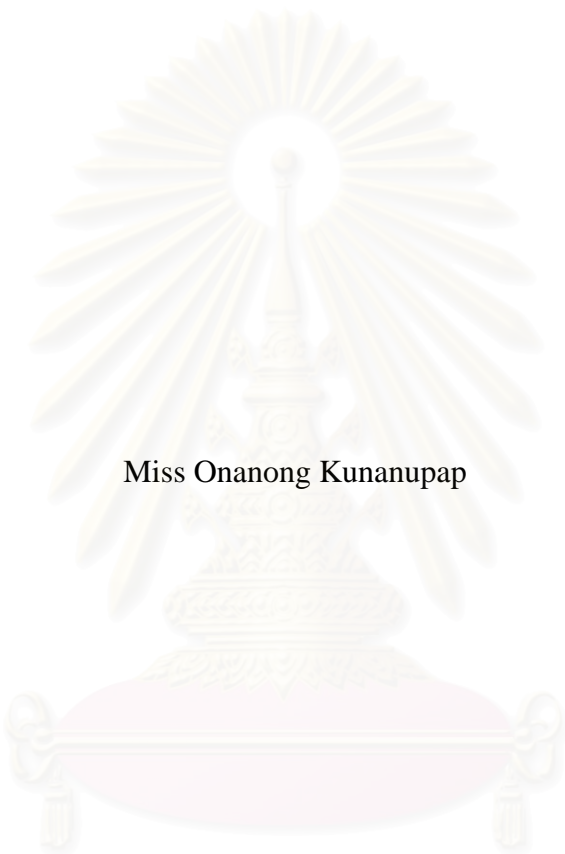


EFFECT OF OPERATING CONDITIONS ON BENZENE REMOVAL USING AQUEOUS
SURFACTANT TWO-PHASE (ASTP) SYSTEM OF CATIONIC AND ANIONIC SURFACTANT
MIXTURES



Miss Onanong Kunanupap

สถาบันวิทยบริการ
จุฬาลงกรณ์มหาวิทยาลัย

A Thesis Submitted in Partial Fulfillment of the Requirements

for the Degree of Master of Science in Environmental Management (Inter-Department)

Graduate School

Chulalongkorn University

Academic Year 2004

ISBN 974-53-1765-9

ผลของภาวะปฏิบัติการในการกำจัดเบนซินด้วยระบบการแบ่งวิภูภาคของสารลดแรงตึงผิวผสม
ชนิดประจุบวกและประจุลบ



นางสาวอรอนงค์ คุณานุกาพ

สถาบันวิทยบริการ

วิทยานิพนธ์นี้เป็นส่วนหนึ่งของการศึกษาตามหลักสูตรปริญญาวิทยาศาสตรมหาบัณฑิต

สาขาวิชาการจัดการสิ่งแวดล้อม (สหสาขาวิชา)

บัณฑิตวิทยาลัย จุฬาลงกรณ์มหาวิทยาลัย

ปีการศึกษา 2547

ISBN 974-53-1765-9

ลิขสิทธิ์ของจุฬาลงกรณ์มหาวิทยาลัย

Thesis Title Effect of Operating Conditions on Benzene Removal Using
 Aqueous Surfactant Two-Phase (ASTP) System of Cationic and
 Anionic Surfactant Mixtures
By Ms. Onanong Kunanupap
Field of study Environmental Management
Thesis Advisor Punjaporn Weschayanwiwat, Ph.D.
Thesis Co-advisor Professor John F. Scamehorn, Ph.D.

Accepted by the Graduate School, Chulalongkorn University in partial
Fulfilment of the Requirements for the Master's Degree

..... Dean of the Graduate School
(Assistant Professor M.R. Kalaya Tingsabadh, Ph.D.)

THESIS COMPLETE

.....Chairman
(Manaskorn Rachakornkij, Ph.D.)

.....Thesis Advisor
(Punjaporn Weschayanwiwat, Ph.D.)

.....Thesis Co-advisor
(Professor John F. Scamehorn, Ph.D.)

.....Member
(Chantra Tongcumpou, Ph.D.)

.....Member
(Assistant Professor Sangobtip Pongstabodee, Ph.D.)

อรรถนงค์ คุณานุกาพ : ผลของภาวะปฏิบัติการในการกำจัดเบนซีนด้วยระบบการแบ่งวัฏภาคของสารลดแรงตึงผิวผสมชนิดประจุบวกและประจุลบ (EFFECT OF OPERATING CONDITIONS ON BENZENE REMOVAL USING AQUEOUS SURFACTANT TWO-PHASE (ASTP) SYSTEM OF CATIONIC AND ANIONIC SURFACTANT MIXTURES) อ. ที่ปรึกษา : ปัญจพร เวชยันตีวิวัฒน์, อ. ที่ปรึกษาร่วม : จอห์น เอฟ สแกมีย์ ฮอร์น 99 หน้า. ISBN 974-53-1765-9.

เทคนิคการแบ่งวัฏภาคของสารลดแรงตึงผิวผสมซึ่งใช้สารลดแรงตึงผิวที่เป็นมิตรต่อสิ่งแวดล้อม เป็นเทคนิคใหม่ที่น่าสนใจในการกำจัดเบนซีนออกจากน้ำเสีย เมื่อผสมสารลดแรงตึงผิวชนิดที่มีประจุบวก และลบในอัตราส่วนและความเข้มข้นที่เหมาะสม สารละลายจะแบ่งออกเป็นสองวัฏภาคที่แยกจากกัน ด้วยขอบเขตที่ชัดเจนคือ วัฏภาคที่มีสารลดแรงตึงผิวอยู่เป็นจำนวนมาก และวัฏภาคที่มีสารลดแรงตึงผิว เป็นจำนวนน้อย สารมลพิษอินทรีย์จะละลายอยู่ในสารลดแรงตึงผิวที่รวมตัวกันในรูปแบบต่าง ๆ และ เข้มข้นอยู่ในวัฏภาคที่มีสารลดแรงตึงผิวอยู่เป็นจำนวนมาก ดังนั้นอีกวัฏภาคหนึ่งที่มีสารลดแรงตึงผิวอยู่ เป็นจำนวนน้อยจึงมีสารมลพิษสะสมอยู่น้อย หรือเปรียบเสมือนกับชั้นของน้ำเสียที่ผ่านการบำบัดแล้ว ผลของอัตราส่วนและความเข้มข้นของสารลดแรงตึงผิวผสม ผลของอุณหภูมิและความเป็นกรด-ด่างของ ระบบการแบ่งวัฏภาคของสารลดแรงตึงผิวผสมระหว่าง ดีแท็บ และ ดาวแฟกซ์ ถูกศึกษาด้วยการทดลอง แบบกะ หลังจากการแบ่งวัฏภาคเกิดขึ้นแล้วปริมาตรสัมพัทธ์ของวัฏภาคจะถูกวัด ความเข้มข้นของสาร ลดแรงตึงผิวและเบนซีนทั้งสองวัฏภาคจะถูกวิเคราะห์ ผลการทดลองพบว่า ผลของอัตราส่วนของสารลด แรงตึงผิวมีความสำคัญมาก การแบ่งวัฏภาคของสารลดแรงตึงผิวผสมจะเกิดเฉพาะที่บางอัตราส่วนของดี แท็บต่อดาวแฟกซ์ เช่น ที่อัตราส่วน 1.6:1, 2:1, 2.2:1 และ 2.4:1 เท่านั้น อย่างไรก็ตามพบว่า อุณหภูมิ และความเป็นกรดเป็นด่างในการสกัดไม่มีผลต่อประสิทธิภาพการสกัดเบนซีนอย่างมีนัยสำคัญ โดย การศึกษานี้พบว่า สภาวะที่เหมาะสมที่สุดในการสกัดเบนซีนออกจากน้ำเสียคือ ที่อัตราส่วนระหว่าง ดีแท็บต่อดาวแฟกซ์เท่ากับ 2:1 โดยความเข้มข้นของสารลดแรงตึงผิวผสมเท่ากับ 50 มิลลิโมลาร์ ณ อุณหภูมิ เท่ากับ 30 องศาเซลเซียส และสารละลายมีสภาพเป็นกลาง ซึ่งที่สภาวะนี้ทำให้มีความแตกต่างของสาร ลดแรงตึงผิวและเบนซีนของสองวัฏภาคเท่ากับ 2700 และ 48 เท่า ตามลำดับ โดยทำให้ประสิทธิภาพการ สกัดเบนซีนออกจากน้ำเสียเท่ากับ 72 เปอร์เซ็นต์

สาขาวิชาการจัดการสิ่งแวดล้อม

ปีการศึกษา 2547

ลายมือชื่ออนิสิต.....

ลายมือชื่ออาจารย์ที่ปรึกษา.....

ลายมือชื่ออาจารย์ที่ปรึกษาร่วม.....

4689515320 : MAJOR ENVIRONMENTAL MANAGEMENT

KEY WORD: AQUEOUS SURFACTANT TWO-PHASE SYSTEM (ASTP) /
CATANIONIC SURFACTANT/ BENZENE / EXTRACTION

ONANONG KUNANUPAP : EFFECT OF OPERATING CONDITIONS ON
BENZENE REMOVAL USING AQUEOUS SURFACTANT TWO-PHASE
(ASTP) SYSTEM OF CATIONIC AND ANIONIC SURFACTANT
MIXTURES. THESIS ADVISOR: PUNJAPORN WESCHAYANWIWAT,
THESIS COADVISOR: JOHN F SCAMEHORN, 99 pp. ISBN 974-53-1765-
9.

A novel class of separation technique utilizing an environmentally friendly surfactant known as an aqueous surfactant two-phase system (ASTP) is a new technique to remove contaminant such as benzene from wastewater. When cationic and anionic surfactants are mixed at certain surfactant concentration and composition, the solution separates into two immisible aqueous phases. One is the surfactant-rich and the other is the surfactant-dilute phase. The organic pollutant will solubilize into the surfactant aggregates and concentrate in the surfactant-rich phase. So, the other phase contains only small amount of surfactant and pollutant as the treated water. The ability of ASTP formed by dodecyltrimethyl ammonium bromide (DTAB) and alkyl diphenyl oxide disulfonate (DOWFAX 8390) to extract benzene from wastewater was investigated in batch experiment. The results showed that the effect of surfactant composition is crucial in which the phase separation only occurred in some particular ratios of DTAB:DOWFAX, i.e., 1.6:1, 2:1, 2.2:1, and 2.4:1. However, the pH and operating temperature for extraction did not have significant effects on the extraction efficiency. From this study, the most suitable condition to extract benzene from wastewater was at 2:1 molar ratio of DTAB:DOWFAX, the total surfactant concentration of 50 mM, operating temperature at 30 °C and at neutral solution (pH 7), in which the surfactant and benzene partition ratio can be as high as 2700 and 48 respectively. Moreover, 72 % of benzene was removed within single stage extraction.

Field of study Environmental Management Student's signature.....

Academic year 2004 Advisor's signature.....

Co-advisor's signature.....

ACKNOWLEDGEMENTS

This work could not be completed without invaluable supports of the following individuals and organization.

First, I would like to thank the National Research Center for Environmental and Hazardous Waste Management (NRC-EHWM) for financial support.

I would like to express my gratitude to Dr. Punjaporn Weschayanwiwat and Prof. John F. Scamehorn for giving me a privilege opportunity to work with them.

I would like to give my appreciation to the advisor, Dr. Punjaporn Weschayanwiwat for her kindness, advice, support and encouragement on this work. I also wish to thank for her consistent attentions on my thesis.

I also express my gratitude to Prof. John F. Scamehorn for his valuable guidances, suggestions and comments.

I would like to give my thankfulness to Dr. Manaskorn Rachakornkij, Dr. Chantra Tongcumpou, and Asst. Prof. Dr. Sangobtip Pongstabodee for serving as my thesis committee.

I would like to show my appreciation to NRC-EHWM staffs for their contributions. Gratitude is also passed to my friends for their love, sincere friendship and encouragement.

My deepest gratitude goes to my parents, brother and sister for their love and warm support made me achieving my goal.

สถาบันวิทยบริการ
จุฬาลงกรณ์มหาวิทยาลัย

TABLE OF CONTENTS

	PAGE
Abstract (in Thai).....	iv
Abstract (in English).....	v
Acknowledgements.....	vi
Table of Contents.....	vii
List of Tables.....	x
List of Figures.....	xi

CHAPTER

I	INTRODUCTION.....	1
II	THEORETICAL BACKGROUND AND LITERATURE REVIEW.....	4
	2.1 Benzene.....	4
	2.1.1 Introduction.....	4
	2.1.2 Identity, Physical, and Chemical Properties....	4
	2.1.2.1 Identity.....	4
	2.1.2.2 Physical and Chemical Properties....	5
	2.1.3 Benzene in the Environment.....	6
	2.1.4 Characteristic of wastewater containing benzene.....	6
	2.1.5 Effects on Humans.....	7
	2.1.5.1 Acute Toxicity.....	7
	2.1.5.2 Effects of Short-and Long-Term Exposures.....	7
	2.1.6 Regulations.....	8
	2.2 Surfactant.....	10
	2.2.1 Introduction.....	10
	2.2.2 Types of Surfactant.....	11
	2.2.2.1 Anionic Surfactant.....	11
	2.2.2.2 Cationic Surfactant.....	11

CHAPTER	page
2.2.2.3 Nonionic Surfactant.....	11
2.2.2.4 Zwitterionic Surfactant.....	11
2.3 Micelle Formation.....	12
2.3.1 Introduction.....	12
2.3.2 Micellar Structure and Shape.....	15
2.3.2.1 Surfactant Structure and Micellar Shape.....	15
2.3.2.2 The Critical Packing Parameter.....	17
2.4 Solubilization.....	19
2.5 Cationic-Anionic Surfactant Mixtures.....	20
2.6 Aqueous Surfactant Two Phase (ASTP) System....	22
2.6.1 ASTP System.....	22
2.6.2 Possible Mechanism of the Formation of ASTP.....	23
2.6.3 Factor Affecting the ASTP System.....	24
2.6.4 Application of ASTP System.....	25
2.6.5 Scaling-up of ASTP system.....	26
 III METHODOLOGY.....	 28
3.1 Cationic-Anionic System Selection.....	28
3.2 CMC Determination.....	29
3.3 Cloud Point Temperature Determination.....	30
3.4 Investigation of Operating Conditions on Benzene Removal via ASTP System.....	30
3.4.1 Materials.....	30
3.4.2 Experimental Methods.....	30
3.4.2.1 The Aqueous Surfactant Two Phase Procedure.....	30
3.4.2.2 Terms Notification.....	33
 IV RESULTS AND DISCUSSIONS.....	 36

CHAPTER	page
4.1 Cationic-Anionic System (ASTP) Selection.....	36
4.2 CMC Determination.....	37
4.3 Cloud Point Temperature (CPT).....	38
4.4 Results of Operating Conditions on Benzene Removal of ASTP System.....	39
4.4.1 Effect of Surfactant Composition.....	39
4.4.2 Effect of Total Surfactant Concentration.....	44
4.4.3 Effect of Temperature.....	48
4.4.4 Effect of pH.....	52
 V CONCLUSIONS.....	 56
5.1 Conclusions.....	56
5.2 Recommendations.....	56
 REFERENCES.....	 58
 APPENDICES.....	 63
APPENDIX A.....	63
APPENDIX B.....	70
APPENDIX C.....	72
APPENDIX D.....	85
APPENDIX E.....	90
APPENDIX F.....	94
APPENDIX G.....	98
 CURRICULUM VITAE.....	 99

LIST OF TABLES

TABLE		page
2.1	Some physical and chemical properties of benzene.....	5
2.2	Characteristic of wastewater from petrochemical refinery.....	7
2.3	Acute toxic effects of benzene.....	8
2.4	Effluent limitations of benzene.....	9
3.1	Relevant properties of surfactants used in this study.....	28
4.1	CMC of the mixture of DTAB and DOWFAX at different composition.....	38



สถาบันวิทยบริการ
จุฬาลงกรณ์มหาวิทยาลัย

LIST OF FIGURES

FIGURE		page
2.1	Surfactant and its characteristic.....	12
2.2	Changes in physical properties of aqueous surfactant solution around the critical micelle concentration.....	13
2.3	Determination of critical micelle concentration from surface tension.....	13
2.4	Vesicle.....	16
2.5	Relation between critical packing parameter and preferred aggregate structures.....	18
2.6	Plot of amount of material solubilized as a function of surfactant concentration in bulk phase.....	19
2.7	Cloud point temperature of AEOS-TTAB.....	21
2.8	Schematic of integrated process including a multistage ASTP extractor and vacuum stripper.....	27
4.1	CMC of DTAB, DOWFAX and mixture of DTAB and DOWFAX at 2:1 ratio.....	38
4.2	Effect of surfactant composition on fractional surfactant-rich phase volume and DOWFAX concentration in the surfactant-rich phase	41
4.3	Effect of surfactant composition on DOWFAX concentration in the surfactant-diluted phase.....	42
4.4	Effect of surfactant composition on surfactant and benzene partition ratio.....	42
4.5	Effect of surfactant composition on benzene concentration in the surfactant-rich and dilute phase.....	43
4.6	Effect of surfactant composition on percentage of benzene removal	43
4.7	Effect of total surfactant concentration on fractional surfactant-rich phase volume and DOWFAX concentration in the surfactant-rich phase.....	45

FIGURE		page
4.8	Effect of total surfactant concentration on DOWFAX concentration in the surfactant-diluted phase.....	46
4.9	Effect of total surfactant concentration on surfactant and benzene partition ratio.....	46
4.10	Effect of total surfactant concentration on benzene concentration in the surfactant-rich and dilute phase.....	47
4.11	Effect of total surfactant concentration on percentage of benzene removal.....	47
4.12	Effect of temperature on fractional surfactant-rich phase volume and DOWFAX concentration in the surfactant-rich phase.....	49
4.13	Effect of temperature on DOWFAX concentration in the surfactant-diluted phase.....	50
4.14	Effect of temperature on surfactant and benzene partition ratio.....	50
4.15	Effect of temperature on benzene concentration in the surfactant-rich and dilute phase.....	51
4.16	Effect of temperature on percentage of benzene removal..	51
4.17	Effect of pH on fractional surfactant-rich phase volume and DOWFAX concentration in the surfactant-rich phase.....	52
4.18	Effect of pH on DOWFAX concentration in the surfactant-diluted phase.....	53
4.19	Effect of pH on surfactant and benzene partition ratio.....	53
4.20	Effect of pH on benzene concentration in the surfactant-rich and dilute phase.....	54
4.21	Effect of pH on percentage of benzene removal	54

CHAPTER I

INTRODUCTION

Wastewater discharge containing a trace amount of volatile organic compounds (VOCs) is an environmental concern because it can cause severe problems due to their toxicity. Benzene is one of VOCs that is widely used in many industries as solvent for organic synthesis, equipment cleansing and other downstream processing purposes. It is classified as priority pollutant regulated by the U.S. Environmental Protection Agency (EPA) due to its carcinogenic and teratogenic properties. It may be associated with the development of leukemia as well as nerve, lung and kidney damage (ATSDR, 1997). Regarding to its toxicity, wastewater discharge containing these VOCs need to be strickly controlled by appropriate technologies.

A novel class of separation process utilizing an environmentally friendly surface active agent called surfactant-based separation is an interesting technology due to a usage of less toxic solvent (surfactant) as an extractant. Moreover, it can be operated at mild condition. A well known example of such aqueous phase separation techniques induced by nonionic or zwitterionic surfactant is known as the cloud point extraction in which the phase separations caused by an elevation of temperature above the cloud point temperature (Hinze and Pramauro, 1993; Quina and Hinze, 1999). In the separated phases, the surfactant micelles concentrate in one phase known as the surfactant-rich phase while the other phase is a bulk aqueous phase containing only a small amount of surfactant micelles known as the surfactant-dilute phase. In the previous studies, it is found that the mixtures of surfactant often possess superior properties than those of single surfactant. Therefore, it becomes topics of interest for numerous technical applications (Ruiz and Aguiar, 2003). A new aqueous two-phase separation system formed by cationic and anionic surfactant mixture (ASTP) is one of systems gaining more attraction currently.

When cationic and anionic surfactant are mixed at certain surfactant concentrations (much higher than CMC, but still very dilute) and compositions (molar ratio), the solution separates spontaneously into two immiscible aqueous phases with clear interfacial boundary between them. One phase is rich and the other is poor in

surfactant. Unlike the cloud point extraction, the formation of ASTP is caused by concentration and composition of surfactant system for example, above critical concentration of two surfactant components. The type of the ASTP system is classified according to the surfactant aggregates which are strongly depended on the molar ratio of surfactants (Yin, Mao *et al.*, 2002). At different surfactant concentration and composition, the aggregates in the separated phases may exist in different forms, i.e., spherical micelles, rodlike micelles, or vesicles, etc. The organic pollutants such as benzene containing in the solution will solubilize into these surfactant aggregates due to its affinity to the aggregates. After phase separation, the organic pollutants will concentrate in the surfactant-rich phase which is generally small in volume. The ASTP system does not only remove the pollutants from wastewater but also pre-concentrate the pollutants in the concentrated form in the surfactant-rich phase that can reduce the amount of waste for further treatment. Therefore, the ASTP is a promising technique in an economic viewpoint due to its pre-concentration ability and being less energy intensive process since the phase separation is governed by surfactant concentration and composition not operating temperature. Furthermore, the surfactant-rich phase can be recovered for reuse by two possible methods. First, the surfactant mixture can be precipitated upon altering the surfactant composition (Xiao, Sivar and Tjerneld, 2000). Unlike the other structures of aggregates, the precipitate cannot solubilize the organic pollutants. So, the pollutants will separate from the surfactant aggregates as another immiscible phase. Second, if the pollutants of interest are VOCs, the surfactant-rich phase can be reused by passing through the vacuum stripper to strip the high volatility VOCs out of the surfactant aggregates leaving the solute-free surfactant aggregates for reuse (Hasegawa, Sabatini and Harwell, 1997; Choori *et al.*, 1998). Therefore, the ASTP technique formed by a mixture of cationic and anionic surfactants show many advantages over the conventional separation techniques which are air stripping, stream stripping activated carbon adsorption. This research focuses on the effect of surfactant concentration and composition, temperature and pH on benzene removal from wastewater using the ASTP system of cationic-anionic surfactant mixtures.

1.1 Objective of the Study

The objectives of this study were to study the ability of ASTP system formed by cationic and anionic surfactant mixtures to remove benzene from wastewater in batch experiments. The effects of surfactant concentration and composition, temperature and pH on the extraction were investigated. In addition, the fractional surfactant-rich phase volume, surfactant and benzene partition ratio and percentage of benzene removal were determined.

1.2 Scope of the Study

Dodecyltrimethyl ammonium bromide (DTAB) and Alkyldiphenyloxide disulfonate (DOWFAX 8390) were used as cationic and anionic surfactant in this study, respectively as regarded to the result from preliminary study in the cationic-anionic system selection. Removal of benzene from synthesis wastewater was done in the batch experiment at fixed initial benzene concentration at 100 ppm. The effect of surfactant composition around neutral charged ratios; 1.6:1, 1.8:1, 2:1, 2.2:1, 2.4:1 DTAB:DOWFAX were determined. The total concentration of 20-140 mM, operating temperature of 20-50 °C, and pH in the range of 4-7 were investigated.

CHAPTER II

THEORETICAL BACKGROUND AND LITERATURE REVIEW

2.1 Benzene

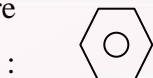
2.1.1 Introduction

Benzene is a ubiquitous component in chemistry. It is commonly used in many industries due to its availability, its relatively low cost and the fact that it is an excellent solvent and a useful starting raw material for organic synthesis. Styrene, phenol cyclohexane and alkylates are examples of the products synthesized from benzene. Because of its toxicity, the usage of benzene has been declining recently. However, it is still used as a solvent in scientific laboratories, paints, rubber cements and artificial leather production (Truhaut, 1968; Goldstein, 1977; IPCS, 1993).

2.1.2 Identity, Physical, and Chemical Properties

2.1.2.1 Identity (IPCS, 1993)

Chemical structure



Chemical formula : C_6H_6 (C 92.55%, H 7.75%)

CAS number : 71-43-2

Common name : Benzene

IUPAC name : Benzene

Common synonyms Annulene, benzine, benzol, benzole, benzol

: coal naphtha, cyclohexatriene, mineral naphtha,
motor benzol, phenol hydride, pyrobenzol,
pyrobenzole

Molecular weight : 78.11

2.1.2.2 Physical and Chemical Properties

Benzene is a naturally clear, colorless, noncorrosive, highly flammable liquid and has an aromatic odour. The principle physical and chemical properties of benzene are shown in Table 2.1.

Table 2.1 Some physical and chemical properties of benzene.
(IPCS,1993)

Physical form (20 °C)	Clear colorless liquid
Relative molecular mass	78.11
Flash point	-11.1 °C
Flammable limits	1.3-7.1%
Melting/freezing point	5.5 °C
Boiling point	80.1 °C at 760 mmHg
Density	0.878
Relative vapour density (air = 1)	2.7
Vapour pressure (26 °C)	13.3 kPa
Solubilities:	
Water	1800 mg/litre at 25 °C
Non-aqueous solvents	Miscible with most
Odour threshold	4.8-15.0 mg/m ³
Taste threshold (water)	0.5-4.5 mg/litre
Log n-octanol/water partition coefficient	1.56-2.15
Sorption coefficient (logKoc – distribution coefficient between benzene adsorbed to soil organic carbon and benzene in solution)	1.8-1.9

2.1.3 Benzene in the Environment

The presence of benzene in environment comes from both natural and man-made sources, in which the latter is a majority of the emission. Eventhough, automobile exhaust, automobile-refuelling operations and industrial emissions are major anthropogenic sources of benzene, it can also volatilize from soil and water (Courage and Davidson, 1999; Zainal, 1999). In addition, benzene contaminated wastewater from petrochemical industries and related chemical industries are significant source of emission. Employees in these industries are probably exposed to benzene at much higher levels than general population. Thus, the emissions of benzene at these sources need to be stricky controlled with an appropriate technology.

2.1.4 Characteristic of wastewater containing benzene

It is known that benzene is used in many industries particularly in petrochemical and related chemical industries. Thus, the main contaminants in wastewater are BTEX (benzene, toluene, ethylbenzene, and xylene) along with other solvents and used chemicals depending on individual industry. Petroleum refinery is one of industries generating the wastewater containing benzene. Wastewater from this industry usually contains hazardous chemicals as hydrocarbon oil, phenol and ammoniacal nitrogen as shown in Table 2.2. There is a case study reporting that the benzene concentration in wastewater ranges from 20 ppm to 200 ppm. Moreover, the amount of benzene discharge depends on the volume of generated wastewater varied by the size of refinery from 100 gallons per minute to over 3,000 gallons per minute. The annual benzene discharge can be as high as 54 tons if the refinery releases 500 gallons per minute of wastewater containing 50 ppm of benzene (Worall and Zuber, 1998).

Table 2.2 Characteristic of wastewater from petroleum refinery (LENNTECH Petrochemical Company, 2005)

Polluted parameter	Approximate quantities
BOD	150-250 mg/L
COD	300-600 mg/L
Phenol	20-200 mg/L
Oil	100-300 mg/L (desalter water) 5000 mg/L in tank bottom
Benzene	1-100 mg/L
Heavy metals	0.1-100 mg/L

2.1.5 Effects on Humans

It is known that benzene produces several adverse health effects. Bone marrow depression leading to aplastic anaemia is the most frequently noted health effect of benzene. Oral exposure and acute inhalation of humans to high concentration of benzene have outcomes in central nervous system depression and death. Haematotoxicity, immunotoxicity and neoplasia are the most reported effect resulting from long-term exposure to lower levels of benzene (IPCS, 1993).

2.1.5.1 Acute Toxicity

Exposures to high concentration in the general population resulting in the acute toxic effects usually cause from accidents and misuse or abuse of benzene. The acute toxic effects of benzene are shown in Table 2.3.

2.1.5.2 Effects of Short- and Long-Term Exposures

Haematotoxicity, immunotoxicity, neurotoxicity and carcinogenicity are the most significant health effects from short- or long-term exposure to benzene. There are three types of bone marrow effects cause from benzene exposure; bone marrow depression leading

to aplastic anaemia, chromosomal changes and carcinogenicity (leukaemia). Although, there is no confirmation of benzene being teratogenic, fetal toxicity has been investigated (Truhaut, 1968; Goldstein, 1977; IPCS, 1993).

Table 2.3 Acute toxic effects of benzene (IPCS, 1993)

Exposure		Effect
Benzene concentration (ppm)	Time	
20,000	5-10 min	fatalities
7,500	30 min	Dangerous to life
1,500	60 min	Serious symptoms
500	60 min	Symptom of illness
50-150	5 h	Headache, lassitude and weakness
25	8 h	Without clinical effect*

*The clinical effects of acute toxicity from benzene include CNS depression, cardiac arrhythmia, and eventually asphyxiation and respiratory failure.

2.1.6 Regulations

It is known that benzene is hazardous air pollutant (HAP). Its Threshold Limit Value (TLV) is 10 ppm (Physical and Theoretical Chemistry Laboratory Oxford University, 2005). National Emission Standards for Hazardous Air Pollutants (NESHAPS) does not permit open process drain since it can evaporate into the atmosphere prior to reaching the wastewater treatment facility (Worrall and Zuber, 1998). So, a closed drainage systems controlled by appropriated technology is required to handle the HAPS contaminated wastewater. Due to its high toxicity, the effluent limitations of benzene are fairly low as shown in Table 2.4. There are several techniques as recommended by Emission Standard Division by U.S. EPA to prevent or control VOCs in wastewater discharges for example, stream or air stripping, activated carbon adsorption and solvent extraction (U.S.EPA, 1997).

However, these conventional techniques have downsides. They are energy intensive processes. Furthermore, some techniques transfer the contaminants from one medium to another by using a large amount of material such as gas/air stripping, they need to treat a large amount of air stream or extract materials before releasing to environment. Thus, the alternative as surfactant based separation technique will be proposed in this thesis. It is of interest because it has been shown as an effective technique for separation with less toxic solvent consummable by using environmentally friendly surfactant as extractant. Moreover, it can be done at mild operating condition and preconcentrate waste to fewer amounts for treatment that is shown economic advantage over the others.

Table 2.4 Effluent limitations of benzene

Source	Effluent limitation	Reference
* Outfall	0.05 mg/l	Missouri Clean Water Law and the Federal Water Pollution Control Act ^(a)
Organic Chemicals, Plastics and Synthetic Fibers Subpart C-Other Fibers Subpart D-Thermoplastic Resins Subpart F-Commodity Organic Chemicals	Maximum 1-day 136 µg/L Maximum monthly average 37 µg/L Maximum 1-day 136 µg/L Maximum monthly average 37 µg/L Maximum 1-day 134 µg/L Maximum monthly average 37 µg/L	40 CFR 414.35 EPA 1993d ^(b) 40 CFR 414.45 EPA 1993c ^(b) 40 CFR 414.65 EPA 1993f ^(b)
Centralized Waste Treatment Industry	Maximum 1-day 0.014-9.0 mg/L Maximum monthly average 0.011-6.8 mg/L	60 FR 5464 EPA 1995a ^(b)
Pharmaceutical Manufacturer Subpart A-Fermentation Subpart B-Extraction	Maximum 1-day 573-796 µg/L Maximum monthly average 212-268 µg/L Maximum 1-day 40-796 µg/L Maximum monthly average 17-268 µg/L	60 FR 215912 EPA 1995c ^(b)

Source	Effluent limitation	Reference
Subpart C-Chemical Synthesis	Maximum 1-day 573-796 µg/L Maximum monthly average 212-268 µg/L	
**General effluent	0.1 mg/L	The Water Pollution Control Law ^(c)
Combination (BTEX) effluent	Annual Average 0.75 mg/L Annual Average 1.12 mg/L	Water Pollution Control Permit ^(d)

*Outfall is discharge of wastewater from shallow groundwater cleanup

**Item related to the protection of human health

- (a) Department of Natural Resources, State of MISSOURI (2004)
- (b) Agency for Toxic Substances and Disease Registry (ATSDR) (2001)
- (c) Ministry of the Environment Government of Japan (2003)
- (d) Mississippi Department of Environment Quality, State of Mississippi (2005)

2.2 Surfactant

2.2.1 Introduction

The surfactant under several names such as detergents, coagulants, dispersants, emulsifiers, de-emulsifiers, foaming agents and deformers is one of the most widely used class of chemicals in industries. They are used in various products such as pharmaceuticals, detergents, drilling muds and flotation agents. Of late, surfactants have applied in such high-technology areas as electronic printing, magnetic recording, biotechnology, micro-electronics and viral research (Rosen, 2004).

The surfactant or surface active agent is a molecule which alters the interfacial properties of any two immiscible phases by concentrating at the interface and changing the interfacial free energy of the interface. The surfactant molecule is an amphiphile molecule consisting of a head group which is a hydrophilic or water liking group and a tail group which is a hydrophobic or water hating group.

2.2.2 Types of Surfactant

Surfactants are classified into 4 types depended on the charge of the hydrophilic group

2.2.2.1 Anionic Surfactant

Anionic surfactants are surfactant molecules possessed a negatively charged in the hydrophilic portion such as Sodium dodecyl sulfate ($\text{CH}_3(\text{CH}_2)_{11}\text{SO}_4^-\text{Na}^+$).

Carboxylate, sulfate, sulfonate and phosphate are the polar group found in this type. Anionic surfactants are used in the greatest volume as the main application surfactant.

