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Project Summary

Design Optimization of the Chlorination Process: Volume 1. Comparison of Optimized Pilot System with Existing Full-Scale Systems

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Parallel wastewater effluent chlorination studies were done on a mobile optimized chlorination pilot system and the full-scale system at eight different treatment plants. Disinfection efficiency was measured by total coliform enumeration and chlorine residual tests. Parallel flow-through fish bioassays were also conducted at each location. The objectives of the study were as follows: achievement of adequate disinfection with minimum use of chlorine; reduction of chlorine-induced toxicity; and writing of a design manual. At 7 of the 8 plants studied the optimized pilot plant achieved an equivalent level of disinfection with significantly lower chlorine dosage, in some cases more than 50% lower, than the full-scale plants. The pilot plant chlorine residuals were also lower by the same proportions. The reasons for the better pilot plant results were rapid initial mixing, improved chlorine control, and plug flow contact.

In most cases the bacterial survival ratio could be expressed as a function of the product of chlorine residual and contact time. There appeared to be, however, a limiting contact time to which this relationship applied. The degree of coliform reduction obtained during initial mixing appeared to be a function of chlorine residual.

This Project Summary was developed by EPA's Municipal Environmental Research Laboratory, Cincinnati, OH, to announce key findings of the research project that is fully documented in a separate report of the same title (see Project Report ordering information at back).

Introduction

Increase in population and its mobility, along with much greater use of waters for recreation and water supply within the past two decades have greatly increased the opportunity for human exposure to wastewaters discharged to the environment. From a public health standpoint, former natural safeguards such as time, distance, and dilution have been reduced due to the large volumes of wastewater that are now discharged and the numerous points of use. Consequently, it is essential to provide effective disinfection of wastewaters prior to their release to the environment. In almost all cases this is accomplished by chlorination of the treated effluent. Residual toxicity in the wastewater has, in many instances, adversely affected aquatic life and since, in part, this toxicity has been associated with the chlorination of wastewater, there is a need to develop effective chlorination techniques which will maximize disinfection and minimize chlorine-induced toxicity.

The typical chlorination system which has been used at wastewater treatment plants does not provide efficient use of chlorine because of design and operational deficiencies. Treatment plant operators have attempted to meet stringent bacteriological requirements by changing the only process variable in the disinfection process over which they have direct control—the chlorine feed rate. Increased chlorine dosages may enable a waste discharger to meet disinfection requirements but the practice may result in the costly waste of chlorine.

The investigation aimed to assess the feasibility of achieving consistent and reliable disinfection with the lowest possible chlorine residual (and the concurrent reduction of toxicity) through improved chlorination process design.

Specific objectives were as follows:

1) Assess the efficacy of selected treatment plants in meeting existing disinfection standards as a function of effluent quality, initial mixing, residence time distribution, chlorine residual and process control;
2) Assess the toxicity concentrations of effluents as a function of chlorine residual and other parameters;
3) Assess the efficacy of a pilot chlorination system of optimum design in providing adequate disinfection of effluents with minimum chlorine residuals at different contact times;
4) Compare the results from the optimized pilot plant to those of the full-scale plant in regard to disinfection efficiency, chlorine residuals and toxicity; and
5) Identify cost savings achievable by optimum design.

Results

Two weeks at each site were devoted to the comparative performance of the pilot system against the full-scale system. Table 1 shows the chlorine dose in the full-scale systems and the pilot system used to achieve approximately the same total coliform level after the same contact time. In all cases shown, the optimized pilot system used significantly lower chlorine dose (18.6 percent reduction at San Pablo to 56.1 percent at Pinole).

The residence time distribution curves of each chlorine contact tank studied, along with those of the pilot plant, were constructed from dye tracer studies performed during daily peak flow periods. The calculated dispersion data are shown in Table 2. It is evident from the table that the pilot tank provided better plug flow hydraulics than most of the full-scale tanks. Also, the calculated t_i (time to the first appearance of tracer) was longer than that of 6 of the full-scale tanks shown. However, 3 of the baffled tanks had a smaller dispersion number than the pilot tank. This indicates that use of the dispersion number alone is not sufficient for the proper evaluation of a tank, and that the t_i values and the extent of dead space must also be considered.

