

CHAPTER V

RESULTS

Data obtained from the completely mixed activated sludge units, bench scale continuous flow reactors with internal cell recycle, were analyzed and recorded so as to determine the combined effects of lead and zinc concentration on a) organic removal efficiency, b) biokinetic coefficients, c) nitrification, and d) metal distribution. The summary of experimental conditions are presented in Table 12. To explicitly present the data, the experimental results from each reactor system studied are presented separately. Table 13 to Table 16 are the summary results for this experiment and raw data for steady state period is depicted in tabular form in Table A1 to Table A16 in Appendix.

Control, receiving no lead and zinc concentration

A reactor was operated to obtain 4 steady state data points at mean cell residence time of 4.9, 6.1 8.0 and 11.7 days. A summary of results obtained from 4 steady state periods is presented in Table 13.

The average influent COD for these four experimental runs was 495 mg/l. The soluble COD removal efficiency was found to exceed 90.8 percent and the total COD removal efficiency exceeded 80.4 percent for each of the runs. The average soluble COD removal efficiency for the four runs was 94.8 percent while the average total COD removal efficiency was 87.25 percent. Total mixed liquor suspended solids concentrations were 1,326, 1,411, 1,556 and 1,872 mg/l at mean cell

TABLE 12
THE SUMMARY OF EXPERIMENTAL CONDITIONS

Metal studies	Influent COD (mg/l)	Influent metal concentration		θ_c , Values Used (days)
		Pb ⁺⁺ (mg/l)	Zn ⁺⁺ (mg/l)	
Non, i.e., Control	495	0	0	4.9, 6.1, 8.0, 11.7
Combination of lead and zinc	497	1.24	1.74	4.3, 9.0, 12.4, 13.5
Combination of lead and zinc	447	5.34	1.54	5.7, 8.9, 11.7, 15.8
Combination of lead and zinc	474	1.30	6.57	5.6, 8.3, 12.1, 16.3

TABLE 13

SUMMARY OF STEADY STATE DATA FOR CONTROL REACTOR, COD = 495 mg/l

Observation	θ_c (days)			
	4.9	6.1	8.0	11.7
Chemical Oxygen Demand				
Feed solution (mg/l)	477	484	495	523
Effluent, filtered (mg/l)	21	19	46	18
Soluble COD Removal Efficiency(%)	95.7	96.1	90.8	96.6
Effluent, Unfiltered (mg/l)	52	55	97	48
Total COD Removal Efficiency (%)	89.2	88.6	80.4	90.8
pH				
Feed solution	7.2	7.2	7.2	7.3
Effluent	7.8	6.7	6.6	6.2
Alkalinity as CaCO ₃				
Feed solution (mg/l)	571	542	587	573
Effluent (mg/l)	507	174	139	93
Net change (%)	-11.0	-67.9	-76.3	-83.7
Microorganism Concentration				
Total Reactor, MLSS (mg/l)	1,326	1,411	1,556	1,872
Total Reactor, MLVSS (mg/l)	1,075	1,262	1,392	1,690
Effluent (mg/l)	53	54	53	33
Specific Utilization Rate (day ⁻¹)	0.76	0.66	0.58	0.54
Specific Growth Rate (day ⁻¹)	0.20	0.16	0.13	0.09
Observed Yield	0.26	0.24	0.22	0.17
Sludge Production (mg/day)	2,194	2,069	1,740	1,444

TABLE 13 (Continued)

Observation	θ_c (days)			
	4.9	6.1	8.0	11.7
NH₃ - N Concentration				
Feed Solution (mg/l)	54.8	55.1	58.0	49.0
Effluent, filtered (mg/l)	47.0	14.6	1.1	0.4
Net change (%)	-14.1	-73.4	-98.2	-99.1
Org-N Concentration				
Feed Solution (mg/l)	21.8	27.2	24.1	34.8
Effluent, filtered (mg/l)	6.3	3.0	3.5	0.0
Net change (%)	-71.5	-88.9	-85.4	-100.0
NO₃-N Concentration				
Effluent, filtered (mg/l)	9.7	18.6	20.7	44.9
Daily Wastage (l/day)	1.40	1.00	0.67	0.55

