REFERENCES

Boonyasuwat, S., Chavadej, S., Malakul, P., and Scamehorn, J.F. (2003). Anionic and cationic surfactant recovery from water using a multistage foam fractionator. Chemical Engineering journal, 93, 241-252.

Boonyasuwat, S., Chavadej, S., Malakul, P., and Scamehorn, J.F. (2005). Surfactant recovery from water using a multistage foam fractionator: part I effects of air flow rate, foam height, feed flow rate and number of stages. Separation Science and Technology, 40, 1835-1853.

Boonyasuwat, S., Chavadej, S., Malakul, P., and Scamehorn, J.F. (2009). Surfactant recovery from water using a multistage foam fractionator: effects of surfactant type. Separation Science and Technology, 44, 1544-1561.

Bourrel, M. and Schechter, R.S. (1988). Microemulsions and Related Systems. New York: Marcel Dekker.

Carleson, T.E. (1989). Adsorptive Bubble Separation Processes. In Surfactant Based Separation Process; Scamehorn, J.F. and Harwell, J.H. (Eds.) New York: Marcel Dekker.

Chamber, D.J. (1994). Foams for Well Stimulation, In Foam: Fundamentals and Applications in the Petroleum Industry; Schramm L.L. (Ed.) Washington, DC: American Chemica Society.

Chavadej, S., Ratanarojanatam, P., Phoochinda, W., Yanatatsaneejit, U., and Scamehorn, J.F. (2004). Clean-up of oily wastewater by froth flotation: effect of microemulsion formation II: use of anionic/nonionic surfactant mixtures. Separation Science and Technology, 39, 3079-3096.

Chavadej, S., Phoochinda, W., Yanatatsaneejit, U., and Scamehorn, J.F. (2004). Clean-up of oily wastewater by froth flotation: effect of microemulsion formation III: use of anionic/nonionic surfactant mixtures and effect of relative volumes of dissimilar phases. Separation Science and Technology, 39, 3097-3112.

Chungchamroenkit, P., Chavadej, S., Scamehorn, J.F., Yanatatsaneejit, U., and Kitiyanan, B. (2009). Separation of carbon black from silica by froth flotation part 1: effect of operational parameters. Separation Science and Technology, 44, 203-226.

Beneventi, D., Carre, B. and Gandini, A. (2001). Role of surfactant structure on surface and foaming properties. Colloids and surfaces, 189, 65-73.

Femg, D. and Aldrich, C. (2000). Removal of Diesel from Aqueous Emulsions by Flotation. Separation Science and Technology, 35, 2159-2172.

Irwin, R.J., Van Mouwerik, M., Stevens, L., Seese, M.D., and Basham, W. (1997) Environmental Contaminants Encyclopedia. National Park Service, Water Resources Division, Fort Collins, Colorado.

Johnson, N.M. (1986) Assessing the Capabilities of Microbial Degradation of Used Lubricating Oil on Soil, M.S. thesis, University of Illinois Urbana-Champaign.

Kirk-Othmer (1981) Lubrication and Lubricants. In Kirk-Othmer Encyclopedia of Chemical Technology, Booser, E.R. (Ed.) New York: Wiley Interscience.

Pal, R. and Maliyah, J. (1990). Oil Recovery from Oil in Water Emulsions Using Flotation Column. Canadian Journal of Chemical Engineering, 68, 959-967.

Pongstabodee, S., Scamehorn, J.F., Chavadej, S., and Harwell, J.H. (1998). Removal ortho-dichlorobenzene by froth flotation under Winsor's type III conditions. Separation Science and Technology, 33, 591-609.

Prud'homme, R.K. and Khan, S.A. (1996) Foams: Theory, Measurements, and Applications: New York: Marcel Dekker.

Rosen, M.J. (2004) Emulsification by Surfactants. In surfactant and Interfacial Phenomena. 3rd ED., New York: John Wiley and Sons.

Scamehorn, J.F. and Harwell, J.H. (1989). Surfactant-Based Separation Processes. New York: Marcel Dekker.

Scamehorn, J.F. and Harwell, J.H. (2000). In surfactant-Based Separations: Science and Technology. Washington, DC. American Chemical Society.

Schramm, L.L. and Wassmuth, F. (1994). Foams: Basic Principles, In foam: Fundamentals and Applications in the Petroleum Industry; Schramm L.L. (Ed.) Washington, DC: American Chemical Society.

Vartanian, P.F. (1991) The chemistry of Modern Petroleum Product Additives. Journal of Chemical Education, 68, 1015-1020.

Vazquez-Duhalt, R. and Greppin, H. (1986) Biodegradation of Used Oil by Bacteria Promotes the Solubilization of Heavy Metals. The Science of the Total Environment, 52, 109-121.

Watcharasing, S., Angkathunyakul, P., and Chavadej, S. (2008). Diesel oil removal from water by froth flotation under low interfacial tension and colloidal gas aphron condition. Separation and Purification Technology, 62, 118-127.

Watcharasing, S., Chavadej, S. and Scamehorn, J.F. (2008). Diesel oil removal from water by froth flotation under low interfacial tension condition II: Continuous mode of operation. Separation Science and Technology, 43, 2048-2071.

