

### Summary of $K_L a$ Values Determined for Type I Gravel

67

$U_G$ (Nm/h)	$U_L$ (m/h)	Clean Water Testing			Dirty Water Testing
		10 C	16 C	24 C	10 C
8	4	16	32	26	46
16	4	24	39	40	42
24	4	32	52	50	43
32	4	38	56	58	
40	4	47	61	62	
8	8	25	24	31	44
16	8	39	36	52	59
24	8	62	43	65	75
32	8	65	53	79	85
40	8	67	69	83	
8	12	21	23	27	64
16	12	39	54	52	107
24	12	52	62	59	136
32	12	64	61	72	155
40	12	76	84	94	136
8	16	21	22	43	
16	16	38	47	59	
24	16	56	53	79	
32	16	67	83	98	
40	16	79	93	87	
8	20				53
16	20				112
24	20				142
32	20				186
40	20				212

### Summary of $K_L a$ Values Determined for Type II Gravel

68

$U_G$ (Nm/h)	$U_L$ (m/h)	Clean Water Testing			Dirty Water Testing
		10 C	16 C	24 C	10 C
8	4	13	24	30	22
16	4	30	39	49	28
24	4	51	44	58	34
32	4	47	56	67	
40	4	49	56	64	
8	8	32	35	40	35
16	8	49	51	72	47
24	8	77	74	90	60
32	8	82	89	84	68
40	8	84	102	114	
8	12	34	52	31	26
16	12	57	68	69	48
24	12	80	108	94	65
32	12	84	104	112	77
40	12	109	129	132	93
8	16	35	15	42	
16	16	70	40	68	
24	16	72	91	102	
32	16	95	90	142	
40	16	98	120	165	
8	20				29
16	20				54
24	20				73
32	20				91
40	20				96

Summary of  $K_L a$  Values Experimentally Determined for L2.7 Media

$U_G$ (Nm/h)	$U_L$ (m/h)	Clean Water Testing			Dirty Water Testing	
		10 C	16 C	24 C	10 C	25 C
8	4	42	64	68	48	
16	4	68	97	106	63	
24	4	82	106	133	83	
32	4	91	142	160	103	
40	4	108	156	176	118	
8	8	59	94	118	68	
16	8	77	129	163	123	
24	8	110	146	195	109	
32	8	104	163	210	120	
40	8	124	188	247	161	
8	12	59	112	147	85	132
16	12	93	150	198	140	162
24	12	130	173	231	144	231
32	12	148	201	263	171	187
40	12	169	230	282	178	176
8	16	83	114	165	99	114
16	16	114	178	228	164	182
24	16	145	194	279	164	
32	16	159	228	330	211	257
40	16	174	267	354	225	277
8	4	39	47	67	46	
16	4	59	87	123	75	
24	4	75	105	158	82	
32	4	88	125	175	81	
40	4	97	158	205	108	
8	8	64	88	127	81	
16	8	79	127	172	119	
24	8	98	153	203	106	
32	8	115	176	244	125	
40	8	124	195	261	139	
8	12	69	110	149	99	89
16	12	82	159	212	145	137
24	12	115	181	240	174	228
32	12	121	208	262	175	192
40	12	149	215	290	185	198
8	16	75	118	167	133	98
16	16	107	146	235	187	151
24	16	147	198	288	162	189
32	16	145	233	322	218	231
40	16	161	269	376	224	265

### Summary of $K_L a$ Values Determined for P3.5 Media

$U_G$ (Nm/h)	$U_L$ (m/h)	Clean Water 10 C	Dirty Water 10 C
8	4	34	41
16	4	62	63
24	4	73	73
32	4	97	89
40	4	99	84
8	8	50	46
16	8	79	97
24	8	91	107
32	8	118	108
40	8	125	125
8	12	62	64
16	12	94	89
24	12	119	98
32	12	132	134
40	12	138	149
8	16	67	76
16	16	93	114
24	16	129	138
32	16	135	148
40	16	162	167
8	4	44	40
16	4	69	65
24	4	83	74
32	4	97	90
40	4	114	93
8	8	41	54
16	8	71	73
24	8	91	100
32	8	104	108
40	8	113	125
8	12	60	56
16	12	86	92
24	12	115	115
32	12	131	135
40	12	126	159
8	16	109	60
16	16	103	104
24	16	140	139
32	16	159	157
40	16	168	180

**SigmaPlot 8.0 Individual Temperature Regressions**

**For Type I Gravel**

$U_G$ (Nm/h)	$U_L$ (m/h)	$K_L a_{(20)}$	Theta	$R^2$
8	4	26	1.022	0.264
16	4	37	1.030	0.674
24	4	48	1.025	0.54
32	4	55	1.025	0.714
40	4	60	1.017	0.7
8	8	28	1.018	0.736
16	8	45	1.025	0.707
24	8	58	1.007	0.048
32	8	69	1.019	0.401
40	8	77	1.016	0.916
8	12	25	1.018	0.995
16	12	51	1.017	0.523
24	12	59	1.008	0.37
32	12	68	1.010	0.595
40	12	89	1.015	0.998
8	16	33	1.063	0.919
16	16	52	1.031	0.996
24	16	68	1.030	0.777
32	16	89	1.026	0.977
40	16	88	1.006	0.201

	<u>Average</u>	<u>St Dev</u>
All $R^2$ value data	1.021	0.012
$R^2 > 0.5$ only	1.024	0.012

**SigmaPlot 8.0 Individual Temperature Regressions**

**For Type II Gravel**

$U_G$ (Nm/h)	$U_L$ (m/h)	$K_L a_{(20)}$	Theta	$R^2$
8	4	25	1.050	0.891
16	4	43	1.035	0.984
24	4	53	1.012	0.378
32	4	61	1.025	0.995
40	4	60	1.019	0.991
8	8	37	1.017	1.000
16	8	63	1.031	0.993
24	8	84	1.013	0.687
32	8	85	1.001	0.056
40	8	106	1.021	0.945
8	12	38	-0.992	0.046
16	12	67	1.012	0.722
24	12	97	1.008	0.164
32	12	106	1.019	0.875
40	12	128	1.012	0.762
8	16	33	1.028	0.141
16	16	60	1.001	0.001
24	16	95	1.023	0.928
32	16	120	1.035	0.806
40	16	141	1.039	0.999

	<u>Average</u>	<u>St Dev</u>
All $R^2$ value data	1.021	0.013
$R^2 > 0.5$ only	1.025	0.011

For L2.7 Media

U <sub>G</sub> (Nm/h)	U <sub>L</sub> (m/h)	K <sub>L</sub> a <sub>(20)</sub>	Theta	R <sup>2</sup>
8	4	60	1.034	0.793
16	4	100	1.039	0.874
24	4	123	1.044	0.932
32	4	145	1.041	0.908
40	4	167	1.040	0.862
8	8	103	1.047	0.958
16	8	141	1.050	0.936
24	8	169	1.044	0.967
32	8	191	1.049	0.919
40	8	214	1.048	0.955
8	12	123	1.053	0.933
16	12	170	1.054	0.919
24	12	200	1.045	0.967
32	12	225	1.044	0.932
40	12	247	1.040	0.956
8	16	137	1.052	0.986
16	16	191	1.052	0.954
24	16	235	1.048	0.997
32	16	268	1.052	0.980
40	16	303	1.052	0.957

All R <sup>2</sup> value data	<b>Average</b>	<b>St Dev</b>
	1.046	0.006

**Summary of  $K_L a$  Values Predicted by Equation for Type I Gravel**

$U_G$ (Nm/h)	$U_L$ (m/h)	Clean Water Testing			Dirty Water Testing
		10 C	16 C	24 C	10 C
8	4	18	21	25	23
16	4	28	33	39	37
24	4	37	42	51	48
32	4	44	51	62	58
40	4	51	59	72	67
8	8	22	25	30	28
16	8	34	40	48	45
24	8	45	52	62	58
32	8	54	62	75	70
40	8	62	72	87	81
8	12	24	28	34	32
16	12	38	44	54	50
24	12	50	58	70	65
32	12	60	70	84	79
40	12	70	81	98	91
8	16	26	30	37	34
16	16	42	48	58	54
24	16	54	63	76	71
32	16	66	76	91	85
40	16	76	87	106	99

**Prediction Parameters**

**Clean Water**

c	3.94
a	0.66
b	0.28
theta	1.024

**Dirty Water**

alpha	1.3
-------	-----

**Summary of  $K_L a$  Values Predicted by Equation for Type II Gravel**

$U_G$ (Nm/h)	$U_L$ (m/h)	Clean Water Testing			Dirty Water Testing
		10 C	16 C	24 C	10 C
8	4	20	23	28	22
16	4	32	37	45	35
24	4	42	49	60	47
32	4	52	60	73	57
40	4	60	70	85	66
8	8	27	31	38	30
16	8	43	50	61	48
24	8	57	67	81	63
32	8	70	81	99	77
40	8	82	95	115	90
8	12	32	37	45	35
16	12	52	60	73	57
24	12	69	80	97	75
32	12	84	97	118	92
40	12	98	113	138	107
8	16	36	42	52	40
16	16	59	68	83	65
24	16	78	90	110	86
32	16	95	110	134	104
40	16	111	128	156	122

**Prediction Parameters**

**Clean Water**

c	3.33
a	0.69
b	0.44
theta	1.025

**Dirty Water**

alpha	1.1
-------	-----

Summary of  $K_L a$  Values Predicted by Void Based Equation for L2.7 Media

$U_G$ (Nm/h)	$U_L$ (m/h)	Clean Water Testing			Dirty Water Testing	
		10 C	16 C	24 C	10 C	25 C
8	4	47	61	87	59	
16	4	65	85	122	82	
24	4	79	104	149	100	
32	4	91	119	171	115	
40	4	102	133	191	128	
8	8	63	82	118	79	
16	8	88	115	165	111	
24	8	107	141	201	135	
32	8	123	162	232	155	
40	8	138	180	258	173	
8	12	75	98	141	95	108
16	12	105	138	197	132	151
24	12	128	168	240	161	183
32	12	147	193	276	186	211
40	12	164	215	308	207	235
8	16	85	111	160	107	122
16	16	119	156	224	150	171
24	16	145	190	272	183	
32	16	167	219	313	210	239
40	16	186	244	349	234	267

Prediction Parameters

Clean Water Factors		Dirty Water Factors	
c	14.51	alpha <sub>(10)</sub>	1.26
a	0.49	alpha <sub>(24)</sub>	0.73
b	0.44		
theta	1.046		

Summary of  $K_L a$  Values Predicted by Volume Based Equation for L2.7 Media based on Liquid Volumes

$U_G$ (Nm/h)	$U_L$ (m/h)	$U_{IL}$ (m/h)	20 C
8	4	14	88
16	4	14	128
24	4	15	158
32	4	15	184
40	4	15	207
8	8	29	120
16	8	29	173
24	8	29	214
32	8	29	250
40	8	29	281
8	12	43	143
16	12	43	207
24	12	44	256
32	12	44	299
40	12	44	336
8	16	57	163
16	16	58	235
24	16	58	291
32	16	58	339
40	16	59	381

Prediction Parameters

Clean Water Factors	
c	15.94
a	0.53
b	0.44
theta	1.046



### Summary of $K_L a$ Values Predicted by Equation for P3.5 Media

$U_G$ (Nm/h)	$U_L$ (m/h)	Clean Water 10 C	Dirty Water 10 C
8	4	44	44
16	4	62	62
24	4	76	76
32	4	88	88
40	4	98	98
8	8	57	57
16	8	80	80
24	8	98	98
32	8	113	113
40	8	126	126
8	12	65	65
16	12	92	92
24	12	113	113
32	12	130	130
40	12	146	146
8	16	73	73
16	16	102	102
24	16	125	125
32	16	145	145
40	16	162	162

#### Prediction Parameters

##### Clean Water

c	14.96
a	0.50
b	0.36
theta	1.046

##### Dirty Water

alpha	1
-------	---

**Summary of Gas Holdup Determination  
For L 2.7 media in lab-scale packed column**

**Clean Water Testing**

<i>Stagnant Gas Holdup for Given Air Velocity (Nm/h)</i>					
<b>temp</b>	<b>8</b>	<b>16</b>	<b>24</b>	<b>32</b>	<b>40</b>
10	3.2%	3.9%	4.1%	3.8%	4.0%
16	4.5%	5.2%	5.0%	4.8%	4.5%
24	4.5%	4.7%	4.5%	4.7%	4.5%
16	4.3%	4.6%	4.3%	4.5%	4.4%
Average	4.1%	4.6%	4.5%	4.5%	4.3%
Std Dev	0.6%	0.5%	0.4%	0.4%	0.2%

<i>Total Gas Holdup for Given Air Velocity (Nm/h)</i>					
<b>temp</b>	<b>8</b>	<b>16</b>	<b>24</b>	<b>32</b>	<b>40</b>
10	3.7%	4.9%	5.3%	5.3%	5.9%
16	5.1%	6.2%	6.4%	6.4%	6.5%
24	5.2%	6.1%	6.6%	7.0%	7.4%
16	5.1%	6.0%	6.6%	7.3%	7.7%
Average	4.8%	5.8%	6.2%	6.5%	6.9%
Std Dev	0.7%	0.6%	0.6%	0.9%	0.8%

<i>Dynamic Gas Holdup for Given Air Velocity (Nm/h)</i>					
	<b>8</b>	<b>16</b>	<b>24</b>	<b>32</b>	<b>40</b>
Average	0.7%	1.2%	1.8%	2.0%	2.5%

**Dirty Water Testing**

<i>Stagnant Gas Holdup for Given Air Velocity (Nm/h)</i>					
<b>temp</b>	<b>8</b>	<b>16</b>	<b>24</b>	<b>32</b>	<b>40</b>
10	7.6%	8.1%	8.4%	7.6%	7.9%
24	7.8%	7.8%	7.5%	8.0%	8.0%
Average	7.7%	8.0%	8.0%	7.8%	7.9%
St Dev	0.1%	0.3%	0.6%	0.3%	0.0%

<i>Total Gas Holdup for Given Air Velocity (Nm/h)</i>					
<b>temp</b>	<b>8</b>	<b>16</b>	<b>24</b>	<b>32</b>	<b>40</b>
10	8.2%	8.9%	9.5%	9.0%	9.4%
24	8.2%	9.0%	8.2%	10.0%	10.3%
Average	8.2%	9.0%	8.8%	9.5%	9.9%
St Dev	0.0%	0.1%	1.0%	0.7%	0.7%

<i>Dynamic Gas Holdup for Given Air Velocity (Nm/h)</i>					
	<b>8</b>	<b>16</b>	<b>24</b>	<b>32</b>	<b>40</b>
Average	0.5%	1.0%	0.9%	1.7%	1.9%

**Summary of Gas Holdup Determination  
For P 3.5 media in lab-scale packed column**

**Clean Water Testing**

<i>Stagnant Gas Holdup for Given Air Velocity (Nm/h)</i>					
<b>temp</b>	<b>8</b>	<b>16</b>	<b>24</b>	<b>32</b>	<b>40</b>
10	3.5%	3.9%	3.1%	3.2%	3.3%

<i>Total Gas Holdup for Given Air Velocity (Nm/h)</i>					
<b>temp</b>	<b>8</b>	<b>16</b>	<b>24</b>	<b>32</b>	<b>40</b>
10	4.2%	5.1%	4.8%	5.3%	5.7%

