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## APPENDIX

### Surface Tension of SDS Solution with Various Concentrations of Added Salts at 25 °C to 27 °C

**Table A1** Surface tension of SDS solution with various concentrations of added NaCl at 25 °C to 27 °C

Initial SDS concentration (mM)	Surface tension (mN/m)			
	[NaCl]* = 5 mM	[NaCl] = 10 mM	[NaCl] = 18 mM	[NaCl] = 25 mM
0.04	71.23	69.9		
0.06	70.44	69.85	68.79	67.93
0.08			67.53	66.87
0.10	69.84	68.3	67.05	65.57
0.15	-	-	65.02	63.23
0.20	67.56	65.45	62.95	60.82
0.28	-	-	60.19	58.15
0.40	64.2	60.35	57.44	54.77
0.60	60.4	56.58	53.75	50.97
0.70	58.75	54.88	51.99	
0.80	57.65	53.73	50.14	47.52
0.90	56.36	52.24	-	-
1.0	55.13	51.36	48.05	44.49
1.4	-	47.64	44.1	40.91
1.5	50.6	-	-	-
1.6	-	45.65	-	-
1.7	-	-	41.87	38.43
2.0	47.5	43.22	39.31	36.09
2.5	-	-	36.51	34.16
3.0	41.44	37.34	33.92	33.97
3.5	-	35.09	-	-
4.0	34.8	34.15	33.85	34.02
5.0	-	33.41	33.78	33.7

\*Note [NaCl] stands for added NaCl concentration.



**Table A2** Surface tension of SDS solution with added  $\text{Cd}(\text{NO}_3)_2$  concentration of 10 mg/L and various concentrations of added NaCl at 25 °C to 27 °C

Initial SDS concentration (mM)	Surface tension (mN/m)			
	[NaCl]* = 5 mM	[NaCl] = 10 mM	[NaCl] = 18 mM	[NaCl] = 25 mM
0.04	70.55	69.04	-	-
0.06	69.99	68.07	68.85	67.70
0.08	-	-	67.79	66.34
0.10	68.34	66.50	66.91	65.41
0.15	-	-	64.45	62.62
0.20	64.35	63.10	62.48	60.31
0.28	-	-	59.72	56.66
0.40	59.08	57.00	56.55	53.87
0.60	55.03	54.01	52.32	50.02
0.70	53.08	52.04	-	-
0.80	51.26	50.50	49.51	46.68
0.90	50.10	49.07	-	-
1.0	49.20	47.50	47.03	43.97
1.4	-	-	43.06	40.39
1.7	-	-	40.67	37.90
2.0	42.06	39.32	38.07	35.91
2.5	-	-	35.55	33.65
3.0	36.79	33.29	34.47	33.55
4.0	32.89	32.23	34.35	33.45
5.0	33.05	32.23	-	-

\*Note [NaCl] stands for added NaCl concentration.

**Table A3** Surface tension of SDS solution with various concentrations of added  $\text{NaNO}_3$  at 25 °C to 27 °C

Initial SDS concentration (mM)	Surface tension (mN/m)			
	$[\text{NaNO}_3]^* = 5$ mM	$[\text{NaNO}_3] = 10$ mM	$[\text{NaNO}_3] = 18$ mM	$[\text{NaNO}_3] = 25$ mM
0.06	69.85	68.92	68.69	68.46
0.08	69.45	68.3	67.81	67.32
0.10	68.69	66.98	66.7	66.42
0.15	67.87	65.82	64.79	63.76
0.20	66.57	64.32	62.84	61.7
0.28	65.09	62.26	60.84	58.74
0.40	63.11	59.69	57.77	55.67
0.60	60.36	56.05	53.96	51.86
0.70	58.5	54.43	51.63	49.53
0.80	57.29	53.42	50.35	48.25
1.0	54.35	50.71	47.67	45.57
1.4	51.05	47.41	43.67	41.57
1.7	48.9	44.8	41.04	38.94
2.0	46.8	42.6	38.72	36.62
2.5	43.15	39.11	36.745	34.38
3.0	40.49	35.88	35.19	34.5
4.0	36.3	33.45	33.925	34.4
5.0	33.31	33.32	33.81	34.3
6.0	33.2	33.4	33.96	34.52
10.0	33.32	33.28	-	-

\*Note  $[\text{NaNO}_3]$  stands for added  $\text{NaNO}_3$  concentration.