2.2.2.2 Cationic Surfactant

Cationic surfactants are surfactant molecules possessed a positively charged in the hydrophilic portion such as quaternary ammonium chloride ($\text{RN}^+(\text{CH}_3)_3\text{Cl}^-$). Due to the positive charge on the hydrophilic portion giving the strong substantivity on negatively charged fibres such as cotton and hair, they are used as fabric and hair conditioners.

2.2.2.3 Nonionic Surfactant

Nonionic surfactants are surfactant molecules without charges in the hydrophilic portion such as monoglyceride of long-chain fatty acid ($\text{RCOOCH}_2\text{CHOHCCH}_2\text{OH}$). They are used extensively as emulsifiers and in low temperature detergency.

2.2.2.4 Zwitterionic Surfactant

Zwitterionic surfactant are surfactant molecules containing both positively and negatively charged in the hydrophilic portion, for example, long-chain amino acid ($\text{RN}^+\text{H}_2\text{CH}_2\text{COO}^-$). This group is milder on the skin particular on eyes than anionic surfactants. So, they are used in toiletries and baby shampoos.

2.3 Micelle Formation

2.3.1 Introduction

Micellization is an important phenomenon in detergency and solubilization. When surfactant molecules (monomers) are dissolved in water at low concentration, the hydrophobic groups distort the structure of the water and increase the free energy of the system. Reorienting the surfactant monomers so that their hydrophobic groups directed away from the water is one way to minimize the system free energy (Rosen, 2004). If the surfactant concentration is increased beyond a point at which the interface is completely covered with surfactant monomers, the aggregation of monomers into clusters called micelles is another way to reduce the free energy of the system. In the clusters, their hydrophobic portions oriented toward the interior of the cluster and their hydrophilic portions directed toward the water as shown in Figure 2.1.

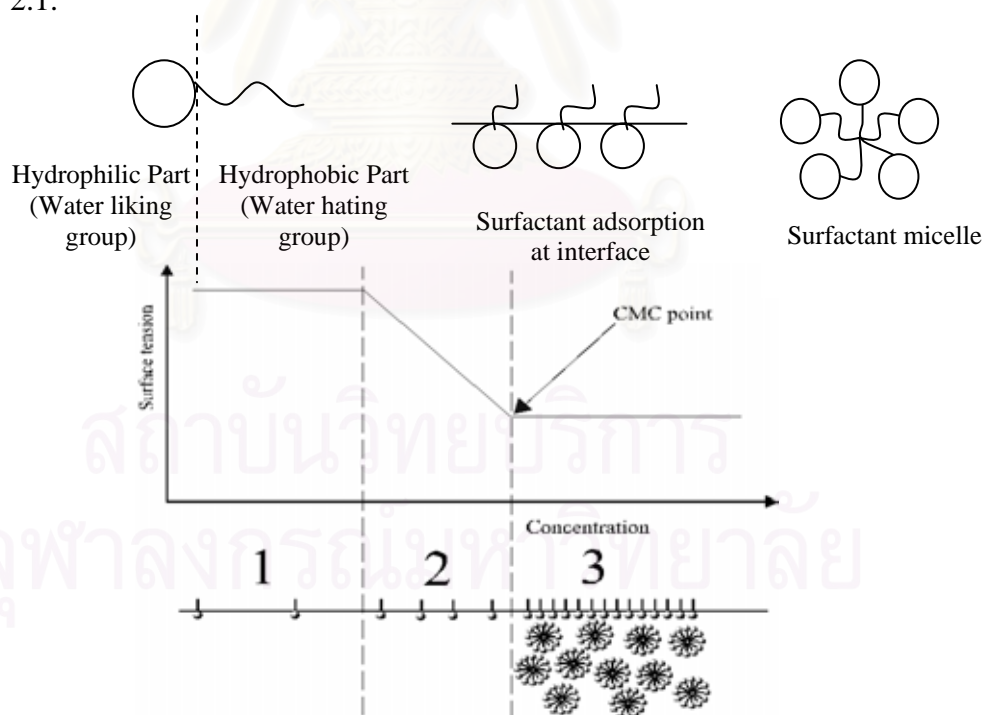


Figure 2.1 Surfactant and its characteristic (KSV Instrument USA, 2005)

The surfactant concentration which the micellization begins to occur is called the critical micelle concentration (CMC). At CMC, the drastic change

in physicochemical properties of an aqueous solution of a surfactant such as surface tension, osmotic pressure, light scattering, solubilization, turbidity, conductivity and self-diffusion can be observed as show in Figure 2.2

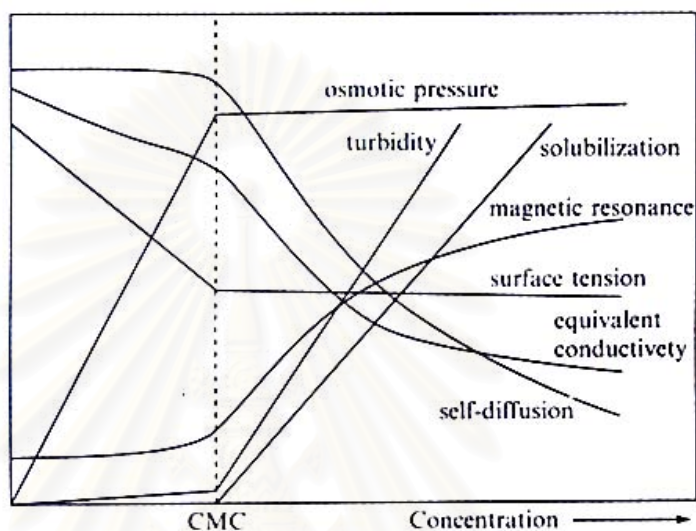


Figure 2.2 Changes in physical properties of aqueous surfactant solution around the critical micelle concentration (Holmberg *et al.*, 2003)

In theory CMC can be determined from the any physical properties shown in Figure 2.2 but the measurement of surface tension as a function of surfactant concentration is perhaps the most commonly used method. From Figure 2.3, it is shown that at CMC the break point is very sharp.

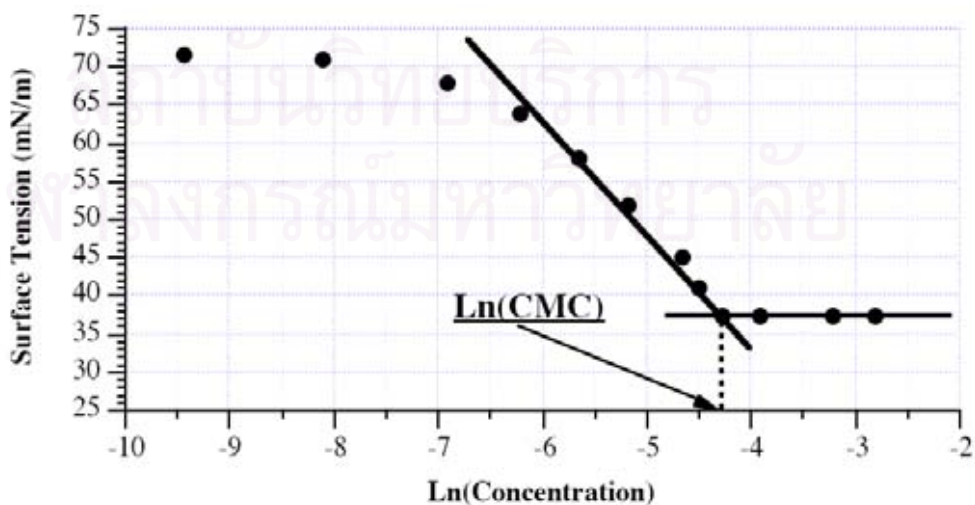


Figure 2.3 Determination of critical micelle concentration from surface tension (Gragson, 2005)

Factors affecting the CMC and micellization are structure of surfactant (hydrophobic volume, chain length, head group area) temperature, additive, pH, surfactant concentration and surfactant composition (for surfactant mixtures) (Rio *et al.*, 1994; Bujan, Vdovic and Filipovic-Vincekovic, 1996; Castedo *et al.*, 1997; Kang, Kim and Lim, 2001; Murphy and Taggart, 2002; Yin, Zhou *et al.*, 2003)

In general, the CMC decreases strongly with increasing CH_2 group. (Clint, 1992; Holmberg *et al.*, 2003; Rosen, 2004) Generally, the presence of electrolyte in aqueous solution causes a change in the CMC.

For ionic surfactants the electrostatic repulsion between head groups in the micelle is considerably reduced upon increasing ionic strength. So, micelles can form easier at lower concentration, thus the CMC is declined. For nonionic and zwitterionic surfactants, the effect of adding electrolytes is more complex as can be described by salting-in and salting-out effects in which the CMC is increased and decreased, respectively. Electrolytes as NaCl, KCl, NaBr and NaNO_3 are capable of salting-out while $\text{Mg}(\text{NO}_3)_2$ and $\text{Al}(\text{NO}_3)_3$ are capable of salting-in (Clint, 1992).

For ionic surfactants containing ionisable groups such as $-\text{NH}_2$, and $-\text{COOH}$, the degree of the dissociation of the polar groups are highly pH dependent. Generally, at pH values where the group is charged, the CMC is high while uncharged, the CMC is low (Clint, 1992).

The temperature dependence of the CMC differs between ionic and nonionic surfactants. For nonionic surfactants based on polyethylene oxide (PEO), the CMC decreases with increasing temperature (Clint, 1992; Holmberg *et al.*, 2003). In contrast, the effect of temperature on CMC of ionic surfactant is more complex such as the CMC of most ionic surfactant passes through a minimum as the temperature is varied from 0 to 70 °C (Krescheck, 1975).

2.3.2 Micellar Structure and Shape

2.3.2.1 Surfactant Structure and Micellar Shape

Surfactants are self-assembly into different structures. The single-phase systems can be divided into isotropic solutions, solid phases and liquid crystalline phases

A. Micelles

(i) Spherical Micelles

Spherical micelles are clusters composing of hydrocarbon chains in the interior core with the hydrophilic head groups facing water. So, the radius of hydrocarbon core is close to the length of the extended alkyl chain. In general, at above CMC unbranched single-tailed surfactants form spherical micelles in aqueous solution (Holmberg *et al.*, 2003).

(ii) Cylindrical Micelles

Cylindrical micelles are the form that the surfactants elongate themselves into tube with the hydrophobic tail oriented into the interior and the hydrophilic head towards the water (Holmberg *et al.*, 2003; Ridell, 2003).

(iii) Vesicles

Vesicles form curved bilayers similar to those of the lamellar phase. The hydrophobic tails are the inner core of the bilayer while the hydrophilic head are located at the bilayer-water interface. The aqueous phase will present in the interior of the structure also. Two long alkyl chains may form vesicles in aqueous media (Rosen, 1989; Buwalda, 2001; Visscher, 2004).



Figure 2.4 Vesicle

(iv) Lamellar Micelles

Lamellars are flat bilayer similar to the cell membranes (Visscher, 2004).

(v) Reverse Micelles

Reverse micelles have the opposite structure arrangement to the normal micelles where the water is in the core surrounding by the surfactant polar head groups and the hydrocarbon chains face the non-polar solvent (Holmberg *et al.*, 2003).

B. Liquid Crystals

Most surfactants form homogeneous single phase known as mesophases or liquid crystals at high concentrations in aqueous solution. Lamellar and hexagonal are two of the most common geometrics. Lamellar liquid crystals, which consist of parallel stacks of surfactant bilayers, are packed from lamellar micelles. Spherical micelles pack together into cubic liquid crystal while cylindrical micelles pack to form hexagonal liquid crystals.

Due to difference in structure, these common aggregates also show different viscosities in the following order: cubic > hexagonal > lamellar. Cubic liquid crystal are more viscous than the others since they have no obvious shear plane and so layers of surfactant aggregates

cannot slide easily. On the other hand, the lamellar liquid crystals are less viscous than others due to the ease in sliding between each parallel layer.

Factors affecting surfactant aggregate are surfactant structure and environment factors such as temperature, concentration, pH, electrolytes and additives such as Cu^{2+} , octane (Clint, 1992; Mao *et al.*, 2002; Yin, Mao *et al.*, 2002; Holmberg *et al.*, 2003; Wang *et al.*, 2003; Yin, Zhou *et al.*, 2003; Rosen, 2004).

These factors can change or rearrange the structure into either higher or lower order of aggregates. For example, some types of micelles change their structure from spherical to cylindrical to lamellar with increasing surfactant concentration. In addition, some systems of cationic surfactant such as Sodium dodecyl sulfate (SDS) and Dodecyl triethyl ammonium bromide (C_{12}NE) micelles are completely transformed into vesicle by increasing temperature (Yin, Zhou *et al.*, 2003).

2.3.2.2 The Critical Packing Parameter

Surfactants can form a broad variety of aggregate morphologies. The shape of aggregates in aqueous solution is very important to determine the properties of surfactant solution such as its viscosity, its capacity to solubilize water-insoluble material and its cloud point (Rosen, 2004). The morphology of the aggregate is the result of the balance between the attractive hydrophobic interactions between the tails and the repulsive electrostatic between the head groups and is determined by the molecular structure of the individual surfactant molecule. The critical packing parameter (P_c) is accounted for the relation between molecular structure and aggregate morphology. As shown in equation 2.1, P_c is calculated by dividing the volume of hydrophobic tail of surfactant (V_H) by the cross-sectional area (a_0) of the hydrophilic head and the length of the hydrophobic tail (l).

$$P_c = \frac{V_H}{a_0 l} \quad (2.1)$$

As shown in Figure 2.5 surfactants form micelles in aqueous solution where P_c is lower than $1/3$. If the head group area decreases relative to hydrophobic part and $1/3 < P_c < 1/2$, hexagonals are formed. Lamellars or vesicles are formed if $P_c \approx 1$ and when $P_c > 1$ reversed micelles are formed.

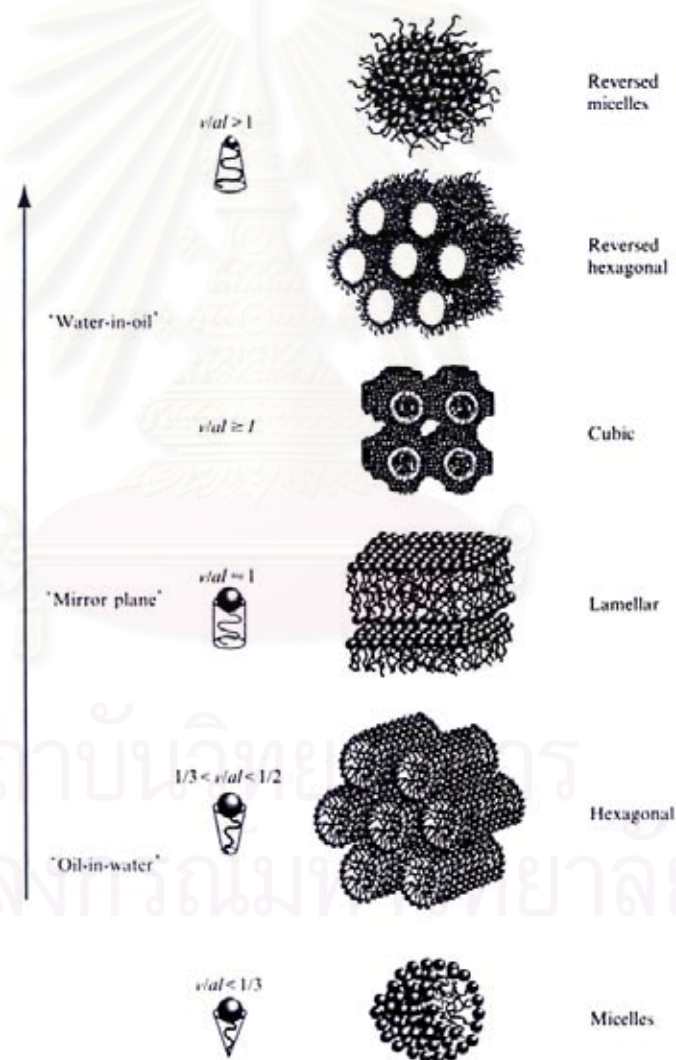


Figure 2.5 Relation between critical packing parameter and preferred aggregate structures (Holmberg *et al.*, 2003)

2.4 Solubilization

Solubilization is an ability to dissolve the water-insoluble hydrophobic molecules (solubilizates) in micelle core which has the oil-like environment (Rosen, 2004). This dissolution of hydrophobic material into water may greatly exceed their normal solubility in water. It is one of the most important properties of surfactant that has been widely utilized in industries such as removal of oily soil, household and agro applications such as detergents pharmaceuticals, cosmetics, insecticides, etc.

As shown in Figure 2.2 and 2.6, the solubility of hydrophobic material is extensively enhanced by the presence of micelles at above CMC.

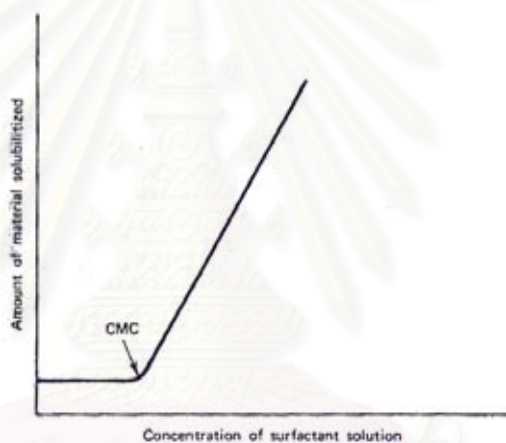


Figure 2.6 Plot of amount of material solubilized as a function of surfactant concentration in bulk phase (Rosen, 2004)

The solubilization ability is influenced by the structure of surfactant and solubilizate, added electrolyte, organic additive, type of aggregate and temperature (Clint, 1992; Li and Zhang *et al.*, 1996; Holmberg *et al.*, 2003; Rosen, 2004).

(i) Structure of Surfactant and Solubilizate

It is known that the shape of the micelle is determined by the critical packing parameter. As this value increases, the volume of the inner core increases. So, the amount of solubilized can be increased.

Generally, the amount of solubilizates that solubilize deep in the palisade layer or in the hydrophobic core of the micelle, i.e., long-chain polar compounds and hydrocarbons increase with increasing the size of the micelle.

Due to the solubilized position of these compounds, an increase in the chain length of the hydrophobic portion of the surfactant leads to increased solubilization capacity for hydrocarbon solubilizates. In addition, the polar compounds that solubilize more deeply in the palisade layer are less soluble than those whose loci of solubilization are closer to the micelle-water interface (Rosen, 2004).

(ii) Effect of Electrolyte

The addition of neutral electrolytes on the ionic surfactant solution typically decreases the CMC and increases in volume of the micelles due to a reduction in the repulsion forces between the similar charged ionic surfactant head groups. So, it results in an increase in hydrocarbon solubilization in the inner core of the micelle (Rosen, 2004).

(iii) Effect of Temperature

For nonionic surfactant especially the polyoxyethylene type, an increase in temperature generally results in an increase in the extent of solubilization for both polar and nonpolar solubilization because micellar size and aggregation number are greatly enhanced (Clint, 1992; Rosen, 2004).

2.5 Cationic-Anionic Surfactant Mixtures

Generally, cationic and anionic surfactants are inharmonious because their mixtures form insoluble complexes known as precipitates. However, there are some surfactant compositions that the mixtures of cationic and anionic surfactant are well formed. When mixing surfactant, not only the properties of components are combined, but also new properties are found in many cases, i.e., being as pseudo-nonionic surfactant; exhibiting the cloud point phenomena and possessing high surface activity; reduction of CMC (Mehreteab, 1999; Minardi, Schulz and Vuano, 2002). Cationic-anionic mixtures with large hydrophilic groups or unsymmetrical and shorter chain lengths have fewer tendencies to form precipitates. Their mixtures are soluble and behave like nonionic surfactants that can exhibit the cloud point

phenomenon. From the previous literature, the cloud point temperature shows the minimum at the composition of cationic-anionic at around neutral charged ratio in which a pseudo-nonionic complex is formed. Figure 2.7 shows that at 0.5 mole fraction of AEOS (alcohol ethoxysulfate), the surfactant mixture behaves like the pseudo-nonionic having lowest cloud point temperature (Mehreteab, 1999).

The CMC of surfactant mixture is much lower than that of either anionic or cationic surfactant alone. Moreover, the mixtures of cationic and anionic have self-assembly ability forming aggregates easier than individual component resulting from a reduction of polar interaction by charge neutralization (Holmberg *et al.*, 2003). In general, individual surfactant forms the spherical micelles at low concentration but aggregate morphologies of cationic-anionic surfactant mixture are usually vesicular. The levels of synergism lean on the charge and molecular structure of the individual surfactant (Minardi *et al.*, 2002; Holmberg *et al.*, 2003).

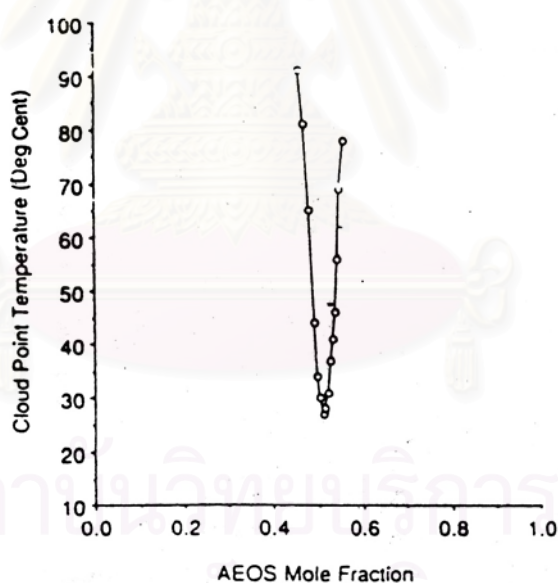


Figure 2.7 Cloud Point Temperature of AEOS-TTAB (Mehreteab, 1999)

The solubility of surfactants in water is caused by the affinity of their hydrophilic part either charged groups of ionic surfactant or polar groups of nonionic surfactant or both to the water. In general, when simple anionic and cationic surfactants are mixed at equimolar composition, the oppositely charged heads neutralize each other leading to a tremendous decrease in their water solubility.

Therefore, the resulting complex falls out of solution as precipitates (Raghavan, Fritz and Kaler, 2002). On the other hand, when either anionic or cationic surfactant is significantly in excess, the precipitation does not occur. In addition, even at the equimolar of mixture of cationic-anionic surfactant, the precipitates may not form if the structure of surfactants are highly branched and have polar head groups and/or contain bulky substitutes in the hydrophobic moiety (Yatcilla *et al.*, 1996; Mehreteab, 1999; Raghavan *et al.*, 2002).

The system containing large polar heads such as C₁₂NE (dodecyltriethyl ammonium bromide) can screen and weaken the electrostatic interactions between the two oppositely ionic head groups, so small spherical micelles and other aggregates such as cylindrical or vesicle are likely to form. The phase separation can be induced and the occurrence of precipitation is inhibited such as the system of C₁₂NE and SPFO (sodium perfluorooctanoate) (Li and Liu, 1995; Yatcilla *et al.*, 1996; Mehreteab, 1999; Tong, Dong and Li, 1999). Furthermore, the surfactant system consisting of linear hydrocarbon tail of unequal lengths such as CTAB (Cetyl trimethyl ammonium bromide) and SHS (sodium hexyl sulfate) mixture at 1:1 ratio forms both small unilamellar and large multi-lamellar vesicle without precipitation (Talhout and Engberts, 1997).

2.6 Aqueous Surfactant Two Phase (ASTP) System

2.6.1 ASTP System

Aqueous two-phase systems were observed originally with polymer solutions as aqueous polymer two-phase systems consisting of an aqueous solution of two particular polymers. Above critical concentration of these components, spontaneous phase separation takes place. One phase is rich in one polymer and the other phase is rich in the other polymer (Zhao and Xiao, 1995). Similarly, the aqueous solution of cationic and anionic surfactants can separate spontaneously into two immiscible aqueous phases with a clear interfacial boundary between them. One phase contains most of surfactant aggregates known as the surfactant-rich phase while the other phase is lean in surfactant aggregates known as the surfactant-dilute phase. This system can be

called the aqueous surfactant two-phases (ASTP) unlike the phase demixing of single nonionic or zwitterionic surfactant that is caused by temperature. The ASTP system has many unique features as follows (Xiao *et al.*, 2000):

- 1) The selectivity for material partitioning into micelle can be controlled by adjusting their net charge via molar ratio of cationic and anionic surfactants.
- 2) After partitioning, surfactants can be separated from the solubilizates by altering the surfactant-rich phase composition or by changing the temperature. The precipitated surfactants can be recycled for reuse.
- 3) Multi-step partitioning procedures are possible by diluting the surfactants-rich phase with water or buffers to an appropriate concentration without the addition of new surfactants.
- 4) ASTP partitioning can be simply operated because of
 - i) low concentration of surfactants (it may be less than 1wt%)
 - ii) low phase viscosity of the surfactant-rich phase, while the viscosity of the surfactant-dilute phase is close to water (solvent)
 - iii) rapid phase separation time
 - iv) low operating temperature (can be successfully done at room temperature)

2.6.2 Possible Mechanism of the Formation of ASTP

The main types of interaction between the surfactant aggregates are classified into 4 types: electrostatic interaction, van der Waals force, steric force, and hydration force. The former two forces are important. The balance of repulsive electrostatic interaction and the attractive van der Waals force introduce to self-assemblies in aggregations (Mao *et al.*, 2002).

The structure of aggregates and type of interaction are the factors controlling the phase behavior. The phase separation in cationic-anionic

mixtures occurs by the difference in the interactions between surfactant aggregates in the upper and lower phase. At the charge neutralizing ratio, charges of surfactant head group are balanced inducing the formation of large aggregates. So, the formation of ASTP system is probably due to the coexistence of different kinds of aggregates in which the large aggregates flocculate and separate out from solution forming the surfactant-rich phase either located at upper or bottom phase (Zhao and Xiao, 1996; Mao *et al.*, 2002; Yin, Mao *et al.*, 2002).

2.6.3 Factor Affecting the ASTP system

Factors affecting the ASTP system are surfactant composition and concentration, temperature, pH and electrolytes (Zhao and Xiao, 1996; Tong, Wu *et al.*, 1998; Akama *et al.*, 1999; Tong, Dong *et al.*, 1999; Xiao *et al.*, 2000; Clint, 2002; Raghavan *et al.*, 2002; Yin, Mao *et al.*, 2002, Yin, Zhou *et al.*, 2003).

(i) Surfactant Composition and Concentration

From the reviews, it is found that the ASTP system occurs at certain surfactant composition and concentration. The regions that phase separation occur are different for each mixtures. Phase separation can be found in the region that cationic or anionic is in excess or even at equimolar. It is shown that the effect of molar ratio is quite strong (Zhao and Xiao, 1996; Xiao *et al.*, 2000).

(ii) Temperature

The main effect of temperature on ASTP is the changes in the structure of aggregate such as the transition of aggregate from micelle to vesicle which will later on affect the solubility of surfactant (Clint, 2002; Yin, Mao *et al.*, 2002; Yin, Zhou *et al.*, 2003).

(iii) pH

The addition of acids such as hydrochloric, acetic, sulfuric and nitric acid or adding base such as sodium hydroxide can cause changes in phase behavior, thus altering phase volume ratio and inducing precipitation (Tong, Wu *et al.*, 1998; Tong, Dong *et al.*, 1999).

(iv) Electrolytes

Addition of salts generally has effect on micellization by screening the electrostatic interaction repulsion between aggregates and promoting a large aggregate formation (Raghavan *et al.*, 2002; Yin, Mao *et al.*, 2002).

2.6.4 Application of ASTP System

The ASTP technique has many applications in partitioning various kinds of substances, for example biomaterials and dyes.

Zhao and Xiao (1996) studied the formations, compositions, and physicochemical properties of ASTP of C₁₂NE (cationic surfactant) and SDS (anionic surfactant). They found that mixture of cationic-anionic surfactant can form ASTP system when either cationic or anionic surfactant is in excess. This system can be formed in the concentration range between the high concentration region and the precipitate-formed region at very narrow molar ratio around equimolar. In addition, the formation of ASTP system is a reversible process and is likely to be due to the coexistence of different kinds of aggregates. It is shown that ASTP system can be applied as partitioning systems to separate the biomaterials.

Tong, Wu *et al.*, studied the extraction abilities of the ASTP of C₁₂NE and SDS to several dyes and porphyrins compounds in 1998. They found that this system was successfully applied to extract dyes, porphyrins and metalloporphyrins. Negatively charged species as sulfonic or carboxyl group substituted porphine and their metal chelates can be effectively extracted into the surfactant-rich phase, which is cationic in excess while positively charged trimethylammonio substituted porphine and its chelate have the extraction

efficiency only about 30 %. They concluded that hydrophobic and electrostatic interactions between solutes and aggregates in the two phases are predominant factors that govern the extraction.

In 1999, Tong, Dong *et al.* studied the formation condition for the system of C₁₂NE and SPFO and their extraction applications to dyes and porphyrin compounds. They found that molecules with high hydrophobicity and positively charged porphyrins can be easily extracted into the surfactant-rich phase with relatively high extraction efficiency since their system is anionic in excess. However, the negatively charged porphyrins distribute into two phases almost uniformly. They concluded that hydrophobic and charge interactions are two important factors governing the partition behavior of molecules to be extracted in the ASTP system that corresponded well with their previous result.

Xiao, Sivars and Tjerneld (2000) studied the ASTP systems of C₁₂NE and SDS focusing on phase behavior of the systems and the partitioning of bovine serum albumin (BSA) and lysozyme. They found that phase behavior, volume ratio and setting time are strongly influenced by total concentration and composition of mixed surfactants. The selectivity of proteins partitioning depends on the charged of the micellar surface, which can be adjusted by changing the molar ratio of cationic to anionic surfactant. Furthermore, proteins still maintain their activity in the ASTP system because of the extremely low CMC of cationic-anionic surfactant mixture that make the concentration of surfactant monomers much lower than that caused protein denaturing.

2.6.5 Scaling-up of ASTP system

To commercialize, the ASTP technique can be scaled-up to a continuous and multi-stage unit. Due to a high volatility of benzene, it can be stripped away from high surfactant concentration solution of the surfactant-rich phase (Hasegawa *et al.*, 1997; Choori *et al.*, 1998). Figure 2.8 shows the integrated flow diagram of the multi-stage ASTP process including a surfactant recovery unit proposed by Trakultamapatam, Scamehorn, and

Osuwan in 2002. The contaminated wastewater and surfactant-solution are fed to the extractor where two streams are mixed at suitable extraction condition. The phase separation takes place inside the extractor. Due to a density difference, the heavy surfactant-rich phase which comprises most of surfactant and solute settles down at the bottom of the extractor as the extract phase. The surfactant-dilute phase, which contains the trace amount of solute, raises up to the top of the extractor as the raffinate phase. If this solution is clean enough as regarded to the regulation, it can be released to the environment. Furthermore, the surfactant-rich phase as well as benzene can be recycled for reuse since the benzene can be stripped by a vacuum stripper due to its high volatility. The benzene in the vapor phase will be condensed in the condenser and separate from the water by a phase splitter due to a density difference.

As previously reviewed, factors affecting the ASTP system are surfactant composition and concentration, temperature, pH and electrolytes. These parameters have the effects on the micelle formation, phase separation and solubilization. Thus, the surfactant composition and concentration, temperature and pH were selected to study in this research.

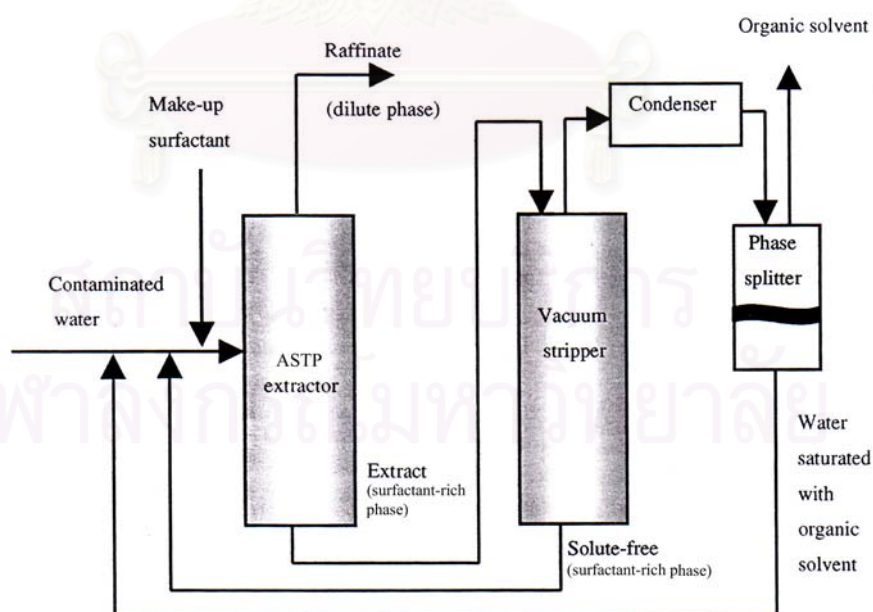


Figure 2.8 Schematic of integrated process including a multistage ASTP extractor and vacuum stripper (Trakultamupatam *et al.*, 2002)

CHAPTER III

METHODOLOGY

3.1 Cationic-Anionic System Selection

The objective of preliminary study is to select the suitable cationic-anionic system for further use. Seven surfactants were used in this step as shown in Table 3.1.