<i>Dynamic Gas Holdup for Given Air Velocity (Nm/h)</i>					
<b>temp</b>	<b>8</b>	<b>16</b>	<b>24</b>	<b>32</b>	<b>40</b>
10	0.7%	1.2%	1.7%	2.1%	2.4%

**Dirty Water Testing**

<i>Stagnant Gas Holdup for Given Air Velocity (Nm/h)</i>					
<b>temp</b>	<b>8</b>	<b>16</b>	<b>24</b>	<b>32</b>	<b>40</b>
10	6.4%	5.4%	5.1%	5.3%	5.7%

<i>Total Gas Holdup for Given Air Velocity (Nm/h)</i>					
<b>temp</b>	<b>8</b>	<b>16</b>	<b>24</b>	<b>32</b>	<b>40</b>
10	7.1%	6.8%	6.9%	7.5%	8.2%

<i>Dynamic Gas Holdup for Given Air Velocity (Nm/h)</i>					
<b>temp</b>	<b>8</b>	<b>16</b>	<b>24</b>	<b>32</b>	<b>40</b>
10	0.7%	1.3%	1.8%	2.1%	2.4%

**Transient Testing to Determine the Reaeration Effect of Stagnant Bubbles**

Temperature (°C)	16		16		24
Water Velocity (mL/min)	540		540		540
Air Velocity (N m/h)	40		40		40
Sample Rate (mL/min)					

Time (min)	DO Saturation %	Time (min)	DO Saturation %	Time (min)	DO Saturation %
0	100.9	0	106.9	0	93.9
1	100.4	1	105.5	1	88.6
2	92	2	98.3	2	58.8
3	80.1	3	84.3	3	39.7
4	67.8	4	70.1	4	28.8
5	56.7	5	58	5	23.6
6	47.1	6	48.1	6	21.2
7	39.7	7	40.9	7	19.8
8	33.7	8	35.2	8	19
9	29.1	9	31	9	18.4
10	25.2	10	27.1	10	18
11	23.6	11	24.5	11	17.5
12	21.8	12	22.6	12	17.3
13	20.3	13	21.2	13	17
14	19.1	14	20.3	14	16.9
15	18.5	15	19.7	15	16.7
16	17.8	16	19.1	16	16.8
17	17.1	17	18.6	17	16.7
18	17.1	18	18.2	18	18.3
19	16.9	19	17.8	19	22.5
20	16.7	20	17.4	20	36.6
21	16.5	21	17	21	46.5
22	17.7	22	17.4	22	52.6
23	20.9	23	22.8	23	57.6
24	29.7	24	29.9	24	60.3
25	38.7	25	37.9	25	62.7
26	45.5	26	43.8	26	65
27	50.4	27	47.3	27	66.9
28	53.9	28	50.5	28	68.2
29	57	29	53.4	29	69.7
30	59.3	30	56.2	30	70.1
31	61.4	31	58.9	31	72.8
32	63.4	32	61.6	32	73.5
33	65.2	33	63.2	33	74.9
34	66.5	34	64.8	34	75.1
35	67.8	35	66.3	35	76.7
36	69.1	36	68	41	79.5
37	70.2	37	68.8	47	81.5
38	71.4	38	69.6	52	84.7
39	72.4	39	70.8	60	86.4
40	73.1	40	71.8	71	88.3
42	75.5	45	77	80	88.9
45	78.2	50	80.5		
50	81	55	83.1		
55	83	60	85.5		
60	85.8	65	87.2		
65	87.6	75	90.6		
70	89.1	85	92		
75	90.5	95	93.9		
80	91.4				
85	91.9				
120	95.1				

**Transient Testing to Determine the Reaeration Effect of Stagnant Bubbles**

Temperature (°C)	10	10	10	10	10	10	10	10	10	10	10	10	10	10
Water Velocity (mL/min)	540	540	540	540	1080	1080	1080	1620	1620	2160	2160	2160	2160	2160
Air Velocity (N m/h)	8	8	40	40	8	8	40	8	40	8	8	8	40	40
Sample Rate (mL/min)	105	70	105	60	75	130	60	70	70	85	80	60	120	60

Time (min)	DO Saturation %													
0	106.6	84.7	97.6	92.6	92.2	99.5	96	108	100.1	100.4	94.6	105	102.1	95.6
1	94.6	76.5	89.3	86.7	91.5	85.3	88.5	104.9	91.1	91.2	89.6	104.9	78.9	87.9
2	77.4	64.1	62.2	66.3	83.6	76.3	65.5	90.8	70.2	84.1	79.9	98.5	69.5	72.6
3	72.2	57.6	50.6	50.8	75.8	74.3	51.9	83.7	58.4	82	75.6	93.2	66.2	61.9
4	70.6	55.2	44.7	40.9	70.8	73.6	46.6	79.8	52.4	81.2	73.2	90.4	65.1	56.5
5	70.7	54.3	42.6	35.7	67.6	73.4	43.5	78.1	50	81.5	73	89.5	63.5	53.5
6	70.6	53.1	42.1	31.6	65.5	73.3	41.5	77.3	48.7	81.4	72.5	90	62.7	52.4
7	71.2	52.7	41.5	29.7	63.9	73.2	40.3	77.1	48.3	81.2	72.6	87.4	62.4	51.3
8	72.1	53.6	41	28.5	63.4	73.4	39.9	76.8	48.1	81	72	87.2	61.5	50.6
9	72.2	52.5	41.2	27.8	62.9	73.1	39.2	74.3	47.4	80.8	72.1	85.9	59.8	49.4
10	71	53.6	41.1	27.2	62.3	73.2	38.6	75.1	47	80.4	71.6	85.2	60.1	48.7
11	69.8	53.3	40.5	27.1	62.4	72.9	38	75.1	46.8	80.2	71.4	84.6	58.3	47.8
12	70.2	53.5	39.7	27.2	62.6	72.9	37.5	75.1	46.1	78.9	71.7	85.8	57.8	47.3
13	70.5	53.7	38.9	27.1	62.7	72.9	37.2	76.7	45.5	78.5	71.8	85.8	59.1	46.7
14	71.2	53.4	38.4	27.1	62.6	72.2	37	76.1	45.2	78.4	71.3	85	55.8	46
15	70.4	54	38.8	27.1	62.4	72	36.8	75.4	44.9	78.4	70.7	82.5	56.8	45.1
16	69.5	53.7	38.7	27.1	62.3	71	36.8	73	44.3	78	70.3	81.8	55.1	44.4
17	67.7	53.7	39	27.2	61.7	70.7	37.2	74.5	44.1	77.8	70.3	83.2	55.6	44
18	68.3	54	39.2	27.1	61.8	70.2	37.5	74.4	43.4	76.8	69.8	81.7	55.6	43.5
19	68.1	53.7	39.3	27	62.1	70.2	37.7	74	43.6	76.8	69.8	81.6	56.3	43.6
20	67.9	53.8	39.2	27	61.8	69.8	37.7	73.6	43.4	76.6	69.3	82.9	56.1	43.2
21	69.7	54	39.5	27.1	62.3	75.3	38.4	74.2	45.2	79.2	71	81.7	69.1	44
22	82.9	63.3	54.8	39.4	67.9	84.5	56.7	82.3	61.9	86	77.9	86.2	75.8	56.2
23	89.5	70.9	67.5	53.1	74.3	88.6	69.5	78.5	73	89	81.7	90.1	79.9	65.4
24	92	76.5	76.1	63.2	79	90.2	77.3	90.2	79.2	90.4	84.5	92.9	83.7	70.7
25	92.8	79.4	80	69.5	81.9	91	82.3	91.6	82.6	90.8	85.2	93.4	84.9	74.1
26	93.5	81.3	82.9	73.5	84.1	91.7	85.2	92.9	84.6	91.6	86.2	93.7	85.1	76
27	93.9	82.2	83.4	76.4	85	92.2	87.3	93.3	86.1	92.5	86.8	96	85.8	77.4
28	94.4	82.7	84.6	78.3	86	93.1	88.4	93.6	86.6	93.7	87.3	96.8	87.4	78.8
29	94.8	83.1	85.4	79.6	86.6	93.5	89	94.2	87.4	93.3	87.6	98.2	88.6	79.7
30	95.1	83.5	86	80.6	87.2	94	89.9	94.3	88.2	94.1	88.2	96.4	89.2	80.8
35	95.8	85.3	88	83	88.3	95.3	92.1	93	91.2	96.5	89.9	98.2	93.9	75.3
40	96.6	86.2	89.6	85.2	90.5	97	94	94.7	93.7	98.2	92.5	102.1	97.6	89.2
45	97.3	86.9	91.3	86.9	91.3	97.6	95.6	95.4	95.4	99.4	93.7	101.1	100.2	91.7
50	97.8	87.6	92.3	87.9	92.5	98.9	97.1	98.4	96.8	100.4	95	104.5	102	93.4
55	98.7	88.8	93.2	88.5	92.8	100	98.1	97.1	97.8	100.8	95.8	104.9	103	95
60	99	89.4	94.2	89	93.3	100.3	99	99.5	99.4	100.4	95.9	105.4	103.8	96.4

### Summary of NH<sub>4</sub>-N Removal Percentages at a Given Aeration Rate

	Date	U <sub>G</sub> Nm/h	U <sub>L</sub> m/h	kg O <sub>2</sub> / m <sup>3</sup> media/d	N Load app (kg N/m <sup>3</sup> /d)	N Load Removal (kg/m <sup>3</sup> /d)	% Removal of NH <sub>4</sub> Achieved
Test Condition 1	11-Oct	12.1	4.2	23.6	1.2	0.83	0.72
	10-Oct	14.5	4.0	28.1	1.0	0.92	0.97
	9-Oct	16.2	3.9	31.4	0.9	0.92	0.98
	8-Oct	16.9	4.0	32.8	0.9	0.82	0.93
	7-Oct	24.1	4.0	46.9	0.8	0.74	0.99
Test Condition 3	15-Nov	14.2	7.3	27.6	1.4	1.14	0.80
	14-Nov	17.7	7.4	34.5	1.4	1.22	0.89
	13-Nov	23.7	7.8	46.1	1.4	1.33	0.95
	12-Nov	27.0	7.8	52.5	1.4	1.38	0.98
Test Condition 4	22-Nov	4.5	10.3	8.7	1.0	0.68	0.69
	21-Nov	5.9	10.3	11.4	1.0	0.86	0.89
	20-Nov	7.1	10.5	13.8	0.9	0.89	0.94
	19-Nov	9.9	10.6	19.2	1.2	1.12	0.92
Test Condition 5	4-Jan	8.6	5.1	16.7	1.5	0.97	0.62
	3-Jan	20.1	4.9	39.1	1.3	1.23	0.97
	2-Jan	25.3	4.9	49.2	1.6	1.46	0.94
	1-Jan	30.0	4.9	58.3	1.2	1.15	0.98
	31-Dec	35.1	5.0	68.3	1.3	1.32	0.98

## Determining Biological Observed Yield

### 24 hour Filter Run

VSS bw	133 mg/L as COD
pCODbw	133 mg/L as COD
Qbw	58 gpm
Tbw	24 min
tCOD Comp Inf	36 mg/L
tCOD Comp Eff	29 mg/L
Qfilter	15.5 gpm
Tfilter	1440 min
NO <sub>3</sub> -N Oxidized	33.3 mg/L
NH <sub>4</sub> -N Removed	34.8 mg/L
Yield	1.3 mg COD/mg COD rem
	0.25 mg COD/mg NO <sub>3</sub> -N Oxid
	0.24 mg COD/mg NH <sub>4</sub> -N Rem

### 48 hour Filter Run

VSS bw	152 mg/L as COD
pCODbw	151 mg/L as COD
Qbw	58 gpm
Tbw	24 min
tCOD Comp Inf	47 mg/L
tCOD Comp Eff	34 mg/L
Qfilter	14.4 gpm
Tfilter	2880 min
NO <sub>3</sub> -N Oxidized	40 mg/L
NH <sub>4</sub> -N Removed	38 mg/L
Yield	0.41 mg COD/mg COD rem
	0.13 mg COD/mg NO <sub>3</sub> -N Oxid
	0.14 mg COD/mg NH <sub>4</sub> -N Rem

\* concentration of VSS in influent is negligible

### Summary of $K_La$ Factors from Aeration Testing for L2.7 Media

porosity 0.297  
 alpha 0.74  
 theta 1.046

	Date	$U_G$ Nm/h	$U_L$ m/h	Temp °C	Predicted $K_La$ ( $h^{-1}$ )	Port Average		Overall	
						Calculated $K_La$ ( $h^{-1}$ )	Enhancement Factor	Calculated $K_La$ ( $h^{-1}$ )	Enhancement Factor
Test Condition 1	10-Oct	14.46	4.0	24.0	87	114	1.3	123	1.4
	9-Oct	16.2	3.9	23.9	91	124	1.4	132	1.4
	8-Oct	16.9	4.0	23.9	94	106	1.1	116	1.2
	7-Oct	24.1	4.0	25.3	118	113	1.0	126	1.1
Test Condition 3	15-Nov	14.2	7.3	18.5	88	117	1.3	101	1.2
	14-Nov	17.7	7.4	19.0	101	131	1.3	118	1.2
	13-Nov	23.7	7.8	18.8	118	151	1.3	142	1.2
	12-Nov	27.0	7.8	20.0	133	158	1.2	162	1.2
Test Condition 4	22-Nov	4.5	10.3	18.3	58	64	1.1	56	1.0
	21-Nov	5.9	10.3	18.1	65	102	1.6	85	1.3
	20-Nov	7.1	10.5	18.0	72	111	1.5	119	1.7
	19-Nov	9.9	10.6	17.9	84	123	1.5	129	1.5
Test Condition 5	4-Jan	8.6	5.1	14.0	48	79	1.6	74	1.5
	3-Jan	20.1	4.9	14.8	75	116	1.6	134	1.8
	2-Jan	25.3	4.9	15.1	85	136	1.6	167	2.0
	1-Jan	30.0	4.9	16.3	97	133	1.4	133	1.4
	31-Dec	35.1	5.0	15.8	102	158	1.5	158	1.5



