loss of sleep, shortness of breath, and headaches following chronic exposure.
5-36 ppm (10-70 mg/m^3)	-	Irritation of conjunctivitis, fatigue, loss of appetite, and insomnia after chronic exposure.
36-78 ppm (70-150 mg/m^3)	-	Increased of eyes, i.e., conjunctivitis and keratitis with photophobia, after several hours of exposure.

Table A-6: Acute exposure of hydrogen sulfide to human (continued)

Concentration	Exposure times	Acute effects
78-160 ppm (150-300 mg/m^3)	1 hour	Irritation to respiratory tract and eyes.
	48 hours	Possible hemorrhage and death.
160-260 ppm (300-500 mg/m^3)	30 minutes	Irritation to respiratory tract and eyes and loss of sense of smell
	4-8 hours	Nervous system depression and slight systemic symptoms.
	48 hours	Hemorrhage and death.
260-360 ppm (500-700 mg/m^3)	30 minutes	Irritation to respiratory tract and eyes and loss of sense of smell.
	8 hours	Hemorrhage and death
360-470 ppm (700-900 mg/m^3)	30 minutes	Serious irritation to respiratory tract and eyes (conjuntiva and epithelium).
	1 hour	Slight systemic symptoms.
	4-8 hours	Unconsciousness and death.
470-750 ppm (900-1,400 mg/m^3)	30 minutes	Systemic symptoms.
	1 hour	Collapse, asphyxia, and death.
750-1,450 ppm (1,400-2,800 mg/m^3)	30 minutes	Immediate systemic symptoms i.e., apnea, collapse, hyperpnea, sphyxia, and death.
> 1,450 ppm (> 2,800 mg/m^3)	-	Systemic effects predominate over local irritant effects. Paralysis of respiratory center, immediate death.

Source: NTIS, 1974

2) Chronic exposure

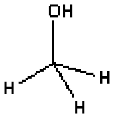
Chronic poisoning may be defined as a prolonged state of symptoms or a debilitated condition which results from a single or repeated long duration exposure to concentrations of hydrogen sulphide that, in themselves, do not produce symptoms of acute or subacute poisoning. The occurrence of neurasthenic symptoms which cannot be explained otherwise have usually constituted the meager basis of the diagnosis of chronic hydrogen sulphide poisoning. A well documented threshold for poisoning does not exist, and there is wide disagreement concerning the very existence of the pathological state defined as chronic poisoning. Therefore, the general feature of chronic poisoning may occur this symptom including local irritation of the eyes and respiratory tract, bradycardia, cold sweats, fatigue, gastrointestinal, disturbances, headache, mental depression, chills and abdominal peripheral reflexes indicative of depression of the nervous system (NTIS, 1974).

4. Methanol

4.1 Chemical identification

Chemical identification of methanol is summarized in Table A-7.

Table A-7: Chemical identification of methanol

Properties	Information
IUPAC	Methanol
Chemical name	Methyl alcohol
Synonyms	Wood alcohol; Carbinol; Methylol; Wood; Columbian spirits; Colonial spirit; Columbian spirit; Methyl hydroxide; Monohydroxymethane; Pyroxylic spirit; Wood naphtha; Wood spirit
Molecular formula	CH_4O
Structural formula	
Family	Aliphatic alcohol

Source: PCD, 2001

4.2 Toxicity of methanol to human

1) Acute exposure

Methanol is easily absorbed following ingestion, inhalation, or dermal exposure and is metabolized by the liver to formaldehyde, then formate. The latter metabolite is responsible for the metabolic acidosis and ocular effects characteristic of acute methanol poisoning. Odor and irritation are not adequate warnings of overexposure to methanol. Upon ingestion or inhalation, methanol initially has a narcotic effect followed by an asymptomatic period of approximately 10 to 15 hours. After this period, methanol may produce nausea, vomiting, dizziness, headaches, vertigo, respiratory difficulty, lethargy, and abdominal pain, pain in the extremities, visual disturbances, and metabolic acidosis. The visual disturbances vary from spots or cloudiness of vision to complete blindness. Methanol toxicity can result in coma and death by respiratory or cardiac arrest (OEHHA, 1999). Table A-8 display acute exposure of methanol to human.

Table A-8: Acute exposure of methanol to human

Concentration (ppm)	Exposure times	Effects
200-375	-	Severe recurrent headaches
1,200 - 8,300	-	Diminution of vision and enlargement of the liver
25,000	-	Immediately Dangerous to Life or Health

Source: ACGIH, 1986

2) Chronic exposure

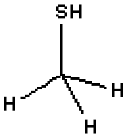
There is limited data on the effects of chronic effects of methanol exposure in humans. However, chronic inhalation exposure to low concentrations of methanol may result in headache, eye irritation and dermatitis (Pritchard, 2006).

5. Methyl mercaptan

5.1 Chemical identification

Chemical identification of methyl mercaptan is summarized in Table A-9.

Table A-9: Chemical identification of methyl mercaptan

Properties	Information
IUPAC	Methyl mercaptan
Chemical name	-
Synonyms	Mercaptomethane; Methanethiol; Methylthioalcohol; Methyl Sulfhydrate; Thiomethanol; Methanethiol-SD (gas); Methyl mercaptain
Molecular formula	CH_4S
Structural formula	
Family	-

Source: PCD, 2001

5.2 Toxicity of methyl mercaptan to human

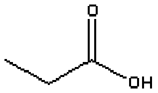
Inhalation of Methyl mercaptan at mild level causes irritation of mucous membranes of the nose and respiratory tract (Key et al., 1977). If inhalation of Methyl mercaptan at high level causes coma and hematologic effect (Shults et al, 1970). Very little is known about the health effects of methyl mercaptan. The only information available is about a worker exposed to very high levels of this compound when he opened and emptied tanks of this compound. He developed anemia, went into a coma, and died about a month later. We do not know whether long-term exposure to low levels of methyl mercaptan can result in harmful health effects such as cancer, birth defects, or problems with reproduction (ATSDR, 1999).

6. Propionic acid

6.1 Chemical identification

Chemical identification of propionic acid is summarized in Table A-10.

Table A-10: Chemical identification of propionic acid

Properties	Information
IUPAC	Propanoic Acid
Chemical name	Propionic Acid
Synonyms	Carboxyethane; Tenox P Grain Preservative; Sentry Grain Preservative; Hydroacrylic acid; Methylacetic acid; Ethylformic acid; Luprosil; Ethanecarboxylic acid; Metacetonic acid; Prozoin; Pseudoacetic acid; Sentry grain preserver; Bugle; Propcorn; (Nat. C-3 Acid)
Molecular formula	$C_3H_6O_2$
Structural formula	
Family	Carboxylic acid

Source: PCD, 2001

6.2 Toxicity of propionic acid to human

1) Acute exposure

Propionic acid is an irritant to skin, eyes and mucous membranes. (Guest; Katz and Astill, 1982) Inhalation may result in dyspnea, pleuritic chest pain, pulmonary edema, hypoxemia, bronchospasm, pneumonitis, tracheobronchitis and persistent pulmonary function abnormalities. Pulmonary dysfunction similar to asthma has been reported. The onset of respiratory symptoms may be delayed for several hours (Rumack, 2007).

2) Chronic exposure

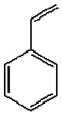
Prolonged or repeated exposure to chromic acid mist can result in dermatitis. Ulcerations may also occur (Rumack, 2007).

7. Styrene

7.1 Chemical identification

Chemical identification of styrene is summarized in Table A-11.

Table A-11: Chemical identification of styrene

Properties	Information
IUPAC	Phenylethene
Chemical name	Styrene; Vinyl benzene
Synonyms	Phenylethylene ; Styrol ; Cinnamene; Ethenylbenzene; Annamene; Styrolene; Cinnamene; Cinnamol; Cinnamenol; Styron; Diarex HZ 77 Styrolene; Phenethylene; Styropol; Styropor; Vinylbenzol; Styrene monomer
Molecular formula	C_8H_8
Structural formula	
Family	Aromatic Hydrocarbons

Source: PCD, 2001

7.2 Toxicity of styrene to human

Symptoms occur from acute exposure of styrene is irritation of the eye and throat, dizziness, nausea, and vomiting as for the chronic effects have not data to toxicity (PCD, 1998b). Table A-12 show acute poisoning of styrene to human.

Table A-12: Acute poisoning of styrene to human

Concentration (ppm)	Exposure times	Effects
100	-	No effect except the temporary irritation of eyes and throat.
200	2-3 minutes	Fatigue, dizziness, nausea, and stupor.
350	1 hour	Irritation of the eye and upper respiratory tract.
2,500	8 hours	Can cause death.
10,000	30-60 minutes	Can cause death.

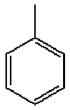
Source: PCD, 2001

8. Toluene

8.1 Chemical identification

Chemical identification of toluene is summarized in Table A-13.

Table A-13: Chemical identification of toluene

Properties	Information
IUPAC	Methyl-Benzene
Chemical name	Toluene; Phenyl methane
Synonyms	Toluol; Methylbenzol; Monomethyl benzene; Methacide; Tolu-sol; Antisal 1a; Tol
Molecular formula	C_7H_8
Structural formula	
Family	Aromatic Hydrocarbons

Source: PCD, 2001

8.2 Toxicity of toluene to human

1) Acute exposure

Acute exposures to toluene are dizziness, headaches, loss of coordination, and toxicity severe over than benzene (PCD, 1998a). Table A-14 show acute poisoning of toluene to human.

2) Chronic exposure

Repeated high-dose exposures associated with solvent abuse can result in impairment of co-ordination and reaction time moreover, irritation of the skin and inflame skin (PCD, 1998a).

Table A-14: Acute poisoning of toluene to human

Concentration (ppm)	Exposure times (hours)	Effects
10-15	-	Odor detection threshold
50-100	-	No effect
200-300	8	Distinct impairment of reaction time and body balance.
400	8	Scatter brain and dizziness.
600-800	3	Fatigue, dizziness, headaches, loss of coordination, nausea, and stupor.
> 800	-	Anemia and liver function was not demonstrated.

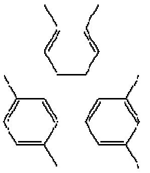
Source: PCD, 1998a

9. Xylene

9.1 Chemical identification

Chemical identification of xylene is summarized in Table A-15.

Table A-15: Chemical identification of xylene

Properties	Information
IUPAC	Dimethylbenzene
Chemical name	Xylene
Synonyms	Xylol; Dimethylbenzene (mixed isomers); Xylene (mixed isomers); Xylenes mixed isomers; Xylenes (o-, m-, p-isomers); Xylene mixture (60% m-xylene, 9% o-xylene, 14% p-xylene, 17% ethylbenzene); Xylene (mixed); Xylene (o-, m-, p-isomers); Except p-xylene, mixed or all isomers; Xylene, mixed or all isomers, except p-; M & p-xylene; Xylenes (mixed); Xylene mixture (m-xylene, o-xylene, p-xylene); Total xylenes; M-,p-,o-Xylene; O-,m-,p-Xylene; Xylene, (total); Xylene mixture; Socal aquatic solvent 3501; Xylenes ; Xylene (o-,m-,p-)
Molecular formula	$C_6H_4(CH_3)_2$
Structural formula	
Family	Aromatic Hydrocarbons

Source: PCD, 2001

9.2 Toxicity of xylene to human

1) Acute exposure

Acute poisoning will occur when expose higher concentration of 200 ppm. These effects are dizziness, headache, nausea, vomiting, sore throat and chest, symptom of respiratory tract i.e. cough; runny nose, and irritation of the eye and skin (PCD, 1998c). Table A-16 show acute poisoning of xylene to human.

