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Circulating the World's Water

Mixing, De-Stratification, And Break-Point Chlorination In San Francisco's Sunset Reservoir

(Large Enclosed Potable Water Reservoir)

White Paper

Updated December 2009

Photographs representative of potable water storage facilities

Background

The San Francisco Public Utilities Commission (SFPUC) is an innovative leader in potable water distribution system research and operation. The SFPUC continually strives to improve water quality by conducting research and implementing operational improvements to surpass increasingly stringent regulatory standards. In 2002, the SFPUC planned a 2004 transition to chloramines as a secondary disinfectant to reduce disinfection byproduct concentrations. The SFPUC anticipated nitrification problems at several oversized distribution reservoirs with excessive water age where chloramine decay and high free ammonia was expected. High ammonia concentrations occur in unmixed dead zones due to natural chloramine decay, and in high disinfectant-demand areas such as biofilm-coated surfaces. Ammonia is reduced to nitrite and then nitrate by autotrophic bacteria. Nitrate increases bacterial growth, furthering residual loss, free ammonia production and nitrification. This positive feedback loop may result in disinfectant loss, potential violation of drinking water regulations and increased health risk to consumers due to re-growth of bacteria and necessitate removal of the reservoir from service or breakpoint chlorination to kill the bacteria and oxidize all nitrogen species to gas.

The SFPUC selected their largest distribution reservoir, Sunset Reservoir South Basin, as a test site for evaluating methods to thoroughly mix the water. Circulating water throughout the reservoir was targeted as a solution to long detention times and dead zones that result from stratification, short-circuiting and physical impediments. A series of studies evaluated mixing alternatives for distribution system reservoirs and tanks (SFPUC / Charlotte Smith & Associates 2004). Tests 1 and 2, described in the 2004 report, and additional analyses indicated that previous inlet/outlet modifications were unlikely to prevent stratification during warm seasons. Test 3 assessed the ability of a single SolarBee unit to mix, destratify and disperse chlorine in Sunset Reservoir. This report describes Test 3 methods and results.

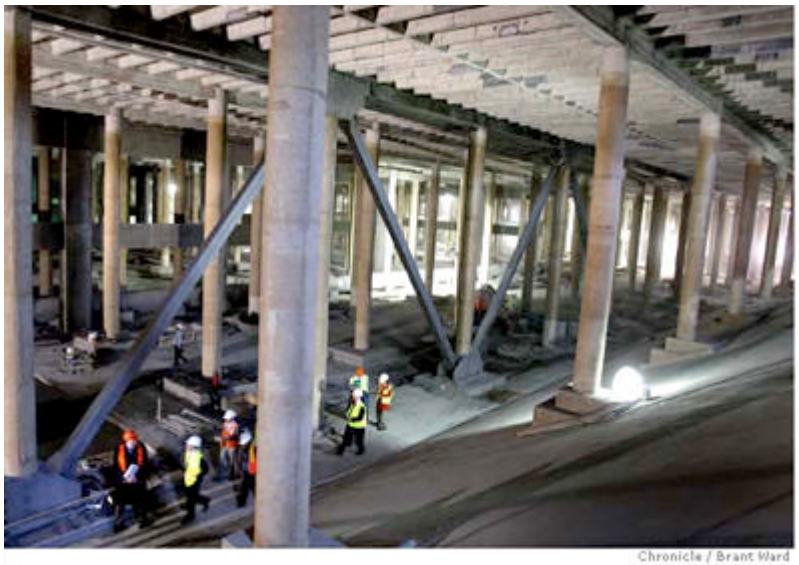

Figure 1. Sunset Reservoir resembles a Roman temple due to its 720 vertical columns, as seen during a retrofit to enhance earthquake resistance.

Sunset Reservoir

Sunset Reservoir is a rectangular, 305 x 152 m (1000 x 500 ft), concrete basin with a surface area of 0.05 km^2 (11.5 acres, about 8 city blocks) constructed in 1960 to store potable water. The reservoir floor slopes upward near the walls (Figure 1). Maximum depth is 9.14 m (30 ft) at the spill level, and maximum storage capacity is 330,466 m^3 (87.3 MG). Flow is inhibited by 720 columns that support the ground-level roof, and by horizontal cross members (Figure 1). Typical daily supply flows are 56,781 m^3 (15 MG). The 1.1 m (42-in) inlet and outlet pipes are positioned on the floor in the northwest corner of the reservoir.

Test 3 Study Objectives

- Evaluate the mixer's ability to circulate water throughout the reservoir
- Evaluate the mixer's ability to break thermal stratification
- Evaluate the mixer's ability to circulate chlorine throughout the reservoir

Test 3 Study Methods

The reservoir was isolated from the distribution system for 2 days to allow inflow energies to dissipate prior to beginning the study. Water volume was 265,358 m^3 (70.1 MG). String temperature thermistors and chlorine probes were positioned spatially in the middle and each of the four corners of the reservoir. Temperature was sampled at the surface and at six depths ranging from 0.03 m (1 ft) below the surface to 0.61 m (2 ft) above the floor. Chlorine was measured at middle, near-top and near-bottom positions at each of the five locations.

