Chemical Analyses of Commercial Shell Egg Wash Water

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Primary Audience: Egg Processing Plant Managers, Sanitation Supervisors, Researchers

SUMMARY

Wash water was collected from the first (W1) and second (W2) egg washers in series in 3 different commercial facilities (plants X, Y, and Z) and evaluated for temperature, pH, chlorine, soluble iron (ferrous), total dissolved solids (TDS), total suspended solids (TSS), total Kjeldahl nitrogen (TKN), and chemical oxygen demand (COD). Temperature of W1 and W2 ranged from 39.7 to 44.1°C and was generally consistent within plants Y and Z. The pH of W1 and W2 varied from 10.0 to 11.4. Chlorine levels in wash water differed by 3- (W2) and 5-fold (W1) between the facilities. Average values of soluble iron W1 and W2 ranged from 0.3 to 1.6 mg/L. Highest values for TDS and TSS occurred in W1 (8,231 and 796 mg/L, respectively) as compared with W2 (3,564 and 429 mg/L, respectively). The TKN values for the wash water ranged from 81 to 302 mg/L, whereas COD values ranged from 1,765 to 7,300 mg/L. Data provided by the present study may be useful for identifying process deficiencies and minimizing organic and inorganic discharge loads in the waste stream.

Key words: shell egg, egg washing, egg-processing wastewater

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DESCRIPTION OF PROBLEM

In 2004, the United States produced approximately 76 billion shell eggs from 287 million laying hens [1]. Virtually all of these eggs were washed to improve the aesthetic appearance by removing adhering feces, dirt, litter, feathers, and other debris from the shells' surface [2, 3, 4, 5]. Comprehensive reviews of the egg-washing process have been provided by Moats [2] and Hutchinson et al. [5], with particular emphasis on the eggshell bacterial levels after washing. The microbiological aspects of commercial shell egg washing have also been addressed in several other publications [6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16].

Commercial washing of shell eggs is typically performed in a mechanical washer in which a series of spray nozzles mist an alkaline detergent over the eggs as flat brushes move side to side across the shells' surfaces [2, 4, 5, 11, 17]. After washing, eggs are sprayed with a final rinse containing an approved sanitizing chemical that is typically a chlorine-based compound [4, 5, 11, 17]. Overflow egg wash water (EWW) and rinse water are combined, filtered through a large mesh screen, collected in the wash tank (recirculation tank), reheated and recycled in the washer [5, 17]. The USDA regulations for facilities with voluntary egg grading require the continuous addition of replacement water in the washer tank, and this

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typically comes from the overflow of final rinse solution [18]. The USDA regulations also require facilities to empty the washer tanks and refill them with potable water after approximately 4 h of operation [18]. During this 4-h time period, there is a build-up of organic material in the EWW that is eventually discharged to the septic tanks or a municipal sewer system.

Pollard [17] reported that 75% of the shell egg processing facilities in the United States use 4.4 gal/min (16.6 L/min) of fresh water during washing, which equates to over 2,100 gal of water each day (8-h d). In their survey of commercial shell egg processing facilities, Jones and Northcutt [19] found that the average water usage during processing was 2.8 gal per case (360 eggs) of eggs (10.6 L/case). Other reports have estimated that the commercial egg industry generates 2.5 billion gal (9.46 billion L) of wastewater each year from routine egg processing and sanitation [20, 21]. Discrepancy in the reported values for water usage during egg processing are related to the point of measure, which may be fresh water [17], total processing water [19], or processing and sanitation water [20, 21].

A few instances occurred in which egg processing establishments were forced to stop operating because of failure to meet the wastewater discharge requirements established by the city in which they operated [22, 23]. Wastewater discharge requirements vary from city to city and state to state; however, most municipalities require that the wastewater not exceed the organic load of domestic sewage (250 mg/L biological oxygen demand; 200 mg/L total suspended solids (TSS); 100 mg/L fat, oil, and grease; pH 5 to 10) [22].

The USDA Food Safety Inspection Service has indicated that they are on the verge of requiring shell egg processing facilities to develop and implement food safety plans that include the concepts outlined in the Hazard Analysis and Critical Control Point (HACCP) System [24, 25]. The Food Safety Inspection Service Egg Safety Action Plan indicates that implementation of a HACCP-based system for shell egg processing and the prerequisite programs (sanitation standard operating procedures and good manufacturing practices) will be required to assist in reducing the number of *Salmonella enteritidis*-containing eggs marketed to the consumer. In the broiler industry, HACCP implementation resulted in a significant increase in water usage during processing. Some broiler facilities temporarily doubled and tripled their water usage after HACCP implementation [26, 27, 28]. Based on this information, it is reasonable to believe that the commercial egg industry will also experience an increase in water usage after HACCP or a comparable program is implemented. Characterization of EWW from commercial shell egg processing facilities could be valuable for identifying water conservation and recycling programs and for establishing the pre-HACCP discharge loads. The present study was conducted to evaluate the chemical composition of EWW from commercial shell egg processing facilities.