**Table A4** Surface tension of SDS solution with added  $\text{Cd}(\text{NO}_3)_2$  concentration of 10 mg/L and various concentrations of added  $\text{NaNO}_3$  at 25 °C to 27 °C

Initial SDS concentration (mM)	Surface tension (mN/m)			
	$[\text{NaNO}_3]^* = 5$ mM	$[\text{NaNO}_3] = 10$ mM	$[\text{NaNO}_3] = 18$ mM	$[\text{NaNO}_3] = 25$ mM
0.06	69.94	69.87	69.13	68.38
0.08	68.74	68.74	67.91	67.07
0.10	67.74	67.56	66.93	66.29
0.15	65.56	64.91	63.89	62.87
0.20	63.44	62.52	61.56	60.60
0.28	61.14	59.98	59.00	58.01
0.40	58.12	56.80	55.61	54.42
0.60	54.06	52.84	51.68	50.51
0.70	52.15	50.64	49.62	48.60
0.80	51.10	49.03	48.07	47.10
1.0	48.62	46.29	45.47	44.65
1.4	45.15	43.17	41.68	40.19
1.7	42.12	40.53	38.74	36.94
2.0	40.09	38.42	36.87	35.31
2.5	37.07	36.20	34.66	33.11
3.0	34.47	33.49	33.35	33.20
4.0	33.15	33.15	33.15	33.15
5.0	33.20	33.20	33.20	33.20
6.0	33.25	33.25	33.23	33.21

\*Note  $[\text{NaNO}_3]$  stands for added  $\text{NaNO}_3$  concentration.

**Table A5** Surface tension of SDS solution with various concentrations of added  $\text{Na}_2\text{SO}_4$  at 25 °C to 27 °C

Initial SDS concentration (mM)	Surface tension (mN/m)		
	$[\text{Na}_2\text{SO}_4]^* = 1$ mM	$[\text{Na}_2\text{SO}_4] = 5$ mM	$[\text{Na}_2\text{SO}_4] = 10$ mM
0.06	71.40	-	68.70
0.08	71.18	68.73	67.42
0.10	70.97	68.59	66.30
0.15	70.49	66.90	64.50
0.20	70.38	65.37	62.73
0.28	69.24	63.53	59.98
0.40	68.05	60.34	56.80
0.60	64.60	57.05	52.92
0.70	-	55.44	51.43
0.80	62.40	54.15	49.64
1.00	60.18	51.47	47.10
1.40	56.02	47.86	42.89
1.70	53.65	45.29	40.62
2.00	51.60	43.29	38.39
2.48	47.32	40.65	34.53
3.00	44.00	37.49	33.24
4.00	38.88	34.07	33.24
5.00	35.29	34.26	33.32
6.00	34.26	34.12	33.34
7.00	34.26	34.20	-

\*Note  $[\text{Na}_2\text{SO}_4]$  stands for added  $\text{Na}_2\text{SO}_4$  concentration.

**Table A6** Surface tension of SDS solution with added  $\text{Cd}(\text{NO}_3)_2$  concentration of 10 mg/L and various concentrations of added  $\text{Na}_2\text{SO}_4$  at 25 °C to 27 °C

Initial SDS concentration (mM)	Surface tension (mN/m)		
	$[\text{Na}_2\text{SO}_4]^* = 1$ mM	$[\text{Na}_2\text{SO}_4] = 5$ mM	$[\text{Na}_2\text{SO}_4] = 10$ mM
0.06	70.38	68.42	68.29
0.08	69.43	68.01	66.46
0.10	69.04	67.10	66.00
0.15	67.30	65.40	63.75
0.20	64.97	62.88	61.66
0.25	63.60	-	-
0.28	-	60.25	59.07
0.40	59.77	57.30	55.64
0.50	57.38	-	-
0.60	55.06	53.60	51.65
0.70	53.35	51.88	49.62
0.80	52.05	50.43	48.44
0.90	50.51	-	-
1.00	49.13	48.11	45.92
1.40	-	44.17	41.39
1.70	-	41.58	39.06
2.00	41.20	39.40	36.15
2.48	-	36.60	33.61
3.00	34.84	34.30	33.43
4.00	33.29	33.30	33.24
5.00	33.32	33.32	33.32
6.00	33.39	33.39	33.34
7.00	33.26	-	-

\*Note  $[\text{Na}_2\text{SO}_4]$  stands for added  $\text{Na}_2\text{SO}_4$  concentration.

**Table A7** Surface tension of SDS solution with various concentrations of added  $\text{KNO}_3$  at 25 °C to 27 °C

Initial SDS concentration (mM)	Surface tension (mN/m)			
	$[\text{KNO}_3]^* = 5$ mM	$[\text{KNO}_3] = 10$ mM	$[\text{KNO}_3] = 15$ mM	$[\text{KNO}_3] = 20$ mM
0.06	-	70.60	70.00	70.50
0.08	-	69.40	68.60	69.10
0.10	69.80	68.50	67.20	67.00
0.15	68.20	66.20	64.30	62.62
0.20	66.60	64.60	61.40	60.50
0.28	64.60	62.50	58.10	57.90
0.40	62.10	59.10	54.30	54.10
0.60	58.80	54.50	49.40	48.50
0.70	56.60	52.50	47.30	46.30
0.80	55.60	50.60	45.40	43.90
1.00	53.20	47.90	42.60	41.40
1.40	49.40	43.50	38.60	-
1.70	46.20	40.90	37.30	-
2.00	43.10	38.40	-	-
2.48	40.10	36.70	-	-
3.00	37.10	-	-	-