residence times of 4.9, 6.1, 8.0 and 11.7 days, respectively. Mixed liquor volatile suspended solids concentrations of 1,075, 1,262, 1,392 and 1,690 mg/l were obtained for mean cell residence times of 4.9, 6.1, 8.0 and 11.7 days, respectively. Specific utilization rate decreased from 0.76 to 0.54 day⁻¹ as mean cell residence time increased. Observed yield was 0.26 at mean cell residence time of 4.6 days and decreased to 0.17 at mean cell residence time of 11.7 days. Sludge production was found to decrease from 2,194 mg/day to 1,444 mg/day as mean cell residence time increased.

Nitrification was found to be a function of mean cell residence time. The reduction of NH₃-N was observed to be between 14.1 to 99.1 percent and an effluent NO₃-N concentration increased from 9.7 to 44.9 mg/l as mean cell residence time increased. Organic nitrogen removal efficiency, found to be dependent on mean cell residence time, was 71.5 to 100.0 percent as mean cell residence time increased from 4.9 to 11.7 days.

Alkalinity destruction occurred at all of the four mean cell residence times analyzed. Destructions of alkalinity were 11.0, 67.9, 76.3 and 83.7 percent at mean cell residence times of 4.9, 6.1, 8.0 and 11.7 days, respectively. A decrease effluent pH was caused by the decrease in alkalinity.

Lead concentration of 1.24 mg/l and Zinc concentration of 1.74 mg/l

Mean cell residence times of 4.3, 9.0, 12.4 and 13.5 days were analyzed for the reactor receiving an average lead concentration of 1.24 mg/l and an average zinc concentration of 1.74 mg/l.

A summary of the steady state data for these four sludge ages is presented in Table 14.

The feed solution contained an average COD concentration of 497 mg/l. Soluble COD removal efficiencies of 90.8, 95.7, 98.1 and 96.1 percent were calculated for mean cell residence times of 4.3, 9.0, 12.4 and 13.5 days, respectively. The total COD removal efficiency was averaged 89.2 percent for the four experimental runs. Total mixed liquor suspended solids concentrations of 902, 1,554, 2,094 and 2,168 mg/l were measured at mean cell residence times of 4.3, 9.0, 12.4 and 13.5 days, respectively. Mixed liquor volatile suspended solids concentrations of 738, 1,365, 1,805 and 1,815 mg/l were obtained for sludge ages of 4.3, 9.0, 12.4 and 13.5 days, respectively. Specific utilization rate decreased from 1.07 day^{-1} to 0.45 day^{-1} as mean cell residence time increased. Observed yield was found to decrease as mean cell residence time increased. The values of observed yield was 0.21, 0.17, 0.15 and 0.16 at mean cell residence times of 4.3, 9.0, 12.4 and 13.5 days, respectively. Sludge production was 1,716 mg/day at mean cell residence time of 4.3 days and decreased to 1,344 mg/day at 13.5 days.

Nitrification was observed in the system at all operating mean cell residence times. Effluent $\text{NO}_3\text{-N}$ concentration was 5.5, 48.3, 47.1 and 47.1 mg/l at mean cell residence times of 4.3, 9.0, 12.4 and 13.5 days, respectively. A decreasing concentration of $\text{NH}_3\text{-N}$ in the system was observed at all operating mean cell residence times. Reduction of $\text{NH}_3\text{-N}$ was 92.6, 98.6, 98.8 and 100.0 percent at mean cell residence times of 4.3, 9.0, 12.4 and 13.5 days, respectively. Organic nitrogen removal efficiencies of 67.9, 98.0, 99.5 and 100.0 percent

TABLE 14
 SUMMARY OF STEADY STATE DATA
 $Pb^{++} = 1.24 \text{ mg/l}$ and $Zn^{++} = 1.74 \text{ mg/l}$, COD = 497 mg/l

