Effects of Ozone on Microscreen Filtration and Water Quality in a Recirculating Rainbow Trout Culture System

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Abstract

Ozone was added to water in a recirculating rainbow trout (Oncorhynchus mykiss) culture system just prior to the culture tanks in order to oxidize nitrite and organic material, improve overall water quality, and assist removal of solids across the microscreen filter. Data from four 8-week studies on ozonation and an 8-week no ozone control indicated that adding ozone reduced the mean concentration of TSS by 35%, COD by 36%, DOC by 17%, and color by 82% within the water entering the culture tanks. Additionally, ozone reduced the mean nitrite concentration by 82% within the culture tanks. Changes brought on by ozonation, particularly as it affected the characteristics of the suspended solids, also improved suspended solids removal across the Triangel™ filter by an average of 33%. In addition, adding ozone decreased plugging of the microscreen filter panels, as indicated by an average of 35% fewer filter wash cycles, 53% less filter sludge flow produced, and 79% more settled solids volume in the Triangel™ filter effluents. Comparison of two different ozone dosing rates indicated that adding ozone to our recirculating system at a rate of 0.025 kg ozone per kilogram feed was about as effective as adding ozone at a rate of 0.036-0.039 kg ozone per kilogram feed.

Introduction

Many aquaculture producers with large modular recirculating systems are using microscreen filters to remove solids. Microscreen filters (Summerfelt et al. 1994) and most conventional clarification techniques (Chen et al. 1994), however, do not readily remove dissolved organic and colloidal solids. If the organic matter is not removed, it can inhibit nitrification, exert an unwanted oxygen demand, and harbor opportunistic pathogens within the recirculated systems (Chen et al. 1994). Methods or processes that improve solids removal also improve water quality, which can potentially enhance production and reduce certain operating costs. Because ozone has been shown to precipitate dissolved organic molecules and microflocculate colloidal organic solids (Maier 1984), ozone can be used to enhance removal of dissolved and colloidal organic matter via sedimentation, flotation, or filtration units.

Ozone has a wide range of aquaculture uses because many contaminants in aquaculture waters are oxidizable. Ozone has the advantages of a rapid reaction rate, few harmful reaction by products in freshwater, and production of oxygen as a reaction end-product. Sterilization of water supplies and/or discharges has been the traditional use of ozone in aquaculture systems. However, ozone has also been used within recirculating aquaculture systems (Otte et al. 1977; Otte and Rosenthal 1979; Rosenthal and Otte 1980; Rosenthal 1981; Williams et al. 1982;

Sutterlin et al. 1984; Rosenthal and Kruner 1985; Paller and Lewis 1988; Poston and Williams 1988; Reid and Arnold 1992; Brazil et al. 1996; Bullock et al. 1996). Ozonation provides recirculating systems with benefits other than disinfection through supportive water treatment that can include color removal, oxidation of nitrite and non-biodegradable organic matter (subsequently making them degradable by bacteria), and improved suspended solids removal by flotation and clarification.

Research by Wilczak et al. (1992) and Rueter and Johnson (1995) showed that ozonation improved solids removal through sedimentation and granular filtration; and, research by Sander and Rosenthal (1975), Otte and Rosenthal (1979), and Williams et al. (1982) showed that ozonation improved removal of organic material through foam fractionation. However, ozone can affect particulates differently, depending upon the particles surface properties and the presence of surfactants; in some cases, ozonation can increase particle stability and decrease microflocculation (Maier 1984; Grasso and Weber 1988; Edward and Benjamin 1991; Wilczak et al. 1992). Additionally, previous research neither described ozone's effect on microscreen filter performance, nor provided criteria that could be used to relate the amount of ozone required with respect to the daily fish feed input. Also, much of the research on ozone was conducted within brackish water systems and with ozone added in a batch manner outside of the main recirculating water loop. Much of this previous research is less useful to freshwater users and users that plan to apply ozone continually to the entire recirculated flow. Therefore, it was clear that research was needed to determine how continuous ozonation affects microscreen filtration and water quality within freshwater systems.

In this research, our objectives were to demonstrate ozone's affect on water quality and microscreen filtration when ozone was added at levels that could be obtained by creating 3-4% ozone within the existing oxygen feed gas before it is transferred into the system. The oxygen feed gas would thus serve to both introduce ozone and to provide a dissolved oxygen supersaturation within each culture tank's influent. An accompanying paper by Bullock et al. (1996) describes the effects of moderate levels of ozone on bacterial gill disease (BGD) epizootics and numbers of heterotrophic bacteria.

