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Review

Animal drinking water sanitation with AOP technology

[1]Pramir Maharjan, [2]Sonja Ingmanson and [3]Susan Watkins

[1,3]Department of Poultry Science, Center of Excellence for Poultry Science, University of Arkansas, Fayetteville, AR 72701.
[2]Research and Development, Silver Bullet Water Treatment Company, Denver, CO 80239.

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Providing good quality drinking water free of microbes and contaminants to poultry and other livestock is an essential component of an optimal animal production system. Regular water sanitation helps keep water and water systems in farms clean and microbiologically safe for animal consumption. Treating water with chemicals is a conventional water sanitation method, which at times has limited efficacy due to growing microbial resistance. Besides, treating water with chemicals can be harmful to the environment and involves unnecessary health risks to site personnel. For these reasons, other methods are being studied as alternatives to chemical methods of treating water. Among the possible alternative options being considered, Advanced Oxidation Processes (AOPs) are emerging as a reliable and safe substitute. Most AOPs historically have been highly recognized as efficient at neutralizing contamination, and are considered environmentally friendly sustainable water treatment technologies. The goal of this article is to reflect, through representative research and case studies on AOPs, an important new perspective that AOPs can be considered for an animal drinking water treatment option.

Key words: animal drinking water quality, AOP, water sanitation.

INTRODUCTION

Water is the most important nutrient and is physiologically required by livestock and poultry. The total content of water for both poultry and other livestock averages from 65-70% of their lean body mass (Ellis and Jehl, 1991; USDA Fact Sheet, 2011). Water consumed by animals is generally utilized for nutrient transport, body temperature regulation, joint lubrication and various intra and extracellular biochemical reactions. Certain aspects of water quality such as ambient temperature (Watkins, 2009; May and Lott, 1992; Winchester and Morris, 1956), humidity and air velocity (May et al., 2000; Arias and Madar, 2011), feed intake (Lott, 1991), dietary formulation (Radu et al., 1987; Marks and Pesti, 1984), drinking water aesthetics (May et al., 1997, Feddes et al., 2002; Quichimbo et al., 2013), age and sex (Pesti et al., 1985), and genetics (Deeb and Cahaner, 2001) govern the amount of daily water intake. Besides these factors, other properties of water such as water temperature (Xin et al., 2002, Harris et al. 1975) and levels of minerals and contaminants (Vodela et al., 1997; Damron and Flunker, 1995) also affect the consumption of water and the overall livestock health and performance. High water consumption is correlated with optimal feed to gain ratio (Marks, 1981).

Various factors such as the microbial level, pH, mineral content, hardness, and organic matter load determine the quality of water and each of these should be within an acceptable range to ensure good quality water. Unless drinking water supplied to animals is safe, achieving the growth and feed efficiency potential provided by intensive genetic selection, ideal grow-out environments and optimal nutrition programs becomes a challenge. Many farms do experience poor flock performance or health related issues for no obvious reasons and often the issues are traced to the water supply (Grizzle et al., 1997; Pearson et al., 1993; Gregory et al., 1997; Sparks, 2009).

Corresponding author. E-mail: pmaharja@uark.edu

Therefore, it should be of primary concern for livestock production personnel and poultry producers to know the quality of the water supplies provided to their livestock and confirm if the parameters are within acceptable ranges. Further, water quality from supplies such as wells or reservoirs is frequently changing as often as season to season. Establishing routine testing of supplies and taking corrective action when necessary can have a significant impact on optimizing husbandry practices. Besides the production perspective, providing adequate and good quality water is listed as a basic animal welfare criterion (National Chicken Council, 2010; American Humane Association™ 2012; Department for Environment, Food & Rural Affairs 2012).

Water sanitation and AOP technology

The goal of water sanitation procedures and sanitizer/disinfectant products is to target microbial challenges that exist and thrive in water supplies whether they are bacterial, fungal, viral or protozoal, without creating excessive chemical residuals in the water. Conventional water sanitation procedures for animal drinking purpose include primarily the use of chemicals such as chlorine based products, chlorine dioxide products and hydrogen peroxide based products. These products create very high residuals in water from freshly a prepared stock solution (Maharjan et al., 2015). Consumption of water with high chemical residuals and harmful disinfection byproducts which can occur when chlorine reacts with organic material can have negative impacts on health and productivity (Gopal et al., 2007; Khan et al., 2010; Hulan et al., 1982). On the other hand, residuals start dissipating very quickly and within a day or two, the efficacy is greatly reduced (Maharjan et al., 2015). So, the conventional water sanitation program does not always provide a consistent sanitation practice. Disinfection products are not always used properly and thus, microbes are showing increased acquired resistance (Ridgway et al., 1982; Russell, 1999). Treating water with chemicals can be harmful to the environment and also potentially involves personnel health risks associated with its use. For these reasons, other methods are being studied as alternatives to chemical methods of treating water. Among the possible alternative options being considered, the EPA recognized Advanced Oxidation Processes (AOP) have emerged as a replacement for traditional chemical based water treatment methods (EPA Guidance Manual, 1999).