Table 3.1 Relevant properties of surfactants used in this study

Surfactant	Type	MW	CMC (mM)	Structure
Dodecyltrimethylammonium bromide (DTAB)	Cationic	308.3	12 ⁽¹⁾ 15.6 ⁽²⁾ 16 ⁽³⁾ 16.03 ⁽⁴⁾	$\begin{array}{c} \text{CH}_2(\text{CH}_2)_{10}\text{CH}_3 \\ \\ \text{CH}_3-\text{N}^+-\text{CH}_3 \text{ Br}^- \\ \\ \text{CH}_3 \end{array}$
Tetradecyltrimethylammonium bromide (TTAB)	Cationic	336.4	3.08 ⁽⁴⁾	$\begin{array}{c} \text{CH}_2(\text{CH}_2)_{12}\text{CH}_3 \\ \\ \text{CH}_3-\text{N}^+-\text{CH}_3 \text{ Br}^- \\ \\ \text{CH}_3 \end{array}$
Cetyltrimethylammonium bromide (CTAB)	Cationic	365	0.8 ⁽⁴⁾ 1.0 ⁽⁵⁾	$\begin{array}{c} \text{CH}_2(\text{CH}_2)_{14}\text{CH}_3 \\ \\ \text{CH}_3-\text{N}^+-\text{CH}_3 \text{ Br}^- \\ \\ \text{CH}_3 \end{array}$
Dodecyltriethylammonium bromide (C ₁₂ NE)	Cationic	350	13 ⁽⁶⁾	$\begin{array}{c} \text{CH}_2(\text{CH}_2)_{10}\text{CH}_3 \\ \\ \text{CH}_3\text{CH}_2-\text{N}^+-\text{CH}_2\text{CH}_3 \text{ Br}^- \\ \\ \text{CH}_2\text{CH}_3 \end{array}$
Sodium dodecyl sulfate (SDS)	Anionic	288.5	7.8 ⁽⁴⁾ 8 ⁽⁵⁾ 8.3 ⁽²⁾	$\begin{array}{c} \text{O} \\ \\ \text{CH}_3(\text{CH}_2)_{11}-\text{O}-\text{S}^--\text{O} \text{ Na}^+ \\ \\ \text{O} \end{array}$

Surfactant	Type	M.W.	CM.C. (mM)	Structure
Alkyl diphenyl oxide disulfonate (DOWFAX 8390)	Anionic	642	3.0 ⁽⁷⁾	
Sodium dihexyl sulfosuccinate (AMA)	Anionic	444		

(1) Minardi *et al.* (2002), (2) Holmberg *et al.* (2003), (3) Clint (1992), (4) Murphy and Taggart (2002), (5) www.med.ufl.edu/biochem/BCH6206/DETERGENTS.pdf, (6) Xiao *et al.* (2000), (7) Dow Chemical Co.

Phase behavior of following cationic-anionic systems were studied; DTAB:SDS, DTAB:DOWFAX, DTAB:AMA, TTAB:SDS, TTAB:DOWFAX, CTAB:SDS, CTAB:DOWFAX and C₁₂NE:SDS at molar ratio of 2:1, 1.5:1, 1:1, 1:1.5 and 1:2, total concentration of 20, 50 and 80 mM, temperature at 30 °C except at 20 °C for C₁₂NE:SDS.

Phase volume ratio and appearances such as boundary between two phases, phase stability, phase separation time and reversibility were the factors used to selecting the suitable cationic-anionic surfactant system. However, the phase separation without precipitation was considered as the first priority in system selection.

The suitable cationic-anionic system in this study was the system of DTAB and DOWFAX that shows a rapid phase separation with clear interfacial boundary between two phases. Furthermore, phase separation is stable and reversible. So, this system was further used to study the effect of operating conditions on benzene removal from wastewater.

3.2 CMC Determination

The CMC of DTAB, DOWFAX and 5 ratios of DTAB:DOWFAX, which were 2.5:1, 2:1, 1.5:1, 1:1 and 1:1.5, were studied by measuring the surface tension of

series of surfactant solution at different concentration. The value of CMCs can be obtained from a sharp change in a plot between surface tension and logarithm of surfactant concentration (Schramm, 2000).

3.3 Cloud Point Temperature Determination

The cloud point is a critical temperature at which the solution starts to turbid. The cloud point was determined at concentration of 0.25, 2, 5 mM and 1 wt % of cationic-anionic surfactants. The solution of DTAB-DOWFAX at ratio 1.6:1, 1.8:1, 2:1, 2.2:1, and 2.4:1 DTAB:DOWFAX at each concentration were prepared in the test tubes and placed into a temperature programmable water bath. The temperature of water bath was gradually varied and the temperature of solution was monitored by thermometer. The cloud point was determined as a lowest temperature at which the solution becomes turbid.

3.4 Investigation of Operating Conditions on Benzene Removal via ASTP System

3.4.1 Materials

Dodecyltrimethyl ammonium bromide (DTAB) with the 99% purity purchased from Robiot (Nanjing, China) and Alkyldiphenyloxide disulfonate (DOWFAX 8390) with 35% active contributed from Dow Chemical Co. were used as the cationic and anionic surfactant in this study. Reagent grade benzene from carlo erba reagents with 99.8% purity was used as a pollutant. All chemicals were used as received. Distilled and deionized water has been used throughout the experiment.

3.4.2 Experimental Methods

3.4.2.1 The Aqueous Surfactant Two Phase Procedure

An aqueous solution, containing cationic surfactant, anionic surfactant and benzene were prepared at different conditions designed for determining the effect of each parameter on benzene removal.

Step 1 To determine the effect of molar ratio of surfactant.

- The ratio of DTAB to DOWFAX was varied as follows: 1.6:1, 1.8:1, 2:1, 2.2:1 and 2.4:1.
- The total surfactant concentration and benzene concentration were controlled at 50 mM and 100 ppm, respectively.
- The temperature was controlled at 30°C.

Step 2 To determine the effect of total surfactant concentration.

- The total surfactant concentration of 20, 50, 80, 110 and 140 mM were studied.
- The optimum ratio of DTAB to DOWFAX received from step 1 was used in this experiment.
- Benzene concentration and temperature were controlled at 100 ppm and 30°C, respectively.

Step 3 To determine the effect of temperature.

- The temperature of 20, 30, 40 and 50°C were studied.
- The optimum ratio of DTAB to DOWFAX and total surfactant concentration received from step 1 and 2 were used in this experiment.
- Benzene concentration was controlled at 100 ppm.

Step 4 To determine the effect of pH.

- The pH of solution in the range of 4, 7 and 10 were studied.
- The optimum ratio of DTAB to DOWFAX, total surfactant concentration and temperature received from step 1 to 3 were used in this experiment.
- Benzene concentration was controlled at 100 ppm.

The solution was homogenized by magnetic stirrer for about 30 minutes and transferred into several identical vials. To prevent headspace loss, the solution must occupy almost all of the vial volume

(22 mL) to neglect the vapor volume. The rubber septa coated with Teflon was used to seal these vials to make sure that no leakage occurs. The vials were equilibrated in an isothermal water bath at temperature assigned in each step until the equilibrium was reached approximately 4 days. The equilibrium time in this work was identified when there was no change in either phase height or concentration of surfactant in the dilute phase.

After the system reached equilibrium, the relative phase volume of each phase was measured by the solution height. The concentrations of surfactant and benzene in both two phases were analyzed. The concentrations of DOWFAX and total surfactant were measured by using UV-Visible spectrophotometer (Thermo Spectronic Model Helios Alpha, UV-Visible spectrophotometer) at 240 nm and Total Organic Carbon analyzer (O.I. analytical 1010) TOC Analyzer), respectively. The concentration of DTAB was indirectly determined via the difference between total surfactant concentration and DOWFAX concentration.

In addition, the presence of benzene in the surfactant solution does not have effect on the measured concentration of DOWFAX by the UV-Visible spectrophotometer due to the difference in absorbed wavelength. The maximum absorption of benzene and DOWFAX occur at wavelength of 256 nm and 240 nm, respectively. Furthermore, to measure the DOWFAX concentration, the surfactant solution will be diluted in several times that makes the concentration of benzene is negligible. Thus, the interference of benzene during the DOWFAX concentration determination is insignificant.

The benzene concentration was analyzed by using a gas chromatography with flame ionization detector (Perkin Elmer Model Clarus 500 Gas Chromatography). For the Elite-wax column with the ultra-pure hydrogen flow rate of 45 mL/min and air with rate of 450 mL/min and detector temperature of 250 °C, the retention time for

benzene was 3.51 minutes. Due to the high volatility of benzene, static headspace sampling (Perkin Elmer, Head Space Sampler Turbomatrix 40) was used as the sample injection technique with no interference of high molecular weight cationic and anionic surfactant. The setting temperature conditions of headspace sampler were 85 °C for sample temperature, 100 °C for needle temperature and 110 °C of transfer temperature. Furthermore, the sampler were proceeded at the pressurization time of 2.0 min, injection time of 0.08 min, withdrawal time of 0.2 min, thermostat time of 20 min and GC cycle time of 5.0 minutes.

The external standard quantitative calibrations were conducted to analyze the surfactant and benzene concentrations in both phases. Mass balances of surfactants and benzene were carried out to assure the reliability of the experiments that there was no surfactant and benzene loss more than 10%.

3.4.2.2 Terms Notification

To investigate the extraction performance, these following terms are introduced.

(i) Percentage of benzene removal

$$\% \text{ Benzene removal} = \left[\frac{[B]_{\text{initial}} - [B]_{\text{dilute}}}{[B]_{\text{initial}}} \right] \times 100$$

Where $[B]_{\text{initial}}$ is the initial concentration of benzene in sample and $[B]_{\text{dilute}}$ is the concentration of benzene in the surfactant-dilute phase.

(ii) Fractional Surfactant-Rich Phase Volume

$$\text{Fractional surfactant rich phase volume} = \frac{\text{surfactant-rich phase volume}}{\text{Total volume}}$$

(iii) Surfactant Partition Ratio

$$\text{Surfactant partition ratio} = \frac{[S]_{\text{rich}}}{[S]_{\text{dilute}}}$$

Where $[S]_{\text{rich}}$ is the concentration of surfactant in the surfactant-rich phase

and $[S]_{\text{dilute}}$ is the concentration of surfactant in the surfactant-dilute phase

(iv) Benzene Partition Ratio

$$\text{Benzene partition ratio} = \frac{[B]_{\text{rich}}}{[B]_{\text{dilute}}}$$

Where $[B]_{\text{rich}}$ is the concentration of benzene in the surfactant-rich phase

and $[B]_{\text{dilute}}$ is the concentration of benzene in the surfactant-dilute phase

(v) Phase Volume Ratio

$$\text{Phase volume ratio} = \frac{[V]_{\text{rich}}}{[V]_{\text{dilute}}}$$

Where $[V]_{\text{rich}}$ is the volume of the surfactant-rich phase

and $[V]_{\text{dilute}}$ is the volume of the surfactant-dilute phase

(vi) Fraction of surfactant in surfactant-rich phase

$$\text{Fraction of surfactant in surfactant-rich phase} = \frac{(F_c)([S]_{\text{rich}})}{(F_c)([S]_{\text{rich}}) + (1 - F_c)([S]_{\text{dil}})}$$

Where F_c is the fractional surfactant-rich phase volume

$[S]_{\text{rich}}$ is the concentration of surfactant in surfactant-rich phase

$[S]_{\text{dil}}$ is the concentration of surfactant in surfactant-dilute phase

(vii) Fraction of benzene in surfactant-rich phase

$$\text{Fraction of benzene in surfactant-rich phase} = \frac{(F_c)([B]_{\text{rich}})}{(F_c)([B]_{\text{rich}}) + (1 - F_c)([B]_{\text{dil}})}$$

Where F_c is fraction of benzene in surfactant-rich phase

$[B]_{\text{rich}}$ is the concentration of benzene in surfactant-rich phase

$[B]_{\text{dil}}$ is the concentration of benzene in surfactant-dilute phase



สถาบันวิทยบริการ
จุฬาลงกรณ์มหาวิทยาลัย

CHAPTER IV

RESULTS AND DISCUSSIONS

4.1 Cationic-Anionic System (ASTP) Selection

The aqueous surfactant two phase (ASTP) system generally forms at either very narrow molar ratio region around equimolar or at equimolar mixtures. For example, in the case of $C_{12}NE$ – SDS, ASTP was observed only in nonequimolar mixtures such as at 50 mM, 1.8:1 molar ratio of $C_{12}NE$ -SDS where as the system of octyl triethylammonium bromide (C_8NE)- sodium decyl sulfate ($C_{10}S$) and C_8NE -SDS, the ASTP could be observed in equimolar mixtures (Zhao and Xiao, 1996). In this study, various kind of cationic and anionic surfactants were used to investigate if the phase separation occurred at prepared concentration and composition. The anionic surfactants were SDS, AMA, DOWFAX, and the cationic surfactants were CTAB, DTAB, TTAB. The results showed that the phase separation could occur in some systems such as CTAB-DOWFAX, CTAB-SDS, DTAB-DOWFAX, DTAB-SDS and DTAB-AMA except TTAB-DOWFAX and TTAB-SDS. Unexpectedly, the system of $C_{12}NE$ -SDS at the same condition reported by Xiao *et al.*(2000) did not show the phase separation that might be caused by the difference of used chemical. In the review, $C_{12}NE$ came from the preparation in laboratory where in this study, the chemical was purchased from company and used as received. The APPENDIX A showed the surfactant composition and concentration of systems that phase separation occurred. The factors using to select the suitable ASTP system are phase volume ratio, phase stability, phase separation time, phase reversibility and its appearances such as clear boundary between two phases. Both phases of ASTP must be homogeneous as transparent solutions with clear interfacial boundary. Therefore, the promising system that was possible to be applied as ASTP to extract benzene from wastewater was DTAB-DOWFAX system. The mixtures of DTAB and DOWFAX at ratio of 2:1, total surfactant concentration of 20-80 mM, temperature of 30 and 40 °C showed the best appearance and characteristic among the others such as having phase

separation forming two homogeneous transparent phases with no precipitation, clear interfacial boundary, low phase volume ratio, fast phase separation time and reversibility. While the other systems, the separated phases are inhomogeneous, not transparent, and some systems the separated phases were unstable.

Thus, the system of DTAB and DOWFAX was selected to be the suitable cationic-anionic surfactant system to conduct the ASTP technique to remove benzene from wastewater.

4.2 CMC Determination

It is known that the value of CMC can be determined from the discontinuity of a plot between surface tension and surfactant concentration. In general, a mixture of cationic and anionic surfactants has a synergistic effect in decreasing CMC values to be lower than individual surfactant. Figure 4.1 showed the relationship between surface tension and surfactant concentration. It was found that the CMC of surfactant mixture of cationic and anionic anionic at ratio 2:1 of DTAB-DOWFAX is the lowest as compared to the CMC of individual surfactant. This agrees with our results that the CMCs values of all the studied ratios (2.5:1, 2:1, 1.5:1, 1:1, 1:1.5 of DTAB:DOWFAX) were lower those of individual DTAB and DOWFAX. From the literatures, the CMC of DTAB was reported by many researchers, i.e., 12 mM (Minardi *et al.*, 2002), 15.6 mM (Holmberg *et al.*, 2003), 16.0 mM (Clint, 1992) and 16.03 mM (Murphy and Taggart, 2002). The CMC of DOWFAX is 3.0 mM reported by the manufacturer (DOW Chemical Co.). In this study, the CMC of DTAB and DOWFAX are formed as 9 mM and 0.4 mM, respectively. The difference in CMC values may come from the difference in the purity of chemicals. From the Table 4.1 it shown that CMC is lowest at ratio 2:1 of DTAB:DOWFAX. This can be explained by the charge neutralization between head groups at this ratio making it easier for micelle formation since the electrostatic repulsion is reduced.

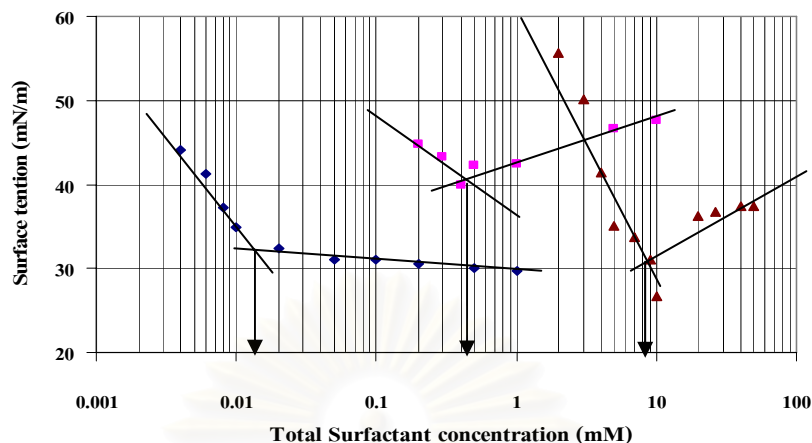


Figure 4.1 CMC of DTAB, DOWFAX and mixture of DTAB and DOWFAX at 2:1 ratio (◆DTAB:DOWFAX at 2:1; ■ DOWFAX; ▲DTAB)

Table 4.1 CMC of the mixture of DTAB and DOWFAX at different composition

Ratio of DTAB:DOWFAX	CMC (mM)
2.5:1	0.022
2:1	0.013
1.5:1	0.05
1:1	0.063
1:1.5	0.13

4.3 Cloud Point Temperature (CPT)

In this study, the CPT of 0.25, 2, 5 and 23.84 mM (1%wt) of cationic-anionic solution at ratio of 1.6:1, 1.8:1, 2:1, 2.2:1 and 2.4:1 of DTAB:DOWFAX were determined. In general, the CPT is determined by observing the temperature at which the turbidity of solution disappears upon cooling or appears upon heating (Mehreteab, 1999). Unexpectedly, the CPT could not be detected in the range of studied temperatures between 5 °C to 80 °C since the phase separation can occur at every temperature.. Consequently, the CPT of this system may be below the freezing point of water. It is beneficial in economic viewpoint because the phase separation can

occur in a wide range of temperature even at ambient temperature. So, an additional of energy is not essential.

4.4 Results of Operating Conditions on Benzene Removal of ASTP System

The results of this study were provided in APPENDIX C-G. Data on the fractional surfactant-rich phase volumes, the concentration of surfactant and benzene in both phases at equilibrium, the fraction of each component in the surfactant-rich phase and the partition ratio of benzene and surfactant were shown in the table. The extraction efficiency on benzene removal was determined in terms of the benzene partition ratio and the fraction of benzene extracted in the surfactant-rich phase.

As mentioned previously that the concentration of DTAB was indirectly determined via the difference between total surfactant concentration analyzed by TOC analyzer and DOWFAX concentration analyzed by UV-spectrophotometer. The result showed that the concentration of DTAB corresponds to the prepared composition prior the phase separation. For example, at the mixture of DTAB:DOWFAX at 2:1 and total surfactant concentration of 50 mM, the result from UV-Visible spectrophotometer showed that DOWFAX concentration in rich phase and dilute phase were 345.36 and 0.16 mM, respectively. From the TOC results after deduction of DOWFAX concentration, the DTAB concentrations were 670.6 and 0.32 mM in surfactant-rich and diluted, respectively. These results support that the ratio of DTAB and DOWFAX after phase separation was about 2 that was equal to that prepared ratio of 2:1. Thus, throughout the study, the DOWFAX concentration can be used as a representative of the total surfactant concentration for convenience since the concentration of DTAB will be 2 times higher than that of DOWFAX and the combination of the two concentrations will be the total surfactant concentration.

4.4.1 Effect of Surfactant Composition

It was shown that the mixtures of DTAB and DOWFAX could form ASTP at certain composition and concentration higher than CMCs. In general, the phase separation forms at composition around equimolar (Zhao and Xiao, 1995; Mao *et al.*, 2002; Yin, Mao *et al.*, 2002). From the previous results

reveal that at some compositions such as 1:1, 1:1.5 and 1:2 of DTAB: DOWFAX, phase separation does not occur. However, the two-phases with a clear interfacial boundary forms at DTAB: DOWFAX molar ratios of 1.6:1, 2:1, 2.2:1 and 2.4:1. The top phase is the surfactant-dilute phase and the bottom phase is the surfactant-rich phase. Unexpectedly, at molar ratio of DTAB to DOWFAX of 1.8:1, it forms three phases with a clear interfacial boundary that has never been reported in any literatures. So, in this study, the molar ratio of DTAB:DOWFAX at 1.8:1 was ignored.

As shown in Figure 4.2, the fractional surfactant-rich phase volume is the highest at ratio of 1.6:1 DTAB:DOWFAX and lowest at ratio of 2:1. It conforms to the highest DOWFAX concentration in surfactant-rich phase as required from material balance at ratio of 2:1. This can be explained that neutral composition of mixture (2:1 in this case), charges between cationic surfactant and anionic surfactant are balanced. At this composition, the surfactant mixture behaves as pseudo-nonionic surfactant in which the aggregates flocculate forming the surfactant-rich phase at highest concentration as compared to other compositions that the charges are weakly electrostatic repulsion (Akama *et al.*, 1999). However, the surfactant concentration in the surfactant-dilute phase at molar ratio of 1.6:1 shows very high concentration about 5.3 mM as compared to 0.1 mM at ratio of 2:1, 0.06 mM at ratio of 2.2:1 and 0.02 mM at ratio 2.4:1 as show in Figure 4.3. Therefore, the surfactant partition ratio, which is the ratio of surfactant concentration in the surfactant-rich phase to that of in the surfactant-dilute phase, is fairly low at the ratio of 1.6:1 and continuously increases as the molar ratio increases as shown in Figure 4.4. However, at the viewpoint of benzene, it was found that the benzene partition ratio at ratio of 2:1 is the greatest since the concentration of benzene in the surfactant-rich phase is also the highest meanwhile the concentration of benzene that still remains in the surfactant-dilute phase is fairly low about 28 ppm from the original contaminant concentration of 100 ppm as shown in Figure 4.4 and 4.5. Since the charges between cationic and anionic are balance at 2:1 molar ratio, the surfactant aggregates form large aggregates providing more volume to

solubilize the pollutants. Therefore, the percentage of benzene removal is highest at this composition as shown in Figure 4.6 in which as high as 72 % of benzene is extracted in the surfactant-rich phase. Moreover, there is about 99 % of the surfactant ending up in the surfactant-rich phase after the phase separation. It was important to note that this result was obtained from a single stage extraction at ambient temperature of 30 °C. The multi-stage extraction can possibly be done to further enhance the extraction efficiency. As compared to the conventional system formed by a nonionic surfactant which was operated at the same condition, the ASTP formed by a mixture of cationic and anionic surfactants obviously shows the greater benzene partition ratio almost 5 folds in which the benzene partition ratio obtained from this study was 48 comparing to 10 from the nonionic surfactant (Trakultamupatam *et al.*, 2002).

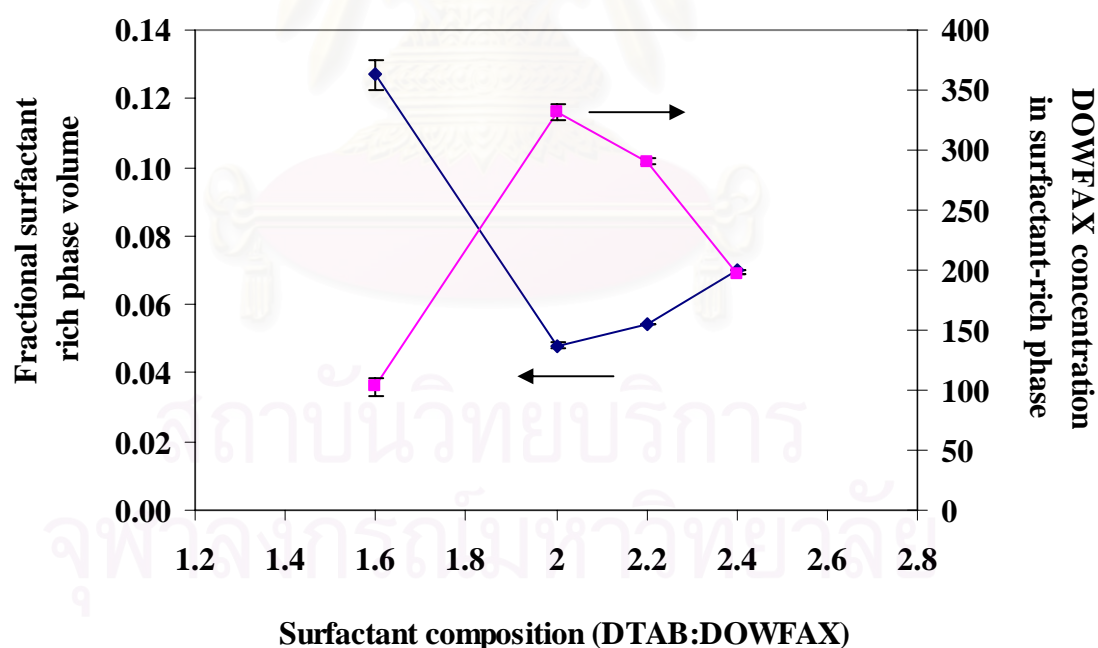


Figure 4.2 Effect of surfactant composition on fractional surfactant-rich phase volume and DOWFAX concentration in the surfactant-rich phase

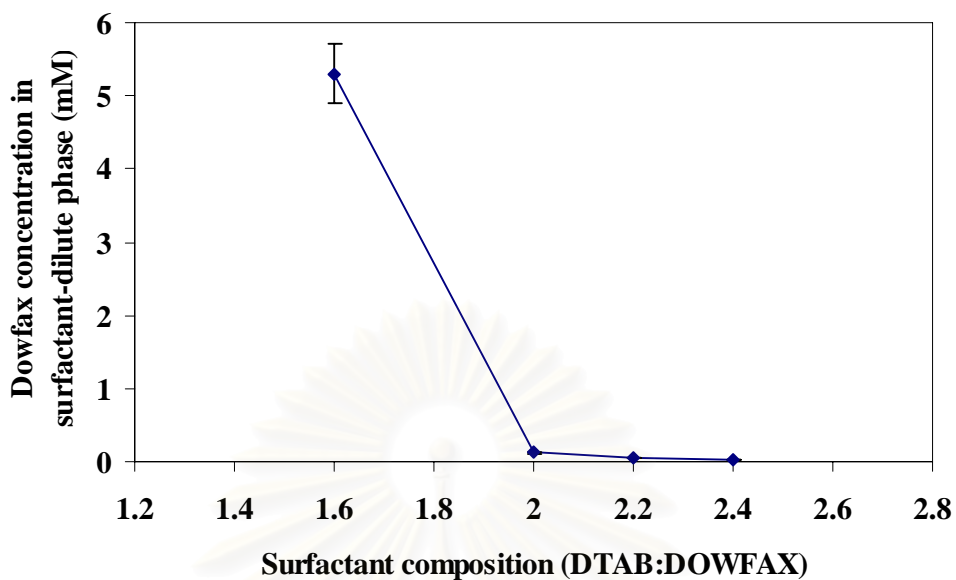


Figure 4.3 Effect of surfactant composition on DOWFAX concentration in the surfactant-dilute phase

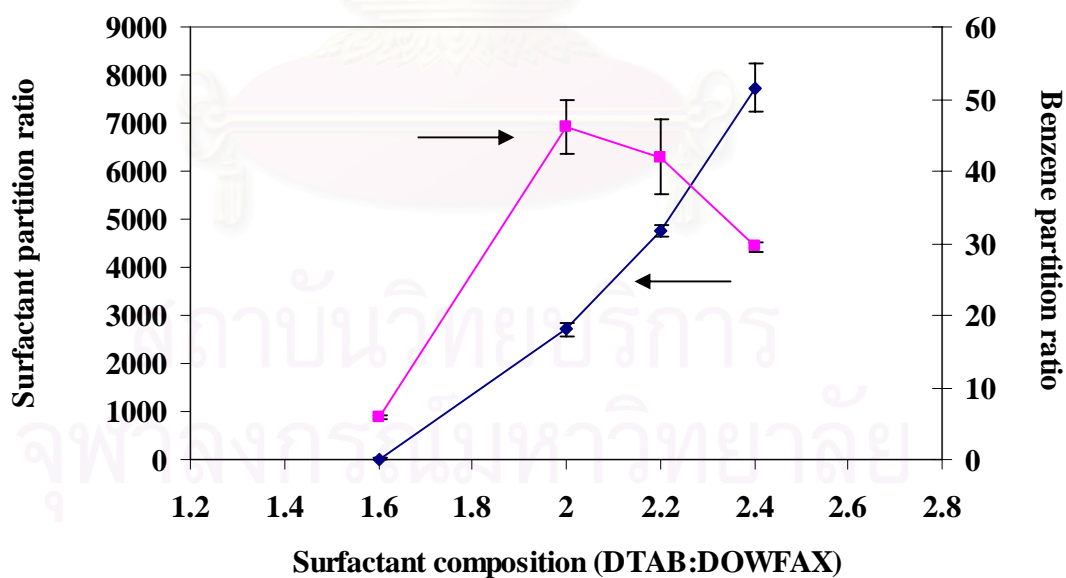


Figure 4.4 Effect of surfactant composition on surfactant partition ratio and benzene partition ratio

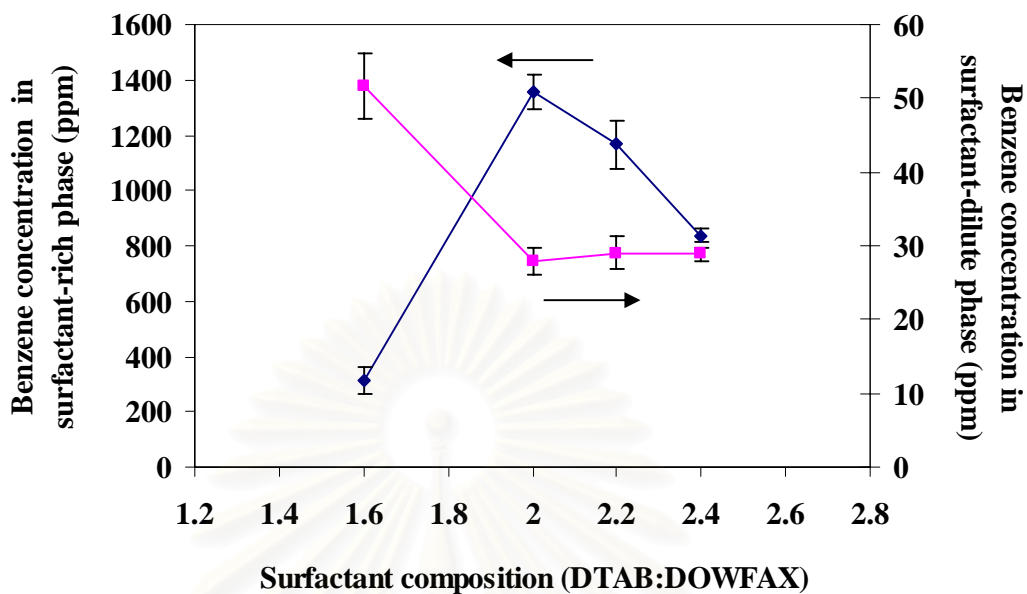


Figure 4.5 Effect of surfactant composition on benzene concentration in the surfactant-rich and dilute phase

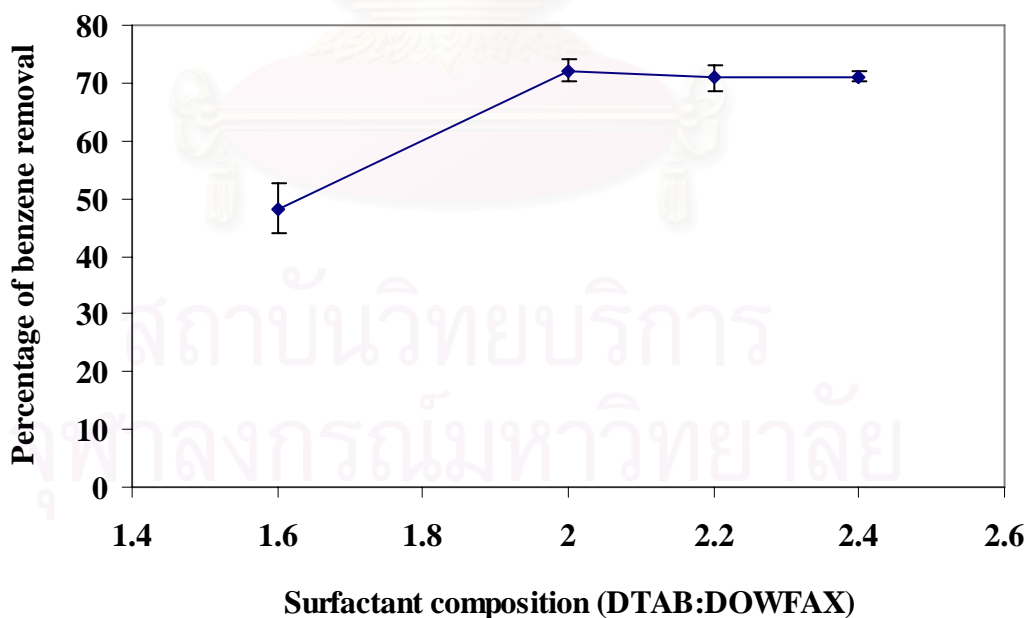


Figure 4.6 Effect of surfactant composition on percentage of benzene removal

4.4.2 Effect of Total Surfactant Concentration

From the above results, the molar ratio of DTAB: DOWFAX at 2:1 was chosen to further study on the effect of surfactant concentration. From Figure 4.7 and 4.8, the concentration of surfactant in the surfactant-rich phase remains almost constant while that of in the surfactant-dilute phase slightly increases as the total surfactant concentration increases from 20 to 140 mM. Thus, the surfactant partition ratio declines with total surfactant concentration while the benzene partition ratio has the highest value at the surfactant concentration of 50 mM as shown in Figure 4.9. Since the concentration of surfactant in the surfactant-rich phase does not increase as the total surfactant concentration increases, the fraction volume of the surfactant-rich phase is raised as required from the material balance as shown in Figure 4.7. From Figure 4.10, the concentration of benzene in the surfactant-rich phase declines as the total surfactant concentration increases due to an increase in volume of the surfactant-rich phase. However, an increase in total surfactant concentration from 20 to 50 mM drastically enhances the effectiveness of extraction as shown by a reduction of benzene concentration in the surfactant-dilute phase and slightly increases in the percentage of benzene extracted in the surfactant-rich phase as demonstrated in Figure 4.10 and 4.11. The further increase of surfactant concentration beyond 50 mM does not substantially improve the extraction efficiency. Interestingly, there is a sharp decrease in benzene concentration in the surfactant-dilute phase at the total concentration of 50 mM, in which the concentration of existed benzene is about 28 ppm as compared to the benzene concentration of 59 ppm at the total surfactant concentration of 20 mM. This can be explained by too low surfactant at concentration of 20 mM to solubilize benzene at this certain concentration. However, when the total surfactant concentration increases, the available aggregates for solubilization is also enhanced. Therefore, the percentage of benzene extracted in the surfactant-rich phase slightly increases. These results correspond well with the results done by Trakultamupatum *et al.* (2002) and Kimchuwaniit *et al.* (2000), which applied this technique to extract benzene

and TCE from wastewater, respectively using the nonionic surfactant. Consequently, the suitable surfactant concentration for this system is at 50 mM since further increase in the surfactant concentration does not show a significant improvement in the extraction efficiency.