## Summary of $K_L a$ Factors from Aeration Testing for Combined Gravel Layer

		<b>Type I Gravel</b>		<b>Type II Gravel</b>		<b>Combined Gravel Layer Characteristics</b>			
		Size	3/4" to 1" dia	Size	3/8" to 3/4" dia			Height	0.5
		Height	0.35 m	Height	0.15 m			porosity	0.413
		porosity	0.44	porosity	0.35				
		alpha	1.38	alpha	1.49				
		theta	1.025	theta	1.024				
	Date	$U_G$ Nm/h	$U_L$ m/h	Temp °C	Predicted $K_L a$			Experimental $K_L a$	
					Type I ( $h^{-1}$ )	Type II ( $h^{-1}$ )	Combined ( $h^{-1}$ )	Calculated $K_L a$ ( $h^{-1}$ )	Enhancement Factor
<b>Test Condition 1</b>	10-Oct	14.46	4.0	24.0	58	56	58	79	1.4
	9-Oct	16.2	3.9	23.9	62	60	62	97	1.6
	8-Oct	16.9	4.0	23.9	65	62	64	51	0.8
	7-Oct	24.1	4.0	25.3	86	81	84	99	1.2
<b>Test Condition 3</b>	15-Nov	14.2	7.3	18.5	65	58	63	34	0.5
	14-Nov	17.7	7.4	19.0	78	68	75	61	0.8
	13-Nov	23.7	7.8	18.8	97	83	93	49	0.5
	12-Nov	27.0	7.8	20.0	109	93	104	27	0.3
<b>Test Condition 4</b>	22-Nov	4.5	10.3	18.3	34	30	33	34	1.0
	21-Nov	5.9	10.3	18.1	41	35	39	3	0.1
	20-Nov	7.1	10.5	18.0	47	40	45	43	0.9
	19-Nov	9.9	10.6	17.9	59	50	56	54	0.9
<b>Test Condition 5</b>	4-Jan	8.6	5.1	14.0	35	34	35		
	3-Jan	20.1	4.9	14.8	64	60	63	80	1.3
	2-Jan	25.3	4.9	15.1	76	70	74	53	0.7
	1-Jan	30.0	4.9	16.3	88	80	85	98	1.1
	31-Dec	35.1	5.0	15.8	97	88	94	70	0.7

### Driving Force Enhancement Calculation

Testing Condition 1	$U_G$ (Nm/h)	Height H(z) [m]	14.5	16.2	16.9	24.1						
	Sample port		$DO_{sat}$ (mg/L)				14.5	16.2	16.9	24.1	$DO_{bulk}$ (mg/L)	
	Influent	0					6.16	6.45	6.12	6.63		
	Port 1	0.55	12.48	12.50	12.61	12.32	4.42	4.27	4.60	7.04		
	Port 2	1.75	10.97	11.15	11.19	11.20	4.35	5.37	5.78	5.66		
	Port 3	2.95	9.58	9.75	9.93	10.04	4.88	5.82	6.16	6.34		
	Port 4	4.15	8.45	8.66	8.97	8.99	7.43	7.65	6.89	7.56		
	Effluent	5.06										
Testing Condition 3	$U_G$ (Nm/h)	Height H(z) [m]	14.2	17.7	23.7	27						
Sample port	$DO_{sat}$ (mg/L)				14.2	17.7	23.7	27	$DO_{bulk}$ (mg/L)			
	Influent	0					7.71	7.66	7.72	7.06		
	Port 1	0.55	14.09	13.87	14.17	14.23	5.26	6.43	6.72	6.72		
	Port 2	1.75	12.61	12.47	12.69	12.20	3.57	3.01	3.72	3.16		
	Port 3	2.95	10.81	10.82	11.22	10.98	5.69	6.04	6.79	7.06		
	Port 4	4.15	9.17	9.37	9.61	9.56	3.25	4.52	6.29	7.95		
	Effluent	5.06										
Testing Condition 4	$U_G$ (Nm/h)	Height H(z) [m]	4.5	5.9	7.1	9.9						
Sample port	$DO_{sat}$ (mg/L)				4.5	5.9	7.1	9.9	$DO_{bulk}$ (mg/L)			
	Influent	0	13.89	14.44	13.98	14.17	8.55	8.45	7.87	7.64		
	Port 1	0.55	13.88	14.33	13.77	14.13	5.49	6.18	6.60	6.93		
	Port 2	1.75	11.60	11.68	11.57	11.92	2.04	3.05	5.40	4.14		
	Port 3	2.95	9.32	9.54	9.40	9.80	1.71	2.98	3.93	5.16		
	Port 4	4.15	7.29	7.90	8.13	8.54	1.63	4.86	7.21	5.91		
	Effluent	5.06										
Testing Condition 5	$U_G$ (Nm/h)	Height H(z) [m]	8.6	20.1	25.3	30	35.1	8.6	20.1	25.3	30	35.1
Sample port	$DO_{sat}$ (mg/L)				$DO_{bulk}$ (mg/L)							
	Influent	0	15.64	15.25	15.20	14.92	15.08	7.71	7.80	7.51	7.48	7.55
	Port 1	0.55	15.50	15.02	15.03	14.67	14.85	7.53	8.60	7.16	8.45	7.92
	Port 2	1.75	13.58	13.60	13.64	13.52	13.62	4.33	4.81	5.18	7.44	8
	Port 3	2.95	10.97	11.82	12.01	11.96	12.14	4.03	4.84	7.41	6.08	7.37
	Port 4	4.15	9.49	10.29	10.47	10.51	10.64	2.63			7.07	6.94
	Effluent	5.06										

### Driving Force Enhancement Calculation

Testing Condition 1	<b>U<sub>G</sub> (Nm/h)</b>	<b>14.5</b>	<b>16.2</b>	<b>16.9</b>	<b>24.1</b>	<b>14.5</b>	<b>16.2</b>	<b>16.9</b>	<b>24.1</b>		
	<b>Sample port</b>	<b>DO<sub>calc</sub> for Boundary Layer (mg/L)</b>				<b>Enhanced driving force factor (C<sub>bl</sub>-C<sub>bl</sub>)/(C<sub>sat</sub>-C<sub>bulk</sub>)</b>					
	Influent	6.16	6.45	6.12	6.63						
	Port 1	4.42	4.27	4.60	7.04	1.00	1.00	1.00	1.00		
	Port 2	2.78	3.02	5.05	5.85	1.24	1.41	1.13	0.97		
	Port 3	2.87	4.15	5.40	6.55	1.43	1.43	1.20	0.94		
	Port 4	5.71	6.57	6.30	7.75	2.69	2.07	1.28	0.87		
	Effluent										
Testing Condition 3	<b>U<sub>G</sub> (Nm/h)</b>	<b>14.2</b>	<b>17.7</b>	<b>23.7</b>	<b>27</b>	<b>14.2</b>	<b>17.7</b>	<b>23.7</b>	<b>27</b>		
	<b>Sample port</b>	<b>DO<sub>calc</sub> for Boundary Layer (mg/L)</b>				<b>Enhanced driving force factor</b>					
	Influent	7.71	7.66	7.72	7.06						
	Port 1	5.26	6.43	6.72	6.72	1.00	1.00	1.00	1.00		
	Port 2	1.40	1.53	2.09	1.93	1.24	1.16	1.18	1.14		
	Port 3	3.03	3.74	4.97	6.16	1.52	1.48	1.41	1.23		
	Port 4	1.11	2.51	4.57	7.00	1.36	1.41	1.52	1.59		
	Effluent										
Testing Condition 4	<b>U<sub>G</sub> (Nm/h)</b>	<b>4.5</b>	<b>5.9</b>	<b>7.1</b>	<b>9.9</b>	<b>4.5</b>	<b>5.9</b>	<b>7.1</b>	<b>9.9</b>		
	<b>Sample port</b>	<b>DO<sub>calc</sub> for Boundary Layer (mg/L)</b>				<b>Enhanced driving force factor</b>					
	Influent	8.55	8.45	7.87	7.64						
	Port 1	5.49	6.18	6.60	6.93	1.00	1.00	1.00	1.00		
	Port 2	1.42	0.75	1.57	0.75	1.06	1.27	1.62	1.44		
	Port 3	0.95	0.81	1.57	2.42	1.10	1.33	1.43	1.59		
	Port 4	0.73	1.46	4.43	3.05	1.16	2.12	4.03	2.09		
	Effluent										
Testing Condition 5	<b>U<sub>G</sub> (Nm/h)</b>		<b>20.1</b>	<b>25.3</b>	<b>30</b>	<b>35.1</b>		<b>20.1</b>	<b>25.3</b>	<b>30</b>	<b>35.1</b>
	<b>Sample port</b>		<b>DO<sub>calc</sub> for Boundary Layer (mg/L)</b>					<b>Enhanced driving force factor</b>			
	Influent		7.80	7.51	7.48	7.55					
	Port 1		8.60	7.16	8.45	7.92		1.00	1.00	1.00	1.00
	Port 2		0.87	1.03	5.40	4.87		1.45	1.49	1.33	1.56
	Port 3		0.84	0.85	3.47	3.80		1.57	2.43	1.44	1.75
	Port 4		0.82	1.06	4.95	4.57				1.62	1.64
	Effluent										

## Bubble Enhancement Theory

	Baseline	Simulation 1						
		0.5	0.6	0.7	0.75	0.8	1	1.2
Initial bubble dia	0.75 cm 0.0075 m	0.005	0.006	0.007	0.0075	0.008	0.01	0.012
Initial bubble vol	2.21E-07 m <sup>3</sup>	6.54E-08	1.13E-07	1.80E-07	2.21E-07	2.68E-07	5.24E-07	9.05E-07
Characteristic cylinder diameter	0.0027 m	0.0027	0.0027	0.0027	0.0027	0.0027	0.0027	0.0027
Characteristic cylinder length	0.039 m	0.011	0.020	0.031	0.039	0.047	0.091	0.158
Characteristic cylinder volume	2.21E-07 m <sup>3</sup>	6.54E-08	1.13E-07	1.80E-07	2.21E-07	2.68E-07	5.24E-07	9.05E-07
Bubble rise velocity	25 cm/s 0.25 m/s	0.25	0.25	0.25	0.25	0.25	0.25	0.25
Bubble/water contact time	0.154 s	0.030	0.053	0.084	0.103	0.125	0.244	0.421
"squeezed" water film thickness	0.001 m	0.001	0.001	0.001	0.001	0.001	0.001	0.001
"squeezed" water film volume	4.83E-07 m <sup>3</sup>	1.68E-07	2.64E-07	3.99E-07	4.83E-07	5.79E-07	1.10E-06	1.87E-06
Initial oxygen conc	3 g/m <sup>3</sup>	0	0	0	0	0	0	0
Available dissolved oxygen	1.45E-06 g O <sub>2</sub> in BL	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Biofilm oxygen consumption rate	0.1 g/m <sup>3</sup> s	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Specific surface area of media	1950 m <sup>2</sup> /m <sup>3</sup>	1950	1950	1950	1950	1950	1950	1950
Rate based on SA	195 g/m <sup>2</sup> s	195	195	195	195	195	195	195
Biofilm SA in contact w/ cyl	4.42E-07 m <sup>2</sup>	1.31E-07	2.26E-07	3.59E-07	4.42E-07	5.36E-07	1.05E-06	1.81E-06
Available O <sub>2</sub>	9.39E-06 g/s of O <sub>2</sub>	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Consumed O <sub>2</sub>	8.61E-05 g/s of O <sub>2</sub>	2.55E-05	4.41E-05	7.00E-05	8.61E-05	1.05E-04	2.04E-04	3.53E-04
<b>RS (Relative Significance)</b>		3.0	5.0	15.0		15.0	3.0	1.7
<b>Demand / Available Ratic</b>				<b>significant</b>		<b>significant</b>		

## Bubble Enhancement Theory

	Baseline	Simulation 2						
		0.5	0.6	0.7	0.75	0.8	1	1.2
Initial bubble dia	0.75 cm 0.0075 m	0.005	0.006	0.007	0.0075	0.008	0.01	0.012
Initial bubble vol	2.21E-07 m <sup>3</sup>	6.54E-08	1.13E-07	1.80E-07	2.21E-07	2.68E-07	5.24E-07	9.05E-07
Characteristic cylinder diameter	0.0027 m	0.0027	0.0027	0.0027	0.0027	0.0027	0.0027	0.0027
Characteristic cylinder length	0.039 m	0.011	0.020	0.031	0.039	0.047	0.091	0.158
Characteristic cylinder volume	2.21E-07 m <sup>3</sup>	6.54E-08	1.13E-07	1.80E-07	2.21E-07	2.68E-07	5.24E-07	9.05E-07
Bubble rise velocity	25 cm/s 0.25 m/s	0.25	0.25	0.25	0.25	0.25	0.25	0.25
Bubble/water contact time	0.154 s	0.030	0.053	0.084	0.103	0.125	0.244	0.421
"squeezed" water film thickness	0.001 m	0.001	0.001	0.001	0.001	0.001	0.001	0.001
"squeezed" water film volume	4.83E-07 m <sup>3</sup>	1.68E-07	2.64E-07	3.99E-07	4.83E-07	5.79E-07	1.10E-06	1.87E-06
Initial oxygen conc	3 g/m <sup>3</sup>	2	2	2	2	2	2	2
Available dissolved oxygen	1.45E-06 g O <sub>2</sub> in BL	3.35E-07	5.29E-07	7.99E-07	9.66E-07	1.16E-06	2.20E-06	3.74E-06
Biofilm oxygen consumption rate	0.1 g/m <sup>3</sup> s	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Specific surface area of media	1950 m <sup>2</sup> /m <sup>3</sup>	1950	1950	1950	1950	1950	1950	1950
Rate based on SA	195 g/m <sup>2</sup> s	195	195	195	195	195	195	195
Biofilm SA in contact w/ cyl	4.42E-07 m <sup>2</sup>	1.31E-07	2.26E-07	3.59E-07	4.42E-07	5.36E-07	1.05E-06	1.81E-06
Available O <sub>2</sub>	9.39E-06 g/s of O <sub>2</sub>	1.10E-05	1.00E-05	9.55E-06	9.39E-06	9.27E-06	9.00E-06	8.88E-06
Consumed O <sub>2</sub>	8.61E-05 g/s of O <sub>2</sub>	2.55E-05	4.41E-05	7.00E-05	8.61E-05	1.05E-04	2.04E-04	3.53E-04
<b>RS (Relative Significance)</b>		1.0	1.7	5.0		5.0	1.0	0.6
<b>Demand / Available Ratic</b>		2.3	4.4	7.3	9.2	11.3	22.7	39.7

## Bubble Enhancement Theory

	Baseline	Simulation 3						
		0.5	0.6	0.7	0.75	0.8	1	1.2
Initial bubble dia	0.75 cm 0.0075 m	0.5	0.6	0.7	0.75	0.8	1	1.2
Initial bubble vol	2.21E-07 m <sup>3</sup>	6.54E-08	1.13E-07	1.80E-07	2.21E-07	2.68E-07	5.24E-07	9.05E-07
Characteristic cylinder diameter	0.0027 m	0.0027	0.0027	0.0027	0.0027	0.0027	0.0027	0.0027
Characteristic cylinder length	0.039 m	0.011	0.020	0.031	0.039	0.047	0.091	0.158
Characteristic cylinder volume	2.21E-07 m <sup>3</sup>	6.54E-08	1.13E-07	1.80E-07	2.21E-07	2.68E-07	5.24E-07	9.05E-07
Bubble rise velocity	25 cm/s 0.25 m/s	25	25	25	25	25	25	25
Bubble/water contact time	0.154 s	0.030	0.053	0.084	0.103	0.125	0.244	0.421
"squeezed" water film thickness	0.001 m	0.001	0.001	0.001	0.001	0.001	0.001	0.001
"squeezed" water film volume	4.83E-07 m <sup>3</sup>	1.68E-07	2.64E-07	3.99E-07	4.83E-07	5.79E-07	1.10E-06	1.87E-06
Initial oxygen conc	3 g/m <sup>3</sup>	4	4	4	4	4	4	4
Available dissolved oxygen	1.45E-06 g O <sub>2</sub> in BL	6.70E-07	1.06E-06	1.60E-06	1.93E-06	2.32E-06	4.39E-06	7.49E-06
Biofilm oxygen consumption rate	0.1 g/m <sup>3</sup> s	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Specific surface area of media	1950 m <sup>2</sup> /m <sup>3</sup>	1950	1950	1950	1950	1950	1950	1950
Rate based on SA	195 g/m <sup>2</sup> s	195	195	195	195	195	195	195
Biofilm SA in contact w/ cyl	4.42E-07 m <sup>2</sup>	1.31E-07	2.26E-07	3.59E-07	4.42E-07	5.36E-07	1.05E-06	1.81E-06
Available O <sub>2</sub>	9.39E-06 g/s of O <sub>2</sub>	2.20E-05	2.01E-05	1.91E-05	1.88E-05	1.85E-05	1.80E-05	1.78E-05
Consumed O <sub>2</sub>	8.61E-05 g/s of O <sub>2</sub>	2.55E-05	4.41E-05	7.00E-05	8.61E-05	1.05E-04	2.04E-04	3.53E-04
<b>RS (Relative Significance)</b>		1.0	1.7	5.0		5.0	1.0	0.6
<b>Demand / Available Ratic</b>		1.2	2.2	3.7	4.6	5.6	11.3	19.9