MATERIALS AND METHODS

Sample Collection

The EWW was collected and evaluated from 3 commercial inline shell egg processing facilities located in the southeast. In an inline shell egg processing facility, eggs are transported to the processing facility via a series of conveyor belts that connect the hen houses directly to the processing facility. Facilities evaluated during this field report were designated as plant X, Y, and Z. Water was sampled from each facility during 3 different visits (replications), and the facilities were visited every 2 wk on a rotational basis (plant X, plant Y, plant Z, plant X, plant Y, plant Z, and so on.). The average processing capacity of each facility was as follows: 373 cases (360 eggs/case) per hour for plant X; 265 cases per hour for plant Y; and 292 cases per hour for plant Z.

During each visit, water was sampled from 3 different sources: tap water (fresh incoming water), washer 1 (W1), and washer 2 (W2). In the facilities, W1 and W2 were end-to-end in series on the processing line (dual washer system). The W1 and W2 samples were collected after the facilities had been operating for 2 h on each sampling day, and in all cases, this was the first 2 h of operation on each sampling day. The W1 and W2 samples were collected from the wastewater stream as the water exited the upper chamber of the washer and before the water passed through the screen and entered the recirculation tank.

Sample Analyses

Water samples were evaluated for temperature, pH, chlorine, soluble iron (ferrous), total dissolved solids (TDS), TSS, total Kjeldahl nitrogen (TKN), and chemical oxygen demand (COD) to provide information about processing efficiency. Water temperature and pH were measured by holding a handheld probe directly into the wash water stream as the water exited the washer [29]. Total chlorine was determined on every sample using a colorimetric reaction with N, N-diethyl-*p*-phenylenediamine (DPD) as recommended by the American Public Health Association [30]. Because DPD is pH sensitive, the pH of W1 and W2 water samples was adjusted to approximately 7.0 using 3 *N* nitric acid. These samples were then filtered through glass fiber filters, and DPD was introduced using self-filling vacu-vials [31]. After 1 min, the vials were inserted into a handheld spectrophotometer, and total chlorine was measured as milligrams per liter [32]. Approximately 100 mL of tap water, W1, and W2 was collected for soluble iron analyses. These samples were placed in amber bottles containing 0.5 to 3 mL of 6 *N* redistilled nitric acid as recommended by the APHA and transported in a cooler with ice [30]. The pH of these solutions was tested to ensure that it was below pH 2.0 for stability during transportation. Soluble iron was determined by the inductively coupled plasma method as outlined by the American Public Health Association [30], and the values were reported as milligrams per liter. The TSS was determined by filtering 200 mL of W1 or W2 through glass fiber filters. The filters were then dried at 220°F (104°C) for 1 h, allowed to cool over night, and then weighed to yield a residue that was reported as milligrams per liter of TSS [30]. The TDS was determined using the portion of water that passed through the glass fiber filters. These solutions were then dried at 356°F (180°C) using 1-h cycles until a constant, cool weight was obtained. The TDS was also reported as milligrams per liter. The TKN was determined using the micro-Kjeldahl method with 1 modification [30]. Prior to digestion, all of the water samples were distilled to evolve nitrogen gas from the detergent and sanitizing chemicals and urine and fecal material in the water. The TKN was reported as milligrams per liter. For the COD determinations, W1 and W2 samples were diluted 1:10 with deionized water, acidified with concentrated sulphuric acid (1 mL added to 9-mL sample), and filtered through carbon filters to remove chloride and chlorine [33]. Samples were then mixed with acidified trivalent manganese and digested for 1 h [33]. After cooling for 30 min, COD in milligrams per liter was determined using a handheld HACH DR 870 colorimeter [33].

Statistical Analyses

Data were analyzed by the ANOVA option of the general linear model procedure of SAS using plant (X, Y, Z), sample (tap water, W1, W2), and replication as the main effects [34]. All first-order interactions were tested for statistical significance ($P < 0.05$), using the residual error mean squares. Data were pooled for all 3 replications and analyzed again after replication, and the associated replication-interactions were found to be nonsignificant ($P > 0.05$). Means were separated using the least squares means option of SAS and reported along with the standard error [34].