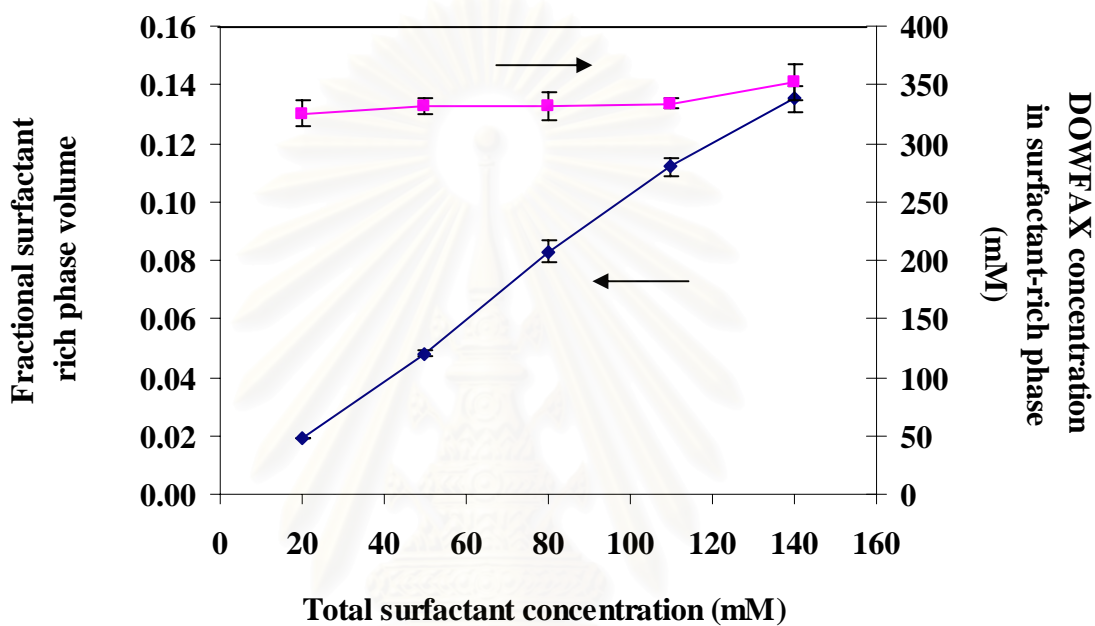


Figure 4.7 Effect of total surfactant concentration on fractional surfactant-rich phase volume and DOWFAX concentration in the surfactant-rich phase

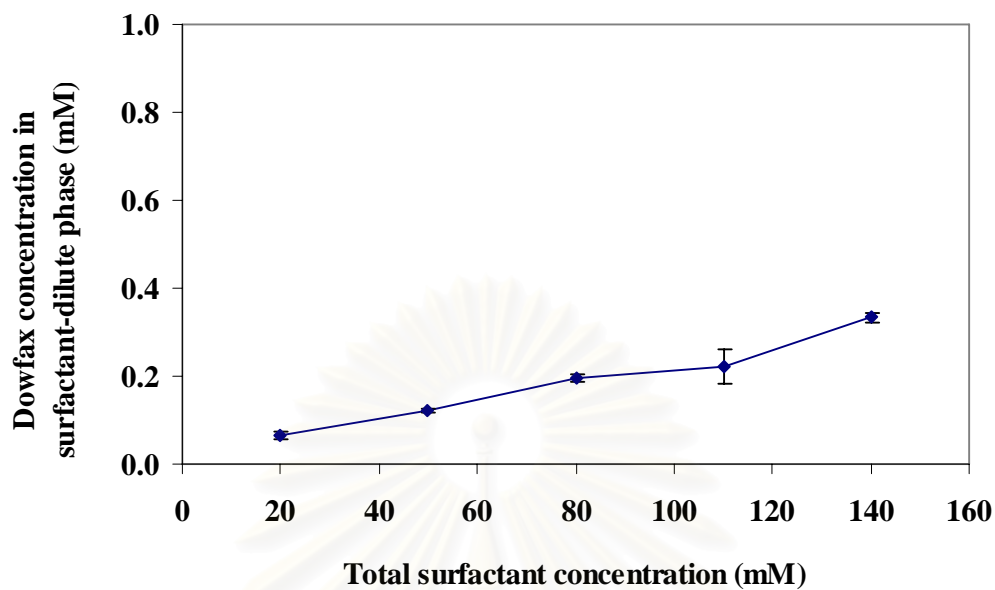


Figure 4.8 Effect of total surfactant concentration on DOWFAX concentration in the surfactant-dilute phase

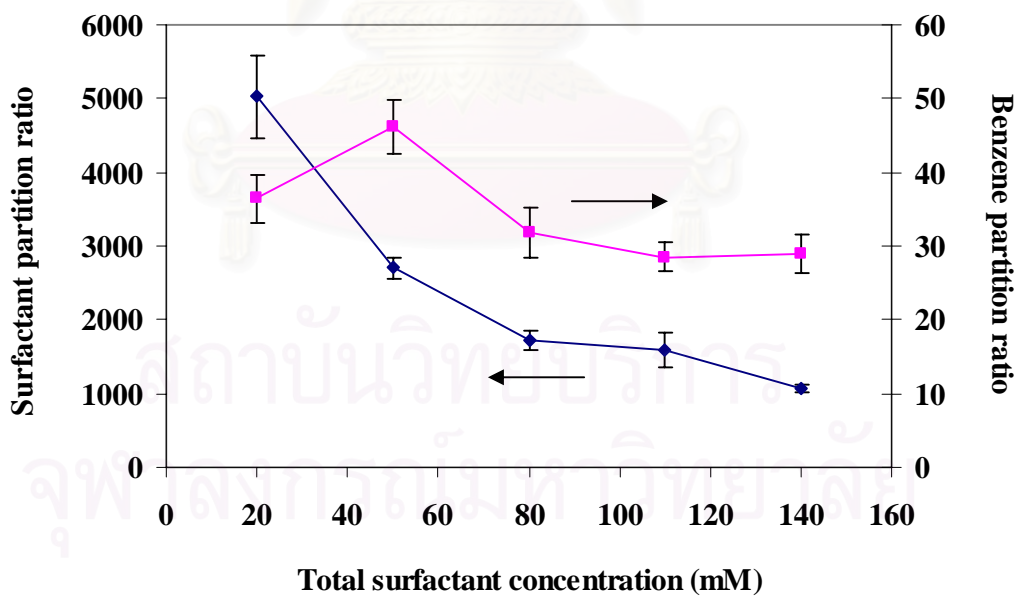


Figure 4.9 Effect of total surfactant concentration on surfactant and benzene partition ratio

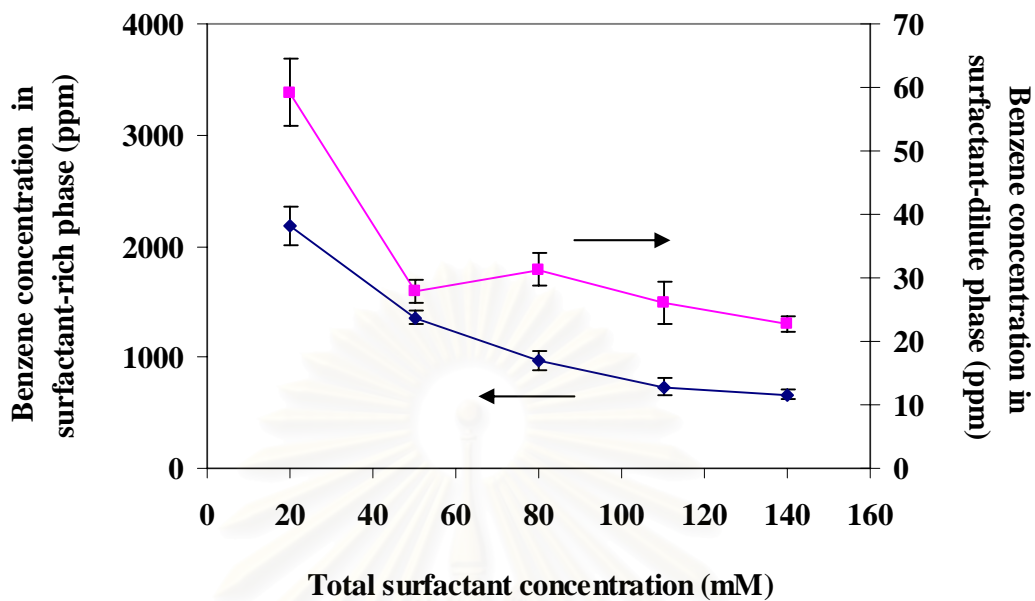


Figure 4.10 Effect of total surfactant concentration on benzene concentration in the surfactant-rich and dilute phase

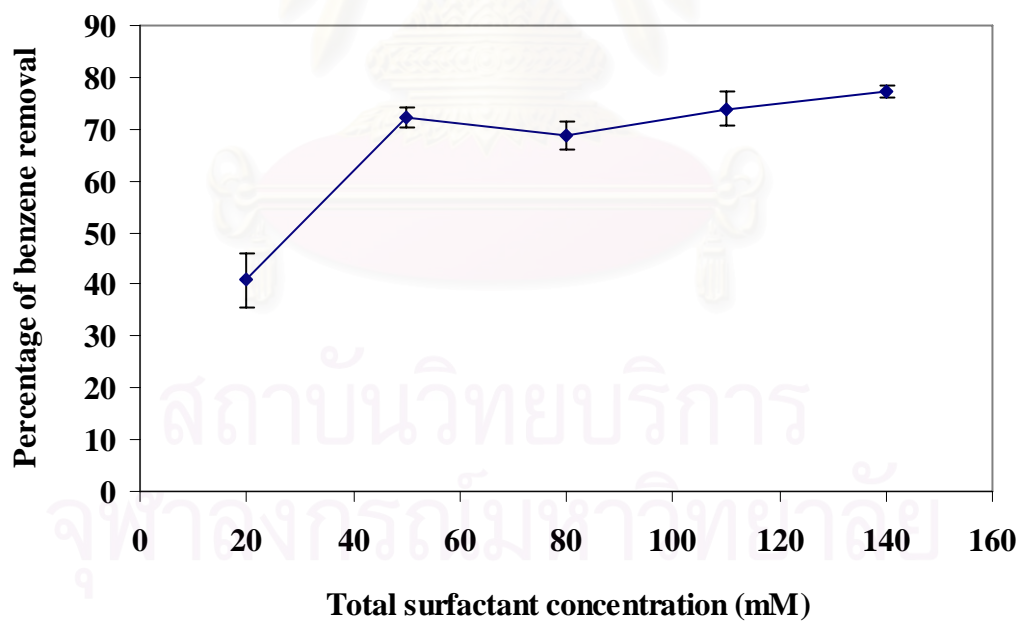


Figure 4.11 Effect of total surfactant concentration on percentage of benzene removal

4.4.3 Effect of Temperature

It is known that the cationic-anionic mixture behaves like pseudo-nonionic surfactant. In nonionic surfactant, the extraction efficiency increases with temperature as can be seen from an increase in surfactant and pollutant partition ratio caused by an enhancement of the dissimilarity between the surfactant-rich and dilute phase when temperature increases above the cloud point. The higher the temperature gap between the operating and cloud point temperature, the greater the extraction performance is observed. As reported previously, the cloud point temperature of this cationic-anionic surfactant mixture is extremely low probably far below the freezing point of water (zero degree Celsius). Therefore, the difference among temperature gap between the cloud point and the operating temperature studied here (20, 30, 40, and 50 °C) is insignificant to show a substantial difference in extraction efficiency. As shown in Figure 4.12, the surfactant concentrations in the surfactant-rich phase are nearly constant with temperature resulting in the constant of fractional surfactant-rich phase volume. From Figure 4.13, 4.14 and 4.15, the surfactant and benzene concentrations in the surfactant-dilute phase slightly increase meanwhile the surfactant and benzene partition ratios slightly decline. Moreover, the extraction efficiency is not much affected by an increase in temperature as illustrated in Figure 4.16. So, the ASTP of cationic-anionic surfactant in this study is temperature-independent giving an advantage in term of saving energy since it does not require an additional energy to induce the phase separation. The wastewater at arbitrary temperatures can be treated by this system. As compared to the nonionic system, this ASTP shows the greater benzene partition ratio of 48 comparing to 25 at even heated condition to temperature of 50 °C from nonionic surfactant (Trakultumupatum *et al.*, 2002). Furthermore, due to the high surfactant partition ratio of 2700 at 30 °C, it makes surfactant recovery more economical because most of surfactant present in the surfactant-rich phase causing the surfactant in the rich phase is 2700 times higher than that of in the diluted phase. Additionally, this ASTP shows the extremely lower fractional surfactant-rich phase volume of 0.048

comparing to 0.2 from nonionic surfactant at the same condition and 0.08 at heated temperature of 50 °C (Trakultumupatum *et al.*, 2002). So, it shows the greater benefit to reduce the processing costs of downstream treatment of the surfactant-rich phase for surfactant recovery. From these results, the ambient temperature of 30 °C is selected as the most suitable operating temperature for further study.

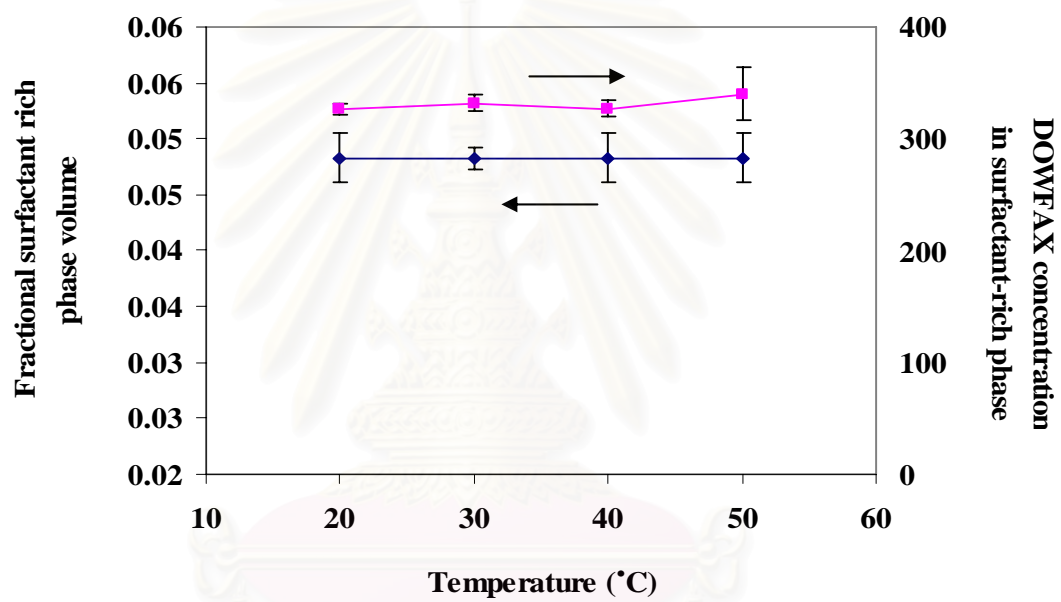


Figure 4.12 Effect of temperature on fractional surfactant-rich phase volume and DOWFAX concentration in the surfactant-rich phase

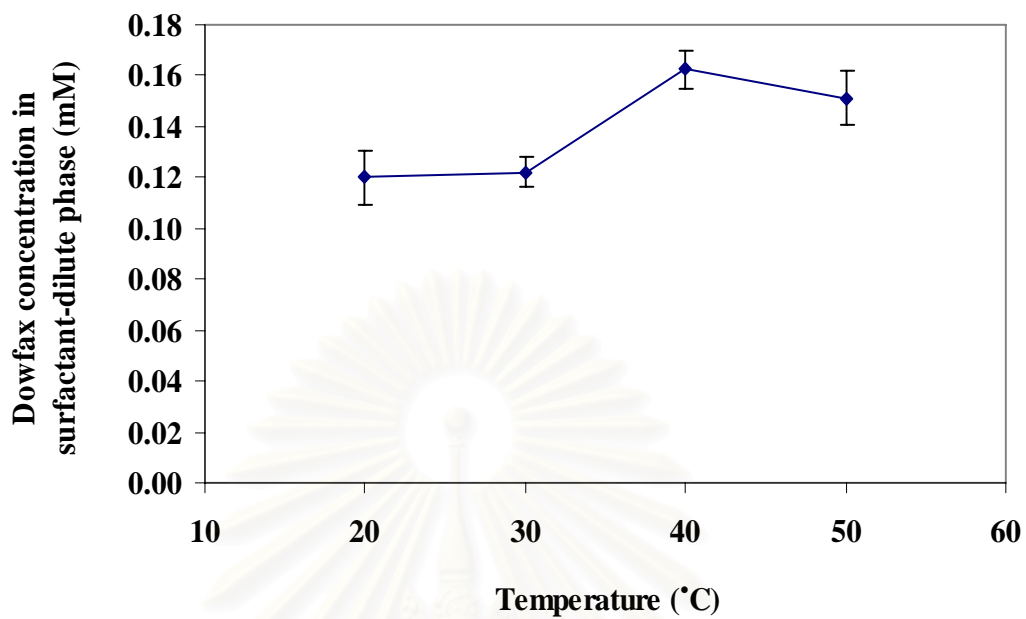


Figure 4.13 Effect of temperature on DOWFAX concentration in the surfactant-dilute phase

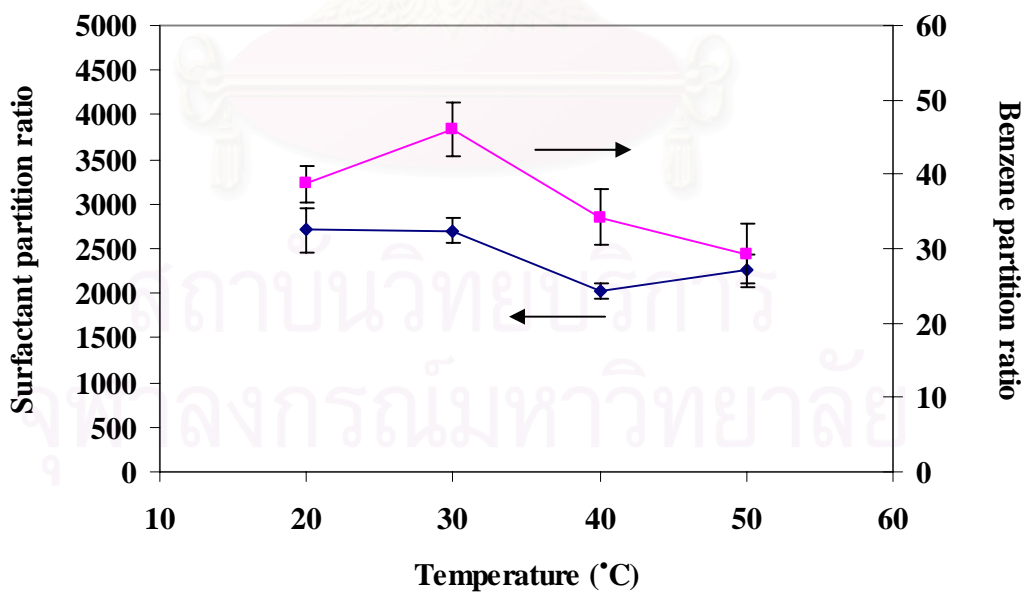


Figure 4.14 Effect of temperature on surfactant and benzene partition ratio

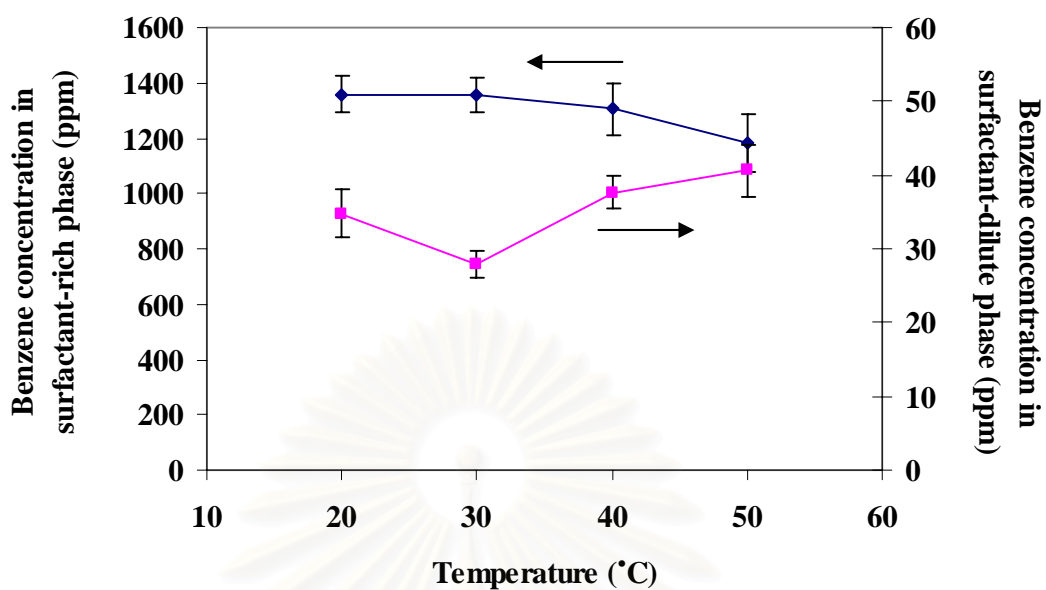


Figure 4.15 Effect of temperature on benzene concentration in the surfactant-rich and dilute phase

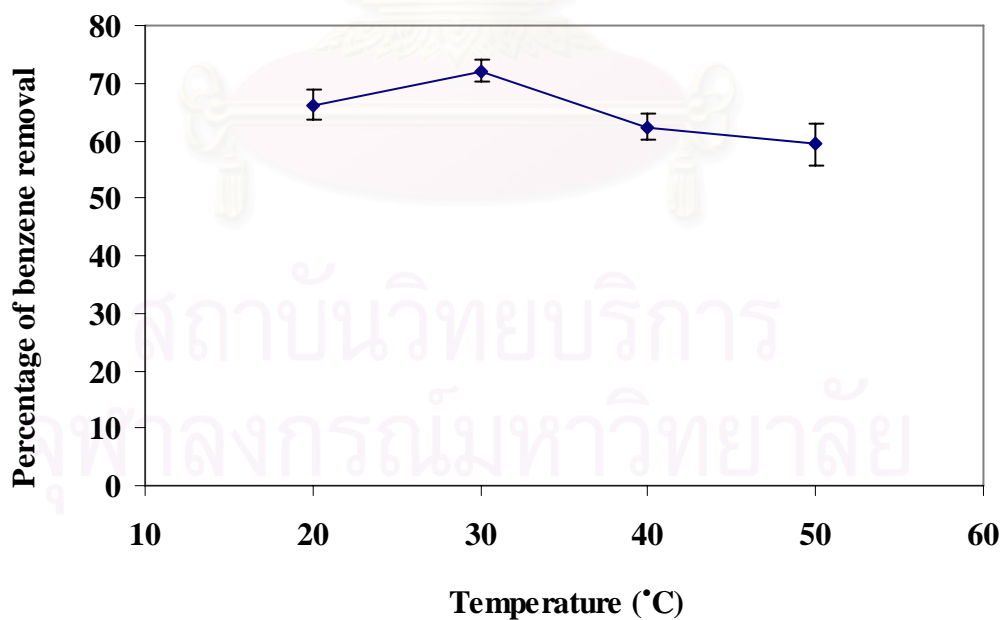


Figure 4.16 Effect of temperature on percentage of benzene removal

4.4.4 Effect of pH

As expected, the pH does not have significant effects on the surfactant concentration in the surfactant-rich and dilute phase. So, the fractional surfactant-rich phase volume and surfactant partition ratio are not much affected by pH as illustrated in Figure 4.17, 4.18 and 4.19. However, the benzene concentration in the surfactant-rich phase slightly decreases at neutral solution (pH=7) resulting in the greatest benzene partition ratio as can be seen in Figure 4.19 and 4.20. The explanation of these results is that at neutral solution, there is no repulsive force between surfactant head group. Thus, the formation of large surfactant aggregates is promoted that enhances the solubilization of solutes in the greater extent. Therefore, the percentage of benzene removal is as high as 72 % at neutral solution as shown in Figure 4.21. These results are in agreement with the conventional ASTP system of nonionic surfactant indicating that pH has little effect on the extraction (Hinze and Pramauro, 1993).

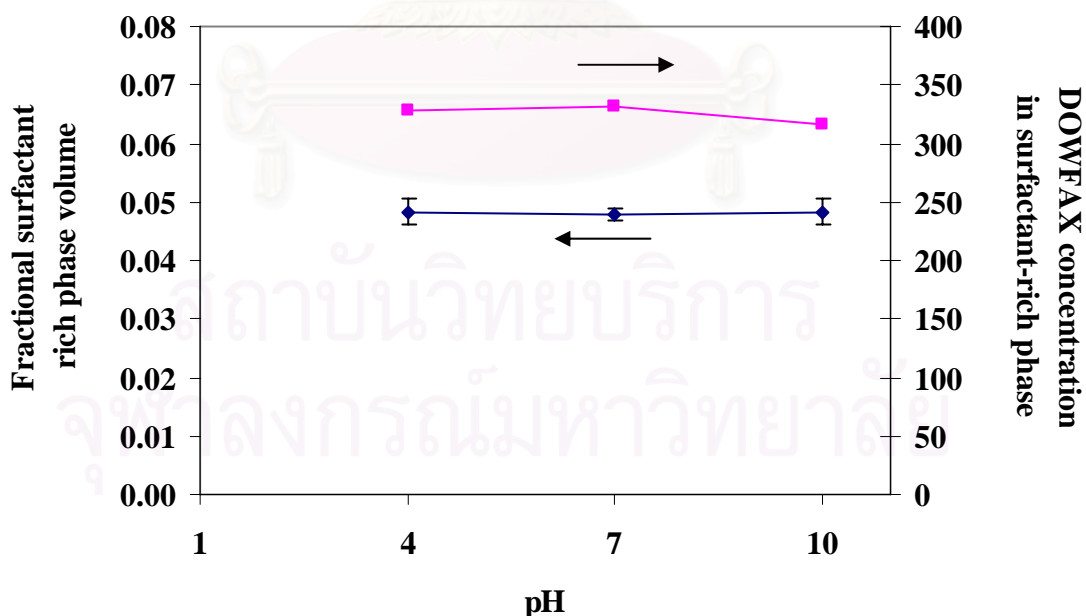


Figure 4.17 Effect of pH on fractional surfactant-rich phase volume and DOWFAX concentration in the surfactant-rich phase

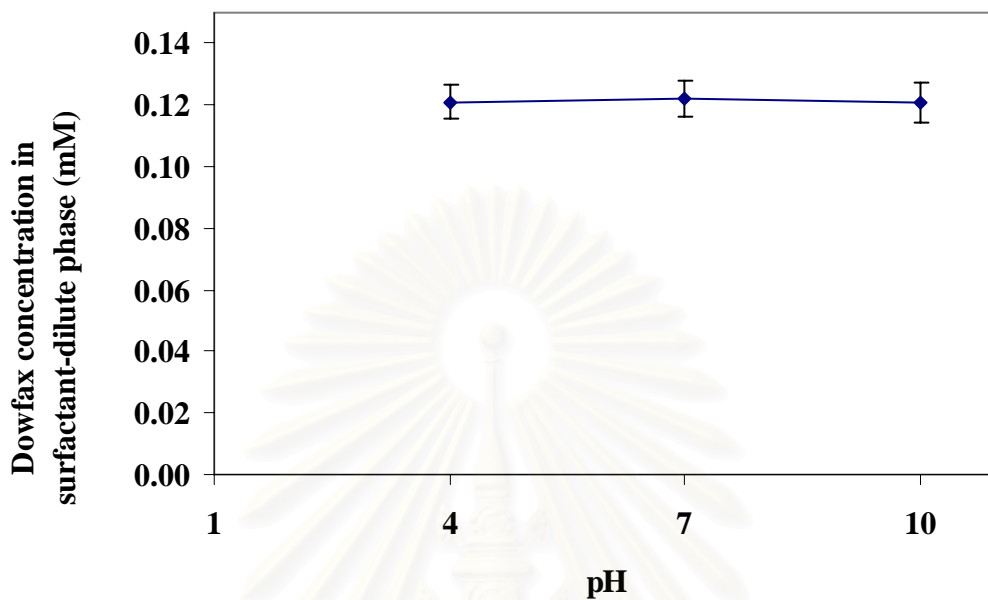


Figure 4.18 Effect of pH on DOWFAX concentration in the surfactant-dilute phase

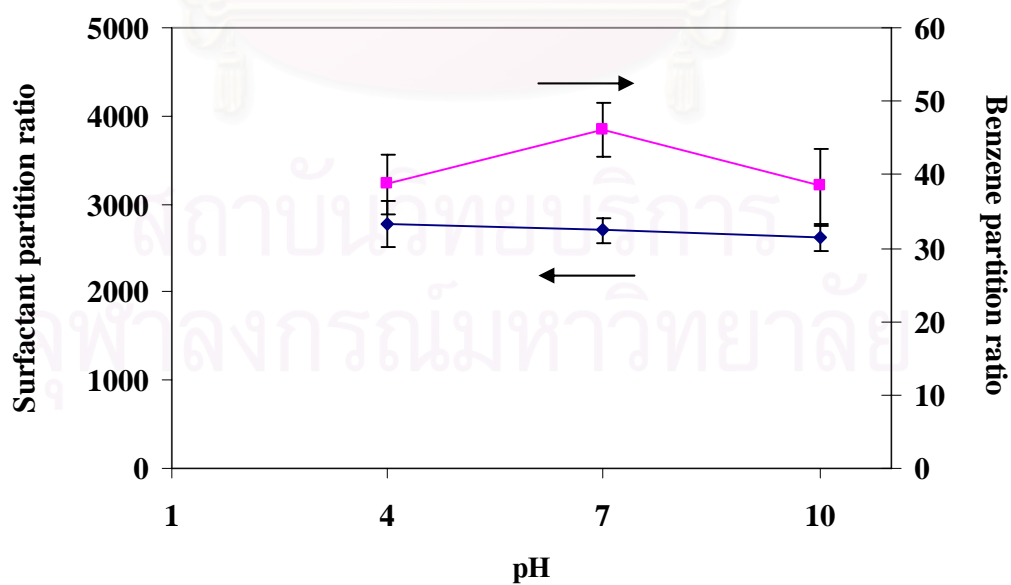


Figure 4.19 Effect of pH on surfactant and benzene partition ratio

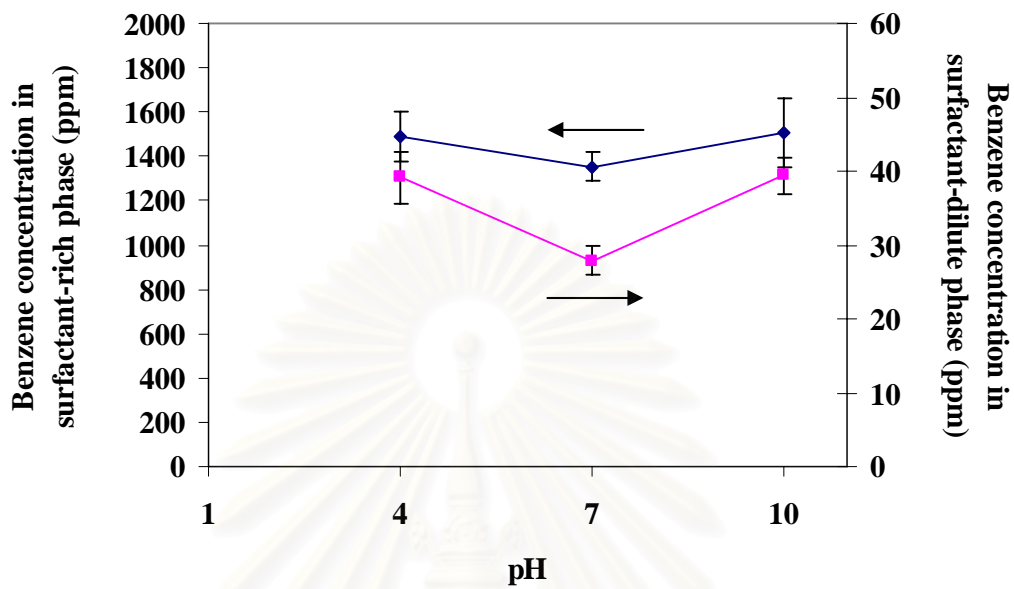


Figure 4.20 Effect of pH on benzene concentration in the surfactant-rich and dilute phase

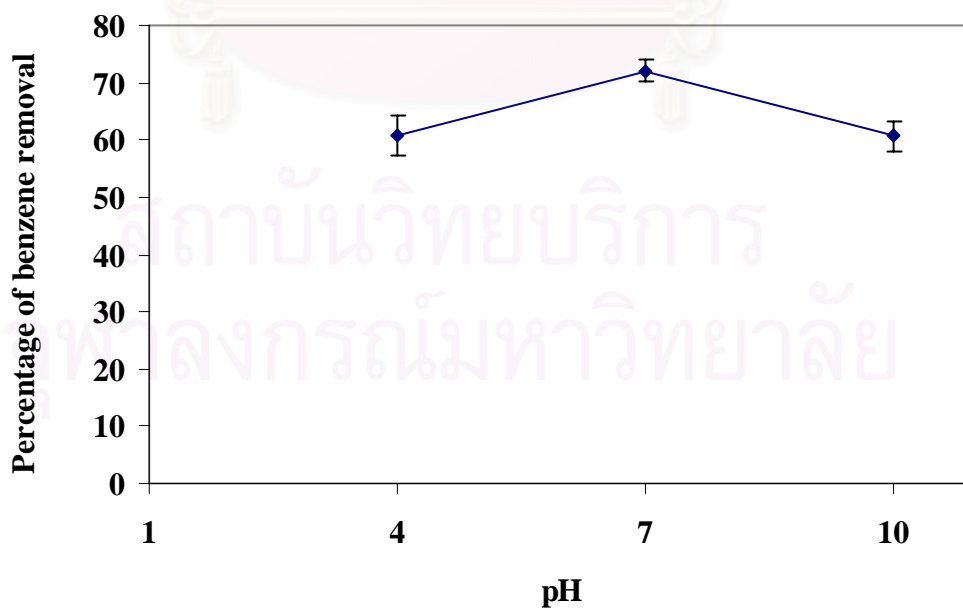


Figure 4.21 Effect of pH on percentage of benzene removal

From the results of operating conditions, the suitable condition of this ASTP technique in this study is at molar ratio of 2:1 DTAB:DOWFAX, total surfactant concentration of 50 mM, ambient temperature of 30 °C and neutral solution (pH=7). This condition resulting in as high as 72% of benzene is extracted and preconcentrated into the surfactant-rich phase. Only 28 ppm of benzene concentration is left in the surfactant-dilute phase from the original concentration of 100 ppm. However, this value still exceeds the effluent limitation as shown in Table 2.4. To compliant the standard, the multi-stage extraction is one approach to enhance the extraction efficiency. Moreover, this system has potential to apply to the real wastewater containing various kinds of organic contaminants since the surfactant aggregates can solubilize these pollutants by the hydrophobic interaction. Thus, those pollutants will be extracted into inner core of aggregates via its affinities to the surfactant aggregates.

