DIESEL REMOVAL FROM WASTEWATER BY FROTH FLOTATION

Panita Angkathunyakul

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
2005

ISBN 974-9651-90-1

Thesis Title: Diesel Removal from Wastewater by Froth Flotation

By: Panita Angkathunyakul

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.

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

Thesis Committee:

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

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

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

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

....
(Asst. Prof. Boonyarach Kitiyanan)

ABSTRACT

4671002063: Petrochemical Technology

Panita Angkathunyakul: Diesel Removal from Wastewater by Froth Flotation.

Thesis Advisors: Assoc. Prof. Sumaeth Chavadej, Prof. John F. Scamehorn, and Assoc. Prof. Pramoch Rangsunvigit 74 pp. ISBN 974-9651-90-1

Keywords: Froth flotation / Diesel removal / Colloidal gas aphrons

Froth flotation is a surfactant-based separation process suitable for treating dilute oily wastewater. The objective of this work was to investigate the relationship between foam stability that can be enhanced by colloidal gas aphron (CGA) and the efficiency of diesel removal from wastewater by froth flotation technique. Branched alcohol propoxylate sulfate sodium salt (Alfoterra 145-5PO) was used to form microemulsions with diesel oil and froth flotation studies. The formation of CGAs was carried out by studying the effect of stirring speed, stirring time, surfactant concentration and salinity in order to determine suitable conditions for froth flotation experiments. Diesel removal using CGAs is possible to obtain high enrichment ratio and oil removal into the aphron phase at optimum conditions. From the results, the system with 0.1 wt% Alfoterra, 3 wt% NaCl, stirring speed of 5000 rpm, stirring time of 5 min at air flow rate 0.30 L/min gave a high oil removal up to 97.07 %. The CGA enhanced oil removal in the froth flotation operation because of higher foam ability and foam stability.

บทคัดย่อ

ปณิตา อังคธัญกุล : กระบวนการแยกน้ำมันดีเซลออกจากน้ำเสียโดยระบบทำให้ลอย (Diesel Removal from Wastewater by Froth Flotation) อ. ที่ปรึกษา : รศ. ดร. สุเมธ ชวเดช ศ. จอห์น เอฟ สเคม์มีฮอร์น และ รศ. ดร. ปราโมช รังสรรค์วิจิตร 74 หน้า ISBN 974-9651-90-1

กระบวนการทำให้ลอย (froth flotation) เป็นหนึ่งในวิธีกระบวนการแยกสารโดยสารลดแรงตึงผิวซึ่งเหมาะสำหรับบำบัดน้ำเสียที่มีการปนเปื้อนของน้ำมันที่เจือจาง งานวิจัยนี้มีวัตถุประสงค์เพื่อศึกษาความสัมพันธ์ระหว่างความเสถียรของฟองซึ่งทำให้สูงขึ้นได้โดยคอลลอยดอลล์ แก๊สแอฟรอนและประสิทธิภาพของการกำจัดน้ำมันดีเซลออกจากน้ำโดยวิธีกระบวนการทำให้ลอย สารลดแรงตึงผิวแบบ บรานช์ อัลกฮอล์ โพรพรอกซีเลต ซัลเฟต โซเดียม ซอลท์ (Alfoterra 145-5PO) ถูกนำมาใช้ในการศึกษาทดลองการเกิดไมโครอิมัลชั่น และกระบวนการทำให้ลอย ในกระบวนการทำให้เกิดคอลลอยดอลล์ แก๊สแอฟรอนได้ศึกษาปัจจัยของความเร็วในการปั่น ระยะเวลาในการปั่น ความเข้มข้นสารลดแรงตึงผิว และความเค็มเพื่อหาสัดส่วนที่เหมาะสมเพื่อนำไปทดลองต่อในส่วนของกระบวนการทำให้ลอย กำจัดน้ำมันดีเซลออกโดยคอลลอยดอลล์ แก๊สแอฟรอนให้ผลค่าสัดส่วนเอ็นริชเม็นต์ และค่าการกำจัดน้ำมันดีเซลในแอฟรอนเฟสสูงเกิดเมื่อได้สัดส่วนที่เหมาะสม จากผลการทดลอง ระบบที่ความเข้มข้นของบรานช์ อัลกฮอล์ โพรพรอกซีเลต ซัลเฟต โซเดียม ซอลท์ 0.1 เปอร์เซ็นต์, ความเข้มข้นของเกลือ 4 เปอร์เซ็นต์, ระยะเวลาในการปั่น 5000 รอบต่อนาที, ระยะเวลาในการปั่น 5 นาที และอัตราการเป่าอากาศ 0.30 ลิตรต่อนาทีให้ประสิทธิภาพการกำจัดน้ำมันที่สูงที่สุดเท่ากับ 97.07 เปอร์เซนต์ คอลลอยดอลล์ แก๊สแอฟรอนทำให้ประสิทธิภาพการกำจัดน้ำมันสูงขึ้นในกระบวนการทำให้ลอย เนื่องจากความสามารถในการเกิดฟอง และความเสถียรของฟองที่สูงขึ้น

ACKNOWLEDGEMENTS

This work would not have been possible without the assistance of the following individuals and organizations.