## Bubble Enhancement Theory

	Baseline	Simulation 4						
		0.5	0.6	0.7	0.75	0.8	1	1.2
Initial bubble dia	0.75 cm 0.0075 m	0.005	0.006	0.007	0.0075	0.008	0.01	0.012
Initial bubble vol	2.21E-07 m <sup>3</sup>	6.54E-08	1.13E-07	1.80E-07	2.21E-07	2.68E-07	5.24E-07	9.05E-07
Characteristic cylinder diameter	0.0027 m	0.0027	0.0027	0.0027	0.0027	0.0027	0.0027	0.0027
Characteristic cylinder length	0.039 m	0.011	0.020	0.031	0.039	0.047	0.091	0.158
Characteristic cylinder volume	2.21E-07 m <sup>3</sup>	6.54E-08	1.13E-07	1.80E-07	2.21E-07	2.68E-07	5.24E-07	9.05E-07
Bubble rise velocity	25 cm/s 0.25 m/s	0.25	0.25	0.25	0.25	0.25	0.25	0.25
Bubble/water contact time	0.154 s	0.030	0.053	0.084	0.103	0.125	0.244	0.421
"squeezed" water film thickness	0.001 m	0.001	0.001	0.001	0.001	0.001	0.001	0.001
"squeezed" water film volume	4.83E-07 m <sup>3</sup>	1.68E-07	2.64E-07	3.99E-07	4.83E-07	5.79E-07	1.10E-06	1.87E-06
Initial oxygen conc	3 g/m <sup>3</sup>	6	6	6	6	6	6	6
Available dissolved oxygen	1.45E-06 g O <sub>2</sub> in BL	1.01E-06	1.59E-06	2.40E-06	2.90E-06	3.47E-06	6.59E-06	1.12E-05
Biofilm oxygen consumption rate	0.1 g/m <sup>3</sup> s	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Specific surface area of media	1950 m <sup>2</sup> /m <sup>3</sup>	1950	1950	1950	1950	1950	1950	1950
Rate based on SA	195 g/m <sup>2</sup> s	195	195	195	195	195	195	195
Biofilm SA in contact w/ cyl	4.42E-07 m <sup>2</sup>	1.31E-07	2.26E-07	3.59E-07	4.42E-07	5.36E-07	1.05E-06	1.81E-06
Available O <sub>2</sub>	9.39E-06 g/s of O <sub>2</sub>	3.30E-05	3.01E-05	2.86E-05	2.82E-05	2.78E-05	2.70E-05	2.66E-05
Consumed O <sub>2</sub>	8.61E-05 g/s of O <sub>2</sub>	2.55E-05	4.41E-05	7.00E-05	8.61E-05	1.05E-04	2.04E-04	3.53E-04
<b>RS (Relative Significance)</b>		3.0	5.0	15.0		15.0	3.0	1.7
<b>Demand / Available Ratio</b>		0.8	1.5	<b>significant</b> 2.4	3.1	<b>significant</b> 3.8	7.6	13.2

## Bubble Enhancement Theory

	Baseline	Simulation 5						
		0.5	0.6	0.7	0.75	0.8	1	1.2
Initial bubble dia	0.75 cm 0.0075 m	0.5	0.6	0.7	0.75	0.8	1	1.2
Initial bubble vol	2.21E-07 m <sup>3</sup>	6.54E-08	1.13E-07	1.80E-07	2.21E-07	2.68E-07	5.24E-07	9.05E-07
Characteristic cylinder diameter	0.0027 m	0.0027	0.0027	0.0027	0.0027	0.0027	0.0027	0.0027
Characteristic cylinder length	0.039 m	0.011	0.020	0.031	0.039	0.047	0.091	0.158
Characteristic cylinder volume	2.21E-07 m <sup>3</sup>	6.54E-08	1.13E-07	1.80E-07	2.21E-07	2.68E-07	5.24E-07	9.05E-07
Bubble rise velocity	25 cm/s 0.25 m/s	25	25	25	25	25	25	25
Bubble/water contact time	0.154 s	0.030	0.053	0.084	0.103	0.125	0.244	0.421
"squeezed" water film thickness	0.001 m	0.001	0.001	0.001	0.001	0.001	0.001	0.001
"squeezed" water film volume	4.83E-07 m <sup>3</sup>	1.68E-07	2.64E-07	3.99E-07	4.83E-07	5.79E-07	1.10E-06	1.87E-06
Initial oxygen conc	3 g/m <sup>3</sup>	8	8	8	8	8	8	8
Available dissolved oxygen	1.45E-06 g O <sub>2</sub> in BL	1.34E-06	2.11E-06	3.19E-06	3.87E-06	4.63E-06	8.78E-06	1.50E-05
Biofilm oxygen consumption rate	0.1 g/m <sup>3</sup> s	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Specific surface area of media	1950 m <sup>2</sup> /m <sup>3</sup>	1950	1950	1950	1950	1950	1950	1950
Rate based on SA	195 g/m <sup>2</sup> s	195	195	195	195	195	195	195
Biofilm SA in contact w/ cyl	4.42E-07 m <sup>2</sup>	1.31E-07	2.26E-07	3.59E-07	4.42E-07	5.36E-07	1.05E-06	1.81E-06
Available O <sub>2</sub>	9.39E-06 g/s of O <sub>2</sub>	4.40E-05	4.01E-05	3.82E-05	3.76E-05	3.71E-05	3.60E-05	3.55E-05
Consumed O <sub>2</sub>	8.61E-05 g/s of O <sub>2</sub>	2.55E-05	4.41E-05	7.00E-05	8.61E-05	1.05E-04	2.04E-04	3.53E-04
<b>RS (Relative Significance)</b>		5.0	8.3	25.0		25.0	5.0	2.8
<b>Demand / Available Ratic</b>		0.6	1.1	<b>significant</b> 1.8	2.3	<b>significant</b> 2.8	5.7	9.9



		<b>Bubble Enhancement Theory</b>						
<b>Baseline</b>		<b>Simulation 6</b>						
Initial bubble dia	0.75 cm 0.0075 m	0.75	0.75	0.75	0.75	0.75	0.75	0.75
Initial bubble vol	2.21E-07 m <sup>3</sup>	2.21E-07	2.21E-07	2.21E-07	2.21E-07	2.21E-07	2.21E-07	2.21E-07
Characteristic cylinder diameter	0.0027 m	0.0001	0.0005	0.001	0.0027	0.003	0.004	0.005
Characteristic cylinder length	0.039 m	28.125	1.125	0.281	0.039	0.031	0.018	0.011
Characteristic cylinder volume	2.21E-07 m <sup>3</sup>	2.21E-07	2.21E-07	2.21E-07	2.21E-07	2.21E-07	2.21E-07	2.21E-07
Bubble rise velocity	25 cm/s 0.25 m/s	25	25	25	25	25	25	25
Bubble/water contact time	0.154 s	75.000	3.000	0.750	0.103	0.083	0.047	0.030
"squeezed" water film thickness	0.001 m	0.001	0.001	0.001	0.001	0.001	0.001	0.001
"squeezed" water film volume	4.83E-07 m <sup>3</sup>	9.72E-05	5.31E-06	1.78E-06	4.83E-07	4.32E-07	3.33E-07	2.89E-07
Initial oxygen conc	3 g/m <sup>3</sup>	0	0	0	0	0	0	0
Available dissolved oxygen	1.45E-06 g O <sub>2</sub> in BL	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Biofilm oxygen consumption rate	0.1 g/m <sup>3</sup> s	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Specific surface area of media	1950 m <sup>2</sup> /m <sup>3</sup>	1950	1950	1950	1950	1950	1950	1950
Rate based on SA	195 g/m <sup>2</sup> s	195	195	195	195	195	195	195
Biofilm SA in contact w/ cyl	4.42E-07 m <sup>2</sup>	4.42E-07	4.42E-07	4.42E-07	4.42E-07	4.42E-07	4.42E-07	4.42E-07
Available O <sub>2</sub>	9.39E-06 g/s of O <sub>2</sub>	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Consumed O <sub>2</sub>	8.61E-05 g/s of O <sub>2</sub>	8.61E-05	8.61E-05	8.61E-05	8.61E-05	8.61E-05	8.61E-05	8.61E-05
<b>RS (Relative Significance)</b>		1.0	1.2	1.6		9.0	2.1	1.2
<b>Demand / Available Ratio</b>								

		<b>Bubble Enhancement Theory</b>						
<b>Baseline</b>		<b>Simulation 7</b>						
Initial bubble dia	0.75 cm 0.0075 m	0.75	0.75	0.75	0.75	0.75	0.75	0.75
Initial bubble vol	2.21E-07 m <sup>3</sup>	2.21E-07	2.21E-07	2.21E-07	2.21E-07	2.21E-07	2.21E-07	2.21E-07
Characteristic cylinder diameter	0.0027 m	0.0001	0.0005	0.001	0.0027	0.003	0.004	0.005
Characteristic cylinder length	0.039 m	28.125	1.125	0.281	0.039	0.031	0.018	0.011
Characteristic cylinder volume	2.21E-07 m <sup>3</sup>	2.21E-07	2.21E-07	2.21E-07	2.21E-07	2.21E-07	2.21E-07	2.21E-07
Bubble rise velocity	25 cm/s 0.25 m/s	25	25	25	25	25	25	25
Bubble/water contact time	0.154 s	75.000	3.000	0.750	0.103	0.083	0.047	0.030
"squeezed" water film thickness	0.001 m	0.001	0.001	0.001	0.001	0.001	0.001	0.001
"squeezed" water film volume	4.83E-07 m <sup>3</sup>	9.72E-05	5.31E-06	1.78E-06	4.83E-07	4.32E-07	3.33E-07	2.89E-07
Initial oxygen conc	3 g/m <sup>3</sup>	2	2	2	2	2	2	2
Available dissolved oxygen	1.45E-06 g O <sub>2</sub> in BL	1.94E-04	1.06E-05	3.56E-06	9.66E-07	8.64E-07	6.65E-07	5.78E-07
Biofilm oxygen consumption rate	0.1 g/m <sup>3</sup> s	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Specific surface area of media	1950 m <sup>2</sup> /m <sup>3</sup>	1950	1950	1950	1950	1950	1950	1950
Rate based on SA	195 g/m <sup>2</sup> s	195	195	195	195	195	195	195
Biofilm SA in contact w/ cyl	4.42E-07 m <sup>2</sup>	4.42E-07	4.42E-07	4.42E-07	4.42E-07	4.42E-07	4.42E-07	4.42E-07
Available O <sub>2</sub>	9.39E-06 g/s of O <sub>2</sub>	2.59E-06	3.54E-06	4.75E-06	9.39E-06	1.04E-05	1.42E-05	1.93E-05
Consumed O <sub>2</sub>	8.61E-05 g/s of O <sub>2</sub>	8.61E-05	8.61E-05	8.61E-05	8.61E-05	8.61E-05	8.61E-05	8.61E-05
<b>RS (Relative Significance)</b>		0.3	0.4	0.5		3.0	0.7	0.4
<b>Demand / Available Ratio</b>		33.2	24.3	18.1	9.2	8.3	6.1	4.5

		<b>Bubble Enhancement Theory</b>						
<b>Baseline</b>		<b>Simulation 8</b>						
Initial bubble dia	0.75 cm 0.0075 m	0.75	0.75	0.75	0.75	0.75	0.75	0.75
Initial bubble vol	2.21E-07 m <sup>3</sup>	2.21E-07	2.21E-07	2.21E-07	2.21E-07	2.21E-07	2.21E-07	2.21E-07
Characteristic cylinder diameter	0.0027 m	0.0001	0.0005	0.001	0.0027	0.003	0.004	0.005
Characteristic cylinder length	0.039 m	28.125	1.125	0.281	0.039	0.031	0.018	0.011
Characteristic cylinder volume	2.21E-07 m <sup>3</sup>	2.21E-07	2.21E-07	2.21E-07	2.21E-07	2.21E-07	2.21E-07	2.21E-07
Bubble rise velocity	25 cm/s 0.25 m/s	25	25	25	25	25	25	25
Bubble/water contact time	0.154 s	75.000	3.000	0.750	0.103	0.083	0.047	0.030
"squeezed" water film thickness	0.001 m	0.001	0.001	0.001	0.001	0.001	0.001	0.001
"squeezed" water film volume	4.83E-07 m <sup>3</sup>	9.72E-05	5.31E-06	1.78E-06	4.83E-07	4.32E-07	3.33E-07	2.89E-07
Initial oxygen conc	3 g/m <sup>3</sup>	4	4	4	4	4	4	4
Available dissolved oxygen	1.45E-06 g O <sub>2</sub> in BL	3.89E-04	2.12E-05	7.13E-06	1.93E-06	1.73E-06	1.33E-06	1.16E-06
Biofilm oxygen consumption rate	0.1 g/m <sup>3</sup> s	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Specific surface area of media	1950 m <sup>2</sup> /m <sup>3</sup>	1950	1950	1950	1950	1950	1950	1950
Rate based on SA	195 g/m <sup>2</sup> s	195	195	195	195	195	195	195
Biofilm SA in contact w/ cyl	4.42E-07 m <sup>2</sup>	4.42E-07	4.42E-07	4.42E-07	4.42E-07	4.42E-07	4.42E-07	4.42E-07
Available O <sub>2</sub>	9.39E-06 g/s of O <sub>2</sub>	5.18E-06	7.08E-06	9.50E-06	1.88E-05	2.07E-05	2.84E-05	3.85E-05
Consumed O <sub>2</sub>	8.61E-05 g/s of O <sub>2</sub>	8.61E-05	8.61E-05	8.61E-05	8.61E-05	8.61E-05	8.61E-05	8.61E-05
<b>RS (Relative Significance)</b>		0.3	0.4	0.5		3.0	0.7	0.4
<b>Demand / Available Ratio</b>		16.6	12.2	9.1	4.6	4.2	3.0	2.2