Furthermore, due to the temperature and pH independent of this system, the wastewater at arbitrary temperature and pH can be treated effectively. So, this technique is beneficial in economic viewpoint from several reasons. Firstly, it can be operated at mild operating condition, i.e., low temperature and atmospheric pressure offering an advantage in term of energy saving. Secondly, the recycle of surfactant and the reuse of aromatic solutes are possible. Thus, the natural resources are saving. Thirdly, this technique can treat many solutes simultaneously and the ability to scale up the system is achievable. Finally, the downstream cost for further recovery and treatment is reduced since it can preconcentrate waste to less amount as can be seen by the extremely low in the volume of fractional surfactant-rich phase.

CHAPTER V

CONCLUSIONS

5.1 Conclusions

In this study, the phase separation can occur at DTAB: DOWFAX molar ratio of 1.6:1, 2:1, 2.2:1 and 2.4:1 except at 1.8:1 in which three phases occurs. The total surfactant concentration and composition have strong effect on the extraction efficiency of benzene while the operating temperature and pH play a minor role. The most suitable surfactant composition is 2:1 of DTAB:DOWFAX since the charge between head groups are balanced promoting the large surfactant aggregates formation. Thus, the solubilization capacity is enhanced to the greater extent. The increment of total surfactant concentration also increases the extraction efficiency because of higher surfactant aggregates presented in the system. Due to the extremely low cloud point temperature of this cationic-anionic mixture, the effect of operating temperature studied here is negligible. In addition, the effect of pH at 2:1 molar ratio of DTAB:DOWFAX is omitted as well since there is no net charge at this molar ratio.

The high surfactant and benzene partition ratio, and extremely low fractional surfactant-rich phase volume proved that the ASTP technique could be applicable to extract and preconcentrate the pollutant of environmental concern from wastewater. In summary, as high as 72% of benzene is extracted and preconcentrate in the surfactant-rich phase at ambient temperature of 30 °C with the total surfactant concentration of 50 mM at 2:1 molar ratio of DTAB:DOWFAX within a single stage.

5.2 Recommendations

Phase behavior of this system should be studied in more detail about phase diagram of precipitate and phase separation regions. Structure of aggregates should be studied both before and after phase separation to explain the real extraction mechanism. Multi-stage extraction with surfactant recovery unit should be continue studied for improving the extraction efficiency and recovery surfactant for reuse. In

addition, the other pollutants of environment concern such as heavy metals can be further studied by this technique. Furthermore, this technique should be applied to treat the real wastewater to further improving the system.



สถาบันวิทยบริการ
จุฬาลงกรณ์มหาวิทยาลัย

REFERENCES

- Agency for Toxic Substances and Disease Registry (ATSDR). (1997). Toxicological profile for benzene. Atlanta: Department of Health and Human Services, Public Health Service.
- Agency for Toxic Substances and Disease Registry (ATSDR). (2001). 7.Regulation and advisories[Online]. Available from: <http://www.atsdr.cdc.gov/toxprofiles/tp3-c7.pdf>[2005, March 19]
- Akama, Y., Tong, A., Ito, M. and Tanaka, S. (1999). The study of the partitioning mechanism of methyl orange in an aqueous two- phase system. Talanta 48: 1133- 1137.
- Bujan, M., Vdovic, N. and Filipovic-Vincekovic, N. (1996). Phase transitions in cationic and anionic surfactant mixtures. Colloid Surf. A 118: 121- 126.
- Buwalda, R. (2001). Molecular aggregation in water: The interplay of hydrophobic and electrostatic interactions. Groningen: University Library Groningen.
- Castedo, A. Castillo, J. L., Suarez- Filloy, M. J. and Rodriguez, J. R. (1997). Effect of temperature on the mixed micellar tetradecyltrimethyl ammonium bromide-butanol system. J. Colloid Interface Sci 196: 148- 156.
- Choori, U. N., Scamehorn, J. F., O'Haver, J. H., Harwell, J. H. (1998). Removal of volatile organic compounds from surfactant solutions by flash vacuum stripping in a packed column. Ground Wat. Monit. Remediation 18: 157- 165.
- Clint, J. H. (1992). Surfactant aggregation. 1 st ed. New York: Marcel Dekker.
- Courage, C. and Davidson, R. D. (1999). IEH report on benzene in the environment: An evaluation of exposure of the UK general population and possible adverse health effects. Norwich: Page Bros.
- Department of natural resources, State of Missouri. (2005). Missouri stage operating permit[Online]. Available from: <http://www.dnr.mo.gov/wpscd/wpcp/permits/issued/0123251.pdf>[2005, April 21]
- Goldstein, B. D. (1997). Introduction. In S. Laskin and B. D. Goldstein (eds.), Benzene toxicity: A critical evaluation, pp. 1-4. Washington: Hemisphere.

- Gragson, D. (2005). Surface tension and the Gibbs adsorption isotherm[Online]. Available from: http://chemweb.calpoly.edu/chem/gragson/teaching/chem354/lab_instructions/cmc_surface_tens.pdf[2005, Jan 11]
- Hasegawa, M. A., Sabatini, D. A. and Harwell, J. H. (1997). Liquid-liquid extraction for surfactant- contaminant separation and surfactant reuse. J. Environ. Eng. Div. Am. Soc. Civil Eng 123: 691- 697.
- Hinze, W. and Pramauro, E. (1993). A critical review of surfactant- mediated phase separations (cloud-point extractions): Theory and applications. Crit. Rev. Anal. Chem 24(2): 133-177.
- Holmberg, K., Jonsson, B., Kronberg, B. and Lindman, B. (2003). Surfactant and polymers in aqueous solution. 2 nd ed. West Sussex: John Wiley & Sons.
- IPCS. (1993). Environmental health criteria 150: Benzene. The international programme on chemical safety. Geneva: World Health Organization.
- Kang, K.- H., Kim, H.- U. and Lim, K.- H. (2001). Effect of temperature on critical micelle concentration and thermodynamic potentials of micellization of anionic ammonium dodecyl sulfate and cationic octadecyl trimethyl ammonium chloride. Colloids Surf. A 189: 113- 121.
- Kimchuwanit, W., Osuwan, S., Scamehorn, J.F., Harwell, F.H. and Haller, K.J. (2000). Use of micellar-rich coacervate phase to extract trichloroethylene from water. Sep. Sci. Technol. 35 (13): 1991- 2000.
- Krescheck, G. C. (1975). Water: A comprehensive treatise. New York: Plenum Press.
- KSV Instrument USA. (2005). Critical micelle concentration: Automated measurement[Online]. Available from: <http://www.ksvinc.com/cmc.htm>[2005, Jan 11]
- Li, X. G. and Liu, F. M. (1995). Phase separation of the aqueous solution and the surface activity of oxyethylenated cationic- anionic surfactants. Colloid Surf. A 96: 113-119.
- Li, X., Zhang, G., Zhang, M. and Wu, G. (1996). The surface activity and solubilization of anionic- cationic surfactants. Colloid Surf. A 111: 161-166.

- Mao, M., Huang, J., Zhu, B. and Ye, J. (2002). The transition from vesicles to micelles induced by octane in aqueous surfactant two-phase systems. J. Phys. Chem. B 106: 219-225.
- Mehreteab, A. (1999). Anionic-cationic surfactant mixtures. In Broze, G. (ed.), Handbook of detergents part A: Properties, pp. 133-155. New York: Marcel Dekker.
- Minardi, R. M., Schulz, P. C. and Vuano, B. (2002). Triangular phase diagram of the cationic system dodecyltrimethylammonium bromide- disodium dodecanephosphate- water. Colloids Surf. A 97: 167- 172.
- Ministry of the environment government of Japan. (2003). Conservation of water environment[Online]. Available: <http://www.env.go.jp/en/pol/wemj/water1.html> [2005, April 22]
- Mississippi Department of Environment Quality, State of Mississippi. (2005). Water pollution control permit[Online]. Available from: http://opc.deq.state.ms.us/get_doc.aspx?dt=dpermit&id=285724[2005, April 21]
- Murphy, A. and Taggart, G. (2002). A comparison of predicted and experimental critical Micelle concentration values of cationic and anionic ternary surfactant mixtures using molecular- thermodynamic theory and pseudophase separation theory. Colloids Surf. A 205: 237- 248.
- Physical and Theoretical Chemistry Laboratory Oxford University. (2005). Safety (MSDS) data for benzene[Online]. Available from: <http://ptcl.chem.ox.ac.uk/MSDS/BE/benzene.html>[2004, August 16]
- Quina, F. H. and Hinze, W. L. (1999). Surfactant- mediated cloud point extractions: An environmentally benign alternative separation approach. Ind. Eng. Chem. Res 38: 4150- 4168.
- Raghavan, S. R., Fritz, G. and Kaler, E. W. (2002). Wormlike micelles formed by synergistic self- assembly by mixtures of anionic and cationic surfactants. Langmuir 18: 3797-3803.
- Ridell, A. (2003). Characterization of aqueous solutions, liquid crystals and solid state of non-ionic polymers in association with amphiphiles and drugs. Uppsala: Universitetstryckeriet.

- Rio, J. M., Pombo, C., Prieto, G., Mosquera, V. and Sarmiento, F. (1994). Effect of temperature and alkyl chain length on the micellar properties of N-alkyltrimethylammonium bromides in a low pH medium. J. Colloid Interface Sci 172: 137- 141.
- Rosen, M. J. (1989). Surfactants and Interfacial Phenomena. 2 nd edition. New York: Wiley.
- Rosen, M. J. (2004). Surfactants and interfacial phenomena. 3 rd ed. New Jersey: John Wiley & Sons.
- Ruiz, C. C. and Aguiar, J. (2003). Mixed Micellization of Octaoxyethylene Monododecyl Ether and N- Alkyltrimethylammonium Bromides. Colloids Surf. A 224, 221-230.
- Schramm, L. L. (2000). Surfactants: Fundamentals and applications in the petroleum industry. Cambridge: Cambridge University Press.
- Talhout, R. and Engbert, J. B. F. N. (1997). Self- assembly in mixtures of sodium alkyl sulfates and alkyltrimethylammonium bromides: Aggregation behavior and catalytic properties. Langmuir 13: 5001-5006.
- Tong, A.- J., Dong, J.- J. and Li, L.- D. (1999). Aqueous two- phase extraction system of sodium perfluorooctanoate and dodecyltriethylammonium bromide mixture and its application to porphyrins and dyes. Analytica Chimica Acta 390: 125- 131.
- Tong, A., Wu, Y., Tan, S., Li, L., Akama, Y. and Tanaka, S. (1998). Aqueous- two phase system of cationic and anionic surfactant mixture and its application to the extraction of porphyrins and metalloporphyrins. Analytica Chimica Acta 369: 11- 16.
- Trakultamupatam, P., Schamehorn, J.F. and Osuwan, S. (2002). Removal of volatile aromatic contaminants from wastewater by cloud point extraction. Sep. Sci. Technol 37(6): 1291-1305.
- Truhaut, R. (1968). Report of the meeting of experts on the safe use of benzene and solvents containing benzene, Meeting of Experts on the Safe Use of Benzene and Solvents Containing Benzene, Geneva, 16-22 May 1967, pp. 4-19.

- U. S. Environmental Protection Agency. (1997). Control technologies assessment[Online]. Available from: <http://www.epa.gov/dfe/pubs/tools/ctsa/ch9/mod9-2.pdf>[2004, April 23]
- Visser, I. (2004). Amphiphiles containing aromatic groups in the hydrophobic part. Groningen: University Library Groningen.
- Wang, C., Wang, S., Huang, J., Li, Z., Gao, Q. and Zhu, B. (2003). Transition between higher-level self- assemblies of ligand- lipid vesicles induced by Cu^{+2} ion. Langmuir 19: 7676-7678.
- Worrall, M. and Zuber, I. (1998). Case studies: Control VOCs in refinery wastewater[Online]. Available from: <http://www.amcec.com/case3.html>[2004, March 11]
- Xiao, J.- X., Sivars, U. and Tjerneld, F. (2000). Phase behavior and protein partitioning in aqueous two- phase systems of cationic- anionic surfactant mixtures. J. Chromatogr. B 743: 327- 338.
- Yatcilla, M. T., Herrington, K. L., Brasher, L. L. and Kaler, E. W. (1996). Phase behavior of aqueous mixtures of cetyltrimethylammonium bromide (CTAB) and sodium octyl sulfate (SOS). J. Phys. Chem. 100: 5874- 5879.
- Yin, H., Mao, M., Huang, J. and Fu, H. (2002). Two- phase region in the DTAB/SL mixed surfactant system. Langmuir 18: 9198- 9203.
- Yin, H., Zhou, Z., Huang, J., Zheng, R. and Zhang, Y. (2003). Temperature- induced micelle to vesicle transition in the sodium dodecylsulfate/ dodecyltriethyl ammonium bromide system. Angew. Chem. Int. Ed 42: 2188- 2191.
- Zainal, C. M. Benzene exposure and health effects[Online]. (1999). Available from: <http://161.142.92.99/penerbitan/buletin/98/BENZENE.html>[2005, February 21]
- Zhao, G.- X. and Xiao, J.- X. (1995). Aqueous two phase systems of the aqueous mixtures of cationic- anionic surfactants. J. Colloid Interface Sci 177: 513- 518.

APPENDIX A

Table a-1 Phase behavior of cationic-anionic surfactant system

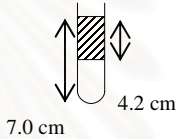
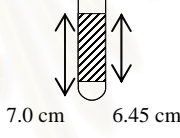

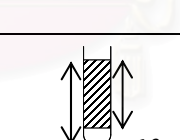
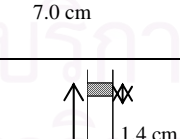
Temperature (°C)	System	Total surfactant conc. mM)	Molar ratio	Volume ratio	Phase appearance	Interfacial boundary
30, 40	CTAB:DOWFAX	20	1.5:1	1.5	 <p>upper: turbid solution lower: clear solution</p>	not clear interface, unstable
30, 40	CTAB:DOWFAX	50	1.5:1	11.7	 <p>upper: turbid solution lower: clear solution, like oil</p>	clear interface
30, 40	CTAB:DOWFAX	50	1:1	0.75	 <p>upper: white turbid solution lower: clear solution</p>	clear interface
50	CTAB:DOWFAX	50	1.5:1	9	 <p>upper: white turbid solution lower: clear solution, like oil</p>	clear interface
50	CTAB:DOWFAX	50	1:1	0.25	 <p>upper: white turbid solution lower: turbid solution</p>	clear interface, unstable

Table a-1 Phase behavior of cationic-anionic surfactant system (cont.)

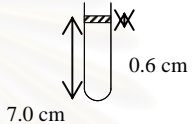
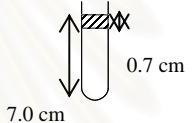

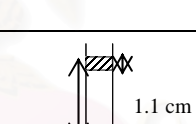
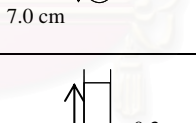
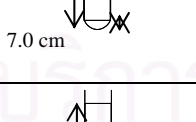
Temperature (°C)	System	Total surfactant conc. (mM)	Molar ratio	Volume ratio	Phase appearance	Interfacial boundary	
30	CTAB:SDS	50	1.5:1	0.09		upper: white solution lower: white turbid solution	clear interface, unstable
30	CTAB:SDS	80	2:1	0.11		upper: white solution lower: white turbid solution	clear interface
30	CTAB:SDS	80	1.5:1	0.19		upper: white solution lower: white turbid solution	clear interface
40	CTAB:SDS	80	1.5:1	0.19		upper: white solution, high viscosity lower: white turbid solution	clear interface
30	DTAB:DOWFAX	20	2:1	0.04		upper: clear solution lower: clear solution, like oil	clear interface
30	DTAB:DOWFAX	50	2:1	0.07		upper: clear solution lower: clear solution, like oil	clear interface

Table a-1 Phase behavior of cationic-anionic surfactant system (cont.)

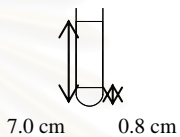
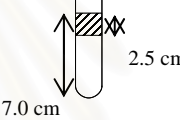
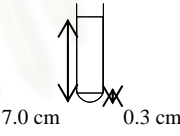
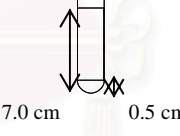
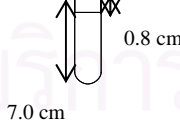
Temperature (°C)	System	Total surfactant conc. (mM)	Molar ratio	Volume ratio	Phase appearance	Interfacial boundary
30	DTAB:DOWFAX	80	2:1	0.13	 <p>upper: clear solution lower: clear solution, like oil</p>	clear interface
30	DTAB:DOWFAX	80	1.5:1	0.56	 <p>upper: white turbid solution with high viscosity lower: clear solution</p>	clear interface
40	DTAB:DOWFAX	20	2:1	0.04	 <p>Upper: pearlescent solution lower: clear solution, like oil</p>	clear interface
40	DTAB:DOWFAX	50	2:1	0.07	 <p>upper: pearlescent solution lower: clear solution, like oil</p>	clear interface
40	DTAB:DOWFAX	80	2:1	0.13	 <p>upper: clear solution, like oil lower: turbid solution</p>	clear interface

Table a-1 Phase behavior of cationic-anionic surfactant system (cont.)

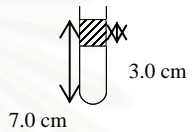
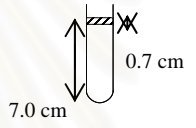
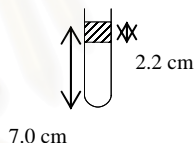
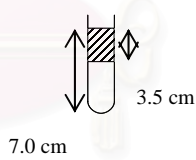
Temperature (°C)	System	Total surfactant conc. (mM)	Molar ratio	Volume ratio	Phase appearance	Interfacial boundary
40	DTAB:DOWFAX	80	1.5:1	0.75	 <p>upper: white turbid solution lower: clear solution</p>	clear interface, unstable
40	DTAB:SDS	20	1:2	0.11	 <p>upper: turbid solution lower: turbid solution</p>	clear interface, unstable
40	DTAB:SDS	50	1:2	0.46	 <p>upper: turbid solution with flocculant lower: clear solution with flocculant</p>	clear interface
30	DTAB:SDS	20	1:2	1	 <p>upper: turbid solution with flocculant lower: clear solution</p>	clear interface

Table a-1 Phase behavior of cationic-anionic surfactant system (cont.)

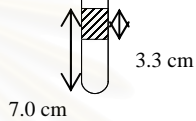
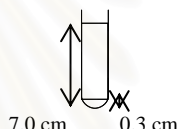
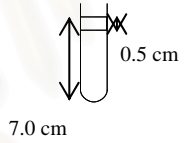
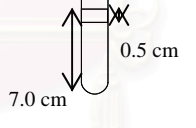
Temperature (°C)	System	Total surfactant conc. (mM)	Molar ratio	Volume ratio	Phase appearance	Interfacial boundary
30	DTAB:SDS	50	1:2	0.89	 <p>upper: turbid solution with flocculant lower: clear solution</p>	clear interface
40	DTAB:AMA	20	1:1	0.04	 <p>upper: clear solution with some oil droplets lower: clear like oil</p>	clear interface
40	DTAB:AMA	50	1:1	0.08	 <p>upper: clear solution, like oil lower: clear solution, pearlescent</p>	clear interface
40	DTAB:AMA	80	1:1	0.08	 <p>upper: clear solution, like oil lower: clear solution</p>	clear interface

Table a-2 CMC determination of DOWFAX

Concentration (mM)	Surface tension (mN/m)
0.2	44.8
0.3	43.2
0.4	39.9
0.5	42.3
1	42.4
5	46.6
10	47.6

Table a-3 CMC determination of DTAB

Concentration (mM)	Surface tension (mN/m)
2	55.7
3	50.2
4	41.4
5	35.0
7	33.7
9	31.0
10	26.7
20	36.2
26.67	36.7
40	37.4
50	37.4

สถาบันวิทยบริการ
จุฬาลงกรณ์มหาวิทยาลัย

Table a-4 CMC determination of DTAB:DOWFAX at 2:1

Concentration (mM)	Surface tension (mN/m)
0.004	44.1
0.006	41.3
0.008	37.2
0.01	34.8
0.02	32.3
0.05	31.1
0.1	31.1
0.2	30.6
0.5	30.0
1	29.6

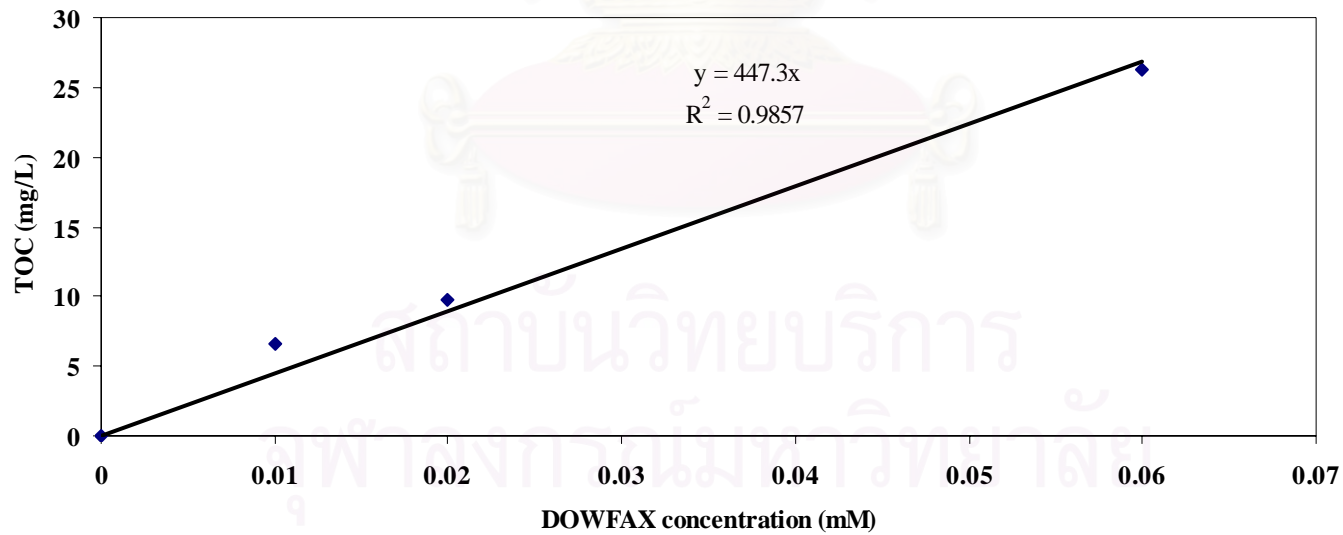


สถาบันวิทยบริการ
จุฬาลงกรณ์มหาวิทยาลัย

APPENDIX B

Table b-1 Standard curve of DTAB and DOWFAX from data of TOC

Sample	(mM)	TOC (mg/L)
		Avg
DOW	0	0
	0.01	6.5
	0.02	9.8
	0.06	26.2
DTAB	0	0.0
	0.02	4.8
	0.05	9.3
	0.1	18.9
	0.2	39.8



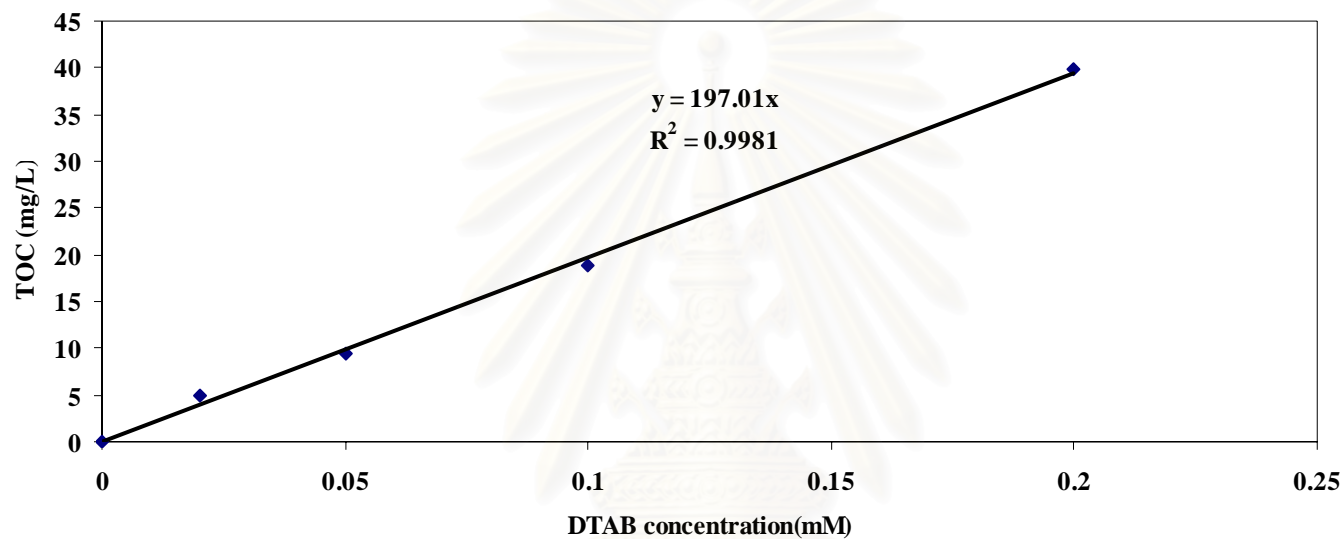


Table b-2 Determination of DTAB concentration from TOC results

DTAB:DOWFAX	Sample	TOC (mg/L)	Abs_UV	[DOWFAX] (mM)	TOC_DOWFAX	TOC_DTAB	[DTAB] (mM)	Molar ratio
		Avg						DTAB:DOW
2.0:1	Surfactant-rich phase	58.9	1.213	356.07	159271.7	135178.3	686.1	1.93
		55.8	1.140	334.64	149686.5	129063.5	655.1	1.96
	Average	57.3	1.177	345.36	154479.1	132120.9	670.6	1.94
	Surfactant-dilute phase	14.4	0.285	0.17	74.8	69.6	0.4	2.11
		12.3	0.250	0.15	65.7	57.6	0.3	1.99
	Average	13.4	0.268	0.16	70.2	63.6	0.3	2.05

