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APPENDICES

Appendix A – Calculation

Calculation A-1 How to Calculate the Volume of Total Gas at Room Conditions to be the Volume at STP

The data obtained from the experiments were the volume of total gas(V_1).

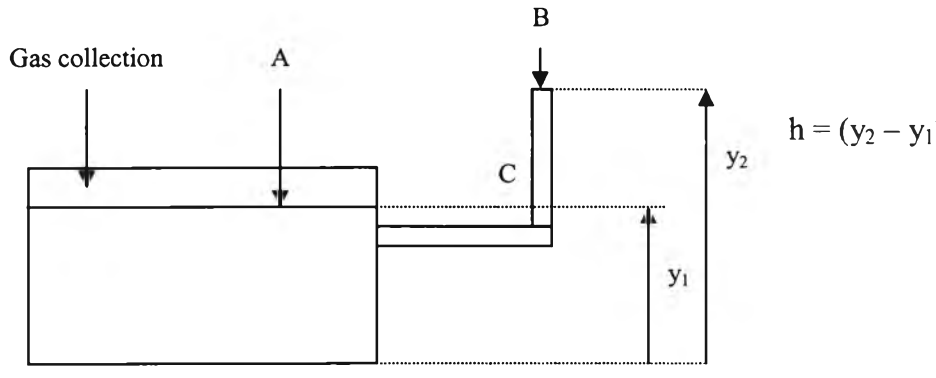


Figure A-1 The gas collecting system

From the raw data obtained from the experiments, the y_1 and y_2 were measured and shown in **Table A-1.**

The average value of y_2-y_1 was 8.5 cm

The average room temperature was 31.5 ^{0}C (273.15+31.5=304.65 K).

Where $h = y_2 - y_1$

$= 8.5 \times 10^{-2}$ m

From FigureA-1, P_A was determined.

Since $P_A = P_C$

$P_A = P_B + \rho gh$

where $P_B = 1.013 \times 10^5$ N/m^2

$\rho = 1000$ kg/m^3

$g = 9.8$ m/s^2

$h = 8.5 \times 10^{-2}$m

$P_A = 101{,}300$ N/m^2+(1000 kg/m^{3}x 9.8m/sec^2 x 8.5x10^{-2}m)

$P_A = 101{,}300 + 833$ N/m^2

$P_A = 102{,}133$

From

$$\frac{P_1V_1}{T_1} = \frac{P_2V_2}{T_2}$$

$$V_2 = \frac{P_1 V_1 T_2}{P_2 T_1}$$

Where,

P_1 = pressure at room temperature(102,182.0N/m^2)

P_2 = pressure at STP (101,300 N/m^2)

T_1 = room temperature (304.65 K)

T_2 = temperature at STP (273.15 K)

V_1 = volume of gas at room temperature (ml)

V_2 = volume of gas at STP (ml)

P_1 is P_A

Thus, $V_2 = \frac{102133 \times V_1 \times 273.15}{101300 \times 304.65}$

$V_2 = 0.9044\ V_1$ (ml)

For this study (in chapter IV),

Volume of gas at STP (ml) = 0.9044 x Volume of total gas (obtained from the experiments at room temperature in ml)

Calculation A-2 How to Calculate the SO_4^{2-} Reduction Rate in the Unit of SO_4^{2-} reduced/ g MLVSS-day.

Data from Table G-1 were used in this calculation. The average MLVSS for all reactors was 9645 mg/l (Table G-5).

For the reactor that contained the COD:S 13.7 (SO_4^{2-} = 700 mg/l),

SO_4^{2-} reduction rate in the first 72 hours (3 days) = $\frac{(700\text{-}324)\ mg/l}{9.645\ g\ MLVSS\ /l \times 3\ days}$

= 13.0 mg SO_4^{2-} reduced/g MLVSS.day

The same calculation was performed for other data.

For the reactor that contained the COD:S 4.5 (SO_4^{2-} = 2,100 mg/l),

SO_4^{2-} reduction rate in the last 48 hours (2 days) = (1956-207) mg/l

9.645 g MLVSS /l x 2 days

= 90.7 mg SO_4^{2-} reduced/g MLVSS.day

For the reactor that contained the COD:S 3.7 (SO_4^{2-} = 2,600 mg/l),

SO_4^{2-} reduction rate in the last 48 hours (2 days) = (2667-1167) mg/l

9.645 g MLVSS /l x 2 days

= 77.8 mg SO_4^{2-} reduced/g MLVSS.day

Appendix A-3 How to Calculate the Amount of CH_4 production.

At the optimum COD:S of 9.

CH_4 produced was 54.1 ml/100 ml of working volume, expressed at STP (Data from Table G-4).

COD removed = (3200 - 445) mg/l (Data from Table 5.1)

= 2755 mg/1000 ml

= 275.5 mg/100 ml (The reactor volume was 100 ml.)

CH_4 produced/COD removed = (54.1 ml / 100 ml) / (275.5 mg/100 ml)

= 0.196 ml/mg

= 196 ml CH_4 produced/ g COD removed

Appendix A-4 How to Calculate the Amount of SO_4^{2-} reduction.

At the optimum COD:S of 9.

SO_4^{2-} reduced was (1100-118) mg/l (Data from Table 5.1).

= 982 mg/l

= 98.2 mg/100 ml

COD removed = (3200 - 445) mg/l (Data from Table 5.1)

= 2755 mg/1000 ml

= 275.5 mg/100 ml (The reactor volume was 100 ml.)

SO_4^{2-} reduced/g COD removed = (98.2 mg/100 ml) / (275.5 mg/100 ml)

= 0.356 g SO_4^{2-} reduced / g COD removed

Appendix A-5 How to Calculate the Specific Methanogenic Activity (SMA).

At the optimum COD:S of 9.

CH_4 produced was 54.1 ml/100 ml of working volume, expressed at STP (Data from Tables G-4 or G-8). So, CH_4 produced was 541 ml/l or $(541 \times 10^{-3})/22.4$ = 0.0245 mol/l at STP or 0.0245 x 16 =0.3864 g/l or 386.4 mg/l

CH_4 gas COD (mg/l) = CH_4 (mg/l) at STP x 4

(The conversion factor to change mg CH_4 to CH_4 gas-COD is 4 (mgCOD/mgCH_4) Section 5.3.3).

Thus, CH_4 gas COD (mg/l) = 386.4 x 4 = 1546 mg CH_4 gas COD /l

SMA (g CH_4 gas COD/g MLVSS) = (1546 mg CH_4 gas COD / l) / (9645 mg MLVSS/l)

= 0.1602 mg CH_4 gas COD/ mg MLVSS

= 0.1602 g CH_4 gas COD/ g MLVSS

Since, the COD that was removed from the system at this condition was 3200-445 mg/l = 2755 mg/l or 275.5 mg (in the reactor volume of 100 ml). That was the COD removal from the system was 0.2755 g

SMA (g CH_4 gas COD/g MLVSS/ gCOD removal)

= 0.1602 g CH_4 gas COD/ g MLVSS /0.2755 g COD removal

= 0.5815 g CH_4 gas COD/ g MLVSS . g COD removal

Appendix B

Photos of the Experiments

Figure B-1 Seed acclimation

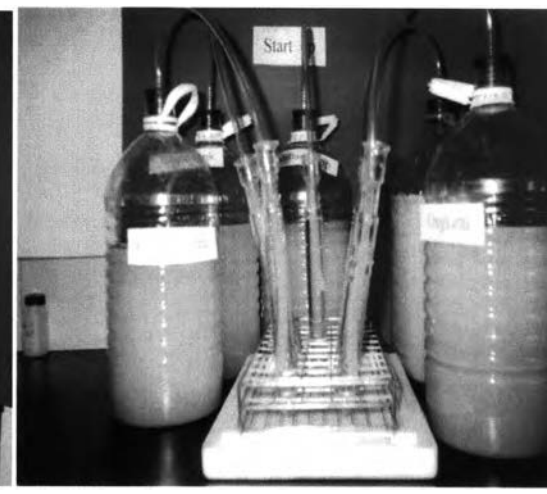
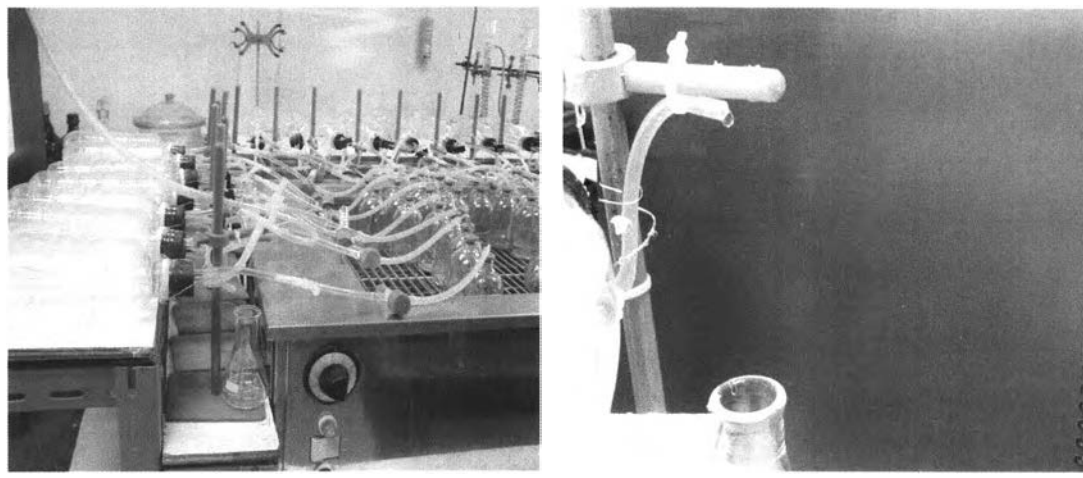


Figure B-2 Start up

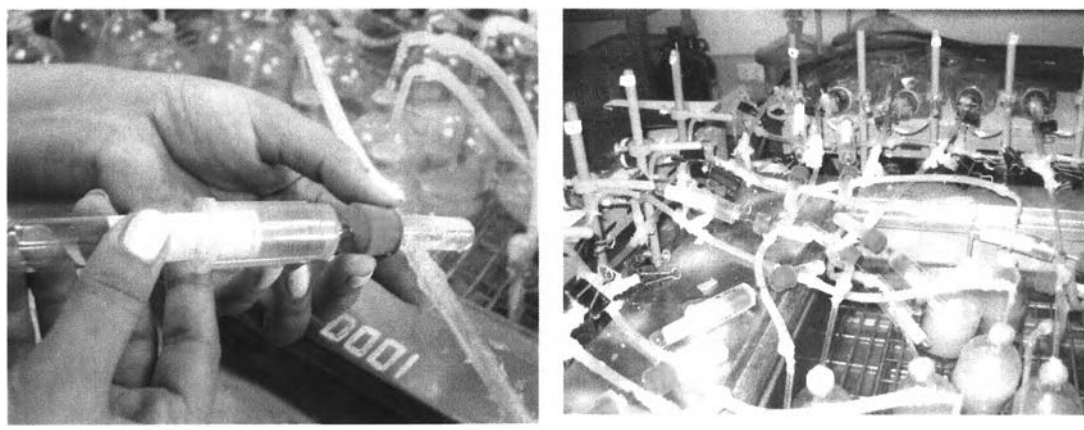
Figure B-3 Reactor operation of Phase 1 Part 1 with gas collection system based on displacement by existing gas from a reactor.

Figure B-4 Experiment set up and operation of Phase 2 and Phase 3.



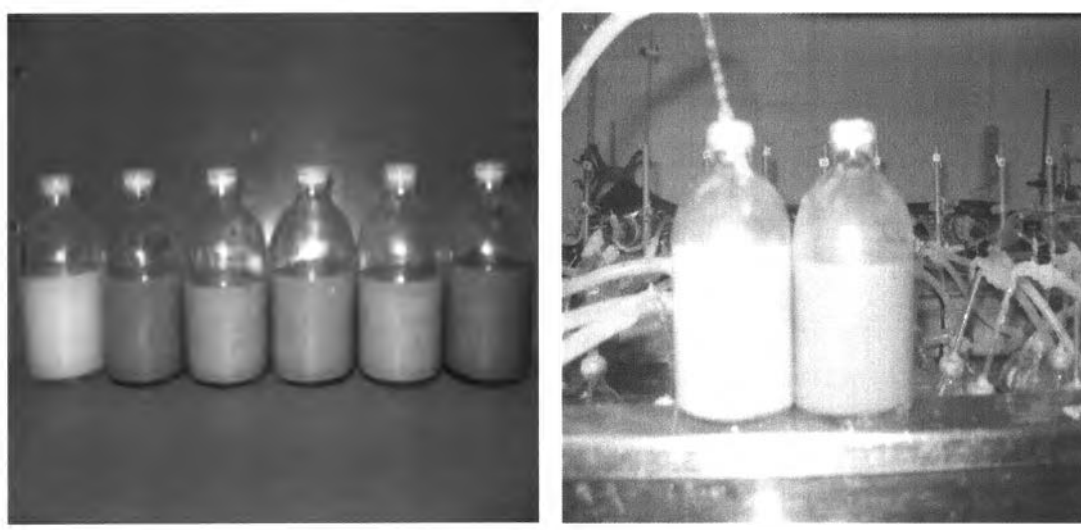
(A) (B)

Figure B-5 (A) and (B) Gas collection system which based on displacement by existing gas from a reactor.



(A) (B)

Figure B-6 (A) and (B) Gas collection for the determination of methane.



(A) (B)

Figure B-7 (A) and (B) Sulfide precipitation by visual observation of the solids indicated a very fine black suspended precipitate appearing in the reactors.

Appendix C

Isolation and Identification of Bacterial Culture

Isolation of Sulfate-Reducing Bacteria

One milliliter of the acclimated sludge was inoculated into melt agar medium containing 0.02% $Fe(SO_4)$ $(NH_4)_2.6H_2O$ as a primary enrichment for sulfate reducing bacteria (SRB). After 3 days of incubation at room temperature, the FeS was observed. The culture receiving 10^{-1}-10^{-2} showed colony formation in medium containing 0.7% agar and 0.2% $Fe(SO_4)$ $(NH_4)_2.6H_2O$ in a plate, after 3 days, and a colony was transferred to the melted agar medium. For examination of the physiological characteristics, sodium lactate (20mM) was evaluated as electron donors. Growth was examined at room temperature, and pH 7 in the medium.

16S rRNA Gene Analysis of the Isolates

Cells were harvested from 1.2 ml of culture on agar medium. The DNA extraction was carried out using a combination of the ISOPLANT II kit Nippon Gene Co., Tokyo, Japan) and DNeasy Tissue kit (QIAGEN K.K. , Tokyo, Japan). The cell was suspended in 400 µl Tris-EDTA buffer (pH 8.0). 8 µl of 50 mg/ml lysozyme was added and then incubated at 37^0 C for 30 minutes. Then 4 µl of the Proteinase K (20 mg/ml) and 20 µl of sodium dodecyl sulfate (SDS 10%) and 4 µl of RNase A (100 mg/ml) were added and then incubated at 37^0 C for 30 minutes. The purification of DNA was carried out using phenol/chloroform extraction. The 16S rRNA gene of the isolates was amplified using the following primers: forward primer 27F 5'-AGAGTTTGATCMTGGCTCAG-3' (*E. coli* positions) and reverse primer 1389R 5'-ACGGGCGGTGTGTACAAG-3' (*E. coli* positions where M is A or C). The reaction mixture (15 µl) contained: 10 pmol of each primer, 2.5 mM of each dNTP, PCR buffer containing 15 mM $MgCl_2$ and 1.25 U *Ex-Tag* (TAKARA, Japan). PCR was performed as follows: 95^0C for 1 minute, followed by 35 cycles consisting of 95^0C for 20 seconds, 50^0C for 30 seconds and 72 ^{0}C for 2 minute, with a final 4 minute extraction at 72^0 C. The PCR products were sequenced using an ABI 377 automated sequencer (Applied Biosystems). The primer 520F 5' CAGCMGCCGCGGTAAT(A/T) C-3' was used for sequencing. Approximately 500 bp of the 16S rRNA genes were initially sequenced using the PCR primers. Sequences were compared using the BLAST program of the National Center for Biotechnology Information (NCBI).

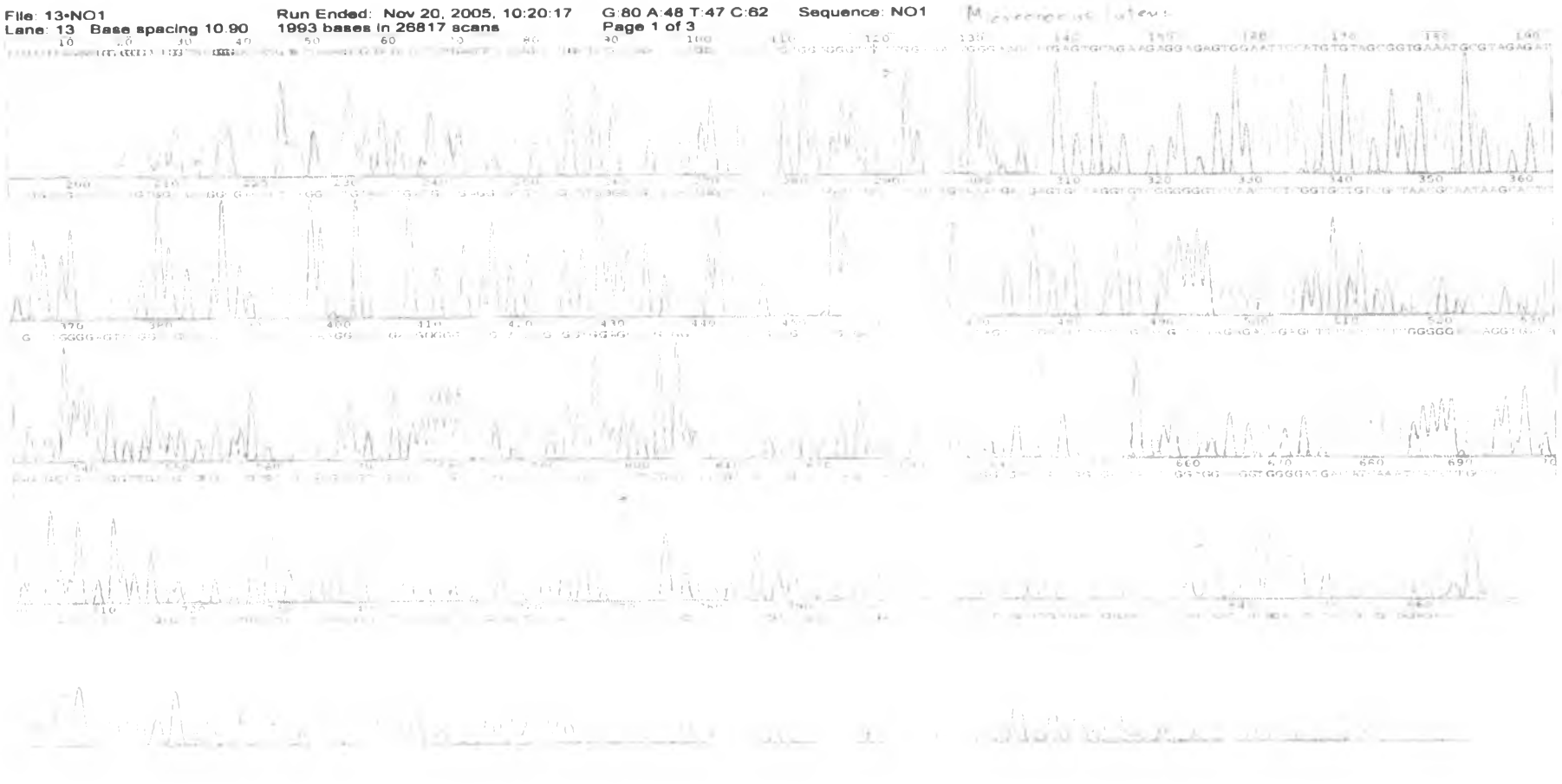


Figure C-1 Electrophoregram of *Micrococcus luteus* from bacterial identification.

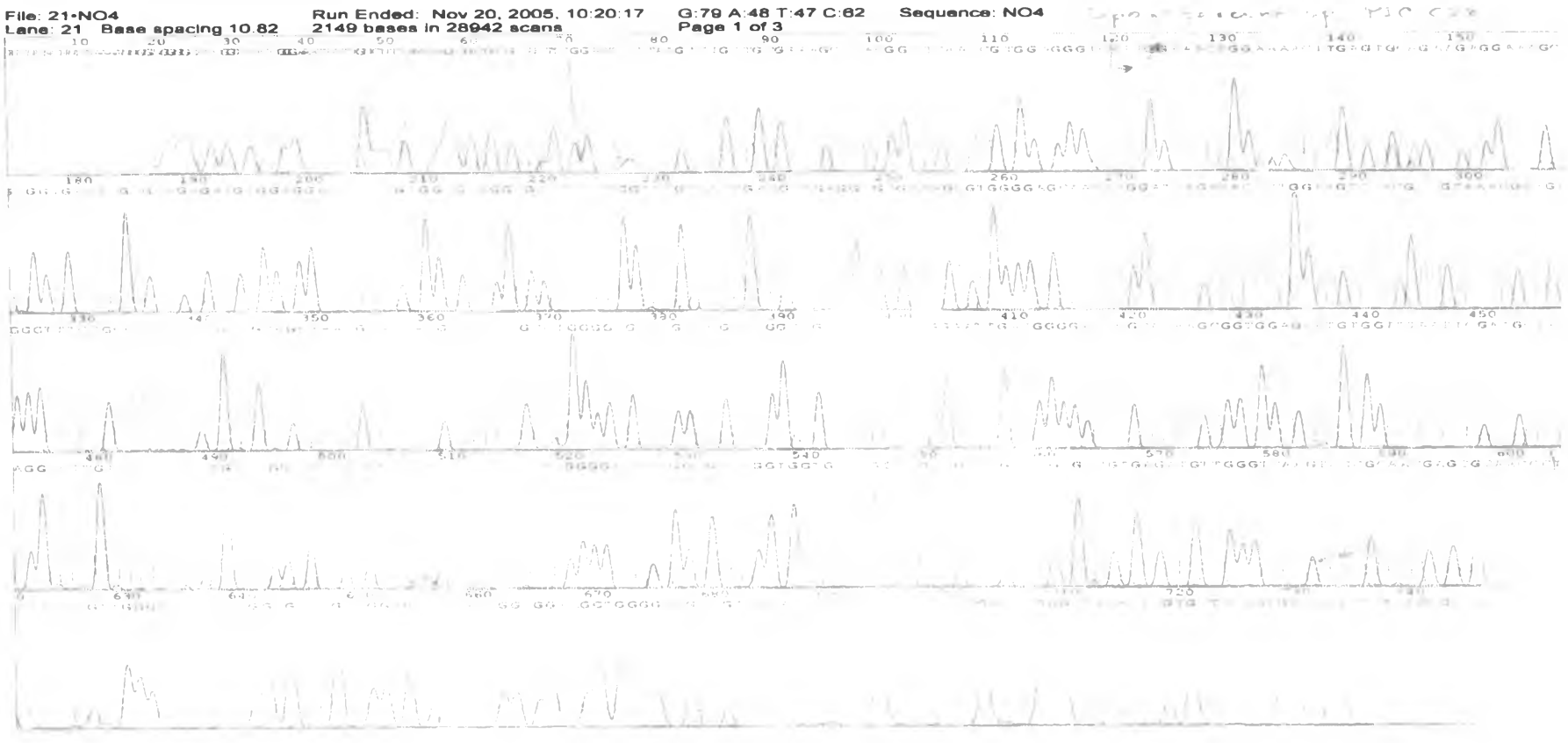


Figure C-2 Electrophoregram of *Sporosarcina* sp. PIC-C28 from bacterial identification.