Table A-16: Acute poisoning of xylene to human

Pathway to body	Number of volunteers	Concentration	Effects
eye	6	460 ppm (1,980 mg/m^3)	Four of six volunteers were eye irritation after exposure
skin	-	undiluted	Skin irritation
inhalation	6	0.2-1 ppm (1-4.3 mg/m^3)	Odor detection threshold
Inhalation	6	40 ppm (17.2 mg/m^3)	Identification threshold
Inhalation	10	100 ppm (431.0 mg/m^3)	Threshold limit value - time weight average (TLV-TWA)
Inhalation	10	200 ppm (860 mg/m^3)	Irritation of the eye, nose, and throat for 3-5 minutes
Inhalation	-	110-460 ppm (472-1,980 mg/m^3)	Irritation of the eye, nose, and throat
inhalation	3	estimate 10,000 ppm (43,100 mg/m^3) about 18.5 hours	One volunteer was death because of hyperemia in the lung and cerebral hemorrhage as for two volunteers were unconscious 19-24 hours furthermore maybe memory difficulties and hypothermia.

Source: PCD, 1998a

2) Chronic exposure

Symptoms occur from long period exposure of xylene will similar acute exposure but symptoms maybe severe over. If expose fumes prolong can cause irritation of the skin, eyes, nose, and throat. If expose liquid of xylene directly skin disease will occur. If inhale vapor of xylene can cause headaches, lack of muscle coordination, dizziness, confusion, changes in one's sense of balance, difficulty in breathing, problems with the lungs, delayed reaction time, memory difficulties, stomach discomfort, and possibly changes in the liver and kidneys.

APPENDIX B
CALIBRATION OF ROTAMETER

1. Result of Calibrating Air Flow Rate

Calibrating the air flow rate twice are before the determination of odor intensity will start and the determination of odor intensity will be finished manifest relationship equation between dry test gas meter (Model: DC-1) and rotameter at various air flow rate as follow.

1.1) The result of first calibration of rotameter get the equation is $y_1 = 1.0206x_1 - 0.0467$ whereas, x_1 means air flow rate from rotameter in first calibration, and y_1 means air flow rate from first calibration. Figure B-1 show the result of first calibration of rotameter.

1.2) The result of second calibration of rotameter get the equation is $y_2 = 1.0040x_2 + 0.0064$ whereas, x_2 means air flow rate from rotameter in second calibration, and y_2 means air flow rate from second calibration. Figure B-2 show the result of second calibration of rotameter.

2. Calculation of Actual Air Flow Rate

Actual air flow rate can be calculated by the average of calibration of air flow rate twice. Table B-1 show actual air flow rate.

Table B-1: Air flow rate from rotameter compare with the dry test gas meter

Air flow rate of rotameter reading (l/min)	Air flow rate from first calibration (l/min)	Air flow rate from second calibration (l/min)	Average actual air flow rate (l/min)
5.0	5.0563	5.0264	5.04
4.9	4.9542	4.9260	4.94
4.8	4.8522	4.8256	4.84
4.7	4.7501	4.7252	4.74
4.6	4.6481	4.6248	4.64
4.5	4.5460	4.5244	4.53
4.5	4.5460	4.5244	4.53
4.4	4.4439	4.4240	4.43
4.3	4.3419	4.3236	4.43
4.2	4.2398	4.2232	4.23
4.1	4.1378	4.1228	4.13
4.0	4.0357	4.0224	4.03

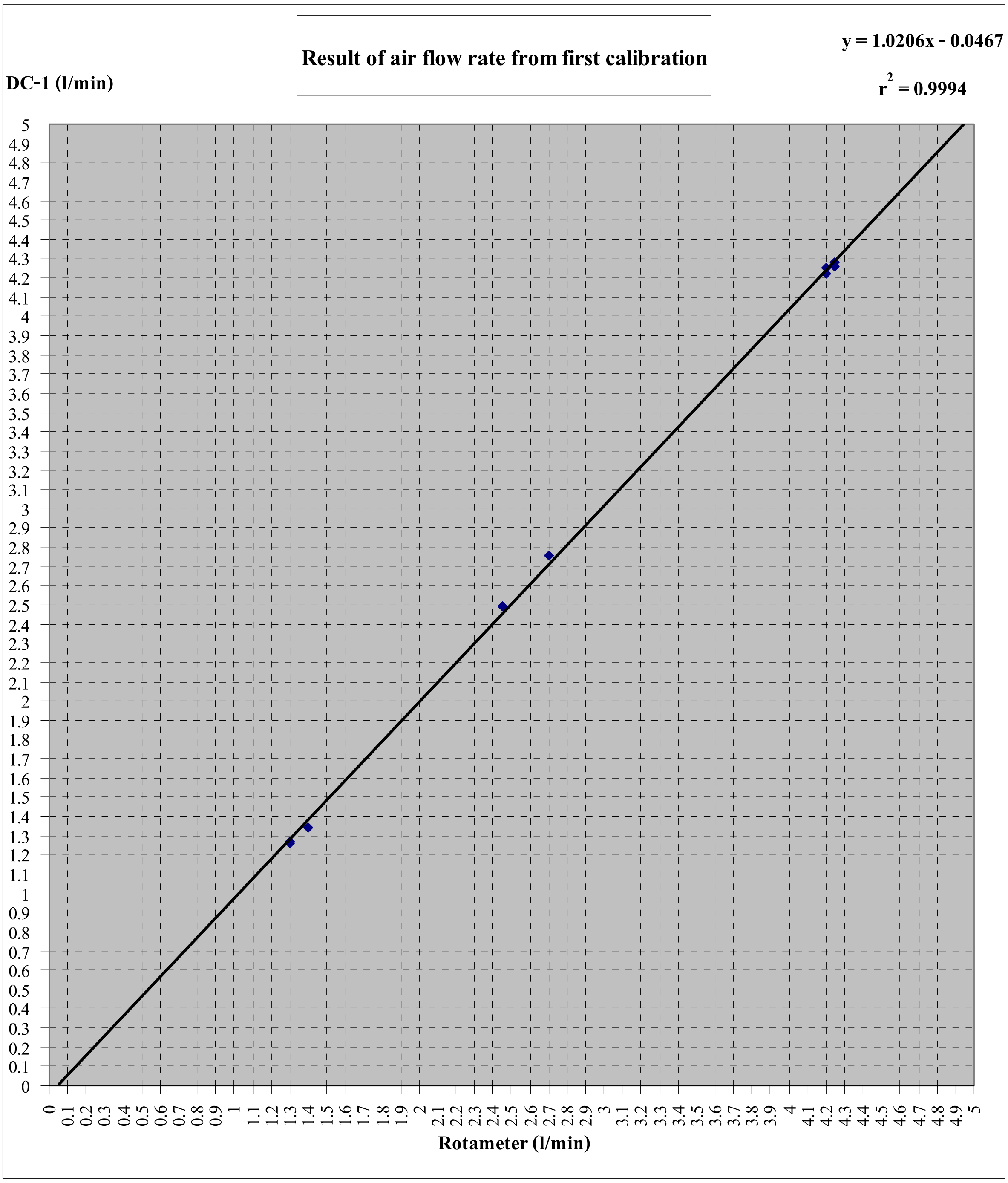


Figure B-1: The result of first calibration of rotameter

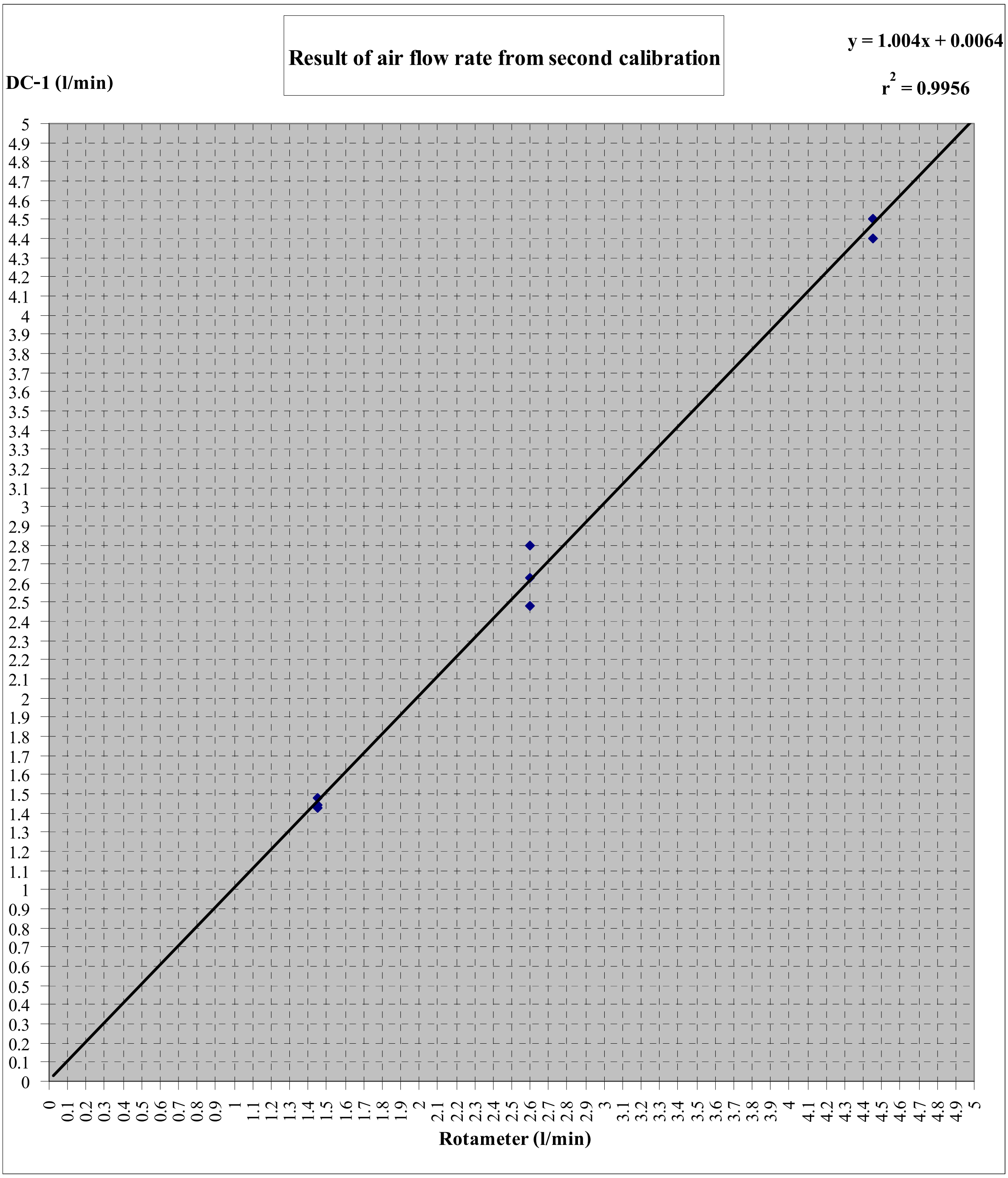


Figure B-2: The result of second calibration of rotameter

APPENDIX C

CALCULATION METHOD OF ODORANT CONCENTRATION

Table C-1: Data for calculation of sample concentration

Chemical reagents	Molecular Weights [a]	Density (g/ml) [b]	Purity (%) [b]
n-Butyl acetate	116.18	0.882	≥ 99.68
Methanol	32.04	0.791-0.793	≥ 99.9
Propionic acid	74.08	0.992	≥ 99.9
Styrene	104.15	0.904-0.908	≥ 99.9
Toluene	92.13	0.865-0.870	≥ 99.9
Xylene	106.16	0.865-0.869	≥ 99.8
Standard gases	**Concentration (ppm)[b]**		
Ammonia	48.9		
Hydrogen sulfide	48.2		
Methyl mercaptan	47.2		

Notes: 1) Purity of chemical reagents is high value, so calculation will be assumed to 100 %.