		<b>Bubble Enhancement Theory</b>						
<b>Baseline</b>		<b>Simulation 9</b>						
Initial bubble dia	0.75 cm 0.0075 m	0.75	0.75	0.75	0.75	0.75	0.75	0.75
Initial bubble vol	2.21E-07 m <sup>3</sup>	2.21E-07	2.21E-07	2.21E-07	2.21E-07	2.21E-07	2.21E-07	2.21E-07
Characteristic cylinder diameter	0.0027 m	0.0001	0.0005	0.001	0.0027	0.003	0.004	0.005
Characteristic cylinder length	0.039 m	28.125	1.125	0.281	0.039	0.031	0.018	0.011
Characteristic cylinder volume	2.21E-07 m <sup>3</sup>	2.21E-07	2.21E-07	2.21E-07	2.21E-07	2.21E-07	2.21E-07	2.21E-07
Bubble rise velocity	25 cm/s 0.25 m/s	25	25	25	25	25	25	25
Bubble/water contact time	0.154 s	75.000	3.000	0.750	0.103	0.083	0.047	0.030
"squeezed" water film thickness	0.001 m	0.001	0.001	0.001	0.001	0.001	0.001	0.001
"squeezed" water film volume	4.83E-07 m <sup>3</sup>	9.72E-05	5.31E-06	1.78E-06	4.83E-07	4.32E-07	3.33E-07	2.89E-07
Initial oxygen conc	3 g/m <sup>3</sup>	6	6	6	6	6	6	6
Available dissolved oxygen	1.45E-06 g O <sub>2</sub> in BL	5.83E-04	3.19E-05	1.07E-05	2.90E-06	2.59E-06	2.00E-06	1.73E-06
Biofilm oxygen consumption rate	0.1 g/m <sup>3</sup> s	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Specific surface area of media	1950 m <sup>2</sup> /m <sup>3</sup>	1950	1950	1950	1950	1950	1950	1950
Rate based on SA	195 g/m <sup>2</sup> s	195	195	195	195	195	195	195
Biofilm SA in contact w/ cyl	4.42E-07 m <sup>2</sup>	4.42E-07	4.42E-07	4.42E-07	4.42E-07	4.42E-07	4.42E-07	4.42E-07
Available O <sub>2</sub>	9.39E-06 g/s of O <sub>2</sub>	7.78E-06	1.06E-05	1.43E-05	2.82E-05	3.11E-05	4.26E-05	5.78E-05
Consumed O <sub>2</sub>	8.61E-05 g/s of O <sub>2</sub>	8.61E-05	8.61E-05	8.61E-05	8.61E-05	8.61E-05	8.61E-05	8.61E-05
<b>RS (Relative Significance)</b>		1.0	1.2	1.6		9.0	2.1	1.2
<b>Demand / Available Ratio</b>		11.1	8.1	6.0	3.1	2.8	2.0	1.5

		<b>Bubble Enhancement Theory</b>						
<b>Baseline</b>		<b>Simulation 10</b>						
Initial bubble dia	0.75 cm 0.0075 m	0.75	0.75	0.75	0.75	0.75	0.75	0.75
Initial bubble vol	2.21E-07 m <sup>3</sup>	2.21E-07	2.21E-07	2.21E-07	2.21E-07	2.21E-07	2.21E-07	2.21E-07
Characteristic cylinder diameter	0.0027 m	0.0001	0.0005	0.001	0.0027	0.003	0.004	0.005
Characteristic cylinder length	0.039 m	28.125	1.125	0.281	0.039	0.031	0.018	0.011
Characteristic cylinder volume	2.21E-07 m <sup>3</sup>	2.21E-07	2.21E-07	2.21E-07	2.21E-07	2.21E-07	2.21E-07	2.21E-07
Bubble rise velocity	25 cm/s 0.25 m/s	25	25	25	25	25	25	25
Bubble/water contact time	0.154 s	75.000	3.000	0.750	0.103	0.083	0.047	0.030
"squeezed" water film thickness	0.001 m	0.001	0.001	0.001	0.001	0.001	0.001	0.001
"squeezed" water film volume	4.83E-07 m <sup>3</sup>	9.72E-05	5.31E-06	1.78E-06	4.83E-07	4.32E-07	3.33E-07	2.89E-07
Initial oxygen conc	3 g/m <sup>3</sup>	8	8	8	8	8	8	8
Available dissolved oxygen	1.45E-06 g O <sub>2</sub> in BL	7.78E-04	4.25E-05	1.43E-05	3.87E-06	3.46E-06	2.66E-06	2.31E-06
Biofilm oxygen consumption rate	0.1 g/m <sup>3</sup> s	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Specific surface area of media	1950 m <sup>2</sup> /m <sup>3</sup>	1950	1950	1950	1950	1950	1950	1950
Rate based on SA	195 g/m <sup>2</sup> s	195	195	195	195	195	195	195
Biofilm SA in contact w/ cyl	4.42E-07 m <sup>2</sup>	4.42E-07	4.42E-07	4.42E-07	4.42E-07	4.42E-07	4.42E-07	4.42E-07
Available O <sub>2</sub>	9.39E-06 g/s of O <sub>2</sub>	1.04E-05	1.42E-05	1.90E-05	3.76E-05	4.15E-05	5.68E-05	7.71E-05
Consumed O <sub>2</sub>	8.61E-05 g/s of O <sub>2</sub>	8.61E-05	8.61E-05	8.61E-05	8.61E-05	8.61E-05	8.61E-05	8.61E-05
<b>RS (Relative Significance)</b>		1.7	2.0	2.6		15.0 <b>significant</b>	3.5	2.0
<b>Demand / Available Ratio</b>		8.3	6.1	4.5	2.3	2.1	1.5	1.1

		<b>Bubble Enhancement Theory</b>						
<b>Baseline</b>		<b>Simulation 11</b>						
Initial bubble dia	0.75 cm 0.0075 m	0.75	0.75	0.75	0.75	0.75	0.75	0.75
Initial bubble vol	2.21E-07 m <sup>3</sup>	0.0075	0.0075	0.0075	0.0075	0.0075	0.0075	0.0075
Characteristic cylinder diameter	0.0027 m	2.21E-07	2.21E-07	2.21E-07	2.21E-07	2.21E-07	2.21E-07	2.21E-07
Characteristic cylinder length	0.039 m	0.0027	0.0027	0.0027	0.0027	0.0027	0.0027	0.0027
Characteristic cylinder volume	2.21E-07 m <sup>3</sup>	0.039	0.039	0.039	0.039	0.039	0.039	0.039
Bubble rise velocity	25 cm/s 0.25 m/s	2.21E-07	2.21E-07	2.21E-07	2.21E-07	2.21E-07	2.21E-07	2.21E-07
Bubble/water contact time	0.154 s	10	15	20	25	30	35	40
"squeezed" water film thickness	0.001 m	0.1	0.15	0.2	0.25	0.3	0.35	0.4
"squeezed" water film volume	4.83E-07 m <sup>3</sup>	0.257	0.171	0.129	0.103	0.086	0.073	0.064
Initial oxygen conc	3 g/m <sup>3</sup>	0.001	0.001	0.001	0.001	0.001	0.001	0.001
Available dissolved oxygen	1.45E-06 g O <sub>2</sub> in BL	4.83E-07	4.83E-07	4.83E-07	4.83E-07	4.83E-07	4.83E-07	4.83E-07
Biofilm oxygen consumption rate	0.1 g/m <sup>3</sup> s	0	0	0	0	0	0	0
Specific surface area of media	1950 m <sup>2</sup> /m <sup>3</sup>	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Rate based on SA	195 g/m <sup>2</sup> s	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Biofilm SA in contact w/ cyl	4.42E-07 m <sup>2</sup>	1950	1950	1950	1950	1950	1950	1950
Available O <sub>2</sub>	9.39E-06 g/s of O <sub>2</sub>	195	195	195	195	195	195	195
Consumed O <sub>2</sub>	8.61E-05 g/s of O <sub>2</sub>	4.42E-07	4.42E-07	4.42E-07	4.42E-07	4.42E-07	4.42E-07	4.42E-07
<b>RS (Relative Significance)</b>		0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
<b>Demand / Available Ratio</b>		8.61E-05	8.61E-05	8.61E-05	8.61E-05	8.61E-05	8.61E-05	8.61E-05
		1.7	2.5	5.0		5.0	2.5	1.7

		<b>Bubble Enhancement Theory</b>						
<b>Baseline</b>		<b>Simulation 12</b>						
Initial bubble dia	0.75 cm 0.0075 m	0.75	0.75	0.75	0.75	0.75	0.75	0.75
Initial bubble vol	2.21E-07 m <sup>3</sup>	2.21E-07	2.21E-07	2.21E-07	2.21E-07	2.21E-07	2.21E-07	2.21E-07
Characteristic cylinder diameter	0.0027 m	0.0027	0.0027	0.0027	0.0027	0.0027	0.0027	0.0027
Characteristic cylinder length	0.039 m	0.039	0.039	0.039	0.039	0.039	0.039	0.039
Characteristic cylinder volume	2.21E-07 m <sup>3</sup>	2.21E-07	2.21E-07	2.21E-07	2.21E-07	2.21E-07	2.21E-07	2.21E-07
Bubble rise velocity	25 cm/s 0.25 m/s	10 0.1	15 0.15	20 0.2	25 0.25	30 0.3	35 0.35	40 0.4
Bubble/water contact time	0.154 s	0.257	0.171	0.129	0.103	0.086	0.073	0.064
"squeezed" water film thickness	0.001 m	0.001	0.001	0.001	0.001	0.001	0.001	0.001
"squeezed" water film volume	4.83E-07 m <sup>3</sup>	4.83E-07	4.83E-07	4.83E-07	4.83E-07	4.83E-07	4.83E-07	4.83E-07
Initial oxygen conc	3 g/m <sup>3</sup>	2	2	2	2	2	2	2
Available dissolved oxygen	1.45E-06 g O <sub>2</sub> in BL	9.66E-07	9.66E-07	9.66E-07	9.66E-07	9.66E-07	9.66E-07	9.66E-07
Biofilm oxygen consumption rate	0.1 g/m <sup>3</sup> s	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Specific surface area of media	1950 m <sup>2</sup> /m <sup>3</sup>	1950	1950	1950	1950	1950	1950	1950
Rate based on SA	195 g/m <sup>2</sup> s	195	195	195	195	195	195	195
Biofilm SA in contact w/ cyl	4.42E-07 m <sup>2</sup>	4.42E-07	4.42E-07	4.42E-07	4.42E-07	4.42E-07	4.42E-07	4.42E-07
Available O <sub>2</sub>	9.39E-06 g/s of O <sub>2</sub>	3.76E-06	5.64E-06	7.51E-06	9.39E-06	1.13E-05	1.31E-05	1.50E-05
Consumed O <sub>2</sub>	8.61E-05 g/s of O <sub>2</sub>	8.61E-05	8.61E-05	8.61E-05	8.61E-05	8.61E-05	8.61E-05	8.61E-05
<b>RS (Relative Significance)</b>		0.6	0.8	1.7		1.7	0.8	0.6
<b>Demand / Available Ratio</b>		22.9	15.3	11.5	9.2	7.6	6.6	5.7

		<b>Bubble Enhancement Theory</b>						
<b>Baseline</b>		<b>Simulation 13</b>						
Initial bubble dia	0.75 cm 0.0075 m	0.75	0.75	0.75	0.75	0.75	0.75	0.75
Initial bubble vol	2.21E-07 m <sup>3</sup>	0.0075	0.0075	0.0075	0.0075	0.0075	0.0075	0.0075
Characteristic cylinder diameter	0.0027 m	2.21E-07	2.21E-07	2.21E-07	2.21E-07	2.21E-07	2.21E-07	2.21E-07
Characteristic cylinder length	0.039 m	0.0027	0.0027	0.0027	0.0027	0.0027	0.0027	0.0027
Characteristic cylinder volume	2.21E-07 m <sup>3</sup>	0.039	0.039	0.039	0.039	0.039	0.039	0.039
Bubble rise velocity	25 cm/s 0.25 m/s	2.21E-07	2.21E-07	2.21E-07	2.21E-07	2.21E-07	2.21E-07	2.21E-07
Bubble/water contact time	0.154 s	10	15	20	25	30	35	40
"squeezed" water film thickness	0.001 m	0.1	0.15	0.2	0.25	0.3	0.35	0.4
"squeezed" water film volume	4.83E-07 m <sup>3</sup>	0.257	0.171	0.129	0.103	0.086	0.073	0.064
Initial oxygen conc	3 g/m <sup>3</sup>	0.001	0.001	0.001	0.001	0.001	0.001	0.001
Available dissolved oxygen	1.45E-06 g O <sub>2</sub> in BL	4.83E-07	4.83E-07	4.83E-07	4.83E-07	4.83E-07	4.83E-07	4.83E-07
Biofilm oxygen consumption rate	0.1 g/m <sup>3</sup> s	4	4	4	4	4	4	4
Specific surface area of media	1950 m <sup>2</sup> /m <sup>3</sup>	1.93E-06	1.93E-06	1.93E-06	1.93E-06	1.93E-06	1.93E-06	1.93E-06
Rate based on SA	195 g/m <sup>2</sup> s	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Biofilm SA in contact w/ cyl	4.42E-07 m <sup>2</sup>	1950	1950	1950	1950	1950	1950	1950
Available O <sub>2</sub>	9.39E-06 g/s of O <sub>2</sub>	195	195	195	195	195	195	195
Consumed O <sub>2</sub>	8.61E-05 g/s of O <sub>2</sub>	4.42E-07	4.42E-07	4.42E-07	4.42E-07	4.42E-07	4.42E-07	4.42E-07
<b>RS (Relative Significance)</b>		7.51E-06	1.13E-05	1.50E-05	1.88E-05	2.25E-05	2.63E-05	3.01E-05
<b>Demand / Available Ratio</b>		8.61E-05	8.61E-05	8.61E-05	8.61E-05	8.61E-05	8.61E-05	8.61E-05
		0.6	0.8	1.7		1.7	0.8	0.6
		11.5	7.6	5.7	4.6	3.8	3.3	2.9