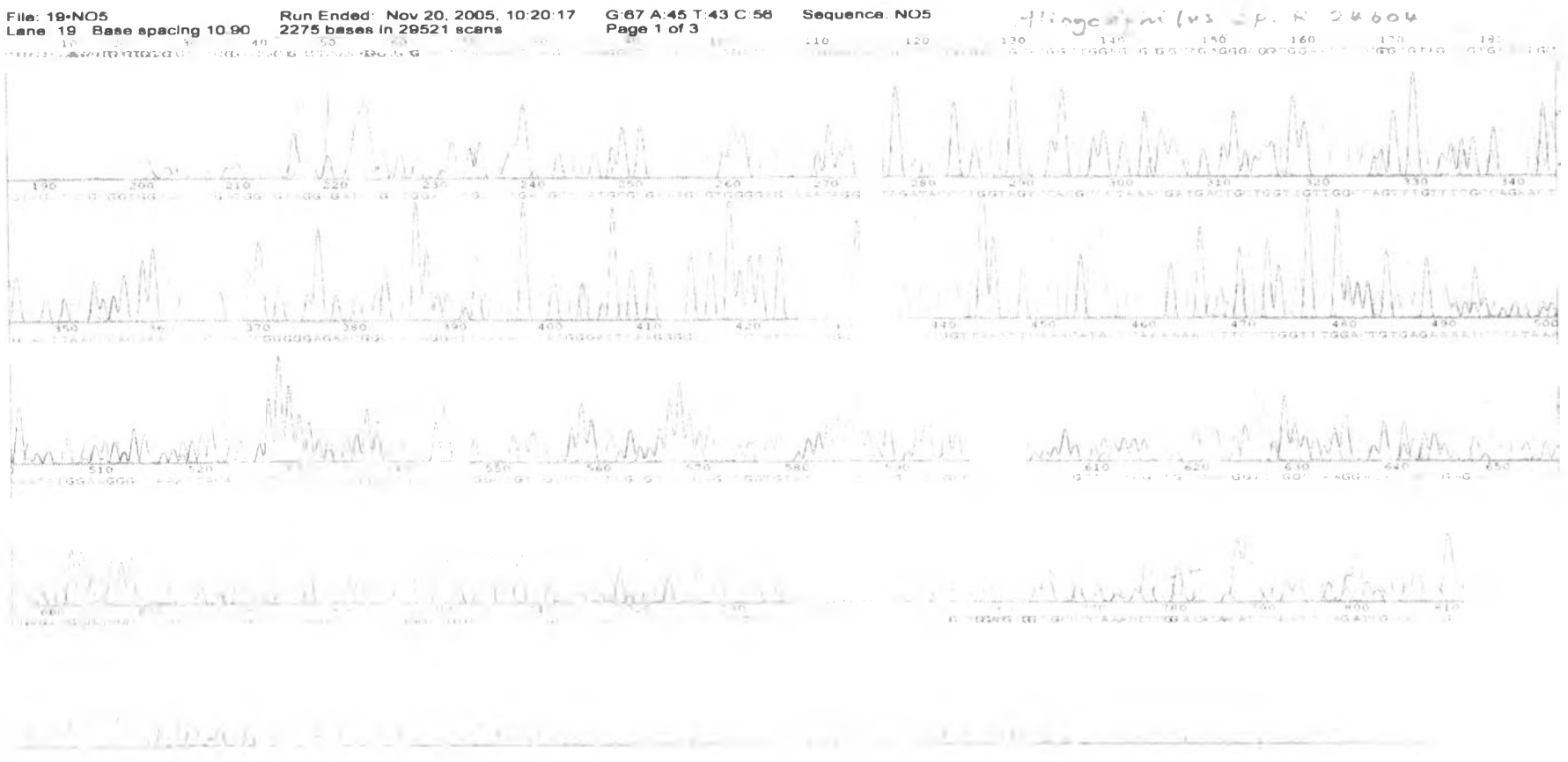


Figure C-3 Electrophoregram of *Alicycliphilus* sp. R-24604 from bacterial identification .

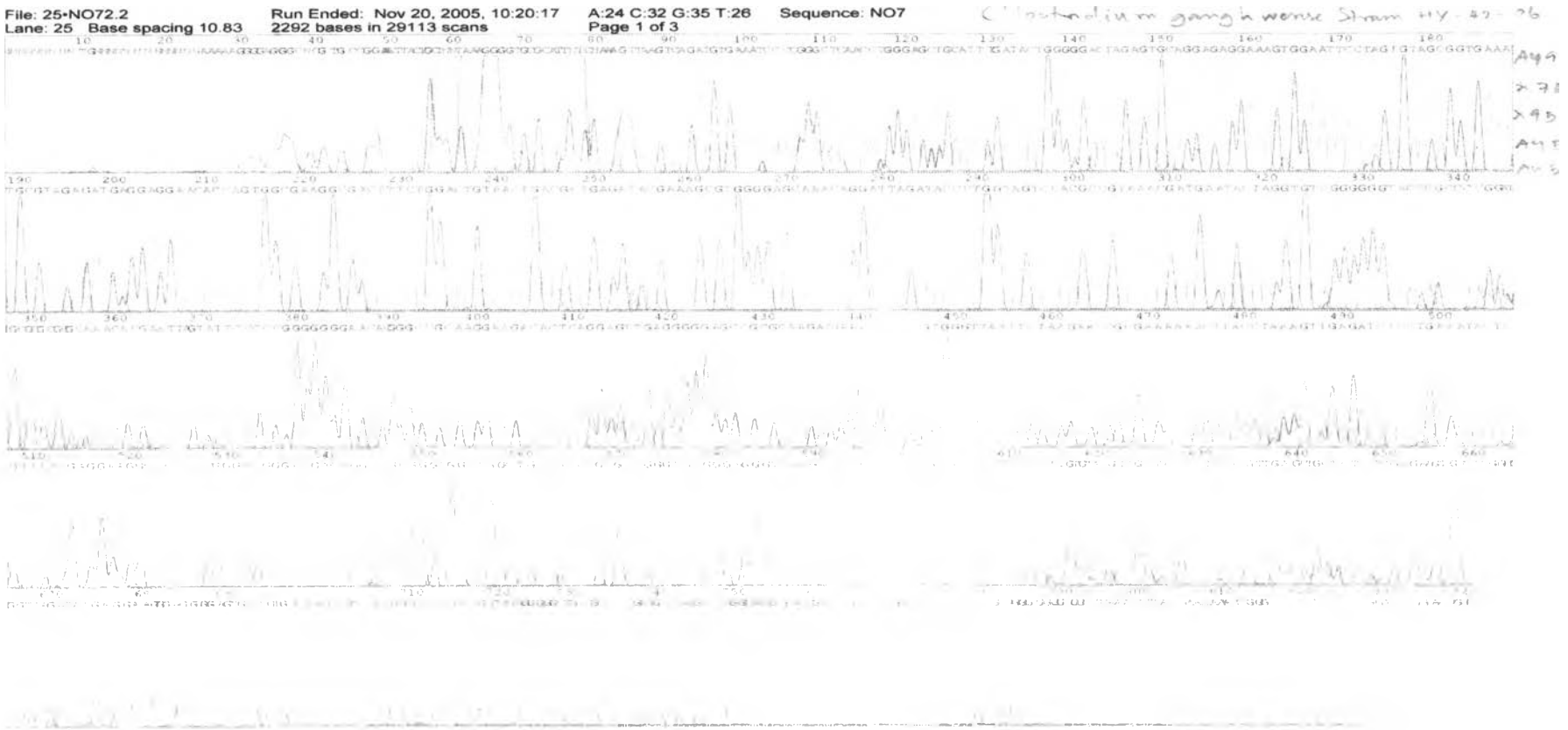


Figure C-4 Electrophoregram of *Clostridium gangahwense* strain HY-42-06 from bacterial identification..

Appendix D

Raw Data of Chapter 4

Comparison of the Potential Effectiveness of Selected Microbial Assemblages in Anaerobic Process of Wastewater Containing High Sulfate and Heavy Metal

Table D-1 The time course of COD and the COD removal from reactors that contained different mixed-bacteria from various sources.

COD (mg/l)									
Time(h)	Septic Liquor	Time(h)	Coastal Sediment	Time(h)	Brewery WWTP	Time(h)	Acidic Sulfate Soil	Time(h)	Leachate
0	20000	0	20000	0	20000	0	20000	0	20000
24	14938	24	19325	24	14583	24	19562	1002	14562
72	15240	72	19440	72	13800	72	18720	1337	17716
112	15103	96	17640	96	13800	96	18600	1390	19020
150	14616	171	16199	171	13276	171	18635	1740	12672
195	14433	195	15741	195	12583	195	18751	2052	12087
243	14100	243	11943	243	10835	651	17661	2313	11616
651	13740	651	9135	700	10751	700	16577		
700	12312	700	7688	1012	9720	913	16577		
913	12192	913	7627	1075	8454	1012	14400		
1012	10800	1012	7620			1075	12337		
1765	9787	1075	7394						
% COD Removal	50		63		57		38		42

Table D-2 MLVSS and growth rate of biomass from reactors that contained different mixed-bacteria from various sources.

Time, t (h)	MLVSS, X (mg/l)			
	Septic Liquor	Coastal Sediment	Brewery Wastewater Treatment Plant	Acidic Sulfate Soil
0	4860	2500	1200	3040
6	2000	2720	1260	2580
8	1840	2380	1260	2560
9	1860	2260	1540	2320
10	1260	2480	1100	2560
18	1680	2360	1080	1920
23	2720	2400	2300	1500
24	1680	2260	1540	1820
27	2480	3140	2080	1880
31	2800	2820	2080	1860
35	2640	2740	1700	1890
50	2280	2920	1100	1940
55	1820	2240	1480	1840
72	1780	2100	1480	2480
76	1880	2500	1460	2280
80	1700	2900	2080	2480
85	1760	2760	1800	2300
90	1400	2860	1500	2420
96	1580	2380	1500	2320
102	1400	2570	1660	2420
106	1840	2620	1760	2620

Table D-2 -continued- MLVSS and growth rate of biomass from reactors that contained different mixed-bacteria from various sources.

Time, t (h)	MLVSS, X (mg/l)			
	Septic Liquor	Coastal Sediment	Brewery Wastewater Treatment Plant	Acidic Sulfate Soil
112	1840	2920	1940	2660
126	1420	2780	1820	2480
150	1560	2800	1980	2680
171	1800	2840	2160	2220
195	1620	2660	2360	2360
219	1500	2740	1800	2680
243	1640	2740	1800	2600
651	2280	4200	4040	3820
700	1880	3360	1900	2800
913	1740	3260	2400	2640
1012	1680	3280	1340	2140

Table D-2 -continued- MLVSS and growth rate of biomass from reactors that contained different mixed-bacteria from various sources.

time, t (h)	MLVSS, X (mg/l)
	Leachate
6	2745
12	2521
35	2773
1002	2941
1121	1569
1337	1709
1390	1737
1740	1597
2313	1793

Table D-3 Computation table to determine **the waste utilization rate, K**.

Septic Liquor					
Time (h)	COD, S(mg/l)	MLVSS, X(mg/l)	$\bar{x}$ (mg/l)	$\bar{x}$ t (mg/l)(h)	Ln S
0	20000				
24	14938	1680	1680	40320	9.6117
72	15240	1780	1730	124560	9.6317
112	15103	1840	1760	197120	9.6226
150	14616	1560	1620	243000	9.5899
195	14433	1620	1650	321750	9.5773
243	14100	1640	1660	403380	9.5539
651	13740	2280	1980	1288980	9.5281
700	12312	1880	1780	1246000	9.4183
913	12192	1740	1710	1561230	9.4085
1012	10800	1680	1680	1700160	9.2873

Table D-3-continued- Computation table to determine **the waste utilization rate, K**.

Coastal Sediment					
Time (h)	COD, S(mg/l)	MLVSS, X(mg/l)	$\bar{x}$ (mg/l)	$\bar{x}$ t (mg/l)(h)	Ln S
0	20000				
24	19325	2260	2260	162720	9.8692
72	19440	2100	2180	156960	9.8751
96	17640	2380	2320	222720	9.7779
171	16199	2840	2550	436050	9.6927
195	15741	2660	2460	479700	9.6640
243	11943	2740	2500	607500	9.3879
651	9135	4200	3230	2102730	9.1199
700	7688	3360	2810	1967000	8.9474
913	7627	3260	2760	2519880	8.9394
1012	7620	3280	2770	2803240	8.9385

Table D-3-continued- Computation table to determine **the waste utilization rate, K**.

Brewery Wastewater Treatment Plant					
Time (h)	COD, S(mg/l)	MLVSS, X(mg/l)	$\bar{x}$ (mg/l)	$\bar{x}$ t (mg/l)(h)	Ln S
0	20000	1200	1200		
72	13800	1480	1340	96480	9.5324
96	13800	1500	1350	129600	9.5324
171	13276	2160	1680	287280	9.4937
195	12583	2360	1780	347100	9.4401
243	10835	1800	1500	364500	9.2905
700	10751	1900	1550	1085000	9.2828
1012	9720	1340	1270	1285240	9.1819

Table D-3-continued- Computation table to determine **the waste utilization rate, K.**

Acidic Sulfate Soil					
Time (h)	COD, S(mg/l)	MLVSS, X(mg/l)	$\bar{x}$ (mg/l)	$\bar{x}$ t (mg/l)(h)	Ln S
0	20000				
24	19562	1820	1820	43680	9.881
72	18720	2480	2150	154800	9.837
96	18600	2320	2070	198720	9.831
171	18635	2220	2020	345420	9.833
195	18751	2360	2090	407550	9.839
651	17661	3820	2820	1835820	9.779
700	16577	2800	2310	1617000	9.716
913	16577	2640	2230	2035990	9.716
1012	14400	2140	1980	2003760	9.575

Table D-3-continued- Computation table to determine **the waste utilization rate, K**.

Leachate					
Time (h)	COD, S(mg/l)	MLVSS, X(mg/l)	$\bar{x}$ (mg/l)	$\bar{x}$ t (mg/l)(h)	Ln S
0	20000				
1002	14562	2941	2941	2946882	9.5862
1337	17716	1709	2325	3108525	9.7822
1390	19020	1737	2339	3251210	9.8532
1740	12672	1597	2269	3948060	9.4472
2052	12087	1373	2157	4426164	9.3999
2313	11616	1793	2367	5474871	9.3602

Table D-4 Computation table to determine **the cellular yield coefficient ($Y_{X/S}$)** and **the endogenous decay rate (k_d)**.

Septic Liquor										
Time (h)	Time, t (day)	COD, S_o (mg/l)	COD, S (mg/l)	So-S (mg/l)	MLVSS, X (mg/l)	$\bar{x}$ (mg/l)	($\bar{x}$ -Xo)* (mg/l)	($\bar{x}$ -Xo) t (mg/l)(d)	(S_o-S)/($\bar{x}$ -Xo) t, (day^{-1})	1/ t, (day^{-1})
0		20000	20000	0						
24	1	20000	14938	5062	1680					
72	3	20000	15240	4760	1780	1730	530	530	8.9811	0.3333
112	4.7	20000	15103	4897	1840	1760	560	1680	2.9149	0.2143
150	6.3	20000	14616	5384	1560	1620	420	1960	2.7469	0.1600
195	8.1	20000	14433	5567	1620	1590	390	2438	2.2839	0.1231
243	10.1	20000	14100	5900	1640	1660	460	3738	1.5786	0.0988
651	27.1	20000	13740	6260	2280	1960	760	7695	0.8135	0.0369
700	29.2	20000	12312	7688	1880	1780	580	15733	0.4887	0.0343
913	38.0	20000	12192	7808	1740	1810	610	17792	0.4389	0.0263

* Xo =1200 mg/l

Table D-4-continued- Computation table to determine **the cellular yield coefficient ($Y_{X/S}$)** and **the endogenous decay rate (k_d)**.

Coastal Sediment										
Time (h)	Time, t (day)	COD, S_o (mg/l)	COD, S (mg/l)	So-S (mg/l)	MLVSS, X (mg/l)	$\bar{x}$ (mg/l)	($\bar{x}$ -Xo)* (mg/l)	($\bar{x}$ -Xo) t (mg/l)(d)	(S_o-S)/($\bar{x}$ -Xo) t, (day^{-1})	1/ t, (day^{-1})
0	0	20000	20000	0						
24	1.0	20000	19325	675	2260	2260	1060	1060	0.6368	
72	3.0	20000	19440	560	2100	2180	980	2940	0.1905	
96	4.0	20000	17640	2360	2380	2320	1120	4480	0.5268	0.2500
171	7.1	20000	16199	3801	2840	2550	1350	9619	0.3952	0.1404
195	8.1	20000	15741	4259	2660	2460	1260	10238	0.4160	0.1231
243	10.1	20000	11943	8057	2740	2500	1300	13163	0.6121	0.0988
651	27.1	20000	9135	10865	4200	3230	2030	55064	0.1973	0.0369
700	29.2	20000	7688	12312	3360	2810	1610	46958	0.2622	0.0343
913	38.0	20000	7627	12373	3260	2760	1560	59345	0.2085	0.0263

* Xo =1200 mg/l

Table D-4-continued- Computation table to determine **the cellular yield coefficient ($Y_{X/S}$)** and **the endogenous decay rate (k_d)**.

Brewery Wastewater Treatment Plant										
Time (h)	Time, t (day)	COD, S_o (mg/l)	COD, S (mg/l)	So-S (mg/l)	MLVSS, X (mg/l)	$\bar{x}$ (mg/l)	($\bar{x}$ -Xo)* (mg/l)	($\bar{x}$ -Xo) t (mg/l)(d)	(S_o-S)/($\bar{x}$ -Xo) t, (day^{-1})	1/ t, (day^{-1})
0		20000	20000	0	1200	1200				
72	3.0	20000	13800	6200	1480	1340	140	420	14.76	0.3333
96	4.0	20000	13800	6200	1500	1350	150	600	10.33	0.2500
171	7.1	20000	13276	6724	2160	1680	480	3420	1.97	0.1404
195	8.1	20000	12583	7417	2360	1780	580	4713	1.57	0.1231
243	10.1	20000	10835	9165	1800	1500	300	3038	3.02	0.0988
700	29.2	20000	10751	9249	1900	1550	350	10208	0.91	0.0343
1012	42.2	20000	9720	10280	1340	1270	70	2952	3.48	0.0237

* Xo =1200 mg/l

Table D-4-continued- Computation table to determine **the cellular yield coefficient ($Y_{X/S}$)** and **the endogenous decay rate (k_d)**.

Acidic Sulfate Soil										
Time (h)	Time, t (day)	COD, S_o (mg/l)	COD, S (mg/l)	So-S (mg/l)	MLVSS, X (mg/l)	$\bar{x}$ (mg/l)	($\bar{x}$ -Xo)* (mg/l)	($\bar{x}$ -Xo) t (mg/l)(d)	(S_o-S)/($\bar{x}$ -Xo) t, (day^{-1})	1/ t, (day^{-1})
0		20000	20000							
24	1	20000	19562	438	1820	1820	620	620	0.7065	
72	3	20000	18720	1280	2480	2150	950	2850	0.4491	0.3333
96	4	20000	18600	1400	2320	2070	870	3480	0.4023	0.2500
171	7.1	20000	18635	1365	2220	2020	820	5843	0.2336	0.1404
195	8.1	20000	18751	1249	2360	2090	890	7231	0.1727	0.1231
651	27.1	20000	17661	2339	3820	2820	1620	43943	0.0532	0.0369
700	29.2	20000	16577	3423	2800	2310	1110	32375	0.1057	0.0343
913	38.0	20000	16577	3423	2640	2230	1030	39183	0.0874	0.0263
1012	42.2	20000	14400	5600	2140	1980	780	32890	0.1703	0.0237

* Xo =1200 mg/l

Table D-4-continued- Computation table to determine **the cellular yield coefficient ($Y_{X/S}$)** and **the endogenous decay rate (k_d)**.

Leachate										
Time (h)	Time, t (day)	COD, S_o (mg/l)	COD, S (mg/l)	So-S (mg/l)	MLVSS, X (mg/l)	$\bar{x}$ (mg/l)	($\bar{x}$ -Xo)* (mg/l)	($\bar{x}$ -Xo) t (mg/l)(d)	(S_o-S)/($\bar{x}$ -Xo) t, (day^{-1})	1/ t, (day^{-1})
0	0.0	20000	20000							
6	0.3	20000								
12	0.5	20000								
35	1.5	20000								
1002	41.8	20000	14562	5438	2941	2941	1741	72687	0.0748	0.02395
1337	55.7	20000	17716	2284	1709	2325	1125	62672	0.0364	0.01795
1390	57.9	20000	19020	980	1737	2339	1139	65967	0.0149	0.01727
1740	72.5	20000	12672	7328	1597	2269	1069	77503	0.0945	0.01379
2052	85.5	20000	12087	7913	1373	2157	957	81824	0.0967	0.01170
2313	96.4	20000	11616	8384	1793	2367	1167	112470	0.0745	0.01038

* Xo =1200 mg/l

Table D-5 The amount of **total gas** production and **rate**.

