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APPENDICES

Appendix A Experimental Data of Biodegradation of Hydrocarbons in Oil Sludge by Nonionic Surfactant.

1. Experimental Data of Effect of oil loading rate $0.5 \text{ kg/m}^3\text{d}$ and $1.0 \text{ kg/m}^3\text{d}$ by Nonionic Surfactant.

1.1 COD Analyzer

Table A-1 Effect of oil loading rate $1.0 \text{ kg/m}^3\text{d}$ by nonionic surfactant concentration $0.1\% \text{ w/v}$

Day	COD Influent (mg/L)	COD Effluent (mg/L)	% Removal
0	2697	531.0	80.31
1	2697	446.0	83.46
3	2697	442.5	83.59
4	2697	512.0	81.02
6	2697	455.5	83.11
7	2697	465.0	82.76
9	2697	514.5	80.92
10	2697	473.5	82.44
11	2697	577.5	78.59
12	2697	560.5	79.22
13	2697	591.5	78.07
14	2697	567.5	78.96
15	2697	574.0	78.72
17	2697	605.0	77.57
Average	2697	579.3	78.52

Table A-2 Effect of oil loading rate $0.5 \text{ kg/m}^3\text{d}$ by nonionic surfactant concentration $0.1\% \text{ w/v}$

Day	COD Influent (mg/L)	COD Effluent (mg/L)	% Removal
1	-	1710	-
2	-	1740	-
3	-	1610	-
4	-	1520	-
5	-	1660	-
6	-	1360	-
7	-	1350	-
8	-	790	-
9	-	960	-
10	2850	1270	55.44
11	2720	1160	57.35
12	2620	1380	47.33
13	2180	1390	55.96
14	2550	1140	55.29
15	2380	1160	51.26
16	2370	1140	51.90
Average	2524.29	1146.67	53.51

1.2 TOC Analyzer

Table A-3 Effect of oil loading rate $1.0 \text{ kg/m}^3\text{d}$ by nonionic surfactant concentration $0.1\% \text{ w/v}$.

Day	TOC Influent (mg/L)	TOC Effluent (mg/L)	% Removal
0	1531.67	303.4	80.19
1	1531.67	181.7	88.14
3	1531.67	187.3	87.77
4	1531.67	184.4	87.96
6	1531.67	297.5	80.58
7	1531.67	315.9	79.38
9	1531.67	391.7	74.43
10	1531.67	365.4	76.15
11	1531.67	395.1	74.21
12	1531.67	431.2	71.85
13	1531.67	435.5	71.57
14	1531.67	433.1	71.72
15	1531.67	431.1	71.85
17	1531.67	432.7	71.75
Average	1531.67	426.43	72.16

Table A-4 Effect of oil loading rate $0.5 \text{ kg/m}^3\text{d}$ by nonionic surfactant concentration $0.1\% \text{ w/v}$.

Day	TOC Influent (mg/L)	TOC Effluent (mg/L)	% Removal
1	-	1002.0	-
2	-	1102.0	-
3	-	1102.0	-
4	-	1049.0	-
5	-	1080.0	-
6	-	1011.0	-
7	-	1142.0	-
8	-	891.1	-
9	-	1183.0	-
10	1508.9	1091.0	27.70
11	1322.0	838.7	36.56
12	1643.8	878.9	46.53
13	1540.1	888.0	42.34
14	1459.1	873.0	40.17
15	1414.0	875.1	38.11
16	1455.0	862.8	40.70
Average	1477.6	869.4	40.74

1.3 TPH Degradation

Table A-5 Effect of oil loading rate 1.0 kg/m³d by nonionic surfactant concentration 0.1% w/v.