From Table 2 it can also be seen that the length-to-width ratio (L/W) does not adequately describe plug flow characteristics. The pilot tank had a much higher L/W ratio than the full-scale tanks but did not have a correspondingly smaller dispersion number. Other studies have indicated that the dispersion number usually decreases with increasing L/W ratio. Apparently factors other than L/W ratio play a role here, such as the depth-to-width ratio (H/W) and the extent of dead space. It appears from the data that the H/W ratio should be 1.0 or less.

Another factor which may influence contact tank design is the flow velocity. All the full-scale baffled tanks had average flow velocities greater than 105 cm/min. (3.5 ft/min.) at peak flow, whereas the pilot tank had a flow velocity of only 46 cm/min. (1.5 ft/min). An adequate flow velocity may help to keep the suspended solids in suspension and reduce dead spaces.

Mixing studies were carried out on the pilot plant and at those full-scale plants where it was possible to sample immediately after mixing. The pilot plant contained two static mixers: one a 76 mm (3-inch) tee in 76 mm (3-inch) pipe, the other a 38 mm (1.5 inch) tee. The chlorine solution was injected through the tee into the flow stream through a 13 mm (1/2-inch) tube. The 76 mm (3-inch) mixer had a Reynolds Number

Table 1. *Mean Chlorine Dosage Used by the Optimized Pilot Plant and Full-Scale Plants in Comparative Studies*[a]

Location	Chlorine Dosage, mg/l[b] Full-Scale Plant	Pilot Plant	Percent Reduction in Pilot Plant
San Pablo	10.2 ± 0.9	8.3 ± 0.4	18.6
Pinole	37.4 ± 9.9	16.4 ± 8.1	56.1
Sacramento	10.5 ± 2.0	5.8 ± 1.3	44.8
Roseville	10.6 ± 3.2	4.7 ± 0.9	55.7
Dublin-San Ramon	16.7 ± 3.7	11.6 ± 1.1	30.5
Ross Valley	14.8 ± 8.5	6.7 ± 0.4	54.8
Overall Mean	16.7 ± 10.5	8.9 ± 4.4	46.7

[a]*During daytime sampling period.*
[b]*Arithmetic mean ± standard deviation.*

Table 2. *Chlorine Contact Tank Dispersion Data from Dye Tracer Studies*[a]

Treatment Plant	L/W	H/W	t_i/T	t_m/T	t_a/T	d	T, min[b]
San Leandro	—	—	0.23	0.57	1.11	0.170	44
San Pablo	15	0.6	0.40	0.68	0.80	0.038	74
Pinole	40	1.0	0.35	0.66	0.76	0.029	48
So. San Francisco	—	—	0.24	0.75	1.80	0.260	25
Sacramento	—	—	0.54	0.74	1.00	0.050	81
Roseville	60	1.0	0.65	0.87	0.92	0.008	104
Dublin-San Ramon	22	1.0	0.66	0.89	0.89	0.008	60
Ross Valley	42	0.2	0.77	0.85	0.90	0.010	23
Pilot Plant	135	2.0	0.63	0.82	0.94	0.023	60
Pilot Plant	270	2.0	0.71	0.92	1.03	0.021	120

[a]*L = length; W = width, H = height; T = theoretical detention time; t_i = minimum detention time; t_m = modal (peak) detention time; t_a = average detention time; d = dispersion number.*
[b]*At time of test.*

38,500 and a G value of 115 sec^{-1}, whereas the 38 mm (1.5 inch) mixer had a Reynolds Number of 77,000 and an estimated G value of 875 sec^{-1}. The G value is the mean velocity gradient in a shearing fluid. The G value is used to estimate the energy spent on mixing the fluid; it is defined as $G = (P/u)^{0.5}$, where P is power input per unit volume and u is the absolute viscosity of the fluid. In addition to the tee there was a 0.76 m (30-inch) length of pipe before the sampling point of the residual analyzer was reached, and an additional length of 50 mm (2-inch) pipe to a sampling tap. A mixing length of 10 pipe diameters is believed to be adequate in tubular mixers provided that the chlorine solution is injected into the center of the flow stream. The total detention time in piping to this sampling tap was approximately 20 seconds.

