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Odor Reduction and Disinfection Performance of MIOX Mixed Oxidant Solution (MOS) in Poultry Processing

Plant Trial Comparison of Bleach vs. MOS for Odor Reduction and Salmonella Inactivation:
Exploring the Limits and Possibilities

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Background

Disinfection within poultry processing operations requires constant monitoring to ensure that bacteria counts for Salmonella and other organisms of concern remain below the regulatory threshold. Another operational concern is to ensure that chlorinous odors associated with the reaction of chlorine with organic materials from the birds is properly controlled and managed. To ensure both of these operational concerns are addressed, the US Food Safety and Inspection Service (FSIS) has established guidelines and regulations for the use of chlorine in poultry processing plants. These include a 50 mg/L Free Available Chlorine (FAC) limit, likely established to control odors and specific microbiological count thresholds. If a cage of birds exceeds the microbiological threshold count, they may not be packaged for sale. One possible mechanism to reduce microbiological counts is to increase the chlorine concentration. In many cases this process change works well. In others, chlorine is not sufficient to both reduce microbiological counts AND minimize odors.

Field studies replacing chlorine with on-site generated mixed oxidant solution (MOS) has consistently led to 1) decreases in offensive odors during plant operations, 2) large decreases in (or complete elimination of) *E. coli* and Salmonella detections on processed birds in both laboratoryⁱ and field studies,ⁱⁱ or 3) both reduced chlorinous odors and increased disinfection efficacy.

While MOS performs better than bleach for both disinfection and odor control, there are specific examples where MOS used at the regulated 50 mg/L FAC kept odors low, but Salmonella detection on finished birds was close to the HACCP limit of 20% positives. However, if bleach or chlorine gas were used, the Salmonella detection was typically above 20% positive, with odors developing within 10-20 minutes.

These third party observations indicated that odors and Salmonella could be controlled if FAC as MOS in the in-plant water were increased to 80 mg/L. This case study assesses whether an increased FAC as MOS concentration in the in-plant water to 80 mg/L would 1) bring Salmonella counts below the limit and 2) cause the offensive chlorinous odors associated with chlorine (as bleach) at 50 mg/L. The results indicate that MOS provides additional efficacy and odor control compared to hypochlorite.

Challenge/Opportunity

At a small poultry processing plant in the U.S., Salmonella counts were out of compliance using chlorine; approximately 50% of the birds were failing inspection with 50 mg/L FAC in the in-plant water. Additionally, chlorinous odors developed at 50 mg/L FAC. The plant operators could not increase the chlorine concentration because they had reached the maximum allowable make-up water concentration of 50 mg/L measured as Free Available Chlorine (FAC) in the pre-chiller and chiller makeup water.

In a series of trials where bleach and OSG MOS were alternated, a third party poultry equipment supplier noted that no chlorinous odors developed in the plant when MOS was used. By contrast, chlorinous odors would develop within 10-20 minutes whenever bleach was used. The in-plant waters

were maintained at the same FAC concentration of 50 mg/L per FSIS regulations. While these results prevented the plant from having to implement additional disinfection regimens, the results for microbiological inactivation began to change. This is not uncommon in dynamic plant operations where birds come from different places and other variables can affect the process chemistry and disinfection. In this case, Salmonella detection on finished birds was often close to the HACCP limit of 20% positives in in-plant plating testing using MOS and usually over 20% using bleach. Yet, the odors with MOS were negligible, indicating that a higher FAC as MOS concentration in in-plant water would minimize Salmonella counts while also controlling offensive odors associated with bleach disinfection.

As a result, MIOX Corporation worked with poultry process consultants and Professor Scott Russell in the Department of Poultry Science at the University of Georgia to evaluate the ability of MOS to disinfect and oxidize organic materials in poultry processing waters at FAC concentrations above 50 mg/L. This report documents a pilot study performed at a poultry processing plant in the United States which compares bleach at 50 mg/L and MOS at 78 mg/L in in-plant water for both odor control and disinfection efficacy. All piloting was performed by a third party contractor in compliance with all U.S. federal regulations.