A floating SolarBee SB10000 was positioned in the middle of the reservoir. A second unit also was installed in Sunset Reservoir, but was not activated during Test 3. The circulation unit (mixer) consisted of an electronic control box, high efficiency motor, impeller, distribution dish and 0.91 m (3 ft) diameter flexible intake hose. A stainless steel plate suspended 0.03 m below the hose was stabilized at about 0.03 m above the floor by three pvc-pipe legs. Water converged between the plate and hose radially in near-laminar flow from long distances. Upflow was rated at 37.85 m^3pm (54,510 m^3pd; 10,000 gpm; 14.4 M gpd).

A liquid chlorine solution (12.5% sodium hypochlorite) was applied to the surface at a dosage of 3.79 m^3 (1,000 gal) near the mixer as it remained off. The chlorine solution fell to the floor, forming a slug beneath the mixer, because the specific gravity of sodium hypochlorite is greater than that of water. Sampling indicated no dispersion of the chlorine due to convection or diffusion as the mixer remained off for 4 days. The chlorine slug migrated to the NW corner of the reservoir during this period due to a 0.61 m elevation drop and the specific gravity of chlorine being >1. The mixer was activated April 29 when the top-to-bottom temperature differential was about 3° C (Figure 2). The mixer remained on until May 5, almost 6 days, the time period required to locate the chlorine slug.

The mixer was relocated to the NW corner directly above the chlorine slug and briefly reactivated. The mixer's intake plate was about 0.15 m above the chlorine slug,

preventing chlorine from being lifted during 45 minutes of circulation on May 7. The mixer was deactivated to remove the pvc-pipe legs, allowing the intake plate to rest on the floor in the chlorine slug. The mixer was reactivated on May 8 for 5 days to disperse the chlorine slug.

Test 3 Water Circulation & Destratification Results

The mixer was activated in the center of the reservoir for almost 6 days as the chlorine slug was being located. Temperature measurements from the four corners of the reservoir indicated that water was being circulated throughout the reservoir. The temperature by depth profile in the NW corner is illustrated in Figure 2. The top-to-bottom temperature differential of about 3°C began to decrease immediately when the mixer was activated on April 29. The temperature differential was about 1°C on May 5 when the mixer was deactivated for relocation to the NW corner to lift and disperse the chlorine slug. The upper 5.2 m (17 ft) of water were destratified during this 6 day period, yielding a destratification rate of about 0.85 mpd (2.8 ft/day). The temperature differential of 1.3°C on May 8 decreased to 0.8°C over 4 days as the mixer operated within the confines of the NW corner to lift the chlorine slug. An additional 1.5 m (5 ft) of water was destratified during this period, yielding a destratification rate of 0.38 mpd (1.25 ft/day). The decrease in the destratification rate from 0.85 to 0.38 mpd was attributed to the mixer's relocation to the NW corner where inflows were restricted to short distances near the reservoir's walls, and maximum inflow distance increasing from about 170 to 341 m (559 to 1118 ft).

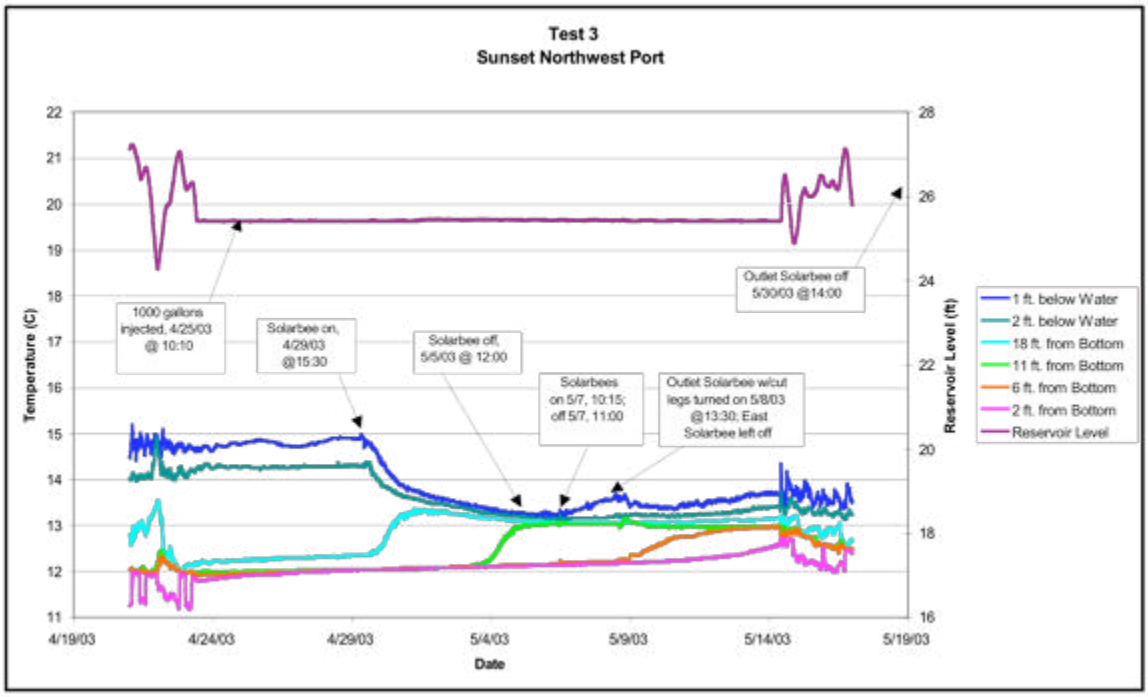

Figure 2. Temperature profile by depth and reservoir level in the NW corner of Sunset Reservoir.