The studies at San Leandro, San Pablo and Pinole were done with the 76 mm (3-inch) tee; the studies at Sacramento and Dublin-San Ramon were done with the 38 mm (1.5 inch) tee. At other sites the 38 mm tee was used, but no adequate data were obtained.

Results of the pilot plant mixing studies are shown in Figures 1 and 2. The data points depict the total coliform reduction in the tubular mixer after 20 seconds detention time. The reduction appears to be related to the chlorine residual, i.e., the higher the residual, the higher the percent reduction. Figure 1 shows the results with the 76 mm (3-inch) mixer which has a low G value. Although there is a wide scatter of points, there is a clear trend toward higher degree of coliform kill with increasing chlorine residual. Figure 2 shows the results for the 38 mm (1.5 inch) mixer. There is much less scatter in the data points. This indicates that the 38 mm (1.5 inch) tee does a better job of mixing, apparently because it creates a higher degree of turbulence. However, the percent coliform reduction is lower than in this mixer which may be due to differences in water quality.

Regarding the full-scale plants, 4 of them used turbine mixers and 2 used hydraulic jumps. The G-values ranged from 250 to 550 sec^{-1} and total coliform reductions were all at least 99%. The data obtained in this study are not adequate to determine which type of mixer is the best one. However, it is clear that rapid mixing is very important ı achieving adequate disinfection efficiency. It appears that a mixer that achieves a total coliform reduction of at least 99% is adequate. The turbine mixers used for chlorination are usually designed for a G value of 500-1,000 sec^{-1}, and this appears to be an appropriate range.

Conclusions

1. At all the seven wastewater treatment plants where comparative studies were made, the optimized pilot system used significantly less chlorine than the existing full-scale systems. In some cases the chlorine dosage saved by the optimized system was in excess of 50%. At these treatment plants the chlorine residuals in the pilot plant effluent were significantly lower than those in the full-scale effluents.
2. Tracer tests were necessary to assess adequately the performance of chlorine contact tanks. The use of the length/width ratio alone was found to be not sufficient.