APPENDIX C

Table c-1 Results of operating condition: Effect of surfactant composition

Molar ratio	Ct (mM)	Temp	Vial	No.	Frac rich vol	Surfactant-rich phase						Surfactant-dilute phase						Rich phase		Dilute phase		[Dow]/rich-p	[Ben]/rich-p	% Error	Mass bal of Benzene(ppm)
						Height	Volume	Abs	Ct(mM)	[Dow]	Dow	Volume	Abs	Ct(mM)	[Dow]	Dow	Area	[Ben]	Area	[Ben]	[Dow]/dil-p				
1.6:1	50	30	1	1	0.124	0.8	2.72	0.315	252.2	97.0	263.8	19.3	0.863	13.8	5.31	102.5	6577.26	329.1	16082	46.7	18.3	7.1	-13.4	81.7	
				2	0.124	0.8	2.72	0.351	281.1	108.1	294.0	19.3	0.805	12.9	4.96	95.6	6323.45	316.4	16227	47.1	21.8	6.7	-7.9	80.5	
				2	0.124	0.8	2.72	0.346	276.6	106.4	289.3	19.3	0.942	15.1	5.80	111.8	7074.69	354.0	18919	54.9	18.3	6.4	-5.2	92.0	
				2	0.124	0.8	2.72	0.327	262.0	100.8	274.0	19.3	0.859	13.8	5.29	102.0	7774.17	389.0	18895	54.8	19.0	7.1	-11.1	96.3	
				M	0.124	0.8	2.72	0.335	268.0	103.1	280.3	19.3	0.867	13.9	5.34	103.0	6937.39	347.1	17531	50.9	19.3	6.8	-9.4	87.6	
1.6:1	50	30	3	1	0.130	0.8	2.80	0.323	258.4	99.4	278.8	19.2	0.9	14.4	5.54	106.4	7432.22	371.9	18129	52.6	17.9	7.1	-9.0	94.1	
				2	0.130	0.8	2.80	0.333	266.4	102.5	287.3	19.2	0.786	12.6	4.84	92.9	7794.15	390.0	18953	55.0	21.2	7.1	-10.1	98.5	
				4	0.130	0.9	2.89	0.336	268.8	103.4	298.7	19.1	0.871	13.9	5.36	102.5	7754.18	388.0	17371	50.4	19.3	7.7	-5.2	94.3	
				2	0.130	0.9	2.89	0.338	270.4	104.0	300.5	19.1	0.873	14.0	5.38	102.7	6854.86	343.0	17853	51.8	19.3	6.6	-4.7	89.7	
				M	0.130	0.8	2.85	0.332	266.0	102.3	291.2	19.2	0.857	13.7	5.28	101.1	7458.85	373.2	18077	52.4	19.4	7.1	-7.3	94.1	
				Avg	0.127	0.8	2.7832	0.333	267.0	102.7	285.8	19.2	0.862	13.8	5.31	102.1	7198.12	360.2	17804	51.7	19.3	7.0	-8.3	90.8	
2.0:1	50	30	1	1	0.048	0.3	1.0198	0.946	999.5	333.1	339.7	21.0	0.179	0.3	0.11	2.2	21855.4	1264.1	15270	27.0	3172.6	46.8	-6.8	87.8	
				2	0.048	0.3	1.0198	0.975	1030.3	343.4	350.2	21.0	0.324	0.6	0.19	4.0	25255.8	1460.8	14986	26.5	1807.4	55.1	-3.4	96.1	
				2	0.048	0.3	1.0198	0.965	1020.4	340.1	346.8	21.0	0.187	0.3	0.11	2.3	21516.2	1244.5	17484	31.0	3091.8	40.2	-4.8	85.9	
				2	0.048	0.3	1.0198	0.884	934.1	311.4	317.5	21.0	0.218	0.4	0.13	2.7	23475	1357.8	14857	26.3	2432.4	51.6	-12.7	92.7	
				M	0.048	0.3	1.0198	0.942	996.1	332.0	338.6	21.0	0.227	0.4	0.13	2.8	23025.6	1331.8	15649	27.7	2491.5	48.1	-6.9	90.3	
2.0:1	50	30	3	1	0.048	0.3	1.0198	0.935	988.3	329.4	335.9	21.0	0.194	0.3	0.11	2.4	22456.2	1298.9	16100	28.5	2889.6	45.6	-7.7	89.5	
				2	0.048	0.3	1.0198	0.964	1018.3	339.4	346.1	21.0	0.204	0.4	0.12	2.5	24396.5	1411.1	15422	27.3	2828.3	51.7	-4.9	93.7	
				4	0.048	0.3	1.0198	0.93	982.7	327.5	334.0	21.0	0.184	0.3	0.11	2.3	24583.2	1421.9	15518	27.5	3032.8	51.8	-8.3	94.4	
				2	0.048	0.3	1.0198	0.942	996.0	332.0	338.5	21.0	0.172	0.3	0.10	2.1	23691.1	1370.3	16354	29.0	3286.8	47.3	-7.1	93.3	
				M	0.048	0.3	1.0198	0.943	996.3	332.1	338.7	21.0	0.189	0.3	0.11	2.3	23781.8	1375.5	15849	28.1	2998.5	49.0	-7.0	92.7	
				Avg	0.048	0.3	1.0198	0.943	996.2	332.0	338.6	21.0	0.208	0.4	0.12	2.6	23403.7	1353.7	15749	27.9	2721.6	48.6	-7.0	91.5	
2.2:1	50	30	1	1	0.054	0.4	1.1898	0.878	953.6	298.0	354.5	20.8	0.105	0.2	0.06	1.2	22130.2	1214.3	17823	31.6	5019.7	38.5	3.5	95.5	
				2	0.054	0.4	1.1898	0.859	932.1	291.3	346.5	20.8	0.119	0.2	0.07	1.4	26124.7	1217.2	15524	27.5	4347.3	44.3	1.2	91.8	
				2	0.054	0.4	1.1898	0.862	935.7	292.4	347.9	20.8	0.111	0.2	0.06	1.3	24882.9	1159.3	16731	29.6	4641.3	42.2	1.6	90.7	
				2	0.054	0.4	1.1898	0.886	961.7	300.5	357.6	20.8	0.09	0.2	0.05	1.1	24924.4	1161.3	17161	30.4	5892.9	38.2	4.3	91.5	
				M	0.054	0.4	1.1898	0.871	945.8	295.6	351.6	20.8	0.106	0.2	0.06	1.3	24515.5	1188.0	16810	29.8	4918.4	39.9	2.7	92.4	
2.2:1	50	30	3	1	0.054	0.4	1.1898	0.846	918.8	287.1	341.6	20.8	0.11	0.2	0.06	1.3	27735.8	1278.3	17948	31.8	4630.8	40.2	-0.3	99.2	
				2	0.054	0.4	1.1898	0.881	955.9	298.7	355.4	20.8	0.122	0.2	0.07	1.4	24394.9	1136.6	16819	29.8	4329.0	38.2	3.8	89.6	
				4	0.054	0.4	1.1898	0.838	909.6	284.3	338.2	20.8	0.108	0.2	0.06	1.3	22144.1	1047.7	15486	27.4	4659.8	38.2	-1.2	82.6	
				2	0.054	0.4	1.1898	0.831	902.3	282.0	335.5	20.8	0.101	0.2	0.06	1.2	29762	1119.5	14381	25.5	4946.7	44.0	-2.1	84.6	
				M	0.054	0.4	1.1898	0.849	921.6	288.0	342.7	20.8	0.11	0.2	0.06	1.3	26009.2	1145.5	16159	28.6	4626.6	40.0	0.1	89.0	
				Avg	0.054	0.4	1.1898	0.86	933.7	291.8	347.1	20.8	0.108	0.2	0.06	1.3	25262.4	1166.8	16484	29.2	4769.9	40.0	1.4	90.7	
2.4:1	50	30	1	1	0.070	0.5	1.5297	0.675	666.7	196.1	300.0	20.5	0.43	0.1	0.03	0.5	17093.8	845.8	16949	30.0	7844.0	28.2	3.8	87.1	
				2	0.070	0.5	1.5297	0.687	678.8	199.7	305.4	20.5	0.361	0.1	0.02	0.4	18915.7	839.2	16750	29.7	9507.1	28.3	5.7	86.3	
				2	0.070	0.5	1.5297	0.692	684.0	201.2	307.7	20.5	0.447	0.1	0.03	0.5	17256	854.6	15501	27.4	7737.3	28.8	6.5	85.3	
				2	0.070	0.5	1.5297	0.676	668.0	196.5	300.5	20.5	0.533	0.1	0.03	0.6	18642	827.4	16349	28.9	6337.4	28.6	4.0	84.8	
				M	0.070	0.5	1.5297	0.683	674.4	198.3	303.4	20.5	0.443	0.1	0.03	0.5	17976.9	841.7	16387	29.0	7702.7	29.7	5.0	87.3	
2.4:1	50	30	3	1	0.070	0.5	1.5297	0.671	662.5	194.9	298.1	20.5	0.482	0.1	0.03	0.6	17884	862.4	16088	28.5	6958.9	28.2	3.2	82.6	
				2	0.070	0.5	1.5297	0.653	644.9	189.7	290.1	20.5	0.413	0.1	0.02	0.5	18474	801.9	15785	27.9	7902.9	29.6	0.4	83.9	
				4	0.070	0.5	1.5297	0.664	655.7	192.8	295.0	20.5	0.499	0.1	0.03	0.6	18141	827.0	15895	28.1	6649.7	29.4	2.1	84.1	
				2	0.070	0.5	1.5297	0.682	673.5	198.1	303.0	20.5	0.43	0.1	0.03	0.5	18282	839.9	16706	29.6	7924.0	28.4	4.9	86.3	
				M	0.070	0.5	1.5297	0.667	659.1	193.9	296.6	20.5	0.456	0.1	0.03	0.5	18195.3	832.8	16118	28.5	7315.7	29.2	2.6	84.8	
				Avg	0.070	0.5	1.5297	0.675	666.8	196.1	300.0	20.5	0.45	0.1	0.03	0.5	18086.1	847.6	16253	28.8	7506.4	29.5	3.8	86.1	

Note: M is mean of values

Table c-2 Standard curve of DOWFAX and total surfactant concentration at 1.6:1 of DTAB:DOWFAX

DTAB:DOWFAX	Total surfactant concentration (mM)	DOWFAX concentration (mM)	Absorbance
1.6:1	0	0	0
	0.09	0.03	0.562
	0.17	0.07	1.099
	0.35	0.13	2.151

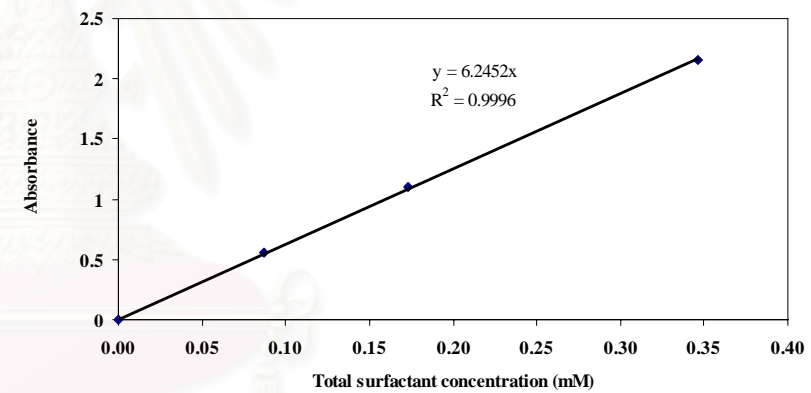
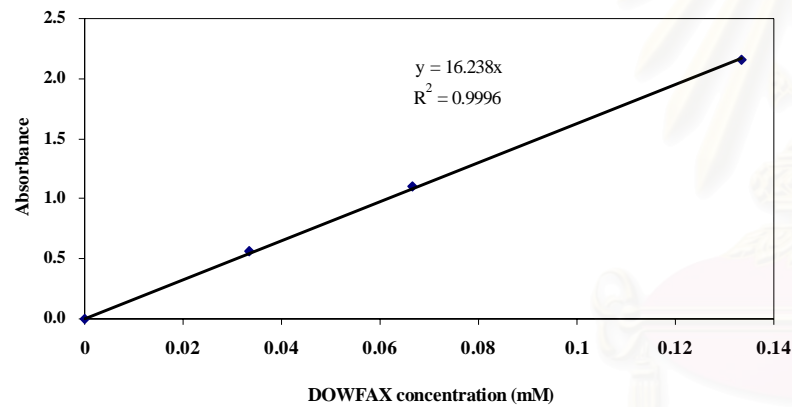
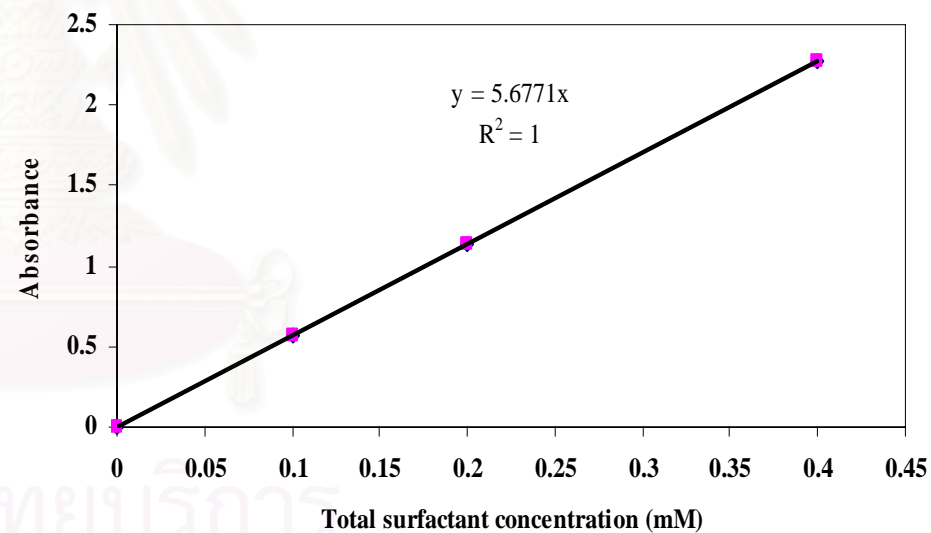
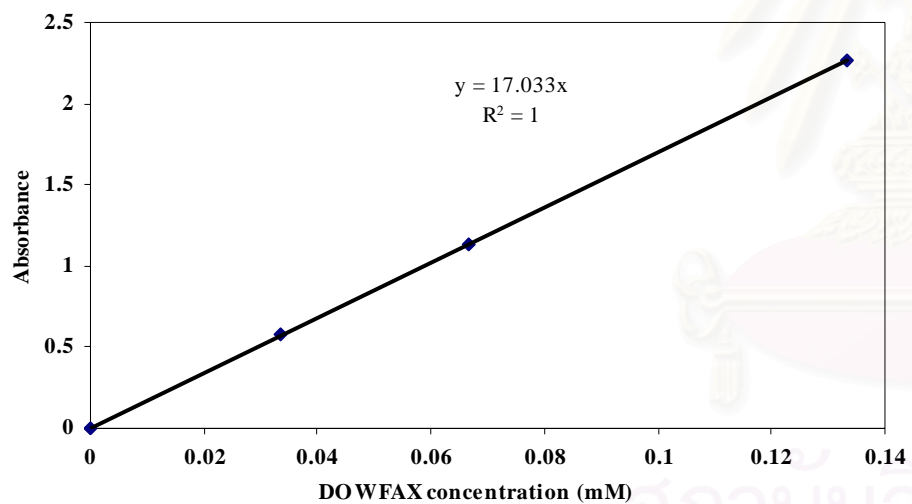


Table c-3 Standard curve of DOWFAX and total surfactant concentration at 2.0:1 of DTAB:DOWFAX

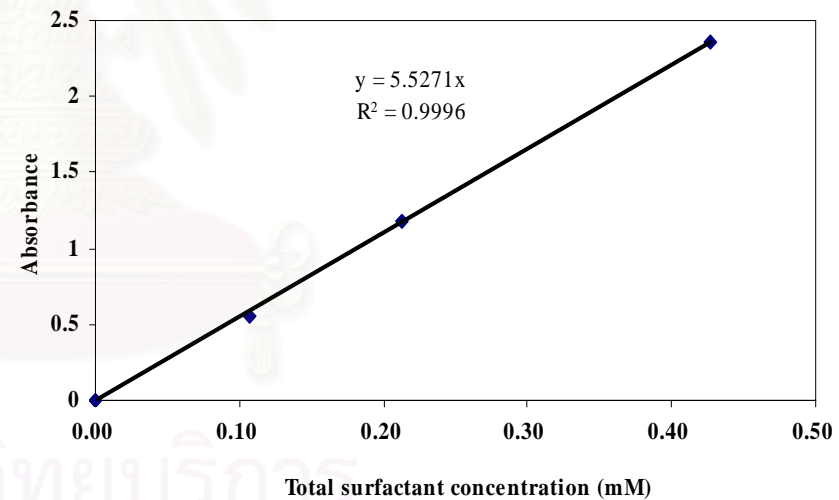
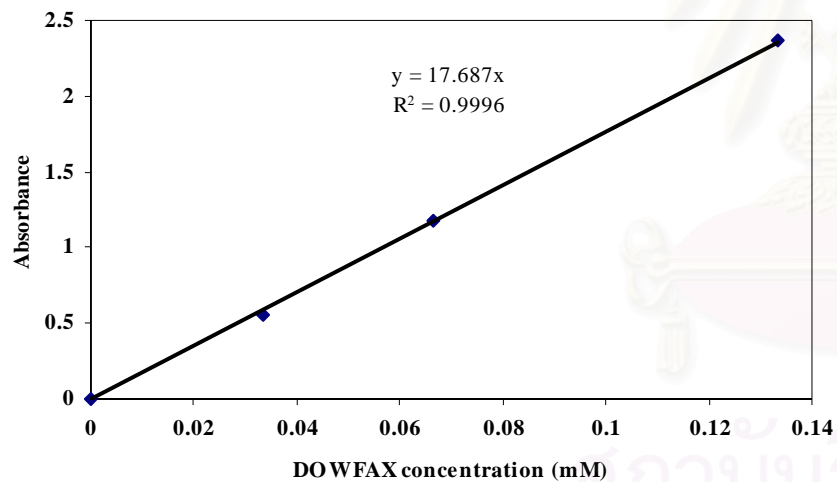
DTAB:DOWFAX	Total surfactant concentration (mM)	DOWFAX concentration (mM)	Absorbance
2.0:1	0	0	0
	0.1	0.03	0.574
	0.2	0.07	1.138
	0.4	0.13	2.268



สถาบันวิทยบริการ
จุฬาลงกรณ์มหาวิทยาลัย

Table c-4 Standard curve of DOWFAX and total surfactant concentration at 2.2:1 of DTAB:DOWFAX

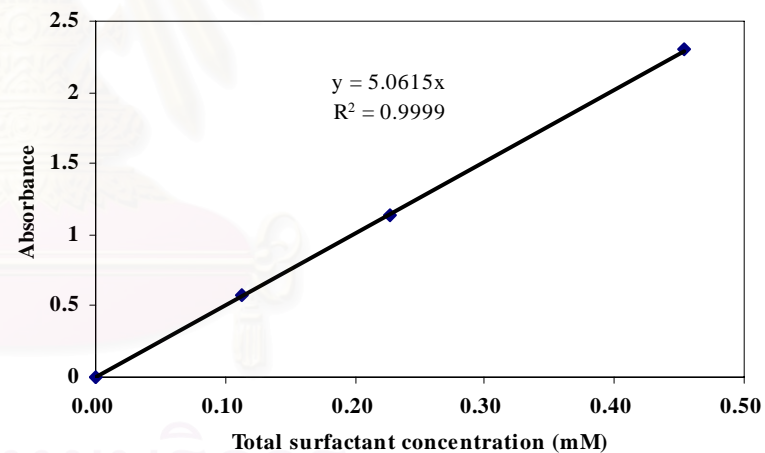
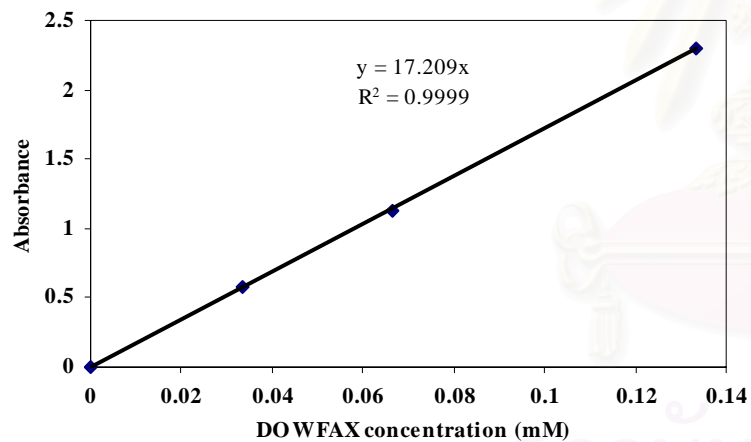
DTAB:DOWFAX	Total surfactant concentration (mM)	DOWFAX concentration (mM)	Absorbance
2.2:1	0	0	0
	0.11	0.03	0.556
	0.21	0.07	1.182
	0.43	0.13	2.365



สถาบันวิทยบริการ
จุฬาลงกรณ์มหาวิทยาลัย

Table c-5 Standard curve of DOWFAX and total surfactant concentration at 2.4:1 of DTAB:DOWFAX

DTAB:DOWFAX	Total surfactant concentration (mM)	DOWFAX concentration (mM)	Absorbance
2.4:1	0	0	0
	0.11	0.03	0.573
	0.23	0.07	1.132
	0.45	0.13	2.302



สถาบันวิทยบริการ
จุฬาลงกรณ์มหาวิทยาลัย

Table c-6 Standard curve of benzene for surfactant-rich phase

DTAB:DOWFAX	[Benzene] (ppm)	Area from GC			
		1	2	3	Avg
1.6:1	0	0	0	0	0
	500	19082.8	10348.2	11112.9	10730.5
	1000	17311.2	19576.7	19438.9	18775.6
	1500	30130.6	30477.9	27188.9	29265.8

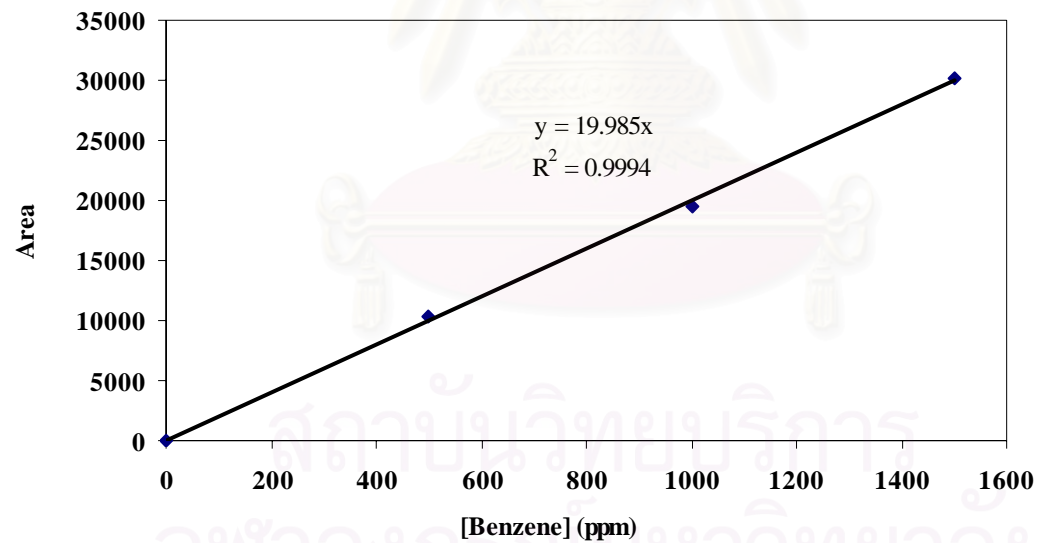


Table c-7 Standard curve of benzene for surfactant-dilute phase

DTAB:DOWFAX	[Benzene] (ppm)	Area from GC			
		1	2	3	Avg
1.6:1	0	0	0	0	0
	20	7122.7	8301.3	7340.8	7588.3
	40	14694.2	15097.2	13319.5	14370.3
	60	20214.3	15381.4	18253.3	17949.6

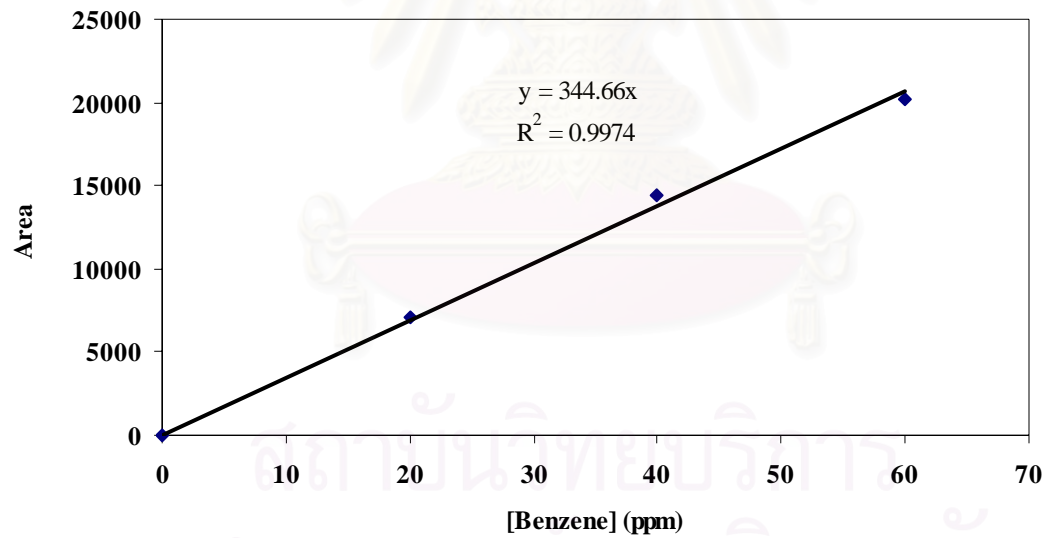


Table c-8 Standard curve of benzene for surfactant-rich phase

DTAB:DOWFAX	[Benzene] (ppm)	Area from GC			
		1	2	3	Avg
2.0:1	0	0	0	0	0
	500	6865.0	6152.3	6630.7	6549.4
	1000	15333.7	18793.7	18951.6	17693.0
	1500	33045.6	26257.3	31538.6	32292.1

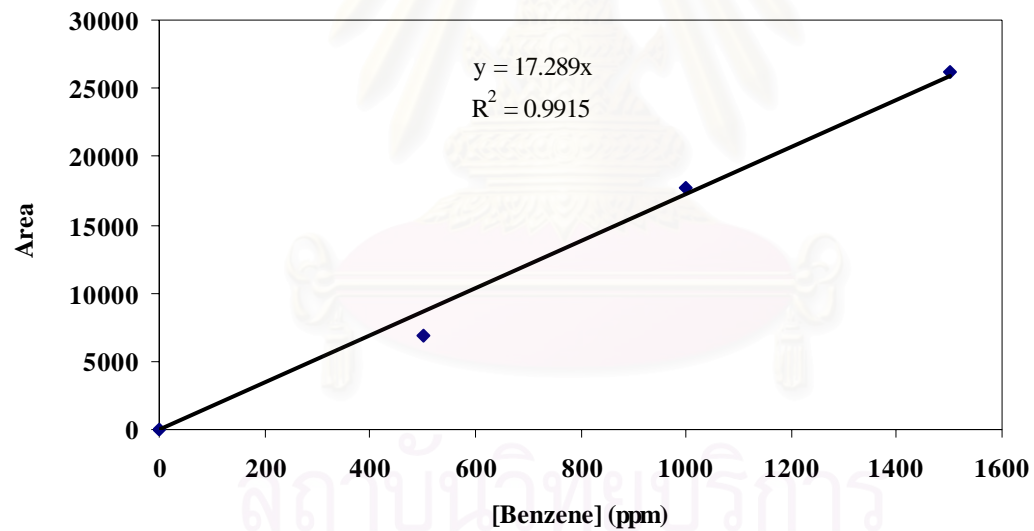


Table c-9 Standard curve of benzene for surfactant-dilute phase

DTAB:DOWFAX	[Benzene] (ppm)	Area from GC			
		1	2	3	Avg
2.0:1	0	0	0	0	0
	20	8808.3	10557.6	12811.2	10725.7
	30	16302.7	17528.1	16474.0	16768.3
	40	18466.6	23017.9	19545.9	20343.5

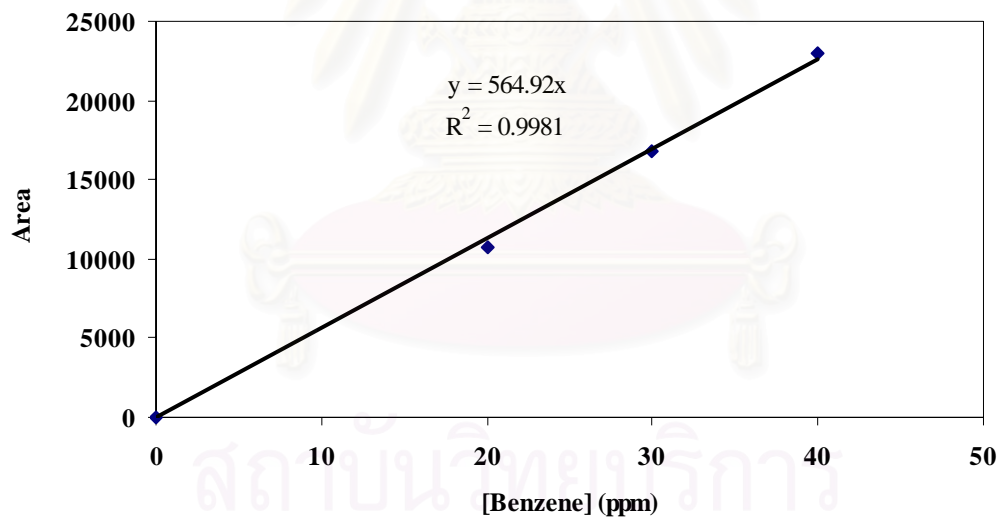


Table c-10 Standard curve of benzene for surfactant-rich phase

DTAB:DOWFAX	[Benzene] (ppm)	Area from GC			
		1	2	3	Avg
2.2:1	0	0	0	0	0
	500	8010.5	7246.8	6782.3	7346.6
	1000	16970.1	15447.6	16473.2	16297.0
	1500	31466.8	30336.8	32305.8	31369.8

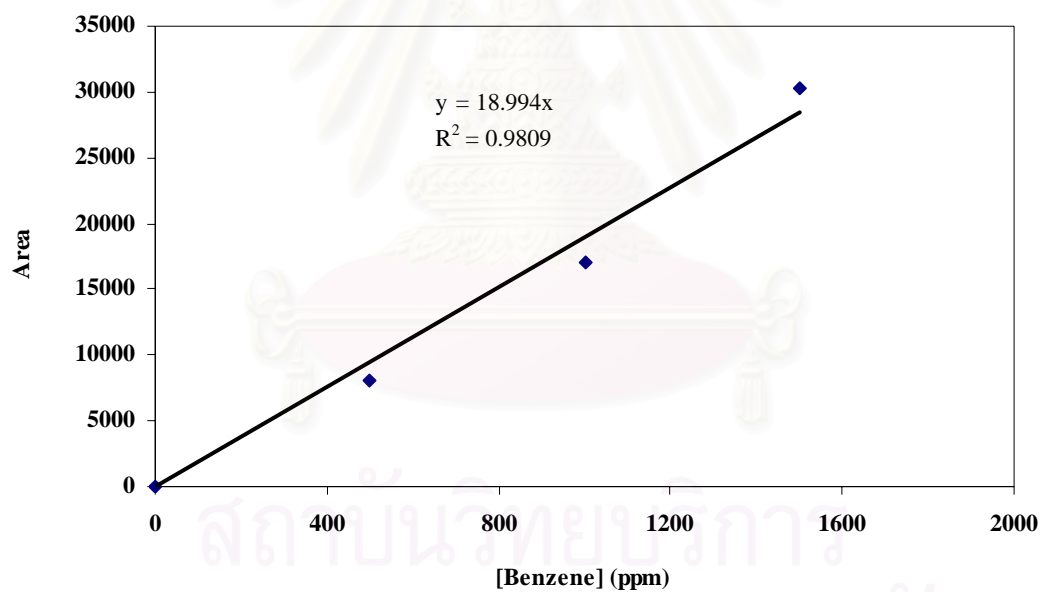


Table c-11 Standard curve of benzene for surfactant-dilute phase

DTAB:DOWFAX	[Benzene] (ppm)	Area from GC			
		1	2	3	Avg
2.2:1	0	0	0	0	0
	20	8808.3	10557.6	12811.2	10725.7
	30	16302.7	17528.1	16474.0	16768.3
	40	18466.6	23017.9	19545.9	20343.5

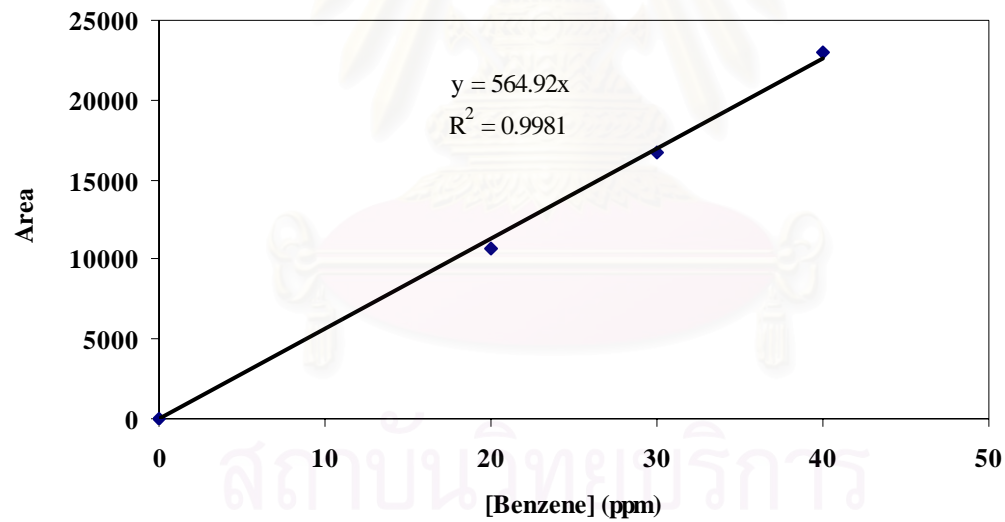


Table c-12 Standard curve of benzene for surfactant-rich phase

DTAB:DOWFAX	[Benzene] (ppm)	Area from GC			
		1	2	3	Avg
2.4:1	0	0	0	0	0
	500	9466.5	9610.7	9529.8	9535.7
	1000	22324.9	19932.0	22039.9	21432.2
	1500	34002.8	33947.2	30963.7	32971.2

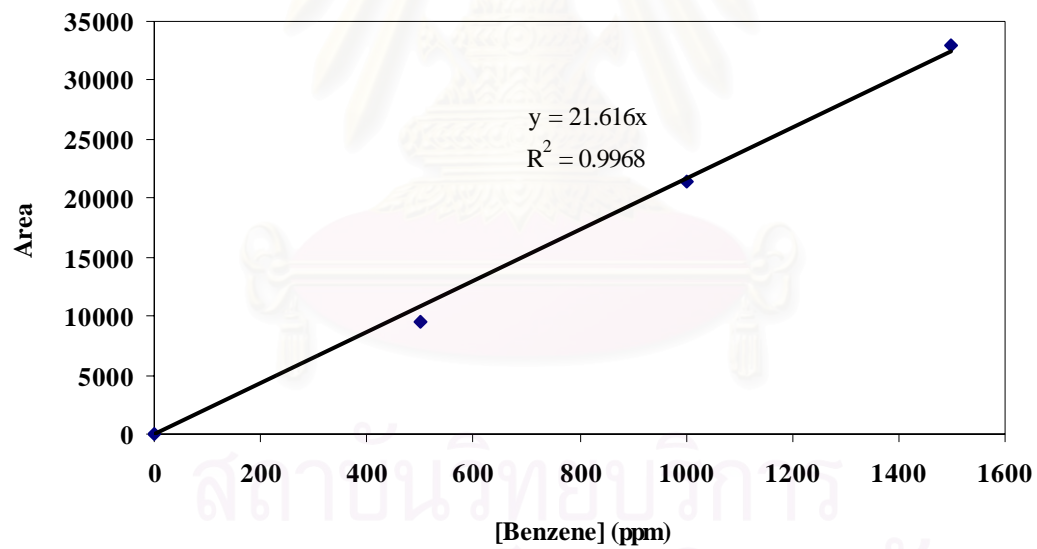
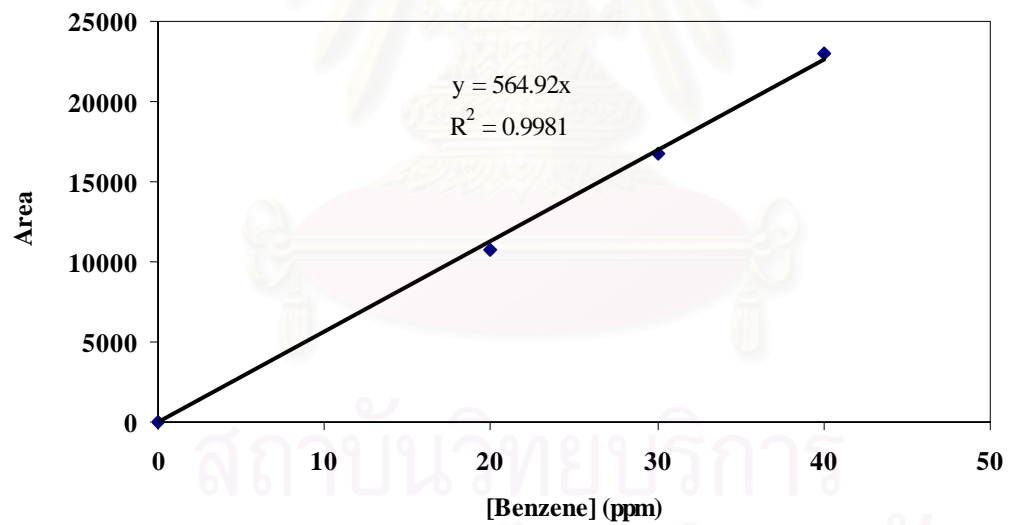