RESULTS AND DISCUSSION

Table 1 shows the temperature and pH of the EWW samples at the time of collection. Incoming tap water had a temperature range of 21.9 to 26.4°C and a pH range of 6.1 to 6.7. The EWW temperature ranged from 39.7 to 44.1°C and was consistent for W1 and W2 in plants Y and Z. In plant X, the average EWW temperature in W1 was approximately 4°C lower than the temperature of the EWW in W2. When the pH of the EWW was measured, both W1 and W2 in plant Z were found to have the highest pH values (pH 11.4 and 11.2, respectively). The pH of the EWW from plants X and Y ranged from 10.0 to 10.6, and these values are comparable to those previously reported by Bartlett et al. [4] and Kinner and Moats [11]. Bartlett et al. [4] evaluated 101 EWW samples

TABLE 1. Temperature and pH values of egg wash water collected from plants X, Y, and Z[1,2]

	Temperature (°C)		pH	
Plant	W1	W2	W1	W2
X	39.7 ± 0.3[c]	43.9 ± 0.8[a]	10.6 ± 0.2[bc]	10.0 ± 0.6[c]
Y	44.1 ± 0.1[a]	43.1 ± 1.0[ab]	10.3 ± 0.3[c]	10.3 ± 0.1[c]
Z	41.5 ± 0.4[bc]	43.3 ± 0.3[ab]	11.4 ± 0.03[a]	11.2 ± 0.2[ab]

[a–c]Means ± standard error in the same heading (temperature or pH) with no common superscripts are significantly different ($P < 0.05$).
[1]Water samples evaluated from 3 different commercial egg-processing facilities include water from washer 1 (W1) and water from washer 2 (W2).
[2]Three replicate visits per facility with triplicate samples (n = 9).

from 5 different egg-processing facilities and found that the average EWW temperature was 41.8°C and the average pH was 10.5. Kinner and Moats [11] reported that most of the commercial shell egg processing plants use 40 to 50°C water to wash eggs, and they suggested that certain bacteria may survive at these temperatures unless the pH is maintained between 10 and 11. Holley and Proulx [35] found that *Salmonella typhimurium* proliferated in EWW at 38 to 42°C, when the pH was ≤9.5, but not when the pH was ≥10.0. During the present study, the pH of the EWW in W2 in plant X was found to be below 10.0 during 2 of the 3 sample collections (readings of pH 9.9, 9.1 and 11.0).

Table 2 shows the total chlorine and soluble iron (ferrous) for EWW collected from plants X, Y, and Z. It is important to note that plant Y used city water to process eggs, whereas plants X and Z used well water to process eggs. Highest chlorine levels were found in EWW from plant Z (4.5 and 2.3 mg/L), followed by the EWW from plants X (2.7 and 2.6 mg/L) and Y (0.9 and 0.9 mg/L). Average values of soluble iron in EWW ranged from 0.3 to 1.6 mg/L. However, iron levels were found to be above the 2.0 mg/L limit that is recommended by the USDA [18] for facilities with voluntary egg grading in W1 in plant X during one of the sample collections (triplicate readings of 2.3, 2.7, and 2.6 mg/L). During another sample collection, iron levels in W1 from plant X were just below the regulatory limit (triplicate readings of 1.6, 1.7, 1.7 mg/L). Although the reason for the higher iron levels is unknown, plant X is an older facility with older equipment than plants Y or Z.

Total dissolved solids and TSS were measured on the EWW to characterize the amount of organic and inorganic product in the recirculation tank [28]. In plants Y and Z, values for TDS and TSS were higher in the EWW collected from W1 as compared with W2 (Table 3). The TDS values reported in the present study were higher than those previously reported by Curtis [23] and Knape et al. [15], who observed values of 4,090 mg/L and 1,400 to 2,850 mg/L, respectively. The TSS values were comparable to those previously reported for EWW by Hills and Hauser [36] (610 to 680 mg/L) but much lower than those observed by

TABLE 2. Chlorine and soluble (ferrous) iron levels found in egg wash water collected from plants X, Y, and Z[1,2]

	Chlorine (mg/L)		Iron (mg/L)	
Plant	W1	W2	W1	W2
X	2.7 ± 0.2[b]	2.6 ± 0.6[b]	1.6 ± 0.3[a]	0.8 ± 0.1[c]
Y	0.9 ± 0.1[c]	0.9 ± 0.1[c]	0.5 ± 0.02[cd]	0.3 ± 0.02[d]
Z	4.5 ± 0.3[a]	2.3 ± 0.3[b]	1.3 ± 0.1[b]	0.4 ± 0.01[d]

[a–d]Means ± standard error in the same heading (chlorine or iron) with no common superscripts are significantly different ($P < 0.05$).
[1]Water samples evaluated from 3 different commercial egg-processing facilities include water from washer 1 (W1) and water from washer 2 (W2).
[2]Three replicate visits per facility with triplicate samples (n = 9).