Septic Liquor					
Time, t (h)	dt (h)	Product, p (ml)	Product, p (ml@STP)	dp (ml)	dp/dt (ml/h)
0	0	0	0	0	0
1	1	0	0	0	0
2	1	0	0	0	0
3	1	174	157	174	174
4	1	478	432	304	304
5	1	808	731	330	330
6	1	1138	1029	330	330
7	1	1630	1474	492	492
8	1	2190	1981	560	560
9	1	2872	2597	682	682
10	1	3658	3308	786	786
11	1	4220	3817	562	562
12	1	4795	4337	575	575
13	1	5383	4868	588	588
18	5	8837	7992	3454	691
19	1	9529	8618	692	692
23	4	11737	10615	2208	552
24	1	12357	11176	620	620
25	1	13017	11773	660	660
26	1	13673	12366	656	656
27	1	14403	13026	730	730
29	2	15093	13650	690	345
31	2	15797	14287	704	352
35	4	16047	14513	250	63
37	2	16145	14602	98	49
48	11	16995	15370	850	77
52	4	17495	15822	500	125

Table D-5-continued- The amount of **total gas** production and **rate**.

Septic Liquor					
Time, t (h)	dt(h)	Product, p (ml)	Product, p (ml@STP)	dp (ml)	dp/dt (ml/h)
55	3	18105	16374	610	203
57	2	18405	16645	300	150
72	15	19685	17803	1280	85
76	4	20235	18301	550	138
80	4	20395	18445	160	40
85	5	20655	18680	260	52
90	5	20845	18852	190	38
96	6	21075	19060	230	38
102	6	21279	19245	204	34
106	4	21343	19303	64	16
112	6	21353	19312	10	2
120	8	21353	19312	0	0
126	6	21353	19312	0	0
150	24	21669	19597	316	13
171	21	21937	19840	268	13
195	24	22297	20165	360	15
219	24	22367	20229	70	3
243	24	22561	20404	194	8
267	24	22763	20587	202	8
315	48	23263	21039	500	10
363	48	23623	21365	360	8
387	24	23749	21479	126	5
489	102	24469	22130	720	7
507	18	24619	22265	150	8
531	24	24904	22523	285	12
581	50	25179	22772	275	6
651	70	25469	23034	290	4
675	24	25541	23099	72	3

Table D-5-continued- The amount of **total gas** production and **rate**.

Septic Liquor					
Time, t (h)	dt(h)	Product, p (ml)	Product, p (ml@STP)	dp (ml)	dp/dt (ml/h)
700	25	25691	23235	150	6
750	50	25825	23356	134	3
820	70	25941	23461	116	2
870	50	26181	23678	240	5
913	43	26331	23814	150	3
990	77	26663	24114	332	4
1012	22	26777	24217	114	5
1060	48	26957	24380	180	4
1182	122	27123	24530	166	1
1387	205	27547	24914	424	2
1675	270	27547	24914	0	0
1786	111	27567	24932	20	0

p = Product = Total Gas

Table D-5-Continued- The amount of total gas production and rate.

Coastal Sediment					
Time, t (h)	dt(h)	Product, p(ml)	Product, p(ml@STP)	dp(ml)	dp/dt(ml/h)
0	0	0	0	0	0
1	1	20	18	20	20
2	1	180	163	160	160
3	1	494	447	314	314
4	1	966	874	472	472
5	1	1396	1263	430	430
6	1	2021	1828	625	625
7	1	2997	2710	976	976
8	1	4105	3713	1108	1108
9	1	5157	4664	1052	1052
10	1	6201	5608	1044	1044
11	1	7099	6420	898	898
12	1	7864	7112	765	765
13	1	8496	7684	632	632
18	5	11786	10659	3290	658
19	1	12406	11220	620	620
23	4	14162	12808	1756	439
24	1	14588	13193	426	426
25	1	15150	13702	562	562
26	1	15356	13888	206	206
27	1	15456	13978	100	100
29	2	15498	14016	42	21
31	2	15570	14082	72	36
35	4	15734	14230	164	41
37	2	15780	14271	46	23
48	11	16290	14733	510	46
52	4	16630	15040	340	85

Table D-5-Continued- The amount of total gas production and rate.

Coastal Sediment					
Time, t (h)	dt(h)	Product, p(ml)	Product, p(ml@STP)	dp(ml)	dp/dt(ml/h)
55	3	17070	15438	440	147
57	2	17360	15700	290	145
72	15	17830	16125	470	31
76	4	17830	16125	0	0
80	4	17830	16125	0	0
85	5	17830	16125	0	0
90	5	17830	16125	0	0
96	6	17946	16230	116	19
102	6	18126	16393	180	30
106	4	18224	16482	98	25
112	6	18310	16560	86	14
120	8	18596	16818	286	36
126	6	18696	16909	100	17
150	24	19602	17728	906	38
171	21	19914	18010	312	15
195	24	20844	18851	930	39
219	24	21468	19416	624	26
243	24	22178	20058	710	30
267	24	22744	20570	566	24
315	48	23994	21700	1250	26
363	48	25118	22717	1124	23
387	24	25642	23191	524	22
489	102	27988	25312	2346	23
507	18	28413	25697	425	24
531	24	29123	26339	710	30
581	50	30073	27198	950	19
651	70	31179	28198	1106	16
675	24	31509	28497	330	14

Table D-5-Continued- The amount of total gas production and rate.

Coastal Sediment					
Time, t (h)	dt(h)	Product, p(ml)	Product, p(ml@STP)	dp(ml)	dp/dt(ml/h)
700	25	31999	28940	490	20
750	50	32559	29446	560	11
820	70	33009	29853	450	6
870	50	33473	30273	464	9
913	43	33793	30562	320	7
990	77	34269	30993	476	6
1012	22	34441	31148	172	8
1060	48	34751	31429	310	6
1182	122	35091	31736	340	3
1387	205	35831	32406	740	4
1675	270	35831	32406	0	0
1786	111	35831	32406	0	0

p = Product = Total Gas

Table D-5-Continued- The amount of total gas production and rate.

Brewery Wastewater Treatment Plant					
Time, t (h)	dt(h)	Product, p(ml)	Product, p(ml@STP)	dp(ml)	dp/dt(ml/h)
0	0	0	0	0	0
1	1	14	13	14	14
2	1	95	86	81	81
3	1	306	277	211	211
4	1	446	403	140	140
5	1	608	550	162	162
6	1	968	875	360	360
7	1	1422	1286	454	454
8	1	2008	1816	586	586
9	1	2668	2413	660	660
10	1	3420	3093	752	752
11	1	4180	3780	760	760
12	1	4842	4379	662	662
13	1	5406	4889	564	564
18	5	8680	7850	3274	655
19	1	9100	8230	420	420
23	4	9958	9006	858	215
24	1	10074	9111	116	116
25	1	10124	9156	50	50
26	1	10124	9156	0	0
27	1	10124	9156	0	0
29	2	10306	9321	182	91
31	2	10516	9511	210	105
35	4	10904	9862	388	97
37	2	11042	9986	138	69
48	11	11392	10303	350	32

Table D-5-Continued- The amount of total gas production and rate.

Brewery Wastewater Treatment Plant					
Time, t (h)	dt(hr)	Product, p(ml)	Product, p (ml@STP)	dp(ml)	dp/dt(ml/h)
52	4	11392	10303	0	0
55	3	11392	10303	0	0
57	2	11392	10303	0	0
72	15	11536	10433	144	10
76	4	11736	10614	200	50
80	4	11852	10719	116	29
85	5	12092	10936	240	48
90	5	12372	11189	280	56
96	6	12600	11395	228	38
102	6	12740	11522	140	23
106	4	12792	11569	52	13
112	6	12808	11584	16	3
120	8	12952	11714	144	18
126	6	12952	11714	0	0
150	24	13382	12103	430	18
171	21	13678	12370	296	14
195	24	13888	12560	210	9
219	24	13972	12636	84	4
243	24	13972	12636	0	0
267	24	13972	12636	0	0
315	48	14592	13197	620	13
363	48	15036	13599	444	9
387	24	15246	13788	210	9
489	102	16116	14575	870	9
507	18	16166	14621	50	3
531	24	16651	15059	485	20
581	50	17361	15701	710	14

Table D-5-Continued- The amount of total gas production and rate.

Brewery Wastewater Treatment Plant					
Time, t (h)	dt(h)	Product, p(ml)	Product, p(ml@STP)	dp(ml)	dp/dt(ml/h)
651	70	18189	16450	828	12
675	24	18481	16714	292	12
700	25	18931	17121	450	18
750	50	19697	17814	766	15
820	70	20431	18478	734	10
870	50	21173	19149	742	15
913	43	21797	19713	624	15
990	77	22657	20491	860	11
1012	22	23037	20835	380	17
1060	48	23543	21292	506	11
1182	122	24393	22061	850	7
1387	205	25453	23020	1060	5
1675	270	25983	23499	530	2
1786	111	26365	23845	382	3

p = Product = Total Gas

Table D-5-Continued- The amount of total gas production and rate.

Acidic Sulfate Soil					
Time, t (h)	dt(h)	Product, p(ml)	Product, p(ml@STP)	dp(ml)	dp/dt(ml/h)
0	0	0	0	0	0
1	1	0	0	0	0
2	1	56	51	56	56
3	1	252	228	196	196
4	1	602	544	350	350
5	1	852	771	250	250
6	1	852	771	0	0
7	1	1096	991	244	244
8	1	1912	1729	816	816
9	1	2772	2507	860	860
10	1	3807	3443	1035	1035
11	1	4587	4148	780	780
12	1	5323	4814	736	736
13	1	6015	5440	692	692
18	5	9787	8851	3772	754
19	1	10565	9555	778	778
23	4	11623	10512	1058	265
24	1	11623	10512	0	0
25	1	11628	10516	5	5
26	1	11628	10516	0	0
27	1	11628	10516	0	0
29	2	11628	10516	0	0
31	2	11628	10516	0	0
35	4	11628	10516	0	0
37	2	11628	10516	0	0
48	11	11628	10516	0	0
52	4	11628	10516	0	0

Table D-5-Continued- The amount of total gas production and rate.

Acidic Sulfate Soil					
Time, t (h)	dt(h)	Product, p(ml)	Product, p(ml@STP)	dp(ml)	dp/dt(ml/h)
55	3	11666	10551	38	13
57	2	11698	10580	32	16
72	15	11698	10580	0	0
76	4	11698	10580	0	0
80	4	11698	10580	0	0
85	5	11698	10580	0	0
90	5	11698	10580	0	0
96	6	11698	10580	0	0
102	6	11698	10580	0	0
106	4	11698	10580	0	0
112	6	11698	10580	0	0
120	8	11698	10580	0	0
126	6	11698	10580	0	0
150	24	11698	10580	0	0
171	21	11718	10598	20	1
195	24	11778	10652	60	3
219	24	11778	10652	0	0
243	24	11778	10652	0	0
267	24	11828	10697	50	2
315	48	11962	10818	134	3
363	48	12006	10858	44	1
387	24	12006	10858	0	0
489	102	12006	10858	0	0
507	18	12052	10900	46	3
531	24	12052	10900	0	0
581	50	12052	10900	0	0
651	70	12052	10900	0	0
675	24	12052	10900	0	0

Table D-5-Continued- The amount of total gas production and rate.

Acidic Sulfate Soil					
Time, t (h)	dt(h)	Product, p(ml)	Product, p(ml@STP)	dp(ml)	dp/dt(ml/h)
700	25	12052	10900	0	0
750	50	12052	10900	0	0
820	70	12052	10900	0	0
870	50	12052	10900	0	0
913	43	12052	10900	0	0
990	77	12052	10900	0	0
1012	22	12052	10900	0	0
1060	48	12052	10900	0	0
1182	122	12052	10900	0	0
1387	205	12052	10900	0	0
1675	270	12052	10900	0	0
1786	111	12052	10900	0	0

p = Product = Total Gas

Table D-5-Continued- The amount of total gas production and rate.

Leachate					
Time, t (h)	dt(h)	Product, p(ml)	Product, p(ml@STP)	dp(ml)	dp/dt(ml/h)
0	0	0	0	0	0
6	6	777	703	777	130
7	1	1018	921	241	241
8	1	1382	1250	364	364
9	1	1418	1282	36	36
10	1	1718	1554	300	300
11	1	2001	1810	283	283
12	1	2133	1929	132	132
13	1	2211	2000	78	78
14	1	2326	2104	115	115
15	1	2441	2208	115	115
16	1	2547	2304	106	106
17	1	2892	2616	345	345
18	1	3192	2887	300	300
19	1	3621	3275	429	429
20	1	4019	3635	398	398
21	1	4660	4215	641	641
22	1	4708	4258	48	48
23	1	4775	4319	67	67
24	1	4887	4420	112	112
30	6	6042	5464	1155	193
31	1	6524	5900	482	482
32	1	7381	6675	857	857
33	1	8347	7549	966	966
34	1	9551	8638	1204	1204
35	1	10503	9499	952	952
36	1	10867	9828	364	364

Table D-5-Continued- The amount of total gas production and rate.

Leachate					
Time, t (h)	dt(h)	Product, p(ml)	Product, p (m@STP)	dp(ml)	dp/dt(ml/h)
37	1	10979	9929	112	112
38	1	10980	9930	1	1
39	1	11257	10181	277	277
40	1	11258	10182	1	1
41	1	11338	10254	80	80
42	1	11339	10255	1	1
43	1	11339	10255	0	0
44	1	11339	10255	0	0
45	1	11339	10255	0	0
46	1	11339	10255	0	0
47	1	11339	10255	0	0
48	1	11339	10255	0	0
54	6	11339	10255	0	0
57	3	11339	10255	0	0
60	3	11357	10271	18	6
63	3	11445	10351	88	29
86	23	11462	10366	17	1
89	3	11463	10367	1	0
108	19	11463	10367	0	0
111	3	11463	10367	0	0
134	23	11463	10367	0	0
136	2	11463	10367	0	0
156	20	11463	10367	0	0
203	47	11463	10367	0	0
253	50	11464	10368	1	0
398	145	11464	10368	0	0
593	195	11513	10412	49	0
612	19	11541	10438	28	1

Table D-5-Continued- The amount of total gas production and rate.

Leachate					
Time, t (h)	dt(h)	Product, p(ml)	Product, p (ml@STP)	dp(ml)	dp/dt(ml/h)
1002	390	12217	11049	676	2
1121	119	13548	12253	1331	11
1137	16	13809	12489	261	16
1237	100	15175	13724	1366	14
1337	100	16029	14497	854	9
1390	53	17633	15947	1604	30
1409	19	17905	16193	272	14
1477	68	19765	17875	1860	27
1572	95	22726	20553	2961	31
1740	168	27537	24904	4811	29
1812	72	28798	26045	1261	18
1932	120	30199	27312	1401	12
2052	120	31207	28224	1008	8
2079	27	31347	28350	140	5
2220	141	31942	28888	595	4
2244	24	31992	28934	50	2
2268	24	32017	28956	25	1
2304	36	32157	29083	140	4
2313	9	32158	29084	1	0
2322	9	32273	29188	115	13

p = Product = Total Gas

Table D-6 Time course of **the percentage of methane.**

Time (h)	%Methane				Time (h)	%Methane
	Septic Liquor	Coastal Sediment	Brewery WWTP	Acidic Sulfate Soil		Leachate
0	0	0	0	0	0	0
18	1.72	0.21	0.65	0.77	27	0.15
24	1.89	0.56	1.04	2.28	32	0.145
27	2.44	1.17	1.42	2.95	37	0.15
50	26.67	22.26	7.14	25.08	38	0.15
55	25.44	20.14	18.55	19.61	39	0.15
72	56.18	47.17	39.75	16.09	40	0.15
76	69.07	53.00	43.11	16.06	41	0.15
80	76.14	54.41	48.58	16.73	42	0.15
85	78.97	67.66	52.11	17.29	47	0.15
90	83.03	76.85	50.17	18.20	48	0.15
96	85.33	80.38	47.70	18.73	60	0.13
102	86.60	80.38	48.05	18.20	106	1.58
106	89.04	88.50	43.46	18.20	108	1.56
112	83.21	78.08	48.05	18.73	1002	33.00
150	99.97	98.43	54.94	22.08	1121	40.00
171	99.97	96.02	51.94	24.02	1137	42.00
175	99.97	88.42	50.36	21.58	1237	52.00
195	99.98	94.64	52.12	24.37	1572	64.00
243	99.98	99.28	59.75	29.70	1740	80.00
387	99.86	99.98	75.68	42.07	1812	82.00
700	99.97	99.97	83.27	45.59	1932	85.00
913	99.97	99.96	99.97	87.42	2313	99.97
1012	99.97	99.97	99.97	85.94	2322	99.97

Table D-7 % Methane from the reactor that contained bacteria from **septic liquor** during bioreaction times.

Time (h)	%Methane	dt (h)	Average Methane (%)	Total Gas, P (ml)	dp Total gas (ml)	dp Methane (ml)	dp/dt Methane (ml/h)	dp/dt Methane (ml/h at STP)	Accumulative Methane (ml)	Accumulative Methane (ml at STP)
0	0	0	0	0	0	0	0.00	0.00	0	0
18	1.72	18	0.86	8837	8837	76	4.22	3.82	76	69
24	1.89	6	1.81	12357	3520	64	10.59	9.58	140	126
27	2.44	3	2.17	14403	2046	44	14.77	13.35	184	166
50	26.67	23	14.56	17495	3092	450	19.57	17.70	634	573
55	25.44	5	26.06	18105	610	159	31.79	28.75	793	717
72	56.18	17	40.81	19685	1580	645	37.93	34.30	1438	1300
76	69.07	4	62.63	20235	550	344	86.11	77.88	1782	1612
80	76.14	4	72.61	20395	160	116	29.04	26.27	1898	1717
85	78.97	5	77.56	20655	260	202	40.33	36.47	2100	1899
90	83.03	5	81.00	20845	190	154	30.78	27.84	2254	2038
96	85.33	6	84.18	21075	230	194	32.27	29.18	2447	2213
102	86.60	6	85.97	21279	204	175	29.23	26.43	2623	2372
106	89.04	4	87.82	21343	64	56	14.05	12.71	2679	2423
112	83.21	6	86.13	21353	10	9	1.44	1.30	2688	2431
150	99.97	38	91.59	21669	316	289	7.62	6.89	2977	2692
171	99.97	21	99.97	21937	268	268	12.76	11.54	3245	2935
195	99.98	24	99.98	22297	360	360	15.00	13.56	3605	3260
243	99.98	48	99.98	22561	264	264	5.50	4.97	3869	3499
387	99.86	144	99.92	23749	1188	1187	8.24	7.46	5056	4572
700	99.97	313	99.92	25691	1942	1940	6.20	5.61	6996	6327
913	99.97	213	99.97	26331	640	640	3.00	2.72	7636	6906
1012	99.97	99	99.97	26777	446	446	4.50	4.07	8082	7309

Table D-7-Continued- % Methane from the reactor that contained bacteria from **coastal sediment** during bioreaction times.

Time (h)	%Methane	dt (h)	Average Methane (%)	Total Gas, P (ml)	dp Total gas (ml)	dp Methane (ml)	dp/dt Methane (ml/h)	dp/dt Methane (ml/h at STP)	Accumulative Methane (ml)	Accumulative Methane (ml at STP)
0	0	0	0	0	0	0	0.00	0.00	0	0
18	0.21	18	0.11	11786	11786	12	0.69	0.62	12	11
24	0.56	6	0.39	14588	2802	11	1.80	1.63	23	21
27	1.17	3	0.87	15456	868	8	2.50	2.26	31	28
50	22.26	23	11.72	16630	1174	138	5.98	5.41	168	152
55	20.14	5	21.20	17070	440	93	18.66	16.87	261	236
72	47.17	17	33.66	17830	760	256	15.05	13.61	517	468
76	53.00	4	50.09	17830	0	0	0.00	0.00	517	468
80	54.41	4	53.71	17830	0	0	0.00	0.00	517	468
85	67.66	5	61.04	17830	0	0	0.00	0.00	517	468
90	76.85	5	72.26	17830	0	0	0.00	0.00	517	468
96	80.38	6	78.62	17946	116	91	15.20	13.75	608	550
102	80.38	6	80.38	18126	180	145	24.11	21.81	753	681
106	88.50	4	84.44	18224	98	83	20.69	18.71	836	756
112	78.08	6	83.29	18310	86	72	11.94	10.80	908	821
150	98.43	38	88.26	19602	1292	1140	30.01	27.14	2048	1852
171	96.02	21	97.23	19914	312	303	14.44	13.06	2351	2126
195	94.64	24	95.33	20844	930	887	36.94	33.41	3238	2928
243	99.28	48	96.96	22178	1334	1293	26.95	24.37	4531	4098
387	99.98	144	99.63	25642	3464	3451	23.97	21.68	7982	7219
700	99.97	313	99.98	31999	6357	6355	20.30	18.36	14338	12967
913	99.96	213	99.97	33793	1794	1793	8.42	7.61	16131	14589
1012	99.97	99	99.97	33965	172	172	1.74	1.57	16303	14744

Table D-7-continued- % Methane from the reactor that contained bacteria from **a brewery wastewater treatment plant** during bioreaction times.

Time (h)	%Methane	dt (h)	Average Methane (%)	Total Gas, P (ml)	dp Total gas (ml)	dp Methane (ml)	dp/dt Methane (ml/h)	dp/dt Methane (ml/h at STP)	Accumulative Methane (ml)	Accumulative Methane (ml at STP)
0	0	0	0.00	0	0	0	0.00	0.00	0	0
18	0.65	18	0.33	8680	8680	28	1.57	1.42	28	26
24	1.04	6	0.85	10074	1394	12	1.96	1.78	40	36
27	1.42	3	1.23	10124	50	1	0.21	0.19	41	37
50	7.14	23	4.28	11392	1268	54	2.36	2.13	95	86
55	18.55	5	12.85	11392	0	0	0.00	0.00	95	86
72	39.75	17	29.15	11536	144	42	2.47	2.23	137	124
76	43.11	4	41.43	11736	200	83	20.72	18.73	220	200
80	48.58	4	45.85	11852	116	53	13.30	12.02	273	248
85	52.11	5	50.35	12092	240	121	24.17	21.86	394	358
90	50.17	5	51.14	12372	280	143	28.64	25.90	537	488
96	47.70	6	48.94	12600	228	112	18.60	16.82	648	590
102	48.05	6	47.88	12740	140	67	11.17	10.10	716	651
106	43.46	4	45.76	12792	52	24	5.95	5.38	739	672
112	48.05	6	45.76	12808	16	7	1.22	1.10	747	679
150	54.94	38	51.50	13382	574	296	7.78	7.03	1042	948
171	51.94	21	53.44	13678	296	158	7.53	6.81	1200	1092
195	52.12	24	52.03	13888	210	109	4.55	4.12	1310	1191
243	59.75	48	55.94	13972	84	47	0.98	0.89	1357	1234
387	75.68	144	67.72	15246	1274	863	5.99	5.42	2219	2018
700	83.27	313	79.48	18931	3685	2929	9.36	8.46	5148	4682
913	99.97	213	91.62	21797	2866	2626	12.33	11.15	7774	7069
1012	99.97	99	99.97	22177	380	380	3.84	3.47	8154	7415

Table D-7-Continued- % Methane from the reactor that contained bacteria from **acidic sulfate soil** during bioreaction times.