Day	TPH Influent (mg/L)	TPH Effluent (mg/L)	% Removal
0	2358.3	1481.67	37.17
1	2358.3	1112.50	52.83
3	2358.3	963.34	59.15
4	2358.3	665.00	71.80
6	2358.3	468.84	80.12
7	2358.3	710.00	69.89
9	2358.3	743.34	68.48
10	2358.3	755.00	67.99
12	2358.3	715.00	69.68
14	2358.3	750.00	68.20
Average	2358.3	734.67	68.85

Table A-6 Effect of oil loading rate 0.5 kg/m³d by nonionic surfactant concentration 0.1% w/v.

Day	TPH Influent (mg/L)	TPH Effluent (mg/L)	% Removal
12	-	1210.00	-
13	-	1580.00	-
14	3476.67	1356.67	60.98
15	3056.67	1236.67	59.54
16	3336.67	1290.00	61.34
Average	3290.00	1294.44	60.62

1.4 Dry Weight Cell Method

Table A-7 Effect of oil loading rate $1.0 \text{ kg/m}^3\text{d}$ by nonionic surfactant concentration 0.1% w/v.

Day	Average Dry weight cell (mg/L)
0	505
3	760
4	785
6	753
7	898
9	925
10	1098
12	1103
14	1153
17	1128

Table A-8 Effect of oil loading rate 0.5 and $1.0 \text{ kg/m}^3\text{d}$ by nonionic surfactant concentration 0.1% w/v.

Day	Dry weight cell of $0.5 \text{ kg/m}^3\text{d}$ (mg/L)	Dry weight cell of $1.0 \text{ kg/m}^3\text{d}$ (mg/L)
14	4940	1110
15	4810	1260
16	4770	1290
Average	4840	1220

2. Experimental Data of Effect of Number of Cycle per Day at oil loading rate 1.0 kg/m³d by Nonionic Surfactant concentration 0.1% w/v.

Table A-9 Effect of 2 cycles per day on biodegradation at oil loading rate 1.0 kg/m³d by nonionic surfactant concentration 0.1% w/v.

Day	Cycle	COD (mg/L)		TOC (mg/L)		TPH (mg/L)		Dry weight cell (mg/L)	% COD	% COD	% TOC	% TOC	% TPH	% TPH
		Influent	Effluent	Influent	Effluent	Influent	Effluent		removal	Average	removal	Average	removal	Average
1	1	4620	1430	3626	1049.0	-	-		69.05	69.72	71.07	69.18	-	-
	2	4830	1430	3170	1037.0	-	-	-	70.39		67.29		-	-
2	1	4710	1700	2923	634.1	-	-		63.91	64.84	78.31	71.73	-	-
	2	5640	1930	2328	811.0	-	-	-	65.78		65.16		-	-
3	1	5010	1780	2962	933.5	-	-		64.47	63.65	68.48	64.86	-	-
	2	5030	1870	2835	1099.0	-	-	-	62.82		61.23		-	-
4	1	5090	1400	2815	1140.0	-	-		72.50	73.38	59.50	56.61	-	-
	2	5130	1320	2580	1194.0	-	-	-	74.27		53.72		-	-
5	1	5050	1160	2331	757.2	4173.33	2193.33		77.03	74.83	67.52	66.38	47.44	46.42
	2	5080	1390	2256	784.0	4206.67	2296.67	3850	72.64		65.25		45.40	
6	1	5120	1300	2069	790.0	4233.33	2283.33		74.61	74.78	61.82	61.56	46.06	46.04
	2	5070	1270	2033	786.9	4723.33	2550.00	3690	74.95		61.29		46.01	
7	1	5110	1310	2110	791.0	4226.67	2116.67		74.36	74.49	62.51	61.92	49.92	48.71
	2	5080	1290	2051	793.1	4386.67	2303.33	3730	74.61		61.33		47.49	
Average		5091.25	1305.00	2280.63	879.53	4325.00	2290.56	3756.67	74.37		61.62		47.06	

Table A-10 Effect of 3 cycles per day on biodegradation at oil loading rate 1.0 kg/m³d by nonionic surfactant concentration 0.1% w/v.

