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APPENDICES

Appendix A Critical Micelle Concentration (CMC) Measurement

1. Critical Micelle Concentration (CMC)

Table A1 Critical micelle concentration (CMC) of $C_{14-15}H_{29-31}-(PO)_8-SO_4Na$ with 4.6 %w/v NaCl at 30 °C

No.	8PO Conc. (μM)	Surface Tension (mN/m)			
		1st	2nd	3rd	Ave.
1	0.02	63.7	66.4	66.1	66.3
2	0.04	66.9	66.7	66.7	66.8
3	0.06	59.5	61	61.5	60.7
4	0.08	63.5	62.3	62.4	62.4
6	0.4	50.3	50.4	50.4	50.4
7	0.5	47.1	46.2	46.7	46.7
8	0.7	45.7	46.6	46.2	46.2
9	2	37.7	37.7	37.7	37.7
10	4	33.5	33.4	33.3	33.4
11	20	34.6	34.0	34.3	34.3
12	60	30.6	30.8	30.8	30.7
13	80	30.1	30.2	30.2	30.2

Table A2 Critical micelle concentration (CMC) of $C_{14-15}H_{29-31}-(PO)_8-SO_4Na$ without NaCl added at 30 °C

No.	8PO Conc. (μM)	Surface Tension (mN/m)			
		1st	2nd	3rd	Ave.
1	4	47.3	47.4	47.3	47.3
2	8	40.8	40.8	40.8	40.8
3	10	39	39	39	39.0
4	20	35.4	35.4	35.4	35.4
5	40	34.7	34.7	34.7	34.7
6	60	34.5	34.6	34.4	34.5
7	100	34.4	34.4	34.4	34.4
8	200	33.9	33.7	33.6	33.7
9	400	33.8	33.8	33.6	33.7
10	600	33.4	33.5	33.5	33.5

Table A3 Critical micelle concentration (CMC) of $C_{12-14}H_{25-29}-(EO)_3-OH$ without NaCl added at 30 °C

No.	3EO Conc. (μM)	Surface Tension (mN/m)			
		1st	2nd	3rd	Ave.
1	4	48.5	48.5	48.5	48.5
2	6	42.4	41.9	41.7	42.0
3	8	39.4	38.8	38.5	38.9
4	10	36.5	35.9	35.6	36.0
5	20	31.1	31.6	31.6	31.4
6	40	29.6	29.4	29.7	29.6
7	60	28.6	28.8	29	28.8
8	200	27.1	27.5	27.3	27.3
9	400	26.8	26.7	26.9	26.8
10	600	26.6	26.5	26.8	26.6

Table A4 Critical Micelle Concentration (CMC) of $C_{12-14}H_{25-29}-(EO)_5-OH$ without NaCl added at 30 °C

No.	5EO Conc. (μM)	Surface Tension (mN/m)			
		1st	2nd	3rd	Ave.
1	4	53.6	53.8	53.7	53.7
2	6	50.5	49.8	50.2	50.2
3	8	47.5	47.4	46.8	47.2
4	10	44.3	43.5	43.1	43.6
5	20	36.2	37	36.5	36.6
6	40	31.6	32.2	32.1	32.0
7	60	29.9	30.4	30.7	30.3
8	200	29	29.2	29.1	29.1
9	400	28.9	28.9	28.9	28.9
10	600	28.8	29	28.9	28.9

Table A5 Critical micelle concentration (CMC) of $C_{12-14}H_{25-29}-(EO)_9-OH$ without NaCl added at 30 °C

No.	9EO Conc. (μM)	Surface Tension (mN/m)			
		1st	2nd	3rd	Ave.
1	4	55.6	56.3	55.9	55.9
2	8	50	50	50	50.0
3	10	47.3	47.4	47.4	47.4
4	20	39.8	40.1	40.2	40.0
5	40	34.9	34.9	34.9	34.9
6	60	33.5	33.7	33.7	33.6
7	80	33.5	33.5	33.5	33.5
8	100	33.5	33.5	33.5	33.5
9	200	33	33	33	33.0
10	400	33.2	33.2	33.2	33.2
11	600	33.2	33.2	33.2	33.2

Table A6 Critical micelle concentration (CMC) of mixed surfactant system by 1:1 molar ratio with 4.6 %w/v NaCl at 30 °C

