

FROTH FLOTATION TO REMOVE CUTTING OIL FROM WASTEWATER

Alweeya Lapee-e

A Thesis Submitted in Partial Fulfilment of the Requirements
for the Degree of Master of Science
The Petroleum and Petrochemical College, Chulalongkorn University
in Academic Partnership with
The University of Michigan, The University of Oklahoma,
Case Western Reserve University and Institut Français du Pétrole

2006

ISBN 974-9937-57-0

Thesis Title: Froth Flotation to Remove Cutting Oil from Wastewater
By: Alweeya Lapee-e
Program: Petrochemical Technology
Thesis Advisors: Assoc. Prof. Sumaeth Chavadej
Prof. John F. Scamehorn
Assoc. Prof. Pramoch Rangsunvigit

Accepted by the Petroleum and Petrochemical College, Chulalongkorn University, in partial fulfilment of the requirements for the Degree of Master of Science.

.....*Nantaya Yanumet*..... College Director
(Assoc. Prof. Nantaya Yanumet)

Thesis Committee:

Sumaeth Chavadej
.....
(Assoc. Prof. Sumaeth Chavadej)

Pramoch Rangsunvigit
.....
(Assoc. Prof. Pramoch Rangsunvigit)

John F. Scamehorn
.....
(Prof. John F. Scamehorn)

Thirasak Rirksomboon
.....
(Assoc. Prof. Thirasak Rirksomboon)

Pomthong Malakul
.....
(Asst. Prof. Pomthong Malakul)

ABSTRACT

4771002063: Petrochemical Technology Program

Alweeya Lapee-e : Froth Flotation to Remove Cutting Oil from Wastewater

Thesis Advisors: Thesis Advisors: Assoc. Prof. Sumaeth Chavadej, Prof. John F. Scamehorn, and Assoc. Prof. Pramoch Rangsunvigit

73 pp. ISBN 974-9937-57-0

Keywords: Froth flotation / Cutting oil removal / Ultra-low interfacial tension / Foam stability

Froth flotation is a surfactant-based separation process suitable for treating dilute oily wastewaters. The objective of this study was to investigate the relationship between the ultra-low interfacial tension (IFT) and the efficiency of cutting oil removal from water by using continuous froth flotation. Branched alcohol propoxylate sulfate, sodium salt (Alfoterra 145-5PO) and sodium bis(2-ethylhexyl) sulfosuccinate (AOT) were used for microemulsion formation. Surfactant concentration, salinity, and oil-to-water ratio were varied in the microemulsion formation experiment in order to determine the compositions required to obtain the ultra-low IFT. The effects of surfactant concentration, salinity, foam height, air flow rate, hydraulic retention time (HRT) and polyelectrolyte on the oil removal were investigated in the froth flotation experiment. From the results, the maximum oil removal efficiency of the froth flotation process did not correspond to the minimum IFT of the system. Foam stability was revealed to be another crucial factor in the froth flotation operation. Sodium dodecyl sulphate (SDS) was added to increase foam stability and foamability in the continuous froth flotation experiment. The system with 0.1 wt% SDS, 5 wt% NaCl, 0.15 L/min air flow rate, 30 cm foam height and 60 min HRT gave the maximum oil removal of 96%.

บทคัดย่อ

อัลเวีย ลาปีอี : กระบวนการแยกน้ำมันหล่อเย็นออกจากน้ำเสียโดยระบบทำให้ลอยแบบต่อเนื่อง (Froth Flotation to Remove Cutting Oil from Wastewater) อ. ที่ปรึกษา: รศ. ดร. สุเมธ ชวเวช ศ. จอห์น เอฟ สเคอร์มึสเซอรัน และ รศ. ดร. ปราโมช รั้งสรรค้วจิตร 73 หน้า ISBN 974-9937-57-0