Watcharasing, S., Kongkowit, W., and Chavadej, S. (2009). Motor oil removal from water by continuous froth flotation using extended surfactant: Effects of air bubble parameters and surfactant concentration. Separation and Purification Technology, 70, 179-189.

Wilson, A.J. (1996) Experimental Techniques for the Characterization of foams, In Foam: Theory, Measurements and Application; Prud'homme, R.K. and Khan, S.A. (Eds.) New York: Marcel Dekker.

Winsor, P.A. (1968). Binary and Multicomponent Solutions of Amphiphillic compounds, Solubilization and the Formation, Structure and Theoretical Significance of Liquid Crystalline Solution. Chemical reviews, 68, 1-40

Wungrattanasoporn, P., Chavadej, S., Scamehorn, J.F., Chintana, S., and Harwell, J.H., (1996). Use of foam flotation to remove tert-

Butylphenol from water. <u>Separation Science and Technology</u>, 31(11), 1523-1540.

Yanatatsaneejit, U., Chavadej, S., Rangsunvigit, P., and Scamehorn, J.F. (2005). Ethylbenzene removal by froth flotation under conditions of middle-phase microemulsion formation II: Effects of air flow rate, oil-to-water ratio and equilibration time. <u>Separation Science and Technology</u>, 40, 1609-1620.

Yanatatsaneejit, U., Chavadej, S., and Scamehorn, J.F. (2008). Diesel oil removal by froth flotation under low interfacial tension condition I: foam characteristics and equilibrium time. <u>Separation Science and Technology</u>, 43, 1520-1534.

APPENDICES

Appendix A Experimental Data of Microemulsion Formation

1. Interfacial tension (IFT)

The interfacial tension of each phase of microemulsion is calculated by following formation :

$$IFT = e\,(Vd)^3\,n^2\,\Delta\rho$$

Where
$e = 3.427 \times 10^{-4}$ (mN cm^3 min^2/m g mm^3)

$V = 0.31$ (mm/sdv)

d = measured drop diameter (sdv)

n = number of revolution (rpm)

$\Delta\rho$ = density difference of two liquids (g/cm^3)

2. Experimental data of interfacial tension

Table A1 Interfacial tension as a function of Alfoterra ($C_{14-15}(PO)_4SO_4Na$) concentration at an oil to water volumetric ratio of 1 : 1

Concentration	Top	Bottom	d (nm)	Speed(n) (rpm)	ρ light (g/mL)	ρ heavy (g/mL)	$\Delta\rho$	IFT (mN/m)
1	5.135	1.935	3.2	2031	0.8993	1.0208	0.1215	167.67
2	4.82	2.32	2.5	1972	0.9025	1.0194	0.1169	72.518
3	4.655	2.155	2.5	1845	0.8876	1.0028	0.1152	62.555
4	4.455	2.355	2.1	1907	0.8921	1.006	0.1139	39.163
5	4.475	2.175	2.3	1872	0.8883	1.0089	0.1203	52.367
7	4.755	1.855	2.9	1957	0.8943	1.0126	0.1183	112.813
9	5.105	1.905	3.2	2115	0.8971	1.0126	0.1155	172.84

Appendix B Experimental Data of Froth Flotation Parameters

1. Removal fraction

The removal fraction can be calculated by this equation

$$\text{The removal fraction of oil} = \frac{O_i - O_e}{O_i}$$

Where o_i = oil concentration in the influent steam (mg/l)

    o_e = oil concentration in the effluent steam (mg/l)

for example o_i = 0.5 mg/l, o_e = 0.317 mg/l

so;   The removal fraction of oil $= \dfrac{0.5 - 0.317}{0.5}$

         $= 0.366$

2. Enrichment ratio

The removal fraction can be calculated by this equation

$$\text{The enrichment ratio of oil} = \frac{O_f}{O_i}$$

Where o_i = oil concentration in the influent steam (mg/l)

    o_f = oil concentration in the collapsed foam (mg/l)

for example o_i = 0.5 mg/l, o_f = 0.625 mg/l

so;   The enrichment ratio of oil $= \dfrac{0.625}{0.5}$

         $= 1.25$

3. Surfactant concentration

To find the surfactant concentration by using TOC (total organic carbon) the calibration curve was made.