2) Volume is volume of clean air must fill to odor test bag.

3) Inject is volume of air sample which suck from odor sample bag for inject to odor test bag.

[a] data from PCD, 2001

[b] data from certificate of analysis report

1. Calculation of liquid reagents

1.1 Equation for calculation of concentration inside odor sample bag volume 20 liters

Equation 1:

$$\boxed{M = DV}$$

Whereas; M means mass of sample reagents for inject to odor sample bag, volume 20 liters (g).

D means density of sample reagents.

V means volume of sample reagents for inject to odor sample bag, volume 20 liters (µl).

Equation 2:

The unit converts equation from ppm into µg/m^3 (at temperature of 0°C and atmospheric presser of 1 bar).

$$B\ (\mu g/m^3) = \frac{N_1\ (ppm)\ X\ MW\ (g)\ X\ 10^3}{22.41}$$

Whereas; N_1 means concentration within odor sample bag, volume 20 liters (ppm)

B means mass of sample reagents for inject to odor sample bag, volume 20 liters (g/ml)

MW means molecular weight of sample reagents (g)

In this research, condition of test is temperature of 28°C and atmospheric presser of 1 bar.

So; $$B\ (\mu g/m^3) = \frac{N_1\ (ppm)\ X\ MW\ (g)\ X\ 10^3}{22.41\ X\ (T_{actual}/\ T_{standard})\ X\ (P_{standard}/P_{actual})}$$

$$B\ (\mu g/m^3) = \frac{N_1\ (ppm)\ X\ MW\ (g)\ X\ 10^3}{22.41\ X\ [(273+28)/(273+0)]\ X\ (1/1)}$$

$$B\ (\mu g/m^3) = \frac{N_1\ (ppm)\ X\ MW\ (g)\ X\ 10^3}{24.71}$$

Therefore, new equation as follow

$$\boxed{\mathbf{N_1\ (ppm) = \frac{B\ (\mu g/m^3)\ X\ 24.71\ X\ 10^3}{MW\ (g)}}}$$

1.2 Equation for calculation of concentration inside odor test bag volume 3 liters

Equation as follow:

From $\mathbf{N_1V_1 = N_2V_2}$

Therefore $$\boxed{\mathbf{N_2 = \frac{N_1V_1}{V_2}}}$$

Whereas; N_1 means concentration of gas sample inside odor sample bag, volume 20 liters (ppm).

N_2 means concentration of gas sample inside odor test bag, volume 3 liters (ppm) or Conc. in Table 3-5.

V_1 means volume of gas sample from odor sample bag, volume 20 liters for inject to odor test bag, volume 3 liters or Inject in Table 3-5 (ml).

V_2 means all volume of air inside odor test bag, volume 3 liters or Tot. vol. in Table 3-5 (ml).

1.3 Example of calculation of xylene

1.3.1 Calculation of concentration inside odor sample bag, volume 20 liters

From equation: $M = DV$

(Table 3-3, define V = 1 µl = 10^{-3} ml; and Table C-1, define density of xylene = 0.865 – 0.869 g/ml which use average of density = 0.867 g/ml and molecular weight of xylene = 106.16 g)

$$M = 0.867 \text{ (g/ml)} \times 10^{-3} \text{ (ml)} \times 10^{6} \text{ (µg/g)}$$

$$M = 0.867 \times 10^{3} \text{ µg}$$

Volume of air inside odor sample bag, volume 20 L = 20.33 L = 20.33×10^{-3} m^3

Therefore, concentration of xylene (µg/m^3) $= \dfrac{0.867 \times 10^{3}}{20.33 \times 10^{-3}}$ (µg/ m^3)

$= 42.646 \times 10^{3}$ (µg/ m^3)

.

From $N_1 \text{ (ppm)} = \dfrac{B \text{ (µg/m}^3) \times 24.71 \times 10^{3}}{MW \text{ (g)}}$

$$N_1 \text{ (ppm)} = \frac{42.646 \times 10^{3} \times 24.71 \times 10^{3}}{106.16 \text{ (g)}}$$

$$N_1 \text{ (ppm)} = 9.926 \text{ ppm}$$

1.3.2 Calculation of concentration inside odor test bag, volume 3 liters

From equation: $N_2 = \dfrac{N_1 V_1}{V_2}$

(At Set 1 of xylene in Table 3-3 define N_1 = 9.926 ppm, and Table 3-6 define V_1 = 300 ml and V_2 = 3,000 ml)

$$N_2 = \frac{9.926 \text{ (ppm)} \times 300 \text{ (ml)}}{3{,}000 \text{ (ml)}}$$

Therefore, N_2 = 0.993 ppm

2. Calculation of gas reagents

2.1 Equation for calculation of concentration inside odor test bag volume of 3 liters

Because of sample substances were gas and verified concentration by produce agencies which has certificate of analysis report therefore the concentration can be used directly calculation. Concentration calculation in odor test bag, volume 3 liters can be calculated as follow:

From equation:

$$N_1V_1 = N_2V_2$$

Therefore

$$\boxed{N_2 = \frac{N_1V_1}{V_2}}$$

Whereas:

N_1 means concentration of gas sample inside odor sample bag, volume 20 liters (ppm) follow on Table 3-4 or C-1

N_2 means concentration of gas sample inside odor test bag, volume 3 liters (ppm)

V_1 means volume of gas sample from odor sample bag, volume 20 liters for inject to odor test bag, volume 3 liters or Inject in Table 3-6 (ml)

V_2 means all volume of air inside odor test bag, volume 3 liters or Tot. vol. in Table 3-6 (ml)

2.2 Example of calculation of hydrogen sulfide

From equation:

$$N_2 = \frac{N_1V_1}{V_2}$$

(At Set 1 of hydrogen sulfide in Table 3-4 or Table C-1 define $N_1 = 48.2$ ppm and Table 3-6 define $V_1 = 45$ ml and $V_2 = 3{,}045$ ml)

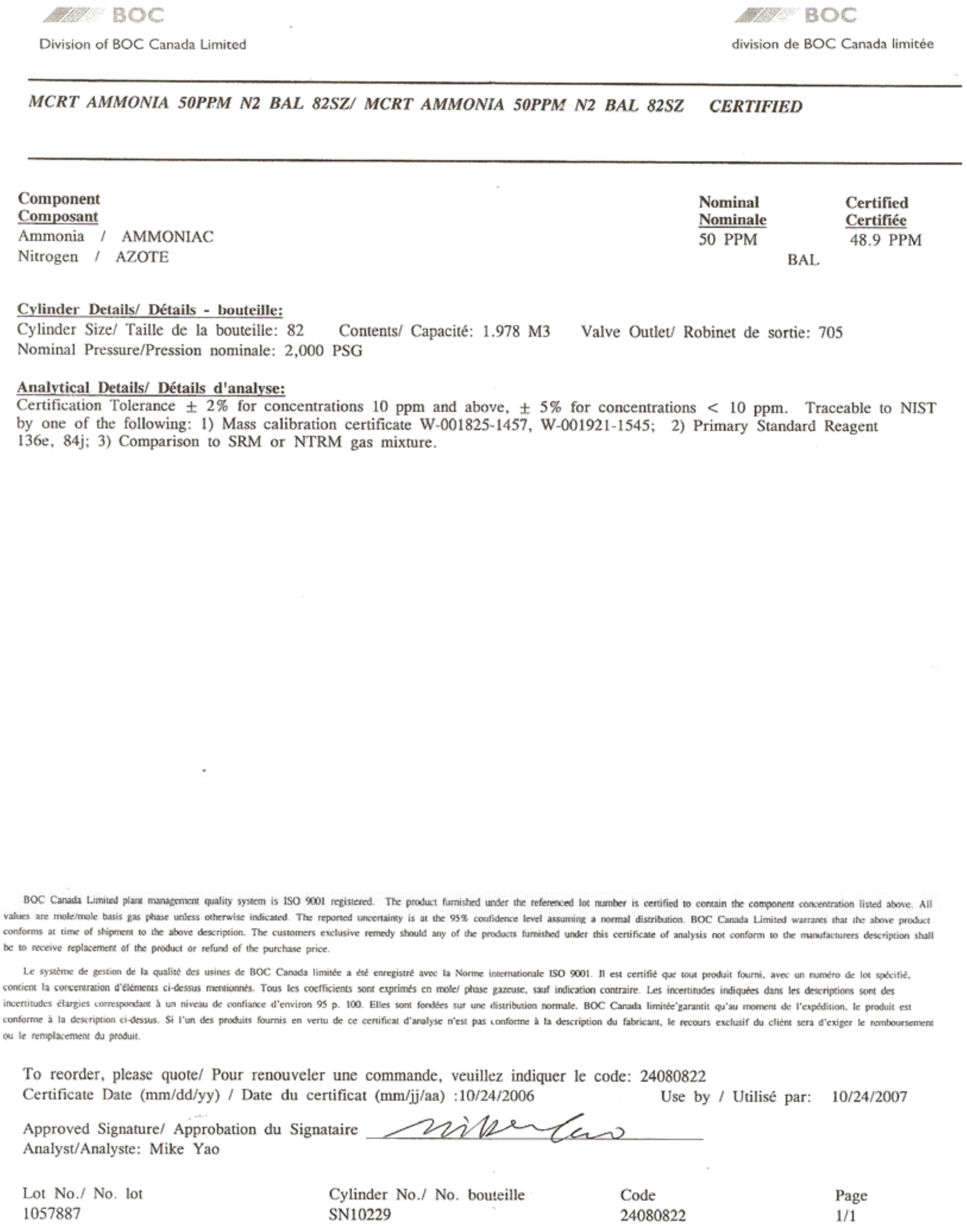
$$N_2 = \frac{48.2\ (\text{ppm}) \times 45\ (\text{ml})}{3{,}045\ (\text{ml})}$$

$$N_2 = 0.71 \quad \text{ppm}$$

APPENDIX D

CERTIFICATE OF ANALYSIS REPORT OF THE THREE GASEOUS ODORANT STANDARDS

1. Certificate of analysis report of ammonia



BOC
Division of BOC Canada Limited

BOC
division de BOC Canada limitée

MCRT AMMONIA 50PPM N2 BAL 82SZ/ MCRT AMMONIA 50PPM N2 BAL 82SZ **CERTIFIED**

Component **Composant**	**Nominal** **Nominale**	**Certified** **Certifiée**
Ammonia / AMMONIAC	50 PPM	48.9 PPM
Nitrogen / AZOTE	BAL	

Cylinder Details/ Détails - bouteille:
Cylinder Size/ Taille de la bouteille: 82 Contents/ Capacité: 1.978 M3 Valve Outlet/ Robinet de sortie: 705
Nominal Pressure/Pression nominale: 2,000 PSG

Analytical Details/ Détails d'analyse:
Certification Tolerance ± 2% for concentrations 10 ppm and above, ± 5% for concentrations < 10 ppm. Traceable to NIST by one of the following: 1) Mass calibration certificate W-001825-1457, W-001921-1545; 2) Primary Standard Reagent 136e, 84j; 3) Comparison to SRM or NTRM gas mixture.