	θ_c (days)			
	4.3	9.0	12.4	13.5
Chemical Oxygen Demand				
Feed solution (mg/l)	485	508	527	468
Effluent, filtered (mg/l)	45	22	10	19
Soluble COD Removal Efficiency(%)	90.8	95.7	98.1	96.1
Effluent, Unfiltered (mg/l)	89	42	24	57
Total COD Removal Efficiency (%)	81.6	91.8	95.4	87.9
Lead Concentration				
Feed solution (mg/l)	1.08	1.33	1.40	1.15
Reactor (mg/l)	7.23	11.97	14.62	28.60
Effluent, filtered (mg/l)	<0.50	<0.50	<0.50	<0.50
Effluent, Unfiltered (mg/l)	<0.50	<0.50	<0.50	<0.50
Lead Removal Efficiency (%)	>54.0	>62.1	>63.6	>56.3
Zinc Concentration				
Feed solution (mg/l)	1.74	1.78	1.79	1.64
Reactor (mg/l)	7.25	5.83	5.87	26.25
Effluent, filtered (mg/l)	0.12	0.58	0.50	0.36
Effluent, Unfiltered (mg/l)	0.50	0.67	0.69	0.60
Zinc Removal Efficiency (%)	93.1	66.6	70.2	77.8
pH				
Feed solution	7.3	7.2	7.2	7.3
Effluent	6.9	6.4	6.3	6.2
Alkalinity as $CaCO_3$				
Feed solution (mg/l)	562	573	568	551
Effluent (mg/l)	219	87	89	83
Net change (%)	-61.1	-84.8	-84.3	-84.8

TABLE 14 (Continued)

	θ_c (days)			
	4.3	9.0	12.4	13.5
Microorganism Concentration				
Total Reactor, MLSS (mg/l)	902	1,554	2,094	2,168
Total Reactor, MLVSS (mg/l)	738	1,365	1,805	1,815
Effluent (mg/l)	37	16	3	24
Specific Utilization Rate (day^{-1})	1.07	0.64	0.52	0.45
Specific Growth Rate (day^{-1})	0.23	0.11	0.08	0.07
Observed Yield	0.2	0.17	0.15	0.16
Sludge Production (mg/day)	1,716	1,517	1,456	1,344
NH ₃ -N Concentration				
Feed Solution (mg/l)	50.2	57.2	58.5	50.6
Effluent, filtered (mg/l)	3.8	0.8	0.7	0.0
Net change (%)	-92.6	-98.6	-98.8	-100.0
Org-N Concentration				
Feed Solution (mg/l)	29.8	29.7	29.2	30.4
Effluent, filtered (mg/l)	9.1	0.6	0.2	0.0
Net change (%)	-67.9	-98.0	-99.5	-100.0
NO ₃ -N Concentration				
Effluent, filtered (mg/l)	5.5	48.3	47.1	47.1
Daily Wastage (l/day)	1.65	0.94	0.78	0.55

were calculated at mean cell residence times of 4.3, 9.0, 12.4 and 13.5 days, respectively.

Alkalinity was found to decrease by 61.1, 84.8, 84.3 and 84.8 percent for mean cell residence times of 4.3, 9.0, 12.4 and 13.5 days, respectively. The effluent pH at each mean cell residence time decreased due to the decrease in alkalinity.

The average influent lead concentration in feed solution was measured as 1.24 mg/l. Lead was found to accumulate in the reactor to a concentration of 7.23, 11.97, 14.62 and 28.60 mg/l at mean cell residence times of 4.3, 9.0, 12.4 and 13.5 days, respectively. The average lead removal efficiency for the four runs measured was higher than 59.0 percent.

The influent zinc concentration averaged 1.74 mg/l for the four experimental runs. Zinc reactor concentrations of 7.25, 5.83, 5.87 and 26.25 mg/l were observed at mean cell residence times of 4.3, 9.0, 12.4 and 13.5 days, respectively. Percent zinc removal efficiency was 93.1, 66.6, 70.2 and 77.8 percent at mean cell residence times of 4.3, 9.0, 12.4 and 13.5 days, respectively.