Materials and methods

A description of the ozone tests, recirculating system design, method of ozone addition, and fish and feeding practice used are provided in the companion paper by Bullock et al. (1996).

Microscreen filter evaluation

Microscreen filters remove water-bound particles that are too large to pass through the openings in their screen panels. Experiments were designed to evaluate the performance of the Triangel™[1] filter when ozone was or was not added to the system. The Triangel™ filters evaluated (Model TF-12-RB; Hydrotech, Villinge, Sweden) used 80-mm opening sieve panels to

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1 Use of trade or manufacturer names does not imply endorsement.

treat each treat 360 l/min. Triangel™ filters operate by distributing flow in a thin layer across a weir and onto one side of a flat sieve panel. Water drips through the sieve and particulates larger than the openings are left behind. As particulates accumulate on the sieve, water level on the sieve panel increases fractionally, and provides the motive force for the flow to travel further down the panel. The flow across the top of the panel pushes a thin barrier of accumulated particulates towards the sludge water drain. Just before the flow reaches the end of the sieve panel, an optical sensor located under the sieve panel detects water falling through the screen. The optical sensor is linked to a mechanically driven high-pressure backwash which washes the accumulated solids into a sludge collection trough located at the end of the sieve panel. Rinse water for sprayers was supplied from the floor sump by a 1.1 kw (1.5-hp) pump (Model HB2515; Goulds Pumps, Inc., Seneca Falls, New York) with a 121 1 (32 gal) pressure tank operating at 414-552 kN/m^2 (60-80 psi).

During each 8-week trial, each Triangel™ filter's influent and effluent total suspended solids (TSS) concentrations were measured once a week, beginning after the first week. Total daily solids removal across each filter was calculated from the difference between the influent and effluent TSS concentrations multiplied by the flow to each filter.

Sludge production rate, sludge settled solids volume, and number of wash cycles were measured weekly by capturing 10 to 20 1 of Triangel™ filter sludge effluent. Daily sludge water production and number of daily wash cycles were determined by extrapolating the results of the sampling period over the entire day.

Determination of water quality

Concentrations of TSS, chemical oxygen demand (COD), total organic carbon (TOC), dissolved organic carbon (DOC), nitrite, water color, and turbidity were measured in the recirculated water before and after each LHOJ when ozone was added, before and after each culture tank, and after each microscreen filter. No samples were taken during the first week of each 8-week trial to allow the system to stabilize. Each trial, TSS, COD, and DOC were measured once weekly, for at least six of the remaining seven weeks, while color, nitrite, and turbidity were measured three times a week each trial. COD concentrations were measured using test procedures, COD2 reagents, COD Reactor, and DR2000 or DR3000 spectrophotometers from Hach Chemical Company (Loveland, CO). Nitrite concentrations were measured using the diazotization method and Hach Chemical Company reagents and either a DR2000 or DR3000 spectrophotometer. TSS concentrations were measured using APHA (1985) method 209 C. Color samples were filtered through 0.5-[tm filter paper before being analyzed based upon a Pt-Co standard using APHA (1985) method 204 B and a Hach Chemical Company DR2000 or DR3000 spectrophotometer at 455 nm wavelength. Turbidity was measured with a Hach Chemical Company Ratio/XR turbidimeter using APHA (1985) method 214 A. DOC samples were filtered through 0.5-µm filter paper before being frozen and shipped to Lancaster Laboratory (Lancaster, PA) where they were analyzed using a persulfate digestion/infrared detection method on an acidified sample which had been purged of carbon dioxide using nitrogen.

Methods used to measure dissolved ozone were described by Bullock et al. (1996).

Results

Water quality

The sample location within the recirculating system that showed the fullest extent of water quality treatment was used here to discuss how ozone affected water quality. The location immediately following the LHO™ (just before entering the fish culture tank) showed the lowest concentration in TSS, COD, DOC, color, and turbidity, and is used here to compare the effect of ozone on water quality. Water entering the LHO™ was the cleanest within the system because it had already been sieved, biofiltered, and air stripped/aerated. Ozone reduced nitrite to the lowest levels within the fish culture tanks, so the concentration data measured in C-1 was used to compare nitrite reductions between trials (Table 1).

Table 1. Mean chemical oxygen demand (COD), total suspended solids (TSS), dissolved organic carbon (DOC), color, and turbidity within the flow entering C-2 and the nitrite concentrations within C-1 during the ozone study.

