Wastewater Treatment Cost Reduction: Stabilizing Chlorine Demand in Wastewater Effluent

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The operation of wastewater treatment facilities requires significant expense, especially when the facilities must provide public access reuse or advanced wastewater treatment-quality water. The highest expenses are normally for power, operations, equipment maintenance, and chemicals. If the facility utilizes sodium hypochlorite for primary and residual disinfection, these are often the highest chemical costs. A new low-cost addition at Polk County's Northeast Regional Wastewater Treatment Facility (Facility) has lowered the consumption of disinfection chemicals, while maintaining a more constant residual. The Facility has been able to stabilize chlorine demand and lower the total chlorine demand, while not significantly modifying the existing infrastructure. Additional benefits include lowered maintenance costs and lower algal growth. The small addition to the Facility is the Environmental Control Company's floating balls, also known as shade balls, to cover the chlorine contact basins (see photo).

Chlorine Demand Before Shade Balls

The Facility is an existing wastewater treatment facility rated for an average annual treatment capacity of 6 mil gal per day (mgd), capable of treatment with effluent discharging below 5/5/5/3 mg/l as five-day carbonaceous biochemical oxygen demand ($CBOD_5$), total suspended solids (TSS), total nitrogen (TN), and total phosphorous (TP). The Facility currently treats an annual average daily flow of 2.5 mgd, with peak month averages approaching 3 mgd.

The wastewater effluent from the Facility has average effluent qualities of 1/0.5/4/1.5 mg/l as defined previously. The contribution of ammonia as nitrogen averages approximately 0.1 mg/l, which is especially important to note due to its high consumption rate of chlorine. During the past two years, the Facility has had an average total chlorine use of approximately 18.2 mg/l +/- 7.2 mg/l (1.96 sigma), with an effluent residual averaging 3 mg/l. This equates to a consumption of 15.2 mg/l with greater than 50 percent variability. Removing the months of January and February 2013 due to assisting a facility owned by others that was known to have higher than typical ammonia and $CBOD_5$ levels, the average total chlorine use was approximately 17.5 mg/l +/- 5.9 mg/l. This would equate to a consumption of 14.5 mg/l with 47 percent variability over a two-year period. Figure 1 shows the monthly average chlorine use as a dosage (mg/l) before the shade balls were installed. The months of January and February 2013 were removed due to an unusual event when the Facility treated flow from another source that required higher than normal chlorine utilization.

With chlorine demand and variability so high and with minimal inorganic demand, Polk

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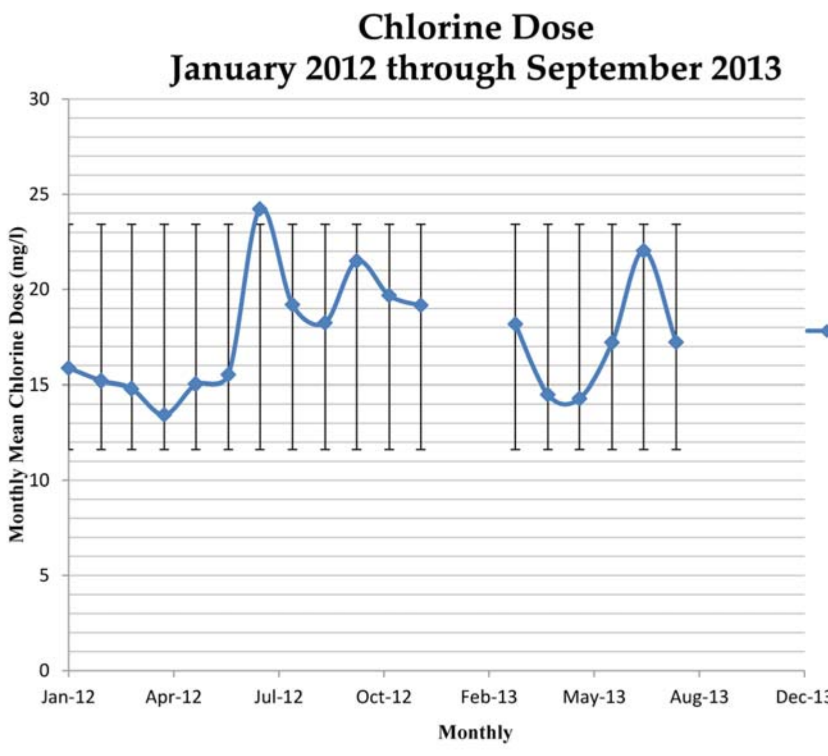