First of all, I would like to express my sincere thankfulness to Professor John F. Scamehorn for serving as my US thesis advisor and Assoc. Prof. Sumaeth Chavadej who acted as my Thai thesis advisor for their useful recommendation, creative comment, problem solving and encouragement and support throughout of my work.

My great appreciation is also extended to Assoc. Prof. Pramoch Rungsunvigit who was my co-advisor for his encouragement, vigorous assistance, and kindly useful suggestions.

I am grateful for the partial scholarship and partial funding of the thesis work provided by Postgraduate Education and Research Programs in Petroleum and Petrochemical Technology (PPT Consortium).

I would like to thank Assoc. Prof. Thirasak Rirksomboon and Asst. Prof. Boonyarach Kitiyanan for being my thesis committee.

I would like to thank Ms. Ummarawadee Yanatatsaneejit and Ms. Sunisa Watcharasing who gave me useful information, practical techniques and valuable eaperience as well as making research a fun filled activity throughout of my work.

I would like to extent special thank all of my friends and PPC staffs who contributed in various degrees to the success of my work.

Finally, I would like to express my deepest gratitude to my family for their support, endless encouragement, understanding, and forever love.

TABLE OF CONTENTS

		PAGE
	Title Page	i
	Abstract (in English)	iii
	Abstract (in Thai)	iv
	Acknowledgements	v
	Table of Contents	vi
	List of Tables	ix
	List of Figures	x
CHAPTER		
I	**INTRODUCTION**	1
II	**BACKGROUND AND LITERATURE SURVEY**	3
	2.1 Surfactants	3
	2.2 Microemulsions	4
	2.3 Froth Flotation	7
	2.4 Colloidal Gas Aphrons (CGAs)	10
III	**EXPERIMENTAL**	16
	3.1 Materials	16
	3.1.1 Surfactants	16
	3.1.2 Studied Oil Contaminant	16
	3.1.3 Water	16
	3.1.4 Electrolyte	17
	3.2 Experimental Procedure	17
	3.2.1 Study of Colloidal Gas Aphrons	17
	3.2.2 Froth Flotation Experiments	18
	3.2.3 Foam Ability and Foam Stability Experiments	19

CHAPTER		PAGE
IV	**RESULTS AND DISCUSSION**	20
	4.1 Microemulsion Formation	20
	4.2 Study of Colloidal Gas Aphrons	22
	4.2.1 Effect of Stirring Speed on Performance of CGAs in diesel removal	22
	4.2.2 Effect of Stirring Time on Performance of CGAs in diesel removal	25
	4.2.3 Effect of Surfactant Concentration on Performance of CGAs in diesel removal	28
	4.2.4 Effect of NaCl Concentration on Performance of CGAs in diesel removal	32
	4.3 Froth Flotation Experiments	35
	4.3.1 Effect of Air Flow Rate on Performance of Froth Flotation	36
	4.3.2 Effect of Colloidal Gas Aphrons (CGAs) on Performance of Froth Flotation	42
	4.2.7 Effect of Equilibration time on Performance of Froth Flotation	48
V	**CONCLUSIONS AND RECOMMENDATIONS**	53
	5.1 Conclusions	53
	5.2 Recommendations	54
	REFERENCES	55
	APPENDICES	59
	Appendix A Experimental Data of Microemulsion Formation	59

CHAPTER	PAGE
Appendix B Experimental Data of Colloidal Gas Aphron studies	64
Appendix C Experimental Data of Froth Flotation Experiment	68
Appendix D Experimental Data of Foam ability and Foam stability Experiment	71
CURRICULUM VITAE	74

LIST OF TABLES

TABLE		PAGE
3.1	General properties of studied surfactant	16
3.2	Experimental conditions for CGAs preparation	18