Treatment	Ozone dose (kg/d)	TSS $\bar{x}$ ±SE (mg/l)	COD $\bar{x}$ ±SE (mg/l)	DOC $\bar{x}$ ±SE (mg/l)	Color $\bar{x}$ ±SE (Pt-Co)	Turbidity $\bar{x}$ ±SE (NTU)	Nitrite $\bar{x}$ ±SE (mg/l)
Treatment 1	0.68	4.0 ±0.6	26.1 ±1.5	NA	5.3 ±0.9	1.49 ±0.14	50 ±12
Control	0.0	6.3 ±1.1	43.6 ±3.8	7.1 ±0.4	17.7 ±1.2	1.58 ±0.08	265 ±15
Treatment 2	0.68	2.9 ±0.6	25.7 ±5.6	6.3 ±0.3	2.9 ±0.4	0.94 ±0.05	24 ±6
Treatment 3	1.0 to 1.3	5.6 ±0.4	36.7 ±5.5	6.0 ±0.3	2.1 ±0.5	2.02 ±0.16	73 ±18
Treatment 4	1.0 to 1.3	3.9 ±1.0	23.8 ±1.4	5.5 ±0.2	2.0 ±0.5	1.13 ±0.06	46 ±20

Ozone reduced the accumulation of suspended particulates, dissolved organics, water color, and nitrite in all trials with respect to the control (Table 1): TSS entering C-1 was reduced from an average of 6.3 mg/l in the control to 2.9-5.6 mg/l; COD entering C-1 was reduced from an average of 43.6 mg/l in the control to 23.8-36.7 mg/l; DOC entering C-1 was reduced from an average of 7.1 mg/l in the control to 5.5-6.3 mg/l; color in the water entering C-1 was reduced from an average of 17.7 Pt-Co units in the control to 2.0-5.3 Pt-Co units; Likewise, nitrite within C-1 was much lower during the ozone trials (means 24-73 μg/1) when compared to the control (265 μ/l).

There were no clear trends in mean turbidity between the control (1.58 NTU) and the ozone trials (0.94-2.02 NTU).

Microscreen filter evaluation

Adding ozone to the recirculating system greatly improved the performance of the Triangel™ filter (Table 2). Ozonation increased the removal of suspended solids across each Triangel™ filter from a mean of 3.4 kg/d in the control to 3.8-4.5 kg/d during the ozone trials. More importantly, based upon the daily feeding rate (Table 2), a larger fraction of the solids fed to the fish were removed when the system was ozonated (0.29-0.35 kg solids removed per kilogram dry feed fed) than when it was not ozonated (0.24 kg solids removed per kilogram dry feed fed). Additionally, adding ozone to the system: (1) reduced daily production of Triangel™ filter sludge from a mean of 4,090 l/d in the control to 1,470-2,520 l/d in the four ozone trials; (2) increased the settled solids volume of the Triangel™ filter sludge effluent from a mean of 20.6 ml/l in the control to 31.5-43.2 ml/l in the four ozone trials; and (3) reduced Triangel™ filter wash requirements from a mean of 3,080 cycles/d in the control to 1,6102,420 cycles/d in the four ozone trials.

Table 2. Triangel™ filter performance during the ozone study.

Treatment	Filter wash frequence, $\bar{x}$ ± SE (#/day)	Settled solids volume of sludge produced, $\bar{x}$ ±SE (ml/l)	Sludge Water Produced, $\bar{x}$ ±SE (l/d)	Solids removed across filter, $\bar{x}$ ±SE (kg/d)	Mean daily dry[a] feed rate (kg/d)	Fraction of dry weight feed removed, (kg/kg)
trial 1	2420 ± 120	31.5 ± 2.3	2520 ± 280	4.5 ± 0.9	13.3	0.33
control	3080 ± 290	20.6 ± 2.3	4090 ± 520	3.4 ± 0.4	14.1	0.24
trial 2	2230 ± 100	34.1 ± 1.9	2090 ± 180	4.5 ± 0.6	13.2	0.34
trial 3	1760 ± 70	38.3 ± 1.4	1610 ± 120	4.1 ± 0.4	11.8	0.35
trial 4	1610 ± 50	43.2 ± 2.1	1470 ± 160	3.8 ± 0.9	12.8	0.29

[a] Dry weight calculated from total weight based on 10% feed moisture content.

Discussion

Adding ozone to the recirculating system resulted in an overall improvement in water quality due to more complete oxidation of nitrite, color, organic material, and suspended solids. Ozone reduced the concentration of suspended particulates, dissolved organics, water color, and nitrite in all trials when compared to the control (Table 1). Over all trials, ozonation reduced the mean concentration of TSS by 35%, COD by 36%, DOC by 17%, and color by 82% within the water entering C-1. Additionally, ozonation reduced the mean nitrite concentration by 82% within C-1. Ozone did not consistently change turbidity. Changes brought on by ozonation, particularly as it affected the characteristics of the suspended solids, also improved the performance of the Triangel™ microscreen filters (Table 2).