Table B-1 Total organic carbon's curve for analyze surfactant concentration

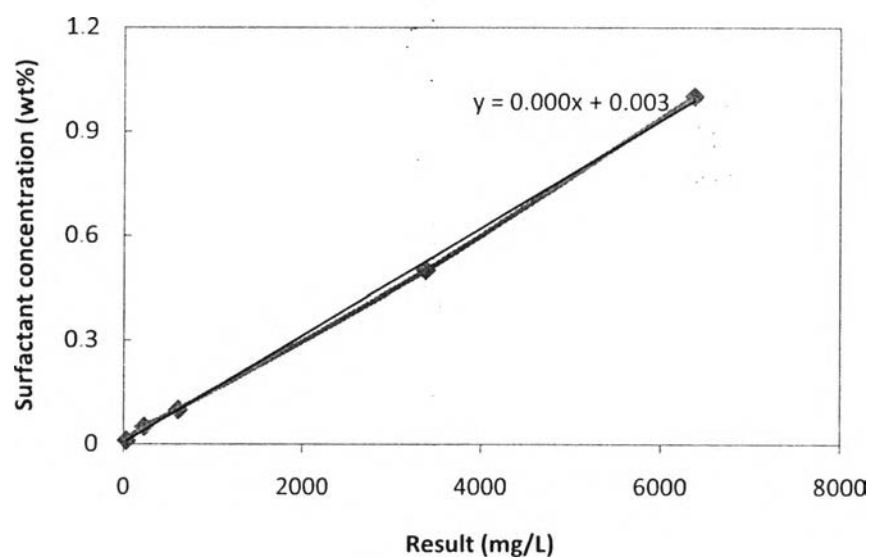| Surfactant concentration (wt%)	Result (mg/L)
0.01	38.54
0.05	231.1
0.1	612
0.5	3378
1	6370

Figure B1 The relationship between the result from TOC (mg/L) and surfactant con centration (wt%).

Equation

$$\text{Surfactant concentration (Y)} = 0.0002X + 0.0038$$

Appendix C Raw Data of Froth Parameter

S_i = surfactant concentration in the influent streams

S_e = surfactant concentration in the effluent streams

S_f = surfactant concentration in the collapsed foam

O_i = oil concentration in the influent streams

O_e = oil concentration in the effluent streams

O_f = oil concentration in the collapsed foam

Table C1 the effect of feed surfactant concentration on separation parameters

Surfactant feed concentration (CMC)	S_i(wt%)	S_e(wt%)	S_f(wt%)	Enrichment ratio	Removal fraction	O_i(ppm)	O_e(ppm)	O_f(ppm)	Enrichment ratio	Removal fraction
3	0.03	0.0116	0.2173	7.243	0.613	500	317	2303	4.604	0.366
5	0.05	0.0176	0.155	3.1	0.648	500	323	1060	2.12	0.354
7	0.07	0.0299	0.136	1.943	0.573	500	277	876	1.752	0.446
10	0.1	0.0473	0.122	1.22	0.527	500	283	580	1.16	0.434

Table C2 the effect of NaCl concentration on separation parameters

NaCl concentration (wt%)	S_i(wt%)	S_e(wt%)	S_f(wt%)	Enrichment ratio	Removal fraction	O_i(ppm)	O_e(ppm)	O_f(ppm)	Enrichment ratio	Removal fraction
0	0.1	0.0457	0.1136	1.136	0.543	500	389	523	1.046	0.222
1	0.1	0.0473	0.122	1.22	0.527	500	283	580	1.16	0.434
2	0.1	0.0465	0.1282	1.282	0.535	500	262	625	1.25	0.476
3	0.1	0.0783	0.1832	1.832	0.217	500	413	797	1.594	0.174

Table C3 the effect of air flow rate on separation parameters

Air flow rate (L/min)	S_i(wt%)	S_e(wt%)	S_l(wt%)	Enrichment ratio	Removal fraction	O_i(ppm)	O_e(ppm)	O_f(ppm)	Enrichment ratio	Removal fraction
30	0.1	0.0442	0.3021	3.021	0.558	500	270	1273	2.546	0.46
50	0.1	0.0465	0.1282	1.282	0.535	500	262	625	1.25	0.476
70	0.1	0.0537	0.103	1.03	0.463	500	327	507	1.014	0.346
100	0.1	0.0653	0.092	0.92	0.347	500	335	502	1.0	0.33

Table C4 the effect of feed flow rate on separation parameters

Feed flow rate (ml/min)	S_i(wt%)	S_e(wt%)	S_f(wt%)	Enrichment ratio	Removal fraction	O_i(ppm)	O_e(ppm)	O_f(ppm)	Enrichment ratio	Removal fraction
30	0.1	0.0526	0.109	1.09	0.473	500	274	490	0.98	0.452
50	0.1	0.0465	0.1282	1.282	0.535	500	262	625	1.25	0.476
70	0.1	0.0481	0.132	1.32	0.519	500	272	635	1.27	0.456
90	0.1	0.0473	0.138	1.38	0.527	500	278	615	1.23	0.444

CURRICULUM VITAE

Name: Mr. Krit Thaiteerasathean

Date of Birth: April 28, 1986

Nationality: Thai

University Education:

    2004-2004   Bachelor Degree of Chemical Engineering, Faculty of Engineering, King Mongkul Institution of Technology, Ladkrabang, Thailand

Work Experience:

    2007   Position: Internship Student

                               Company name: SriThai Superware CO., LTD.

                               Chonburi, Thailand

Proceedings:

1. Thaiteerasathean, K., and Chavadej, S. (2011, April 26) Motor Oil Removal by Multistage Froth Flotation. Proceedings of The 2nd Research Symposium on Petroleum, Petrochemicals, and Advanced Materials and The 17th PPC Symposium on Petroleum, Petrochemicals, and Polymers, Bangkok, Thailand