BOC Canada Limited plant management quality system is ISO 9001 registered. The product furnished under the referenced lot number is certified to contain the component concentration listed above. All values are mole/mole basis gas phase unless otherwise indicated. The reported uncertainty is at the 95% confidence level assuming a normal distribution. BOC Canada Limited warrants that the above product conforms at time of shipment to the above description. The customers exclusive remedy should any of the products furnished under this certificate of analysis not conform to the manufacturers description shall be to receive replacement of the product or refund of the purchase price.

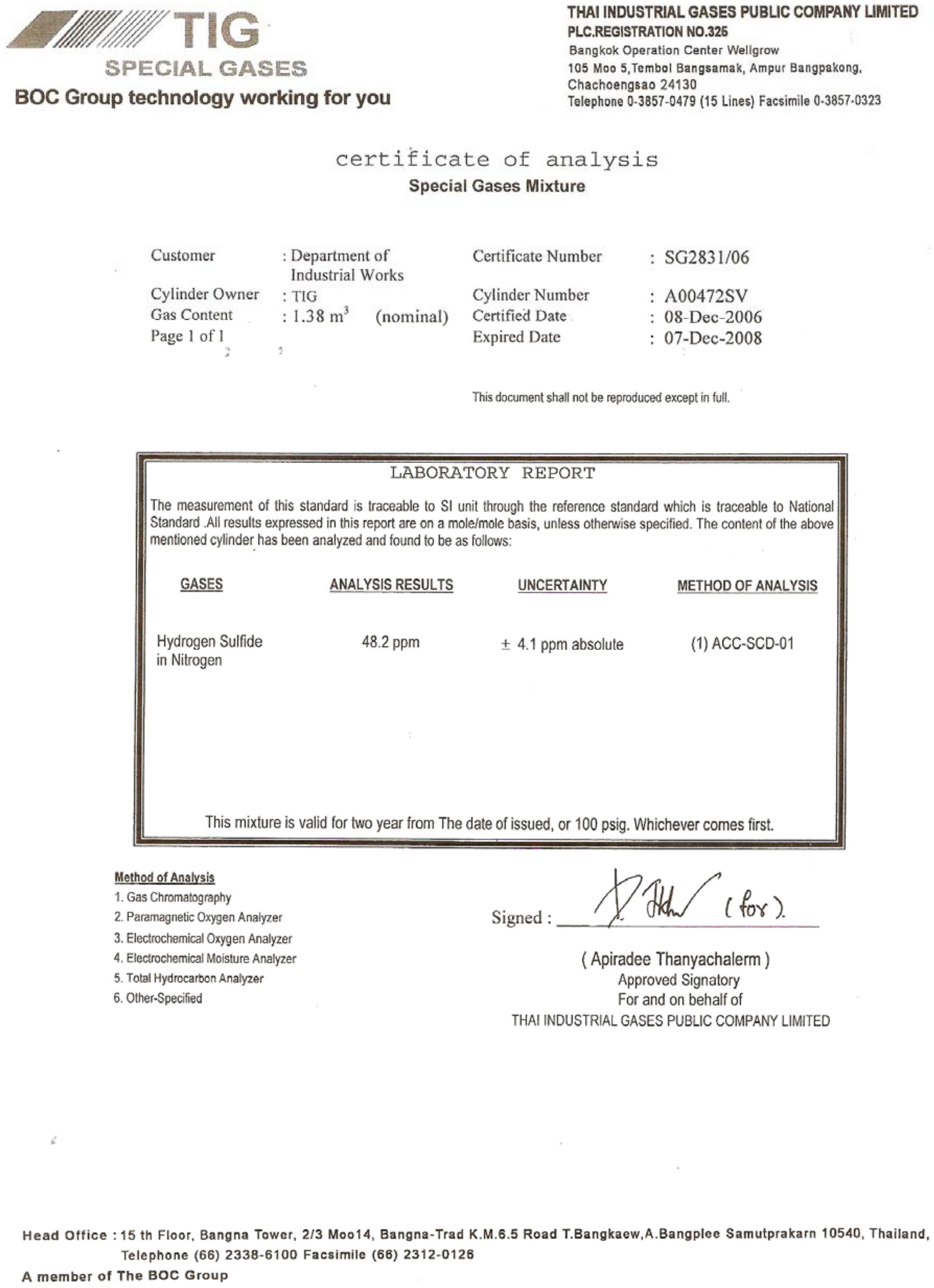
Le système de gestion de la qualité des usines de BOC Canada limitée a été enregistré avec la Norme internationale ISO 9001. Il est certifié que tout produit fourni, avec un numéro de lot spécifié, contient la concentration d'éléments ci-dessus mentionnés. Tous les coefficients sont exprimés en mole/ phase gazeuse, sauf indication contraire. Les incertitudes indiquées dans les descriptions sont des incertitudes élargies correspondant à un niveau de confiance d'environ 95 p. 100. Elles sont fondées sur une distribution normale. BOC Canada limitée'garantit qu'au moment de l'expédition, le produit est conforme à la description ci-dessus. Si l'un des produits fournis en vertu de ce certificat d'analyse n'est pas conforme à la description du fabricant, le recours exclusif du client sera d'exiger le remboursement ou le remplacement du produit.

To reorder, please quote/ Pour renouveler une commande, veuillez indiquer le code: 24080822
Certificate Date (mm/dd/yy) / Date du certificat (mm/jj/aa) :10/24/2006 Use by / Utilisé par: 10/24/2007

Approved Signature/ Approbation du Signataire
Analyst/Analyste: Mike Yao

Lot No./ No. lot	Cylinder No./ No. bouteille	Code	Page
1057887	SN10229	24080822	1/1

2. Certificate of analysis report of hydrogen sulphide



TIG
SPECIAL GASES
BOC Group technology working for you

THAI INDUSTRIAL GASES PUBLIC COMPANY LIMITED
PLC.REGISTRATION NO.325
Bangkok Operation Center Wellgrow
105 Moo 5,Tembol Bangsamak, Ampur Bangpakong,
Chachoengsao 24130
Telephone 0-3857-0479 (15 Lines) Facsimile 0-3857-0323

certificate of analysis

Special Gases Mixture

Customer	: Department of Industrial Works	Certificate Number	: SG2831/06
Cylinder Owner	: TIG	Cylinder Number	: A00472SV
Gas Content	: 1.38 m^3 (nominal)	Certified Date	: 08-Dec-2006
Page 1 of 1		Expired Date	: 07-Dec-2008

This document shall not be reproduced except in full.

LABORATORY REPORT

The measurement of this standard is traceable to SI unit through the reference standard which is traceable to National Standard .All results expressed in this report are on a mole/mole basis, unless otherwise specified. The content of the above mentioned cylinder has been analyzed and found to be as follows:

GASES	ANALYSIS RESULTS	UNCERTAINTY	METHOD OF ANALYSIS
Hydrogen Sulfide in Nitrogen	48.2 ppm	± 4.1 ppm absolute	(1) ACC-SCD-01

This mixture is valid for two year from The date of issued, or 100 psig. Whichever comes first.

Method of Analysis

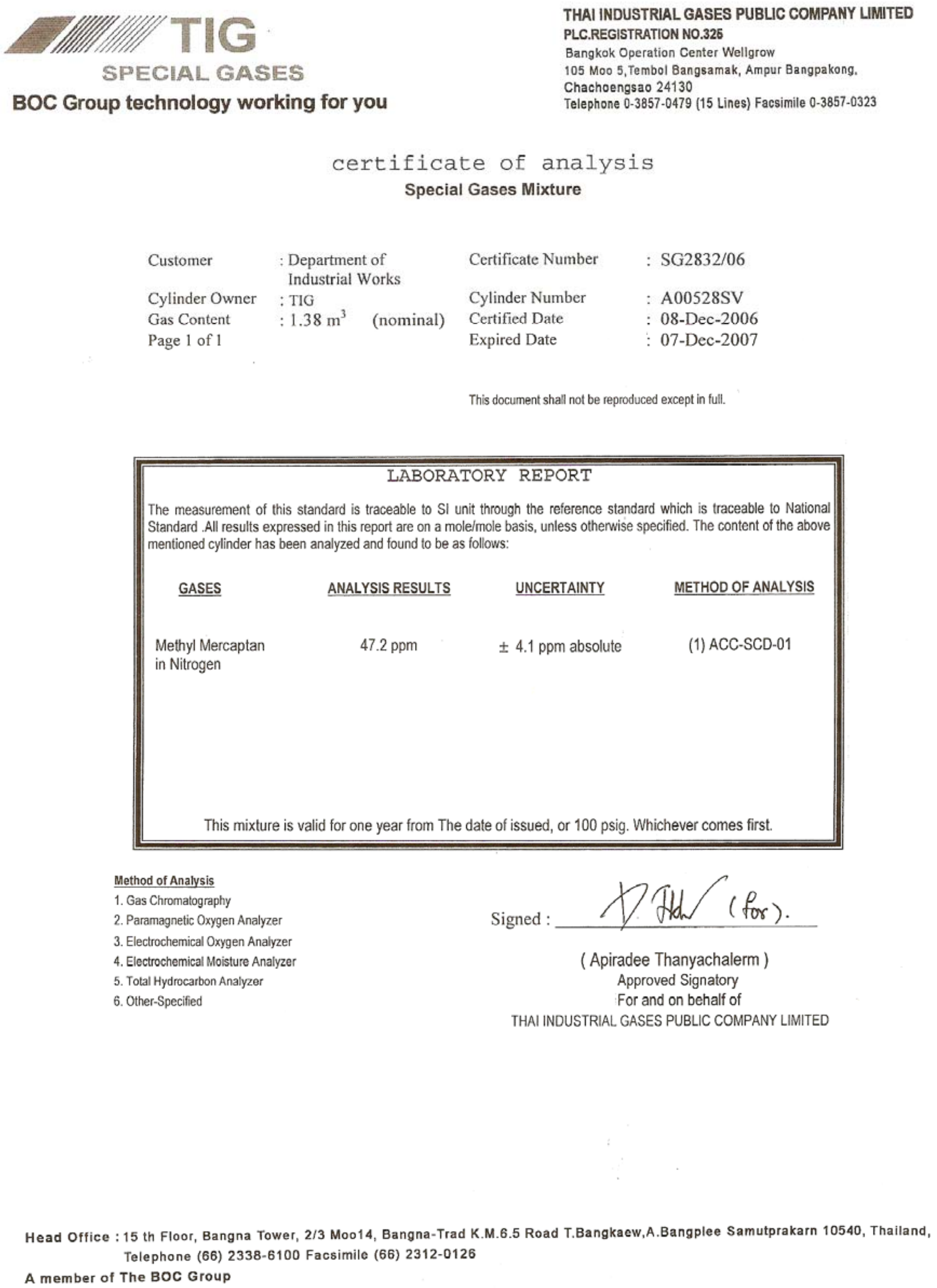
1. Gas Chromatography
2. Paramagnetic Oxygen Analyzer
3. Electrochemical Oxygen Analyzer
4. Electrochemical Moisture Analyzer
5. Total Hydrocarbon Analyzer
6. Other-Specified

Signed : (for).