Time (h)	%Methane	dt (h)	Average Methane (%)	Total Gas, P (ml)	dp Total gas (ml)	dp Methane (ml)	dp/dt Methane (ml/h)	dp/dt Methane (ml/h at STP)	Accumulative Methane (ml)	Accumulative Methane (ml at STP)
0	0	0	0.00	0	0	0	0.00	0.00	0	0
18	0.77	18	0.39	9787	9787	38	2.09	1.89	38	34
24	2.28	6	1.53	11623	1836	28	4.67	4.22	66	59
27	2.95	3	2.62	11628	5	0	0.04	0.04	66	60
50	25.08	23	14.02	11628	0	0	0.00	0.00	66	60
55	19.61	5	22.35	11666	38	8	1.70	1.54	74	67
72	16.09	17	17.85	11698	32	6	0.34	0.30	80	72
76	16.06	4	16.08	11698	0	0	0.00	0.00	80	72
80	16.73	4	16.40	11698	0	0	0.00	0.00	80	72
85	17.29	5	17.01	11698	0	0	0.00	0.00	80	72
90	18.20	5	17.75	11698	0	0	0.00	0.00	80	72
96	18.73	6	18.47	11698	0	0	0.00	0.00	80	72
102	18.20	6	18.47	11698	0	0	0.00	0.00	80	72
106	18.20	4	18.20	11698	0	0	0.00	0.00	80	72
112	18.73	6	18.47	11698	0	0	0.00	0.00	80	72
150	22.08	38	20.41	11698	0	0	0.00	0.00	80	72
171	24.02	21	23.05	11718	20	5	0.22	0.20	85	77
195	24.37	24	24.20	11778	60	15	0.60	0.55	99	90
243	29.70	48	27.04	11778	0	0	0.00	0.00	99	90
387	42.07	144	35.89	12006	228	82	0.57	0.51	181	164
700	45.59	313	43.83	12052	46	20	0.06	0.06	201	182
913	87.42	213	66.51	12052	0	0	0.00	0.00	201	182
1012	85.94	99	86.68	12052	0	0	0.00	0.00	201	182

Table D-7-continued- % Methane from reactors that contained bacteria from **leachate** during bioreaction times.

Time (h)	%Methane	dt (h)	Average Methane (%)	Total Gas, P (ml)	dp Total gas (ml)	dp Methane (ml)	dp/dt Methane (ml/h)	dp/dt Methane (ml/h at STP)	Accumulative Methane (ml)	Accumulative Methane (ml at STP)
0	0	0	0	0	0	0				
32	0.145	32	0.07	7381	7381	5	0.17	0.15	5	5
48	0.15	16	0.15	11339	3958	6	0.36	0.33	11	10
60	0.13	12	0.14	11357	18	0	0.00	0.00	11	10
108	1.56	48	0.85	11463	106	1	0.02	0.02	12	11
1002	33	894	17.28	12217	754	130	0.15	0.13	142	128
1121	40	119	36.50	13548	1331	486	4.08	3.69	628	568
1137	42	16	41.00	13809	261	107	6.69	6.05	735	665
1237	52	100	47.00	15175	1366	642	6.42	5.81	1377	1245
1572	64	335	58.00	22726	7551	4380	13.07	11.82	5756	5206
1740	80	168	72.00	27537	4811	3464	20.62	18.65	9220	8339
1812	82	72	81.00	28798	1261	1021	14.19	12.83	10242	9263
1932	85	120	83.50	30199	1401	1170	9.75	8.82	11412	10321
2313	99.97	381	92.49	32158	1959	1812	4.76	4.30	13223	11959
2322	99.97	9	99.97	32273	115	115	12.77	11.55	13338	12063

Table D-8 Computation table to determine **the specific methane production rate, K_P.**

Septic Liquor									
Time (h)	MLVSS, X (mg/l)	$\bar{x}$ (mg/l)	$\bar{x}t$ (mg/l-h)	Accumulated Total Gas (ml)	Accumulated Total Gas (ml at STP)	dp Total Gas (ml at STP)	Average % Methane	dp CH_4 (ml at STP)	P, Accumulated Methane (ml at STP)
0				0	0		0		
24	1680	1680	40320	12357	11176	11176	2.88	322	
72	1780	1730	124560	19685	17808	6632	9.52	631	953
112	1840	1760	197120	21353	19312	1504	44.50	669	1623
150	1560	1620	243000	21669	19597	285	99.54	284	1906
195	1620	1650	321750	22297	20165	568	99.98	568	2474
243	1640	1660	403380	22561	20404	239	99.98	239	2713
651	2280	1980	1288980	25469	23034	2630	99.98	2629	5343
700	1880	1780	1246000	25691	23235	201	99.98	201	5543
913	1740	1710	1561230	26331	23814	579	99.98	579	6122
1012	1680	1680	1700160	26777	24217	403	99.98	403	6525

p , or P = Product= Methane

Slope = K_p= (dp/dt)X

Table D-8-continued- Computation table to determine **the specific methane production rate, K_P.**

Coastal Sediment									
Time (h)	MLVSS, X (mg/l)	$\bar{x}$ (mg/l)	$\bar{x}$ t (mg/l-h)	Accumulated Total Gas (ml)	Accumulated Total Gas (ml at STP)	dp Total Gas (ml at STP)	Average % Methane	dp CH_4 (ml at STP)	P, Accumulated Methane (ml at STP)
0							0		
24	2260	2260	54240	14588	13193	13193	0.67	88	88
72	2100	2180	156960	17830	16125	2932	15.09	442	530
96	2380	2320	222720	17946	16230	105	80.36	84	615
171	2840	2550	436050	19914	18010	1780	92.40	1645	2260
195	2660	2460	479700	20844	18851	841	94.64	796	3055
243	2740	2500	607500	22178	20058	1207	99.28	1198	4254
651	4200	3230	2102730	31179	28198	8140	99.62	8109	12363
700	3360	2810	1967000	31999	28940	742	99.97	742	13105
913	3260	2760	2519880	33793	30562	1622	99.97	1622	14726
1012	3280	2770	2803240	34441	31148	586	99.97	586	15312

p , or P = Product= Methane

Slope = K_p= (dp/dt)X

Table D-8-continued- Computation table to determine **the specific methane production rate, K_P.**

Brewery Wastewater Treatment Plant

Time (h)	MLVSS, X (mg/l)	$\bar{x}$ (mg/l)	$\bar{x}t$ (mg/l-h)	Accumulated Total Gas (ml)	Accumulated Total Gas (ml at STP)	dp Total Gas (ml at STP)	Average % Methane	dp CH_4 (ml at STP)	P, Accumulated Methane (ml at STP)
0	1200	1200							
72	1480	1340	96480	11536	10433	10433	1.21	126	126
96	1500	1350	129600	12600	11395	962	48.36	465	591
171	2160	1680	287280	13678	12370	975	49.66	484	1075
195	2360	1780	347100	13888	12560	190	52.12	99	1174
243	1800	1500	364500	13972	12636	76	52.12	40	1214
700	1900	1550	1085000	18931	17121	4485	99.97	4484	5698
1012	1340	1270	1285240	23037	20835	3714	99.97	3713	9411

p , or P = Product= Methane

Slope = K_p= (dp/dt)X

Table D-8-continued- Computation table to determine **the specific methane production rate, K_P.**

Acidic Sulfate Soil									
Time (h)	MLVSS, X (mg/l)	$\bar{x}$ (mg/l)	$\bar{x}t$ (mg/l-h)	Accumulated Total Gas (ml)	Accumulated Total Gas (ml at STP)	dp Total Gas (ml at STP)	Average % Methane	dp CH_4 (ml at STP)	P, Accumulated Methane (ml at STP)
0									
24	1820	1820	43680	11698	10580	10580	1.34	141.8	141.8
72	2480	2150	154800	11698	10580	0	16.09	0.0	141.8
96	2320	2070	198720	11718	10598	18	18.73	3.4	145.2
171	2220	2020	345420	11778	10652	54	24.02	13.0	158.1
195	2360	2090	407550	11778	10652	0	24.37	0.0	158.1
651	3820	2820	1835820	12052	10900	248	48.43	120.1	278.2
700	2800	2310	1617000	12052	10900	0	45.59	0.0	278.2
913	2640	2230	2035990	12052	10900	0	87.42	0.0	278.2
1012	2140	1980	2003760	12052	10900	0	85.94	0.0	278.2

p , or P = Product= Methane

Slope = K_p= (dp/dt)X

Table D-8-continued- Computation table to determine **the specific methane production rate, K_P.**

Leachate									
Time (h)	MLVSS, X (mg/l)	$\bar{x}$ (mg/l)	$\bar{x}t$ (mg/l-h)	Accumulated Total Gas (ml)	Accumulated Total Gas (ml at STP)	dp Total Gas (ml at STP)	Average % Methane	dp CH_4 (ml at STP)	P, Accumulated Methane (ml at STP)
0				0	0				
6				777	703	703	0	0	0
12				2133	1929	1226	0	0	0
35				10503	9499	7570	0.14	11	11
1002	2941	2941	2946882	12217	11049	1550	7.13	111	121
1337	1709	2325	2946882	16029	11497	448	52	233	354
1390	1737	2339	3108525	17633	15947	4450	64	2848	3202
1740	1597	2269	3251210	27537	24904	8957	80	7166	10368
2052	1373	2157	3948060	31207	28224	3320	99.97	3319	13687
2313	1793	2367	4426164	32158	29084	860	99.97	860	14546

p , or P = Product= Methane

Slope = K_p= (dp/dt)X

Table D-9 Computation table to determine **the methane production yield coefficient, $Y_{P/S}$.**

Septic Liquor										
Time (h)	COD, S_o (mg/l)	COD, S (mg/l)	S_o-S_t (mg/l)	Accumulated Total Gas (ml)	Accumulated Total Gas (ml at STP)	dp Total Gas (ml at STP)	Average % Methane	dp , Methane (ml at STP)	P, Accumulated Methane (ml at STP/5.5 l *)	P, Accumulated Methane (ml at STP/1 l)
0	20000	20000		0	0		0			
24	20000	14938	-5062	12357	11176	11176	2.88	322	322	59
72	20000	15240	-4760	19685	17808	6632	9.52	631	953	173
112	20000	15103	-4897	21353	19312	1504	44.50	669	1623	295
150	20000	14616	-5384	21669	19597	285	99.54	284	1906	347
195	20000	14433	-5567	22297	20165	568	99.98	568	2474	450
243	20000	14100	-5900	22561	20404	239	99.98	239	2713	493
651	20000	13740	-6260	25469	23034	2630	99.98	2629	5343	971
700	20000	12312	-7688	25691	23235	201	99.98	201	5543	1008
913	20000	12192	-7808	26331	23814	579	99.98	579	6122	1113
1012				26777	24217	403	99.98	403	6525	1186

S_o-S_t = Waste utilized
p , or P = Product
* 5.5 l = 5.5 liter working volume of a reactor

Table D-9-continued- Computable table for the determination of methane production yield coefficient, $Y_{P/S}$

Coastal Sediment										
Time (h)	COD, S_o (mg/l)	COD, S (mg/l)	S_o- S_t (mg/l)	Accumulated Total Gas (ml)	Accumulated Total Gas (ml at STP)	dp Total Gas (ml at STP)	Average % Methane	dp , Methane (ml at STP)	P, Accumulated Methane (ml at STP/5.5 l*)	P, Accumulated Methane (ml at STP/1 l)
0	20000	20000					0			
24	20000	19325	-675	14588	13193	13193	0.67	88	88	16
72	20000	19440	-560	17830	16125	2932	15.09	442	530	96
96	20000	17640	-2360	17946	16230	105	80.36	84	615	112
171	20000	16199	-3801	19914	18010	1780	92.40	1645	2260	411
195	20000	15741	-4259	20844	18851	841	94.64	796	3055	556
243	20000	11943	-8057	22178	20058	1207	99.28	1198	4254	773
651	20000	9135	-10865	31179	28198	8140	99.62	8109	12363	2248
700	20000	7688	-12312	31999	28940	742	99.97	742	13105	2383
913	20000	7627	-12373	33793	30562	1622	99.97	1622	14726	2677
1012	20000	7620	-12380	34441	31148	586	99.97	586	15312	2784

S_o-S_t = Waste utilized
p , or P = Product
* 5.5 l = 5.5 liter working volume of a reactor

Table D-9-continued- Computable table for the determination of methane production yield coefficient, $Y_{P/S}$

Brewery Wastewater Treatment Plant										
Time (h)	COD, S_o (mg/l)	COD, S (mg/l)	S_o- S_t (mg/l)	Accumulated Total Gas (ml)	Accumulated Total Gas (ml at STP)	dp Total Gas (ml at STP)	Average % Methane	dp , Methane (ml at STP)	P, Accumulated Methane (ml at STP/5.5 l*)	P, Accumulated Methane (ml at STP/1 l)
0	20000	20000								
72	20000	13800	-6200	11536	10433	10433	1.21	126	126	23
96	20000	13800	-6200	12600	11395	962	48.36	465	591	107
171	20000	13276	-6724	13678	12370	975	49.66	484	1075	196
195	20000	12583	-7417	13888	12560	190	52.12	99	1174	214
243	20000	10835	-9165	13972	12636	76	52.12	40		
700	20000	10751	-9249	18931	17121	4485	99.97	4484	4484	815
1012	20000	9720	-10280	23037	20835	3714	99.97	3713	8197	1490

S_o-S_t = Waste utilized
p , or P = Product
* 5.5 l = 5.5 liter working volume of a reactor

Table D-9-continued- Computable table for the determination of methane production yield coefficient, $Y_{P/S}$

Acidic Sulfate Soil										
Time (h)	COD, S_o (mg/l)	COD, S (mg/l)	S_o- S_t (mg/l)	Accumulated Total Gas (ml)	Accumulated Total Gas (ml at STP)	dp Total Gas (ml at STP)	Average % Methane	dp , Methane (ml at STP)	P, Accumulated Methane (ml at STP/5.5 l*)	P, Accumulated Methane (ml at STP/1 l)
0	20000	20000								
24	20000	19562	-438	11698	10580	10580	1.34	141.8	141.8	26
72	20000	18720	-1280	11698	10580	0	16.09	0.0	141.8	26
96	20000	18600	-1400	11718	10598	18	18.73	3.4	145.2	26
171	20000	18635	-1365	11778	10652	54	24.02	13.0	158.1	29
195	20000	18751	-1249	11778	10652	0	24.37	0.0	158.1	29
651	20000	17661	-2339	12052	10900	248	48.43	120.1	278.2	51
700	20000	16577	-3423	12052	10900	0	45.59	0.0	278.2	51
913	20000	16577	-3423	12052	10900	0	87.42	0.0	278.2	51
1012	20000	14400	-5600	12052	10900	0	85.94	0.0	278.2	51

S_o-S_t = Waste utilized
p , or P= Product
* 5.5 l = 5.5 liter working volume of a reactor

Table D-9-continued- Computable table for the determination of methane production yield coefficient, $Y_{P/S}$

Leachate										
Time (h)	COD, S_o (mg/l)	COD, S (mg/l)	S_o- S_t (mg/l)	Accumulated Total Gas (ml)	Accumulated Total Gas (ml at STP)	dp Total Gas (ml at STP)	Average % Methane	dp , Methane (ml at STP)	P, Accumulated Methane (ml at STP/5.5 l*)	P, Accumulated Methane (ml at STP/1 l)
0	20000	20000		0	0					
6	20000			777	703	703	0	0	0	0
12	20000			2133	1929	1226	0	0	0	0
35	20000			10503	9499	7570	0.14	11	11	2
1002	20000	14562	-5438	12217	11049	1550	7.13	111		
1337	20000	17716	-2284	16029	11497	448	52	233	233	42
1390	20000	19020	-980	17633	15947	4450	64	2848	3081	560
1740	20000	12672	-7328	27537	24904	8957	80	7166	10247	1863
2052	20000	12087	-7913	31207	28224	3320	99.97	3319	13566	2466
2313	20000	11616	-8384	32158	29084	860	99.97	860	14425	2623

S_o-S_t = Waste utilized
p , or P = Product
* 5.5 l = 5.5 liter working volume of a reactor

Table D-10 VFA's (mg/l) in each reactor at various times.

Time (h)	VFA's (mg/l)											
	Septic Liquor			Coastal Sediment			Brewery Wastewater Treatment Plant			Acidic Sulfate Soil		
	Acetic	Propionic	Butyric	Acetic	Propionic	Butyric	Acetic	Propionic	Butyric	Acetic	Propionic	Butyric
10			3966			3462			2442		74	3282
50		48	3012	22128	36	2148	25662	36	2004	6318	19	1686
72	28266	75	3456	22212	29	3750	33666	29	2730	3954	59	3102
90	25338	101	3036	3330	69	6366	7398	69	4488	5640	91	4902
150	15216	195	15180	5016	74	10770	6048	103	7002	7236	112	6684

Table D-11 Acetic acid in reactors that contained different mixed-bacteria from various sources during bioreaction times.

Time (h)	Acetic Acid (mg/l)			
	Septic Liquor	Coastal Sediment	Brewery Wastewater Treatment Plant	Acidic Sulfate Soil
50		22128	25662	6318
72	28266	22212	33666	3954
90	25338	3330	7398	5640
150	15216	5016	6048	4824

Table D-12 The time course of sulfate from reactors that contained different mixed-bacteria from various sources.

Time (h)	SO_4^{2-} (mg/l)				
	Septic Liquor	Coastal Sediment	Brewery Wastewater Treatment plant	Acidic Sulfate Soil	Leachate
0.5	1122	1118	1157	1094	1035
4	1640				
8		1169	1059	1075	1051
46	859	929	690	761	725
98		686	628	229	479
147	791	734	827	163	589
245		752			
984	870	127	796	114	264
1320	936	145	536	97	105

Table D-13 The computation table to determine **the specific sulfate reduction rate** from **Group A** reactors(that contained **sulfate**).

Time (h)	Septic Liquor				
	SO_4^{2-} (mg/l)	MLVSS, X(mg/l)	$\bar{x}$ (mg/l)	$\bar{x}$ t (mg/l-h)	Ln SO_4
0.5	1122	2180	2180	1090	7.023
4	1640	1640	1910	7640	7.402
46	859	2120	2150	98900	6.756
147	791	2740	2460	361620	6.673
984	870	2140	2160	2125440	6.768
1320	936	1960	2070	2732400	6.842

Table D-13 -continued- The computation table to determine **the specific sulfate reduction rate** from **Group A** reactors(that contained **sulfate**).

Time (h)	Coastal Sediment				
	SO_4^{2-} (mg/l)	MLVSS, X(mg/l)	$\bar{x}$ (mg/l)	$\bar{x}$ t (mg/l-h)	Ln SO_4
0.5	1118				
8	1169	2480	2480	1240	7.019
46	929	1920	2200	17600	7.064
98	686	2160	2320	106720	6.834
147	734	2840	2660	260680	6.531
245	752	2040	2260	332220	6.599
984	127	3460	2970	727650	6.623
1320	145	3080	2780	2735520	4.844

Table D-13 -continued- The computation table to determine **the specific sulfate reduction rate** from **Group A** reactors(that contained **sulfate**).

Time (h)	Brewery Wastewater Treatment Plant				
	SO_4^{2-} (mg/l)	MLVSS, X(mg/l)	$\bar{x}$ (mg/l)	$\bar{x}$ t (mg/l-h)	Ln SO_4
0.5	1157				
8	1059	1640	1640	13120	6.965
46	690	1900	1770	81420	6.537
98	628	2340	1990	195020	6.443
147	827	2100	1870	274890	6.718
984	796	1480	1560	1535040	6.680
1320	536	1760	1700	2244000	6.284

Table D-13 -continued- The computation table to determine **the specific sulfate reduction rate** from **Group A** reactors(that contained **sulfate**).

Time (h)	Acidic Sulfate Soil				
	SO_4^{2-} (mg/l)	MLVSS, X(mg/l)	$\bar{x}$ (mg/l)	$\bar{x}$ t (mg/l-h)	Ln SO_4
0.5	1094				
8	1075	1160	1160	9280	6.980
46	761	2500	1830	84180	6.635
98	229	2260	1710	167580	5.434
147	163	1920	1540	226380	5.094
984	114	1460	1310	1289040	4.736
1320	97	1800	1480	1953600	4.575

Table D-13 -Continued- The determination of specific sulfate reduction rate for reactor containing sulfate (that contained **sulfate**).

Time (h)	Leachate				
	SO_4^{2-} (mg/l)	MLVSS, X(mg/l)	$\bar{x}$ (mg/l)	$\bar{x}$ t (mg/l-h)	Ln SO_4
0.5	1035	2980	2980	1490	6.942
8	1051	2520	2750	22000	6.957
46	725	2760	2870	132020	6.586
98	479	2320	2650	259700	6.172
147	589	1920	2450	360150	6.378
984	264	1420	1870	1840080	5.576
1320	105	2160	2570	3392400	4.654

Table D-14 The computation table to determine **the specific sulfate reduction rate** from **Group B** reactors (that contained **sulfate** and **copper**).

Time (h)	Septic Liquor				
	SO_4^{2-} (mg/l)	MLVSS, X(mg/l)	$\bar{x}$	$\bar{x}$ t (mg/l-h)	Ln SO_4
0.5	1047	1340	1340	670	6.954
8	1275	2720	2030	16240	7.151
46	796	1900	1620	74520	6.680
147	668	1660	1500	220500	6.504
984	360	1180	1260	1239840	5.886
1320	255	1700	1520	2006400	5.541

Table D-14 -continued- The computation table to determine **the specific sulfate reduction rate** from **Group B** reactors (that contained **sulfate** and **copper**).