LIST OF FIGURES

FIGURE **PAGE**

2.1 Schematic of surfactant molecule monomer 3

2.2 Schematic diagram for oil-in-water (O/W) and water-in-oil (W/O) microemulsion structures 5

2.3 Demonstration of microemulsion phase behavior for a model system 6

2.4 Schematic diagram of a froth flotation column 8

2.5 Experimental configurations for froth flotation 9

2.6 Structure of CGA proposed by Sebba 11

3.1 Schematic experiment of colloidal gas aphrons in diesel removal 17

3.2 Schematic experiment of froth flotation 19

4.1 I FT as a function of Alfoterra concentration at 3 wt% of NaCl with oil to water ratio = 1:1 (v:v), and 30 °C 21

4.2 Colloidal gas aphron stability at different stirring speed: [Alfoterra] = 0.10 wt%, [NaCl] = 3 wt%, oil:water ratio = 1:19 23

4.3 Gas hold up at different stirring speed: [Alfoterra] = 0.10 wt%, [NaCl] = 3 wt%, oil:water ratio = 1:19 23

4.4 Removal efficiency of diesel oil at different stirring speed: [Alfoterra] = 0.10 wt%, [NaCl] = 3 wt%, oil:water ratio = 1:19 24

4.5 Separation ratio of diesel oil at different stirring speed: [Alfoterra] = 0.10 wt%, [NaCl] = 3 wt%, oil:water ratio = 1:19 24

4.6 Enrichment ratio of diesel oil at different stirring speed: [Alfoterra] = 0.10 wt%, [NaCl] = 3 wt%, oil:water ratio = 1:19 25

FIGURE		PAGE
4.7	Colloidal gas aphron stability at different stirring time: [Alfoterra] = 0.10 wt%, [NaCl] = 3 wt%, oil:water ratio = 1:19, stirring speed = 5000 rpm	26
4.8	Gas hold up at different stirring time: [Alfoterra] = 0.10 wt%, [NaCl] = 3 wt%, oil:water ratio = 1:19, stirring speed = 5000 rpm	26
4.9	Removal efficiency of diesel oil at different stirring time: [Alfoterra] = 0.10 wt%, [NaCl] = 3 wt%, oil:water ratio = 1:19, stirring speed = 5000 rpm	27
4.10	Separation ratio of diesel oil at different stirring time: [Alfoterra] = 0.10 wt%, [NaCl] = 3 wt%, oil:water ratio = 1:19, stirring speed = 5000 rpm	27
4.11	Enrichment ratio of diesel oil at different stirring time: [Alfoterra] = 0.10 wt%, [NaCl] = 3 wt%, oil:water ratio = 1:19, stirring speed = 5000 rpm	28
4.12	Colloidal gas aphron stability at different surfactant concentration: [NaCl] = 3 wt%, oil:water ratio = 1:19, stirring speed = 5000 rpm, stirring time = 5 min	29
4.13	Gas hold up at different surfactant concentration: [NaCi] = 3 wt%, oil:water ratio = 1:19, stirring speed = 5000 rpm, stirring time = 5 min	30
4.14	Removal efficiency of diesel oil at different surfactant concentration: [NaCl] = 3 wt%, stirring speed = 5000 rpm, stirring time = 5 min	30
4.15	Separation ratio of diesel oil at different surfactant concentration: [NaCl] = 3 wt%, stirring speed = 5000 rpm, stirring time = 5 min	31
4.16	Enrichment ratio of diesel oil at different surfactant concentration: [NaCl] = 3 wt%, stirring speed = 5000 rpm, stirring time = 5 min	31

FIGURE PAGE

4.17 Colloidal gas aphron stability at different NaCl concentration: [Alfoterra] = 0.10 wt%, stirring speed = 5000 rpm, stirring time = 5 min 33

4.18 Gas hold up at different NaCl concentration: [Alfoterra] = 0.10 wt%,stirring speed = 5000 rpm, stirring time = 5 min 33

4.19 Removal efficiency of diesel oil at different NaCl concentration: [Alfoterra] = 0.10 wt%, stirring speed = 5000 rpm, stirring time = 5 min 34

4.20 Separation ratio of diesel oil at different NaCl concentration: [Alfoterra] = 0.10 wt%, stirring speed = 5000 rpm, stirring time = 5 min 34

4.21 Enrichment ratio of diesel oil at different NaCl concentration: [Alfoterra] = 0.10 wt%, oil:water ratio = 1:19, stirring speed = 5000 rpm, stirring time = 5 min 35

4.22 Dynamic oil removal efficiency of non-equilibrium system at different air flow rates: [Alfoterra] = 0.10 wt%, [NaCl] =3 wt%, oil:water ratio = 1:19 37