		<b>Bubble Enhancement Theory</b>						
<b>Baseline</b>		<b>Simulation 14</b>						
Initial bubble dia	0.75 cm 0.0075 m	0.75	0.75	0.75	0.75	0.75	0.75	0.75
Initial bubble vol	2.21E-07 m <sup>3</sup>	2.21E-07	2.21E-07	2.21E-07	2.21E-07	2.21E-07	2.21E-07	2.21E-07
Characteristic cylinder diameter	0.0027 m	0.0027	0.0027	0.0027	0.0027	0.0027	0.0027	0.0027
Characteristic cylinder length	0.039 m	0.039	0.039	0.039	0.039	0.039	0.039	0.039
Characteristic cylinder volume	2.21E-07 m <sup>3</sup>	2.21E-07	2.21E-07	2.21E-07	2.21E-07	2.21E-07	2.21E-07	2.21E-07
Bubble rise velocity	25 cm/s 0.25 m/s	10 0.1	15 0.15	20 0.2	25 0.25	30 0.3	35 0.35	40 0.4
Bubble/water contact time	0.154 s	0.257	0.171	0.129	0.103	0.086	0.073	0.064
"squeezed" water film thickness	0.001 m	0.001	0.001	0.001	0.001	0.001	0.001	0.001
"squeezed" water film volume	4.83E-07 m <sup>3</sup>	4.83E-07	4.83E-07	4.83E-07	4.83E-07	4.83E-07	4.83E-07	4.83E-07
Initial oxygen conc	3 g/m <sup>3</sup>	6	6	6	6	6	6	6
Available dissolved oxygen	1.45E-06 g O <sub>2</sub> in BL	2.90E-06	2.90E-06	2.90E-06	2.90E-06	2.90E-06	2.90E-06	2.90E-06
Biofilm oxygen consumption rate	0.1 g/m <sup>3</sup> s	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Specific surface area of media	1950 m <sup>2</sup> /m <sup>3</sup>	1950	1950	1950	1950	1950	1950	1950
Rate based on SA	195 g/m <sup>2</sup> s	195	195	195	195	195	195	195
Biofilm SA in contact w/ cyl	4.42E-07 m <sup>2</sup>	4.42E-07	4.42E-07	4.42E-07	4.42E-07	4.42E-07	4.42E-07	4.42E-07
Available O <sub>2</sub>	9.39E-06 g/s of O <sub>2</sub>	1.13E-05	1.69E-05	2.25E-05	2.82E-05	3.38E-05	3.94E-05	4.51E-05
Consumed O <sub>2</sub>	8.61E-05 g/s of O <sub>2</sub>	8.61E-05	8.61E-05	8.61E-05	8.61E-05	8.61E-05	8.61E-05	8.61E-05
<b>RS (Relative Significance)</b>		1.7	2.5	5.0		5.0	2.5	1.7
<b>Demand / Available Ratio</b>		7.6	5.1	3.8	3.1	2.5	2.2	1.9

		<b>Bubble Enhancement Theory</b>						
<b>Baseline</b>		<b>Simulation 15</b>						
Initial bubble dia	0.75 cm 0.0075 m	0.75	0.75	0.75	0.75	0.75	0.75	0.75
Initial bubble vol	2.21E-07 m <sup>3</sup>	0.0075	0.0075	0.0075	0.0075	0.0075	0.0075	0.0075
Characteristic cylinder diameter	0.0027 m	2.21E-07	2.21E-07	2.21E-07	2.21E-07	2.21E-07	2.21E-07	2.21E-07
Characteristic cylinder length	0.039 m	0.0027	0.0027	0.0027	0.0027	0.0027	0.0027	0.0027
Characteristic cylinder volume	2.21E-07 m <sup>3</sup>	0.039	0.039	0.039	0.039	0.039	0.039	0.039
Bubble rise velocity	25 cm/s 0.25 m/s	2.21E-07	2.21E-07	2.21E-07	2.21E-07	2.21E-07	2.21E-07	2.21E-07
Bubble/water contact time	0.154 s	10	15	20	25	30	35	40
"squeezed" water film thickness	0.001 m	0.1	0.15	0.2	0.25	0.3	0.35	0.4
"squeezed" water film volume	4.83E-07 m <sup>3</sup>	0.257	0.171	0.129	0.103	0.086	0.073	0.064
Initial oxygen conc	3 g/m <sup>3</sup>	0.001	0.001	0.001	0.001	0.001	0.001	0.001
Available dissolved oxygen	1.45E-06 g O <sub>2</sub> in BL	4.83E-07	4.83E-07	4.83E-07	4.83E-07	4.83E-07	4.83E-07	4.83E-07
Biofilm oxygen consumption rate	0.1 g/m <sup>3</sup> s	8	8	8	8	8	8	8
Specific surface area of media	1950 m <sup>2</sup> /m <sup>3</sup>	3.87E-06	3.87E-06	3.87E-06	3.87E-06	3.87E-06	3.87E-06	3.87E-06
Rate based on SA	195 g/m <sup>2</sup> s	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Biofilm SA in contact w/ cyl	4.42E-07 m <sup>2</sup>	1950	1950	1950	1950	1950	1950	1950
Available O <sub>2</sub>	9.39E-06 g/s of O <sub>2</sub>	195	195	195	195	195	195	195
Consumed O <sub>2</sub>	8.61E-05 g/s of O <sub>2</sub>	4.42E-07	4.42E-07	4.42E-07	4.42E-07	4.42E-07	4.42E-07	4.42E-07
<b>RS (Relative Significance)</b>		1.50E-05	2.25E-05	3.01E-05	3.76E-05	4.51E-05	5.26E-05	6.01E-05
<b>Demand / Available Ratio</b>		8.61E-05	8.61E-05	8.61E-05	8.61E-05	8.61E-05	8.61E-05	8.61E-05
		2.8	4.2	8.3		8.3	4.2	2.8
		5.7	3.8	2.9	2.3	1.9	1.6	1.4

		Bubble Enhancement Theory						
		Baseline	Simulation 16					
Initial bubble dia	0.75 cm 0.0075 m	0.75	0.75	0.75	0.75	0.75	0.75	0.75
Initial bubble vol	2.21E-07 m <sup>3</sup>	2.21E-07	2.21E-07	2.21E-07	2.21E-07	2.21E-07	2.21E-07	2.21E-07
Characteristic cylinder diameter	0.0027 m	0.0027	0.0027	0.0027	0.0027	0.0027	0.0027	0.0027
Characteristic cylinder length	0.039 m	0.039	0.039	0.039	0.039	0.039	0.039	0.039
Characteristic cylinder volume	2.21E-07 m <sup>3</sup>	2.21E-07	2.21E-07	2.21E-07	2.21E-07	2.21E-07	2.21E-07	2.21E-07
Bubble rise velocity	25 cm/s 0.25 m/s	25	25	25	25	25	25	25
Bubble/water contact time	0.154 s	0.103	0.103	0.103	0.103	0.103	0.103	0.103
"squeezed" water film thickness	0.001 m	0.0005	0.0007	0.0009	0.001	0.0012	0.0016	0.002
"squeezed" water film volume	4.83E-07 m <sup>3</sup>	2.05E-07	3.07E-07	4.21E-07	4.83E-07	6.16E-07	9.21E-07	1.28E-06
Initial oxygen conc	3 g/m <sup>3</sup>	0	0	0	0	0	0	0
Available dissolved oxygen	1.45E-06 g O <sub>2</sub> in BL	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Biofilm oxygen consumption rate	0.1 g/m <sup>3</sup> s	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Specific surface area of media	1950 m <sup>2</sup> /m <sup>3</sup>	1950	1950	1950	1950	1950	1950	1950
Rate based on SA	195 g/m <sup>2</sup> s	195	195	195	195	195	195	195
Biofilm SA in contact w/ cyl	4.42E-07 m <sup>2</sup>	4.42E-07	4.42E-07	4.42E-07	4.42E-07	4.42E-07	4.42E-07	4.42E-07
Available O <sub>2</sub>	9.39E-06 g/s of O <sub>2</sub>	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Consumed O <sub>2</sub>	8.61E-05 g/s of O <sub>2</sub>	8.61E-05	8.61E-05	8.61E-05	8.61E-05	8.61E-05	8.61E-05	8.61E-05
<b>RS (Relative Significance)</b>		2.0	3.3	10.0		5.0	1.7	1.0
<b>Demand / Available Ratio</b>								

		<b>Bubble Enhancement Theory</b>						
<b>Baseline</b>		<b>Simulation 17</b>						
Initial bubble dia	0.75 cm 0.0075 m	0.75	0.75	0.75	0.75	0.75	0.75	0.75
Initial bubble vol	2.21E-07 m <sup>3</sup>	2.21E-07	2.21E-07	2.21E-07	2.21E-07	2.21E-07	2.21E-07	2.21E-07
Characteristic cylinder diameter	0.0027 m	0.0027	0.0027	0.0027	0.0027	0.0027	0.0027	0.0027
Characteristic cylinder length	0.039 m	0.039	0.039	0.039	0.039	0.039	0.039	0.039
Characteristic cylinder volume	2.21E-07 m <sup>3</sup>	2.21E-07	2.21E-07	2.21E-07	2.21E-07	2.21E-07	2.21E-07	2.21E-07
Bubble rise velocity	25 cm/s 0.25 m/s	25	25	25	25	25	25	25
Bubble/water contact time	0.154 s	0.103	0.103	0.103	0.103	0.103	0.103	0.103
"squeezed" water film thickness	0.001 m	0.0005	0.0007	0.0009	0.001	0.0012	0.0016	0.002
"squeezed" water film volume	4.83E-07 m <sup>3</sup>	2.05E-07	3.07E-07	4.21E-07	4.83E-07	6.16E-07	9.21E-07	1.28E-06
Initial oxygen conc	3 g/m <sup>3</sup>	2	2	2	2	2	2	2
Available dissolved oxygen	1.45E-06 g O <sub>2</sub> in BL	4.09E-07	6.14E-07	8.43E-07	9.66E-07	1.23E-06	1.84E-06	2.56E-06
Biofilm oxygen consumption rate	0.1 g/m <sup>3</sup> s	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Specific surface area of media	1950 m <sup>2</sup> /m <sup>3</sup>	1950	1950	1950	1950	1950	1950	1950
Rate based on SA	195 g/m <sup>2</sup> s	195	195	195	195	195	195	195
Biofilm SA in contact w/ cyl	4.42E-07 m <sup>2</sup>	4.42E-07	4.42E-07	4.42E-07	4.42E-07	4.42E-07	4.42E-07	4.42E-07
Available O <sub>2</sub>	9.39E-06 g/s of O <sub>2</sub>	3.98E-06	5.97E-06	8.19E-06	9.39E-06	1.20E-05	1.79E-05	2.49E-05
Consumed O <sub>2</sub>	8.61E-05 g/s of O <sub>2</sub>	8.61E-05	8.61E-05	8.61E-05	8.61E-05	8.61E-05	8.61E-05	8.61E-05
<b>RS (Relative Significance)</b>		0.7	1.1	3.3		1.7	0.6	0.3
<b>Demand / Available Ratio</b>		21.7	14.4	10.5	9.2	7.2	4.8	3.5

		<b>Bubble Enhancement Theory</b>						
<b>Baseline</b>		<b>Simulation 18</b>						
Initial bubble dia	0.75 cm 0.0075 m	0.75	0.75	0.75	0.75	0.75	0.75	0.75
Initial bubble vol	2.21E-07 m <sup>3</sup>	0.0075	0.0075	0.0075	0.0075	0.0075	0.0075	0.0075
Characteristic cylinder diameter	0.0027 m	2.21E-07	2.21E-07	2.21E-07	2.21E-07	2.21E-07	2.21E-07	2.21E-07
Characteristic cylinder length	0.039 m	0.0027	0.0027	0.0027	0.0027	0.0027	0.0027	0.0027
Characteristic cylinder volume	2.21E-07 m <sup>3</sup>	0.039	0.039	0.039	0.039	0.039	0.039	0.039
Bubble rise velocity	25 cm/s 0.25 m/s	2.21E-07	2.21E-07	2.21E-07	2.21E-07	2.21E-07	2.21E-07	2.21E-07
Bubble/water contact time	0.154 s	25	25	25	25	25	25	25
"squeezed" water film thickness	0.001 m	0.25	0.25	0.25	0.25	0.25	0.25	0.25
"squeezed" water film volume	4.83E-07 m <sup>3</sup>	0.103	0.103	0.103	0.103	0.103	0.103	0.103
Initial oxygen conc	3 g/m <sup>3</sup>	0.0005	0.0007	0.0009	0.001	0.0012	0.0016	0.002
Available dissolved oxygen	1.45E-06 g O <sub>2</sub> in BL	2.05E-07	3.07E-07	4.21E-07	4.83E-07	6.16E-07	9.21E-07	1.28E-06
Biofilm oxygen consumption rate	0.1 g/m <sup>3</sup> s	4	4	4	4	4	4	4
Specific surface area of media	1950 m <sup>2</sup> /m <sup>3</sup>	8.19E-07	1.23E-06	1.69E-06	1.93E-06	2.47E-06	3.69E-06	5.12E-06
Rate based on SA	195 g/m <sup>2</sup> s	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Biofilm SA in contact w/ cyl	4.42E-07 m <sup>2</sup>	1950	1950	1950	1950	1950	1950	1950
Available O <sub>2</sub>	9.39E-06 g/s of O <sub>2</sub>	195	195	195	195	195	195	195
Consumed O <sub>2</sub>	8.61E-05 g/s of O <sub>2</sub>	4.42E-07	4.42E-07	4.42E-07	4.42E-07	4.42E-07	4.42E-07	4.42E-07
<b>RS (Relative Significance)</b>		7.96E-06	1.19E-05	1.64E-05	1.88E-05	2.40E-05	3.58E-05	4.98E-05
<b>Demand / Available Ratio</b>		8.61E-05	8.61E-05	8.61E-05	8.61E-05	8.61E-05	8.61E-05	8.61E-05
		0.7	1.1	3.3		1.7	0.6	0.3
		10.8	7.2	5.3	4.6	3.6	2.4	1.7

		Bubble Enhancement Theory						
		Baseline	Simulation 19					
Initial bubble dia	0.75 cm 0.0075 m	0.75	0.75	0.75	0.75	0.75	0.75	0.75
Initial bubble vol	2.21E-07 m <sup>3</sup>	2.21E-07	2.21E-07	2.21E-07	2.21E-07	2.21E-07	2.21E-07	2.21E-07
Characteristic cylinder diameter	0.0027 m	0.0027	0.0027	0.0027	0.0027	0.0027	0.0027	0.0027
Characteristic cylinder length	0.039 m	0.039	0.039	0.039	0.039	0.039	0.039	0.039
Characteristic cylinder volume	2.21E-07 m <sup>3</sup>	2.21E-07	2.21E-07	2.21E-07	2.21E-07	2.21E-07	2.21E-07	2.21E-07
Bubble rise velocity	25 cm/s 0.25 m/s	25	25	25	25	25	25	25
Bubble/water contact time	0.154 s	0.103	0.103	0.103	0.103	0.103	0.103	0.103
"squeezed" water film thickness	0.001 m	0.0005	0.0007	0.0009	0.001	0.0012	0.0016	0.002
"squeezed" water film volume	4.83E-07 m <sup>3</sup>	2.05E-07	3.07E-07	4.21E-07	4.83E-07	6.16E-07	9.21E-07	1.28E-06
Initial oxygen conc	3 g/m <sup>3</sup>	6	6	6	6	6	6	6
Available dissolved oxygen	1.45E-06 g O <sub>2</sub> in BL	1.23E-06	1.84E-06	2.53E-06	2.90E-06	3.70E-06	5.53E-06	7.68E-06
Biofilm oxygen consumption rate	0.1 g/m <sup>3</sup> s	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Specific surface area of media	1950 m <sup>2</sup> /m <sup>3</sup>	1950	1950	1950	1950	1950	1950	1950
Rate based on SA	195 g/m <sup>2</sup> s	195	195	195	195	195	195	195
Biofilm SA in contact w/ cyl	4.42E-07 m <sup>2</sup>	4.42E-07	4.42E-07	4.42E-07	4.42E-07	4.42E-07	4.42E-07	4.42E-07
Available O <sub>2</sub>	9.39E-06 g/s of O <sub>2</sub>	1.19E-05	1.79E-05	2.46E-05	2.82E-05	3.59E-05	5.37E-05	7.47E-05
Consumed O <sub>2</sub>	8.61E-05 g/s of O <sub>2</sub>	8.61E-05	8.61E-05	8.61E-05	8.61E-05	8.61E-05	8.61E-05	8.61E-05
<b>RS (Relative Significance)</b>		2.0	3.3	10.0		5.0	1.7	1.0
<b>Demand / Available Ratio</b>		7.2	4.8	3.5	3.1	2.4	1.6	1.2