Time (h)	Coastal Sediment				
	SO_4^{2-} (mg/l)	MLVSS, X(mg/l)	$\bar{x}$	$\bar{x}$ t (mg/l-h)	Ln SO_4
0.5	1086	1120	1120	560	6.9903
8	1122	2220	1670	13360	7.0229
46	745	2380	1750	80500	6.613
98	774	1700	1410	138180	6.652
124	776	2320	1720	213280	6.654
245	752	2460	1790	438550	6.623
984	123	1600	2030	1997520	4.812
1320	79	2920	2020	2666400	4.369

Table D-14 -continued- The computation table to determine **the specific sulfate reduction rate** from **Group B** reactors (that contained **sulfate** and **copper)**.

Time (h)	Brewery Wastewater Treatment Plant				
	SO_4^{2-} (mg/l)	MLVSS, X(mg/l)	$\bar{x}$	$\bar{x}$ t (mg/l-h)	Ln SO_4
0.5	1153	980	980	490	7.050
98	875	1980	1480	145040	6.774
147	756	1980	1480	217560	6.628
245	642	2160	1570	384650	6.465
984	495	1740	1360	1338240	6.205
1320	151	1980	1480	1953600	5.017

Table D-14 -continued- The computation table to determine **the specific sulfate reduction rate** from **Group B** reactors (that contained **sulfate** and **copper)**.

Time (h)	Acidic Sulfate Soil				
	SO_4^{2-} (mg/l)	MLVSS, X(mg/l)	$\bar{x}$	$\bar{x}$ t (mg/l-h)	Ln SO_4
0.5	1188	1420	1420	710	7.080
8	1110	2620	2020	16160	7.012
46	737	2540	1980	91080	6.603
98	273	1980	1700	166600	5.609
984	145	1720	1570	1544880	4.977
1320	75	2940	2180	2877600	4.317

Table D-14 -continued- The computation table to determine **the specific sulfate reduction rate** from **Group B** reactors (that contained **sulfate** and **copper**).

Time (h)	Leachate				
	SO_4^{2-} (mg/l)	MLVSS, X(mg/l)	$\bar{x}$	$\bar{x}$ t (mg/l-h)	Ln SO_4
0.5	1208	1180	1180	590	7.097
46	949	2960	2070	95220	6.855
98	787	2180	1680	164640	6.668
147	449	2400	1790	263130	6.107
984	180	2500	1840	1810560	5.193
1320	150	2760	1970	2600400	5.011

Table D-15 The influent, effluent COD and the percentage of COD removal **(without any toxicants*)**.

Bacterial Sources	COD (mg/l)		
	Initial	Final	% COD removal
Septic Liquor	20000	9787	50
Coastal Sediment	20000	7394	63
Brewery WWTP	20000	8454	57
Acidic Sulfate Soil	20000	12337	38
Leachate	20000	11616	42

* Data for Section 4.4.2

Table D-15 - continued- The influent, effluent COD and the percentage of COD removal from **Group A** reactors **(with SO_4^{2-} 2,100 mg/l)**.

Bacterial sources	COD (mg/l)		
	Initial	Final	% COD removal
Septic Liquor	20000	16413	18
Coastal Sediment	20000	14169	29
Brewery WWTP	20000	17975	10
Acidic Sulfate Soil	20000	16132	19
Leachate	20000	16501	18

Table D-15 - continued- The influent, effluent COD and the percentage of COD removal from **Group B** reactors **(with SO_4^{2-} 2100 mg/l and Cu 10 mg/l)**.

Bacterial sources	COD (mg/l)		
	Initial	Final	% COD removal
Septic Liquor	20000	15280	24
Coastal Sediment	20000	14060	30
Brewery WWTP	20000	13195	34
Acidic Sulfate Soil	20000	13654	32
Leachate	20000	14817	26

Table D-16 Comparison on the percentage of COD removal.

Bacterial Sources	% COD removal		
	without SO_4^{2-} and Cu	with SO_4^{2-} 2100 mg/l	with SO_4^{2-} 2100 mg/l + Cu 10 mg/l
Septic Liquor	50	18	24
Coastal Sediment	63	29	30
Brewery WWTP	57	10	34
Acidic Sulfate Soil	38	19	32
Leachate	42	18	26

Appendix E

Chromatogram from GC and the Standard graph from AAS

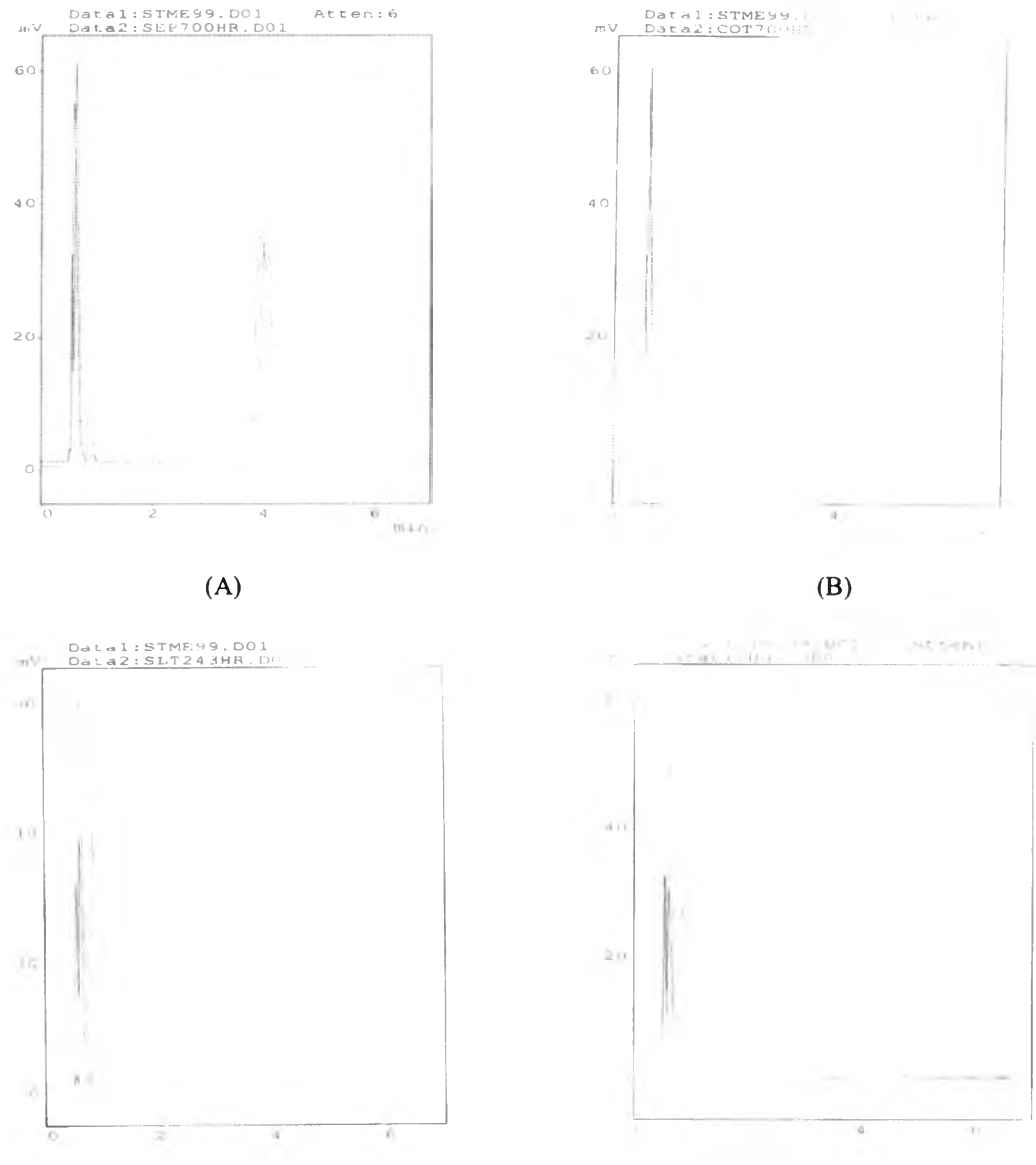


Figure E-1 Chromatogram of gas produced from reactors that contained different mixed-bacteria at time 243 hours: (A) Septic liquor, (B) Coastal sediment, (C) Brewery wastewater treatment plant and (D) Acidic sulfate soil. The standard methane 99.99% is shown to compare with the gas produced from the reactors. Peak at time 4 minutes is methane.

Figure E-2 Chromatogram of gas produced from reactors that contained different mixed-bacteria at time 387 hours. Peak at time 4 minutes is methane. The standard methane 99.99% (the highest peak) is compared to quantify the amount of methane.

Data File C:\HPCHEM\1\DATA\VFAS\NMIXACID.D Sample Name: mixed acic
microbial toxicity

Injection Date : 6/13/04 3:31:10 AM
Sample Name : mixed acid Vial :
Acq. Operator : NRS Inj : 1
Inj Volume : Manually
Method : C:\HPCHEM\1\METHODS\NRSVFA.M
Last changed : 6/13/04 2:21:05 AM by NRS
(modified after loading)

External Standard Report

Sorted By : Signal
Multiplier : 1.0000
Dilution : 1.0000
Sample Amount : 1.20000 [ng/ul] (not used in calc.)

Summed Peaks Report

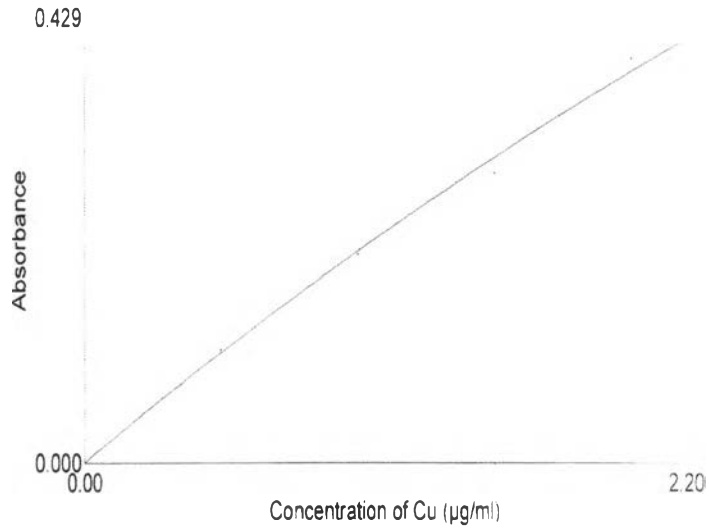
Signal 1: FID1 A,

Final Summed Peaks Report

Signal 1: FID1 A,

Instrument 1 6/13/04 3:37:13 AM NRS Page 1 of 2

Figure E-3 Chromatogram of VFA's. The peaks at time 1.915, 2.248 and 2.796 (under the tested conditions) are acetic, propionic and butyric acid.



Analysis	
Filename	C:\Program Files\GBC Avanta Ver 2 01\
Date	Sun Jul 04 21:53:34 2004
Method	
Training GBC AvantaPM	
Instrument Parameters	
System Type	Flame
Element	Cu
Matrix	in water
Lamp Current	3.0 mA
Wavelength	324.7 nm
Slit Width	0.5 nm
Slit Height	Normal
Instrument Mode	Abs. BC On
Sample Measurement Parameters	
Measurement Mode	Integration
Sample Introduction	Manual
Read Time	3.0 s
Time Constant	0.0
Replicates	3
Calibration Parameters	
Calibration Mode	Conc Least Squares
Overrange Sample Action	None
Conc. Units	µg/ml
Conc. Decimal Places	3
Calibration Failure On	None
Calibration Failure Action	Stop
Measure Sample Blank After Cal.	Yes
Auto Save Method After Cal.	Yes

Figure E-4 The standard graph of Cu from atomic absorption spectrophotometry (flame technic).

Appendix F

SEM - EDX

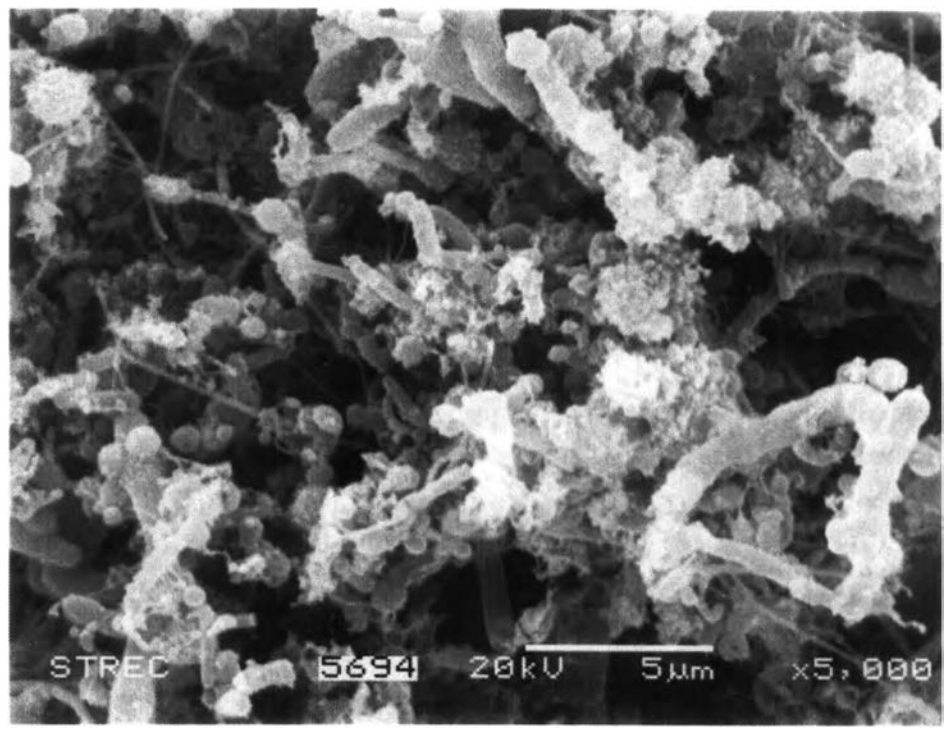


Figure F-1 Scanning Electron Micrograph of glucose acclimated bacteria from a brewery wastewater treatment plant.

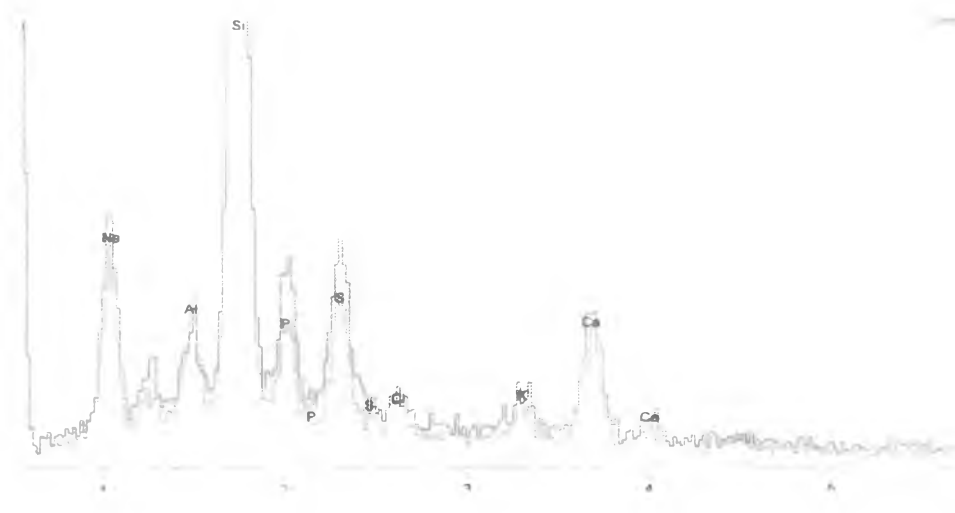


Figure F-2 EDX spectrum to show the peak of sulfide before (red line) and after (blue line) precipitation with Cd.

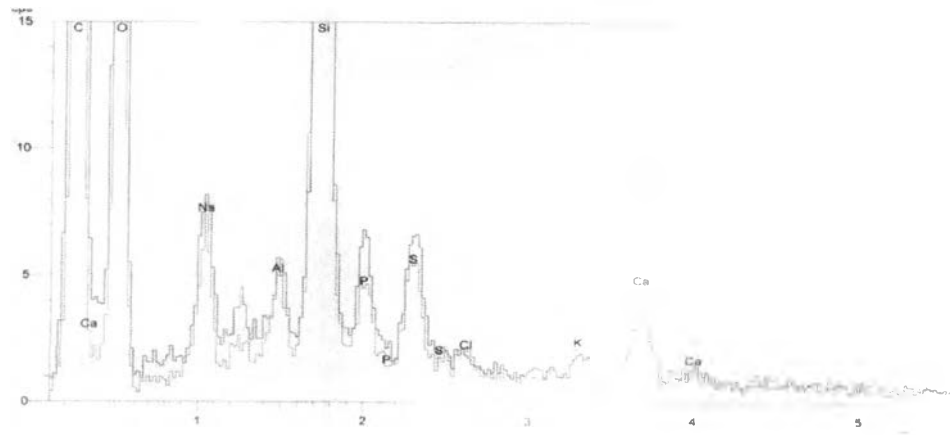


Figure F-3 EDX spectrum to show the peak of sulfide before (red line) and after (blue line) precipitation with Cu.

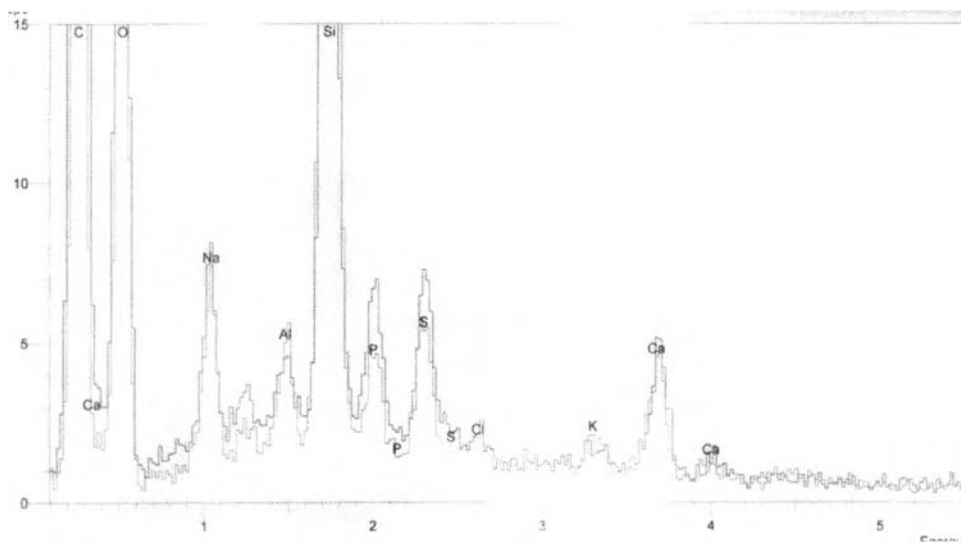


Figure F-4 EDX spectrum to show the peak of sulfide before (red line) and after (blue line) precipitation with Zn.

Appendix G

Raw Data of Chapter 5

Optimum Reactor Conditions for Simultaneous Control of Sulfate and Heavy metals in Complex Wastewater Streams

Table G-1 The time course of SO_4^{2-} presented in the effluent with various SO_4^{2-} starting concentrations and the percentage of SO_4^{2-} removal.

	Residual SO_4^{2-}(mg/l)			
COD:S	1 hour	72 hours	120 hours	**% SO_4^{2-} Removal**
13.7	700	324	0	100.0
9	1100	702	118	89.3
7.4	1300	756	106	91.9
4.5	2100	1956	207	90.1
3.7	2600	2667	1167	55.1

Table G-2 The SO_4^{2-} removed and average rate of SO_4^{2-} reduction in 120 hours (mg/l-h).

COD:S	Initial SO_4^{2-} (mg/l)	Final SO_4^{2-} (mg/l)	**SO_4^{2-} removed** (mg/l)	**Average Rate of SO_4^{2-} Reduction** in 120 hours (mg/l-h)
13.7	700	0	700	5.83
9	1100	118	982	8.19
7.4	1300	106	1194	9.95
4.5	2100	207	1893	15.77
3.7	2600	1167	1433	11.94

Table G-3 The amount of total gas (STP), the percentage and the amount of methane from various reactors that contained different COD:S ratios.

	COD:S = 13.7			COD:S = 9			COD:S = 7.4		
Time (hour)	Total Gas (ml at STP)	%CH_4	CH_4 (ml at STP)	Total Gas (ml at STP)	%CH_4	CH_4 (ml at STP)	Total Gas (ml at STP)	%CH_4	CH_4 (ml at STP)
0									
1	4.67	1.86	0.09	6.37	3.75	0.24	6.10	4.60	0.28
3	20.97	22.00	4.61	24.56	20.00	4.91	23.05	24.00	5.53
6	13.04	42.39	5.53	16.81	46.59	7.83	15.68	48.85	7.66
12	6.14	68.86	4.23	13.22	79.26	10.48	14.17	66.85	9.47
24	16.81	54.03	9.08	27.39	68.03	18.64	27.39	64.35	17.63
48	0.00	35.96	0.00	9.35	46.38	4.34	5.20	43.46	2.26
72	1.32	34.94	0.46	10.49	37.68	3.95	9.64	41.01	3.95
96	1.10	35.07	0.38	9.27	38.54	3.57	10.77	34.61	3.73
120	0.00	19.86	0.00	0.50	20.18	0.10	0.30	28.52	0.09
Total Gas (ml at STP)	64.05		24.39	117.97		54.07	112.29		50.59

Table G-3-continued- The amount of total gas (STP), the percentage and the amount of methane from various reactors that contained different COD:S ratios.

	COD:S = 4.5			COD:S = 3.7		
Time (hour)	Total Gas (ml at STP)	%CH_4	CH_4 (ml at STP)	Total Gas (ml at STP)	%CH_4	CH_4 (ml at STP)
0						
1	6.19	2.00	0.12	6.28	1.99	0.13
3	24.75	19.00	4.70	25.60	17.00	4.35
6	13.98	43.38	6.06	13.79	38.89	5.36
12	12.75	67.72	8.64	10.11	59.55	6.02
24	26.45	53.72	14.21	25.51	47.75	12.18
48	5.86	35.00	2.05	7.93	32.15	2.55
72	0.19	35.36	0.07	9.26	33.34	3.09
96	3.19	34.62	1.10	10.17	23.50	2.39
120	0.50	11.17	0.06	0.50	12.34	0.06
Total Gas (ml at STP)	93.86		37.01	109.15		36.13

Table G-4 The percentage, the amount of methane and the accumulated methane in reactors, expressed at STP.