No.	Total Conc. (μM)	Surface Tension (mN/m)			
		1st	2nd	3rd	Ave.
1	0.2	73.9	73.9	73.9	73.9
2	0.4	63.1	62.5	63.1	62.9
3	0.6	58.9	58.2	58.1	58.4
4	0.8	57.4	56.5	57.2	57.0
5	2	46.9	47.9	47.5	47.4
6	4	43.3	42.3	42.6	42.7
7	6	37.9	40.9	38	38.9
8	8	30.6	34.3	34.2	34.3
9	20	33.3	32.9	32.7	33.0
10	40	31.9	31.8	31.8	31.8

Table A7 Critical micelle concentration (CMC) of mixed surfactant system by 1:1 molar ratio without NaCl added at 30 °C

No.	Total Conc. (μM)	Surface Tension (mN/m)			
		1st	2nd	3rd	Ave.
1	0.2	74.1	74.4	74.2	74.2
2	0.4	71.7	71.6	70.8	70.8
3	0.6	68.1	68	68.1	68.1
4	0.8	66	66.1	66.1	66.1
5	2	55.9	56	55.7	55.9
6	4	50	49.9	49.2	49.2
8	8	40.9	42.4	41	41.0
9	20	35.7	35.8	35.8	35.8
10	40	32.8	32.5	32.7	32.7
11	60	31.7	31.7	31.7	31.7
12	80	31.4	31.5	31.5	31.5
13	100	31.4	31.4	31.4	31.4

Table A8 Critical micelle concentration (CMC) of mixed surfactant system by 1:0.1 molar ratio with 4.6 %w/v NaCl added at 30 °C

No.	Total Conc. (μM)	Surface Tension (mN/m)			
		1st	2nd	3rd	Ave.
1	0.2	65.4	65.9	65.9	65.7
2	0.4	61.9	61.9	61.9	61.9
3	0.6	58	58.4	58.2	58.2
4	0.8	55.2	54.9	55.2	55.1
5	2	45.8	45.8	45.8	45.8
6	4	54.7	54.7	54.7	54.7
7	6	47.7	47.7	47.7	47.7
8	8	39.3	39.3	39.3	39.3
9	20	39.2	39.2	29.2	39.2
10	40	37.5	37.2	37.4	37.4

Appendix B Hydrophilic-Lipophilic Balance (HLB) Calculation

1. Hydrophilic-Lipophilic Balance (HLB)

1.1 Anionic Surfactant

To calculate HLB value of anionic surfactant (Rosen, 2012) using Equation B.1

$$\begin{aligned} \text{HLB} &= 7 + \sum(\# \text{ hydrophilic groups}) - \sum(\# \text{ hydrophobic groups}) \\ &= 7 + [(\text{Sulfate}) + (\# \text{EO})] - [(\# \text{CH}_3) + (\# \text{PO})] \end{aligned} \quad (\text{B.1})$$

Remark Sulfate = 38.7; -CH₃, -CH₂ = 0.475; EO = 0.33; PO = 0.15

1.2 Nonionic Surfactant

To calculate HLB value of nonionic surfactant (Rosen, 2012) using Equation B.2

$$\text{HLB} = 20 \times \frac{\text{Molecular mass of hydrophilic}}{\text{Molecular mass}} \quad (\text{B.2})$$

Table B1 Hydrophilic-Lipophilic Balance (HLB) of each surfactant

Surfactant Type	Chemical Structure	HLB Value
Anionic Extended	C ₁₄₋₁₅ H ₂₉₋₃₁ -(PO) ₈ -SO ₄ Na	37.6
Nonionic	C ₁₂₋₁₄ H ₂₅₋₂₉ -(EO) ₃ -OH	8.0
	C ₁₂₋₁₄ H ₂₅₋₂₉ -(EO) ₅ -OH	10.5
	C ₁₂₋₁₄ H ₂₅₋₂₉ -(EO) ₉ -OH	13.3

Appendix C Effective Area Per Molecule (A_s) Calculation

1. Surface Area Per Molecule (A_s)

Table C1 Surface area per molecule A_s of each surfactant system

Surfactant Type	Chemical Structure	Slope (dx/dlogC)	Γ (mol/1000m ²)	Surface Area Per Molecule ^c (°A ²)
Single Systems				
anionic extended	C ₁₄₋₁₅ H ₂₉₋₃₁ -(PO) ₈ -SO ₄ Na/ 4.6%w/v NaCl ^a	-7.33	6.32E-11	262.96
		-6.51	1.12E-10	148.04
nonionic	C ₁₂₋₁₄ H ₂₅₋₂₉ -(EO) ₃ -OH ^b	-11.7	2.02E-10	82.37
	C ₁₂₋₁₄ H ₂₅₋₂₉ -(EO) ₅ -OH ^b	-11.3	1.95E-10	85.29
	C ₁₂₋₁₄ H ₂₅₋₂₉ -(EO) ₉ -OH ^b	-9.41	1.62E-10	102.42
Mixed Surfactant Systems				
1:1	C ₁₄₋₁₅ H ₂₉₋₃₁ -(PO) ₈ -SO ₄ Na/	-20	1.72E-11	96.37
1:1	C ₁₂₋₁₄ H ₂₅₋₂₉ -(EO) ₃ -OH/	-11.2	1.93E-10	86.05
1:0.1	4.6%w/v NaCl ^a	-7.37	1.27E-10	130.76

