THE USE OF CHLORINE DIOXIDE TO CONTROL BIOFOULING IN AN ORGANIC BEEF FARM WATER SYSTEM

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INTRODUCTION

An organic beef farm in northern Colorado was experiencing excessive biofilm growth on the 20-μm filters through which its cattle drinking water is pumped. The source is groundwater, pumped from a 70-foot well into a 2,000-gallon holding tank, and from there pumped (16 gpm) through a bank of four 20-μm, spiral-wound filters and then distributed to the cattle drinking troughs. Some of the water is also used for plant processes. The excessive biofilm growth on the filters was evidenced by a significant decrease in house-water pressure and flow rate and required the farm to replace the filters approximately every 5 days at a cost of $800/month.

Prior to evaluating chlorine dioxide (ClO_2), the farm had examined another chemical process in an attempt to mitigate the rapid biofilm development on the filters. The process claims to form a combination of oxygen and hydroxyl radicals, which are strong, relatively short-lived oxidants, as well as to produce a low level of hydrogen peroxide to provide a longer residual. The results were mediocre, however, and the process did not significantly impact the biofilm growth. During an initial site inspection by CDG personnel the use of chlorine dioxide appeared to be a feasible alternative. Chlorine dioxide is a very effective, well-documented biocide that is used for disinfection in drinking water plants and can persist for 1-2 hours in most groundwater sources. The objective was to dose into the line coming from the well, prior to the holding tank, to provide a residual through the tank and, most importantly, at the filters to prevent biofilm development, which are located just several feet downstream from the tank effluent pump. A 45-day trial was commenced in early April, 2014.

MATERIALS AND METHODS

Water quality. Table 1 provides typical raw water quality data for the well water used at the beef farm, from a sample collected in August, 2014 and analyzed by a State of Colorado laboratory. Of particular importance in Table 1 is the sulfate level of 14 mg/L. Although an assay of the biofilm on the 20-μm filters was not performed, its black color is typically indicative of the presence of sulfate-reducing bacteria (Figure 1). The black color is due to the presence of metal sulfides formed from the reaction between hydrogen sulfide--released by the bacteriological reduction of sulfate--and dissolved metals such as iron. Also noteworthy, at the bottom of Table 1, are the microbiological results that showed total coliform bacteria were present (prior to ClO_2 addition) but that *Escherichia coli* was not detected. In a later sample (Table 2) *E. coli* were detected among other coliform bacteria.

Chlorine dioxide system. The source of ClO_2 was a 0.3 percent aqueous solution (3000 mg/L) that was virtually free of unwanted contaminants such as free chlorine and chlorite ion (*Solution 3000*™, www.cdgenvironmental.com). *Solution 3000* is a ready-to-use, pure chlorine dioxide solution and requires no mixing or activation of chemicals. Using a standard wall-mounted peristaltic pump (Stenner Pumps**,** model 85MHP40), it was fed from a 55-gallon drum and injected into a 2"PVC line conveying the well water to the 2,000-gallon holding tank (Figure 2). The pump head is equipped with Santoprene™ tubing pre-installed by the manufacturer. Santoprene™, also known as thermoplastic rubbing tubing, provides excellent mechanical properties over a wide temperature range and is highly chemically resistant, an important characteristic for pumping a chlorine dioxide solution. As suggested by the manufacturer, the tubing is replaced every 3-4 months. The 55-gallon drum comes equipped with a quick-connect fitting (Colder Products Company) that allows easy connection of the suction tubing to the drum and minimizes operator contact with chlorine dioxide gas.

The goal in dosing the chlorine dioxide was to achieve a residual of 0.3 – 0.4 mg/L at the 20-μm filters, downstream of the holding tank. Given the relatively low ClO_2 demand of the groundwater and short detention time in the holding tank (approximately 30 min.), it was

Table 1. Beef farm well water quality data (sample collected in August, 2014).