(Apiradee Thanyachalerm)
Approved Signatory
For and on behalf of
THAI INDUSTRIAL GASES PUBLIC COMPANY LIMITED

Head Office : 15 th Floor, Bangna Tower, 2/3 Moo14, Bangna-Trad K.M.6.5 Road T.Bangkaew,A.Bangplee Samutprakarn 10540, Thailand,
Telephone (66) 2338-6100 Facsimile (66) 2312-0126
A member of The BOC Group

3. Certificate of analysis report of methyl mercaptan



TIG
SPECIAL GASES
BOC Group technology working for you

THAI INDUSTRIAL GASES PUBLIC COMPANY LIMITED
PLC.REGISTRATION NO.326
Bangkok Operation Center Wellgrow
105 Moo 5,Tembol Bangsamak, Ampur Bangpakong,
Chachoengsao 24130
Telephone 0-3857-0479 (15 Lines) Facsimile 0-3857-0323

certificate of analysis
Special Gases Mixture

Customer : Department of Industrial Works
Cylinder Owner : TIG
Gas Content : 1.38 m^3 (nominal)
Page 1 of 1

Certificate Number : SG2832/06
Cylinder Number : A00528SV
Certified Date : 08-Dec-2006
Expired Date : 07-Dec-2007

This document shall not be reproduced except in full.

LABORATORY REPORT

The measurement of this standard is traceable to SI unit through the reference standard which is traceable to National Standard .All results expressed in this report are on a mole/mole basis, unless otherwise specified. The content of the above mentioned cylinder has been analyzed and found to be as follows:

GASES	ANALYSIS RESULTS	UNCERTAINTY	METHOD OF ANALYSIS
Methyl Mercaptan in Nitrogen	47.2 ppm	± 4.1 ppm absolute	(1) ACC-SCD-01

This mixture is valid for one year from The date of issued, or 100 psig. Whichever comes first.

Method of Analysis

1. Gas Chromatography
2. Paramagnetic Oxygen Analyzer
3. Electrochemical Oxygen Analyzer
4. Electrochemical Moisture Analyzer
5. Total Hydrocarbon Analyzer
6. Other-Specified

Signed : (for).

(Apiradee Thanyachalerm)
Approved Signatory
For and on behalf of
THAI INDUSTRIAL GASES PUBLIC COMPANY LIMITED

Head Office : 15 th Floor, Bangna Tower, 2/3 Moo14, Bangna-Trad K.M.6.5 Road T.Bangkaew,A.Bangplee Samutprakarn 10540, Thailand,
Telephone (66) 2338-6100 Facsimile (66) 2312-0126
A member of The BOC Group

APPENDIX E
THE ARITHMETIC MEAN OF
ODOR INTENSITY FOR EACH CONCENTRATION SET

Table E-1: The arithmetic mean of odor intensity for each concentration set of ammonia

Series	Concentration (ppm)				
	0.340	**1.006**	**2.876**	**7.738**	**17.687**
1	0	0.25	0.5	1.25	3
2	1.5	0.75	1.75	1.5	2
3	0.75	0	1	1.75	3

Table E-2: The arithmetic mean of odor intensity for each concentration set of n-butyl acetate

Series	Concentration (ppm)					
	0.086	**0.286**	**0.857**	**2.851**	**8.496**	**27.682**
1	1	1.75	3.5	3.5	4.5	4.75
2	1.25	1.5	2.75	2.75	4	5
3	0.75	1.5	2	3	4	5

Table E-3: The arithmetic mean of odor intensity for each concentration set of hydrogen sulfide

Series	Concentration (ppm)					
	0.0032	**0.0096**	**0.032**	**0.080**	**0.240**	**0.712**
1	0.75	2.25	2.5	3.75	4.5	5
2	1.5	1.5	2.25	4	4.75	4.5
3	0.5	1.25	2.75	4	4.25	5

Table E-4: The arithmetic mean of odor intensity for each concentration set of methanol

Series	Concentration (ppm)				
	24.792	**82.448**	**245.712**	**800.546**	**2,481.693**
1	0	0.25	1	3	2.5
2	0	0	0.25	1	2.5
3	0.75	1	1	3	3.5

Table E-5: The arithmetic mean of odor intensity for each concentration set of methyl mercaptan

Series	Concentration (ppm)				
	0.0003	**0.0011**	**0.0031**	**0.0094**	**0.0314**
1	0.75	1.75	2.5	3.5	3.75
2	0	0.75	1.25	2.75	4
3	0	1	1.25	2.5	3.75

Table E-6: The arithmetic mean of odor intensity for each concentration set of propionic acid

Series	Concentration (ppm)					
	0.011	**0.036**	**0.109**	**0.363**	**1.083**	**3.528**
1	0.25	0.5	1	1.25	3	3.75
2	0.25	0.25	1	2	3	3.5
3	0.25	0	0.5	1.75	3.25	4.75

Table E-7: The arithmetic mean of odor intensity for each concentration set of styrene

Series	Concentration (ppm)				
	0.042	**0.127**	**0.421**	**1.256**	**4.093**
1	0.5	2.5	3.25	4.25	5
2	1	2.25	3.25	4.75	5
3	0.75	1.75	3.75	4	5

Table E-8: The arithmetic mean of odor intensity for each concentration set of toluene

Series	Concentration (ppm)				
	1.292	**4.296**	**12.804**	**41.718**	**129.325**
1	0.75	2.25	2.75	4	4.25
2	0.5	1.5	3	4.75	5
3	1.25	1	3.5	3.75	4.75

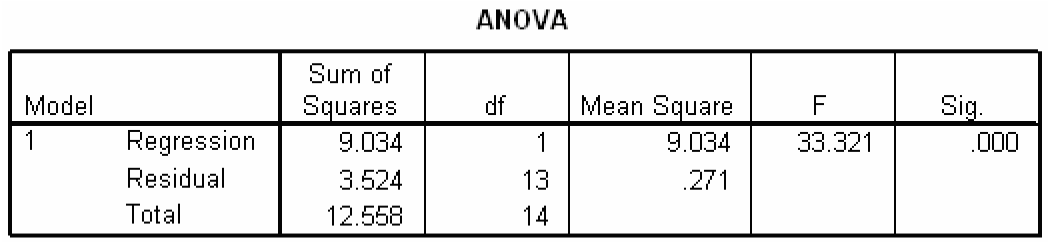
Table E-9: The arithmetic mean of odor intensity for each concentration set of xylene

Series	Concentration (ppm)			
	0.033	**0.098**	**0.320**	**0.993**
1	0.25	1.25	1.5	2.5
2	0	1.25	2.5	4
3	0	1	3	4

APPENDIX F
P-VALUE FROM STATISTICAL ANALYSIS PROGRAM

1. Ammonia

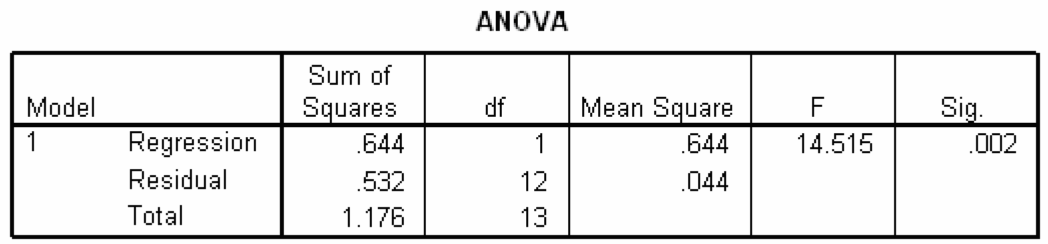
1.1 Odorant concentration and odor intensity



ANOVA

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	9.034	1	9.034	33.321	.000
	Residual	3.524	13	.271		
	Total	12.558	14			

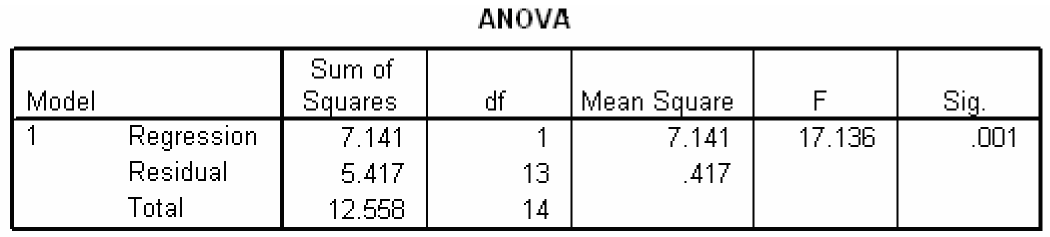
1.2 Odorant concentration and logarithm of odor intensity



ANOVA

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	.644	1	.644	14.515	.002
	Residual	.532	12	.044		
	Total	1.176	13			

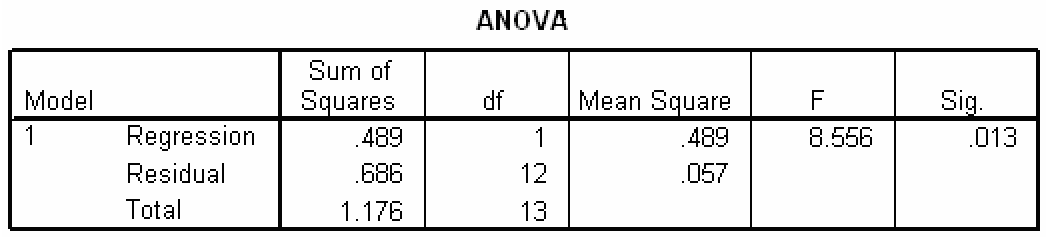
1.3 Logarithm of odorant concentration and odor intensity