^aCalculate based on Equation 2.2

^bCalculate based on Equation 2.3

^cCalculate based on Equation 2.4

Appendix D Dynamic Interfacial Tension (IFT) Measurement

1. Dynamic Interfacial Tension (IFT)

Table D1 Dynamic interfacial tension (IFT) of $C_{14,15}H_{29,31}-(PO)_8-SO_4Na$ with different NaCl concentration after 20 min at 30 °C

NaCl Concentration (%w/v)	Measuring Time (20 mins)			
	1st	2nd	3rd	Ave.
0	1.7762	1.776	1.776	1.7761
2	0.1413	0.1412	0.1413	0.1413
4	0.0986	0.0986	0.0986	0.0986
4.2	0.0861	0.0861	0.0861	0.0861
4.4	0.0401	0.0400	0.0401	0.0401
4.6	0.0250	0.0250	0.0250	0.0250
4.8	0.0325	0.0324	0.0325	0.0325
5	0.1698	0.1697	0.1698	0.1698
7	0.2598	0.2599	0.2597	0.2598

Table D2 Dynamic interfacial tension (IFT) of $C_{12-14}H_{25-29}-(EO)_n-OH$ with different EO groups after 20 min at 30 °C

#EO	Measuring Time (20 mins)			
	1st	2nd	3rd	Ave.
3	2.1800	2.2769	2.2284	2.2284
5	0.9700	0.9700	0.9700	0.9700
9	0.5369	0.5368	0.5369	0.5369

Table D3 Dynamic interfacial tension (IFT) of mixed surfactant system (1:1 by molar ratio) after 20 min at 30 °C

NaCl Concentration (%w/v)	Measuring Time (20 mins)			
	1st	2nd	3rd	Ave.
0	0.8482	0.8481	0.8482	0.8482
4.6	0.0240	0.0239	0.0240	0.0240

Table D4 Dynamic interfacial tension (IFT) of mixed surfactant system (1:0.1 by molar ratio) after 20 min at 30 °C

NaCl Concentration (%w/v)	Measuring Time (20 mins)			
	1st	2nd	3rd	Ave.
0	1.4129	1.4549	1.434	1.4339
4.6	0.0229	0.0229	0.0228	0.0229

Appendix E Palm Stearin Solubilization Capacity Calculation

1. Palm Stearin Removal and Solubility

Table E1 Palm stearin removal with different operated time

Operated Time (hr)	No.	Surfactant Concentration (μM)	Sample Concentration (%)	Ave. % Semi-Solid Fat Removal	SD
		Initial Concentration	1.18425		
			1.11701		
			1.20218		
12	1.1	50000	0.68755	8.32	0.27
	1.2		0.88296		
	1.3		0.93302		
24	2.1	50000	0.93341	13.90	2.13
	2.2		0.8006		
	2.3		0.83662		
48	3.1	50000	0.72949	19.24	1.57
	3.2		0.75387		
	3.3		0.75596		
72	4.1	50000	0.57405	35.07	0.82
	4.2		0.56902		
	4.3		0.55516		
96	5.1	50000	0.4398	32.91	0.27
	5.2		0.59416		
	5.3		0.58955		

Table E2 Palm stearin removal with different NaCl concentrations

NaCl Concentration (%w/v)	No.	Surfactant Concentration (μM)	Sample Concentration (%)	Ave. % Semi-Solid Fat Removal	SD
0	1.1	50000	0.88362	7.72	1.03
	1.2		0.86236		
	1.3		0.90108		
2	2.1	50000	0.74605	20.52	0.75
	2.2		0.73336		
	2.3		0.74125		
4	3.1	50000	0.6898	24.65	0.07
	3.2		0.6757		
	3.3		0.69101		
4.6	4.1	50000	0.56902	35.07	0.82
	4.2		0.57405		
	4.4		0.55516		
5	5.1	50000	0.47503	42.26	0.62
	5.2		0.4855		
	5.3		0.50195		
7	6.1	50000	0.48641	41.77	0.04
	6.2		0.48559		
	6.3		0.48634		