AOPs Chemistry

The AOP method of water treatment is an aqueous phase oxidation that destroys organic/inorganic pollutants with highly reactive species such as hydroxyl radicals (OH^{-}) (Comninellis et al., 2008). Other oxidizing molecules involved in the AOP can involve superoxide anions $(O_2^{\cdot-})$ and oxygen singlets $(^1O_2)$; the lifetime of which in solution are microseconds while these molecules undergo fast rate reactions with organic/inorganic molecules (Fernández-Castro et al., 2015). Hydroxyl radicals have a strong oxidation potential compared to other oxidants (Techcommentary, 1996; and Carey, 1992) (Table 1). AOPs require relatively less time to treat larger water flow rates, have the potential to detoxify a wide range of organic and inorganic pollutants and pathogens and therefore, have a non-selective oxidative nature (James, 2008). There are various methods that can generate hydroxyl radicals. One example is the Fenton process, where hydroxyl radicals are generated by reacting hydrogen peroxide with ferrous (iron) salts in a lower pH solution (Neyens and Baeyens, 2003).

$H_20_2 + Fe^{++} \rightarrow OH^{\cdot} + OH^{-} + Fe^{+++}$

Other methods of generating hydroxyl radicals through AOP technologies include O_3/H_2O_2, O_3/UV, UV/H_2O_2, TiO_2/UV, H_2O_2/catalyst, photo-Fenton processes and the use of ultrasound (Chin and Berube, 2005; Wang et al., 2000; Toor and Mohseni, 2007; Vilhunen et al., 2010; Gehringer and Eschweiler, 1996; Matilainen and Sillanpaa, 2010).

Water treatment by AOPs can cover a wide range of applications such as effluent treatments in distilleries, various processes in synthetic dye houses (Arslan et al., 1999), pulp and paper industries (Parez et al., 2002); hospitals and pharmaceuticals to treat hazardous effluents (Klavarioti et al., 2009; Lester et al., 2011); slaughterhouses (Luiz et al., 2009; EPA 1999); and in many others (Klavarioti et al., 2009; Lester et al., 2011; EPA 1999. This technology of water treatment has been introduced to treat animal drinking water and has proven to be beneficial and even more successful over conventional methods of water treatment. The supportive results of AOP technology studied for animal drinking water sanitation are discussed in this paper.

AOPs in Poultry and Livestock Drinking Water Sanitation

It is important that growers in poultry operations know the microbial quality of water that is being supplied to birds in their farm. Table 2 gives the acceptable levels of bacteria in colony forming units (cfu) per milliliter (ml) in drinking water for poultry operations (Watkins, 2008; Watkins, 2007).

An acceptable bacteria level at the source does not mean the level present at the end of the drinker line where birds are drinking is also within safe microbial levels. The following field evaluations (Table 3) conducted by the Water Lab, Poultry Science Department, University of Arkansas demonstrate how the microbial levels can significantly change by the time the water supply reaches the end of the drinker system from the source, if the drinker system is not well maintained (Watkins, 2008).

Table 1.

Oxidizing species	Relative oxidation power (mV)
Chlorine	1
Hypochlorous acid	1.1
Permanganate	1.24
Hydrogen peroxide	1.31
Ozone	1.52
Atomic oxygen	1.78
Hydroxyl radical	2.05

Table 2. Drinking Water Quality Standards for Poultry (cfu/ml).

Source	Good	Maximum acceptable	Unacceptable
Main water supply	<100	< 300	> 300
Total aerobic plate counts	0	<1000	>1000
Total coliforms	0	50	>50
Fecal coliforms	0	0	1
E. coli	0	0	1
Pseudomonas	0	0	1

Table 3. Aerobic bacteria levels in water samples (cfu/ml) collected on poultry farms.

Farms	*Sample location	
	Source	End of nipple drinker line
A	2,700	26,600
B	600	282,000
C	0	4,775,000

*distance between the sample locations were ≤ 125 m.

Microbial contamination above the acceptable levels in drinking water directly affects health and performance (King, 1996). Treating water to bring the microbial levels into an acceptable range is important and the AOP method has been found to be an effective option.

A test was conducted at the University of Arkansas by Maharjan et al., 2014, with the objective of determining baseline information on efficacies over time for different sanitizers- chlorine based, and hydrogen peroxide versus AOP technology on microbial sub-optimal quality water (>4 $\log_{10}$ cfu/ml) obtained from a poultry farm. The results showed that the AOP technology had a better and higher bacterial kill in both trials tested (Table: 4 and 5).