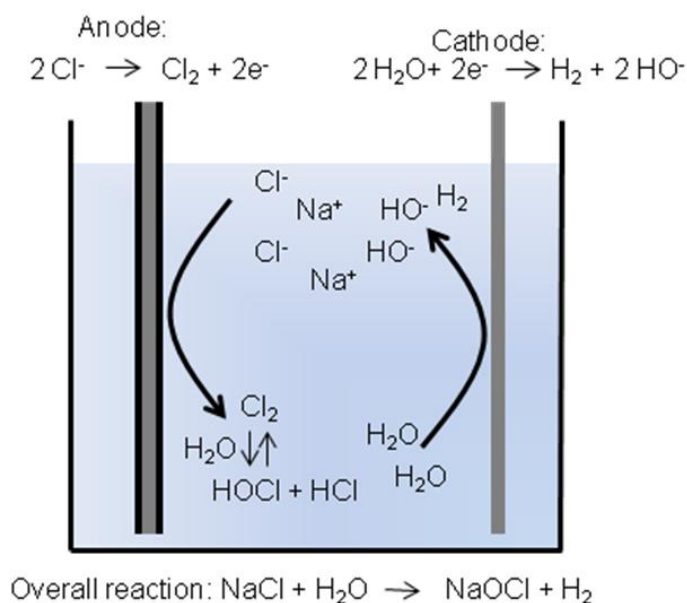
Introduction

Poultry processing operations are regulated by the Food Safety and Inspection Service (FSIS) and operators must follow specific guidelines for the use of disinfectants to protect both the product and the workers at the plant. During poultry processing, water is an excellent media to wash and disinfect poultry carcasses. Initial water and make-up water is used to fill or supplement tanks, respectively, at various points along the poultry processing line. FAC is commonly used to provide disinfection for poultry, and can be provided as chlorine gas, concentrated bulk hypochlorite (bleach), solid calcium hypochlorite or as on-site generated hypochlorite, or OSG.

On-Site Generation: the MIOX System

The MIOX MOS is generated electrolytically from dilute (~15 g/L) sodium chloride (NaCl) brine on-site as needed. Compared to other disinfection options, OSG is safer and no hazardous materials are used or produced. During on-site generation (OSG) of hypochlorite, a voltage is applied across an electrolytic cell, thus converting the chloride from salt water into chlorine gas which immediately forms hypochlorite in solution. The schematic illustrates the electrolytic process.

By tuning the energy input and engineering the system, other oxidants may be formed that have demonstrable efficacy benefits compared to hypochlorite. However from a regulatory and process chemistry monitoring perspective, the measurable component is



the FAC. FAC is measured routinely in testing and field application using the DPD colorimetric field test kits which conform to standardized methodsⁱⁱⁱ.

Although FAC measurement is often all that is required in field applications, Total Chlorine (TC) measurements coupled with FAC measurements can help process chemists better understand where sources of chlorinous odors arise within the process. Chlorinous odors are due, primarily, to volatile di- and trichloramines (NHCl_2 and NCl_3 , respectively) formed by the reaction of FAC with ammonia ($\text{NH}_3\text{-N}$ and/or $\text{NH}_4^+\text{-N}$). The FAC in the in-plant water that is not consumed as oxidant demand is largely converted to inorganic ($\text{NH}_3\text{-N}$) and organic chloramines (aka “combined chlorine”). The sum of the FAC and combined chlorine is referred to and measured as Total Chlorine (TC). In practice, the concentrations of ammonia and organic nitrogen-containing compounds in poultry process waters, especially the chillers, are so high that the FAC in the in-plant water is rapidly consumed as oxidant demand and converted to chloramines and organic chloramines. Thus, even though the in-plant water is continually being “dosed” at an FAC concentration of ~50 mg/L, the actual FAC concentrations in the chillers is typically <2 mg/l. And TC measurements can be ~50 mg/L.

However, substantial disinfection and oxidation evidence indicates that MOS contains oxidants other than FAC alone such that the chemical and biocidal behavior of MOS is substantially different from that of a solution containing only chlorine.^{iv,v} Numerous inactivation studies demonstrate the increased efficacy of MOS compared to equal concentrations of bleach.^{vi}

MOS Benefits in Poultry Processing

Microbiological: Laboratory studies comparing the inactivation efficacy of hypochlorite and MOS at equal concentration and times show increased efficacy with MOS.ⁱ In these studies, four problem bacteria in the food processing industry, *Salmonella typhimurium*, *Staphylococcus aureus*, *Listeria monocytogenes*, and *Escherichia coli* were evaluated in Professor Russell’s laboratory. Russell wrote that the “MIOX [mixed-oxidant solution] was superior in terms of eliminating the four types of bacteria evaluated when compared to bleach at equivalent concentrations of free available chlorine”. A non-parametric evaluation (W.L. Bradford, 4 June 2001, unpublished) of Dr. Russell’s data from 269 paired comparisons of inactivation using bleach and MOS as the sources of disinfectant indicates that the MOS was more effective than bleach by the following factors: *S. typhimurium* – 2.3; *St. aureus* – 2.5; *L. monocytogenes* – 12.0; *E. coli* – 5.0.