Table E3 Palm stearin removal with different EO groups in nonionic surfactant $[\text{C}_{12-14}\text{H}_{25-29}(\text{EO})_n\text{-OH}]$

#EO group	No.	Surfactant Concentration (μM)	Sample Concentration (%)	Ave. % Semi-Solid Fat Removal	SD
3	1.1	50000	0.32603	59.59	0.20
	1.2		0.27514		
	1.3		0.27184		
5	2.1	50000	0.66709	49.56	4.20
	2.2		0.4286		
	2.3		0.35779		
9	3.1	50000	0.73364	20.09	1.32
	3.2		0.75587		
	3.3		0.68084		

Table E4 Palm stearin removal with different surfactant molar ratios

Surfactant System	No.	Surfactant Concentration (μM)	Sample Concentration (%)	Ave. % Semi-Solid Fat Removal	SD
1:0.1/ 4.6 %NaCl	1.1	50000	0.50751	43.21	0.57
	1.2		0.46415		
	1.3		0.4738		
1:0.1	2.1	50000	0.8258	12.49	1.14
	2.2		0.84509		
	2.3		0.9482		
1:1/ 4.6 %NaCl	3.1	50000	0.25548	61.57	0.41
	3.2		0.24714		
	3.3		0.24678		
1:1	4.1	50000	0.50569	39.79	0.48
	4.2		0.51376		
	4.3		0.46475		

Table E5 Palm stearin removal with different surfactant $[\text{C}_{14-15}\text{H}_{29-31}-(\text{PO})_8-\text{SO}_4\text{Na}]$ concentrations

No.	Surfactant Concentration (μM)	Sample Concentration (%)	Ave. % Semi-Solid Fat Removal	SD
1.1	0.4	0.81109	10.68	0.02
1.2		0.85728		
1.3		0.85691		
2.1	0.8	0.84434	12.30	0.78
2.2		0.83123		
2.3		0.78929		
3.1	20	0.85222	14.12	0.99
3.2		0.86896		
3.3		0.82335		
4.1	200	0.8512	10.27	0.10
4.2		0.80565		
4.3		0.8529		
5.1	2000	0.82518	11.10	1.37
5.2		0.7842		
5.3		0.76108		

Table E5 Palm stearin removal with different surfactant [C₁₄₋₁₅H₂₉₋₃₁-(PO)₈-SO₄Na] concentrations (continued)

No.	Surfactant Concentration (μM)	Sample Concentration (%)	Ave. % Semi-Solid Fat Removal	SD
6.1	10000	0.81861	17.76	0.50
6.2		0.73848		
6.3		0.74687		
7.1	15000	0.77071	21.51	2.20
7.2		0.73657		
7.3		0.71912		
8.1	18000	0.66314	27.62	1.07
8.2		0.64017		
8.3		0.6615		
9.1	20000	0.76289	24.40	0.93
9.2		0.70127		
9.3		0.68556		
10.2	50000	0.56902	35.07	0.82
10.1		0.57405		
10.2		0.55516		

Table E6 Palm stearin removal with different surfactant [C₁₄₋₁₅H₂₉₋₃₁-(PO)₈-SO₄Na/C₁₂₋₁₄H₂₅₋₂₉-(EO)₃-OH] concentrations of 1:1 by molar ratio

No.	Surfactant Concentration (μM)	Sample Concentration (%)	Ave. % Semi-Solid Fat Removal	SD
1.1	0.4	0.89656	8.31	1.32
1.2		0.87424		
1.3		0.9624		
2.1	0.8	1.05104	7.86	0.96
2.2		0.8826		
2.3		0.89886		
3.1	20	0.89425	-17.49	
3.2		0.81776		
3.3		0.88971		
4.1	200	0.86023	10.42	0.00
4.2		0.91079		
4.3		0.8602		

Table E6 Palm stearin removal with different surfactant [$C_{14,15}H_{29,31}-(PO)_8-SO_4Na/C_{12-14}H_{25-29}-(EO)_3-OH$] concentrations of 1:1 by molar ratio (continued)

No.	Surfactant Concentration (μM)	Sample Concentration (%)	Ave. % Semi-Solid Fat Removal	SD
5.1	2000	0.54925	27.06	0.65
5.2		0.77399		
5.3		0.78489		
6.1	3200	0.61749	31.49	1.04
6.2		0.6		
6.3		0.6893		
7.1	8000	0.35959	45.21	12.91
7.2		0.5305		
7.3		0.66693		
8.1	10000	0.43006	50.19	0.13
8.2		0.38559		
8.3		0.43222		
9.1	12000	0.33133	55.23	0.68
9.2		0.31979		
9.3		0.59707		
10.2	20000	0.30241	56.84	0.64
10.1		0.31499		
10.2		0.30132		