Figure 1. Chlorine Dose at Facility Without Shade Balls

County decided to investigate options for decreasing the total chlorine demand. The County considered installing an overhead shade at the Facility to decrease the temperature and ultraviolet (UV) consumption of chlorine. The County has installed an overhead shade at the Northwest Regional Wastewater Treatment Facility (Northwest Facility) with good results, and the County desired to implement similar measures throughout its service area. At the Facility, the chlorine contact basins had a much larger footprint than the Northwest Facility, and the installation of an overhead shade would have been much more expensive. The County found a less invasive option by contacting a neighboring utility. The City of Lakeland (City) had been utilizing the floating balls to limit algal growth in a basin within the County. The City had decided to decommission the use of the balls, and the County requested the use of the balls for trial purposes. By inserting the floating balls into the chlorine contact at the Facility, it had hoped to accomplish similar results to the overhead shade, but found that additional benefits were gained and results were better than expected.

Chlorine Calculations

The County's chlorine use at the Facility is attributable to disinfection and maintenance use. Disinfection chlorine consumed in a contact basin is attributable to the initial demand ($CBOD_5$, inorganics), evaporation losses (off-gassing), UV losses, and losses due to oxidation of unwanted material growth in the basin. The initial demand was already minimized through treatment process optimization in the chlorine contact basin, but the other losses were still affecting the operational stability of the Facility.

The initial demand can be directly measured by comparing the dose to the residual immediately after dose. Before the shade balls were put into the Facility, the average dosage was desired to be approximately 13.5 mg/l, leaving an 8 mg/l just after dose. The target set point was elevated due to changing field conditions to leave an effluent residual of 3 mg/l, which resulted in an actual average dosage of approximately 17 mg/l. The average instantaneous chlorine demand was calculated to be approximately 5.5 mg/l under normal conditions. It should be noted that the maintenance amount averages about 0.5 mg/l for cleaning other parts of the plant, such as the tertiary filters and clarifiers.

The next type of loss that can be estimated is evaporation. Utilizing Raoult's Law of partial pressures and Off-Site Consequences Analysis (OCA) Guidance (Kirk-Othmer), which is a modified version of Mackay and Matsugu's calculations for evaporation, the average amount of chlorine lost due to evaporation can be estimated. The calculations assume an average concentration in the contact basin of 8 mg/l, a water temperature of 27°C, and an average wind speed of 10 mi per hour (mph), which are similar conditions to the average in Davenport.

The chlorine average loss due to evaporation is estimated to be approximately 1.1 mg/l. It should be noted that this calculation assumes the evaporation losses of water to be relatively inconsequential compared to the losses of chlorine (Sung, H.M.); it should also be noted that the main contributor to the losses is wind. Although temperature plays a role, it is relatively constant. While vapor pressure of chlorine increases at elevated temperatures, the solubility capabilities of water increases. If the water temperature increases 10°C (a greater variability than exists in the effluent), the losses only increase by 0.5 mg/l. However, if the wind speed increases by 10 mph, the losses increase by 0.8 mg/l. The following equation shows example calculations:

$$E = \frac{0.284 * U^{0.78} * M^{\frac{2}{3}} * A * P_v}{82.05 * T}$$

E = Evaporation rate in lb/min
U = Wind speed in m/s
M = Molecular weight of compound
A = Area of exposed liquid surface in ft^2
P_V = Partial vapor pressure of compound evaporated
T = Absolute temperature in kelvin

To calculate the partial pressure using Raoult's Law, the vapor pressure of chlorine at the known temperature must be considered. Utilizing the Air Liquide Encyclopedia, the pure vapor pressure is 7 bar (5,250 mmHg). With a mol fraction of 2.03 X 10-6, the partial pressure of chlorine gas is approximately 0.011 mmHg.