กระบวนการทำให้ลอย (froth flotation) เป็นหนึ่งในกระบวนการแยกสารโดยสารลดแรงตึงผิวซึ่งเหมาะสำหรับบำบัดน้ำเสียที่มีการปนเปื้อนของน้ำมันที่เจือจาง งานวิจัยนี้มีวัตถุประสงค์เพื่อศึกษาความสัมพันธ์ระหว่างแรงตึงผิวที่มีค่าต่ำมากและประสิทธิภาพของการกำจัดน้ำมันหล่อเย็นออกจากน้ำโดยกระบวนการทำให้ลอยแบบต่อเนื่อง สารลดแรงตึงผิวแบบบรานซ์ อัลคอสอล โพรพอกซีเลต ซัลเฟต โซเดียม ซอลท์ (Alfoterra 145-5PO) และโซเดียมซัลโฟซัคซิเนต (AOT) ถูกนำมาใช้ในการศึกษาทดลองการเกิดไมโครอิมัลชัน ปัจจัยของความเข้มข้นสารลดแรงตึงผิว ความเค็ม และอัตราส่วนน้ำต่อน้ำมันได้ถูกศึกษาในการทดลองการเกิดไมโครอิมัลชันเพื่อหาสัดส่วนประกอบที่ให้ค่าแรงตึงผิวที่ต่ำมาก ๆ เพื่อนำไปทดลองต่อในส่วนของการกระบวนการทำให้ลอย ในกระบวนการทำให้ลอยได้ทำการศึกษาปัจจัยของความเข้มข้นสารลดแรงตึงผิว ความเค็ม ความสูงของฟอง อัตราการเป่าอากาศ และเวลาเก็บกักต่อการกำจัดน้ำมัน จากผลการทดลอง พบว่าประสิทธิภาพของการกำจัดน้ำมันสูงสุดไม่ได้สอดคล้องกับค่าแรงตึงผิวระหว่างวิฤภาคต่ำสุด โดยพบว่าความเสถียรของฟองเป็นอีกปัจจัยที่มีความสำคัญต่อกระบวนการทำให้ลอย ระบบของสารลดแรงตึงผิวที่ใช้ โซเดียมโคเดคซิล ซัลเฟต ถูกนำมาใช้เพื่อเพิ่มความเสถียรของฟองในกระบวนการทำให้ลอย ความเข้มข้นโซเดียมโคเดคซิล ซัลเฟต 0.1 เปอร์เซ็นต์, ความเข้มข้นของเกลือ 5 เปอร์เซ็นต์, อัตราการเป่าอากาศ 0.15 ลิตรต่อนาที, ความสูงของฟอง 30 เซนติเมตร และเวลากักเก็บ 60 นาที ให้ประสิทธิภาพการกำจัดน้ำมันที่สูงที่สุดเท่ากับ 96 เปอร์เซ็นต์

ACKNOWLEDGEMENTS

This work has been a very memorable and valuable experience as well as a lot of knowledge to the author. It would not have been succeeded without the assistance of a number of individuals including organizations. The author would like to thank all of them for making this work a success.

First of all, my great appreciation is also extended to Assoc. Prof. Sumaeth Chavadej who acted as my Thai advisor for providing many necessary things throughout this work. I would like to thank him for his constant valuable advice and support. This thesis would not have been succeeded without his professional aids.

I would like to express my highly gratefulness to Professor John F. Scamehorn for serving as my US advisor for his guidance, insightful discussion and professional advice throughout my work.

Thank is also offered to Assoc. Prof. Pramoch Rangsunvigit, my co-advisor for his encouragement, vigorous assistance, and kindly useful suggestions.

The surfactant (branched alcohol propoxylate sulfate, sodium salt (Alfoterra 145-5PO Sulfate)) used in this research work was supplied by Sasol North America Inc., Texas, USA.

The Petroleum and Petrochemical Technology is also acknowledged for providing all research facilities and a scholarship for the author.

I would like to express my deep appreciation to Ms. Sunisa Watcharasing, a Ph. D. student for her excellent suggestions and encouragements as well as making this research to be a fun filled activity. Besides, I would like to especially thank for her efforts to develop my technical writing style.

I would like to express my sincerely gratitude to all faculties and staff of the Petroleum and Petrochemical College for their kind assistance to facilitate all works.