Baseline		Bubble Enhancement Theory						
		Simulation 20						
Initial bubble dia	0.75 cm 0.0075 m	0.75	0.75	0.75	0.75	0.75	0.75	0.75
Initial bubble vol	2.21E-07 m <sup>3</sup>	2.21E-07	2.21E-07	2.21E-07	2.21E-07	2.21E-07	2.21E-07	2.21E-07
Characteristic cylinder diameter	0.0027 m	0.0027	0.0027	0.0027	0.0027	0.0027	0.0027	0.0027
Characteristic cylinder length	0.039 m	0.039	0.039	0.039	0.039	0.039	0.039	0.039
Characteristic cylinder volume	2.21E-07 m <sup>3</sup>	2.21E-07	2.21E-07	2.21E-07	2.21E-07	2.21E-07	2.21E-07	2.21E-07
Bubble rise velocity	25 cm/s 0.25 m/s	25	25	25	25	25	25	25
Bubble/water contact time	0.154 s	0.103	0.103	0.103	0.103	0.103	0.103	0.103
"squeezed" water film thickness	0.001 m	0.0005	0.0007	0.0009	0.001	0.0012	0.0016	0.002
"squeezed" water film volume	4.83E-07 m <sup>3</sup>	2.05E-07	3.07E-07	4.21E-07	4.83E-07	6.16E-07	9.21E-07	1.28E-06
Initial oxygen conc	3 g/m <sup>3</sup>	8	8	8	8	8	8	8
Available dissolved oxygen	1.45E-06 g O <sub>2</sub> in BL	1.64E-06	2.46E-06	3.37E-06	3.87E-06	4.93E-06	7.37E-06	1.02E-05
Biofilm oxygen consumption rate	0.1 g/m <sup>3</sup> s	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Specific surface area of media	1950 m <sup>2</sup> /m <sup>3</sup>	1950	1950	1950	1950	1950	1950	1950
Rate based on SA	195 g/m <sup>2</sup> s	195	195	195	195	195	195	195
Biofilm SA in contact w/ cyl	4.42E-07 m <sup>2</sup>	4.42E-07	4.42E-07	4.42E-07	4.42E-07	4.42E-07	4.42E-07	4.42E-07
Available O <sub>2</sub>	9.39E-06 g/s of O <sub>2</sub>	1.59E-05	2.39E-05	3.28E-05	3.76E-05	4.79E-05	7.16E-05	9.96E-05
Consumed O <sub>2</sub>	8.61E-05 g/s of O <sub>2</sub>	8.61E-05	8.61E-05	8.61E-05	8.61E-05	8.61E-05	8.61E-05	8.61E-05
<b>RS (Relative Significance)</b>		3.3	5.6	16.7		8.3	2.8	1.7
<b>Demand / Available Ratio</b>		5.4	3.6	2.6	2.3	1.8	1.2	0.9

		<b>Bubble Enhancement Theory</b>						
<b>Baseline</b>		<b>Simulation 21</b>						
Initial bubble dia	0.75 cm 0.0075 m	0.75	0.75	0.75	0.75	0.75	0.75	0.75
Initial bubble vol	2.21E-07 m <sup>3</sup>	2.21E-07	2.21E-07	2.21E-07	2.21E-07	2.21E-07	2.21E-07	2.21E-07
Characteristic cylinder diameter	0.0027 m	0.0027	0.0027	0.0027	0.0027	0.0027	0.0027	0.0027
Characteristic cylinder length	0.039 m	0.039	0.039	0.039	0.039	0.039	0.039	0.039
Characteristic cylinder volume	2.21E-07 m <sup>3</sup>	2.21E-07	2.21E-07	2.21E-07	2.21E-07	2.21E-07	2.21E-07	2.21E-07
Bubble rise velocity	25 cm/s 0.25 m/s	25	25	25	25	25	25	25
Bubble/water contact time	0.154 s	0.103	0.103	0.103	0.103	0.103	0.103	0.103
"squeezed" water film thickness	0.001 m	0.001	0.001	0.001	0.001	0.001	0.001	0.001
"squeezed" water film volume	4.83E-07 m <sup>3</sup>	4.83E-07	4.83E-07	4.83E-07	4.83E-07	4.83E-07	4.83E-07	4.83E-07
Initial oxygen conc	3 g/m <sup>3</sup>	0	0	0	0	0	0	0
Available dissolved oxygen	1.45E-06 g O <sub>2</sub> in BL	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Biofilm oxygen consumption rate	0.15 g/m <sup>3</sup> s	0.1	0.12	0.14	0.15	0.16	0.18	0.2
Specific surface area of media	1950 m <sup>2</sup> /m <sup>3</sup>	1950	1950	1950	1950	1950	1950	1950
Rate based on SA	292.5 g/m <sup>2</sup> s	195	234	273	292.5	312	351	390
Biofilm SA in contact w/ cyl	4.42E-07 m <sup>2</sup>	4.42E-07	4.42E-07	4.42E-07	4.42E-07	4.42E-07	4.42E-07	4.42E-07
Available O <sub>2</sub>	9.39E-06 g/s of O <sub>2</sub>	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Consumed O <sub>2</sub>	1.29E-04 g/s of O <sub>2</sub>	8.61E-05	1.03E-04	1.21E-04	1.29E-04	1.38E-04	1.55E-04	1.72E-04
<b>RS (Relative Significance)</b>		3.0	5.0	15.0		15.0	5.0	3.0
<b>Demand / Available Ratio</b>		11608	9673	8291	7739	7255	6449	5804



		<b>Bubble Enhancement Theory</b>						
<b>Baseline</b>		<b>Simulation 22</b>						
Initial bubble dia	0.75 cm 0.0075 m	0.75	0.75	0.75	0.75	0.75	0.75	0.75
Initial bubble vol	2.21E-07 m <sup>3</sup>	0.0075	0.0075	0.0075	0.0075	0.0075	0.0075	0.0075
Characteristic cylinder diameter	0.0027 m	2.21E-07	2.21E-07	2.21E-07	2.21E-07	2.21E-07	2.21E-07	2.21E-07
Characteristic cylinder length	0.039 m	0.0027	0.0027	0.0027	0.0027	0.0027	0.0027	0.0027
Characteristic cylinder volume	2.21E-07 m <sup>3</sup>	0.039	0.039	0.039	0.039	0.039	0.039	0.039
Bubble rise velocity	25 cm/s 0.25 m/s	2.21E-07	2.21E-07	2.21E-07	2.21E-07	2.21E-07	2.21E-07	2.21E-07
Bubble/water contact time	0.154 s	25	25	25	25	25	25	25
"squeezed" water film thickness	0.001 m	0.25	0.25	0.25	0.25	0.25	0.25	0.25
"squeezed" water film volume	4.83E-07 m <sup>3</sup>	0.103	0.103	0.103	0.103	0.103	0.103	0.103
Initial oxygen conc	3 g/m <sup>3</sup>	0.001	0.001	0.001	0.001	0.001	0.001	0.001
Available dissolved oxygen	1.45E-06 g O <sub>2</sub> in BL	4.83E-07	4.83E-07	4.83E-07	4.83E-07	4.83E-07	4.83E-07	4.83E-07
Biofilm oxygen consumption rate	0.15 g/m <sup>3</sup> s	2	2	2	2	2	2	2
Specific surface area of media	1950 m <sup>2</sup> /m <sup>3</sup>	9.66E-07	9.66E-07	9.66E-07	9.66E-07	9.66E-07	9.66E-07	9.66E-07
Rate based on SA	292.5 g/m <sup>2</sup> s	0.1	0.12	0.14	0.15	0.16	0.18	0.2
Biofilm SA in contact w/ cyl	4.42E-07 m <sup>2</sup>	1950	1950	1950	1950	1950	1950	1950
Available O <sub>2</sub>	9.39E-06 g/s of O <sub>2</sub>	195	234	273	292.5	312	351	390
Consumed O <sub>2</sub>	1.29E-04 g/s of O <sub>2</sub>	4.42E-07	4.42E-07	4.42E-07	4.42E-07	4.42E-07	4.42E-07	4.42E-07
<b>RS (Relative Significance)</b>		4.42E-07	4.42E-07	4.42E-07	4.42E-07	4.42E-07	4.42E-07	4.42E-07
<b>Demand / Available Ratio</b>		9.39E-06	9.39E-06	9.39E-06	9.39E-06	9.39E-06	9.39E-06	9.39E-06
		8.61E-05	1.03E-04	1.21E-04	1.29E-04	1.38E-04	1.55E-04	1.72E-04
		1.0	1.7	5.0		5.0	1.7	1.0
		9.2	11.0	12.8	13.8	14.7	16.5	18.3

		<b>Bubble Enhancement Theory</b>						
<b>Baseline</b>		<b>Simulation 23</b>						
Initial bubble dia	0.75 cm 0.0075 m	0.75	0.75	0.75	0.75	0.75	0.75	0.75
Initial bubble vol	2.21E-07 m <sup>3</sup>	0.0075	0.0075	0.0075	0.0075	0.0075	0.0075	0.0075
Characteristic cylinder diameter	0.0027 m	2.21E-07	2.21E-07	2.21E-07	2.21E-07	2.21E-07	2.21E-07	2.21E-07
Characteristic cylinder length	0.039 m	0.0027	0.0027	0.0027	0.0027	0.0027	0.0027	0.0027
Characteristic cylinder volume	2.21E-07 m <sup>3</sup>	0.039	0.039	0.039	0.039	0.039	0.039	0.039
Bubble rise velocity	25 cm/s 0.25 m/s	2.21E-07	2.21E-07	2.21E-07	2.21E-07	2.21E-07	2.21E-07	2.21E-07
Bubble/water contact time	0.154 s	25	25	25	25	25	25	25
"squeezed" water film thickness	0.001 m	0.25	0.25	0.25	0.25	0.25	0.25	0.25
"squeezed" water film volume	4.83E-07 m <sup>3</sup>	0.103	0.103	0.103	0.103	0.103	0.103	0.103
Initial oxygen conc	3 g/m <sup>3</sup>	0.001	0.001	0.001	0.001	0.001	0.001	0.001
Available dissolved oxygen	1.45E-06 g O <sub>2</sub> in BL	4.83E-07	4.83E-07	4.83E-07	4.83E-07	4.83E-07	4.83E-07	4.83E-07
Biofilm oxygen consumption rate	0.15 g/m <sup>3</sup> s	4	4	4	4	4	4	4
Specific surface area of media	1950 m <sup>2</sup> /m <sup>3</sup>	1.93E-06	1.93E-06	1.93E-06	1.93E-06	1.93E-06	1.93E-06	1.93E-06
Rate based on SA	292.5 g/m <sup>2</sup> s	0.1	0.12	0.14	0.15	0.16	0.18	0.2
Biofilm SA in contact w/ cyl	4.42E-07 m <sup>2</sup>	1950	1950	1950	1950	1950	1950	1950
Available O <sub>2</sub>	9.39E-06 g/s of O <sub>2</sub>	195	234	273	292.5	312	351	390
Consumed O <sub>2</sub>	1.29E-04 g/s of O <sub>2</sub>	4.42E-07	4.42E-07	4.42E-07	4.42E-07	4.42E-07	4.42E-07	4.42E-07
<b>RS (Relative Significance)</b>		1.88E-05	1.88E-05	1.88E-05	1.88E-05	1.88E-05	1.88E-05	1.88E-05
<b>Demand / Available Ratio</b>		8.61E-05	1.03E-04	1.21E-04	1.29E-04	1.38E-04	1.55E-04	1.72E-04
		1.0	1.7	5.0		5.0	1.7	1.0
		4.6	5.5	6.4	6.9	7.3	8.3	9.2

		<b>Bubble Enhancement Theory</b>						
<b>Baseline</b>		<b>Simulation 24</b>						
Initial bubble dia	0.75 cm 0.0075 m	0.75	0.75	0.75	0.75	0.75	0.75	0.75
Initial bubble vol	2.21E-07 m <sup>3</sup>	0.0075	0.0075	0.0075	0.0075	0.0075	0.0075	0.0075
Characteristic cylinder diameter	0.0027 m	2.21E-07	2.21E-07	2.21E-07	2.21E-07	2.21E-07	2.21E-07	2.21E-07
Characteristic cylinder length	0.039 m	0.0027	0.0027	0.0027	0.0027	0.0027	0.0027	0.0027
Characteristic cylinder volume	2.21E-07 m <sup>3</sup>	0.039	0.039	0.039	0.039	0.039	0.039	0.039
Bubble rise velocity	25 cm/s 0.25 m/s	2.21E-07	2.21E-07	2.21E-07	2.21E-07	2.21E-07	2.21E-07	2.21E-07
Bubble/water contact time	0.154 s	25	25	25	25	25	25	25
"squeezed" water film thickness	0.001 m	0.25	0.25	0.25	0.25	0.25	0.25	0.25
"squeezed" water film volume	4.83E-07 m <sup>3</sup>	0.103	0.103	0.103	0.103	0.103	0.103	0.103
Initial oxygen conc	3 g/m <sup>3</sup>	0.001	0.001	0.001	0.001	0.001	0.001	0.001
Available dissolved oxygen	1.45E-06 g O <sub>2</sub> in BL	4.83E-07	4.83E-07	4.83E-07	4.83E-07	4.83E-07	4.83E-07	4.83E-07
Biofilm oxygen consumption rate	0.15 g/m <sup>3</sup> s	6	6	6	6	6	6	6
Specific surface area of media	1950 m <sup>2</sup> /m <sup>3</sup>	2.90E-06	2.90E-06	2.90E-06	2.90E-06	2.90E-06	2.90E-06	2.90E-06
Rate based on SA	292.5 g/m <sup>2</sup> s	0.1	0.12	0.14	0.15	0.16	0.18	0.2
Biofilm SA in contact w/ cyl	4.42E-07 m <sup>2</sup>	195	234	273	292.5	312	351	390
Available O <sub>2</sub>	9.39E-06 g/s of O <sub>2</sub>	4.42E-07	4.42E-07	4.42E-07	4.42E-07	4.42E-07	4.42E-07	4.42E-07
Consumed O <sub>2</sub>	1.29E-04 g/s of O <sub>2</sub>	2.82E-05	2.82E-05	2.82E-05	2.82E-05	2.82E-05	2.82E-05	2.82E-05
<b>RS (Relative Significance)</b>		8.61E-05	1.03E-04	1.21E-04	1.29E-04	1.38E-04	1.55E-04	1.72E-04
<b>Demand / Available Ratio</b>		3.0	5.0	15.0	15.0	15.0	5.0	3.0
				<b>significant</b>	<b>significant</b>			
		3.1	3.7	4.3	4.6	4.9	5.5	6.1