The other losses (UV and oxidation of unwanted materials) can be grouped together as they are interrelated. The UV and nitrates present in effluent wastewater cause growth to occur, while the UV also reacts with the chlorine to decrease the residual. From the previous equations and known information, the following can be deduced:

Total chlorine average:	17.5 mg/l
Maintenance use:	0.5 mg/l
Initial/instantaneous demand:	5.5 mg/l
Evaporation losses:	1.1 mg/l
Effluent residual:	3.0 mg/l
Additional losses:	7.4 mg/l
Total Chlorine Consumption:	**14.5 mg/l**

This leaves an average of approximately 7.4 mg/l of chlorine consumed by UV or oxidation of material growth. Both UV consumption and the evaporation consumption are highly variable and depend on atmospheric conditions.

Theoretical Calculations for Shade Ball Addition

The addition of the shade balls had some apparent benefits. The majority of the chlorine contact basin liquid was shaded from sunlight, resulting in lower temperatures and lower UV light exposure. Reviewing literature from the manufacturer, the balls would cover 91 percent of the surface where they are applied, effectively allowing only 9 percent of the water to be exposed to UV light. The added benefit was that with only 9 percent of the water surface being exposed, there was significantly less area for the chlorine to off-gas from the liquid where the balls are present. This would notably decrease the variability of evaporation losses and decrease the consumption of chlorine. Based on the area exposed and the decreased chlorine demand, it is estimated that the average chlorine losses from evaporation should decrease from approximately 1.1 mg/l to 0.2 mg/l, or a reduction of 0.9 mg/l in chlorine demand.

The UV and other materials demand should decrease by at least the same level. Assuming that the UV losses were decreased by the fractional area where the shade balls were added, it is expected that the UV demand will drop from 7.4 mg/l to 1.9 mg/l, or a reduction of 5.5 mg/l in chlorine demand.

Adding the chlorine consumption savings together, it is estimated that the shade balls would save approximately 6.4 mg/l of chlorine. This would be a drop in total chlorine consumption from 14.5 mg/l to 8.1 mg/l (excluding the effluent residual). Decreasing outside demands, such as UV and evaporation, should also decrease the variability of the chlorine demand. As demonstrated previously, the chlorine demand had a variability of 47 percent within two standard deviations. If the variability of demand decreases by the amount of liquid exposed, the theoretical variability in chlorine demand should drop to 12 percent of the demand value. That should result in a chlorine demand decrease from 14.5 +/- 5.9 mg/l to 8.1 +/- 1.5 mg/l, excluding effluent residual.

Shade Ball Results

At the start of September 2013, the shade balls were installed and it was almost immediately noted that the chlorine residual stayed much

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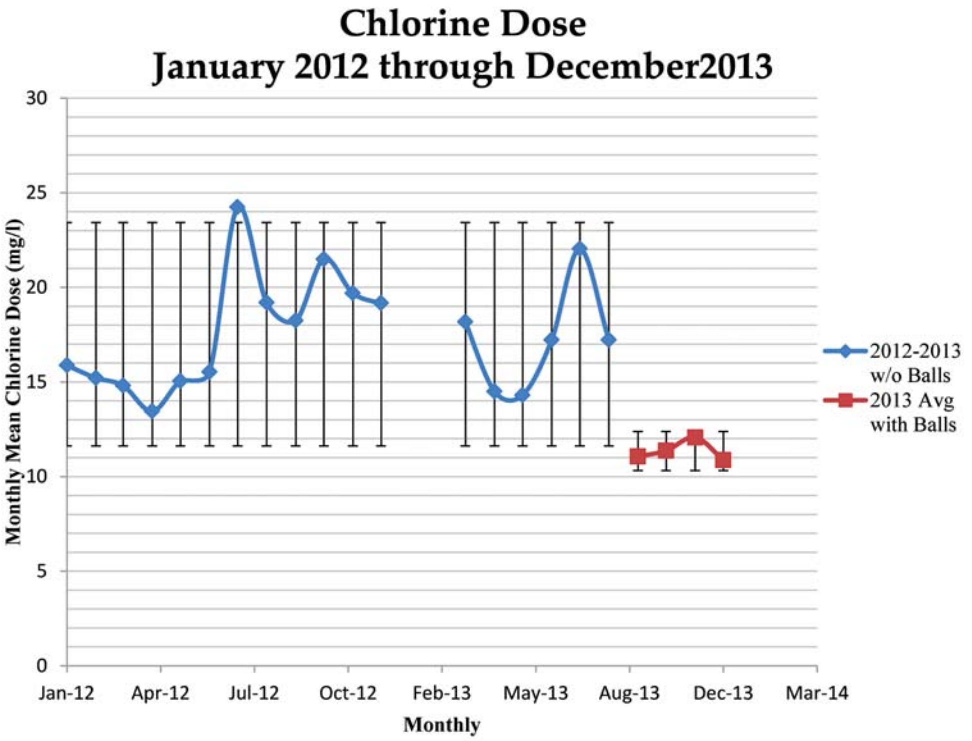