The expenses of this research work were mainly supported by The Research Units of Applied Surfactants for Separation and Pollution Control, The Ratchadapisek Somphot Fund, Chulalongkorn University, Thailand Research Fund (TRF) and Postgraduate Education and Research Programs in Petroleum and Petrochemical Technology Consortium.

Special thanks go to all PPC Ph.D. students and all PPC friends for their friendly assistance, cheerfulness, creative suggestions, and encouragement. The author had the most enjoyable time working with all of them.

Finally, the author would like to express deep appreciation to my parents, my sister, and my brother for their endless support and love throughout the two year study period.

TABLE OF CONTENTS

	PAGE
Title Page	i
Abstract (in English)	iii
Abstract (in Thai)	iv
Acknowledgements	v
Table of Contents	vii
List of Tables	x
List of Figures	xi
 CHAPTER	
I INTRODUCTION	1
 II BACKGROUND AND LITERATURE SURVEY	 3
2.1 Surfactants	3
2.2 Microemulsions	7
2.3 Froth Flotation	12
 III EXPERIMENTAL	 18
3.1 Materials	18
3.1.1 Surfactants	19
3.1.2 Studied Oil Contaminant	17
3.1.3 Water	19
3.1.4 Electrolyte	19
3.2 Experimental Procedure	20
3.2.1 Study of Microemulsion Formation	20
3.2.2 Froth Flotation Experiment	21
3.2.3 Foam Ability and Foam Stability Experiments	22
 IV RESULTS AND DISCUSSION	 23
4.1 Microemulsion Formation	23

CHAPTER	PAGE
4.1.1 Effect of Single Surfactant Concentration on IFT	24
4.1.2 Effect of Mixed Surfactant Concentration on IFT	26
4.1.3 Effect of NaCl Concentration on IFT of Single and Mixed Surfactant Systems	28
4.1.3.1 IFT with Single Surfactant System	28
4.1.3.2 IFT with Mixed Surfactant System	28
4.1.4 Effect of Oil to Water Ratio on IFT	30
4.2 Froth Flotation Experiment	33
4.2.1 Effect of Single Surfactant Concentration on Performance of Froth Flotation	34
4.2.2 Effect of NaCl Concentration on Performance of Froth Flotation	42
4.2.5 Effect of Air Flow Rate on Performance of Froth Flotation	48
4.2.6 Effect of Hydraulic Retention Time (HRT) on Performance of Froth Flotation	52
4.2.7 Effect of Foam Height on Performance of Froth Flotation	56
V CONCLUSIONS AND RECOMMENDATIONS	60
5.1 Conclusions	60
5.2 Recommendations	60
REFERENCES	62

CHAPTER	PAGE
APPENDIX Experimental data of microemulsion formation.	63
CURRICULUM VITAE	73

LIST OF TABLES

TABLE		PAGE
3.1	General properties of studied surfactants	19

LIST OF FIGURES

FIGURE	PAGE
2.1 Schematic of surfactant molecule monomer	4
2.2 Schematic illustration of surfactant of surfactant association structures	6
2.3 Schematic diagram of an ionic surfactant solution showing monomeric surfactant in solution and adsorbed at the air/solution interface and micelle aggregate	6
2.4 Schematic diagram for oil-in-water (O/W) and water-in-oil (W/O) microemulsion structures	8
2.5 Demonstration of microemulsion phase behavior for a model system	9
2.6 Schematic diagram of a froth flotation column	11
2.7 xperimental configurations for froth flotation	13
3.1 Schematic experiment of microemulsion formation	19
3.2 Schematic diagram of the froth flotation apparatus	20
4.1 IFT as a function of Alfoterra concentration at 3 wt% of NaCl with oil to water ratio = 1:1 (v:v), and 30 °C	22
4.2 IFT as a function of SDS concentration at 0.1 wt% Alfoterra, 3 wt% NaCl, oil to water ratio = 1:19, and 30 °C.	24
4.3 IFT as a function of salinity at Alfoterra concentration = 0.1 wt% and initial oil to water ratio = 1:1 (v:v)	25
4.4 Foamability of mixed surfactant system at different NaCl concentrations	26
4.5 Foam stability of mixed surfactant system at different NaCl concentrations	27
4.6 IFT of the mixed surfactant system as a function of salinity with an initial oil to water ratio = 1:19 (v:v)	27