In dairy cows, water consumption is directly related to milk production, therefore maintaining water quality is an important aspect of dairy production. A study was conduc-

Table 4. Trial 1: Aerobic Plate Count (APC) before (0 hour) and after (1, 6, 18, and 24 hours) treatment given in $\log_{10}$ cfu/ml. Experiment was conducted in replicates with 1 liter of volume of suboptimal water.

Hours	AOP[1]	HP[2]	Cl[3]
0	4.59^{b}	5.17^{a}	4.53^{b}
1	4.7^{b}	3.49^{c}	4.19^{b}
6	4.53^{b}	4.29^{c}	3.54^{c}
18	1.60^{d}	3.84^{c}	3.52^{c}
24	1.91^{d}	3.77^{c}	3.19^{c}

$^{a,\ b,c,d}$ values with no common superscript in a row and column differ significantly

- AOP[1]: 0.33 liter per minute (LPM) of continuous gas diffusion directly into the suboptimal water to create the test solution.
- HP[2]: Hydrogen Peroxide based product (50 % stabilized hydrogen peroxide concentration): Stock solution was prepared **b**y mixing 4ml of the product with 128 ml deionized water. 1ml of the stock was then added to 128ml of suboptimal water to create the test solution.
- Cl[3]: Chlorine based product-(8.25% sodium hypochlorite): Stock solution was made by mixing 4ml of the product with 128 ml deionized water. 1ml of the stock was then added to 128ml of suboptimal water to create the test solution.

Table 5. Trial 2. Aerobic Plate Count (APC) before (0 hour) and after (1, 6, 18, and 24 hours) treatment given in $\log_{10}$ cfu/ml.

Hours	AOP[1]	HP[2]	Cl[3]	Control
0	4.71^{a}	4.7^{a}	4.81^{a}	4.52^{a}
1	2.11^{b}	2.93^{b}	2.69^{b}	4.26^{a}
6	1.33^{d}	2.66^{c}	2.14^{c}	4.23^{a}
12	1.19^{d}	2.61^{c}	1.68^{d}	4.1^{a}
24	0.66^{ef}	2.52^{c}	1.49^{d}	4.16^{ba}

$^{a,\ b,c,d,e,f}$ values with no common superscript in a row and column differ significantly.

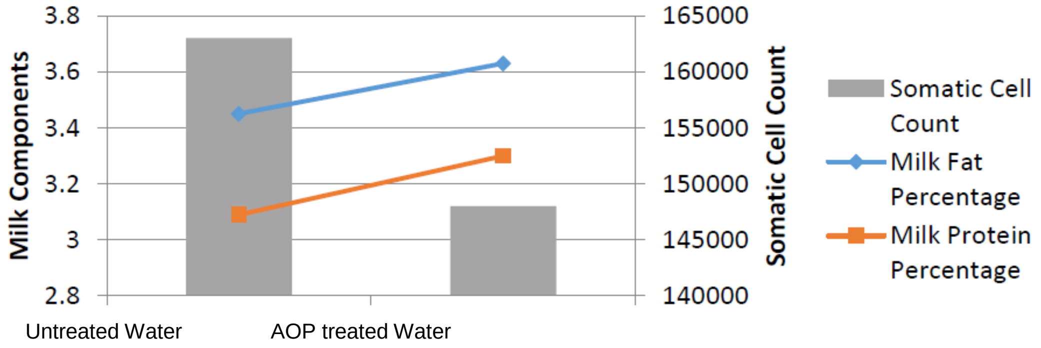
- AOP[1]: 0.33 liter per minute (LPM) of continuous gas diffusion directly into the suboptimal water to create the test solution.
- HP[2]: Hydrogen Peroxide based product (50 % stabilized hydrogen peroxide concentration): Stock solution was prepared **b**y mixing 4ml of the product with 128 ml deionized water. 1ml of the stock was then added to 128ml of suboptimal water to create the test solution.
- Cl[3]: Chlorine based product-(8.25% sodium hypochlorite): Stock solution was made by mixing 4ml of the product with 128 ml deionized water. 1ml of the stock was then added to 128ml of suboptimal water to create the test solution.

ted by Wailes and Dib, 2012, to review the impact of water quality on milk production in high producing dairy cows where AOP technology was involved to treat water. Four dairy farms with 5650 primiparous/multiparous cows (181 average lactation length) were examined over a 9 week period, with 2 weeks of prior adaptation. It was found that cows consuming AOP treated water had better milk parameters than those which were given untreated water (Graph 1). Further, AOP treated water was overall low in microbial populations at the cow's drinking water troughs at each farm during the study (Graph 2).