		<b>Bubble Enhancement Theory</b>						
<b>Baseline</b>		<b>Simulation 25</b>						
Initial bubble dia	0.75 cm 0.0075 m	0.75	0.75	0.75	0.75	0.75	0.75	0.75
Initial bubble vol	2.21E-07 m <sup>3</sup>	0.0075	0.0075	0.0075	0.0075	0.0075	0.0075	0.0075
Characteristic cylinder diameter	0.0027 m	2.21E-07	2.21E-07	2.21E-07	2.21E-07	2.21E-07	2.21E-07	2.21E-07
Characteristic cylinder length	0.039 m	0.0027	0.0027	0.0027	0.0027	0.0027	0.0027	0.0027
Characteristic cylinder volume	2.21E-07 m <sup>3</sup>	0.039	0.039	0.039	0.039	0.039	0.039	0.039
Bubble rise velocity	25 cm/s 0.25 m/s	2.21E-07	2.21E-07	2.21E-07	2.21E-07	2.21E-07	2.21E-07	2.21E-07
Bubble/water contact time	0.154 s	25	25	25	25	25	25	25
"squeezed" water film thickness	0.001 m	0.25	0.25	0.25	0.25	0.25	0.25	0.25
"squeezed" water film volume	4.83E-07 m <sup>3</sup>	0.103	0.103	0.103	0.103	0.103	0.103	0.103
Initial oxygen conc	3 g/m <sup>3</sup>	0.001	0.001	0.001	0.001	0.001	0.001	0.001
Available dissolved oxygen	1.45E-06 g O <sub>2</sub> in BL	4.83E-07	4.83E-07	4.83E-07	4.83E-07	4.83E-07	4.83E-07	4.83E-07
Biofilm oxygen consumption rate	0.15 g/m <sup>3</sup> s	8	8	8	8	8	8	8
Specific surface area of media	1950 m <sup>2</sup> /m <sup>3</sup>	3.87E-06	3.87E-06	3.87E-06	3.87E-06	3.87E-06	3.87E-06	3.87E-06
Rate based on SA	292.5 g/m <sup>2</sup> s	0.1	0.12	0.14	0.15	0.16	0.18	0.2
Biofilm SA in contact w/ cyl	4.42E-07 m <sup>2</sup>	1950	1950	1950	1950	1950	1950	1950
Available O <sub>2</sub>	9.39E-06 g/s of O <sub>2</sub>	195	234	273	292.5	312	351	390
Consumed O <sub>2</sub>	1.29E-04 g/s of O <sub>2</sub>	4.42E-07	4.42E-07	4.42E-07	4.42E-07	4.42E-07	4.42E-07	4.42E-07
<b>RS (Relative Significance)</b>		4.42E-07	4.42E-07	4.42E-07	4.42E-07	4.42E-07	4.42E-07	4.42E-07
<b>Demand / Available Ratio</b>		3.76E-05	3.76E-05	3.76E-05	3.76E-05	3.76E-05	3.76E-05	3.76E-05
		8.61E-05	1.03E-04	1.21E-04	1.29E-04	1.38E-04	1.55E-04	1.72E-04
		5.0	8.3	25.0	25.0	25.0	8.3	5.0
				<b>significant</b>		<b>significant</b>		
		2.3	2.8	3.2	3.4	3.7	4.1	4.6

**ENDOGENOUS RESPIRATION PROFILE AT TEST CONDITION 3**

Date 11/13/02  
 Hours of Filtration 51

**Water Quality Characteristics**

Sample	Height m	Temp oC	DO Conc mg/L	Humidity %	pH	Alk, mg/L as CaCO3	DOC			HACH NH4-N		Colorimetric		
							Rep 1 (ppm)	Rep 2 (ppm)	Rep 3 (ppm)	Rep 1 mg/L	Rep 2 mg/L	NO2-N mg/L	NO3-N Rep 1 mg/L    Rep 2 mg/L	
Influent	0.00	18.9	7.72	83.0	7.64	164.0				0.5	0.5	0.05	3.52	3.42
Port 1	0.50	18.9	7.12	76.4										
Port 2	1.73	18.7	3.60	38.6										
Port 3	2.97	18.4	1.05	11.2										
Port 4	4.20	17.4	0.31	3.1										
Effluent	5.11	19.0	0.32	3.4	7.75	139.0				0.5	0.5	0.06	4.66	4.59

Date 11/14/02  
 Hours of Filtration 23

**Water Quality Characteristics**

Sample	Height m	Temp oC	DO Conc mg/L	Humidity %	pH	Alk, mg/L as CaCO3	DOC			HACH NH4-N		Colorimetric		
							Rep 1 (ppm)	Rep 2 (ppm)	Rep 3 (ppm)	Rep 1 mg/L	Rep 2 mg/L	NO2-N mg/L	NO3-N Rep 1 mg/L    Rep 2 mg/L	
Influent	0.00	19.5	8.01	87.4	7.09	88.0	6.75	6.92	6.91	0.5	0.5	0.05	3.57	3.45
Port 1	0.50	19.3	7.23	78.3										
Port 2	1.73	19.3	3.41	37.1										
Port 3	2.97	19.1	0.60	6.5										
Port 4	4.20	18.8	0.22	2.3										
Effluent	5.11	19.6	0.25	2.7	6.94	82.0	6.77	6.91	6.93	0.5	0.5	0.07	4.88	5.07

**ENDOGENOUS RESPIRATION PROFILE AT TEST CONDITION 4**

Date 11/19/02  
 Hours of Filtration 25

**Water Quality Characteristics**

Sample	Height m	Temperature oC	DO Conc mg/L	Humidity %	pH	Alk, mg/L as CaCO3	NH4-N		NO2-N mg/L	NO3-N Rep 2 mg/L
							Rep 1 mg/L	Rep 2 mg/L		
Influent	0.00	18.6	7.77	83.2	7.09	82.0	0.5	0.5	0.05	3.3948
Port 1	0.50	18.5	7.44	79.4						
Port 2	1.73	18.1	5.76	61.1						
Port 3	2.97	18.1	3.11	32.9						
Port 4	4.20	17.5	1.15	12.1						
Effluent	5.11	18.3	0.97	11.7	6.98	77.0	0.5	0.5	0.05	3.8968

Date 11/20/02  
 Hours of Filtration 48.6

**Water Quality Characteristics**

Sample	Height m	Temperature oC	DO Conc mg/L	Humidity %	pH	Alk, mg/L as CaCO3	NH4-N		NO2-N mg/L	NO3-N Rep 2 mg/L
							Rep 1 mg/L	Rep 2 mg/L		
Influent	0.00	18.7	7.92	84.9	7.04	67.0	0.5	0.5	0.05	3.5017
Port 1	0.50	18.6	7.33	78.2						
Port 2	1.73	18.5	5.65	60.4						
Port 3	2.97	18.3	3.35	35.6						
Port 4	4.20	18.2	1.43	15.0						
Effluent	5.11	18.7	1.03	11.2	6.91	65.0	0.5	0.5	0.05	4.1539

**Nitrogen Species Loading Distribution Profile**

Sample port	Height H(z) [m]	Remaining NH <sub>4</sub> -N Load (kg N/m <sup>3</sup> of media/day)					Generated NO <sub>2</sub> -N Load (kg N/m <sup>3</sup> of media/day)							
		12.1	14.5	16.2	16.9	24.1	12.1	14.5	16.2	16.9	24.1			
<b>Condition 1</b> Testing	U <sub>G</sub> (Nm/h)													
	Influent	1.16	1.16	1.18	1.03	0.96	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Port 1		0.95	0.93	0.88	0.75		0.03	0.03	0.06	0.12		0.06	0.12
	Port 2		0.42	0.44	0.32	0.25		0.10	0.15	0.23	0.40		0.23	0.40
	Port 3		0.14	0.18	0.16	0.09		-0.01	0.00	0.07	0.24		0.07	0.24
Port 4		0.01	0.04	0.07	0.03		-0.01	-0.01	0.00	0.00		0.00	0.00	
Effluent	5.06	0.33	0.03	0.01	0.07	0.01	0.00	-0.01	0.00	0.03		0.03	0.07	
<b>Condition 2</b> Testing	U <sub>G</sub> (Nm/h)													
	Influent	7.2	9	12.1	13.3	7.2	7.2	9	12.1	13.3	7.2	9	12.1	13.3
	Port 1	1.41	1.25	1.44	1.41	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Port 2	1.29	1.15	1.32	1.33	0.05	0.04	0.06	0.05	0.05	0.05	0.04	0.06	0.05
	Port 3	0.90	0.74	0.73	0.85	0.09	0.07	0.08	0.09	0.09	0.09	0.07	0.08	0.09
Port 4	0.45	0.32	0.16	0.38	0.07	0.04	0.09	0.12	0.12	0.12	0.04	0.09	0.12	
Effluent	5.06	0.27	0.22	0.17	0.19	0.13	0.06	0.08	0.14	0.14	0.06	0.08	0.14	
<b>Condition 3</b> Testing	U <sub>G</sub> (Nm/h)													
	Influent	14.2	17.7	23.7	27	14.2	14.2	17.7	23.7	27	14.2	17.7	23.7	27
	Port 1	1.55	1.53	1.55	1.49	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Port 2	1.42	1.36	1.41	1.41	0.06	0.06	0.05	0.05	0.05	0.05	0.06	0.04	0.06
	Port 3	1.01	0.89	0.89	0.56	0.05	0.06	0.04	0.06	0.06	0.06	0.06	0.04	0.06
Port 4	0.58	0.48	0.44	0.28	0.04	0.03	0.02	0.02	0.02	0.02	0.03	0.02	0.04	
Effluent	5.06	0.17	0.04	0.03	0.03	0.02	0.02	0.01	0.00	0.00	0.02	0.01	0.00	
<b>Condition 4</b> Testing	U <sub>G</sub> (Nm/h)													
	Influent	4.5	5.9	7.1	9.9	4.5	4.5	5.9	7.1	9.9	4.5	5.9	7.1	9.9
	Port 1	1.12	1.15	1.11	1.36	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Port 2	0.99	1.01	0.94	1.21	0.02	0.03	0.03	0.03	0.05	0.05	0.03	0.03	0.05
	Port 3	0.68	0.48	0.50	0.60	0.04	0.04	0.04	0.04	0.05	0.05	0.04	0.04	0.05
Port 4	0.43	0.14	0.11	0.18	0.01	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	
Effluent	5.06	0.20	0.03	0.04	0.04	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	
<b>Condition 5</b> Testing	U <sub>G</sub> (Nm/h)													
	Influent	8.6	20.1	25.3	30	8.6	8.6	20.1	25.3	30	8.6	20.1	25.3	30
	Port 1	1.35	1.47	1.71	1.42	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Port 2	1.55	1.27	1.55	1.17	0.09	0.09	0.09	0.08	0.11	0.11	0.09	0.08	0.11
	Port 3	1.17	0.77	0.99	0.84	0.12	0.12	0.12	0.02	0.06	0.06	0.03	0.02	0.04
Port 4	0.68	0.33	0.54	0.41	0.47	0.47	0.47	0.02	0.04	0.04	0.02	0.02	0.04	
Effluent	5.06	0.48	0.12	0.02	0.06	0.02	0.02	0.00	0.01	0.01	0.00	0.02	0.01	
		0.58	0.10	0.02	0.03	0.04	0.00	0.00	0.01	0.01	0.00	0.01	0.00	

**Nitrogen Species Loading Distribution Profile**

Sample port	Height H(z) [m]	Generated NO <sub>3</sub> -N Load (kg N/m <sup>3</sup> of media/day)				
<b>U<sub>G</sub> (Nm/h)</b>		<b>12.1</b>	<b>14.5</b>	<b>16.2</b>	<b>16.9</b>	<b>24.1</b>
Influent	0	0.00	0.00	0.00	0.00	0.00
Port 1	0.55	0.00	0.00	0.00	0.00	0.00
Port 2	1.75	0.52	0.27	0.20	0.16	0.16
Port 3	2.95	0.73	0.69	0.54	0.51	0.51
Port 4	4.15	0.78	0.83	0.86	0.77	0.77
Effluent	5.06	0.56	0.93	1.03	0.59	0.65
<b>Condition 1 Testing</b>						
<b>U<sub>G</sub> (Nm/h)</b>		<b>7.2</b>	<b>9</b>	<b>12.1</b>	<b>13.3</b>	
Influent	0	0.00	0.00	0.00	0.00	
Port 1	0.55	0.11	0.20	0.02	0.05	
Port 2	1.75	0.35	0.65	0.56	0.48	
Port 3	2.95	0.72	0.89	1.02	0.71	
Port 4	4.15	1.01	1.05	1.13	1.18	
Effluent	5.06	1.13	0.97	1.20	1.13	
<b>Condition 2 Testing</b>						
<b>U<sub>G</sub> (Nm/h)</b>		<b>14.2</b>	<b>17.7</b>	<b>23.7</b>	<b>27</b>	
Influent	0	0.00	0.00	0.00	0.00	
Port 1	0.55	0.04	0.05	0.05	0.05	
Port 2	1.75	0.50	0.53	0.60	0.71	
Port 3	2.95	0.94	0.95	1.06	1.22	
Port 4	4.15	1.34	1.48	1.53	1.60	
Effluent	5.06	1.26	1.36	1.45	1.59	
<b>Condition 3 Testing</b>						
<b>U<sub>G</sub> (Nm/h)</b>		<b>4.5</b>	<b>5.9</b>	<b>7.1</b>	<b>9.9</b>	
Influent	0	0.00	0.00	0.00	0.00	
Port 1	0.55	0.03	0.05	0.08	0.04	
Port 2	1.75	0.33	0.47	0.49	0.46	
Port 3	2.95	0.53	0.74	0.84	0.91	
Port 4	4.15	0.78	0.99	1.02	1.21	
Effluent	5.06	0.74	0.90	0.95	1.15	
<b>Condition 4 Testing</b>						
<b>U<sub>G</sub> (Nm/h)</b>		<b>8.6</b>	<b>20.1</b>	<b>25.3</b>	<b>30</b>	<b>35.1</b>
Influent	0	0.00	0.00	0.00	0.00	0.00
Port 1	0.55	0.00	0.04	0.00	0.02	0.02
Port 2	1.75	0.31	0.58	0.57	0.54	0.57
Port 3	2.95	0.73	1.04	0.98	1.09	1.10
Port 4	4.15	1.03	1.35	1.48	1.56	1.43
Effluent	5.06	0.99	1.38	1.41	1.57	1.51
<b>Condition 5 Testing</b>						



**Effluent NH<sub>4</sub>-N Load Achieved in Comparison to the Targeted Load as a Function of the Aeration Rates** 115

Test Condition	Experimental Aeration Rate U <sub>G</sub> (Nm/h)	Theoretical Aeration Rate Estimated (Nm/h)	Targeted Maximum NH <sub>4</sub> -N Effluent Load (kg N/m <sup>3</sup> /day)	Experimental NH <sub>4</sub> -N Effluent Load (kg N/m <sup>3</sup> /day)
1	12.1	8.7	0.33	0.03
1	14.5		0.03	
1	16.2		0.01	
1	16.9		0.07	
1	24.1		0.01	
2	7.2	15.1	0.27	0.10
2	9.0		0.22	
2	12.1		0.17	
2	13.3		0.19	
3	14.2	18.0	0.28	0.05
3	17.7		0.14	
3	23.7		0.08	
3	27.0		0.04	
4	4.5	13.8	0.32	0.07
4	5.9		0.07	
4	7.1		0.06	
4	10.6		0.09	
5	8.6	25.0	0.58	0.03
5	20.1		0.04	
5	25.3		0.10	
5	30.0		0.02	
5	35.1		0.03	