ANOVA

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	7.141	1	7.141	17.136	.001
	Residual	5.417	13	.417		
	Total	12.558	14			

1.4 Logarithm of odorant concentration and logarithm of odor intensity

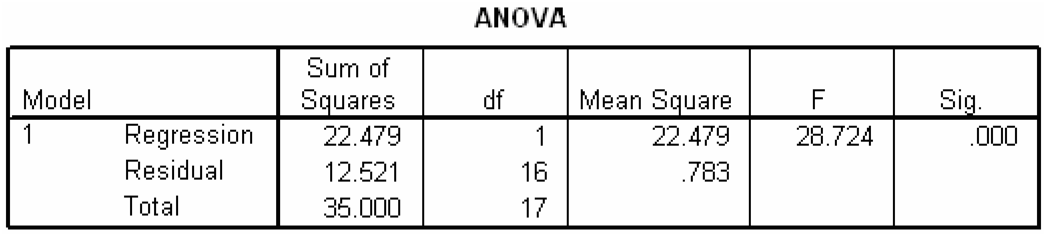


ANOVA

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	.489	1	.489	8.556	.013
	Residual	.686	12	.057		
	Total	1.176	13			

2. n-Butyl acetate

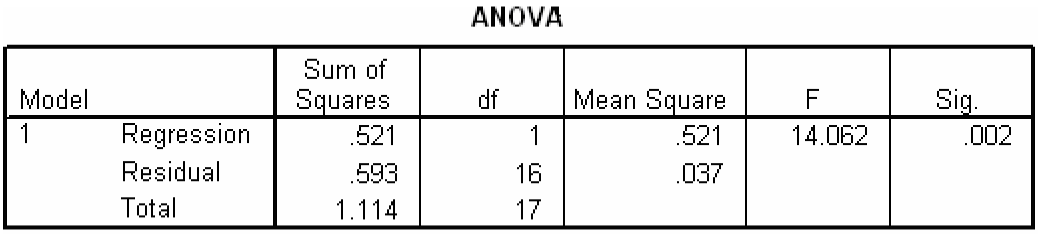
2.1 Odorant concentration and odor intensity



ANOVA

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	22.479	1	22.479	28.724	.000
	Residual	12.521	16	.783		
	Total	35.000	17			

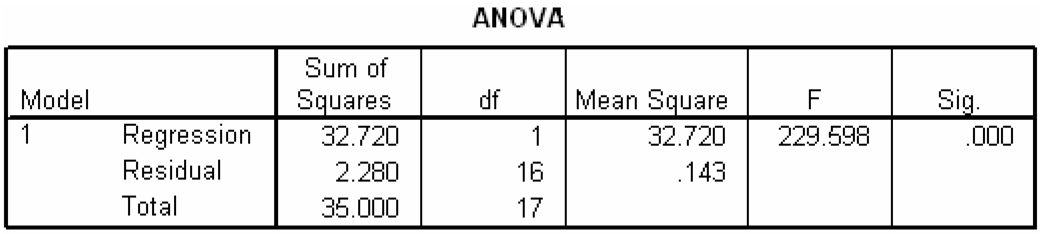
2.2 Odorant concentration and logarithm of odor intensity



ANOVA

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	.521	1	.521	14.062	.002
	Residual	.593	16	.037		
	Total	1.114	17			

2.3 Logarithm of odorant concentration and odor intensity



ANOVA

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	32.720	1	32.720	229.598	.000
	Residual	2.280	16	.143		
	Total	35.000	17			

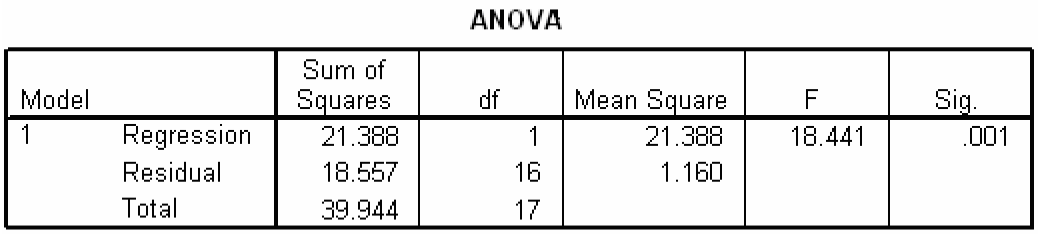
2.4 Logarithm of odorant concentration and logarithm of odor intensity

ANOVA

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	.997	1	.997	137.097	.000´
	Residual	.116	16	.007		
	Total	1.114	17			

3. Hydrogen sulfide

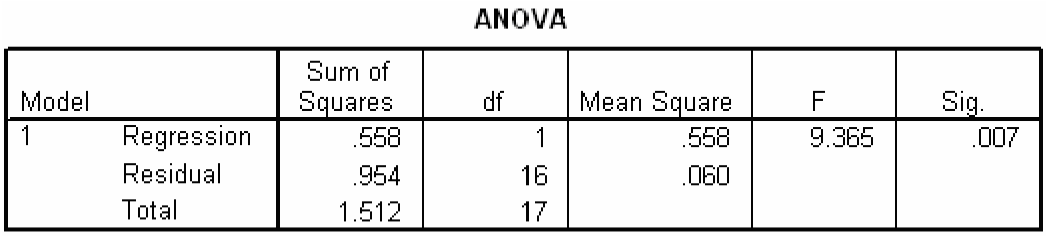
3.1 Odorant concentration and odor intensity



ANOVA

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	21.388	1	21.388	18.441	.001
	Residual	18.557	16	1.160		
	Total	39.944	17			

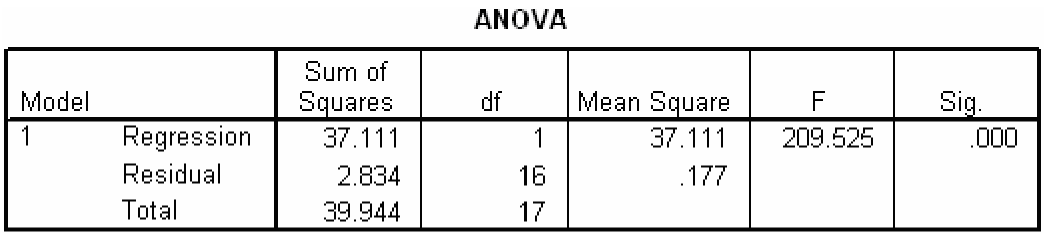
3.2 Odorant concentration and logarithm of odor intensity



ANOVA

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	.558	1	.558	9.365	.007
	Residual	.954	16	.060		
	Total	1.512	17			

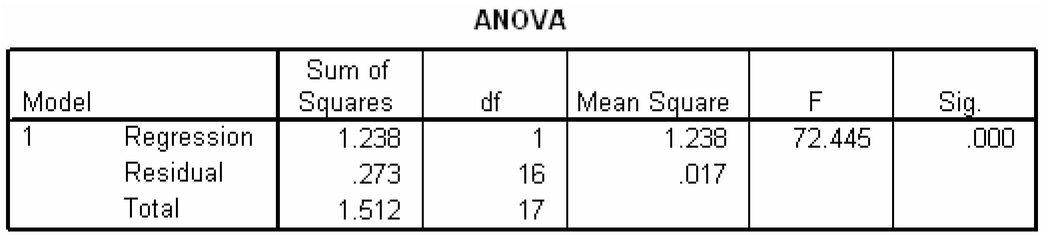
3.3 Logarithm of odorant concentration and odor intensity



ANOVA

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	37.111	1	37.111	209.525	.000
	Residual	2.834	16	.177		
	Total	39.944	17			

3.4 Logarithm of odorant concentration and logarithm of odor intensity

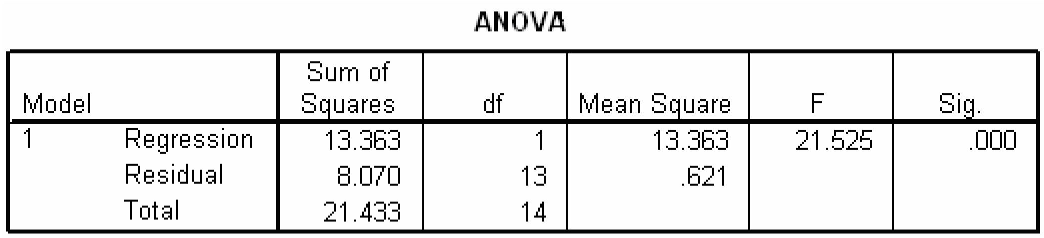


ANOVA

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	1.238	1	1.238	72.445	.000
	Residual	.273	16	.017		
	Total	1.512	17			

4. Methanol

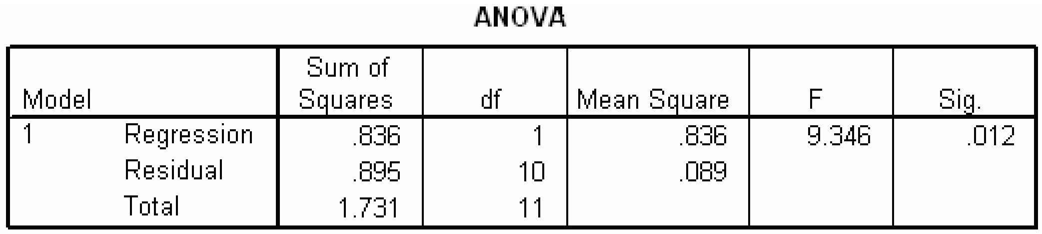
4.1 Odorant concentration and odor intensity



ANOVA

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	13.363	1	13.363	21.525	.000
	Residual	8.070	13	.621		
	Total	21.433	14			

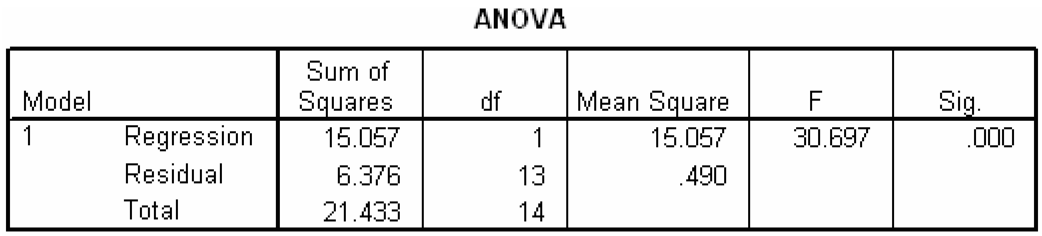
4.2 Odorant concentration and logarithm of odor intensity



ANOVA

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	.836	1	.836	9.346	.012
	Residual	.895	10	.089		
	Total	1.731	11			