Table c-13 Standard curve of benzene for surfactant-dilute phase

DTAB:DOWFAX	[Benzene] (ppm)	Area from GC			
		1	2	3	Avg
2.4:1	0	0	0	0	0
	20	8808.3	10557.6	12811.2	10725.7
	30	16302.7	17528.1	16474.0	16768.3
	40	18466.6	23017.9	19545.9	20343.5



APPENDIX D

Table d-1 Results of operating condition: Effect of total surfactant concentration

Molar ratio	Ct (mM)	Temp	Vial	No.	Frac rich vol	Surfactant-rich phase						Surfactant-dilute phase						Rich phase		Dilute phase		[Dow]/rich-p	[Ben]/rich-p/	% Error	Mass bal of Benzene
						Height	Volume	Abs	Ct(mM)	[Dow]	Dow	Volume	Abs	Ct(mM)	[Dow]	Dow	Area	[Ben]	Area	[Ben]	[Dow]/dil-p	[Ben]/dil-p			
2.0:1	20	30	1	1	0.019	0.125	0.42	1.012	1069.5	337.3	143.3	21.575	0.108	0.19	0.06	1.29	48542.6	2375	26460	57.8	5621.7	41.1	-1.4	102.6	
				2	0.019	0.125	0.42	0.96	1014.6	320.0	136.0	21.575	0.126	0.22	0.07	1.51	43322.5	2119.6	28428	62.1	4571.4	34.1	-6.3	101.8	
				2	0.019	0.125	0.42	0.991	1047.3	330.3	140.3	21.575	0.144	0.25	0.08	1.73	46678.6	2283.8	25544	55.8	4128.8	40.9	-3.1	98.8	
2.0:1	20	30	3	1	0.019	0.125	0.42	0.988	1043.8	329.2	139.9	21.575	0.126	0.22	0.07	1.51	39244.9	1920.1	24766	54.1	4702.9	35.5	-3.6	90.1	
				2	0.019	0.125	0.42	0.993	1049.5	331.0	140.6	21.575	0.108	0.19	0.06	1.29	44892.2	2196.4	25269	55.2	5516.7	39.8	-3.2	96.6	
				2	0.019	0.125	0.42	1.004	1060.6	334.5	142.1	21.575	0.126	0.22	0.07	1.51	48340.3	2365.1	23759	51.9	4778.6	45.6	-2.1	96.6	
				4	1	0.019	0.125	0.42	0.991	1047.3	330.3	140.3	21.575	0.126	0.22	0.07	1.51	40850.2	1998.6	26048	56.9	4718.6	35.1	-3.3	94.4
				2	0.019	0.125	0.42	0.939	992.41	313.0	133.0	21.575	0.108	0.19	0.06	1.29	40375.2	1975.4	28474	62.2	5216.7	31.8	-8.4	99.2	
2.0:1	20	30	5	1	0.019	0.125	0.42	0.985	1040.6	328.2	139.5	21.575	0.122	0.21	0.07	1.46	44030.8	2154.3	26093	57.0	4906.9	38.0	-3.9	97.5	
				2	0.019	0.125	0.42	0.978	1033.9	326.1	138.6	21.575	0.126	0.22	0.07	1.51	46284.1	2264.5	24262	53.0	4658.6	42.7	-4.5	95.7	
				2	0.019	0.125	0.42	0.944	997.48	314.6	133.7	21.575	0.126	0.22	0.07	1.51	42361.9	2072.6	30076	65.7	4494.3	31.5	-7.8	104.5	
				6	1	0.019	0.125	0.42	0.946	1000	315.4	134.0	21.575	0.108	0.19	0.06	1.29	47224.3	2310.5	30992	67.7	5256.7	34.1	-7.7	111.0
				2	0.019	0.125	0.42	0.934	987.02	311.3	132.3	21.575	0.126	0.22	0.07	1.51	43917.3	2148.7	30488	66.6	4447.1	32.3	-8.8	106.8	
2.0:1	20	30	7	1	0.019	0.125	0.42	0.968	1022.8	322.6	137.1	21.575	0.108	0.19	0.06	1.29	48340.3	2365.1	26505	57.9	5376.7	40.8	-5.7	102.5	
				2	0.019	0.125	0.42	0.981	1036.5	326.9	138.9	21.575	0.126	0.22	0.07	1.51	45906	2246	27467	60.0	4670.0	37.4	-4.3	102.2	
				8	1	0.019	0.125	0.42	1.014	1071.4	337.9	143.6	21.575	0.108	0.19	0.06	1.29	37777.4	1848.3	27009	59.0	5631.7	31.3	-1.2	93.6
				2	0.019	0.125	0.42	0.979	1034.6	326.3	138.6	21.575	0.126	0.22	0.07	1.51	45407.3	2221.6	27513	60.1	4661.4	37.0	-4.4	101.8	
				M	0.019	0.125	0.42	0.968	1023	322.6	137.1	21.575	0.119	0.21	0.07	1.43	44652.3	2184.7	28039	61.3	4899.6	35.9	-5.6	102.3	
2.0:1	50	30	1	Avg	0.019	0.125	0.42	0.976	1031.8	325.4	138.3	21.575	0.12	0.21	0.07	1.44	44341.6	2169.5	27066	59.1	4903.2	36.9	-4.7	99.9	
				2	0.046	0.3	1.02	0.968	1023.2	322.7	139.1	20.98	0.216	0.38	0.12	2.52	30325.3	1483.7	12360	27.0	2689.2	55.0	-9.6	94.5	
				2	0.046	0.3	1.02	0.997	1053.9	332.4	139.0	20.98	0.198	0.35	0.11	2.31	26319.3	1287.7	12131	26.5	3021.8	48.6	-6.9	85.0	
				2	0.054	0.35	1.19	0.99	1046.3	330.0	139.6	20.81	0.216	0.38	0.12	2.50	30039.2	1469.7	14191	31.0	2750.0	47.4	7.8	108.8	
				2	0.054	0.35	1.19	0.993	1049.5	331.0	139.8	20.81	0.198	0.35	0.11	2.29	24138.5	1181	12040	26.3	3009.1	44.9	8.0	88.7	
2.0:1	50	30	3	1	0.054	0.35	1.19	1.074	1135.1	358.0	142.9	20.81	0.216	0.38	0.12	2.50	29855.2	1460.7	13047	28.5	2983.3	51.3	16.8	106.0	
				2	0.054	0.35	1.19	0.965	1019.4	321.5	138.5	20.81	0.198	0.35	0.11	2.29	27570.2	1348.9	12497	27.3	2922.7	49.4	4.9	98.8	
				4	1	0.046	0.3	1.02	1.037	1096.1	345.7	135.2	20.98	0.234	0.41	0.13	2.73	27386.2	1339.9	12589	27.5	2659.2	48.7	-3.1	88.3
				2	0.046	0.3	1.02	1.046	1105.6	348.7	135.6	20.98	0.216	0.38	0.12	2.52	23721.5	1160.6	13230	28.9	2905.8	40.2	-2.3	81.4	
				M	0.050	0.325	1.10	1.009	1066.1	336.3	137.4	20.895	0.212	0.37	0.12	2.46	27419.4	1341.5	12761	27.9	2867.7	48.2	2.0	93.8	
2.0:1	50	30	5	1	0.046	0.3	1.02	0.949	1003.2	316.4	132.7	20.98	0.234	0.41	0.13	2.73	29832.8	1459.6	13321	29.1	2433.8	50.2	-11.3	95.4	
				2	0.046	0.3	1.02	1.034	1092.9	344.7	135.5	20.98	0.234	0.41	0.13	2.73	28984.5	1418.1	12681	27.7	2651.5	51.2	-3.4	92.2	
				6	1	0.054	0.35	1.19	0.968	1022.8	322.6	138.8	20.81	0.216	0.38	0.12	2.50	28316.2	1385.4	12726	27.8	2688.3	49.8	5.4	101.2
				2	0.054	0.35	1.19	1.035	1094.2	345.1	140.6	20.81	0.234	0.41	0.13	2.71	24167.1	1182.4	13779	30.1	2654.6	39.3	12.7	92.4	
2.0:1	50	30	7	1	0.054	0.35	1.19	0.956	1010.8	318.8	137.3	20.81	0.234	0.41	0.13	2.71	30701.4	1502.1	11445	25.0	2452.3	60.1	4.2	104.9	
				2	0.054	0.35	1.19	0.974	1029.2	324.6	138.2	20.81	0.234	0.41	0.13	2.71	25714.3	1258.1	14374	31.4	2496.9	40.1	6.1	97.7	
				8	1	0.046	0.3	1.02	0.966	1020.9	322.0	138.4	20.98	0.216	0.38	0.12	2.52	25029.6	1224.6	12269	26.8	2683.3	45.7	-9.8	82.3
				2	0.046	0.3	1.02	0.964	1018.7	321.3	137.7	20.98	0.234	0.41	0.13	2.73	30521.6	1493.3	11490	25.1	2471.5	59.5	-9.9	93.2	
				M	0.050	0.325	1.10	0.981	1036.6	326.9	136.3	20.895	0.23	0.40	0.13	2.66	27908.4	1365.5	12761	27.9	2566.6	49.5	-0.7	95.0	
				Avg	0.050	0.325	1.10	0.995	1051.4	331.6	136.3	20.895	0.221	0.39	0.12	2.56	27663.9	1353.5	12761	27.9	2717.1	48.8	0.6	94.4	

Table d-1 Results of operating condition: Effect of total surfactant concentration (cont.)

Molar ratio	Ct (mM)	Temp	Vial	No.	Frac rich vol	Surfactant-rich phase						Surfactant-dilute phase						Rich phase		Dilute phase		[Dow]rich-p/	[Ben]rich-p/	%Error	Mass bal of Benzene
						Height	Volume	Abs	Ct(mM)	[Dow]	Dow	Volume	Abs	Ct(mM)	[Dow]	Dow	Area	[Ben]	Area	[Ben]	[Dow]dil-p	[Ben]dil-p			
2.0:1	80	30	1	1	0.085	0.55	1.87	0.937	990	312.3	583.9	20.13	0.378	0.67	0.21	4.23	20504.4	1003.2	15748	34.4	1487.1	29.2	0.2	116.7	
				2	0.085	0.55	1.87	1.005	1062	335.0	626.3	20.13	0.342	0.60	0.19	3.82	22509.5	1101.3	15381	33.6	1763.2	32.8	7.4	124.3	
				2	0.085	0.55	1.87	0.99	1046	330.0	617.0	20.13	0.342	0.60	0.19	3.82	18863.2	922.9	12497	27.3	1736.8	33.8	5.8	103.4	
				2	0.085	0.55	1.87	1.02	1078	340.0	635.7	20.13	0.36	0.63	0.20	4.03	18985.8	928.9	13230	28.9	1700.0	32.1	9.0	105.4	
2.0:1	80	30	3	1	0.085	0.55	1.87	0.983	1039	327.7	612.7	20.13	0.36	0.63	0.20	4.03	20357.2	996.0	15610	34.1	1638.5	29.2	5.1	115.8	
				2	0.085	0.55	1.87	0.932	984	310.5	580.5	20.13	0.36	0.63	0.20	4.03	20005.7	978.8	12772	27.9	1552.5	35.1	-0.4	108.7	
				4	1	0.085	0.55	1.87	1.033	1092	344.3	643.7	20.13	0.342	0.60	0.19	3.82	20154.9	986.1	12681	27.7	1812.1	35.6	10.4	109.1
				2	0.085	0.55	1.87	1.031	1090	343.7	642.6	20.13	0.378	0.67	0.21	4.23	18820.2	920.8	14054	30.7	1636.7	30.0	10.3	106.3	
2.0:1	80	30	5	M	0.085	0.55	1.87	0.991	1048	330.4	617.8	20.13	0.358	0.63	0.20	4.00	20025.1	979.8	13997	30.6	1665.9	32.2	6.0	111.2	
				1	0.085	0.55	1.87	1.002	1059	333.9	624.3	20.13	0.36	0.63	0.20	4.03	18666.9	913.3	14237	31.1	1669.5	29.4	7.1	106.1	
				2	0.085	0.55	1.87	1.023	1082	341.1	637.7	20.13	0.324	0.57	0.18	3.62	18507.5	905.5	14008	30.6	1895.0	29.6	9.3	105.0	
				6	1	0.085	0.55	1.87	0.967	1022	322.4	602.8	20.13	0.36	0.63	0.20	4.03	20968.4	1025.9	14100	30.8	1612.0	33.3	3.4	115.4
2.0:1	80	30	7	1	0.085	0.55	1.87	0.972	1027	324.0	605.8	20.13	0.36	0.63	0.20	4.03	19455.9	951.9	15610	34.1	1620.0	27.9	3.9	112.1	
				2	0.085	0.55	1.87	1.013	1071	337.8	631.6	20.13	0.342	0.60	0.19	3.82	20819.2	1018.6	15793	34.5	1777.9	29.5	8.3	118.1	
				8	1	0.085	0.55	1.87	1.028	1087	342.7	640.7	20.13	0.378	0.67	0.21	4.23	19742	965.9	14603	31.9	1631.9	30.3	9.9	111.3
				2	0.085	0.55	1.87	0.991	1047	330.2	617.3	20.13	0.36	0.63	0.20	4.03	22656.6	1108.5	14466	31.6	1651.0	35.1	5.9	123.1	
2.0:1	80	30	7	M	0.085	0.55	1.87	1.001	1058	333.8	624.1	20.13	0.353	0.62	0.20	3.95	19904.3	973.8	14735	32.2	1704.9	30.3	7.1	112.2	
				Avg	0.085	0.55	1.87	0.996	1053	332.1	621.0	20.13	0.356	0.63	0.20	3.98	19964.7	976.8	14366	31.4	1685.4	31.3	6.5	111.7	
				1	0.116	0.75	2.55	1.004	1061	334.6	853.1	19.451	0.36	0.63	0.20	3.89	14654.8	717.0	12269	26.8	1673.0	26.8	6.2	106.8	
				2	0.116	0.75	2.55	0.989	1045	329.7	840.6	19.451	0.414	0.73	0.23	4.47	15192.3	743.3	11857	25.9	1433.5	28.7	4.8	109.0	
2.0:1	110	30	1	2	0.112	0.725	2.46	1.008	1065	336.0	828.1	19.535	0.45	0.79	0.25	4.88	14434	706.2	10300	22.5	1344.0	31.4	3.3	99.1	
				2	0.112	0.725	2.46	0.988	1044	329.3	811.6	19.535	0.396	0.70	0.22	4.30	14908.2	729.4	10437	22.8	1496.8	32.0	1.1	102.0	
				3	1	0.112	0.725	2.46	1.011	1069	337.0	830.5	19.535	0.486	0.86	0.27	5.27	12880.7	630.2	10437	22.8	1248.1	27.6	3.6	90.8
				2	0.112	0.725	2.46	1.025	1083	341.7	842.1	19.535	0.342	0.60	0.19	3.71	15513.2	759.0	12818	28.0	1798.4	27.1	4.9	109.9	
2.0:1	110	30	3	1	0.116	0.75	2.55	1.003	1060	334.3	852.3	19.451	0.45	0.79	0.25	4.86	13297.6	650.6	10163	22.2	1337.2	29.3	6.3	95.0	
				2	0.116	0.75	2.55	1.014	1072	338.0	861.7	19.451	0.324	0.57	0.18	3.50	14998.1	733.8	13184	28.8	1877.8	25.5	7.3	110.5	
				M	0.114	0.738	2.51	1.005	1062	335.1	840.0	19.493	0.403	0.71	0.22	4.36	14484.9	708.7	11433	25.0	1526.1	28.5	4.7	102.9	
				1	0.116	0.75	2.55	0.991	1047	330.3	842.1	19.451	0.36	0.63	0.20	3.89	15278.2	747.5	10712	23.4	1651.5	31.9	4.9	107.3	
2.0:1	110	30	5	2	0.116	0.75	2.55	1.031	1089	343.5	875.7	19.451	0.504	0.89	0.28	5.45	16077.3	786.6	12177	26.6	1226.8	29.6	9.2	114.7	
				6	1	0.112	0.725	2.46	0.992	1049	330.7	815.0	19.535	0.378	0.67	0.21	4.10	19034.8	931.3	10758	23.5	1574.8	39.6	1.5	125.2
				2	0.112	0.725	2.46	1.001	1058	333.8	822.7	19.535	0.414	0.73	0.23	4.49	14881.6	728.1	14741	32.2	1451.3	22.6	2.5	110.2	
				1	0.112	0.725	2.46	1.037	1096	345.8	852.2	19.535	0.36	0.63	0.20	3.91	17593.9	860.8	13596	29.7	1729.0	29.0	6.1	122.8	
2.0:1	110	30	7	2	0.112	0.725	2.46	0.989	1046	329.8	812.8	19.535	0.342	0.60	0.19	3.71	13792.2	674.8	13871	30.3	1735.8	22.3	1.2	102.5	
				8	1	0.116	0.75	2.55	0.981	1037	327.1	833.9	19.451	0.414	0.73	0.23	4.47	14534.2	711.1	11582	25.3	1422.2	28.1	3.9	104.8
				2	0.116	0.75	2.55	0.998	1055	332.7	848.2	19.451	0.36	0.63	0.20	3.89	14041.6	687.0	12360	27.0	1663.5	25.4	5.6	103.5	
				M	0.114	0.738	2.51	1.003	1060	334.2	837.8	19.493	0.392	0.69	0.22	4.24	15654.2	765.9	12475	27.3	1556.9	28.6	4.4	111.4	
2.0:1	110	30	7	Avg	0.114	0.738	2.51	1.004	1061	334.6	838.9	19.493	0.397	0.70	0.22	4.30	15069.5	737.3	11954	26.1	1541.5	28.6	4.5	107.1	

จุฬาลงกรณ์มหาวิทยาลัย

Table d-1 Results of operating condition: Effect of total surfactant concentration (cont.)

Molar ratio	Ct (mM)	Temp	Vial	No.	Frac rich vol	Surfactant-rich phase					Surfactant-dilute phase					Rich phase		Dilute phase		[Dow]rich-p	[Ben]rich-p	%Error	Mass bal of Benzene		
						Height	Volume	Abs	Ct(mM)	[Dow]	Dow	Volume	Abs	Ct(mM)	[Dow]	Dow	Area	[Ben]	Area	[Ben]	[Dow]dil-p			[Ben]dil-p	
2.0:1	140	30	1	1	0.139	0.9	3.06	1.03	1088.5	343.3	1050	18.941	0.558	0.98	0.31	5.87	14248	697.1	9933.8	21.7	1107.4	32.1	2.9	115.6	
				2	0.139	0.9	3.06	1.066	1126.5	355.3	1087	18.941	0.63	1.11	0.35	6.63	13571.5	664.0	10712	23.4	1015.1	28.4	6.5	112.5	
				2	0.139	0.9	3.06	1.022	1080.2	340.7	1042	18.941	0.576	1.01	0.32	6.06	11725.9	573.7	10300	22.5	1064.7	25.5	2.1	99.2	
				2	0.139	0.9	3.06	1.012	1069.5	337.3	1032	18.941	0.612	1.08	0.34	6.44	12890.9	630.7	10620	23.2	992.1	27.2	1.1	107.7	
2.0:1	140	30	3	1	0.139	0.9	3.06	1.102	1164.6	367.3	1124	18.941	0.612	1.08	0.34	6.44	12549.5	614.0	9842.3	21.5	1080.3	28.6	10.1	103.9	
				2	0.139	0.9	3.06	1.121	1184.9	373.7	1143	18.941	0.594	1.05	0.33	6.25	13671.6	668.9	10025	21.9	1132.4	30.5	12.0	111.9	
				4	1	0.139	0.9	3.06	1.059	1119.2	353.0	1080	18.941	0.576	1.01	0.32	6.06	14364.5	702.8	9842.3	21.5	1103.1	32.7	5.8	116.2
				2	0.139	0.9	3.06	1.004	1061.2	334.7	1024	18.941	0.594	1.05	0.33	6.25	13181.1	644.9	10208	22.3	1014.2	28.9	0.3	108.9	
2.0:1	140	30	5	M	0.139	0.9	3.06	1.052	1111.8	350.7	1073	18.941	0.594	1.05	0.33	6.25	13275.4	649.5	10186	22.3	1063.7	29.2	5.1	109.5	
				1	0.139	0.9	3.06	1.077	1137.9	358.9	1098	18.941	0.612	1.08	0.34	6.44	15041.1	638.4	10392	22.7	1055.6	28.1	7.6	108.3	
				2	0.139	0.9	3.06	1.04	1099.6	346.8	1061	18.941	0.612	1.08	0.34	6.44	14526	735.9	10575	23.1	1020.0	31.9	4.0	122.2	
				6	1	0.139	0.9	3.06	1.018	1076.1	339.4	1038	18.941	0.594	1.05	0.33	6.25	12580.2	710.7	9888	21.6	1028.5	32.9	1.7	117.4
2.0:1	140	30	7	1	0.139	0.9	3.06	1.025	1083.4	341.7	1045	18.941	0.594	1.05	0.33	6.25	13775.9	659.9	10804	23.6	1035.5	28.0	2.4	112.1	
				2	0.139	0.9	3.06	1.033	1091.6	344.3	1053	18.941	0.594	1.05	0.33	6.25	13506.1	674.0	10804	23.6	1043.3	28.6	3.2	114.0	
				8	1	0.139	0.9	3.06	1.109	1172.5	369.8	1131	18.941	0.612	1.08	0.34	6.44	14366.6	660.8	11216	24.5	1087.6	27.0	10.8	113.0
				2	0.139	0.9	3.06	1.106	1169.3	368.8	1128	18.941	0.594	1.05	0.33	6.25	13791.5	702.9	9704.9	21.2	1117.6	33.2	10.5	116.0	
2.0:1	140	30	M	1	0.139	0.9	3.06	1.062	1122	353.9	1083	18.941	0.601	1.06	0.33	6.32	13884.4	674.8	10683	23.3	1060.4	29.1	6.1	113.9	
				Avg	0.139	0.9	3.06	1.057	1116.9	352.3	1078	18.941	0.597	1.05	0.33	6.29	13579.9	656.6	10435	22.8	1062.0	29.2	5.6	110.9	

สถาบันวิทยบริการ
จุฬาลงกรณ์มหาวิทยาลัย

Table d-2 Standard curve of benzene in surfactant-rich phase

[Benzene] (ppm)	Area from GC			
	1	2	3	Avg
0	0	0	0	0
500	8886.5	9211.5	8562.4	8886.8
1000	15799.7	17840.4	20170.6	17936.9
1500	32355.1	34291.2	29991.5	31173.3

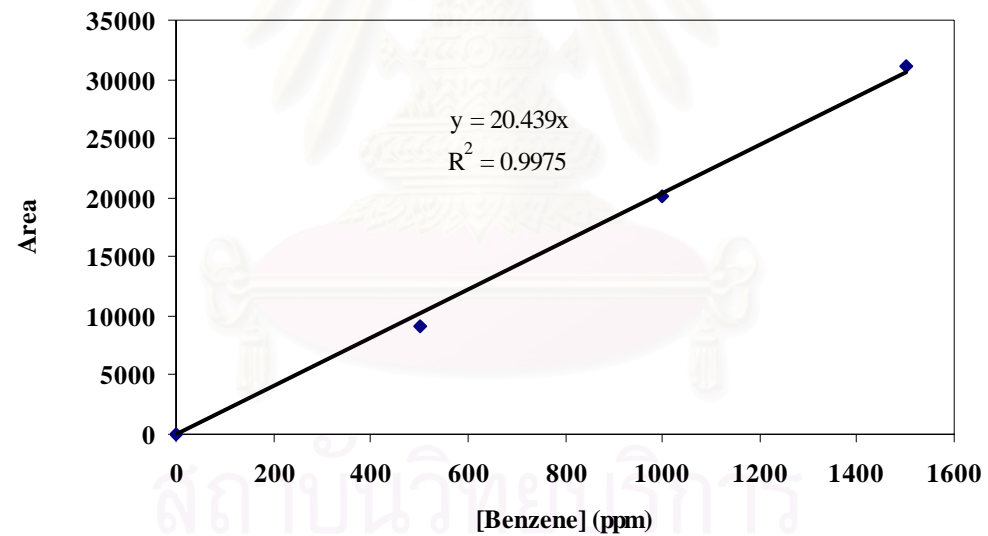
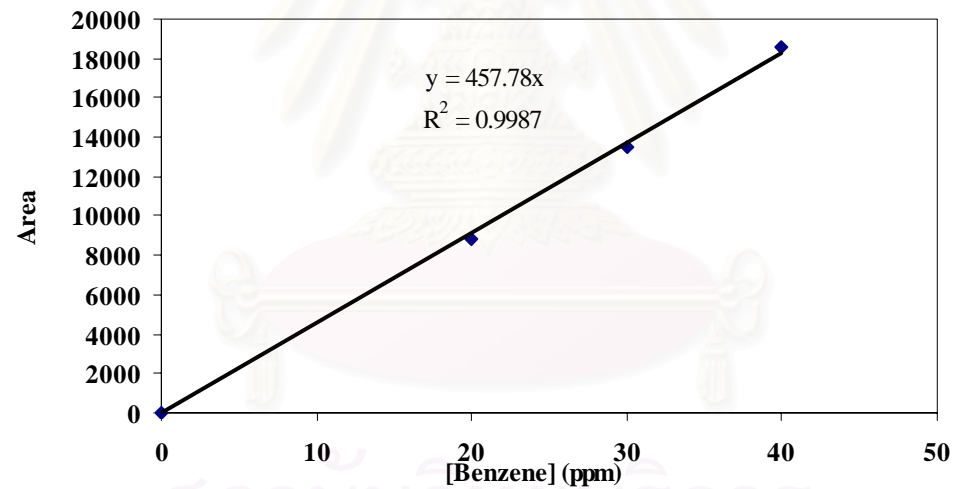


Table d-3 Standard curve of benzene in surfactant-dilute phase

[Benzene] (ppm)	Area from GC			
	1	2	3	Avg
0	0	0	0	0
20	8824.5	6340.0	7753.4	7639.3
30	14793.8	14823.1	13541.8	14386.2
40	24429.7	24797.8	18620.6	22616.0



สถาบันวิทยบริการ
จุฬาลงกรณ์มหาวิทยาลัย

APPENDIX E

Table e-1 Results of operating condition: Effect of temperature

Molar ratio	Ct (mM)	Temp	Vial	No.	Frac rich vol	Surfactant-rich phase						Surfactant-dilute phase						Rich phase		Dilute phase		[Dow]rich-p/ [Ben]rich-p	[Dow]dil-p/ [Ben]dil-p	%Error	Mass bal of Benzene(ppm)
						Height	Volume	Abs	Ct(mM)	[Dow]	Dow	Volume	Abs	Ct(mM)	[Dow]	Dow	Area	[Ben]	Area	[Ben]					
2.0:1	50	20	1	1	0.046	0.30	1.0	0.963	1017.8	321	327	21.0	0.216	0.38	0.12	2.52	28267	1383	15473	33.8	2675.0	40.9	-10.0	96.3	
				2	0.046	0.30	1.0	0.990	1046.3	330	337	21.0	0.216	0.38	0.12	2.52	27401	1341	16801	36.7	2750.0	36.5	-7.5	97.1	
				2	0.046	0.30	1.0	1.002	1059	334	341	21.0	0.234	0.41	0.13	2.73	28112	1375	17808	38.9	2569.2	35.4	-6.4	100.9	
				2	0.046	0.30	1.0	1.004	1060.9	335	341	21.0	0.216	0.38	0.12	2.52	26642	1304	13962	30.5	2788.3	42.7	-6.3	89.5	
2.0:1	50	20	3	1	0.050	0.33	1.1	0.963	1017.8	321	355	20.9	0.198	0.35	0.11	2.30	26309	1287	14969	32.7	2918.2	39.4	-2.7	95.7	
				2	0.050	0.33	1.1	0.978	1033.6	326	360	20.9	0.234	0.41	0.13	2.72	28680	1403	14191	31.0	2507.7	45.3	-1.0	99.9	
				4	1	0.050	0.33	1.1	0.961	1015.6	320	354	20.9	0.234	0.41	0.13	2.72	25406	1243	16663	36.4	2463.8	34.1	-2.8	97.0
				2	0.050	0.33	1.1	0.984	1040	328	362	20.9	0.216	0.38	0.12	2.51	28907	1414	16297	35.6	2733.3	39.7	-0.5	104.8	
				M	0.050	0.31	1.1	0.981	1036.4	327	347	20.9	0.221	0.39	0.12	2.56	27465	1344	15771	34.5	2675.7	39.3	-4.6	97.7	
2.0:1	50	20	5	1	0.046	0.30	1.0	0.947	1000.7	316	322	21.0	0.252	0.44	0.14	2.94	28361	1388	15473	33.8	2254.3	41.1	-11.4	96.6	
				2	0.046	0.30	1.0	0.980	1036.2	327	333	21.0	0.198	0.35	0.11	2.31	29211	1429	14329	31.3	2970.9	45.7	-8.5	96.1	
				6	1	0.046	0.30	1.0	1.016	1074.2	339	346	21.0	0.234	0.41	0.13	2.73	27235	1333	16709	36.5	2606.2	36.5	-5.0	96.6
				2	0.046	0.30	1.0	0.992	1048.5	331	337	21.0	0.234	0.41	0.13	2.73	27251	1333	14741	32.2	2543.8	41.4	-7.3	92.5	
2.0:1	50	20	7	1	0.050	0.33	1.1	0.935	987.65	312	344	20.9	0.216	0.38	0.12	2.51	26513	1297	16663	36.4	2595.8	35.6	-5.5	99.7	
				2	0.050	0.33	1.1	0.953	1006.7	318	351	20.9	0.216	0.38	0.12	2.51	25236	1235	13642	29.8	2645.8	41.4	-3.7	90.3	
				8	1	0.050	0.33	1.1	0.994	1050.4	331	366	20.9	0.198	0.35	0.11	2.30	28835	1411	15107	33.0	3011.8	42.8	0.4	102.2
				2	0.050	0.33	1.1	0.983	1038.7	328	362	20.9	0.216	0.38	0.12	2.51	29888	1462	16663	36.4	2730.0	40.2	-0.6	108.0	
				M	0.048	0.31	1.1	0.975	1030.4	325	345	20.9	0.221	0.39	0.12	2.57	27816	1361	15416	33.7	2669.8	40.6	-5.2	97.7	
				Avg	0.049	0.31	1.1	0.978	1033	326	346	20.9	0.221	0.39	0.12	2.56	27641	1352	15593	34.1	2672.8	39.9	-4.9	97.7	
2.0:1	50	30	1	1	0.046	0.30	1.0	0.972	1027.3	324	330	21.0	0.27	0.48	0.15	3.15	28496	1394	13276	29.0	2160.0	48.1	-9.0	92.3	
				2	0.046	0.30	1.0	1.034	1092.6	345	351	21.0	0.252	0.44	0.14	2.94	25904	1267	13779	30.1	2461.4	42.1	-3.4	87.5	
				2	1	0.046	0.30	1.0	0.961	1015.6	320	327	21.0	0.252	0.44	0.14	2.94	28208	1380	13733	30.0	2287.9	46.0	-10.1	92.6
				2	0.046	0.30	1.0	0.987	1043.1	329	336	21.0	0.198	0.35	0.11	2.31	27860	1363	13047	28.5	2990.9	47.8	-7.9	90.4	
2.0:1	50	30	3	1	0.050	0.33	1.1	1.002	1059	334	369	20.9	0.198	0.35	0.11	2.30	28829	1411	14191	31.0	3036.4	45.5	1.3	100.3	
				2	0.050	0.33	1.1	0.996	1052.7	332	367	20.9	0.234	0.41	0.13	2.72	26037	1274	11582	25.3	2553.8	50.4	0.8	88.0	
				4	1	0.050	0.33	1.1	0.990	1046.3	330	365	20.9	0.234	0.41	0.13	2.72	31449	1539	11948	26.1	2538.5	59.0	0.2	102.1
				2	0.050	0.33	1.1	0.974	1028.9	325	359	20.9	0.216	0.38	0.12	2.51	28850	1412	13642	29.8	2704.2	47.4	-1.5	99.2	
				M	0.048	0.31	1.1	0.989	1045.7	330	350	20.9	0.232	0.41	0.13	2.70	28204	1380	13150	28.7	2591.6	48.3	-3.7	94.0	
2.0:1	50	30	5	1	0.046	0.30	1.0	1.021	1079.3	340	347	21.0	0.198	0.35	0.11	2.31	27427	1342	12360	27.0	3094.5	49.7	-4.7	88.0	
				2	0.046	0.30	1.0	1.024	1082.1	341	348	21.0	0.198	0.35	0.11	2.31	28680	1403	12131	26.5	3102.7	53.0	-4.4	90.3	
				6	1	0.046	0.30	1.0	1.010	1067.9	337	343	21.0	0.216	0.38	0.12	2.52	29115	1425	12406	27.1	2806.7	52.6	-5.6	91.9
				2	0.046	0.30	1.0	1.005	1061.8	335	342	21.0	0.216	0.38	0.12	2.52	24367	1192	13733	30.0	2790.8	39.7	-6.2	83.9	
2.0:1	50	30	7	1	0.050	0.33	1.1	0.990	1046	330	364	20.9	0.216	0.38	0.12	2.51	28823	1410	12452	27.2	2749.2	51.8	0.1	96.7	
				2	0.050	0.33	1.1	0.998	1054.6	333	367	20.9	0.216	0.38	0.12	2.51	29451	1441	11261	24.6	2771.7	58.6	0.9	95.7	
				8	1	0.050	0.33	1.1	0.991	1047.3	330	365	20.9	0.216	0.38	0.12	2.51	24545	1201	13001	28.4	2752.5	42.3	0.2	87.3
				2	0.050	0.33	1.1	1.022	1079.6	341	376	20.9	0.198	0.35	0.11	2.30	24562	1202	11948	26.1	3095.5	46.0	3.2	85.1	
				M	0.048	0.31	1.1	1.008	1064.8	336	357	20.9	0.209	0.37	0.12	2.43	27121	1327	12412	27.1	2895.4	49.2	-2.1	89.9	
				Avg	0.048	0.31	1.1	0.998	1055	333	354	20.9	0.2	0.39	0.12	2.56	27663	1353	12781	27.9	2743.5	48.7	-2.9	92.0	

จุฬาลงกรณ์มหาวิทยาลัย

Table e-1 Results of operating condition : Effect of temperature (cont.)