Day	Cycle	COD (mg/L)		TOC (mg/L)		TPH (mg/L)		Dry weight cell (mg/L)	% COD removal	% TOC removal	% TPH removal
		Influent	Effluent	Influent	(mg/L)	Influent	Effluent				
1	1	3590	760	1466	755.9	-	-	-	78.83	69.52	-
	2	3350	1410	1632	780.2	-	-		57.91	61.18	-
	3	2980	1150	1501	704.7	-	-		61.41	67.36	-
2	1	3070	1500	1793	650	-	-	-	51.14	69.77	-
	2	3730	1210	1588	789.5	-	-		67.56	61.53	-
	3	3700	1480	1690	441.4	-	-		60.00	78.57	-
3	1	3660	1470	1610	578.7	-	-	-	59.84	71.70	-
	2	3600	1410	1899	632.8	-	-		60.83	69.28	-
	3	3480	1400	1537	774.5	-	-		59.77	62.26	-
4	1	3340	1390	1929	749.9	-	-	-	58.38	61.12	-
	2	3710	1380	1891	878.8	-	-		62.80	53.53	-
	3	3390	1400	2106	858.7	-	-		58.70	59.23	-
5	1	3710	1400	2480	878.5	4666.67	1930.00	2120	62.26	64.58	58.64
	2	3660	1410	2010	818.5				61.48	59.28	
	3	3710	1420	2159	869.4				61.73	59.73	
6	1	3720	1440	2150	878.3	4870.00	1970.00	2050	61.29	59.15	59.55
	2	3760	1420	2052	821.9				62.23	59.95	
	3	3780	1450	2060	823.3				61.64	60.03	
7	1	3820	1440	2045	804.5	4700.00	1723.33	2180	62.30	60.66	63.33
	2	3760	1420	2060	775.8				62.23	62.34	
	3	3740	1430	2052	831.7				61.76	59.47	
Average		3675.00	1416.67	2082.83	832.44	4745.56	1874.44	2116.67	61.40	59.92	60.51

3. Enhanced Solubilization of Hydrocarbons in Oil Sludge by Nonionic Surfactant

3.1 Effect of the Enhanced-Solubilization of Hydrocarbons at the Various Concentrations and the Weight of Solubilized Carbon to Weight of Surfactant Ratio.

Table A-11 Enhanced-Solubilization of Hydrocarbons at the Various Concentrations and the Weight of Solubilized Carbon to Weight of Surfactant Ratio

[SFT],%	TOC (mg/L)		Enhanced Solubilization (mg/L)	Wt C _{suf} (g)	Wt C / Wt SFT Ratio
	SFT	Oil + SFT			
0	0	35.08	35.08	0	0
0.05	439.2	594.8	155.6	0.0156	9.974
0.1	933.5	1895.0	961.5	0.0223	43.117
0.2	1621.0	5676.0	4055.0	0.0404	100.371
0.5	4081.0	9861.0	5780.0	0.1056	54.735
1.0	9128.0	16680.0	7552.0	0.2004	37.685
5.0	46340.0	54960.0	8620.0	1.0027	8.597

C = Carbon, SFT = Nonionic surfactant, O = Oil sludge, Wt = Weight (g or mg)

3.2 Determination of Contact Time Required for Solubilization of Oil Sludge by Nonionic Surfactant System

Table A-12 Contact Time Required for Solubilization of Oil Sludge by Nonionic Surfactant System

Day	TOC SFT (mg/L)	TOC Oil (mg/L)	TOC Oil+SFT (mg/L)	Enhanced Solubilization (mg/L)
1	913.3	43.69	1091.0	134.01
2	937.9	36.08	1400.0	426.02
3	928.1	46.81	1524.0	549.09
4	931.0	39.89	1633.0	662.11
5	912.8	39.75	1620.0	667.45
6	910.6	40.89	1627.0	675.51
7	928.5	47.86	1642.0	665.64

4. Experimental Data of Effect of Number of Cycle per Day at oil loading rate 1.0 kg/m³d by Nonionic Surfactant concentration 0.2% w/v.