Constituent	Value
pH (std. units)	8.20
Alkalinity (mg/L as $CaCO_3$)	140
Total Organic Carbon (mg/L)	110
Turbidity (NTU)	112
Hardness (mg/L as $CaCO_3$)	24
Iron, total (mg/L)	0.034
Manganese, total (mg/L)	0.018
Sulfate (mg/L)	14
Total Dissolved Solids (mg/L)	200
Conductivity (mS/cm)	404
Total Coliforms (≥ 1 per 100 mL)	PRESENT
E. coli (≥ 1 per 100 mL)	NOT DETECTED

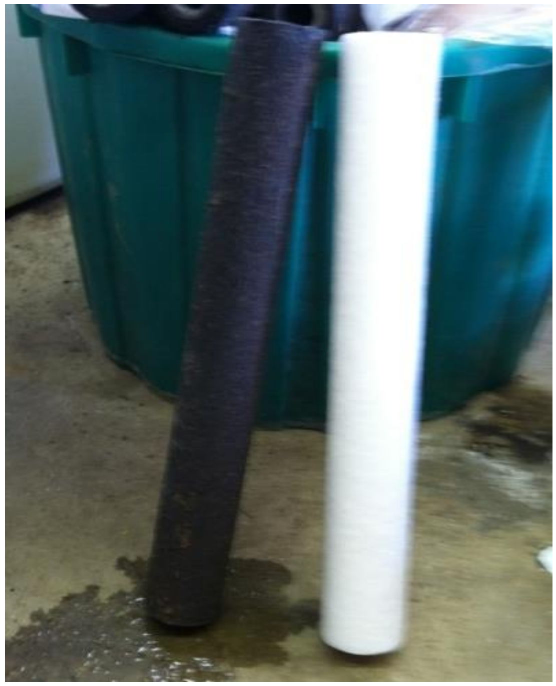

Figure 1. A 20-μm filter after 5 days of service (left), prior to the implementation of chlorine dioxide, compared to a new filter. The black color of the biofilm is indicative of the presence of sulfate-reducing bacteria.

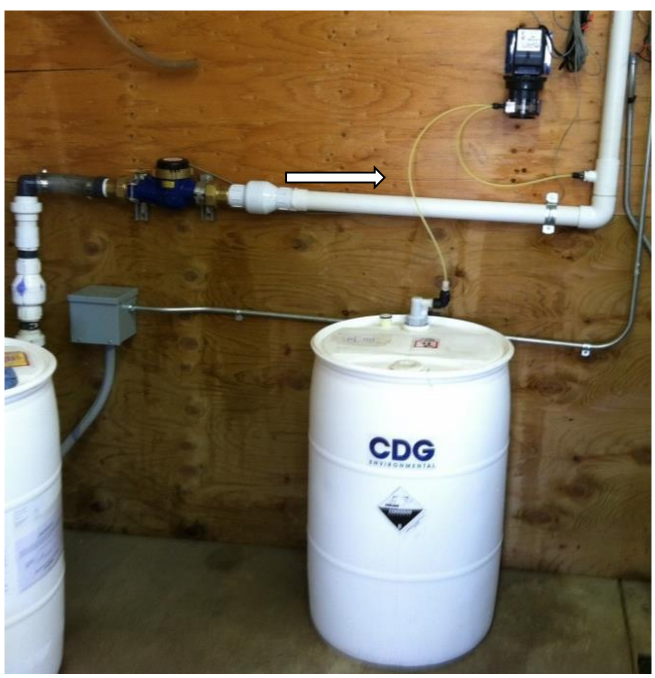

Figure 2. Chlorine dioxide feed system. The 0.3% aqueous solution is contained in the white 55-g drum. Arrow shows the direction of water flow. Peristaltic pump is in the upper right corner.

found that an applied dose of 0.70 mg/L was sufficient to achieve the target residual at the filters. Although the 30-min. detention time in the tank is relatively short, it is more than adequate for ClO_2 to inactivate a large spectrum of microorganisms, particularly bacteria (99.9% inactivation of most bacteria can be achieved at a low dose within 60 seconds, for example). Chlorine dioxide residuals were measured using the glycine-DPD method (equivalent to Standard Methods, 4500-ClO_2-d).