Studies by Waldroup^{vii} showed increased efficacy by MOS in poultry processing lines. Subsequent studies (unpublished) by Waldroup have shown that the shelf-life of MOS-treated chickens is increased by at least 3 days (or 33% longer) over that of chlorine-treated chickens using the same FAC concentrations in the processing line.

Odor reduction: When replacing bleach as the disinfection treatment in swimming pools, users report that MOS tends to reduce the intensity of chlorinous odors in the air space above the pool. The evidence manifests in the reduction, and in some cases elimination, of complaints of odors and burning eyes by swimmers and day-long occupants of the pools, such as teachers and lifeguards.^{viii} Measurements of chlorine in the air have shown that the air spaces above MOS-treated pools contain 1/3rd to 1/4th the chlorine concentrations as were in those same pools when being treated with bleach. These observations and measurements suggested that MOS performs the breakpoint reaction faster than hypochlorite. A thorough analysis of water samples collected at selected pools further reinforced this hypothesis.^{ix} The faster breakpoint chemistry leads to reduced odors in aquatic facilities and other



indoor facilities, so it seemed likely that the same results would also be seen in poultry processing plants, where exposure to volatile chloramines can be harmful to human health.

Trial Objectives and Results

Investigators testing MOS in poultry processing operations have remarked that the concentrations of Total Chlorine in chillers could be raised considerably above 50 mg/L without chlorinous odors becoming noticeable. Thus, by having at least 70 mg/L FAC as MOS in the in-plant water, the birds were expected to pass microbiological testing while reducing odors in the plant.

The objective of the trial was to demonstrate the effectiveness of MOS at up to 100 mg/L FAC in in-plant water used for all processing operations to: (1) remove fecal material and disinfect poultry carcasses; while (2) not producing chlorinous odors in the workplace air to an extent deemed uncomfortable or unsafe for workers and inspectors. The effectiveness of this treatment was evaluated during processing by 1) monitoring the pathogenic and indicator bacteria, Salmonella, and 2) qualitatively assessing the presence/absence of odors using worker and inspector responses after the change from bleach to MOS.

Because the objective of the trial was to demonstrate the effectiveness of MOS as a direct replacement for bleach, the trial was conducted in a smaller poultry processing plant that relies almost exclusively on bleach as the source of chlorine in processing waters (washing and chilling) used after the transfer from the picker to the venter operations.

A trial consisted of one 8-hour shift of workers in normal processing operations. Trials were coordinated with worker shifts so that a relevant olfactory baseline was collected and changes monitored during normal processing. Evaluation of any difference in the levels of chlorinous odors between the controls and the trial were based on comments and/or complaints by workers and inspectors. Because the assessment of chlorinous odors involved using workers without formal training in this science, they were not informed of the experiment. This prevented any biased perception in the differences by avoiding heightened worker awareness to a potential change. Further, these workers had a track record of lodging complaints if the odors became too great. Thus, if complaints were lodged, the trial would have been considered unsuccessful. Plans to lower the FAC concentration in the in-plant water or abort the experiment were not implemented because no odor complaints were lodged during the trial.

Microbiological controls included baseline counts of Salmonella on finished birds exiting the main chiller in the shift before the trial and in the shift after the trial. These baseline data were collected when in-plant water was being disinfected with hypochlorite at 50 mg/L FAC. The trial collected the Salmonella hits from birds processing with plant water containing 80 – 100 mg/L FAC as MOS. In all cases, the finished birds were sampled at the same exit from the main chiller and at the same rate as that used to establish the controls.

The plant where the trial took place donated one cage of birds (240) for the test. In the shift just prior to the test using birds from the same source lot, Salmonella occurrences on birds out of the main chiller (before a subsequent wash) were running ~ 50%. At the end of the shift prior to the test, the FAC of the in-plant water was increased to 78 mg/L using MOS, the pre-chiller was changed fully with this water, and the main chiller was purged for 20 minutes with this water as makeup to achieve a FAC of 27 mg/L.