Figure 2. Chlorine Dose at Facility With and Without Shade Balls

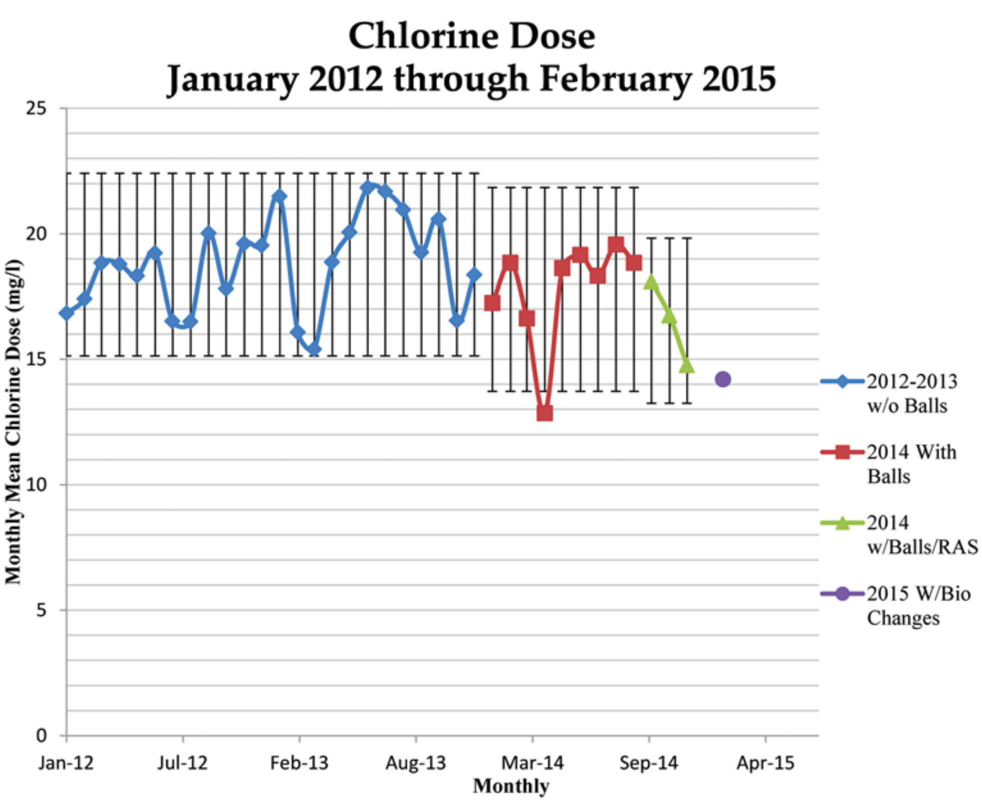

Figure 3. Chlorine Dose at Southwest Facility With and Without Shade Balls

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more constant. Due to the tighter controls, the effluent residual is now 4 mg/l rather than the expected 3 mg/l and the dose set point residual is now 5.5 mg/l with a dosage of 11 mg/l. From September 2013 through the end of December 2013, the chlorine use and flow was tracked to determine the demand. Removing the 4.0 mg/l average residual from the calculations, the total chlorine demand is now 7.3 +/- 1.0 mg/l for the four-month period, including 5.5 mg/l of instantaneous chlorine demand. The results were better than calculations predicted, but it is possible that a 12-month period will have a closer correlation to the expected 8.1 +/- 1.5 mg/l. It is also possible that the majority of the evaporation and UV exposure was occurring where the shade balls were added. The following is the estimated breakdown of chlorine uses after the shade ball's addition:

Total chlorine average:	11.3 mg/l
Maintenance use:	0.5 mg/l
Initial/instantaneous demand:	5.5 mg/l
Evaporation losses:	0.2 mg/l
Effluent residual:	4.0 mg/l
Additional losses:	1.3 mg/l
Total Chlorine Consumption:	**7.3 mg/l**

Figure 2 illustrates the monthly average chlorine use as a dosage since the shade balls were added.