Chlorine Dispersion Results

The chlorine was considered to be dispersed when concentrations at the top, middle and bottom sampling sites at each test location were ≥0.2 mg/L chlorine above background concentrations. The distances and chlorine arrival times at each sampling site are shown in Table 1. There was little overall variance in arrival times at the top, middle and bottom sites due to the small temperature differentials. The longest arrival time, <118 hrs (<4.92 days), was at middle depth in the SE test location, a distance of about 221m (726 ft) from the mixer. Most arrival times in Table 1 are indicated as less than (<) because sampling intervals were limited to 1 sample every 1-3 days, potentially inflating those values. The observed complete-dispersion time of <4.92 days corresponded well with the theoretical complete-dispersion time of 4.87 days, derived by dividing the reservoir volume of 265,358 m^3 by the mixer's flow rate of 54,510 m^3pd. The dispersion rate was estimated to be >3.75 mph (12.3 ft/hr) based on the arrival times, a value likely deflated due to the low sampling frequency.

Table 1. Chlorine arrival times and distances from the mixer

Sampling Locations & Depth[1]		Distance (m/ft)	Arrival Time (Hrs)
NW	Top		14
	Middle	64.6/212	<22
	Bottom		<22
NE	Top		<95
	Middle	213.7/701	<95
	Bottom		<95
MID	Top		42
	Middle	128/420	<42
	Bottom		<42
SW	Top		4
	Middle	60.7/199	<22
	Bottom		<23
SE	Top		<95
	Middle	221.3/726	**<118**
	Bottom		<95
Average	Top		<50
	Middle	137.8/452	<56
	Bottom		<56
Complete-Dispersion Time[2]		-	**<118 (<4.92 days)**

[1] Top = 6.7 m above floor; Middle = 3.7 m above floor; Bottom = 0.6 m above floor; Reservoir level ~ 7.7 m

[2] Equivalent to the longest arrival time

Discussion & Conclusions

Both the temperature and chlorine concentration data indicated that a single mixer circulated water throughout the 7.7 m depth of the entire 0.05 km^2 reservoir. The temperature data indicated that destratification occurred at a rate of 0.85 mpd while the mixer operated in the middle of the reservoir. Although the mixer was relocated before destratification was complete, total destratification would have occurred in <3 days of additional mixing, based upon the observed destratification rate. The chlorine data indicated that the observed complete-dispersion time closely matched the theoretical time of 4.87 days. The SFPUC concluded that a single mixer could circulate water throughout the reservoir, break thermal stratification, and disperse chlorine throughout the reservoir. Data from a subsequently conducted Test 4 indicated that destratification prior to chlorine injection increases the rate at which chlorine is evenly dispersed

throughout the water column. The utility further concluded that continual use of two mixers would enable them to breakpoint chlorinate the reservoir in about 2.5 days. The SFPUC choose SolarBee circulation units over submersible pumps for mixing Sunset and other reservoirs (Boozarpour *et al*., 2007). Two SolarBee SB10000 mixers continue to operate in Sunset Reservoir, each powered by a 320 watt solar panel array mounted on the roof of the reservoir. The SFPUC currently operates 10 additional SolarBee circulation units in other distribution reservoirs. SolarBee mixers have successfully prevented nitrification at these reservoirs since the SFPUC's conversion to chloramine disinfectant 5 years ago.

SolarBee, Inc. Recommendations

SolarBee, Inc. recommends that utilities select a single mixer or combination of mixers with flow rates sufficient to turn over all the water in enclosed reservoirs or tanks within 2 days. Utilities with limited drawdowns or storage receptacles that tend to strongly stratify may opt to select excess circulation capacity to ensure rapid mixing of cool inflow water. The need for breakpoint chlorination is reduced when stratification is well controlled and disinfectant is circulated to all surfaces, preventing the development of biofilms. SolarBee, Inc. manufactures portable systems that inject chlorine from a truck-mounted tank to the base of the mixer for boosting disinfectant levels or accomplishing break-point chlorination as needed.

The complete SFPUC report and appendices are available at: http://www.solarbee.com/potablewater.html. For additional information visit the SolarBee home page: http://www.solarbee.com/, or call 866-437-8076.

Reference:

Boozarpour M, Wilczak A, DeGraca A, Weintraub J, Garrett S. Impact of chloramine on San Francisco's water quality three years after conversion from free chlorine. American Water Works Association, Annual Conference & Exposition, June 25, 2007.

Water Quality Bureau, SFPUC. SolarBee Mixer Study: Sunset Reservoir South Basin. August, 2004.

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