Table E7 Palm stearin removal with different surfactant [$C_{14,15}H_{29,31}-(PO)_8-SO_4Na/C_{12-14}H_{25-29}-(EO)_3-OH$] concentrations of 1:0.1 by molar ratio

No.	Surfactant Concentration (μM)	Sample Concentration (%)	Ave. % Semi-Solid Fat Removal	SD
1.1	0.4	0.882	8.39	0.28
1.2		0.103589		
1.3		0.88677		
2.1	0.8	0.99454	8.19	0.52
2.2		0.89116		
2.3		0.88235		
3.1	20	0.89771	7.33	0.08
3.2		0.89631		
3.3		0.86297		

Table E7 Palm stearin removal with different surfactant [$C_{14-15}H_{29-31}-(PO)_8-SO_4Na$ and $C_{12-14}H_{25-29}-(EO)_3-OH$] concentrations of 1:0.1 by molar ratio (continued)

No.	Surfactant Concentration (μM)	Sample Concentration (%)	Ave. % Semi-Solid Fat Removal	SD
4.1	200	0.75565	7.92	1.51
4.2		0.90279		
4.3		0.87726		
5.1	2000	0.63075	28.13	2.14
5.2		0.72835		
5.3		0.6669		
6.1	5000	0.51447	40.24	1.20
6.2		0.49417		
6.3		0.44907		
7.1	10000	0.35736	42.72	0.95
7.2		0.48276		
7.3		0.46678		
8.1	20000	0.34477	26.43	0.31
8.2		0.28782		
8.3		0.34998		

Table E8 Palm stearin solubility of different surfactant [$C_{14-15}H_{29-31}-(PO)_8-SO_4Na$] concentrations with 4.6 %w/v NaCl

No.	Surfactant Concentration (M)	Sample Concentration (%)	Solubility (mg/L)	Ave. Solubility (M)
	water	0.99281	2004.05	0.0025
		0.97616	2170.55	
		0.9845	2553.05	
1.1	0.002	0.82518	3680.35	0.0025
1.2		0.7842	4090.15	
1.3		0.76108	4321.35	
2.1	0.01	0.81861	3746.05	0.0029
2.2		0.73848	4547.35	
2.3		0.74687	4463.45	
3.1	0.015	0.77071	4225.05	0.0031
3.2		0.73657	4566.45	
3.3		0.71912	4740.95	
4.1	0.02	0.76289	4303.25	0.0035
4.2		0.70127	4919.45	
4.3		0.68556	5076.55	

Table E9 Palm stearin solubility of different surfactant [$C_{14-15}H_{29-31}-(PO)_8-SO_4Na$ and $C_{12-14}H_{25-29}-(EO)_3-OH$] concentrations of 1:1 by molar ratio with 4.6 %w/v NaCl

No.	Surfactant Concentration (M)	Sample Concentration (%)	Solubility (mg/L)	Ave. Solubility (M)
1.1	0.002	0.54925	6439.65	0.0039
1.2		0.77399	4192.25	
1.3		0.78489	4083.25	
2.1	0.0032	0.61749	5757.25	0.0045
2.2		0.6	5932.15	
2.3		0.6893	5039.15	
3.1	0.01	0.43006	7631.55	0.0072
3.2		0.38559	8076.25	
3.3		0.43222	7609.95	
4.1	0.012	0.33133	8618.85	0.0079
4.2		0.31979	8734.25	
4.3		0.59707	5961.45	

Table E10 Palm stearin solubility of different surfactant [$C_{14-15}H_{29-31}-(PO)_8-SO_4Na$ and $C_{12-14}H_{25-29}-(EO)_3-OH$] concentrations of 1:0.1 by molar ratio with 4.6 %w/v NaCl

No.	Surfactant Concentration (M)	Sample Concentration (%)	Solubility (mg/L)	Ave. Solubility (M)
1.1	0.002	0.63075	5624.65	0.0040
1.2		0.72835	4648.65	
1.3		0.6669	5263.15	
2.1	0.008	0.30901	8842.05	0.0050
2.2		0.49233	7008.85	
2.3		0.53251	6607.05	
3.1	0.01	0.35736	8358.55	0.0061
3.2		0.48276	7104.55	
3.3		0.46678	7264.35	
4.1	0.02	0.34477	8484.45	0.0076
4.2		0.28782	9053.95	
4.3		0.34998	8432.35	

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