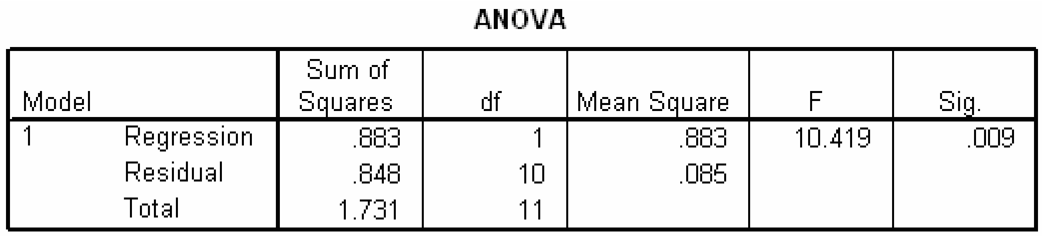
4.3 Logarithm of odorant concentration and odor intensity



ANOVA

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	15.057	1	15.057	30.697	.000
	Residual	6.376	13	.490		
	Total	21.433	14			

4.4 Logarithm of odorant concentration and logarithm of odor intensity

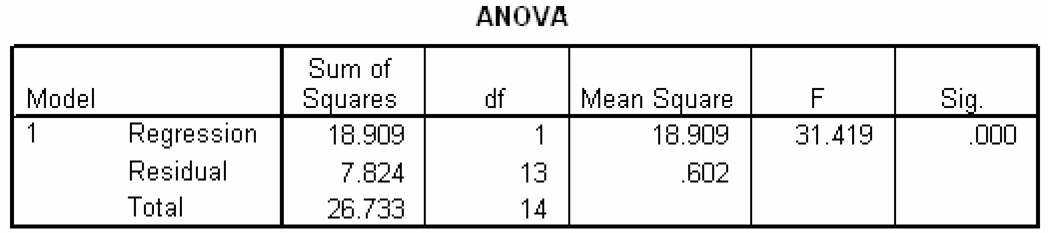


ANOVA

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	.883	1	.883	10.419	.009
	Residual	.848	10	.085		
	Total	1.731	11			

5. Methyl mercaptan

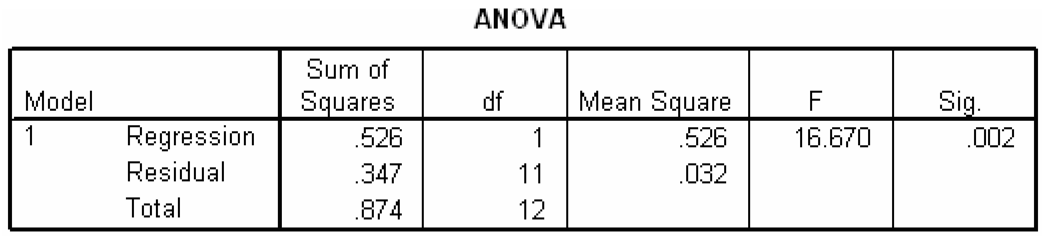
5.1 Odorant concentration and odor intensity



ANOVA

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	18.909	1	18.909	31.419	.000
	Residual	7.824	13	.602		
	Total	26.733	14			

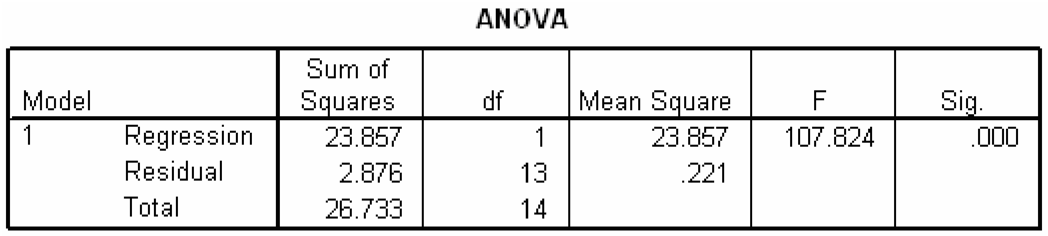
5.2 Odorant concentration and logarithm of odor intensity



ANOVA

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	.526	1	.526	16.670	.002
	Residual	.347	11	.032		
	Total	.874	12			

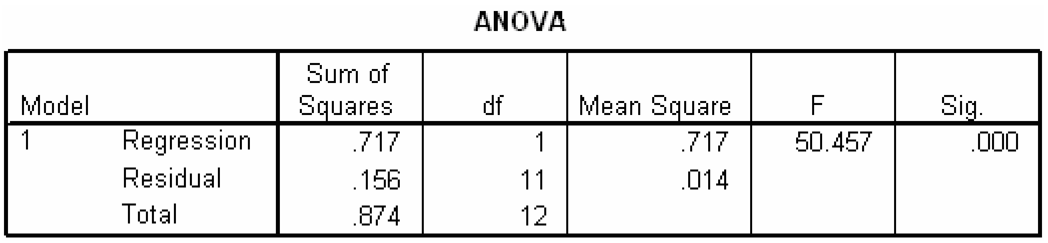
5.3 Logarithm of odorant concentration and odor intensity



ANOVA

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	23.857	1	23.857	107.824	.000
	Residual	2.876	13	.221		
	Total	26.733	14			

5.4 Logarithm of odorant concentration and logarithm of odor intensity

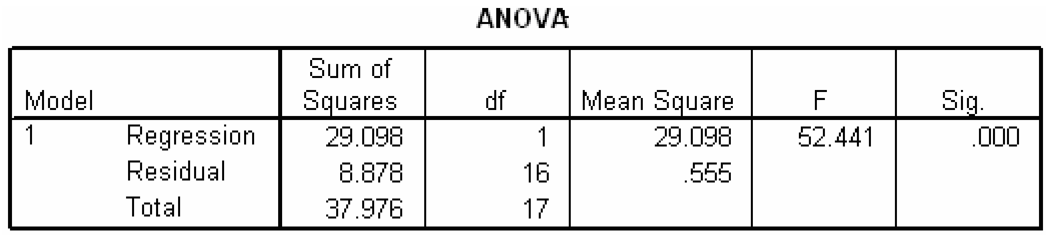


ANOVA

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	.717	1	.717	50.457	.000
	Residual	.156	11	.014		
	Total	.874	12			

6. Propionic acid

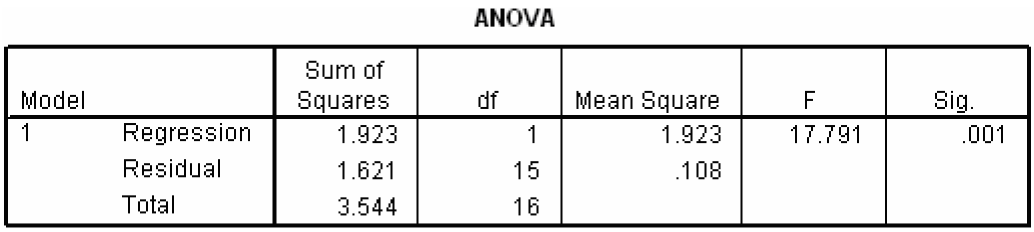
6.1 Odorant concentration and odor intensity



ANOVA

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	29.098	1	29.098	52.441	.000
	Residual	8.878	16	.555		
	Total	37.976	17			

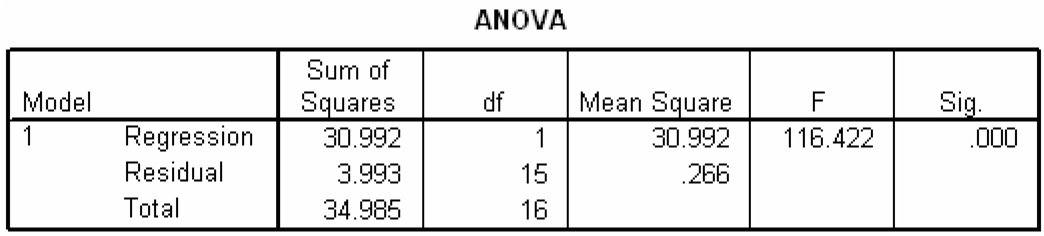
6.2 Odorant concentration and logarithm of odor intensity



ANOVA

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	1.923	1	1.923	17.791	.001
	Residual	1.621	15	.108		
	Total	3.544	16			

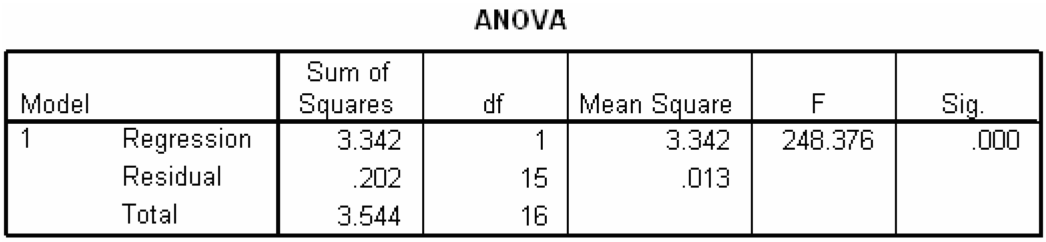
6.3 Logarithm of odorant concentration and odor intensity



ANOVA

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	30.992	1	30.992	116.422	.000
	Residual	3.993	15	.266		
	Total	34.985	16			

6.4 Logarithm of odorant concentration and logarithm of odor intensity

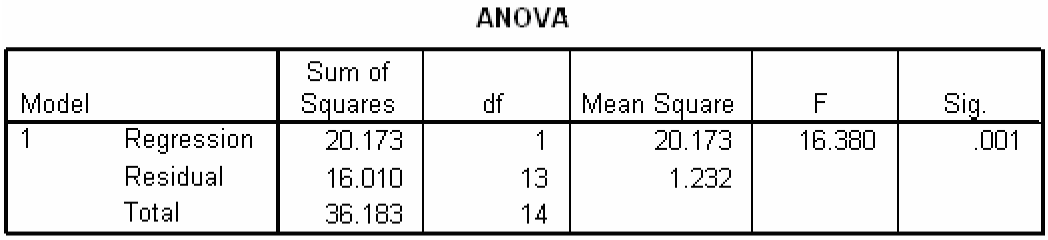


ANOVA

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	3.342	1	3.342	248.376	.000
	Residual	.202	15	.013		
	Total	3.544	16			

7. Styrene

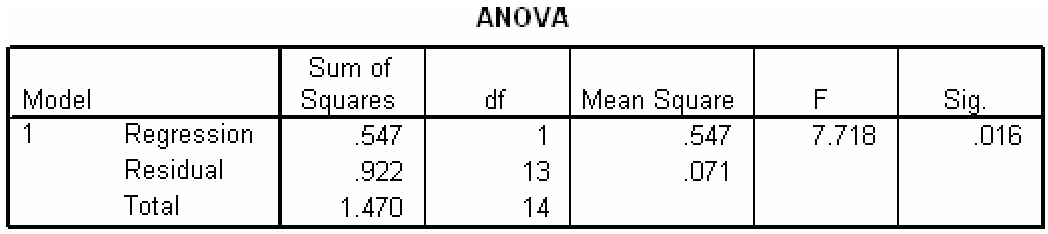
7.1 Odorant concentration and odor intensity



ANOVA

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	20.173	1	20.173	16.380	.001
	Residual	16.010	13	1.232		
	Total	36.183	14			