Table A-13 Effect of 1 cycles per day on biodegradation at oil loading rate 1.0 kg/m³d by nonionic surfactant concentration 0.1% w/v.

Day	COD (mg/L)		TOC (mg/L)		TPH (mg/L)		Dry weight cell (mg/L)	% COD removal	% TOC removal	% TPH removal
	Influent	Effluent	Influent	Effluent	Influent	Effluent				
1	4570	1110	2113	755.4	-	-	-	75.71	64.25	-
2	4710	1010	2248	731.8	-	-	-	78.56	67.45	-
3	4470	730	2931	775.2	-	-	-	83.67	73.55	-
4	4850	950	3129	882.8	-	-	-	80.41	71.79	-
5	4830	930	3162	894.8	5810.00	686.67	2100	80.75	71.70	88.18
6	4850	920	3213	891.4	5103.33	663.33	2080	81.03	72.26	87.00
7	4860	940	3139	889.1	5066.67	646.67	2260	80.66	71.68	87.24
Average	4847.5	935	3160.75	889.53	5326.67	665.56	2146.67	80.71	71.86	87.47

Table A-14 Effect of 2 cycles per day on biodegradation at oil loading rate 1.0 kg/m³d by nonionic surfactant concentration 0.1% w/v.

Day	Cycle	COD (mg/L)		TOC (mg/L)		TPH (mg/L)		Dry weight cell (mg/L)	% COD removal	% TOC removal	% TPH removal
		Influent	Effluent	Influent	Effluent	Influent	Effluent				
1	1	2340	1650	1726	1390.0	-	-	-	29.49	15.90	-
	2	2690	1630	1408	1349.0	-	-	-	39.41	3.19	-
2	1	2930	1840	1535	1279.0	-	-	-	37.20	16.68	-
	2	2940	1660	1786	1318.0	-	-	-	43.54	26.20	-
3	1	2450	1650	2113	1498.0	-	-	-	32.65	29.11	-
	2	2880	1400	1852	1219.0	-	-	-	51.39	13.42	-
4	1	4270	1010	2281	964.2	-	-	-	76.35	57.73	-
	2	4080	970	2288	813.0	-	-	-	76.23	64.47	-
5	1	3800	880	2430	851.5	-	-	-	76.84	64.96	-
	2	3780	970	2727	893.2	11430.00	1516.67	3290	74.34	67.25	86.73
6	1	3940	890	3017	815.8	-	-	-	77.41	72.96	-
	2	4050	910	2650	854.1	10080.00	1790.00	3340	77.53	67.77	82.24
7	1	3950	940	2628	805.6	-	-	-	76.20	69.35	-
	2	4020	980	2782	854.9	11776.67	1376.67	3560	75.62	69.27	88.31
Average		3986.25	943.75	2029.25	634.39	11095.56	1561.11	3396.67	76.31	66.72	85.76

Table A-15 Effect of 3 cycles per day on biodegradation at oil loading rate 1.0 kg/m³d by nonionic surfactant concentration 0.1% w/v.

Day	Cycle	COD (mg/L)		TOC (mg/L)		TPH (mg/L)		Dry Weight Cell (mg/L)	% COD removal	% TOC removal	% TPH removal
		Influent	Effluent	Influent	Effluent	Influent	Effluent				
1	1	1440	1460	1202	1401				-1.39	-16.56	
	2	1610	860	1883	1332	-	-	-	46.58	29.26	-
	3	2320	1830	1358	1272				21.12	6.33	
2	1	3070	2040	1859	1379				33.55	25.82	
	2	1860	1550	1405	1344	-	-	-	16.67	4.34	-
	3	2150	1920	1441	1338				10.70	7.15	
3	1	2720	1560	2035	1387				42.65	31.84	
	2	3900	1850	2262	1473	-	-	-	52.56	34.88	-
	3	2510	1690	2478	1298				32.67	47.62	
4	1	3080	1540	2695	1295				50.00	51.95	
	2	3260	1560	2017	1292	-	-	-	52.15	35.94	-
	3	3140	1580	2075	1264				49.68	39.08	
5	1	2910	1570	2029	1324				46.05	34.75	
	2	3690	1510	2520	1277	14986.67	2560.00	3540	59.08	49.33	82.92
	3	3860	1530	2358	1310				60.36	44.44	
6	1	3720	1570	2388	1392				57.80	41.71	
	2	3700	1540	2254	1361	15056.67	2460.00	3790	58.38	39.62	83.66
	3	4240	1560	2664	1350				63.21	49.32	
7	1	3720	1510	2269	1260				59.41	44.47	
	2	3680	1560	2287	1231	15003.33	2533.33	3850	57.61	46.17	83.11
	3	3830	1550	2342	1244				59.53	46.88	
Average		3569.17	1548.33	2324.83	1300.00	15015.56	2517.78	3726.67	56.10	43.64	83.23