4.23 Total oil removal effici ency of non-equilibrium system at different air flow rates: [Alfoterra] = 0.10 wt%, [NaCl] =3 wt%, oil:water ratio = 1:19 37

4.24 Enrichment ratio of diesel oil in non-equilibrium system at different air flow rates: [Alfoterra] = 0.10 wt%, [NaCl] =3 wt%, oil:water ratio = 1:19 38

4.25 Foam wetn ess of non-equilibrium system at different air flow rates: [Alfoterra] = 0.10 wt%, [NaCl] =3 wt%, oil:water ratio = 1:19 39

FIGURE PAGE

4.26 Foam flow r ate of non-equilibrium system at different air flow rates : [Alfoterra] = 0.10 wt%, [NaCl] =3 wt%, oil:water ratio = 1:19 39

4.27 Total surfactant removal efficiency of non-equilibrium system at different air flow rates: [Alfoterra] = 0.10 wt%, [NaCl] =3 wt%, oil:water ratio = 1:19 40

4.28 Foam ability of non-equilibrium system at different air flow rates: [Alfoterra] = 0.10 wt%, [NaCl] =3 wt%, oil:water ratio = 1:19 41

4.29 Foam stability of non-equilibrium system at different air flow rates: [Alfoterra] = 0.10 wt%, [NaCl] =3 wt%, oil:water ratio = 1:19 41

4.30 Dynamic oil removal efficiency of non-equilibrium system with CGAs: [Alfoterra] = 0.10 wt%, [NaCl] =3 wt%, oil:water ratio = 1:19 43

4.31 Total oil removal effici ency of non-equilibrium system with CGAs: [Alfoterra] = 0.10 wt%, [NaCl] =3 wt%, oil:water ratio = 1:19 43

4.31 The comparison of total oil removal between non-equilibrium system and non-equilibrium system with CGAs: [Alfoterra] = 0.10 wt%, [NaCl] =3 wt%, oil:water ratio = 1:19 44

4.32 The comparison of foam ability between non-equilibrium system and non-equilibrium system with CGAs: [Alfoterra] = 0.10 wt%, [NaCl] =3 wt% 44

4.33 The comparison foam stability between non-equilibrium system and non-equilibrium system with CGAs: [Alfoterra] = 0.10 wt%, [NaCl] =3 wt% 45

FIGURE PAGE

4.35 T he comparison of total surfactant removal between non-equilibrium system and non-equilibrium system with CGAs: [Alfoterra] = 0.10 wt%, [NaCl] =3 wt%, oil:water ratio = 1:19 46
4.36 The comparison of enrichment ratio between non-equilibrium system and non-equilibrium system with CGAs: [Alfoterra] = 0.10 wt%, [NaCl] =3 wt%, oil:water ratio = 1:19 46
4.37 The comparison of foam wetness between non-equilibrium system and non-equilibrium system with CGAs: [Alfoterra] = 0.10 wt%, [NaCl] =3 wt%, oil:water ratio = 1:19 47
4.38 The comparison of foam flow rate between non-equilibrium system and non-equilibrium system with CGAs: [Alfoterra] = 0.10 wt%, [NaCl] =3 wt%, oil:water ratio = 1:19 47
4.39 The comparison of total oil removal at different systems: [Alfoterra] = 0.10 wt%, [NaCl] =3 wt%, oil:water ratio = 1:19 48
4.39 The comparison of total surfactant removal at different systems: [Alfoterra] = 0.10 wt%, [NaCl] =3 wt%, oil:water ratio = 1:19 49
4.40 The comparison of foam flow rate at different systems with CGAs: [Alfoterra] = 0.10 wt%, [NaCl] =3 wt%, oil:water ratio = 1:19 50
4.42 The comparison of foam wetness at different systems with CGAs: [Alfoterra] = 0.10 wt%, [NaCl] =3 wt%, oil:water ratio = 1:19 50
4.43 The comparison of enrichment ratio at different systems with CGAs: [Alfoterra] = 0.10 wt%, [NaCl] =3 wt%, oil:water ratio = 1:19 51

FIGURE **PAGE**

4.43 The comparison of foam ability at different systems with CGAs: [Alfoterra] = 0.10 wt%, [NaCl] =3 wt%, oil:water ratio = 1:19 52

4.44 The comparison of foam stability at different systems with CGAs: [Alfoterra] = 0.10 wt%, [NaCl] =3 wt%, oil:water ratio = 1:19 52