Over a 4-hour shift, the cage of birds (240) was processed. All 240 birds were sampled at exit from the main chiller (before a final rinse) and tested for Salmonella by in-house plating (with follow-on confirmation of suspected positives by an outside laboratory). The entire cage of birds was condemned since the process chemistry change during the trial required disposal of the birds regardless of case study outcome. For a more detailed description of the Methods and Procedures, see Appendix A.

Results of MOS in Poultry Processing Plant Trial

- Salmonella positives – only **2+ suspected of 240 total birds sampled**, significantly below the 48 birds that would be an acceptable limit per the regulations;
- Chlorinous odors – **no change in the odor level in the plant at 78 mg/L FAC as MOS** (the odor level had been minimal in the previous shift with in-plant water at 50 mg/L FAC as MOS, and no workers or inspectors commented on any odors during the test. These workers included a new shift that would have been expected to have heightened olfactory senses by virtue of the fact that they had not been exposed to chemicals that may have desensitized their ability to notice chlorinous odors.
- Adverse effects on finished bird carcasses – **no adverse effects** such as graying of the skins were noted.

The microbial results were negative, in that there were only two possible Salmonella counts of all 240 birds tested. This is far below the regulatory threshold of <20% positives. In fact, the greatest percentage is <0.01% with MOS at the 78 mg/L level. While bleach was not tested at 78 mg/L, the results are outstanding, especially in light of the absence of odors at the higher FAC concentration used.

Conclusions

MOS is more effective than hypochlorite at 50 mg/L FAC in the in-plant water. Further, when the FAC as MOS is increased to 78 mg/L, microbiological efficacy increases and odors are minimized. Salmonella counts were far below the compliance levels required in the U.S. and odors were not noticeable at this level of MOS. In contrast, using bleach as the source of disinfecting chlorine, when concentrations of FAC in the in-plant waters rise above 50 mg/L, odors persist. While the microbial efficacy of bleach at 78 mg/L was not tested in this particular trial, laboratory data wherein MOS and bleach were used in equal concentrations and times show that MOS is better at inactivating Salmonella than bleach alone.

The pilot successfully demonstrates that MOS effectively solved both the odor and inactivation goals at the case study plant at 78 mg/L FAC in the in-plant water whereas chlorine as bleach cannot. On-site generated MOS could offer superior results in poultry chiller water and processing applications compared to chlorine. The next step in cases where a higher concentration of MOS as FAC is required includes working with inspectors and regulators to design detailed studies that would conclusively demonstrate MOS efficacy compared to bleach.



APPENDIX A:

METHODOLOGY AND PROCEDURES

- The in-plant water (containing 80 – 100 mg/L FAC as MOS) was used solely as processing waters (washing and chilling) after the transfer from the picker to the venter operations.
- A trial consisted of up to one 8-hour shift of workers in normal processing. If excessive odors occurred during the trial, the FAC of the in-plant water would be lowered in stages until the odors disappeared or, in the worst case, the trial would have been discontinued.
- To establish evaluation control on each trial, baseline counts of Salmonella on finished birds exiting the main chiller (at 50 mg/L FAC as bleach in in-plant water) were determined on the shift preceding the trial and on the shift following the trial. The number of finished birds sampled was sufficient to establish statistical confidence in the baseline counts and in the trial counts.
- In preparation for the full-up shift in which the trial occurred, the concentration of the FAC in the water used to fill the pre-chiller, chiller, and red water system, as well as makeup water and in-plant water used for washing operations was increased to 80 – 100 mg/L FAC as MOS.
- All shifts were conducted normally without notice of the change in the increase in FAC concentration or the source of disinfectant given to workers or inspectors.
- Finished birds were sampled at the same location (exit of the main chiller) and at the same rate in the trial as that used to establish controls.
- At conclusion of the trial shift and in preparation for the next shift, the concentration of FAC in the water used to fill the pre-chiller, chiller, and red water system, as well as makeup water and in-plant water used for washing operations was returned to 50 mg/L FAC as bleach.

Procedures for Sampling and Analysis of Finished Birds – Controls and Tests

- All control and test samples were taken from the exit end of the main chiller.
- Each sample bird was placed aseptically into a sterile collection bag and then vigorously rinsed with 400 mL of 0.1% sterile buffered peptone water; 100 mL of the rinsate was aseptically transferred into a sterile 100 mL container, sealed, labeled as “control” or “test”, and shipped, chilled, to a certified third party research laboratory for determination of presence/absence of Salmonella (The Whole Carcass Rinse Procedure currently used by the USDA for in-plant testing).^x
- A separate aliquot of the rinsate was taken for in-plant plating to obtain an early indication of presence/absence of Salmonella.