5. The F/M ratio of the various SBR operations in the presence of Tween 80 concentration 0.2%w/v.

Table A-16 The F/M ratio of the various SBR operation in the presence of Tween 80 concentration 0.2%w/v

Day	F/M ratio		
	1 cycle	2 cycles	3 cycles
4	0.0908	0.0469	0.0215
5	0.0908	0.0422	0.0262
6	0.0915	0.0456	0.0313
7	0.0913	0.0445	0.0296
Average	0.0911	0.0448	0.0271

$$\text{F/M ratio} = \frac{(\text{COD}_{\text{in}} - \text{COD}_{\text{out}}) \times \text{Flowrate}}{\text{Amount of bacteria} \times \text{Volume of aeration tank}}$$

Flowrate = 0.05 Liter/Day

Amount of bacteria = 1,000 mg/L

Volume of aeration tank = 1 Liter

6. Yield of Bacteria and Yield of TPH Degradation

Table A-17 Yield of Bacteria and Yield of TPH Degradation at various cycles of SBR operation

Day	1 cycle			2 cycles			3 cycles		
	TPH degradation	yield of bacteria	yield of TPH	TPH degradation	yield of bacteria	yield of TPH	TPH degradation	yield of bacteria	yield of TPH
5	5123.33	0.4099	2.4397	9913.33	0.3319	3.0132	14986.67	0.2362	4.2335
6	4440.00	0.4685	2.1346	8290.00	0.4029	2.4820	12596.67	0.3009	3.3237
7	4420.00	0.5113	1.9558	10400.00	0.3423	2.9213	12470.00	0.3087	3.2390
Average	4661.11	0.4605	2.1713	9534.44	0.3590	2.8055	13351.11	0.2819	3.5987

Appendix B Analytical Method.

1. Enhanced Solubilization

$$= (\text{Solubilization}_{\text{oil+surf.}} - \text{Solubilization}_{\text{surf}}) - \text{Solubilization}_{\text{control}}$$

where Surf = Surfactant

2. % Enhanced Solubilization

$$= (\text{Enhanced solubilization} \times 100) / \text{Solubilization}_{\text{control}}$$

3. TPH Degradation

$$= \text{TPH}_{\text{control}} - \text{TPH}_d$$

Where TPH = Total Petroleum Hydrocarbon

d = Day 1 to Day7

4. % TPH Degradation

$$= (\text{TPH degradation} \times 100) / \text{TPH}_{\text{control}}$$

5. Yield of Bacteria

$$= \text{Dry weight cell} / \text{TPH degradation}$$

6. Rate of TPH Degradation

$$= \text{TPH degradation} / 7 \text{ days}$$

$$= \text{TPH degradation} / (7 \text{ days} \times \text{dry weight cell})$$

7. F/M Ratio

$$= \frac{(\text{COD}_{\text{in}} - \text{COD}_{\text{out}}) \times \text{Flowrate}}{\text{Amount of bacteria} \times \text{Volume of aeration tank}}$$

Amount of bacteria x Volume of aeration tank

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