FIGURE	PAGE
4.7 IFT as a function of oil to water ratio at 0.1 wt% Alfoterra, 0.5 wt% SDS, and 4 wt% NaCl	28
4.8 Dynamic oil removal of batch froth flotation unit operated at 0.10 wt% Alfoterra, 3 wt% NaCl, oil:water ratio = 1:19, air flow rate = 300 mL/min, and foam height = 26.6 cm, hydraulic retention time = 67 min	30
4.9 Foam stability of single system at different Alfoterra concentrations when (NaCl concentration = 3 wt%, and oil:water ratio = 1:19 between the non-agitated system and the well-agitated system with speed 2000 rpm for 1 hour)	31
4.10 Oil removal efficiency of mixed surfactant system at different feed SDS concentrations	34
4.11 Foam production flow rate of mixed surfactant system at different feed SDS concentrations	34
4.12 Foamability of mixed surfactant system at different feed SDS concentrations	35
4.13 Rate of foam generation of mixed surfactant system at different feed SDS concentrations	35
4.14 Enrichment ratio of mixed surfactant system at different feed SDS concentrations	36
4.15 Foam stability of mixed surfactant system at different initial SDS concentrations	36
4.16 Foam wetness of mixed surfactant system at different feed SDS concentrations	37
4.17 Surfactant removal of mixed system at different feed SDS concentrations	37
4.18 Enrichment of surfactant of mixed surfactant system at different feed SDS concentrations	38

FIGURE	PAGE
4.19 Removal efficiency of diesel with different feed NaCl concentrations	40
4.20 Foamability with different initial NaCl concentrations	41
4.21 Foam stability with different initial NaCl concentrations	41
4.22 IFT with different initial NaCl concentrations	42
4.23 Enrichment ratio of diesel with different feed NaCl concentrations	42
4.24 Foam production rate with different feed NaCl concentrations	43
4.25 Foam wetness with at different feed NaCl concentrations	43
4.26 Surfactant removal with at different feed NaCl concentrations	44
4.27 Enrichment ratio of surfactant with different feed NaCl concentrations	44
4.28 Removal efficiency of diesel of system at different feed oil to water ratios	46
4.29 Foamability of system at different feed oil to water ratios	47
4.30 Foam stability of system at different initial oil to water ratios	47
4.31 Foam production rate of system at different feed oil to water ratios	48
4.32 Enrichment ratio of diesel of system at different feed oil to water ratios	48
4.33 Foam wetness of system at different feed oil to water ratios	49
4.34 Surfactant removal of system at different feed oil to water ratios	49
4.35 Enrichment ratio of surfactant of system at different feed oil to water ratios	50

FIGURE	PAGE
4.36 Oil removal of system at different air flow rates	51
4.37 Foamability of diesel of system at different air flow rates	52
4.38 Foam wetness of system at different air flow rates	53
4.39 Foam production rate of system at different air flow rates	53
4.40 Foam stability of diesel of system at different air flow rates	54
4.41 Enrichment ratio of diesel of system at different air flow rates	54
4.42 Surfactant removal of system at different air flow rates	55
4.43 Enrichment ratio of surfactant of system at different air flow rates	55
4.44 Oil removal of system at different HRTs	57
4.45 Enrichment ratio of diesel of system at different HRTs	57
4.46 Foam wetness of system at different HRTs	58
4.47 Foam production rate of system at different HRTs	58
4.48 Surfactant removal of system at different HRTs	59
4.49 Enrichment ratio of surfactant of system at different HRTs	59
4.50 Oil removal of system at different foam heights	61
4.51 Foam production rate of system at different foam heights	61
4.52 Enrichment ratio of diesel of system at different foam heights	62
4.53 Foam wetness of system at different foam heights	62
4.54 Surfactant removal of system at different foam heights	63
4.55 Enrichment ratio of surfactant of system at different foam heights	63