Lead concentration of 5.34 mg/l and Zinc concentration of 1.54 mg/l

Four experimental runs at mean cell residence times of 5.7, 8.9, 11.7 and 15.8 days were obtained for the reactor receiving an average lead concentration of 5.34 mg/l and an average zinc concentration of 1.54 mg/l. A summary of the steady state data for these four mean cell residence times is depicted in Table 15.

The feed solution had an average COD concentration of 447 mg/l. The effluent soluble COD concentration was between 11 mg/l and

TABLE 15
 SUMMARY OF STEADY STATE DATA
 $Pb^{++} = 5.34 \text{ mg/l}$ and $Zn^{++} = 1.54 \text{ mg/l}$, COD = 447 mg/l

	θ_c (days)			
	5.7	8.9	11.7	15.8
Chemical Oxygen Demand				
Feed solution (mg/l)	436	445	445	460
Effluent, filtered (mg/l)	27	10	26	11
Soluble COD Removal Efficiency(%)	93.8	97.9	94.1	97.7
Effluent, Unfiltered (mg/l)	49	33	51	32
Total COD Removal Efficiency(%)	88.7	92.7	88.5	93.2
Lead Concentration				
Feed solution (mg/l)	5.36	5.15	5.32	5.52
Reactor (mg/l)	26.68	36.93	52.02	46.73
Effluent, filtered (mg/l)	<0.50	<0.50	<0.50	<0.50
Effluent, Unfiltered (mg/l)	<0.53	<0.79	0.80	<0.50
Lead Removal Efficiency(%)	>90.7	>90.9	>90.6	>90.9
Zinc Concentration				
Feed solution (mg/l)	1.47	1.36	1.62	1.69
Reactor (mg/l)	9.31	12.92	11.82	45.95
Effluent, filtered (mg/l)	0.08	0.37	0.33	0.38
Effluent, Unfiltered (mg/l)	0.37	0.76	0.70	0.69
Zinc Removal Efficiency (%)	94.3	72.2	79.6	77.6
pH				
Feed solution	7.4	7.4	7.4	7.4
Effluent	7.2	6.2	6.2	6.2
Alkalinity as $CaCO_3$				
Feed solution (mg/l)	552	567	570	573
Effluent (mg/l)	230	76	77	76
Net change (%)	-58.4	-86.7	-86.5	-86.8

TABLE 15 (Continued)

	θ_c (days)			
	5.7	8.9	11.7	15.8
Microorganism Concentration				
Total Reactor, MLSS (mg/l)	1,104	1,464	1,793	2,249
Total Reactor, MLVSS (mg/l)	985	1,190	1,471	1,822
Effluent (mg/l)	7	10	11	11
Specific Utilization Rate (day^{-1})	0.75	0.66	0.51	0.44
Specific Growth Rate (day^{-1})	0.18	0.11	0.09	0.06
Observed Yield	0.24	0.17	0.18	0.14
Sludge Production (mg/day)	1,728	1,337	1,257	1,153
NH ₃ -N Concentration				
Feed solution (mg/l)	49.0	54.9	56.1	54.1
Effluent, filtered (mg/l)	7.1	0.0	0.0	0.0
Net change (%)	-85.6	-100.0	-100.0	-100.0
Org-N Concentration				
Feed solution (mg/l)	31.3	29.4	27.6	31.8
Effluent, filtered (mg/l)	9.7	0.4	0.4	0.3
Net change (%)	-68.5	-98.5	-98.2	-99.1
NO ₃ -N Concentration				
Effluent, filtered (mg/l)	2.8	42.3	45.7	46.8
Daily Wastage (l/day)	1.65	1.01	0.75	0.55

27 mg/l for all operating mean cell residence times. The soluble COD removal efficiency was higher than 93.8 percent at all operating mean cell residence times. The average total COD removal efficiency was 90.8 percent. Total mixed liquor suspended solids concentration increased from 1,104 mg/l to 2,249 mg/l as mean cell residence time increased from 5.7 days to 15.8 days. Mixed liquor volatile suspended solids concentrations of 985, 1,190, 1,471 and 1,822 mg/l were obtained for mean cell residence times of 5.7, 8.9, 11.7 and 15.8 days, respectively. Specific utilization rate decreased from 0.75 to 0.44 day⁻¹ as mean cell residence time increased.