RESULTS

Filter performance. A significant improvement in filter performance—in terms of no increase in head loss across the filters—was observed within a few days of starting up the ClO_2 system. As noted previously, prior to the implementation of ClO_2 the 20-μm filters needed to be replaced every 4-5 days and were typically clogged with black biofilm (Figure 1). After two weeks of chlorine dioxide application the filters were visually inspected and no significant biofilm development was observed (Figure 3). The light-brown color of the filters in Figure 3 was due to the accumulation of suspended solids and had no effect on the head loss across the filters. After another 4 weeks (6 weeks total operation) the filters were removed and inspected again. Their condition was virtually unchanged from the 2-week inspection, as shown in Figure 3.

Following the positive results from the initial 6-week trial, although no significant decrease in performance was observed, the filters were replaced. With a continual chlorine dioxide residual present, in the range of 0.4 – 0.5 mg/L, the next set of four filters remained in operation for approximately 5 months. Even after this duration (compared to 5 days prior to ClO_2) head loss due to biofilm growth was not an issue. The filters had, however, accumulated a significant amount of suspended solids, as shown in Figure 4, which prompted their replacement.

Bacterial inactivation. Prior to the start-up of the ClO_2 system, it was clear from the rapid growth of biofilm on the filters that there was a significant bacterial population in the well water. From the sulfate level in the water (14 mg/L) and the distinctive black color of the filters, at least some of these appeared to be sulfate reducing bacteria (SRB), which would have thrived in the anaerobic conditions within the layers of biofilm. As noted in Table 1 and confirmed in Table 2 below, coliform bacteria, including *E. coli*, were also detected in the raw well water samples. The addition of chlorine dioxide, as shown in Table 2, reduced the counts of all aerobic and coliform bacteria to zero, in a sample collected downstream of the 20-μm filters. Although anaerobic bacteria such as SRB were not measured in that sample, it is a safe assumption that they were also completely inactivated, as evidenced by the absence of biofilm on the filters.

Cost savings. Prior to the implementation of chlorine dioxide, the rate of replacement of the 20-μm filters was every 5 days, at an approximate cost of $800/month, not including the labor required. The application of chlorine dioxide has increased the filter run time to 5+ months. Including the cost of *Solution 3000*, the overall filter budget has been decreased by approximately 50 percent at the organic beef farm.

Table 2. Impact of chlorine dioxide on bacteria counts (September 19, 2014).

Sample ID	Approximate cfu/mL	
	Aerobic bacteria[1]	Coliforms[2]
Well influent, prior to ClO_2	3	2
Holding tank effluent (post-ClO_2)	0	0

[1] *Pseudomonas stutzeri* accounted for 2 cfu/mL.

[2] *Escherichia coli* accounted for 1 cfu/mL.