The average savings of 6.2 mg/l of chlorine (17.5 mg/l versus 11.3 mg/l consumption) represents a daily savings of nearly 129 gal per day (gpd) of chlorine solution (12 percent wt/vol). At a low cost of $0.70/gal, this represents a yearly savings of nearly $33,000. The balls have a 10-year warranty and are replaced if there are any issues within the life of the ball. This would represent a chemical savings of $330,000 over a 10-year period, even if the chlorine cost did not increase and the influent flow remained unchanged.

The improved operational performance at the Facility is as important as the cost savings. The shade balls have tightened the chlorine contact control capability, leaving only 17 percent of the previous deviation in chlorine demand. This is a decrease in deviation from +/- 5.9 mg/l to only +/- 1.0 mg/l, increasing the operation staff's confidence in the Facility to provide water with adequate chlorine residual.

It has also been noted that the maintenance on the chlorine contact basins has decreased. Previously, a tank had to be taken down for preventative maintenance and scrubbed one day per month to remove iron deposits, algae growth, and dirt that had accumulated. The time it took to scrub a tank was approximately four hours. The tanks are now taken down one day every two and a half months, but do not

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need to be scrubbed. They are also taken down to remove dirt or sand deposits from the floor that may have blown in, and the time has decreased to only about one hour of work. This represents a decrease of about 43 hours/year for maintenance. At a loaded cost of roughly $25/hour, that represents a yearly savings of over $1,075 and, more importantly, it allows staff to complete tasks that may be of higher priority.

The cost to purchase the shade balls would have been only $4,700, or $2.45 per sq ft of surface area. To keep the shade balls within the basin, a vertical grate was installed in each channel of the chlorine contact basin upstream of the overflow weir. The grate allows water to flow through it, limiting excessive forces and keeping the balls in their floating position. The total cost would have been less than $10,000 for all equipment and installation if performed by a contractor. The cost savings in chlorine alone pays for the ball installation in less than one year.

With the positive results observed at the Facility, Polk County implemented the use of shade balls at the Southwest Regional Wastewater Treatment Facility (Southwest Facility) at the start of 2014. The total average chlorine dosage at the facility was 18.8 mg/l from Jan. 1, 2012, through Dec. 31, 2014. After adding the shade balls, between Jan. 1, 2014, and Sept. 30, 2014, the average chlorine dosage had dropped by 1.0 mg/l to 17.8 mg/l.

In late September 2014, additional changes were made to the biological treatment process, changing how the return activated sludge (RAS) was sent back to the activated sludge process at the Southwest Facility. The RAS changes resulted in 1.3 mg/l less chlorine demand for a total savings of 2.3 mg/l. The chlorine dosage at the Southwest Facility averaged 16.5 mg/l between Oct. 1, 2014, and Dec. 31, 2014. Figure 3 depicts the savings, along with the deviation in demand for those periods.

Note that in the first month of 2015, the biological treatment process was notably changed at the Southwest Facility, altering anoxic return and providing for an environment that would allow simultaneous nitrification/denitrification. The result of the changes was a decrease in chlorine demand of an additional 2.3 mg/l. The resulting monthly average chlorine dosage decreased from 18.8 mg/l to 14.2 mg/l between 2012 and 2015. The total decrease in chlorine demand at the facility resulted in a savings of approximately 61 gal/day or an annual savings of $15,600.

Acknowledgment

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References

- Northeast Regional Wastewater Treatment Facility Staff – Jason Jennings, Jeff Goolsby, and James Hickman.
- Southwest Regional Wastewater Treatment Facility Staff – Todd Potter, William Altman, James Hall, William Mack, and Cynthia Sammons.
- Kirk-Othmer, Encyclopedia of Chemical Technology, 4th ed., Wiley, New York, 1991.
- Mackay, D. and Matsugu, R., "Evaporation Rate of Hydrocarbon Spill on Water and Land," Canadian Journal of Chemical Engineering, p. 434, Vol 5., 1973.
- Sung, H.M., "Accidental Releases Analysis for Toxic Aqueous Solutions," Trinity Consultants, 1998.
- Air Liquide Gas Encyclopedia, Chlorine/Dichlorine Gas, Vapor Pressure Graph, 2013.