Molar ratio	Ct (mM)	Temp	Vial	No.	Frac rich vol	Surfactant-rich phase						Surfactant-dilute phase						Rich phase		Dilute phase		[Dow]rich-p/ [Dow]dil-p	[Ben]rich-p/ [Ben]dil-p	%Error	Mass bal of Benzene(ppm)
						Height	Volume	Abs	Ct(mM)	[Dow]	Dow	Volume	Abs	Ct(mM)	[Dow]	Dow	Area	[Ben]	Area	[Ben]					
2.0:1	50	40	1	1	0.050	0.33	1.1	1.002	1059	334	369	20.9	0.306	0.54	0.17	3.55	26454	1294	17029	37.2	1964.7	34.8	1.6	100.3	
				2	0.050	0.33	1.1	0.960	1015	320	354	20.9	0.306	0.54	0.17	3.55	29195	1428	17808	38.9	1882.4	36.7	-2.6	108.7	
			2	1	0.050	0.33	1.1	0.996	1053	332	367	20.9	0.270	0.48	0.15	3.13	27431	1342	15839	34.6	2213.3	38.8	0.9	100.3	
				2	0.050	0.33	1.1	0.981	1037	327	361	20.9	0.306	0.54	0.17	3.55	28670	1403	16801	36.7	1923.5	38.2	-0.5	105.3	
2.0:1	50	40	3	1	0.050	0.33	1.1	0.977	1032	326	360	20.9	0.306	0.54	0.17	3.55	27544	1348	18128	39.6	1915.3	34.0	-0.9	105.3	
				2	0.050	0.33	1.1	0.990	1046	330	365	20.9	0.306	0.54	0.17	3.55	26174	1281	16251	35.5	1941.2	36.1	0.4	98.0	
			4	1	0.046	0.30	1.0	0.953	1007	318	324	21.0	0.270	0.48	0.15	3.15	24919	1219	16068	35.1	2118.0	34.7	-10.8	90.0	
				2	0.046	0.30	1.0	0.999	1056	333	340	21.0	0.288	0.51	0.16	3.36	25492	1247	17258	37.7	2081.3	33.1	-6.5	93.8	
				M	0.049	0.32	1.1	0.982	1038	327	355	20.9	0.295	0.52	0.16	3.42	26985	1320	16898	36.9	2005.0	35.8	-2.3	100.2	
2.0:1	50	40	5	1	0.050	0.33	1.1	0.987	1043	329	363	20.9	0.270	0.48	0.15	3.13	23505	1150	17670	38.6	2192.7	29.8	0.0	94.4	
				2	0.050	0.33	1.1	0.991	1047	330	365	20.9	0.288	0.51	0.16	3.34	26732	1308	18586	40.6	2064.4	32.2	0.4	104.2	
			6	1	0.050	0.33	1.1	1.002	1059	334	369	20.9	0.306	0.54	0.17	3.55	27411	1341	16114	35.2	1964.1	38.1	1.6	100.8	
				2	0.050	0.33	1.1	0.935	988	312	344	20.9	0.270	0.48	0.15	3.13	28776	1408	16892	36.9	2078.0	38.2	-5.2	105.7	
2.0:1	50	40	7	1	0.050	0.33	1.1	0.986	1042	329	363	20.9	0.288	0.51	0.16	3.34	26587	1301	17213	37.6	2054.4	34.6	0.0	101.0	
				2	0.050	0.33	1.1	1.013	1070	338	373	20.9	0.324	0.57	0.18	3.76	27681	1354	16068	35.1	1875.0	38.6	2.7	101.3	
			8	1	0.046	0.30	1.0	0.962	1016	321	327	21.0	0.306	0.54	0.17	3.57	24124	1180	17853	39.0	1885.3	30.3	-9.9	91.9	
				2	0.046	0.30	1.0	0.981	1036	327	333	21.0	0.306	0.54	0.17	3.57	26583	1301	18677	40.8	1922.9	31.9	-8.1	99.2	
				M	0.049	0.32	1.1	0.982	1038	327	355	20.9	0.295	0.52	0.16	3.43	26425	1293	17384	38.0	2004.6	34.2	-2.3	99.8	
				Avg	0.049	0.32	1.1	0.982	1038	327	355	20.9	0.295	0.52	0.16	3.43	26705	1307	17141	37.4	2004.8	35.0	-2.3	100.0	
2.0:1	50	50	1	1	0.050	0.33	1.1	0.969	1024	323	357	20.9	0.252	0.44	0.14	2.93	24294	1189	20325	44.4	2307.1	26.8	-1.9	101.9	
				2	0.050	0.33	1.1	1.026	1084	342	378	20.9	0.270	0.48	0.15	3.13	22794	1115	17029	37.2	2280.0	30.0	3.9	91.3	
			2	1	0.046	0.30	1.0	0.930	983	310	316	21.0	0.252	0.44	0.14	2.94	26945	1318	16114	35.2	2214.3	37.5	-13.0	94.7	
				2	0.046	0.30	1.0	1.110	1173	370	377	21.0	0.270	0.48	0.15	3.15	26162	1280	18037	39.4	2466.7	32.5	3.8	96.9	
2.0:1	50	50	3	1	0.046	0.30	1.0	1.017	1075	339	346	21.0	0.306	0.54	0.17	3.57	24053	1177	20692	45.2	1994.7	26.0	-4.7	97.7	
				2	0.046	0.30	1.0	1.016	1074	339	345	21.0	0.234	0.41	0.13	2.73	21026	1029	18265	39.9	2605.4	25.8	-5.1	85.7	
			4	1	0.050	0.33	1.1	1.095	1157	365	403	20.9	0.288	0.51	0.16	3.34	26947	1318	16617	36.3	2281.3	36.3	10.9	100.7	
				2	0.050	0.33	1.1	0.990	1046	330	365	20.9	0.252	0.44	0.14	2.93	23634	1156	18632	40.7	2357.1	28.4	0.2	96.7	
				M	0.048	0.31	1.1	1.019	1077	340	361	20.9	0.266	0.47	0.15	3.09	24482	1198	18214	39.8	2313.3	30.4	-0.7	95.7	
2.0:1	50	50	5	1	0.050	0.33	1.1	1.019	1077	340	375	20.9	0.288	0.51	0.16	3.34	22189	1086	17670	38.6	2123.8	28.1	3.3	91.2	
				2	0.050	0.33	1.1	1.034	1093	345	381	20.9	0.288	0.51	0.16	3.34	21774	1065	18494	40.4	2153.8	26.4	4.7	91.9	
			6	1	0.046	0.30	1.0	1.054	1114	351	358	21.0	0.288	0.51	0.16	3.36	26336	1289	17670	38.6	2195.6	33.4	-1.4	96.5	
				2	0.046	0.30	1.0	1.038	1097	346	353	21.0	0.270	0.48	0.15	3.15	24985	1222	20509	44.8	2306.0	27.3	-2.9	99.4	
2.0:1	50	50	7	1	0.046	0.30	1.0	1.001	1058	334	340	21.0	0.252	0.44	0.14	2.94	21432	1049	18037	39.4	2382.9	26.6	-6.4	86.2	
				2	0.046	0.30	1.0	0.992	1048	331	337	21.0	0.288	0.51	0.16	3.36	24674	1207	20829	45.5	2066.3	26.5	-7.1	99.3	
			8	1	0.050	0.33	1.1	1.046	1105	349	385	20.9	0.306	0.54	0.17	3.55	25798	1262	18677	40.8	2050.6	30.9	6.0	102.1	
				2	0.050	0.33	1.1	1.022	1080	341	376	20.9	0.270	0.48	0.15	3.13	24102	1179	20325	44.4	2270.0	26.6	3.4	101.4	
				M	0.048	0.31	1.1	1.026	1084	342	363	20.9	0.281	0.50	0.16	3.27	23911	1170	19026	41.6	2193.6	28.2	0.0	96.0	
				Avg	0.048	0.31	1.1	1.022	1081	341	362	20.9	0.273	0.48	0.15	3.18	24196	1184	18620	40.7	2253.5	29.3	-0.4	95.8	

Table e-2 Standard curve of benzene in surfactant-rich phase

[Benzene] (ppm)	Area from GC			
	1	2	3	Avg
0	0	0	0	0
500	8886.5	9211.5	8562.4	8886.8
1000	15799.7	17840.4	20170.6	17936.9
1500	32355.1	34291.2	29991.5	31173.3

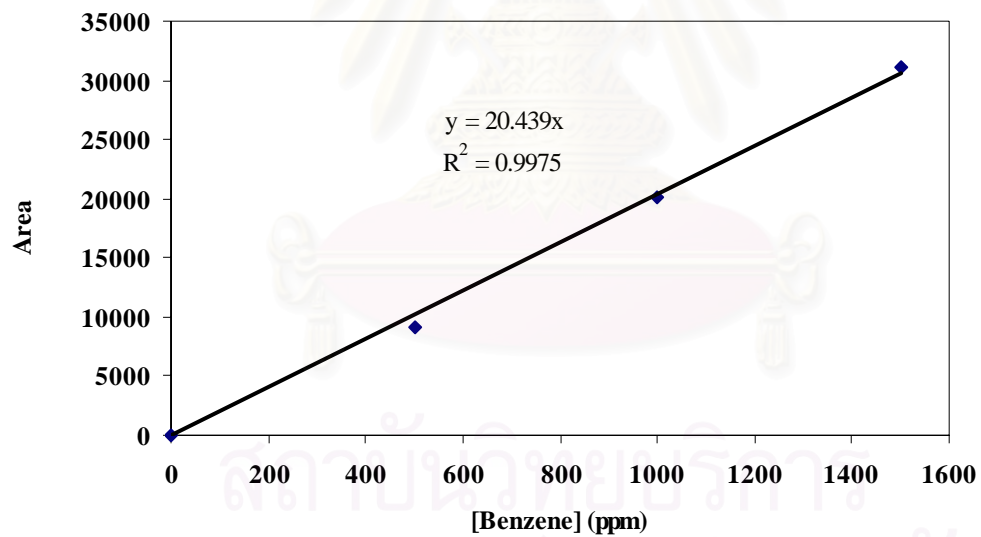
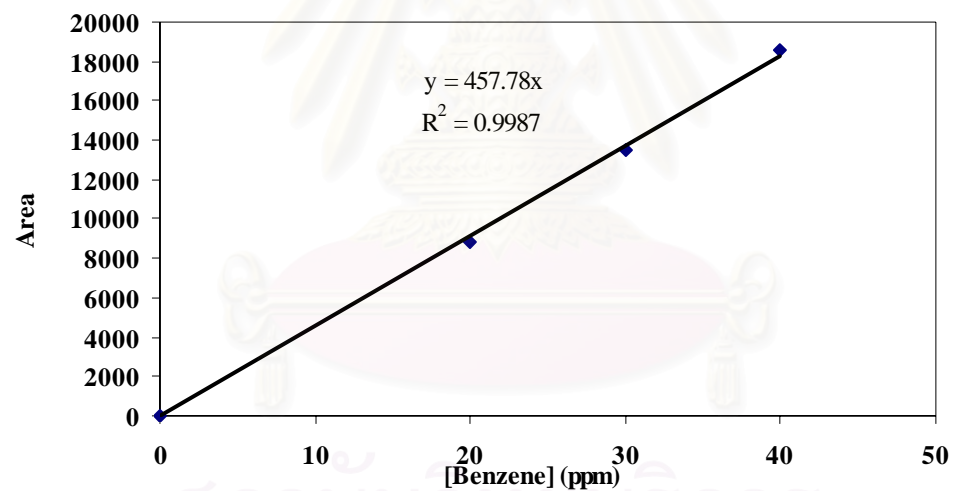


Table e-3 Standard curve of benzene in surfactant-dilute phase

[Benzene] (ppm)	Area from GC			
	1	2	3	Avg
0	0	0	0	0
20	8824.5	6340.0	7753.4	7639.3
30	14793.8	14823.1	13541.8	14386.2
40	24429.7	24797.8	18620.6	22616.0



สถาบันวิทยบริการ
จุฬาลงกรณ์มหาวิทยาลัย

APPENDIX F

Table f-1 Results of operating condition : Effect of pH

Molar ratio	Ct (mM)	Temp	pH	Vial	No.	Frac rich vol	Surfactant-rich phase						Surfactant-diluted phase						Rich phase		Dilute phase		[Dow]rich-p/[Ben]rich-p	[Dow]dil-p/[Ben]dil-p	%Error	Mass bal of Benzene
							Height	Volume	Abs	Ct(mM)	[Dow]	Dow	Volume	Abs	Ct(mM)	[Dow]	Dow	Area	[Ben]	Area	[Ben]					
2.0:1	50	30	4	1	1	0.046	0.30	1.0	0.987	1043	329	336	21.0	0.198	0.35	0.11	2.31	30225	1479	15336	33.5	2990.9	44.1	-7.9	100.5	
					2	0.046	0.30	1.0	0.974	1030	325	331	21.0	0.216	0.38	0.12	2.52	30160	1476	18357	40.1	2705.8	36.8	-9.0	106.6	
					2	0.046	0.30	1.0	0.996	1053	332	339	21.0	0.216	0.38	0.12	2.52	29162	1427	18082	39.5	2766.7	36.1	-7.0	103.8	
					2	0.046	0.30	1.0	0.990	1046	330	337	21.0	0.216	0.38	0.12	2.52	29103	1424	14832	32.4	2750.0	43.9	-7.5	96.9	
2.0:1	50	30	4	3	1	0.050	0.33	1.1	0.984	1040	328	362	20.9	0.216	0.38	0.12	2.51	34818	1704	17853	39.0	2733.3	43.7	-0.5	122.6	
					2	0.050	0.33	1.1	1.015	1073	338	374	20.9	0.216	0.38	0.12	2.51	28069	1373	17167	37.5	2819.2	36.6	2.6	104.6	
					4	1	0.050	0.33	1.1	0.959	1014	320	353	20.9	0.198	0.35	0.11	2.30	31161	1525	17029	37.2	2906.4	41.0	-3.0	111.9
					2	0.050	0.33	1.1	0.955	1009	318	352	20.9	0.216	0.38	0.12	2.51	32334	1582	18861	41.2	2652.5	38.4	-3.4	118.6	
					M	0.048	0.31	1.1	0.983	1038	328	348	20.9	0.212	0.37	0.12	2.46	30629	1499	17190	37.6	2790.6	40.1	-4.5	108.1	
2.0:1	50	30	4	5	1	0.046	0.30	1.0	1.002	1059	334	341	21.0	0.234	0.41	0.13	2.73	30691	1502	18861	41.2	2569.2	36.4	-6.4	108.9	
					2	0.046	0.30	1.0	0.984	1040	328	334	21.0	0.234	0.41	0.13	2.73	27398	1341	19318	42.2	2523.1	31.8	-8.0	102.4	
					6	1	0.046	0.30	1.0	0.963	1018	321	327	21.0	0.216	0.38	0.12	2.52	30035	1470	20097	43.9	2675.0	33.5	-10.0	110.0
					2	0.046	0.30	1.0	0.996	1053	332	339	21.0	0.216	0.38	0.12	2.52	27069	1324	16709	36.5	2766.7	36.3	-7.0	96.2	
2.0:1	50	30	4	7	1	0.050	0.33	1.1	0.959	1014	320	353	20.9	0.216	0.38	0.12	2.51	30620	1498	19639	42.9	2665.0	34.9	-3.0	116.0	
					2	0.050	0.33	1.1	0.990	1046	330	365	20.9	0.216	0.38	0.12	2.51	33207	1625	17625	38.5	2750.0	42.2	0.1	118.2	
					8	1	0.050	0.33	1.1	0.985	1041	328	363	20.9	0.216	0.38	0.12	2.51	30900	1512	17899	39.1	2736.7	38.7	-0.4	113.1
					2	0.050	0.33	1.1	0.983	1039	328	362	20.9	0.216	0.38	0.12	2.51	32747	1602	17441	38.1	2731.7	42.1	-0.5	116.6	
					M	0.048	0.31	1.1	0.983	1039	328	348	20.9	0.221	0.39	0.12	2.56	30334	1484	18449	40.3	2677.2	37.0	-4.4	110.0	
				Avg	0.048	0.31	1.1	0.983	1039	328	348	20.9	0.216	0.38	0.12	2.51	30481	1491	17819	38.9	2733.9	38.5	-4.4	109.1		
2.0:1	50	30	7	1	1	0.046	0.30	1.0	0.996	1053	332	339	21.0	0.216	0.38	0.12	2.52	28662	1402	12635	27.6	2766.7	50.8	-7.0	91.3	
					2	0.046	0.30	1.0	1.002	1059	334	341	21.0	0.234	0.41	0.13	2.73	26706	1307	12681	27.7	2569.2	47.2	-6.4	87.0	
					2	0.046	0.30	1.0	0.977	1033	326	332	21.0	0.216	0.38	0.12	2.52	28308	1385	12085	26.4	2714.2	52.5	-8.7	89.4	
					2	0.046	0.30	1.0	0.994	1051	331	338	21.0	0.234	0.41	0.13	2.73	27875	1364	12131	26.5	2549.2	51.5	-7.1	88.5	
2.0:1	50	30	7	3	1	0.050	0.33	1.1	0.972	1027	324	358	20.9	0.216	0.38	0.12	2.51	24703	1209	12314	26.9	2700.0	44.9	-1.7	86.2	
					2	0.050	0.33	1.1	0.973	1028	324	358	20.9	0.198	0.35	0.11	2.30	26959	1319	13779	30.1	2948.2	43.8	-1.7	94.8	
					4	1	0.050	0.33	1.1	1.007	1064	336	371	20.9	0.234	0.41	0.13	2.72	27537	1347	13093	28.6	2581.5	47.1	1.9	94.8
					2	0.050	0.33	1.1	0.966	1021	322	356	20.9	0.198	0.35	0.11	2.30	27893	1365	12726	27.8	2927.3	49.1	-2.4	94.9	
					M	0.048	0.31	1.1	0.986	1042	329	349	20.9	0.218	0.38	0.12	2.54	27330	1337	12681	27.7	2719.5	48.4	-4.1	90.9	
2.0:1	50	30	7	5	1	0.046	0.30	1.0	1.013	1070	338	344	21.0	0.216	0.38	0.12	2.52	29365	1437	13505	29.5	2813.3	48.7	-5.4	94.7	
					2	0.046	0.30	1.0	1.017	1075	339	346	21.0	0.234	0.41	0.13	2.73	27071	1325	12681	27.7	2607.7	47.8	-5.0	87.8	
					6	1	0.046	0.30	1.0	1.029	1088	343	350	21.0	0.234	0.41	0.13	2.73	28359	1388	11628	25.4	2638.5	54.6	-3.9	88.5
					2	0.046	0.30	1.0	1.020	1078	340	347	21.0	0.234	0.41	0.13	2.73	26906	1316	12543	27.4	2615.4	48.0	-4.7	87.2	
2.0:1	50	30	7	7	1	0.050	0.33	1.1	1.002	1059	334	369	20.9	0.198	0.35	0.11	2.30	28582	1398	14466	31.6	3036.4	44.3	1.3	100.2	
					2	0.050	0.33	1.1	0.987	1043	329	363	20.9	0.216	0.38	0.12	2.51	27482	1345	18220	39.8	2741.7	33.8	-0.2	105.3	
					8	1	0.050	0.33	1.1	0.990	1046	330	365	20.9	0.234	0.41	0.13	2.72	27932	1367	13825	30.2	2538.5	45.3	0.2	97.3
					2	0.050	0.33	1.1	1.017	1075	339	375	20.9	0.216	0.38	0.12	2.51	28345	1387	10163	22.2	2825.8	62.5	2.9	90.7	
					M	0.048	0.31	1.1	1.009	1067	336	357	20.9	0.223	0.39	0.12	2.59	28005	1370	13379	29.2	2727.1	48.1	-1.9	94.0	
				Avg	0.048	0.31	1.1	0.998	1054	333	353	20.9	0.221	0.39	0.12	2.57	27668	1354	13030	28.5	2723.3	48.2	-3.0	92.5		

จุฬาลงกรณ์มหาวิทยาลัย

Table f-1 Results of operating condition : Effect of pH (cont.)

Molar ratio	Ct (mM)	Temp	pH	Vial	No.	Frac rich vol	Surfactant-rich phase						Surfactant-diluted phase						Rich phase		Dilute phase		[Dow]rich-p/[Dow]dil-p	[Ben]rich-p/[Ben]dil-p	%Error	Mass bal of Benzene
							Height	Volume	Abs	Ct(mM)	[Dow]	Dow	Volume	Abs	Ct(mM)	[Dow]	Dow	Area	[Ben]	Area	[Ben]					
2.0:1	50	30	10	1	1	0.050	0.33	1.1	0.963	1018	321	355	20.9	0.198	0.35	0.11	2.30	27591	1350	17029	37.2	2918.2	36.3	-2.7	103.1	
					2	0.050	0.33	1.1	0.951	1005	317	350	20.9	0.234	0.41	0.13	2.72	30340	1484	17533	38.3	2438.5	38.8	-3.7	110.9	
					2	1	0.050	0.33	1.1	0.935	988	312	344	20.9	0.198	0.35	0.11	2.30	28059	1373	18632	40.7	2833.6	33.7	-5.5	107.6
					2	0.050	0.33	1.1	0.930	983	310	342	20.9	0.234	0.41	0.13	2.72	27611	1351	17945	39.2	2384.6	34.5	-5.9	105.1	
2.0:1	50	30	10	3	1	0.050	0.33	1.1	0.936	989	312	345	20.9	0.216	0.38	0.12	2.51	31560	1544	19227	42.0	2600.0	36.8	-5.3	117.4	
					2	0.050	0.33	1.1	0.936	989	312	345	20.9	0.216	0.38	0.12	2.51	34037	1665	18357	40.1	2600.0	41.5	-5.3	121.7	
					4	1	0.046	0.30	1.0	0.978	1034	326	332	21.0	0.216	0.38	0.12	2.52	34947	1710	18998	41.5	2716.7	41.2	-8.6	118.8
					2	0.046	0.30	1.0	0.984	1040	328	334	21.0	0.198	0.35	0.11	2.31	30783	1506	17625	38.5	2981.8	39.1	-8.1	106.5	
2.0:1	50	30	10	5	M	0.049	0.32	1.1	0.952	1006	317	344	20.9	0.214	0.38	0.12	2.48	30616	1498	18168	39.7	2684.2	37.7	-5.6	111.5	
					1	0.050	0.33	1.1	0.948	1002	316	349	20.9	0.234	0.41	0.13	2.72	31752	1554	15702	40.1	2430.8	45.3	-4.0	116.1	
					2	0.050	0.33	1.1	0.961	1016	320	354	20.9	0.216	0.38	0.12	2.51	31341	1533	20417	34.3	2670.0	34.4	-2.8	109.6	
					6	1	0.050	0.33	1.1	0.933	986	311	344	20.9	0.216	0.38	0.12	2.51	33455	1637	16938	44.6	2591.7	44.2	-5.6	124.6
2.0:1	50	30	10	7	1	0.050	0.33	1.1	0.917	969	306	338	20.9	0.234	0.41	0.13	2.72	35838	1753	17441	41.4	2351.5	46.0	-7.2	127.4	
					2	0.050	0.33	1.1	0.956	1010	319	352	20.9	0.216	0.38	0.12	2.51	28351	1387	17533	38.1	2655.8	36.2	-3.3	105.8	
					8	1	0.046	0.30	1.0	0.935	988	312	318	21.0	0.216	0.38	0.12	2.52	30804	1507	17808	38.3	2595.8	38.7	-12.7	106.4
					2	0.046	0.30	1.0	0.960	1015	320	326	21.0	0.198	0.35	0.11	2.31	30867	1510	17893	38.9	2909.1	38.6	-10.4	107.1	
2.0:1	50	30	10	M	0.049	0.32	1.1	0.941	994	314	340	20.9	0.221	0.39	0.12	2.56	30943	1514	17836	39.1	2568.9	39.2	-6.7	111.7		
					Avg	0.049	0.32	1.1	0.946	1000	315	342	20.9	0.217	0.38	0.12	2.52	30779	1506	18002	39.6	2626.5	38.4	-6.2	111.8	

Table f-2 Standard curve of benzene in surfactant-rich phase

[Benzene] (ppm)	Area from GC			
	1	2	3	Avg
0	0	0	0	0
500	8886.5	9211.5	8562.4	8886.8
1000	15799.7	17840.4	20170.6	17936.9
1500	32355.1	34291.2	29991.5	31173.3

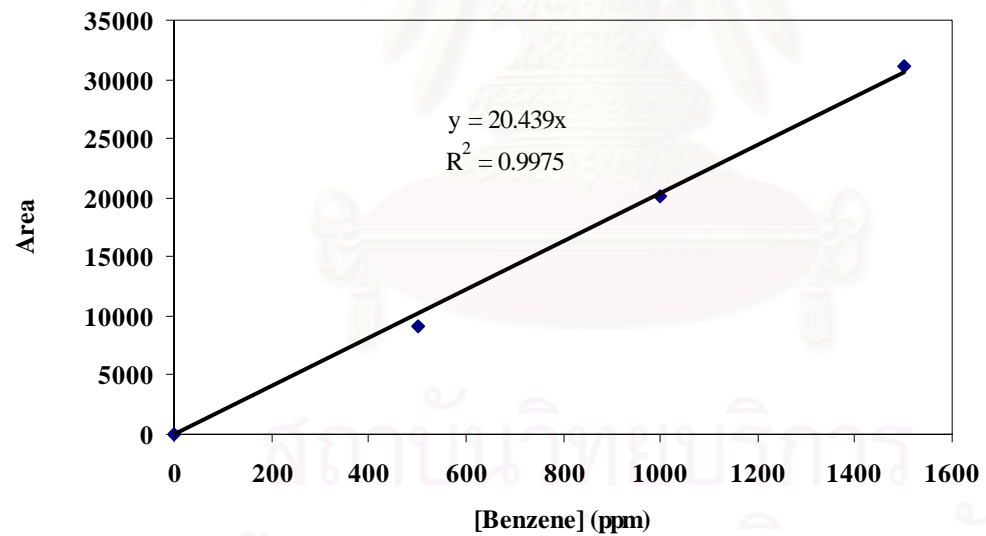
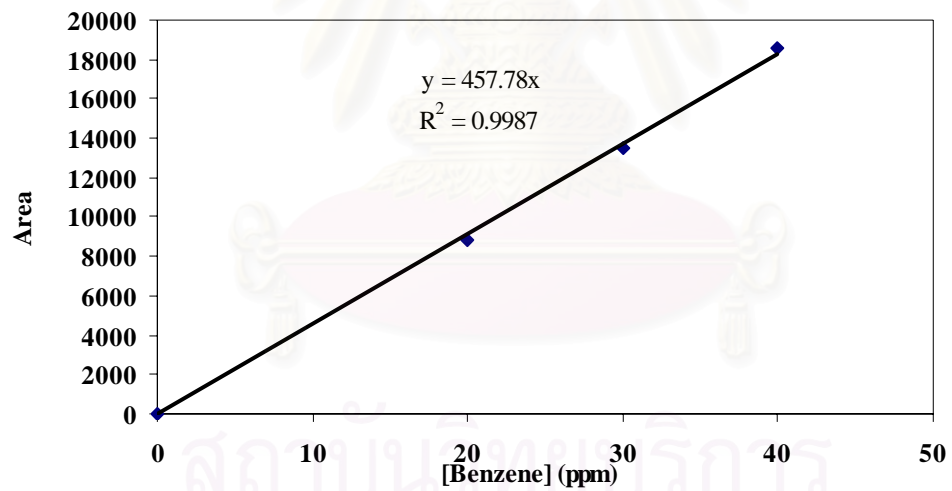


Table f-3 Standard curve of benzene in surfactant-dilute phase

[Benzene] (ppm)	Area from GC			
	1	2	3	Avg
0	0	0	0	0
20	8824.5	6340.0	7753.4	7639.3
30	14793.8	14823.1	13541.8	14386.2
40	24429.7	24797.8	18620.6	22616.0



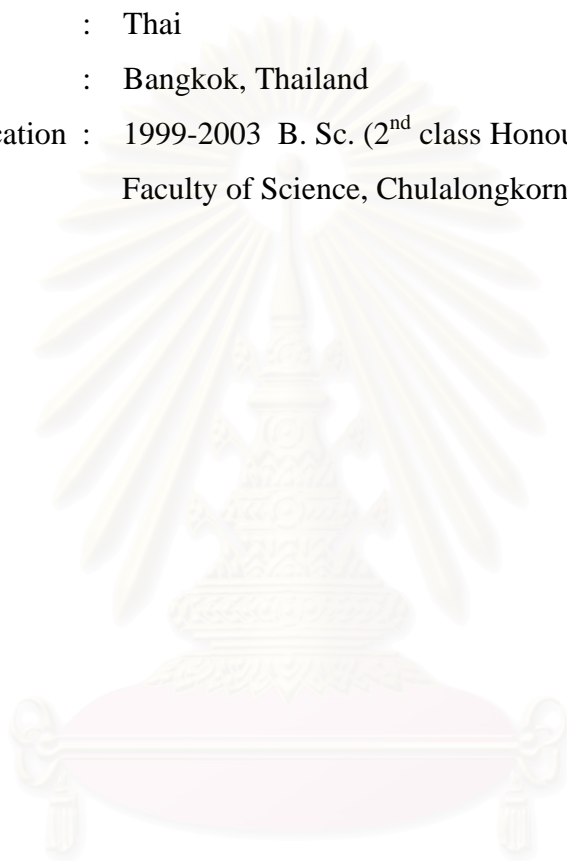
APPENDIX G

Table g-1 Summary of data obtained from ASTP system of DTAB and DOWFAX on benzene removal

Temperature (°C)	pH	Fractional surfactant-rich phase volume	[DOWFAX] (mM)		[Benzene] (ppm)		Fraction in surfactant rich phase		Partition ratio = [in rich]/[in dilute]	
			Dilute	Rich	Dilute	Rich	DOWFAX	Benzene	DOWFAX	Benzene
30	7	0.127	5.31	102.7	51.7	360.2	0.738	0.503	19.3	7.0
30	7	0.048	0.12	332.0	27.9	1353.7	0.993	0.710	2721.6	48.6
30	7	0.054	0.06	291.8	29.2	1166.8	0.996	0.695	4769.9	40.0
30	7	0.07	0.03	196.1	28.8	847.6	0.998	0.689	7506.4	29.5
30	7	0.019	0.07	325.4	59.1	2169.5	0.990	0.416	4903.2	36.9
30	7	0.048	0.12	331.6	27.9	1353.5	0.993	0.710	2717.1	48.8
30	7	0.083	0.20	332.1	31.4	976.8	0.994	0.738	1685.4	31.3
30	7	0.112	0.22	334.6	26.1	737.3	0.995	0.781	1541.5	28.6
30	7	0.135	0.33	352.3	22.8	656.6	0.994	0.818	1062.0	29.2
20	7	0.048	0.12	326.7	34.1	1352.0	0.993	0.667	2672.8	39.9
30	7	0.048	0.12	333.0	27.9	1353.7	0.993	0.710	2743.5	48.7
40	7	0.048	0.16	327.3	34.7	1307.0	0.990	0.655	2004.8	35.0
50	7	0.048	0.15	341.0	40.7	1183.8	0.991	0.595	2253.5	29.3
30	4	0.048	0.12	328.3	38.9	1489.9	0.993	0.659	2733.9	38.5
30	7	0.048	0.12	333.0	28.5	1353.7	0.993	0.705	2723.3	48.2
30	10	0.048	0.12	315.8	39.6	1505.6	0.992	0.657	2626.5	38.4

CURRICULUM VITAE

Name : Onanong Kunanupap
Date of Birth : November 30, 1980
Nationality : Thai
Place of Birth : Bangkok, Thailand
University Education : 1999-2003 B. Sc. (2nd class Honours) in General Science
Faculty of Science, Chulalongkorn University



สถาบันวิทยบริการ
จุฬาลงกรณ์มหาวิทยาลัย