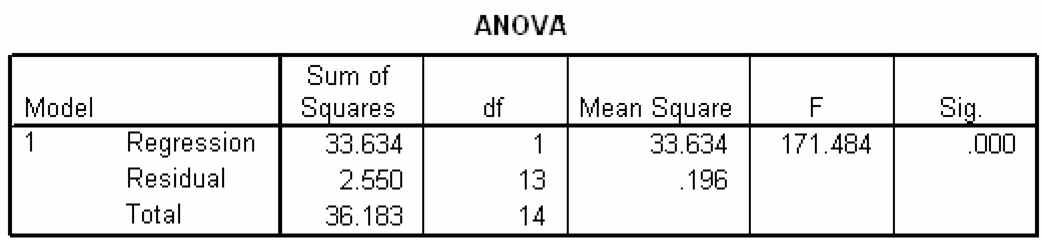
7.2 Odorant concentration and logarithm of odor intensity



ANOVA

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	.547	1	.547	7.718	.016
	Residual	.922	13	.071		
	Total	1.470	14			

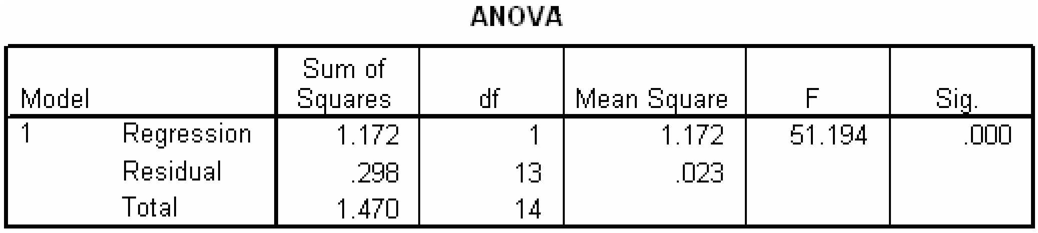
7.3 Logarithm of odorant concentration and odor intensity



ANOVA

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	33.634	1	33.634	171.484	.000
	Residual	2.550	13	.196		
	Total	36.183	14			

7.4 Logarithm of odorant concentration and logarithm of odor intensity

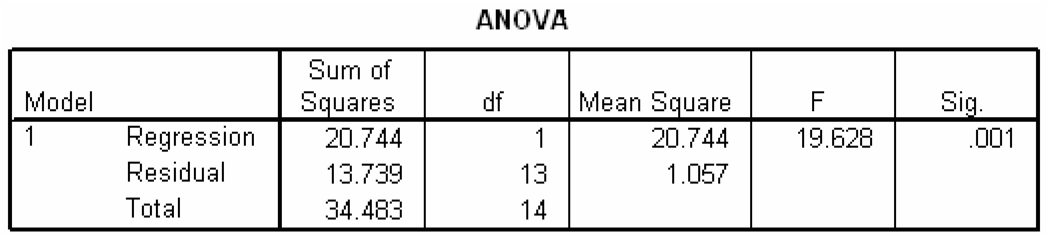


ANOVA

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	1.172	1	1.172	51.194	.000
	Residual	.298	13	.023		
	Total	1.470	14			

8. Toluene

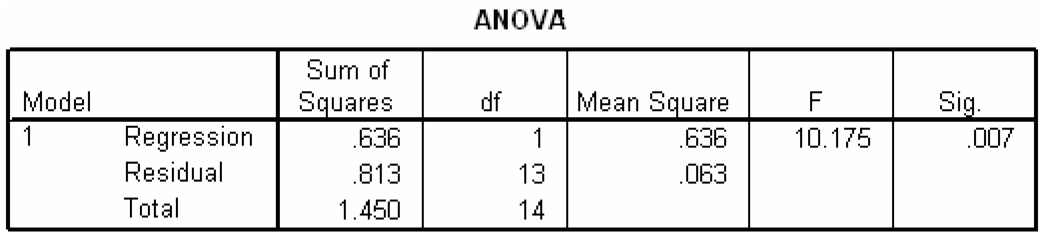
8.1 Odorant concentration and odor intensity



ANOVA

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	20.744	1	20.744	19.628	.001
	Residual	13.739	13	1.057		
	Total	34.483	14			

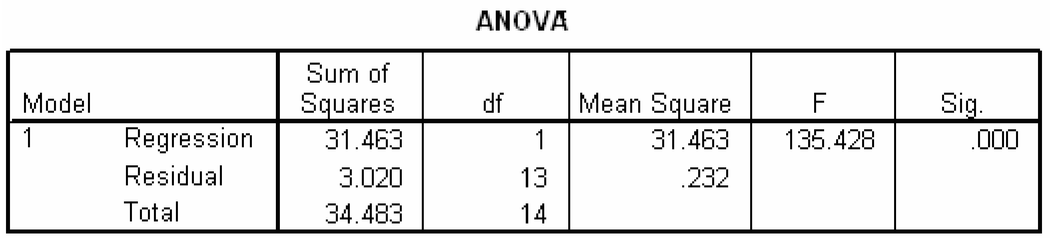
8.2 Odorant concentration and logarithm of odor intensity



ANOVA

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	.636	1	.636	10.175	.007
	Residual	.813	13	.063		
	Total	1.450	14			

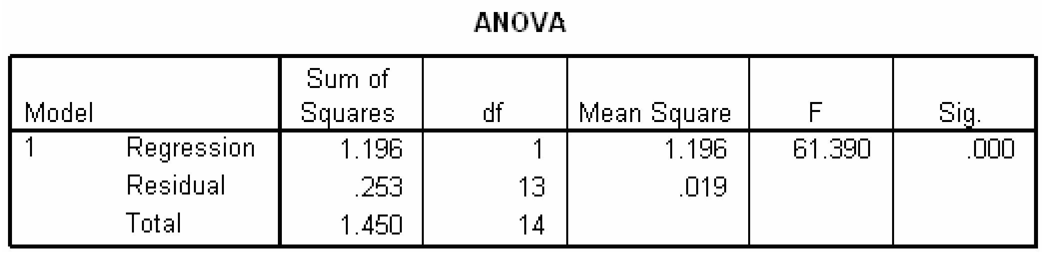
8.3 Logarithm of odorant concentration and odor intensity



ANOVA

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	31.463	1	31.463	135.428	.000
	Residual	3.020	13	.232		
	Total	34.483	14			

8.4 Logarithm of odorant concentration and logarithm of odor intensity

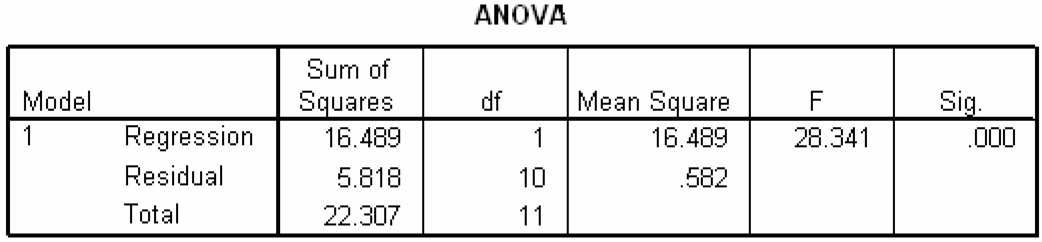


ANOVA

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	1.196	1	1.196	61.390	.000
	Residual	.253	13	.019		
	Total	1.450	14			

9. Xylene

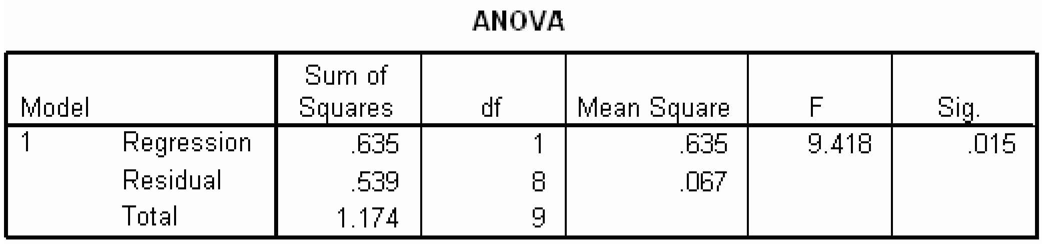
9.1 Odorant concentration and odor intensity



ANOVA

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	16.489	1	16.489	28.341	.000
	Residual	5.818	10	.582		
	Total	22.307	11			

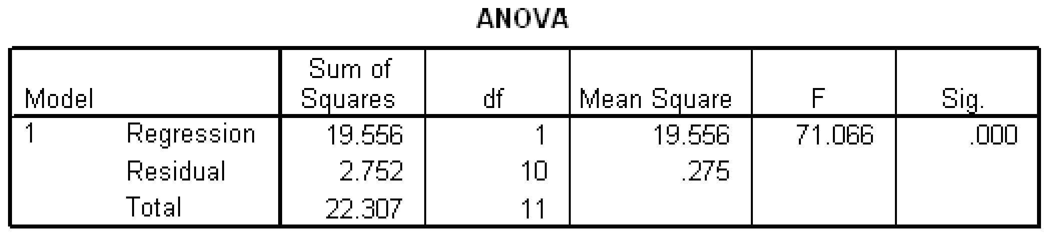
9.2 Odorant concentration and logarithm of odor intensity



ANOVA

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	.635	1	.635	9.418	.015
	Residual	.539	8	.067		
	Total	1.174	9			

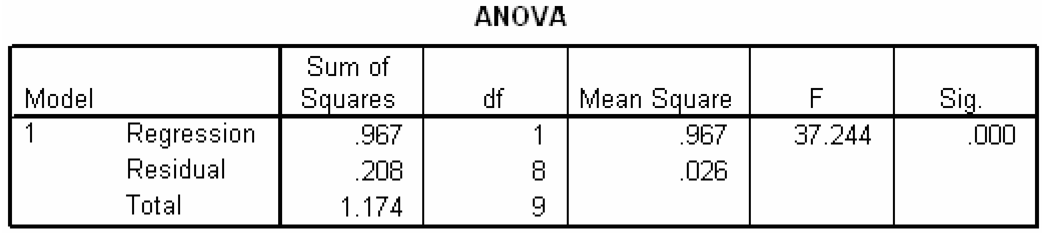
9.3 Logarithm of odorant concentration and odor intensity



ANOVA

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	19.556	1	19.556	71.066	.000
	Residual	2.752	10	.275		
	Total	22.307	11			

9.4 Logarithm of odorant concentration and logarithm of odor intensity



ANOVA

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	.967	1	.967	37.244	.000
	Residual	.208	8	.026		
	Total	1.174	9			

BIOGRAPHY

NAME	Mister Tewan Chawangwongsanukun
DATE OF BIRTH	20 June 1983
PLACE OF BIRTH	Bangkok, Thailand
INSTITUTIONS ATTENDED	Mahidol University, 2005 Bachelor of Science (Public Health) Mahidol University, 2007 Master of Science (Technology of Environmental Management)
HOME ADDRESS	5 Soi Maharaj 2, Tumbon Chongkhae, Umphur Takhli, Nakhonsawan, 60210 E-mail: srikanchai@hotmail.com