**\*Note**  $[\text{KNO}_3]$  stands for added  $\text{KNO}_3$  concentration.

**Table A8** Surface tension of SDS solution with added  $\text{Cd}(\text{NO}_3)_2$  concentration of 10 mg/L and various concentrations of added  $\text{KNO}_3$  at 25 °C to 27 °C

Initial SDS concentration (mM)	Surface tension (mN/m)			
	$[\text{KNO}_3]^* = 5$ mM	$[\text{KNO}_3] = 10$ mM	$[\text{KNO}_3] = 15$ mM	$[\text{KNO}_3] = 20$ mM
0.06	71.50	70.90	70.20	69.80
0.08	70.30	69.60	68.80	68.40
0.10	69.30	68.70	66.70	66.30
0.15	66.70	65.50	62.50	62.70
0.20	64.40	63.40	59.90	60.20
0.28	60.80	59.60	56.50	57.40
0.40	57.50	55.40	52.70	53.50
0.60	53.70	51.00	48.50	48.30
0.70	51.50	49.20	46.20	45.80
0.80	50.10	47.60	44.30	43.60
1.00	47.40	44.70	41.40	40.70
1.40	42.90	39.60	36.80	-
1.70	40.40	37.50	35.70	-
2.00	37.90	35.60	-	-
2.48	35.20	-	-	-
3.00	32.50	-	-	-

\*Note  $[\text{KNO}_3]$  stands for added  $\text{KNO}_3$  concentration.

**Table A9** Surface tension of SDS solution with various concentrations of added  $\text{Mg}(\text{NO}_3)_2$  at 25 °C to 27 °C

Initial SDS concentration (mM)	Surface tension (mN/m)		
	$[\text{Mg}(\text{NO}_3)_2]^* = 0.1 \text{ mM}$	$[\text{Mg}(\text{NO}_3)_2] = 0.25 \text{ mM}$	$[\text{Mg}(\text{NO}_3)_2] = 0.5 \text{ mM}$
0.06	71.60	70.00	69.80
0.08	71.00	69.00	68.40
0.10	69.80	67.90	66.90
0.15	68.00	65.60	63.90
0.20	65.50	63.20	60.90
0.28	63.40	60.70	58.20
0.40	60.40	57.40	54.70
0.60	56.70	53.30	50.50
0.70	54.60	51.80	48.60
0.80	53.50	50.40	47.10
1.00	51.30	47.70	44.70
1.40	47.30	44.00	40.80
1.70	44.70	41.50	38.50
2.00	42.70	39.30	36.40
2.48	40.20	37.00	34.50
3.00	37.30	34.70	-
4.00	34.40	-	-

\*Note  $[\text{Mg}(\text{NO}_3)_2]$  stands for added  $\text{Mg}(\text{NO}_3)_2$  concentration.



**Table A10** Surface tension of SDS solution with added  $\text{Cd}(\text{NO}_3)_2$  concentration of 10 mg/L and various concentrations of added  $\text{Mg}(\text{NO}_3)_2$  at 25 °C to 27 °C

Initial SDS concentration (mM)	Surface tension (mN/m)		
	$[\text{Mg}(\text{NO}_3)_2]^* = 0.1 \text{ mM}$	$[\text{Mg}(\text{NO}_3)_2] = 0.25 \text{ mM}$	$[\text{Mg}(\text{NO}_3)_2] = 0.5 \text{ mM}$
0.06	72.00	69.80	69.30
0.08	71.00	69.30	67.50
0.10	69.80	68.00	66.00
0.15	67.00	65.00	63.40
0.20	63.50	63.10	60.00
0.28	60.60	59.70	57.00
0.40	57.60	56.40	54.00
0.60	53.60	51.90	50.00
0.70	51.70	50.70	48.50
0.80	50.50	48.90	46.80
1.00	48.00	46.60	44.20
1.40	44.00	42.50	40.10
1.70	41.70	39.60	38.00
2.00	40.00	37.60	35.90
2.48	37.30	34.70	34.40
3.00	35.50	34.70	-
4.00	33.50	-	-

\*Note  $[\text{Mg}(\text{NO}_3)_2]$  stands for added  $\text{Mg}(\text{NO}_3)_2$  concentration.