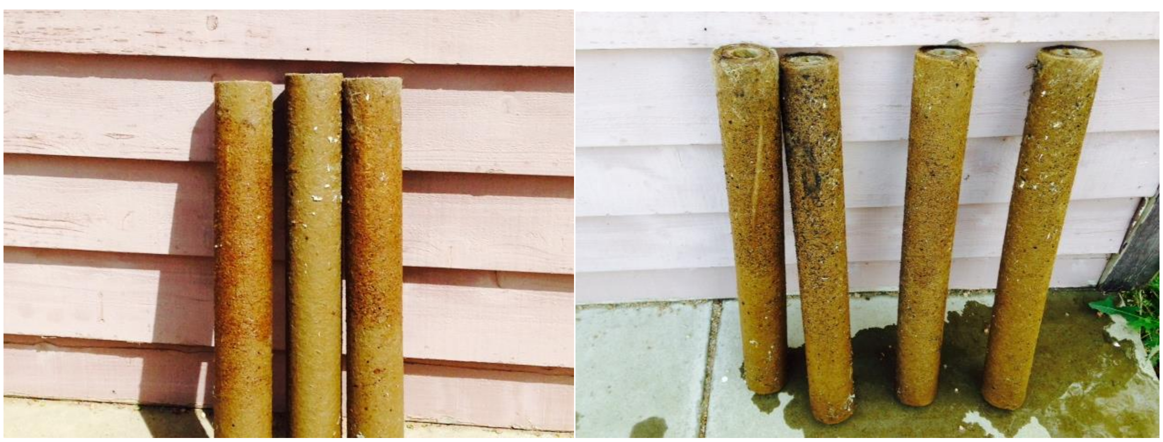

Figure 3. The 20-µm filters approximately 2 weeks (left) and 6 weeks (right) after the start-up of the ClO_2 system. Virtually no change was detected in the performance of these filters during this period (contrast with filter in Figure 1 after 5 days, prior to ClO2 addition).

Conclusion

The use of *Solution 3000™*, a ready-to-use, 0.3% aqueous chlorine dioxide solution , has dramatically improved the water quality and system performance at an organic beef farm in Colorado by preventing the growth of biofilm on its 20-µm filters and eliminating coliform bacteria in the water supply. The application of a relatively low chlorine dioxide dose (0.7 mg/L), provided with a short detention time, has proved to be effective for 1) bacterial inactivation of the incoming raw water, 2) preventing biofilm growth on the filters that are approximately 30 minutes downstream of the injection point, 3) increasing the filter run times from 5 days to 5+ months, and 4) decreasing the overall filter budget of the plant by approximately 70 percent.

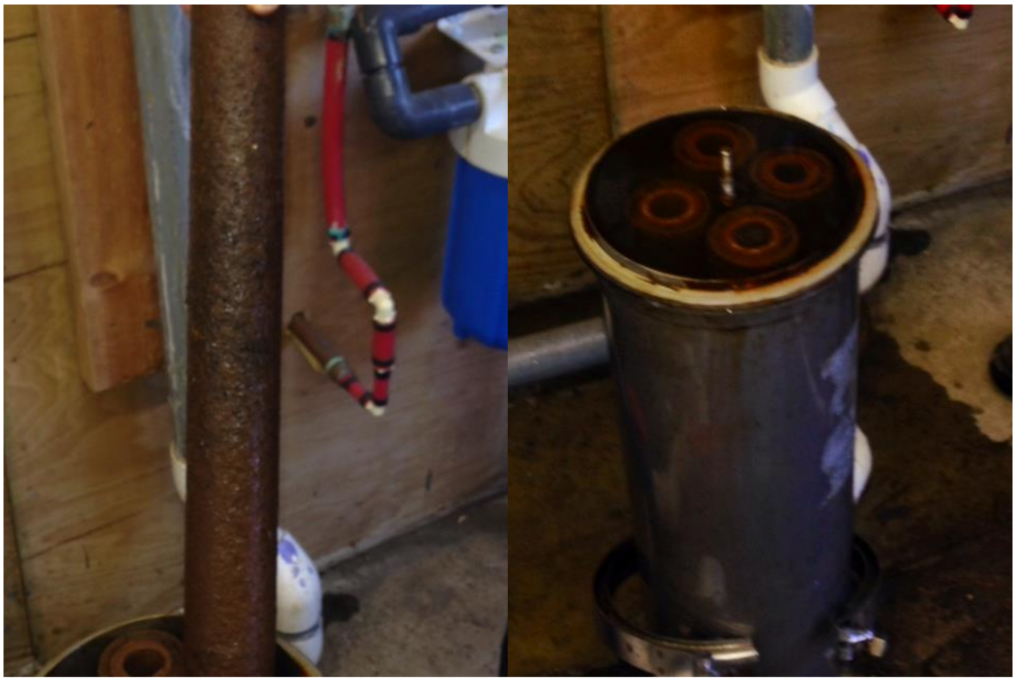

Figure 4. A 20-μm filter after approximately 5 months of service (left), following implementation of the chlorine dioxide system. The pressurized filter housing unit is shown on the right.