Olfactory Evidence from Workers Complaints or Remarks during the Workday

- Worker and inspector remarks and/or complaints of odors or burning eyes were noted and used to evaluate any change in the level of chlorinous odors between the controls and the trial.



- If chlorinous odors developed in the workplace air to an extent deemed uncomfortable or unsafe for workers and inspectors, the FAC of the in-plant water would have been lowered in stages until the odors disappeared or, in the worst case, the trial would have been discontinued.
- One of the unique features of creating MOS is that it is made on-site without adding any toxic chemicals. Only food grade salt solution at approximately 15 g/L NaCl (~ 5 % of saturation) is used as an electrolyte in the electrolysis process. During the electrolysis process, small amounts of chlorine gases off. These are easily vented to the open atmosphere outside the processing area. The MOS was generated and the in-plant water produced in a room where the venting can be accomplished without risk to the operators, the workers or the environment.
- All products treated with the MOS and in-plant water made with MOS were not artificially inoculated or contaminated with additional pathogens.
- Measurement procedures were applied to the test target carcasses in the same manner as the control and under actual live plant conditions.
- The host processing plant had previously installed all necessary equipment, spray cabinet's inline or post chiller tank at its own expense. No disruption of the normal day to day process or inspection occurred. The MOS and in-plant water made with MOS were prepared in a separate holding room and piped to the existing feed lines and applied with plant-provided spray cabinets and chillers.

ⁱ Russell, S.M., 2001, "A Comparison of MIOX versus Bleach for Eliminating Pathogenic Bacteria Associated with Poultry Products", Department of Poultry Science, University of Georgia, Athens, June 1, 2001.

ⁱⁱ Nolen, G.M., 1999, "Use of MIOX Onsite Disinfect (sic) Generators in Food Processing Industries", a presentation summarizing results of numerous studies, received November 4, 1999.

ⁱⁱⁱ American Public Health Association, American Water Works Association, and Water Environment Federation, 1992, *Standard Methods for the Examination of Water and Wastewater*, 18th Edition, and 20th Edition, 1998, APHA, Washington, DC.

^{iv} Venczel, L.V., 1997, "Evaluation and Application of a Mixed Oxidant Disinfection System for Waterborne Disease Prevention", Ph.D. Dissertation, Department of Environmental Sciences and Engineering, University of North Carolina, Chapel Hill, NC.

^v Venczel, L.V., C.A. Likirdopulos, C.E. Robinson, and M.D. Sobsey, 2004, "Inactivation of Enteric Microbes in Water by Electro-Chemical Oxidant from Brine (NaCl) and Free Chlorine", *Wat. Sci. Technol.*, 50(1):141-146.

^{vi} Casteel, M.J. M.D. Sobsey, and M.J. Arrowood, 1999, "Inactivation of *Cryptosporidium parvum* Oocysts in Water and Wastewater by Electrochemically Generated Mixed Oxidants", presented at the International Conference on Minimizing the Risk from *Cryptosporidium* and Other Waterborne Particles, Paris, France, April 19-23, 1999, International Association on Water Quality, International Water Services Association, and the International Ozone Association. Published at *Wat. Sci. Technol.*, 41(7):127-134, 2000.

^{vii} Waldroup, Amy, 1997, "Results of Initial Laboratory Studies Comparing MIOX Mixed-Oxidant Solution with Hypochlorite in Disinfection of a Poultry Processing Line", presented at Poultry Industry Conference, University of Arkansas, Fayetteville, January 27, 1997.

^{viii} Bradford, W.L., 2000, "Some Benefits of the Use of Mixed Oxidants in Swimming Pools: Speculation on Chemical Mechanisms for Lack of Swimmer's Complaints Using Mixed-Oxidant Solution", Los Alamos Technical Associates, Inc., Los Alamos, NM, 23 May 2000; updated 2 January 2004.

^{ix} Bradford, W.L. and R. Dempsey, 2005, "Observations on the Use of Mixed Oxidant in Swimming Pools: Mechanisms for Lack of Swimmer's Complaints in the Presence of a Persistent Combined Chlorine Measurement", Los Alamos Technical Associates, Inc., Los Alamos, NM, and Simply Water, LLC, Houston, TX, 17 June 2005.

^x United States Department of Agriculture. FSIS volume 61, #141, 38914-38940.