Time (hour)	COD:S = 13.7 (SO_4^{2-} = 700 mg/l)			
	Total Gas (ml at STP)	%CH_4	CH_4 (ml at STP)	**Accumulated CH_4 (ml at STP)**
1	4.7	1.85	0.1	0.1
3	21.0	22.00	4.6	4.7
6	13.0	42.39	5.5	10.2
12	6.1	68.86	4.2	14.5
24	16.8	54.03	9.1	23.5
48	0.0	35.96	0.0	23.5
72	1.3	34.94	0.5	24.0
96	1.1	35.07	0.4	24.4
120	0.0	19.86	0.0	24.4
	64.0		24.4	

Table G-4 -continued- The percentage, the amount of methane and the accumulated methane in reactors, expressed at STP.

Time (hour)	COD:S = 9 (SO_4^{2-} = 1100 mg/l)			
	Total gas (ml at STP)	%CH_4	CH_4 (ml at STP)	**Accumulated CH_4 (ml at STP)**
1	6.4	3.75	0.2	0.2
3	24.6	20.00	4.9	5.2
6	16.8	46.59	7.8	13.0
12	13.2	79.26	10.5	23.5
24	27.4	68.03	18.6	42.1
48	9.4	46.38	4.3	46.4
72	10.5	37.68	4.0	50.4
96	9.3	38.54	3.6	54.0
120	0.5	20.18	0.1	54.1
	118.0		54.1	

Table G-4 -continued- The percentage, the amount of methane and the accumulated methane in reactors, expressed at STP.

Time (hour)	COD:S = 7.4 (SO_4^{2-} = 1300 mg/l)			
	Total Gas (ml at STP)	%CH_4	CH_4 (ml at STP)	**Accumulated CH_4 (ml at STP)**
1	6.1	4.60	0.3	0.3
3	23.0	24.00	5.5	5.8
6	15.7	48.85	7.7	13.5
12	14.2	66.85	9.5	22.9
24	27.4	64.35	17.6	40.6
48	5.2	43.46	2.3	42.8
72	9.6	41.01	4.0	46.8
96	10.8	34.61	3.7	50.5
120	0.3	28.52	0.1	50.6
	112.3		50.6	

Table G-4 -continued- The percentage, the amount of methane and the accumulated methane in reactors, expressed at STP.

Time (hour)	COD:S = 4.5 (SO_4^{2-} = 2100 mg/l)			
	Total Gas (ml at STP)	%CH_4	CH_4 (ml at STP)	**Accumulated CH_4 (ml at STP)**
1	6.2	2.00	0.1	0.1
3	24.7	19.00	4.7	4.8
6	14.0	43.38	6.1	10.9
12	12.8	67.72	8.6	19.5
24	26.4	53.72	14.2	33.7
48	5.9	35.00	2.0	35.8
72	0.2	35.36	0.1	35.9
96	3.2	34.62	1.1	37.0
120	0.5	11.17	0.1	37.0
	93.9		37.0	

Table G-4 -continued- The percentage, the amount of methane and the accumulated methane in reactors, expressed at STP.

Time	COD:S = 3.7 (SO_4^{2-} = 2600 mg/l)			
(hour)	Total Gas (ml at STP)	%CH_4	CH_4 (ml at STP)	**Accumulated CH_4 (ml at STP)**
1	6.3	1.99	0.1	0.1
3	25.6	17.00	4.4	4.5
6	13.8	38.89	5.4	9.8
12	10.1	59.55	6.0	15.9
24	25.5	47.75	12.2	28.0
48	7.9	32.15	2.6	30.6
72	9.3	33.34	3.1	33.7
96	10.2	23.50	2.4	36.1
120	0.5	12.34	0.1	36.1
	109.1		36.1	

Table G-5 The **specific methanogenic activities** (SMAs) from glucose.

Influent COD (mg/l)	Effluent COD (mg/l)	SO_4^{2-} (mg/l)	COD:S	Initial MLVSS (mg/l)	CH_4 gas COD* (mg/l)	SMAs g CH_4 gas COD/ g MLVSS	**SMAs ** gCH_4 gas COD/ g COD removal -g MLVSS**
3200	560	700	13.7	9645	696	0.0722	0.2736
3200	445	1100	9	9645	1546	0.1602	0.5813
3200	526	1300	7.4	9645	1447	0.1499	0.5605
3200	526	2100	4.5	9645	1057	0.1096	0.4100
3200	775	2600	3.7	9645	1031	0.1070	0.4413

* and ** Calculation was shown in Appendix A-5.

Table G-6 The influent, effluent and the percentage of COD removal.

SO_4^{2-} (mg/l)	COD:S	Influent COD(mg/l)	Effluent COD(mg/l) at t=120 h	**%COD Removal**
700	13.7	3200	560	82.50
1100	9	3200	445	86.09
1300	7.4	3200	526	83.56
2100	4.5	3200	526	83.56
2600	3.7	3200	775	75.78

Table G-7 The initial and final pH presented in the wastewater.

Initial SO_4^{2-} (mg/l)	COD:S	**Initial pH**	**Final pH** at t=120 hours
700	13.7	7.0	7.97
1100	9	7.0	7.69
1300	7.4	7.0	7.74
2100	4.5	7.0	7.68
2600	3.7	7.0	7.74

Table G-8 Computation table to determine the recovered CH_4-COD in gas phase (CH_4 gas COD) for reactors that contained different COD:S ratios.

COD:S	CH_4(ml at STP)/ 100 ml *	CH_4(ml at STP)/ 1 liter	CH_4** (mol/ l at STP)	CH_4 gas COD		
				CH_4** * (g/ l at STP)	CH_4 (mg/ l at STP)	**CH_4 gas COD** ** * (mg/l)**
13.7	24.4	244	0.01089	0.1742	174.2	696
9	54.1	541	0.02415	0.3864	386.4	1546
7.4	50.6	506	0.02258	0.3614	361.4	1447
4.5	37.0	370	0.01651	0.2642	264.3	1057
3.7	36.1	361	0.01611	0.2578	257.8	1031

*Total working volume
** 1 mol of gas at STP = 22.4 liters
** * CH4 1mol = 16 g
** * * CH_4 gas COD (mg/l) = CH_4 (mg/ l at STP) x 4

Table G-9 Computation table to determine ΔSO_4^{2-} COD for reactors that contained different COD:S ratios.

COD:S	Initial SO_4^{2-} (mg/l)	SO_4^{2-} Removed* (mg/l)	**ΔSO_4^{2-}- COD(mg/l)**
13.7	700	700	466
9	1100	982	654
7.4	1300	1194	796
4.5	2100	1983	1262
3.7	2600	1333	888

* Data from Table G-2
** ΔSO_4^{2-}- COD(mg/l) = SO_4^{2-} Removed x 2/3

Table G-10 Balance of COD and distribution of electrons to methanogenesis and sulfate reduction.

COD:S	COD				% Electron Flow		
	Effluent (mg/l)	CH_4 gas COD (mg/l)	ΔSO_4^{2-}COD (mg/l)	Others (%)	MPB*	SRB**	% COD Balance
13.7	17.5	651 (21.77)	466 (14.59)	46.14	58.28	41.72	53.86
9	13.9	1546 (48.27)	654 (19.91)	17.92	70.81	29.19	82.08
7.4	16.43	1447 (45.17)	796 (24.50)	13.9	64.84	35.19	86.10
4.5	16.43	1057 (33.05)	1262 (40.00)	10.52	45.24	54.76	89.48
3.7	24.21	1031 (32.25)	888 (29.03)	14.51	52.64	47.36	85.49

Data in the parenthesis is in the unit of per cent.

* % Electron flow to MPB = $(CH_4gas\text{-}COD + CH_4aq\text{-}COD) / (CH_4gas\text{-}COD + CH_4aq\text{-}COD + \Delta SO_4^{2-}\text{-}COD)$

** % Electron flow to MPB = $(\Delta SO_4^{2-}\text{-}COD) / (CH_4gas\text{-}COD + CH_4aq\text{-}COD + \Delta SO_4^{2-}\text{-}COD)$

Table G-11 The amount of VFA's at time 120 hours.

SO_4^{2-} (mg/l)	COD:S	**VFA's** (mg/l) at t =120 hours		
		Acetic Acid	Propionic Acid	Butyric Acid
700	13.7	609	1497	848
1100	9	374	1179	734
2100	4.5	502	1367	805
2600	3.7	901	1748	1614

Appendix H

Raw data of Chapter 6

The Maximum Concentration of Heavy Metals in Wastewater that will not Cause Synergistic Inhibition to Anaerobic Wastewater Treatment

Table H-1 The amount of total gas (STP), the percentage and the amount of methane from various reactors after dozing **a single metal.**

Time (hour)	R 1		
	Total gas (ml at STP)	$\%CH_4$	CH_4 (ml at STP)
0			
1	5.12	1.81	0.09
3	23.62	18.00	4.25
6	16.06	47.17	7.57
12	11.52	77.32	8.91
24	23.24	56.26	13.07
48	9.45	43.54	4.11
72	6.80	44.83	3.05
96	5.68	20.81	1.18
120	0.00	18.00	0.00
Total Gas (ml at STP)	101.48		42.25

R 1 = No metal control, COD:S = 9

Table H-1-continued- The amount of total gas (STP), the percentage and the amount of methane from various reactors after dozing **a single metal.**

Time (hour)	R 2			R 3		
	Total Gas (ml at STP)	$\%CH_4$	CH_4 (ml at STP)	Total Gas (ml at STP)	$\%CH_4$	CH_4 (ml at STP)
0						
1	2.24	0.43	0.01	2.78	0.43	0.01
3	3.78	1.00	0.04	5.10	0.80	0.04
6	6.42	2.19	0.14	5.29	1.17	0.06
12	3.40	10.39	0.35	1.98	0.91	0.02
24	16.81	45.92	7.72	7.93	16.98	1.35
48	25.60	27.88	7.14	33.06	47.32	15.64
72	5.57	20.03	1.12	5.10	26.01	1.33
96	7.18	14.37	1.03	9.87	19.59	1.93
120	2.39	14.98	0.36	1.50	15.22	0.23
Total Gas (ml at STP)	73.41		17.91	72.62		20.61

R 2 = COD:S = 9, Cd =5 mg/l
R 3 = COD:S = 9, Cd =10 mg/l

Table H-1-continued- The amount of total gas (STP), the percentage and the amount of methane from various reactors after dozing **a single metal.**

Time (hour)	R 4			R 5		
	Total Gas (ml at STP)	$\%CH_4$	CH_4 (ml at STP)	Total Gas (ml at STP)	$\%CH_4$	CH_4 (ml at STP)
0						
1	2.78	0.69	0.02	2.78	0.71	0.02
3	4.25	0.50	0.02	3.59	0.84	0.03
6	5.86	1.19	0.07	4.53	1.01	0.05
12	1.32	1.23	0.02	1.79	0.92	0.02
24	2.74	0.85	0.02	0.94	1.31	0.01
48	28.91	44.85	12.96	4.82	5.36	0.26
72	23.43	35.86	8.40	30.79	48.25	14.86
96	3.99	25.13	1.00	4.39	14.26	0.63
120	5.58	18.11	1.01	1.89	13.72	0.26
Total Gas (ml at STP)	78.86		23.53	55.54		16.13

R 4 = COD:S = 9, metal Cd = 15 mg/l
R 5 = COD:S = 9, metal Cd = 20 mg/l

Table H-1-continued- The amount of total gas (STP), the percentage and the amount of methane from various reactors after dozing **a single metal.**

Time (hour)	R 6			R 7		
	Total Gas (ml at STP)	$\%CH_4$	CH_4 (ml at STP)	Total Gas (ml at STP)	$\%CH_4$	CH_4 (ml at STP)
0						
1	2.51	0.78	0.02	2.78	0.48	0.01
3	16.44	14.00	2.30	9.92	10.00	0.99
6	17.76	35.14	6.24	18.33	22.47	4.12
12	8.60	35.22	3.03	7.08	39.69	2.81
24	24.94	61.23	15.27	28.15	71.76	20.20
48	9.45	37.26	3.52	13.70	37.22	5.10
72	9.92	37.67	3.74	7.46	34.37	2.56
96	10.57	35.68	3.77	9.27	22.08	2.05
120	0.60	20.50	0.12	1.70	21.29	0.36
Total Gas (ml at STP)	100.78		38.01	98.39		38.21

R 6 = COD:S = 9, metal Cu = 0.5 mg/l
R 7 = COD:S = 9, metal Cu = 1 mg/l

Table H-1-continued- The amount of total gas (STP), the percentage of methane analyzed and the amount of methane determined from various reactors after dozing **a single metal.**

Time (hour)	R 8			R 9		
	Total Gas (ml at STP)	$\%CH_4$	CH_4 (ml at STP)	Total Gas (ml at STP)	$\%CH_4$	CH_4 (ml at STP)
0						
1	2.69	0.53	0.01	2.15	0.57	0.01
3	8.03	6.40	0.51	7.56	5.60	0.42
6	19.84	17.16	3.40	17.19	13.07	2.25
12	5.67	34.96	1.98	5.57	37.31	2.08
24	24.75	75.55	18.70	23.43	66.82	15.65
48	13.79	50.65	6.99	14.36	38.96	5.59
72	9.64	46.81	4.51	4.82	34.14	1.64
96	7.48	34.28	2.56	8.38	21.84	1.83
120	0.20	20.48	0.04	0.20	8.23	0.02
Total Gas (ml at STP)	92.08		38.71	83.65		29.50

R 8 = COD:S = 9, metal Cu = 1.5 mg/l
R 9 = COD:S = 9, metal Cu = 2mg/l

Table H-1-continued- The amount of total gas (STP), the percentage and the amount of methane from various reactors after dozing **a single metal.**

Time (hour)	R 10			R 11		
	Total Gas (ml at STP)	%CH_4	CH_4 (ml at STP)	Total Gas (ml at STP)	%CH_4	CH_4 (ml at STP)
0						
1	2.15	1.37	0.03	2.01	1.63	0.03
3	3.87	2.50	0.10	4.03	2.00	0.08
6	7.75	3.37	0.26	6.28	2.22	0.14
12	5.48	21.52	1.18	0.89	3.76	0.03
24	17.76	57.04	10.13	7.81	26.20	2.05
48	20.97	45.84	9.61	29.56	73.53	21.73
72	4.91	18.87	0.93	4.75	28.52	1.36
96	8.18	19.02	1.56	4.75	36.75	1.75
120	0.80	4.08	0.03	1.05	44.42	0.47
Total Gas (ml at STP)	71.87		23.82	61.12		27.63

R 10 = COD:S = 9, metal, Zn = 5 mg/l
R 11 = COD:S = 9, metal, Zn = 10 mg/l

Table H-1-continued- The amount of total gas (STP), the percentage of methane analyzed and the amount of methane determined from various reactors after dozing **a single metal**.

	R 12			R 13		
Time (hour)	Total Gas (ml at STP)	$\%CH_4$	CH_4 (ml at STP)	Total Gas (ml at STP)	$\%CH_4$	CH_4 (ml at STP)
0						
1	3.14	2.45	0.08	3.50	0.00	0.00
3	4.35	2.30	0.10	7.84	1.30	0.10
6	7.84	2.09	0.16	7.75	2.98	0.23
12	1.23	2.12	0.03	1.13	6.18	0.07
24	0.47	4.86	0.02	0.19	6.78	0.01
48	1.79	13.40	0.24	0.00	6.20	0.00
72	33.16	81.92	27.16	0.00	5.97	0.00
96	13.06	70.11	9.16	0.80	3.47	0.03
120	1.20	43.04	0.51	3.09	10.59	0.33
Total Gas (ml at STP)	66.24		37.47	24.30		0.77

R 12 = COD:S = 9, metal, Zn = 20 mg/l
R 13 = COD:S = 9, metal, Zn = 30 mg/l

Table H-2 The effect of **a single metal** on total gas and methane in terms of methane production activity ($AVCH_4$ (% of control)).

Cd (mg/l)	Cd (meq/l)	Average MLVSS(mg/l)	Cd(meq/kgMLVSS)	Total Gas (ml at STP)	AV Total Gas(%)	CH_4 (ml at STP)	$AVCH_4$(%)
0	0.000	10040	0	101.5	100	42.3	100
5	0.089	13740	6.48	73.4	72.32	17.9	42.32
10	0.178	14220	12.51	72.6	71.53	20.6	48.70
15	0.267	16140	16.54	78.9	77.73	23.5	55.56
20	0.356	13727	25.92	55.5	54.68	16.1	38.06

Table H-2 -continued- The effect of **a single metal** on total gas and methane inhterms of methane production activity ($AVCH_4$ (% of control)).

Cu(mg/l)	Cu (meq/l)	Average MLVSS(mg/l)	Cu(meq/kgMLVSS)	Total Gas (ml at STP)	AV Total Gas(%)	CH_4 (ml at STP)	$AVCH_4$(%)
0	0.000	10040	0.000	101.5	100	42.3	100
0.5	0.016	12740	1.234	100.8	99.31	38.0	89.83
1	0.031	14920	2.108	98.4	96.95	38.2	90.31
1.5	0.047	14660	3.218	92.1	90.74	38.7	91.49
2	0.063	13940	4.512	83.7	82.46	29.5	69.74

Table H-2 -continued- The effect of **a single metal** on total gas and methane in terms of methane production activity ($AVCH_4$ (% of control)).

Zn(mg/l)	Zn (meq/l)	Average MLVSS(mg/l)	Zn(meq/kgMLVSS)	Total Gas (ml at STP)	AV Total Gas(%)	CH_4 (ml at STP)	$AVCH_4$(%)
0	0.000	10040	0.00	101.50	100	42.3	100
5	0.153	13740	11.13	71.90	70.84	23.8	56.26
10	0.306	12560	24.35	61.10	60.20	27.63	65.32
20	0.612	13380	45.71	66.20	65.22	37.5	88.65
30	0.917	11780	77.88	24.30	23.94	0.77	1.82

Table H-3 The amount of total gas (STP), the percentage and the amount of methane from various reactors after dozing **combined metals**.

Time (hour)	R 1		
	Total Gas (ml at STP)	$\%CH_4$	CH_4 (ml at STP)
0			
1	2.69	0.63	0.02
3	3.40	3.00	0.10
6	3.59	7.80	0.28
12	4.44	23.01	1.02
24	8.03	26.68	2.14
48	8.69	24.08	2.09
72	5.95	19.96	1.19
96	6.48	26.41	1.71
120	2.49	25.64	0.64
Total Gas (at STP)	45.77		9.19

R 1 = No metal control , COD:S 9

Table H-3-continued- The amount of total gas (STP), the percentage and the amount of methane from various reactors after dozing **combined metals**.

Time (hour)	R 2			R 3			R 4		
	Total Gas (ml at STP)	$\%CH_4$	CH_4 (ml at STP)	Total Gas (ml at STP)	$\%CH_4$	CH_4 (ml at STP)	Total Gas (ml at STP)	$\%CH_4$	CH_4 (ml at STP)
0									
1	3.77	0.88	0.03	3.77	0.84	0.03	4.94	1.17	0.06
3	2.36	1.10	0.03	2.64	0.90	0.02	3.68	1.00	0.04
6	1.04	1.34	0.01	0.47	0.98	0.00	0.66	0.81	0.01
12	0.09	0.82	0.00	0.19	0.95	0.00	0.19	0.38	0.00
24	0.00	0.80	0.00	0.00	0.85	0.00	0.00	0.40	0.00
48	4.44	1.08	0.05	6.71	0.74	0.05	2.64	0.62	0.02
72	1.42	1.10	0.02	1.98	0.61	0.01	9.35	0.36	0.03
96	0.00	0.00	0.00	0.20	0.66	0.00	1.50	0.30	0.00
120	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Total Gas (at STP)	13.12		0.14	15.97		0.13	22.96		0.16

R 2 = COD:S 9, Zn5+Cd5
R 3 = COD:S 9, Zn10+Cd5
R 4 = COD:S 9, Zn20+Cd5

Table H-3-continued- The amount of total gas (STP), the percentage and the amount of methane from various reactors after dozing **combined metals**.

Time (hour)	R 5			R 6			R 7		
	Total Gas (ml at STP)	$\%CH_4$	CH_4 (ml at STP)	Total Gas (ml at STP)	$\%CH_4$	CH_4 (ml at STP)	Total Gas (ml at STP)	$\%CH_4$	CH_4 (ml at STP)
0									
1	4.13	0.43	0.02	4.13	0.90	0.04	5.03	0.81	0.04
3	2.27	1.00	0.02	2.27	0.87	0.02	4.25	1.00	0.04
6	0.28	1.42	0.00	0.28	0.83	0.00	1.04	1.27	0.01
12	0.09	1.03	0.00	0.09	0.29	0.00	0.38	0.64	0.00
24	0.00	0.95	0.00	0.00	0.35	0.00	0.00	0.90	0.00
48	2.36	0.92	0.02	2.36	0.40	0.01	3.87	1.48	0.06
72	0.00	1.01	0.00	0.00	0.00	0.00	6.23	0.46	0.03
96	0.00	0.00	0.00	0.00	0.00	0.00	0.90	0.41	0.00
120	0.00	0.00	0.00	0.00	0.00	0.00	0.10	0.36	0.00
Total Gas (at STP)	9.13		0.067	9.13		0.069	21.80		0.188

R 5 = COD:S 9, Zn5+Cd10
R 6 = COD:S 9, Zn10+Cd10
R 7 = COD:S 9, Zn20+Cd10

Table H-3-continued- The amount of total gas (STP), the percentage and the amount of methane from various reactors after dozing **combined metals**.

Time (hour)	R 8			R 9			R 10		
	Total Gas (ml at STP)	$\%CH_4$	CH_4 (ml at STP)	Total Gas (ml at STP)	$\%CH_4$	CH_4 (ml at STP)	Total Gas (ml at STP)	$\%CH_4$	CH_4 (ml at STP)
0									
1	2.87	0.66	0.02	3.05	0.60	0.02	4.85	0.93	0.05
3	3.97	0.80	0.03	2.36	0.63	0.01	2.74	0.93	0.03
6	1.32	0.70	0.01	1.04	0.64	0.01	0.85	0.92	0.01
12	0.19	1.37	0.00	0.19	0.48	0.00	0.19	0.37	0.00
24	12.75	17.78	2.27	0.00	0.51	0.00	0.00	0.40	0.00
48	13.22	18.41	2.43	7.84	0.52	0.04	11.90	0.65	0.08
72	6.23	11.23	0.70	0.85	0.43	0.00	1.32	0.51	0.01
96	4.49	12.37	0.56	0.20	0.73	0.00	0.00	0.00	0.00
120	0.00	0.00	0.00	0.10	2.12	0.00	0.00	0.00	0.00
Total Gas (at STP)	45.05		6.02	15.63		0.09	21.85		0.16

R 8 = COD:S 9, Zn5+Cu1
R 9 = COD:S 9, Zn10+Cu1
R 10 = COD:S 9, Zn20+Cu1

Table H-3-continued- The amount of total gas (STP), the percentage and the amount of methane from various reactors after dozing **combined metals**.