Observed yield was 0.24, 0.17, 0.18 and 0.14 at operating mean cell residence times of 5.7, 8.9, 11.7 and 15.8 days, respectively. Sludge production was found to decrease from 1,728 mg/day at sludge age of 5.7 days to 1,153 mg/day at sludge age of 15.8 days.

Nitrification was found in the system at all of operating mean cell residence times. A decrease in NH₃-N of 85.6 percent occurred at mean cell residence time of 5.7 days and 100.0 percent occurred at mean cell residence times of 8.9, 11.7 and 15.8 days. Effluent NO₃-N concentration increased by 2.8, 42.3, 45.7 and 46.8 mg/l as mean cell residence time increased. Percent reduction of organic nitrogen was 68.5, 98.5, 98.2 and 99.1 percent at mean cell residence times of 5.7, 8.9, 11.7 and 15.8 days, respectively.

Destructions of alkalinity found at all operating mean cell residence times were 58.4, 86.7, 86.5 and 86.8 percent as mean cell residence time increased. Effluent pH was decreased according to the destruction of alkalinity.

The average influent lead concentration was 5.34 mg/l while the concentration of lead accumulated in the reactor were 26.68, 36.93, 52.02 and 46.73 mg/l at mean cell residence times of 5.7, 8.9, 11.7 and 15.8 days, respectively. Percent lead removal efficiency was found to exceed 90.6 percent for all experimental runs.

The average influent zinc concentration was 1.54 mg/l. Zinc concentration in the reactor was 9.31, 12.92, 11.82 and 45.92 mg/l at mean cell residence times of 5.7, 8.9, 11.7 and 15.8 days, respectively. Zinc removal efficiencies were 94.3, 72.2, 79.6 and 77.6 percent at mean cell residence times of 5.7, 8.9, 11.7 and 15.8 days, respectively.

Lead concentration of 1.30 mg/l and Zinc concentration of 6.57 mg/l

A reactor was operated to obtain 4 steady state data points at mean cell residence times of 5.6, 8.3, 12.1 and 16.3 days. The feed solution contained an average lead concentration of 1.30 mg/l and an average zinc concentration of 6.57 mg/l, in combination. A summary of steady state data obtained from four steady state periods is presented in Table 16.

The average COD concentration of the feed solution during the four steady state periods was 474 mg/l. The soluble COD removal efficiency was between 94.7 percent and 98.3 percent for these operating mean cell residence time. The average total COD removal efficiency of 89.6 percent was calculated for the four steady state periods. Total mixed liquor suspended solids concentration increased from 1,201 mg/l to 2,396 mg/l as mean cell residence time increased from 5.6 days to 16.3 days. Mixed liquor volatile suspended solids concentrations of 1,045, 1,305, 1,643 and 1,975 mg/l were obtained

TABLE 16
 SUMMARY OF STEADY STATE DATA
 $Pb^{++} = 1.30 \text{ mg/l}$ and $Zn^{++} = 6.57 \text{ mg/l}$, COD = 474 mg/l

	θ_c (days)			
	5.6	8.3	12.1	16.3
Chemical Oxygen Demand				
Feed solution (mg/l)	447	465	510	472
Effluent, filtered (mg/l)	16	16	27	8
Soluble COD Removal Efficiency(%)	96.4	96.5	94.7	98.3
Effluent, Unfiltered (mg/l)	52	46	58	41
Total COD Removal Efficiency(%)	88.4	90.1	88.5	91.2
Lead Concentration				
Feed solution (mg/l)	1.13	1.30	1.48	1.30
Reactor (mg/l)	8.36	9.08	11.17	16.46
Effluent, filtered (mg/l)	<0.50	<0.50	<0.50	<0.50
Effluent, Unfiltered (mg/l)	<0.50	<0.50	0.63	<0.50
Lead Removal Efficiency (%)	>55.8	>39.9	>66.2	>61.4
Zinc Concentration				
Feed solution (mg/l)	6.33	6.73	6.87	6.36
Reactor (mg/l)	36.23	38.88	46.73	58.10
Effluent, filtered (mg/l)	0.27	0.71	1.68	1.16
Effluent, Unfiltered (mg/l)	1.71	2.20	2.66	1.66
Zinc Removal Efficiency (%)	95.8	89.5	75.3	81.8
pH				
Feed solution	7.3	7.3	7.3	7.3
Effluent	7.1	6.7	6.5	6.4
Alkalinity as $CaCO_3$				
Feed solution (mg/l)	562	573	606	574
Effluent (mg/l)	240	145	96	85
Net change (%)	-57.3	-74.7	-84.2	-85.2