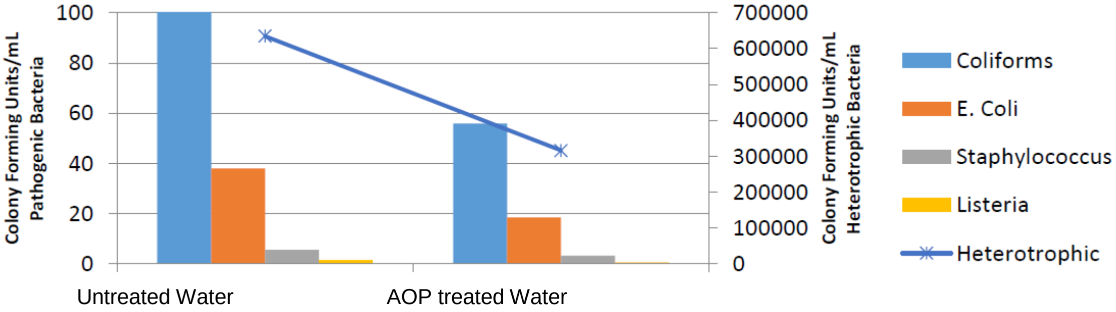
Other studies conducted by various universities in the US on AOPs also demonstrated that this technology can be applicable in improving the drinking water quality for animals. A 110- day case study was conducted by Texas Panhandle Grow yard, (2012), with 310 calves randomly split into two groups of 155 to investigate the performance differences between AOP treated water and untreated water. The first group was the control group which drank untreated water, whereas the other group drank AOP treated water; both groups were reared in identical husbandry practices. The study showed significantly better daily weight gains, and feed conversion and less mortality with the group which received AOP treated water. Similarly, Linden et al., 2014 tested an AOP technology for microbial water sanitation. Their results showed that the infusion of AOP gas at 2 Liter Per Minute (LPM) resulted in more than 1.2 to 2.5 $\log_{10}$ inactivation of *E. coli* contaminated water within 5 minutes of contact .

The H_2O_2/UV AOP is effective as a preventive treatment against *Pseudomonas aeruginosa,* PAO1 biofilm-forming

Graph 1.



Graph 2.



bacteria, in the presence of varying levels of natural organic matter (Lakretz et al., 2011). Many studies have shown that various forms of AOPs can be applied to remove organic matter present in water (Matilainen and Sillanpaa, 2010; Oturan et al., 2000; Pignatello et al., 2006; Li et al., 2010).

AOPs have been documented to solve mineral issues in water and water systems. Iron issues in water have been reported from many farms, especially those that use underground water. A higher level of dissolved iron in water is associated with bad odor and taste, and thus water consumption by animals can be greatly impacted (Genther and Beede, 2013). Dissolved iron in water promotes bacterial growth (Lankford, 1973; Church et al., 2000). Iron levels in water for poultry above 0.03 ppm can be problematic to poultry performance (The Poultry Site, 2012). AOP technology has been successfully proven to oxidize dissolved iron present in ground water (Ijepellar et al., 2002) so that it can be removed with filtration. AOPs can also oxidize out dissolved manganese in water (Jeirani, et al., 2015), of which its higher concentration can bring neurological health impacts (Kondakis, 1989). Elevated levels of arsenic in drinking water is harmful to both livestock and humans and is a chronic issue in different parts of the world such as Bangladesh, India (BGS, 1999; Mazumder et al., 1998) and the US (Nordstrom, 2002). The AOP method for water treatment can be successfully applied to reduce arsenic level in water (Zaw and Emett, 2002; Sorlini et al., 2010).

Anaerobic microorganisms in surface water or the presence of sulfates in the ground can eventually contaminate water resulting in production of hydrogen sulfide. Hydrogen sulfide can cause serious odor and corrosion problems in water distribution systems and may be associated with a bitter taste that could potentially discourage animals from consuming adequate amounts of water. AOPs have been described to remove taste and odors resulting from various types of sulfide pollutants (Antonopoulou et al., 2014).

SUMMARY AND CONCLUSIONS

The AOP method of water treatment is EPA recognized and is an environmentally friendly option over conventional chemical methods of water sanitation. This technology of water treatment is proven to be beneficial in various fields, including drinking water sanitation for livestock and poultry as demonstrated by numerous studies. The substantially strong oxidizing nature of hydroxyl radicals along with other excited oxygen species produced during electron chain reactions in AOP mechanisms makes this method of disinfection a reliable tool to effectively decontaminate microbes, organic and inorganic pollution in water. Added benefits of this technology include helping to remove and prevent scale, controlling mineral problems, and dealing with taste and odor related issues in water.

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