Time (hour)	R 11			R 12			R 13		
	Total Gas (ml at STP)	$\%CH_4$	CH_4 (ml at STP)	Total Gas (ml at STP)	$\%CH_4$	CH_4 (ml at STP)	Total Gas (ml at STP)	$\%CH_4$	CH_4 (ml at STP)
0									
1	2.60	0.60	0.02	3.50	0.67	0.02	4.58	1.58	0.07
3	2.93	0.50	0.01	3.40	0.74	0.03	3.12	2.20	0.07
6	1.32	0.55	0.01	0.66	0.78	0.01	0.57	2.72	0.02
12	0.57	1.50	0.01	0.19	0.64	0.00	0.09	2.88	0.00
24	5.20	13.62	0.71	0.09	0.81	0.00	0.00	2.60	0.00
48	4.72	12.37	0.58	3.50	0.89	0.03	6.80	1.55	0.11
72	3.40	16.29	0.55	0.38	0.54	0.00	0.00	0.00	0.00
96	7.38	14.44	1.07	0.00	0.00	0.00	0.00	0.00	0.00
120	4.89	15.21	0.74	0.00	0.00	0.00	0.00	0.00	0.00
Total Gas (at STP)	33.00		3.70	11.72		0.09	15.16		0.26

R 11 = COD:S 9, Zn5+Cu2
R 12 = COD:S 9, Zn10+Cu2
R 13 = COD:S 9, Zn20+Cu2

Table H-3-continued- The amount of total gas (STP), the percentage and the amount of methane from various reactors after dozing **combined metals**.

Time (hour)	R 14			R 15		
	Total Gas (ml at STP)	$\%CH_4$	CH_4 (ml at STP)	Total Gas (ml at STP)	$\%CH_4$	CH_4 (ml at STP)
0						
1	3.23	1.03	0.03	3.68	2.56	0.09
3	2.36	1.20	0.03	2.08	5.50	0.11
6	0.66	1.00	0.01	0.57	6.95	0.04
12	0.28	1.50	0.00	0.19	5.01	0.01
24	10.86	34.04	3.70	0.00	4.80	0.00
48	8.22	34.00	2.79	5.10	4.28	0.22
72	2.83	31.00	0.88	1.89	3.17	0.06
96	1.20	28.99	0.35	0.10	3.38	0.00
120	2.59	0.64	0.02	0.00	0.00	0.00
Total Gas (at STP)	32.24		7.81	13.60		0.54

R 14 = COD:S 9, Cd5+Cu1
R 15 = COD:S 9, Cd10+Cu1

Table H-3-continued- The amount of total gas (STP), the percentage and the amount of methane from various reactors after dozing **combined metals**.

Time (hour)	R 16			R 17		
	Total Gas (ml at STP)	$\%CH_4$	CH_4 (ml at STP)	Total Gas (ml at STP)	$\%CH_4$	CH_4 (ml at STP)
0						
1	2.74	1.31	0.04	2.60	2.06	0.05
3	4.03	2.00	0.08	2.27	3.40	0.08
6	0.72	2.03	0.01	0.57	4.71	0.03
12	0.08	2.48	0.00	0.09	5.45	0.01
24	9.02	27.46	2.48	0.00	4.80	0.00
48	10.07	38.05	3.83	4.16	3.00	0.12
72	2.90	43.02	1.25	2.46	1.08	0.03
96	1.69	30.76	0.52	0.00	0.00	0.00
120	2.58	46.55	1.20	0.00	0.00	0.00
Total Gas (at STP)	33.82		9.41	12.14		0.31

R 16 = COD:S 9, Cd5+Cu2
R 17 = COD:S 9, Cd10+Cu2

Table H-3-continued- The amount of total gas (STP), the percentage and the amount of methane from various reactors after dozing **combined metals**.

Time (hour)	R 18			R 19			R 20		
	Total Gas (ml at STP)	$\%CH_4$	CH_4 (ml at STP)	Total Gas (ml at STP)	$\%CH_4$	CH_4 (ml at STP)	Total Gas (ml at STP)	$\%CH_4$	CH_4 (ml at STP)
0									
1	4.40	1.03	0.05	3.77	0.00	0.00	5.29	1.71	0.09
3	2.17	1.60	0.03	5.10	0.40	0.02	4.72	2.20	0.10
6	1.04	2.02	0.02	0.66	0.79	0.01	1.04	3.19	0.03
12	0.19	1.85	0.00	0.00	0.21	0.00	0.09	2.84	0.00
24	0.00	1.70	0.00	0.00	0.30	0.00	0.00	2.70	0.00
48	5.86	1.52	0.09	13.60	0.31	0.04	4.63	2.40	0.11
72	0.38	1.29	0.00	0.57	0.31	0.00	13.32	1.96	0.26
96	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
120	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Total Gas (at STP)	14.03		0.20	23.70		0.07	29.10		0.60

R 18 = COD:S 9, Cd5+Zn5+Cu1
R 19 = COD:S 9, Cd10+Zn10+Cu1.5
R 20 = COD:S 9, Cd20+Zn20+Cu2

Table H-4 The effect of **combined metals** on methane in terms of **methane production activity ($AVCH_4$ (% of control))**.

Zn Concentration (mg/l)	AV CH_4 (%)* from Zn	AV CH_4 (%)* from **Cd 5 mg/l**	CH_4 (ml at STP) from Zn + Cd 5mg/l	AV CH_4(%) from **Zn + Cd 5mg/l**
0	100	42.32	9.194	100 (no-metal control)
5	56.26	42.32	0.137	1.490
10	65.32	42.32	0.125	1.360
20	88.65	42.32	0.155	1.686
30	1.82			

* from Table H-2

Table H-4 -continued- The effect of **combined metals** on methane in terms of methane production activity ($AVCH_4$ (% of control)).

Zn Concentration (mg/l)	AV CH_4(%) from Zn	AV CH_4 (%) from **Cd 10 mg/l**	CH_4 (ml at STP) from Zn + Cd 10 mg/l	AV CH_4(%) from **Zn + Cd 10 mg/l**
0	100	48.70	9.194	100 (no-metal control)
5	56.26	48.70	0.067	0.729
10	65.32	48.70	0.069	0.750
20	88.65	48.70	0.188	2.045
30	1.82			

Table H-4 –continued-The effect of **combined metals** on methane in terms of **methane production activity ($AVCH_4$ (% of control))**.

Zn Concentration (mg/l)	AV CH_4(%) from Zn	AV CH_4 (%) from **Cu 1 mg/l**	CH_4 (ml at STP) from Zn + Cu 1mg/l	AV CH_4(%) from **Zn + Cu 1 mg/l**
0	100	96.95	9.194	100 (no-metal control)
5	56.26	96.95	6.02	65.48
10	65.32	96.95	0.089	0.97
20	88.65	96.95	0.163	1.77
30	1.82			

Table H-4 -continued- The effect of **combined metals** on methane in terms of **methane production activity ($AVCH_4$ (% of control))**.

Zn Concentration (mg/l)	AV CH_4(%) from Zn	Av CH_4 (%) from **Cu 2 mg/l**	CH_4 (ml at STP) from Zn + Cu 2 mg/l	AV CH_4(%) from **Zn + Cu 2mg/l**
0	100	69.74	9.914	100 (no-metal control)
5	56.26	69.74	3.701	37.33
10	65.32	69.74	0.089	0.90
20	88.65	69.74	0.264	2.66
30	1.82			

Table H-4-continued- The effect of **combined metals** on methane in terms of **methane production activity (AVCH_4 (% of control))**.

Cd Concentration (mg/l)	AV CH_4(%) from **Cd**	AV CH_4 (%) from Cu 1 mg/l	CH_4 (ml at STP) from Cd + Cu 1mg/l	AV CH_4(%) from **Cd + Cu 1mg/l**
0	100	96.95	9.914	100 (no-metal control)
5	42.32	96.95	7.808	78.76
10	48.70	96.95	0.539	5.44
15	55.56			
20	38.06			

Table H-4 -continued- The effect of **combined metals** on methane in terms of **methane production activity (AVCH_4 (% of control))**.

Cd Concentration (mg/l)	AV CH_4(%) from **Cd**	AV CH_4 (%) from Cu 2 mg/l	CH_4 (ml at STP) from Cd + Cu 2 mg/l	AV CH_4(%) from **Cd + Cu 2mg/l**
0	100	69.74	9.914	100 (no-metal control)
5	42.32	69.74	9.407	94.89
10	48.70	69.74	0.314	3.17
15	55.56	69.74		
20	38.06	69.74		

Table H-5 The effect of **a single metal** on COD in terms of **COD production activity (AVCOD (% of control))**.

Cd Concentration (mg/l)	Cd Concentration (meq/l)	Influent COD (mg/l)	Effluent COD (mg/l)	COD removal (mg/l)	AV COD (% of control)
0	0	3200	517	2683	100 (no-metal control)
5	0.089	3200	876	2324	86.6
10	0.178	3200	1394	1806	67.3
15	0.267	3200	1354	1846	68.8
20	0.356	3200	1633	1567	58.4

Table H-5-continued- The effect of **a single metal** on COD in terms of **COD production activity (AVCOD (% of control))**.

Cu Concentration (mg/l)	Cu Concentration (meq/l)	Influent COD (mg/l)	Effluent COD (mg/l)	COD removal (mg/l)	AV COD (% of control)
0	0	3200	517	2683	100 (no-metal control)
0.5	0.016	3200	517	2683	100
1	0.031	3200	562	2638	98.3
1.5	0.047	3200	562	2638	98.3
2	0.063	3200	562	2638	98.3

Table H-5-continued- The effect of **a single metal** on COD in terms of **COD production activity (AVCOD (% of control))**.

Zn Concentration (mg/l)	Zn Concentration (meq/l)	Influent COD (mg/l)	Effluent COD (mg/l)	COD removal (mg/l)	AV COD (% of control)
0	0	3200	517	2683	100 (no-metal control)
5	0.153	3200	602	2598	96.8
10	0.306	3200	1061	2139	79.7
20	0.612	3200	1422	1778	66.3
30	0.917	3200	3129	71	2.7

Table H-6 The effect of **combined metals** on COD in terms of **COD removal activity (AVCOD (% of control))**.

	Zn			
Zn Concentration (mg/l)	Influent COD (mg/l)	Effluent COD (mg/l)	COD Removal (mg/l)	**AV COD(%) from Zn**
0	3200	517	2683	100 (no-metal control)
5	3200	602	2598	96.8
10	3200	1061	2139	79.7
20	3200	1422	1778	66.3
30	3200	3129	71	2.7

Table H-6-continued- The effect of **combined metals** on COD in terms of **COD removal activity (AVCOD (% of control))**.

Cd		**Zn +Cd 5 mg/l**		
Cd Concentration (mg/l)	AV COD (%)* from **Cd 5 mg/l**	Effluent COD (mg/l)	COD Removal (mg/l)	**AV COD(%) from Zn +Cd 5 mg/l**
5	86.6 (no-metal control)	422	2778	100 (no-metal control)
5	86.6	3200	0	0
5	86.6	2951	249	8.96
5	86.6	3200	0	0
5	86.6			

* Data from Table H-5

Table H-6-continued- The effect of **combined metals** on COD in terms of **COD removal activity (AVCOD (% of control))**.

	Zn			
Zn Concentration (mg/l)	Influent COD (mg/l)	Effluent COD (mg/l)	COD Removal (mg/l)	**AVCOD(%) from Zn**
0	3200	517	2683	100 (no-metal control)
5	3200	602	2598	96.8
10	3200	1061	2139	79.7
20	3200	1422	1778	66.3
30	3200	3129	71	2.7

Table H-6-continued- The effect of **combined metals** on COD in terms of **COD removal activity (AVCOD (% of control))**.

Cd		**Zn +Cd 10**		
Cd Concentration (mg/l)	AVCOD (%) * from **Cd 10 mg/l**	Effluent COD (mg/l)	COD Removal (mg/l)	**AV COD(%) from Zn + Cd 10 mg/l**
10	67.3(no-metal control)	422	2778	100 (no-metal control)
10	67.3	3200	0	0.0
10	67.3	3200	0	0.0
10	67.3	3200	0	0.0
10	67.3			

* Data from H-5

Table H-6-continued- The effect of **combined metals** on COD in terms of **COD removal activity (AVCOD (% of control))**.

	Zn			
Zn Concentration (mg/l)	Influent COD (mg/l)	Effluent COD (mg/l)	COD Removal (mg/l)	AVCOD(%) from **Zn**
0	3200	517	2683	100 (no-metal control)
5	3200	602	2598	96.8
10	3200	1061	2139	79.7
20	3200	1422	1778	66.3
30	3200	3129	71	2.7

Table H-6-continued- The effect of **combined metals** on COD in terms of **COD removal activity (AVCOD (% of control))**.

Cu		**Zn +Cu 1**		
Cu Concentration (mg/l)	AV COD (%) * from **Cu 1 mg/l**	Effluent COD (mg/l)	COD Removal (mg/l)	**AV COD (%)** from **Zn + Cu 1 mg/l**
1	98.3 (no-metal control)	422	2778	100 (no-metal control)
1	98.3	843	2357	84.8
1	98.3	3200	0	0.0
1	98.3	3200	0	0.0

* Data from H-5

Table H-6-continued- The effect of **combined metals** on COD in terms of **COD removal activity (AVCOD (% of control))**.

	Zn			
Zn Concentration (mg/l)	Influent COD (mg/l)	Effluent COD (mg/l)	COD Removal (mg/l)	**AV COD(%) from Zn**
0	3200	517	2683	100 *
5	3200	602	2598	96.8
10	3200	1061	2139	79.7
20	3200	1422	1778	66.3
30	3200	3129	71	2.7

Table H-6-continued- The effect of combined metals on COD in terms of COD production activity (AVCOD (% of control)).

Cu		**Zn +Cu2**		
Cu Concentration (mg/l)	AV COD (%)* from **Cu 2 mg/l**	Effluent COD(mg/l)	COD Removal (mg/l)	**AVCOD(%) from Zn + Cu 2mg/l**
2	98.3(no-metal control)	422	2778	100 (no-metal control)
2	98.3	996	2204	79.3
2	98.3	3200	0	0.0
2	98.3	3200	0	0.0

* Data from Table H-5

Table H-6 -continued- The effect of combined metals on COD in terms of **COD removal activity (AVCOD (% of control))**.

	Cd			
Cd Concentration (mg/l)	Influent COD (mg/l)	Effluent COD (mg/l)	COD Removal (mg/l)	**AV COD(%)** from **Cd**
0	3200	517	2683	100 (no-metal control)
5	3200	876	2324	86.62
10	3200	1394	1806	67.31
15	3200	1354	1846	68.80
20	3200	1633	1567	58.40

Table H-6-continued- The effect of combined metals on COD in terms of **COD removal activity (AVCOD (% of control))**.

Cu		**Cd +Cu 1**		
Cu Concentration (mg/l)	AV COD (%)* from **Cu 1 mg/l**	Effluent COD (mg/l)	COD Removal (mg/l)	**AVCOD(%)** from **Cd + Cu 1mg/l**
1	98.3 (Control)	422	2778	100 (no-metal control)
1	98.3	958	2242	80.7
1	98.3	3200	0	0.0
1	98.3			

* Data from H-5

Table H-6-continued- The effect of combined metals on COD in terms of **COD removal activity (AVCOD (% of control))**.

	Cd			
Cd Concentration (mg/l)	Influent COD (mg/l)	Effluent COD (mg/l)	COD Removal (mg/l)	**AV COD(%) from Cd**
0	3200	517	2683	100 (no-metal control)
5	3200	876	2324	86.6
10	3200	1394	1806	67.3
15	3200	1354	1846	68.8
20	3200	1633	1567	58.4

Table H-6-continued- The effect of combined metals on COD in terms of **COD removal activity (AVCOD (% of control))**.

Cu		**Cd +Cu 2**		
Cu Concentration (mg/l)	AV COD (%) * from **Cu 2 mg/l**	Effluent COD (mg/l)	COD Removal (mg/l)	**AV COD(%) from Cd + Cu 2 mg/l**
2	98.3 (Control)	422	2778	100 (no-metal control)
2	98.3	1456	1744	62.8
2	98.3	3181	19	0.7
2	98.3			

* Data from Table H-5

Table H-7 The effect of **three combined metals** on COD in terms of **COD removal activity (AVCOD (% of control)).**

Cd		Cu		Zn		**AV(%) Zn5 +Cd5 +Cu1**	**AV(%) Zn10 +Cd10 +Cu 1.5**	**AV(%) Zn 20 +Cd 20 +Cu 2**
Cd Concentration (mg/l)	**AV COD (%) from Cd**	Cu Concentration (mg/l)	**AV COD (%) from Cu**	Zn Concentration (mg/l)	**AV COD (%) from Zn**			
0	100 (no-metal control)	0	100 (no-metal control)	0	100 (no-metal control)	100 (no-metal control)	100 (no-metal control)	100 (no-metal control)
5	87	0.5	100	5	96.83	0	0	0
10	67	1	98.3	10	79.72	0	0	0
15	69	1.5	98.3	20	66.27	0	0	0
20	58	2	98.3	30	2.73			

Table H-8 The **methane production activities (%AVCH$_4$)** of **combined metals** at toxicant loading 0-30 meq/kg MLVSS.

Combined Metals and Concentration (mg/l)	Initial Concentration (meq/l)	MLVSS (kg/l)	Metal Loading (meq/kg MLVSS)	Final Metal Concentration (meq/l)	Soluble Metal Loading (meq/kg MLVSS)	CH_4 (ml at STP)	**$AVCH_4$ (% of control)**
No-metal control	0.0000	0.01012	0.00	0.000	0.00	97.93	100
Cd 8 + Cu 1	0.1738	0.01184	14.68	NA	NA	82.48	84.23
Cd 6 + Cu 2	0.1697	0.01128	15.04	0.0055	0.4876	77.29	78.93
Cd 4 + Zn 4	0.1935	0.01076	17.98	0.0051	0.4739	71.60	73.11
Cd 4 + Zn 2	0.1323	0.01104	11.99	NA	NA	NA	NA
Cd 2 + Zn 4	0.1579	NA	16.08	NA	NA	NA	NA
Cd 2 + Zn 2	0.0967	0.00692	13.98	NA	NA	89.08	90.96
Cu 2 + Zn 6	0.2464	0.01056	23.46	NA	NA	59.53	60.79
Cu 2 + Zn 4	0.1852	NA	16.69	NA	NA	NA	NA
Cu 2 + Zn 2	0.1241	0.01094	11.34	NA	NA	81.10	82.81
Cd 0.5 + Cu 0.5 + Zn 0.5	0.0399	NA	3.94	NA	NA	NA	NA
Cd 1 + Cu 1 + Zn 1	0.0798	0.01084	7.36	NA	NA	81.29	83.01
Cd 2 + Cu 2 + Zn 2	0.1596	NA	20.79	NA	NA	NA	NA
Cd 4 + Cu 2 + Zn 2	0.1952	0.00846	23.08	0.0066	0.7801	71.25	72.75
Cd 1 + Cu 2 + Zn 4	0.2030	0.00974	20.84	NA	NA	NA	NA
Cd 2 + Cu 2 + Zn 4	0.2208	0.01148	19.23	0.0109	0.9495	74.99	76.57
Cd 3 + Cu 1 + Zn 4	0.2072	NA	22.42	NA	NA	NA	NA
Cd 4 + Cu 1 + Zn 4	0.2249	0.01074	20.94	0.0086	0.8007	67.49	68.91
Cd 5 + Cu 2 + Zn 5	0.3048	0.01042	29.25	0.0090	0.8637	65.66	67.04

NA = Not Analyzed

Table H-9 The **COD removal activities (% AV COD)** of **combined metals** at toxicant loading 0-30 meq/kg MLVSS.

Combined Metals and Concentration (mg/l)	Initial Metal Concentration (meq/l)	MLVSS (kg/l)	Metal Loading (meq/kg MLVSS)	Final Metal Concentration (meq/l)	Soluble Metal Loading (meq/kg MLVSS)	Influent COD (mg/l)	Effluent COD (mg/l)	COD Removal (mg/l)	% COD Removal	**AVCOD (% of control)**
No-metal control	0	0.01012	0	0.000	0.00	5329	209	5120	96.08	100
Cd 8 + Cu 1	0.1738	0.01184	14.68	NA	NA	5329	209	5120	96.08	100
Cd 6 + Cu 2	0.1697	0.01128	15.04	0.0055	0.4876	5329	209	5120	96.08	100
Cd 4 + Zn 4	0.1935	0.01076	17.98	0.0051	0.4739	5329	257	5072	95.17	99.06
Cd 4 + Zn 2	0.1323	0.01104	11.99	NA	NA	5329	212	5117	96.02	99.94
Cd 2 + Zn 4	0.1579	NA	16.08	NA	NA	5329	190	5139	96.43	100
Cd 2 + Zn 2	0.0967	0.00692	13.98	NA	NA	5329	209	5120	96.08	100
Cu 2 + Zn 6	0.2464	0.01056	23.46	NA	NA	5329	392	4937	92.64	96.43
Cu 2 + Zn 4	0.1852	NA	16.69	NA	NA	5329	224	5105	95.80	99.71
Cu 2 + Zn 2	0.1241	0.01094	11.34	NA	NA	5329	201	5128	96.22	100
Cd 0.5 + Cu 0.5 + Zn 0.5	0.0399	NA	3.94	NA	NA	5329	235	5094	95.59	99.50
Cd 1 + Cu 1 + Zn 1	0.0798	0.01084	7.36	NA	NA	5329	246	5083	95.38	99.28
Cd 2 + Cu 2 + Zn 2	0.1596	NA	20.79	NA	NA	5329	179	5150	96.64	101
Cd 4 + Cu 2 + Zn 2	0.1952	0.00846	23.08	0.0066	0.7801	5329	NA	NA	NA	NA
Cd 1 + Cu 2 + Zn 4	0.2030	0.00974	20.84	NA	NA	5329	358	4971	93.28	97.09
Cd 2 + Cu 2 + Zn 4	0.2208	0.01148	19.23	0.0109	0.9495	5329	257	5072	95.17	99.06
Cd 3 + Cu 1 + Zn 4	0.2072	NA	22.42	NA	NA	5329	280	5049	94.75	98.62
Cd 4 + Cu 1 + Zn 4	0.2249	0.01074	20.94	0.0086	0.8007	5329	396	4933	92.57	96.35
Cd 5 + Cu 2 + Zn 5	0.3048	0.01042	29.25	0.0090	0.8637	5329	NA	NA	NA	NA
Average							257		95.29	

NA = Not Analyzed

Table H-10 The time course of volatile organic compounds after dosing **a single metal** at toxicant loading 0-80 meq/kgMLVSS.