TABLE 16 (Continued)

	θ_c (days)			
	5.6	8.3	12.1	16.3
Microorganism Concentration				
Total Reactor, MLSS (mg/l)	1,201	1,469	2,010	2,396
Total Reactor, MLVSS (mg/l)	1,045	1,305	1,643	1,975
Effluent (mg/l)	10	17	9	9
Specific Utilization Rate (day^{-1})	0.74	0.62	0.53	0.42
Specific Growth Rate (day^{-1})	0.18	0.12	0.08	0.06
Observed Yield	0.24	0.19	0.15	0.14
Sludge Production (mg/day)	1,866	1,572	1,358	1,212
NH ₃ -N Concentration				
Feed solution (mg/l)	48.8	51.0	59.1	51.2
Effluent, filtered (mg/l)	9.3	2.7	1.2	0.0
Net change (%)	-80.6	-94.7	-98.0	-100.0
Org-N Concentration				
Feed solution (mg/l)	27.1	25.1	29.8	25.0
Effluent, filtered (mg/l)	6.7	1.0	0.2	0.8
Net change (%)	-75.4	-95.9	-99.4	-96.8
NO ₃ -N Concentration				
Effluent, filtered (mg/l)	12.2	30.7	43.5	46.7
Daily Wastage (l/day)	1.65	1.01	0.75	0.55

for mean cell residence times of 5.6, 8.3, 12.1 and 16.3 days, respectively. Specific utilization rate decreased as mean cell residence time increased. Specific utilization rate was 0.74 day^{-1} at mean cell residence time of 5.6 days and decreased to 0.42 day^{-1} at mean cell residence time of 16.3 days. Observed yield decreased from 0.24 to 0.14 as mean cell residence time increased. Sludge production was found to decrease from 1,866 mg/day to 1,212 mg/day as mean cell residence time increased.

Nitrification occurred in the system at all of mean cell residence times. $\text{NH}_3\text{-N}$ reductions of 80.6, 94.7, 98.0 and 100.0 percent at mean cell residence times of 5.6, 8.3, 12.1 and 16.3 days, respectively. Effluent $\text{NO}_3\text{-N}$ concentration increased from 12.2 to 46.7 mg/l as mean cell residence time increased. Organic nitrogen removal efficiencies were 75.4, 95.9, 99.4 and 96.8 percent at mean cell residence times of 5.6, 8.3, 12.1 and 16.3 days, respectively.

Destruction of alkalinity was found to be dependent on sludge age. Alkalinity destructions were 57.3, 74.7, 84.2 and 85.2 percent as mean cell residence time increased. A decrease effluent pH was observed due to the destruction of alkalinity.

The average lead concentration in the feed solution was 1.30 mg/l. The accumulation of lead in the reactor was found to increase with increasing mean cell residence time. Lead reactor concentration was found to increase from 8.36 mg/l to 16.46 mg/l as mean cell residence time increased from 5.6 days to 16.3 days. Lead removal efficiency averaged higher than 60.8 percent for the four experimental runs.

The influent zinc concentration averaged 6.57 mg/l. Zinc reactor concentration increased from 36.23 mg/l to 58.10 mg/l as mean cell residence time increased. The average zinc removal efficiency for the four sludge ages measured was 85.6 percent.