TSS and COD

The accumulation of solids and oxygen demanding matter in recirculating systems is dependent upon the rate of feeding, the rate that solids are removed in a clarifier, and the rate that they are entrained out of the system during water exchange (Liao and Mayo 1992). Reduction in the accumulation of TSS and COD were likely due to improved filtration resulting from ozone--induced microflocculation, as discussed in the improvements in microflocculation section (below). Although the two ozone doses evaluated within this study did show excellent reduction in TSS and COD concentrations, the higher ozone dosing rate (0.036-0.039 kg ozone per kilogram feed) did not reduce TSS or COD concentrations beyond those achieved by the lower dosing rate (0.025 kg ozone per kilogram feed).

TSS and COD that accumulated within the system were those solids and organics that could not be removed by passage through the 80-μm microscreen panel, even with the oxidative assistance provided by ozone. In an earlier study, we determined that the TSS that were not removed across the 80-μm microscreen panel were colloids that could not be removed by a screen filter with openings ≥40 μm (Heinen et al., 1996).

DOC and color

Non-biodegradable organic compounds tend to accumulate in recirculating systems (Otte et al. 1977; Rosenthal and Otte 1980; Hirayama 1988). Ozone can decrease the accumulation of non-biodegradable organic compounds in recirculating systems (Rosenthal and Otte 1980), because ozone and its reaction by products are capable of oxidizing a great many organic substances (Rice et al. 1981; Bablon et al. 1991). Ozone oxidation removes color and makes organic molecules more biodegradable.

We found that ozonation greatly reduced color but only slightly reduced DOC levels (Table 1). However, color and DOC reductions at the higher dosing rate were similar to the reductions made at the lower ozone dosing rate. Reduction in the accumulation of color and DOC levels were likely due to a combination of oxidation, enhanced biodegradation, increased precipitation, and adsorption onto particulates.

Otte and Rosenthal (1979) reported that color removal was improved by ozone-enhanced foam fractionation and biofiltration in a recirculating system used to culture tilapia and European eels. Sutterlin et al. (1984) found that ozone assisted with color removal within a recirculating system that produced Atlantic salmon smolts. Rosenthal and Kruner (1985) used a synthetic fish water containing ammonia, nitrite, and peptone to show that high levels of ozone can be used to oxidize BOD, but that it required > 10 g ozone to oxidize 1 g BOD. Under normal conditions, Rosenthal and Otte (1980) reported that ozonation did not substantially affect the overall BOD within recirculating fish culture systems.

Reaction with ozone can occur directly or through an ozone decomposition product.

Organic matter in recirculating aquaculture water tends to destabilize ozone; alkalinity, on the other hand, can prevent the destabilization of ozone (Staehelin and Hoigne 1985). Direct ozone oxidation has been reported to be highly selective; however, ozone decomposition products such as the hydroxide radical often exhibit little substrate specificity. Decomposition products are extremely strong oxidants capable of reacting with almost any organic compound (Hoigné and Bader 1979). The mechanism of ozone reaction was not determined in this research; yet mechanism of ozone reaction was significant in that ozone could increase biodegradation of organic molecules through: (1) the direct ozone oxidation of higher order covalent bonds in organic molecules that may not be readily biodegradable; and (2) the tendency for decomposition products to oxidize and chop large molecules into smaller fragments (Rice et al. 1981).

Under the conditions used in aquaculture, ozone does not oxidize organic carbon all the way to carbon dioxide but breaks the organic molecule into more small molecules (Maier 1984; Rice et al. 1981).

Nitrite

Within our system, ozonation reduced nitrite to lower mean concentrations in the fish culture tank water than in the water just after the LHO™ (the point where ozone was added). We think that the lower levels of nitrite within the culture tanks were caused by residual ozone (0.02 - 0.18 mg/1) entering the culture tanks which continued to oxidize nitrite. Although the two ozone doses evaluated within this study did show excellent reduction in nitrite (Table 1), the higher ozone dosing rate did not improve nitrite reduction within the fish culture tank with respect to the lower dosing rate.