TABLE 3. Total dissolved solids (TDS) and total suspended solids (TSS) found in egg wash water collected from plants X, Y, and Z[1,2]

	TDS (mg/L)		TSS (mg/L)	
Plant	W1	W2	W1	W2
X	3,217 ± 403[cd]	3,031 ± 429[cd]	388 ± 49[cd]	467 ± 37[c]
Y	4,415 ± 553[b]	2,666 ± 64[d]	620 ± 31[b]	306 ± 26[d]
Z	8,231 ± 430[a]	3,564 ± 155[c]	796 ± 55[a]	429 ± 42[c]

[a–d]Means ± standard error in the same heading (TDS or TSS) with no common superscripts are significantly different ($P < 0.05$).
[1]Water samples evaluated from 3 different commercial egg-processing facilities include water from washer 1 (W1) and water from washer 2 (W2).
[w]Three replicate visits per facility with triplicate samples (n = 9).

Curtis [23] (1,013 mg/L) or Xu et al. [20] (1,856 to 4,150 mg/L). In the latter study [20], EWW was collected from egg-breaking facilities, in which losses to the waste stream are typically greater than that found in a shell egg processing facility. Both Curtis [23] and Knape et al. [15] indicated that the higher levels of organic material can decrease the effectiveness of the sanitizer and reduce the EWW pH.

Table 4 shows the TKN and COD for the EWW collected from plants X, Y, and Z. The TKN levels reflect the amount of protein lost to the waste stream, whereas COD is a measure of the organic material present in the waste stream. The TKN was determined on samples after they were distilled to evolve nitrogen gas that did not originate from protein. Highest values for TKN were found in EWW from W1 in plant Z (301.8 mg/L), followed by W1 and W2 in plant X (204.9 and 203.7 mg/L, respectively). Plant Y had the lowest TKN values (126.7 and 81.4 mg/L). Previous reports have shown that TKN values for EWW may range from 80 to 690 mg/L [36]. Variation in EWW TKN could be related to numerous factors in live production and processing variables. Genetic variations in hens, hen diet, hen age during lay, and hen management are a few of the factors that could affect the eggshell quality and the number of eggs broken in the washers [37]. Equipment maintenance, presence or absence of a rewash belt, cuticle removal, and oiling of eggs could also affect the number of broken eggs [37, 38, 39]. Plants X and Z both use rewash belts in which eggs continuously cycle through the washers until they are either cleaned or broken. This may explain the lower TKN values associated with EWW from plant Y where eggs are not rewashed. Ball et al. [38] and Wong et al. [39] suggested that oiling of eggs improved the shell strength, particularly when the oil was applied before washing and provided protection for the cuticle. The TKN values found in the EWW from plant X may have been lower than the TKN values found in the EWW from plant Z because plant X oils their eggs.

TABLE 4. Total Kjeldahl nitrogen (TKN) and chemical oxygen demand (COD) found in egg wash water collected from plants X, Y, and Z[1,2]

	TKN (mg/L)		COD (mg/L)	
Plant	W1	W2	W1	W2
X	204.9 ± 25.5[b]	203.7 ± 32.1[b]	3,243.6 ± 215.4[c]	3,157.3 ± 352.1[c]
Y	126.7 ± 5.22[c]	81.4 ± 11.1[d]	2,399.2 ± 135.5[cd]	1,764.2 ± 65.43[d]
Z	301.8 ± 13.2[a]	128.3 ± 11.8[c]	7,287.5 ± 820.7[a]	5,563.3 ± 954.7[b]

[a–d]Means ± standard error in the same heading (TKN or COD) with no common superscripts are significantly different ($P < 0.05$).
[1]Water samples evaluated from 3 different commercial egg-processing facilities include water from washer 1 (W1) and water from washer 2 (W2).
[2]Three replicate visits per facility with triplicate samples (n = 9).

Highest values for COD were found in the EWW from W1 and W2 in plant Z. Values for W1 at plant Z were more than double the values found in the EWW from W1 at the other 2 facilities. Similarly, COD values for the EWW from W2 at plant Z were 40 and 70% higher than the COD values for EWW from W2 in the other 2 facilities. These values are similar to those previously reported by Hills and Hauser [36] and by Hamm et al. [40] who found that EWW had COD values that the range from 1,350 to 15,760 and 1,200 to 26,300 mg/L, respectively. Similarly, Harris and Moats [41] found that COD varied from 2,500 to 66,000 mg/L.

CONCLUSIONS AND APPLICATIONS

1. The EWW from W1 in plant Z had the highest pH, chlorine, TDS, TSS, TKN, and COD.
2. The commercial egg-processing facility, which did not rewash their eggs (plant Y), had the lowest TKN and COD values in the EWW, suggesting that rewashing increases the likelihood that more eggs will be broken in the washers.
3. The commercial egg-processing facility, which oiled and rewashed their eggs (plant X), had lower TKN and COD values in the EWW than the facility that also rewashed eggs but did not oil them (plant Z). This suggests that oiling reduces the likelihood that the eggs will be broken during return visits to the washer.
4. Characterization of EWW from commercial shell egg processing facilities may be valuable for establishing pre-HACCP wastewaster discharge loads.

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