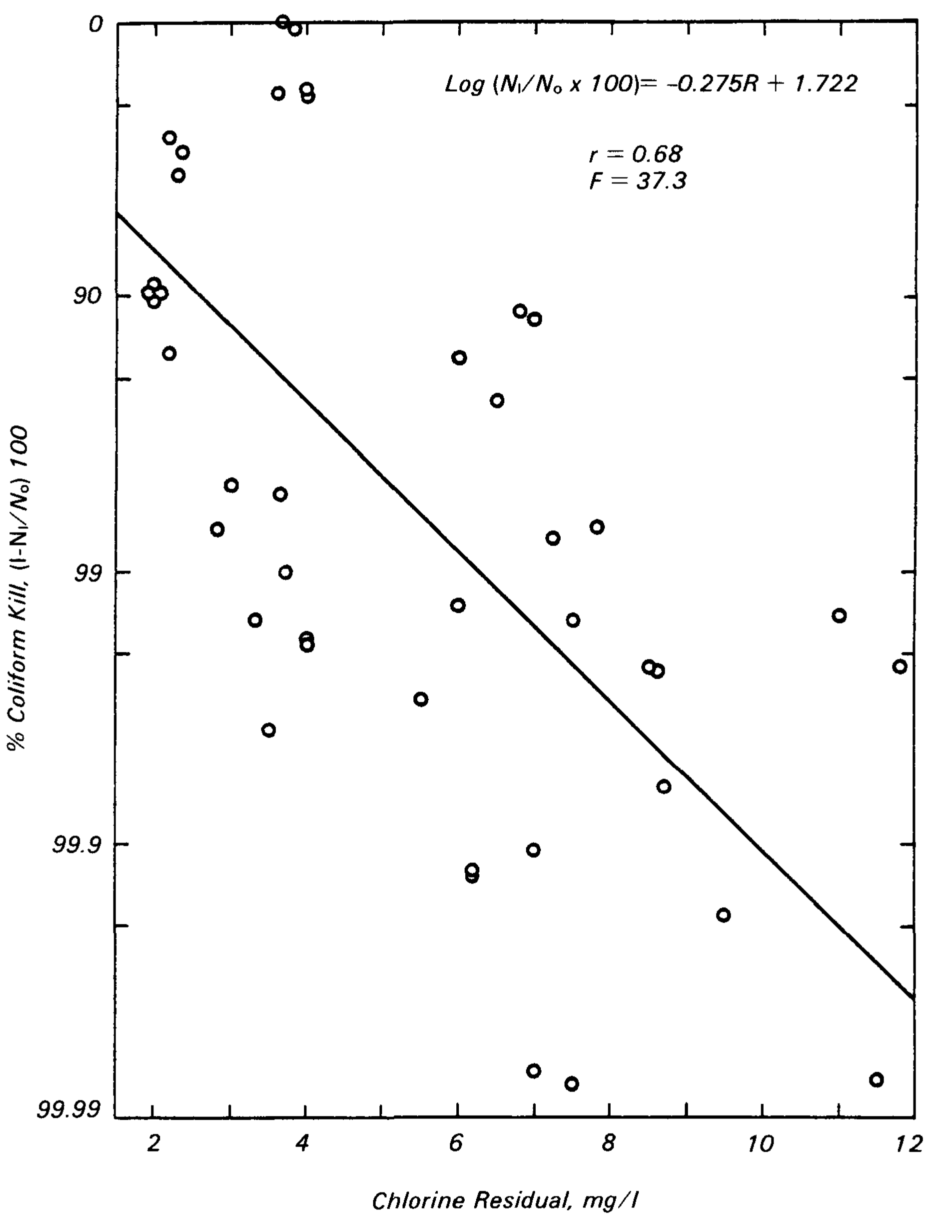

Figure 1. *Coliform kill in 76 mm mixer as a function chlorine residual.*

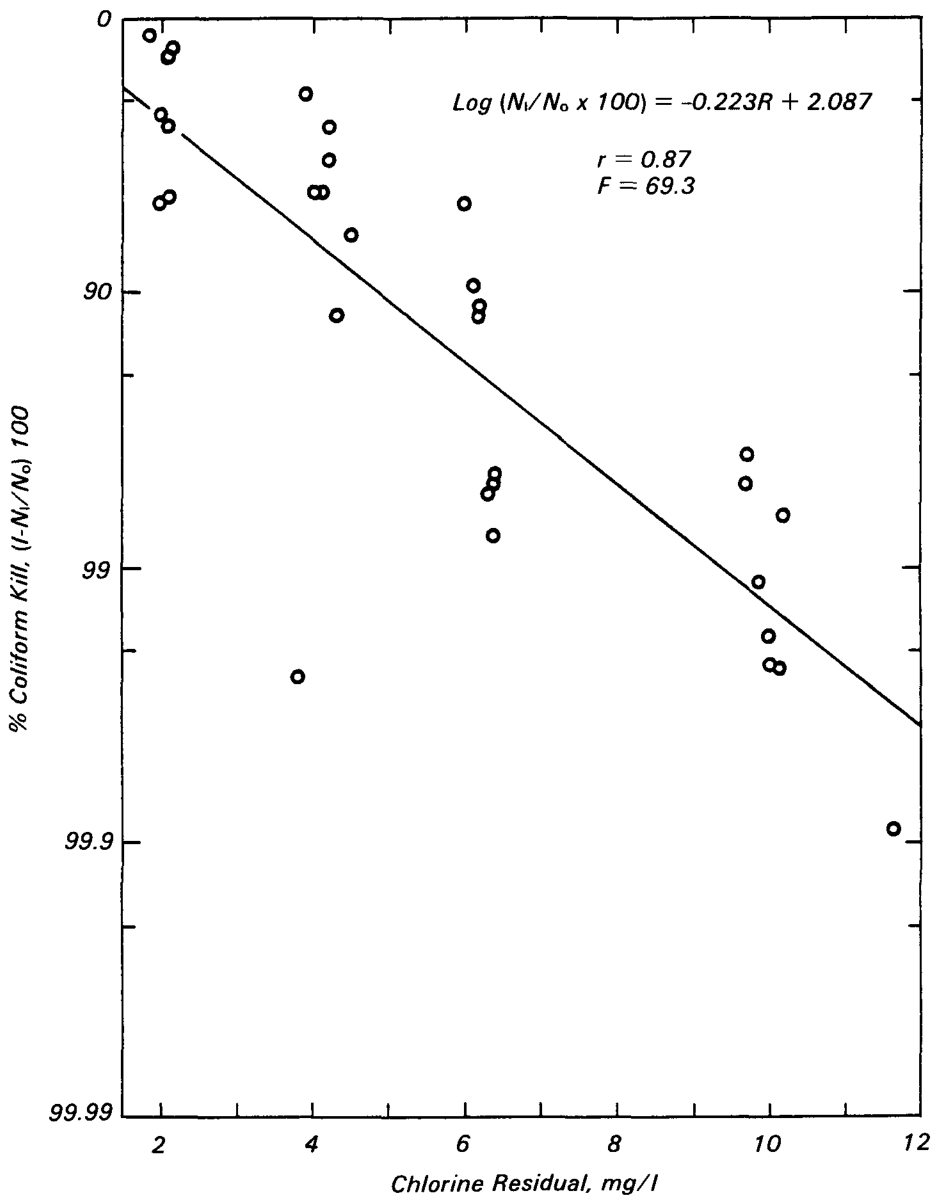

Figure 2. Coliform kill in 38 mm mixer as a function of chlorine residual.

3. Total coliform destruction during initial mixing was a function of chlorine residual; i.e.,' the higher the residual the higher the degree of destruction.
4. The coliform destruction observed in the full-scale chlorine mixers was greater than 99%.
5. The pilot plant chlorine control system performed significantly better than the full-scale systems, because of the following factors; a) very short loop time, b) adequate initial mixing, c) constant flow rate, d) instrument compatibility, and e) good operation and maintenance. In most cases the pilot system maintained the control residual within the desired ± 0.5 mg/l range. It appears that poorly designed and/or operated chlorine control systems were responsible for a major portion of the excessive chlorine dosage used at most of the full-scale plants studied.

The pilot chlorine contact tank also performed better than most of the full-scale tanks due to better plug flow and longer minimum contact time.

6. With effluents containing high levels of suspended solids the chlorine residual analyzer used clogged up and did not perform well.
7. Significant cost savings can be effected by good design and operation of chlorination systems. The cost savings realized are mainly due to savings in chemical costs.
8. The design of wastewater chlorination facilities, following secondary or higher treatment, should include the following optimum features: a) rapid initial mixing, b) reliable and well adjusted automatic chlorine residual control and c) adequate contact time (at least 30 minutes at maximum flow) in a well designed contact tank approaching plug flow conditions.
9. Operator attendance is mandatory to keep the chlorine controls in order, including daily cleaning and calibration of the chlorine residual analyzers. Therefore better operator training is necessary in chlorination system operation and maintenance.
10. Small treatment plants which cannot afford a closed loop chlorine control system should, as a minimum, install flow proportional control paced on effluent flow.

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The complete report, entitled "Design Optimization of the Chlorination Process: Volume 1. Comparison of Optimized Pilot System with Existing Full-Scale Systems," (Order No. PB 82-100 835; Cost: $12.50, subject to change) will be available only from:
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