**Table A11** Surface tension of SDS solution with various concentrations of added  $\text{Ca}(\text{NO}_3)_2$  at 25 °C to 27 °C

Initial SDS concentration (mM)	Surface tension (mN/m)	
	$[\text{Ca}(\text{NO}_3)_2]^* = 0.1 \text{ mM}$	$[\text{Ca}(\text{NO}_3)_2] = 0.25 \text{ mM}$
0.08	71.10	-
0.10	70.00	67.20
0.15	66.70	63.20
0.20	64.80	60.50
0.28	61.70	57.60
0.40	58.80	53.70
0.60	54.60	50.20
0.70	53.00	47.92
0.80	51.60	46.50
1.00	49.00	44.00
1.40	46.00	40.90
1.70	43.70	-
2.00	42.00	-

\***Note**  $[\text{Ca}(\text{NO}_3)_2]$  stands for added  $\text{Ca}(\text{NO}_3)_2$  concentration.

**Table A12** Surface tension of SDS solution with added  $\text{Cd}(\text{NO}_3)_2$  concentration of 10 mg/L and various concentrations of added  $\text{Ca}(\text{NO}_3)_2$  at 25 °C to 27 °C

Initial SDS concentration (mM)	Surface tension (mN/m)	
	$[\text{Ca}(\text{NO}_3)_2]^* = 0.1 \text{ mM}$	$[\text{Ca}(\text{NO}_3)_2] = 0.25 \text{ mM}$
0.08	69.40	-
0.10	67.90	66.90
0.15	64.80	63.00
0.20	63.00	59.80
0.28	60.00	57.08
0.40	55.80	53.95
0.60	52.80	49.50
0.70	51.00	47.20
0.80	49.80	45.90
1.00	47.40	43.50
1.40	43.40	40.20
1.70	41.70	-
2.00	38.80	-

\*Note  $[\text{Ca}(\text{NO}_3)_2]$  stands for added  $\text{Ca}(\text{NO}_3)_2$  concentration.

## CURRICULUM VITAE

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**Publications:**

1. Rujirawanich, V.; Chavadej, S.; O'Haver, J. H.; and Rujiravanit, R. (2010). Removal of trace  $Cd^{2+}$  using continuous multistage ion foam fractionation: Part I—The effect of feed SDS/Cd molar ratio. *Journal of Hazardous Materials*, 182(1-3), 812-819.
2. Rujirawanich, V.; Chavadej, S.; O'Haver, J. H.; and Rujiravanit, R. (2011). Removal of trace  $Cd^{2+}$  using continuous multistage ion foam fractionation: Part II—The effects of operational parameters. (Manuscript accepted for publication in *Separation Science and Technology*).
3. Rujirawanich, V.; Chavadej, S.; O'Haver, J. H.; and Rujiravanit, R. (2011). Removal of trace  $Cd^{2+}$  using continuous multistage ion foam fractionation: Effect of salt addition. (Manuscript submitted to *Colloid and Surface A: Physicochemical and Engineering Aspects*).
4. Rujirawanich, V.; Chuyingsakultip, N.; Triroj, M.; Malakul, P.; and Chavadej, S. (2011). Recovery of Surfactant from an Aqueous Solution Using Continuous Multistage Foam Fractionation: Influence of Design Parameters. (Manuscript submitted to *Chemical Engineering and Processing*)
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**Presentations:**

1. Rujirawanich, V.; Soonsinpai, K.; Chavadej, S.; and O'Haver, J. H. (2008, August 19-20) Recovery of surfactants from water using multistage foam fractionation: Effects of surfactant structure and salinity. Paper presented at The Thai-Japan Joint Symposium on Advances in Materials Science and Environmental Technology, Bangkok, Thailand.
2. Rujirawanich, V.; Chavadej, S.; and O'Haver, J. H. (2009, May 3-6) Simultaneous recovery of trace heavy metals and surfactants using multi-stage foam fractionation. Paper presented at 100<sup>th</sup> AOCS Annual Meeting & Expo, Orlando, USA.
3. Rujirawanich, V.; Chavadej, S.; O'Haver, J. H.; and Rujiravanit, R. (2009, October 11-14) The effect of anions on removal efficiency of trace Cd<sup>2+</sup> and SDS using continuous multi-stage ion foam fractionation. Paper presented at The 3<sup>rd</sup> Asian Conference on Colloid and Interface Science, Jeju Island, South Korea.
4. Rujirawanich, V.; Chavadej, S.; O'Haver, J. H.; and Rujiravanit, R. (2010, April 1-3) Removal of trace Cd<sup>2+</sup> using continuous multi-stage ion foam fractionation. Paper presented at The 11<sup>st</sup> RGJ-Ph.D. Congress, Pattaya, Thailand.
5. Rujirawanich, V.; Chavadej, S.; O'Haver, J. H.; and Rujiravanit, R. (2010, May 16-19) The effect of salts addition on separation efficiency of trace Cd<sup>2+</sup> using continuous multi-stage ion foam fractionation. Paper presented at 101<sup>th</sup> AOCS Annual Meeting & Expo, Phoenix, USA.