Others have reported that ozone oxidized nitrite (Rosenthal 1980; Sutterlin et al. 1984; Rosenthal and Kruner 1985; Bablon et al. 1991) within recirculating aquaculture production systems. The reports on nitrite indicate that roughly stoichiometric proportions of ozone are required to oxidize nitrite to nitrate, about 1.04 mg ozone per mg nitrite (Bablon et al. 1991). That ozone reduces nitrite, which is toxic to fish at low concentrations, is a substancial benefit provided by ozonation because elevated levels nitrite are often encountered when the biofilter loses function. The drawback to ozonation occurs when addition of ozone is interrupted. Because ozone is responsible for removing a fairly large fraction of the total nitrite produced in the recirculating system, ozone actually reduces the nitrite concentration going to the biofilter. Long-term ozonation resulted in a reduction in the total nitrite removal capacity of the biofilter as indicated by rapid nitrite accumulation when ozone addition was interrupted (unpublished data). The health of the fish can be threatened by the nitrite accumulation occurring after ozonation has been stopped.

Turbidity

Ozonation did not consistently change turbidity at any location within the recirculating system. Microflocculation produced by ozonation can change both the concentration and size of the colloids within the system, which affects the turbidity (Grasso and Weber 1988; Wilczak et al. 1992; Rueter and Johnson 1995). However, within our system turbidity did not consistently represent the changes in colloid size distribution.

Improvements in microscreen filter performance

Adding ozone increased solids removal across the Triangel™ filter from a mean of about 24% of the feed fed to nearly 33% of the total feed fed. The 24% solids removal measured during the control was supported by previous research within the same system when ozone was not used (Heinen, in press).

Ozone improved suspended solids removal across the Triangel™ filter by an average of 33% (Table 2). The improved solids removal was probably due to oxidation producing precipitation of dissolved organic molecules and microflocculation of colloidal organic solids, as first described by Maier (1984). The oxidized organic compounds are usually smaller and contain more polar compounds that are richer in oxygen and poorer in double bonds due to increased hydroxyl, carbonyl and carboxyl functional groups (Maier 1984). Creation of the more polar functional groups can cause dissolved organics to precipitate and can also produce polyelectrolyte characteristics among the suspended particles that increase enmeshment, adsorption, and cross-linking between the solids--i.e., microflocculation (Maier 1984).

Chang and Singer (1991) reported that the optimum ozone dosage for enhanced flocculation of organic solids was dependent upon the total organic carbon (TOC) levels and, to some extent, the relative ratio of hardness to TOC. Chang and Singer (1991) reported that a ratio of hardness to TOC of 2:5 was adequate to produce flocculation of organic material. Within our research, water hardness and TOC levels where ozone was added were about 250 mg/l and 8 mg/l, respectively, which produced a ratio of hardness to TOC more than adequate to support flocculation.

Ozonation also decreased plugging of the microscreen filter panels, as indicated by an average of 35% (range 21-48%) fewer filter wash cycles required, 53% (range 38-64%) less filter sludge flow produced, and 79% (range 53-1 10%) more settled solids volume in the Triangel™ filter effluents (Table 2). The decreased filter plugging was not due to sterilization of the microscreen filter surface, because no ozone residual reached the microscreen filters. Rather, we can hypothesize that ozone oxidation changed the particle characteristics in a manner that reduced filter plugging. That ozone decreased the TSS in the influents to each culture tank indicates that ozone decreased the amount of solids that typically passed through the microscreen filter (Table 1).

Solids production in our system came from three sources: uneaten feed, feces, and biofloc. The contribution of these as a percentage of daily feed fed were, respectively: $\leq$ 1% (our estimate), about 30% (Westers 1995), and 8-12% (Chen et al. 1991). By removing solids averaging nearly 33% of the total feed fed, ozone-enhanced microscreen filtration removed a large proportion of the net solids produced daily within the recirculating system. Additionally, the Triangel™ filters did not store the solids removed for any appreciable time (36-54 s, based upon the wash frequency), when compared to other solids separation technologies, such as particulate filters, settling basins, and tube or plate settlers. Storing solids within the recirculating system is undesirable because, while solids are present, the opportunity exists for nutrients to leach into the water.

In conclusion, the results indicate that adding ozone to our recirculating system at a rate of 0.025 kg ozone per kilogram feed improved water quality, supported microscreen filtration, and, according to the data in the accompanying paper (Bullock et al. 1996), reduced BGD associated mortalities and chemical treatments required to control BGD epizootics. Adding ozone at a higher rate (0.036-0.039 kg ozone per kilogram feed) produced similar results but was much more likely to produce fish mortality, when on occasion ozone accumulated to toxic levels (Bullock et al. 1996). Because ozonation equipment is expensive, it is rational to add ozone at the lowest effective rate necessary to achieve the desired results. Adding ozone at the lower rate is also justified to reduce potential for fish to be exposed to ozone, particularly when little hydraulic retention time is available between the fish culture tank and the ozone transfer point.

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