Metal Concentrations (mg/l)	Butyric Acid (mg/l)			Propionic Acid (mg/l)			Acetic Acid (mg/l)		
	Time = 1 hour	Time = 72 hours	Time = 120 hours	Time = 1 hour	Time = 72 hours	Time = 120 hours	Time = 1 hour	Time = 72 hours	Time = 120 hours
No-metal control	90	1248	864	1066	317	1443	476	946	468
Cd=5	97	1438	924	1365	444	1262	645	284	592
10	88	1176	751	1740	349	1226	873	189	412
15	39	1438	533	1070	444	1095	487	324	270
20	41	1124	1021	1012	368	1598	416	230	558
Cu=0.5	67	766	688	1491	1365	1152	738	1000	249
1	54	885	386	1296	1668	794	608	1313	447
1.5	0	783	570	840	1365	1140	296	1188	566
2	31	664	285	961	1156	799	325	938	269
Zn=5	47	664	482	819	1327	887	394	1125	507
10	617	528	464	876	948	875	223	813	481
20	845	545	337	1276	967	918	259	688	327
30	804	579	653	1228	1213	1404	338	1000	1069

Table H -11 The time course of volatile organic compound after dosing **combined metals** at 0-80 meq/kg MLVSS.

Combined Metals and Concentrations (mg/l)	Butyric Acid (mg/l)			Propionic Acid (mg/l)			Acetic Acid (mg/l)		
	Time = 1 hour	Time = 72 hours	Time = 120 hours	Time = 1 hour	Time = 72 hours	Time = 120 hours	Time = 1 hour	Time = 72 hours	Time = 120 hours
No metal control	107	82	20	804	510	483	752	816	747
Zn5+Cd5	381	188	207	1127	1151	1119	1182	694	1331
Zn10+Cd5	166	59	61	758	903	1020	276	304	320
Zn20+Cd5	210	718	252	982	878	525	390	511	178
Zn5+Cd10	169	916	267	1098	1348	1328	650	1368	4165
Zn10+Cd10	173	123	267	945	1029	615	415	413	989
Zn20+Cd10	96	202	56	660	1102	655	267	533	183
Zn5+Cu1	129	632	243	1009	973	594	507	1301	862
Zn10+Cu1	59	628	54	635	547	591	212	258	406
Zn20+Cu1	17	142	55	784	397	591	273	168	784
Zn5+Cu2	352	655	117	930	1191	291	1136	1493	197
Zn10+Cu2	89	ND	ND	754	611	295	490	ND	ND
Zn20+Cu2	123	ND	ND	775	661	330	422	ND	ND
Cd5+Cu1	305	628	442	1446	1271	498	2200	1125	458
Cd10+Cu1	83	49	303	915	994	623	1236	1412	237
Cd5+Cu2	646	518	132	1589	1102	267	1347	1258	612
Cd10+Cu2	156	98	216	1043	873	415	237	1536	816
Zn5+Cd5+Cu1	340	182	636	699	793	1542	743	1125	1529
Zn10+Cd10+Cu1.5	67	803	92	546	1264	536	347	1601	154
Zn20+Cd10+Cu2	30	83	54	693	829	159	382	699	542

ND = Not Detectable

Table H-12 The time course of volatile organic compounds after dosing **combined metals** at toxicant loading 0-30 meq/kgMLVSS.

Combined Metals and Concentrations (mg/l)	Butyric Acid (mg/l)			Propionic Acid (mg/l)			Acetic Acid (mg/l)		
	Time = 1 hour	Time = 72 hours	Time= 120 hours	Time = 1 hour	Time = 72 hours	Time= 120 hours	Time = 1 hour	Time = 72 hours	Time= 120 hours
Control	67	217	71	994	408	158	1630	369	ND
Cd8+Cu1	91	41	ND	1081	176	241	1892	ND	ND
Cd6+Cu2	57	19	79	977	282	53	1439	ND	ND
Cd4+Zn4	80	ND	75	455	62	42	927	ND	ND
Cd4+Zn2	57	49	129	376	68	123	1756	ND	ND
Cd2+Zn4	67	95	78	216	259	65	623	336	ND
Cd2+Zn2	25	39	31	329	381	149	868	ND	ND
Zn6+Cu2	4	43	65	133	277	86	416	ND	ND
Zn4+Cu2	12	25	66	331	83	104	573	519	ND
Zn2+Cu2	7	ND	35	373	428	38	784	ND	ND
Cd0.5+Cu0.5+Zn0.5	94	33	ND	500	107	95	2167	ND	ND
Cd1+Cu1+Zn1	28	ND	41	950	150	89	1833	ND	ND
Cd2+Cu2+Zn2	38	ND	ND	724	215	112	1582	ND	ND
Cd4+Cu2+Zn2	43	ND	27	762	153	85	1597	ND	ND
Cd1+Cu2+Zn4	32	ND	41	524	52	75	1777	ND	ND
Cd2+Cu2+Zn4	9	ND	35	369	96	88	95	ND	ND
Cd3+Cu1+Zn4	23	ND	28	137	121	48	106	ND	ND
Cd4+Cu1+Zn4	13	ND	27	243	107	26	147	ND	ND
Cd5+Cu2+Zn5	16	ND	36	106	63	53	335	ND	ND

ND = Not Detectable

Table H-13 The time course of sulfate and the percentage of sulfate removal after dosing **a single metal** at toxicant loading 0-80 mg/kgMLVSS.

Metal Concentration (mg/l)	Metal Concentration (meq/l)	MLVSS (kg/l)	Metal Loading, K (meq/kgMLVSS)	SO_4^{2-} Concentration (mg/l)				
				Initial SO_4^{2-} Concentration (mg/l)	Time = 1hour	Time= 72hours	Time= 120hours	**% SO_4^{2-} Removal**
0 (No-metal control)	0.0000	0.01004	0.00	1100	1501	431	85	92
Cd=5	0.0890	0.01374	6.47	1100	1191	511	132	88
10	0.1779	0.01422	12.5	1100	1652	587	165	85
15	0.2669	0.01614	16.5	1100	1238	658	344	69
20	0.3559	0.01373	25.9	1100	781	938	485	56
Cu = 0.5	0.0157	0.01274	1.23	1100	974	400	14	99
1	0.0314	0.01492	2.11	1100	767	489	66	94
1.5	0.0472	0.01466	3.22	1100	988	560	24	98
2	0.0629	0.01394	4.51	1100	1049	391	56	95
Zn = 5	0.1529	0.01374	11.1	1100	998	569	38	97
10	0.3058	0.01256	24.3	1100	1002	511	89	92
20	0.6116	0.01338	45.7	1100	1581	NA	NA	NA
30	0.9174	0.01178	77.9	1100	734	933	673	39
Average								82.77

NA = Not Analyzed

Table H-14 The time course of sulfate after dosing **combined metals** at toxicant loading 0-80 mg/kg MLVSS.

Combined Metals and Concentration (mg/l)	Combined Metals and Concentration (meq/l)	MLVSS (kg/l)	Metal Loading, K (meq/kgMLVSS)	SO_4^{2-} Concentration (mg/l)				
				Initial SO_4^{2-} Concentration (mg/l)	Time = 1 hour	Time = 72 hours	Time = 120hours	% SO_4^{2-} Removal
No-metal control	0	0.0127	0	1100	873	492	26	97.61
Zn5+Cd5	0.2419	0.0130	18.7	1100	868	748	816	25.84
Zn10+Cd5	0.3948	0.0137	28.8	1100	556	820	611	44.50
Zn20+Cd5	0.7006	0.0127	55.2	1100	660	702	747	32.06
Zn5+Cd10	0.3308	0.0094	35.3	1100	566	715	558	49.28
Zn10+Cd10	0.4837	0.0129	37.5	1100	561	1102	937	14.83
Zn20+Cd10	0.7896	0.0144	54.7	1100	426	859	579	47.37
Zn5+Cu1	0.1844	0.0119	15.5	1100	509	584	216	80.38
Zn10+Cu1	0.3373	0.0103	32.8	1100	613	505	537	51.20
Zn20+Cu1	0.6431	0.0125	51.4	1100	629	630	926	15.79
Zn5+Cu2	0.2158	0.0125	17.3	1100	452	597	279	74.64
Zn10+Cu2	0.3687	0.0129	28.5	1100	509	833	626	43.06
Zn20+Cu2	0.6745	0.0139	48.5	1100	655	767	753	31.58
Cd5+Cu1	0.1204	0.0114	10.5	1100	504	393	316	71.29
Cd10+Cu1	0.2094	0.0133	15.8	1100	577	754	632	42.58
Cd5+Cu2	0.1519	0.0131	11.6	1100	634	662	342	68.90
Cd10+Cu2	0.2408	0.0132	18.3	1100	613	649	547	50.24
Cd5+Zn5+Cu1	0.2733	0.0134	20.4	1100	468	734	637	42.11
Cd10+Zn10+Cu1.5	0.5309	0.0140	37.9	1100	764	813	626	43.06
Cd20+Zn20+Cu2	1.0304	0.0127	81.3	1100	758	675	595	45.93
Average								46.03

Table H-15 The influent and effluent COD and the percentage of COD removal of various reactors after dosing **a single metal.**

Metal Concentration (mg/l)	COD (mg/l)		
	Influent COD (mg/l)	Effluent COD (mg/l)	%COD Removal
0 (No-metal control)	3200	517	83.84
Cd =5	3200	876	72.63
10	3200	1394	56.44
15	3200	1354	57.69
20	3200	1633	48.97
Cu = 0.5	3200	517	83.84
1	3200	562	82.44
1.5	3200	562	82.44
2	3200	562	82.44
Zn = 5	3200	602	81.19
10	3200	1061	66.84
20	3200	1422	55.56
30	3200	3129	2.22

Table H-16 The time course of sulfate after dosing **combined metals** at toxicant loading 0-30 mg/kgMLVSS.

Combined Metals and Concentrations (mg/l)	Initial Metal Concentration (meq/l)	Metal Loading (meq/kg MLVSS)	SO_4^{2-} Concentration (mg/l)				
			Initial SO_4^{2-} Concentration (mg/l)	Time = 1 hour	Time = 72 hours	Time = 120 hours	% SO_4^{2-} Removal
No-metal control	0.0000	0.00	1100	303	55	55	94.98
Cd 8 + Cu 1	0.1738	14.68	1100	272	50	60	94.57
Cd 6 + Cu 2	0.1697	15.04	1100	292	60	60	94.57
Cd 4 + Zn 4	0.1935	17.98	1100	344	65	74	93.31
Cd 4 + Zn 2	0.1323	11.99	1100	256	75	92	91.64
Cd 2 + Zn 4	0.1579	16.08	1100	297	75	60	94.57
Cd 2 + Zn 2	0.0967	13.98	1100	303	95	92	91.64
Cu 2 + Zn 6	0.2464	23.46	1100	431	135	78	92.89
Cu 2 + Zn 4	0.1852	16.69	1100	313	140	74	93.31
Cu 2 + Zn 2	0.1241	11.34	1100	179	150	60	94.57
Cd 0.5 + Cu 0.5 + Zn 0.5	0.0399	3.94	1100	374	140	69	93.73
Cd 1 + Cu 1 + Zn 1	0.0798	7.36	1100	395	190	78	92.89
Cd 2 + Cu 2 + Zn 2	0.1596	20.79	1100	364	130	74	93.31
Cd 4 + Cu 2 + Zn 2	0.1952	23.08	1100	369	165	83	92.48
Cd 1 + Cu 2 + Zn 4	0.2030	20.84	1100	390	155	97	91.22
Cd 2 + Cu 2 + Zn 4	0.2208	19.23	1100	441	160	106	90.39
Cd 3 + Cu 1 + Zn 4	0.2072	22.42	1100	374	180	92	91.64
Cd 4 + Cu 1 + Zn 4	0.2249	20.94	1100	456	145	97	91.22
Cd 5 + Cu 2 + Zn 5	0.3048	29.25	1100	NA	NA	NA	NA
							92.94

NA= not analyzed

Table H-17 The percentage of heavy metal removal after dosing **a single metal** (0-80 meq/kgMLVSS).

Cd Concentration (mg/l)			Cu Concentration (mg/l)			Zn Concentration (mg/l)		
Initial Concentration (mg/l)	Final Concentration (mg/l)	Cd Removal (%)	Initial Concentration (mg/l)	Final Concentration (mg/l)	Cu Removal (%)	Initial Concentration (mg/l)	Final Concentration (mg/l)	Zn Removal (%)
5	0.068	98.64	0.5	0.056	88.80	5	0.636	87.28
10	0.036	99.64	1	0.052	94.80	10	0.788	92.12
15	0.044	99.71	1.5	0.028	98.13	20	0.748	96.26
20	0.036	99.82	2	0.020	99.00	30	0.388	98.71
		99.45			95.18			93.59

Table H-18 The percentage of heavy metal removal after dosing **combined metals** (0-80 meq/kgMLVSS).

Combined Metals (mg/l)	Metal Loading, K (meq/kg MLVSS)	Initial Metals (Time = 0 h) (meq/l)	Final Metals (Time = 120 h) (meq/l)	% Metal Removal
Control	0	0	0	
Zn 5 + Cd 5	18.7	0.2419	0.0098	95.95
Zn 10 + Cd 5	28.8	0.3948	0.0105	97.34
Zn 20 + Cd 5	55.2	0.7006	0.0165	97.64
Zn 5 + Cd 10	35.3	0.3308	0.0178	94.63
Zn 10 + Cd 10	37.5	0.4837	0.0262	94.59
Zn 20 + Cd 10	54.7	0.7896	0.0276	96.50
Zn 5 + Cu 1	15.5	0.1844	NA	NA
Zn 10 + Cu 1	32.8	0.3373	0.0174	94.85
Zn 20 + Cu 1	51.4	0.6431	0.0325	94.94
Zn 5 + Cu 2	17.3	0.2158	0.0011	89.04
Zn 10 + Cu 2	28.5	0.3687	0.0182	95.08
Zn 20 + Cu 2	48.5	0.6745	0.0331	95.09
Cd 5 + Cu 1	10.5	0.1204	0.0053	95.58
Cd 10+ Cu 1	15.8	0.2094	0.0113	94.63
Cd 5+ Cu 2	11.6	0.1519	0.0103	93.20
Cd 10 + Cu 2	18.3	0.2408	NA	NA
Zn 5 + Cd 5 + Cu 1	20.4	0.2733	0.0153	94.40
Zn 10 + Cd10 + Cu1.5	37.9	0.5309	0.0196	96.31
Zn 20 + Cd 20 + Cu2	81.3	1.0304	0.0236	97.71
Average				95.14

Table H-19 The percentage of heavy metal removal after dosing **combined metals** (0-30 meq/kgMLVSS).

Combined Metals (mg/l)	Toxicant Loading, K (meq/kg MLVSS)	Initial Metals (Time = 0 h) (meq/l)	Final Metals (Time = 120 h) (meq/l)	% Metal Removal
Control	0.00	0.0000	0.0000	0.00
Cd 8 + Cu 1	14.68	0.1738	NA	NA
Cd 6 + Cu 2	15.04	0.1697	0.0055	96.77
Cd 4 + Zn 4	17.98	0.1935	0.0051	97.39
Cd 4 + Zn 2	11.99	0.1323	NA	NA
Cd 2 + Zn 4	16.08	0.1579	NA	NA
Cd 2 + Zn 2	13.98	0.0967	NA	NA
Cu 2 + Zn 6	23.46	0.2464	NA	NA
Cu 2 + Zn 4	16.69	0.1852	NA	NA
Cu 2 + Zn 2	11.34	0.1241	NA	NA
Cd 0.5 + Cu 0.5 + Zn 0.5	3.94	0.0399	NA	NA
Cd 1 + Cu 1 + Zn 1	7.36	0.0798	NA	NA
Cd 2 + Cu 2 + Zn 2	20.79	0.1596	NA	NA
Cd 4 + Cu 2 + Zn 2	23.08	0.1952	0.0066	96.63
Cd 1 + Cu 2 + Zn 4	20.84	0.2030	NA	NA
Cd 2 + Cu 2 + Zn 4	19.23	0.2208	0.0109	95.08
Cd 3 + Cu 1 + Zn 4	22.42	0.2072	NA	NA
Cd 4 + Cu 1 + Zn 4	20.94	0.2249	0.0086	96.19
Cd 5 + Cu 2 + Zn 5	29.25	0.3048	0.0090	97.05
Average				96.51

NA = Not Analyzed

Table H-20 The **pH** of influent and effluent after dosing **a single metal** (0-80meq/kgMLVSS).

Metal (mg/l)	Metal Loading, K (meq/kg MLVSS)	Initial pH	Final pH
0	0.00	7	7.79
Cd=5	6.47	7	7.65
10	12.5	7	7.70
15	16.5	7	7.53
20	25.9	7	7.68
Cu = 0.5	1.23	7	7.68
1	2.11	7	7.68
1.5	3.22	7	7.71
2	4.51	7	7.99
Zn = 5	11.1	7	7.67
10	24.3	7	7.73
20	45.7	7	7.61
30	77.9	7	7.12

Table H-21 The influent and effluent **pH** after dosing **combined metals** (0-80 meq/kg MLVSS).

Combined Metals (mg/l)	Metal Loading, K (meq/kg MLVSS)	Initial pH	Final pH
No-metal control	0	7	7.42
Zn5+Cd5	18.7	7	6.78
Zn10+Cd5	28.8	7	6.69
Zn20+Cd5	55.2	7	6.72
Zn5+Cd10	35.3	7	6.71
Zn10+Cd10	37.5	7	6.69
Zn20+Cd10	54.7	7	6.67
Zn5+Cu1	15.5	7	7.19
Zn10+Cu1	32.8	7	6.78
Zn20+Cu1	51.4	7	6.68
Zn5+Cu2	17.3	7	7.23
Zn10+Cu2	28.5	7	6.73
Zn20+Cu2	48.5	7	6.72
Cd5+Cu1	10.5	7	7.17
Cd10+Cu1	15.8	7	6.79
Cd5+Cu2	11.6	7	7.27
Cd10+Cu2	18.3	7	6.75
Cd5+Zn5+Cu1	20.4	7	6.73
Cd10+Zn10+Cu1.5	37.9	7	6.75
Cd20+Zn20+Cu2	81.3	7	6.72

Table H-22 The influent and effluent **pH** after dosing **combined metals** (0-30 meq/kgMLVSS).

Combined Metals (mg/l)	Metal Loading, K (meq/kg MLVSS)	Initial pH	Final pH
No-metal control	0	7	7.44
Cd 8 + Cu 1	14.68	7	7.50
Cd 6 + Cu 2	15.04	7	7.42
Cd 4 + Zn 4	17.98	7	7.39
Cd 4 + Zn 2	11.99	7	7.41
Cd 2 + Zn 4	16.08	7	7.41
Cd 2 + Zn 2	13.98	7	7.40
Cu 2 + Zn 6	23.46	7	7.41
Cu 2 + Zn 4	16.69	7	7.41
Cu 2 + Zn 2	11.34	7	7.37
Cd 0.5 + Cu 0.5 + Zn 0.5	3.94	7	7.33
Cd 1 + Cu 1 + Zn 1	7.36	7	7.39
Cd 2 + Cu 2 + Zn 2	20.79	7	7.37
Cd 4 + Cu 2 + Zn 2	23.08	7	7.39
Cd 1 + Cu 2 + Zn 4	20.84	7	7.40
Cd 2 + Cu 2 + Zn 4	19.23	7	7.42
Cd 3 + Cu 1 + Zn 4	22.42	7	7.36
Cd 4 + Cu 1 + Zn 4	20.94	7	7.38
Cd 5 + Cu 2 + Zn 5	29.25	7	7.39

Table H-23 The reactor number and the toxicant in each reactor.

Reactor Number	Toxicant Concentration (mg/l)
1	SO_4^{2-} 700
2	SO_4^{2-} 1,100
3	SO_4^{2-} 1,300
4	SO_4^{2-} 2,100
5	SO_4^{2-} 2,600
Reactor Number	**Metal (mg/l) + SO_4^{2-} 1,100**
6	No-metal control
7	Cd 5
8	Cd 10
9	Cd 15
10	Cd 20
11	Cu 0.5
12	Cu 1
13	Cu 1.5
14	Cu 2
15	Zn 5
16	Zn 10
17	Zn 20
18	Zn 30

Table H-23 -continued- The reactor number and the toxicant in each reactor.

Reactor Number	Metals (mg/l) + SO_4^{2-} 1,100 mg/l
1	No-metal control
2	Zn5+Cd5
3	Zn10+Cd5
4	Zn20+Cd5
5	Zn5+Cd10
6	Zn10+Cd10
7	Zn20+Cd10
8	Zn5+Cu1
9	Zn10+Cu1
10	Zn20+Cu1
11	Zn5+Cu2
12	Zn10+Cu2
13	Zn20+Cu2
14	Cd5+Cu1
15	Cd10+Cu1
16	Cd5+Cu2
17	Cd10+Cu2
18	Cd5+Zn5+Cu1
19	Cd10+Zn10+Cu1.5
20	Cd20+Zn20+Cu2

Table H-23 -continued- The reactor number and the toxicant in each reactor.

Reactor Number	Metals (mg/l) + SO_4^{2-} 1,100 mg/l
1	No-metal control
2	Cd 8 + Cu 1
3	Cd 6 + Cu 2
4	Cd 4 + Zn 4
5	Cd 4 + Zn 2
6	Cd 2 + Zn 4
7	Cd 2 + Zn 2
8	Cu 2 + Zn 6
9	Cu 2 + Zn 4
10	Cu 2 + Zn 2
11	Cd 0.5 + Cu 0.5 + Zn 0.5
12	Cd 1 + Cu 1 + Zn 1
13	Cd 2 + Cu 2 + Zn 2
14	Cd 4 + Cu 2 + Zn 2
15	Cd 1 + Cu 2 + Zn 4
16	Cd 2 + Cu 2 + Zn 4
17	Cd 3 + Cu 1 + Zn 4
18	Cd 4 + Cu 1 + Zn 4
19	Cd 5 + Cu 2 + Zn 5

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