DESCRIPTION OF PROBLEM

Broiler processors in the United States annually slaughter approximately $9 \times 10^9$ broilers with a total live weight of $23 \times 10^6$ metric tons ($50 \times 10^6$ lb) [1]. An average of 26 L (7 gal) of potable water per broiler is used during processing [2], thus a US processing plant typically uses over 5 million L (1.3 million gal) of water daily. Water is primarily used for scalding, feather picking, carcass washing, chilling, and cleaning of equipment and facilities. Water is also the pri-
mary means used to transport offal (i.e., processing by-products) out of various production areas in a cumulative poultry processing wastewater (PPW) stream [3].

After shackle-broiler carcasses have been stunned, killed, bled, and scalded, feathers are removed in a series of automated pickers which use rubber fingers to pull feathers from the carcass. Water sprays are used to flush feathers from the pickers into a flume which transports the feathers and any associated external debris to an offal recovery area within the processing plant [4].

The PPW generated by the feather picking system combines with PPW produced in the other broiler slaughter functions and travels by a single flume to an offal recovery system. Offal recovery from the slaughter PPW flume typically consists of a primary internal-rotary mechanical screen that is designed to capture and remove the feathers, allowing PPW effluent to pass through the screen surface for further treatment. A portion of the effluent from this screen is typically recirculated back through the flumes to conserve water. The average amount of water used in a typical feather picking system has been estimated to be 10.6 L (2.8 gal) per broiler, where 50% of the water used is potable and the other 50% is recirculated [5].

Limited data has been published establishing the actual environmental effect of offal feather fluming on the total PPW stream, which is determined by calculating the mass or load of a particular wastewater parameter. This lack of data stems from the practice of screening and recirculating feather flume PPW. This practice prevents an accurate determination of the volume of water used under full-scale commercial plant conditions, which is required for accurate PPW load calculation. A laboratory bench-scale method was developed to model the flume transport of offal feathers for use in calculating predictive PPW loading rates. The resulting PPW loadings can be used by poultry processors in the management of current full-scale commercial PPW systems and in future planning of new PPW systems.

Two experiments on offal feather rinse PPW using a laboratory bench-scale method were conducted to (1) measure the variation between individuals and groups of carcasses based on 2 bleed times and 2 scald temperatures and (2) establish mean carcass PPW loads in grams per kilogram of live weight (g/kgLW) for the common wastewater analytical parameters of chemical oxygen demand (COD), total solids (TS), total suspended solids (TSS), total volatile solids (TVS), and total Kjeldahl nitrogen (TKN).

MATERIALS AND METHODS

Experiment 1

Male broilers were selected from a University of Georgia farm flock reared at a stocking density of 0.07 m²/bird (0.75 ft²/bird), to 8 wk of age in six 32-bird pens on pine shavings. Four broilers were randomly selected from each pen (n = 24) and then randomly assigned to 1 of 4 treatments (n = 6): (1) short bleed, soft scald; (2) short bleed, hard scald; (3) long bleed, soft scald; and (4) long bleed, hard scald.

Bleed time levels were set at short (60 s) or long (120 s). Experimental bleed times were established based on common industry practices. Modern broilers must be bled a minimum of 60 s to ensure exsanguination before entry into immersion scalding tanks. Conversely, anecdotal evidence in commercial processing plants indicates that feather removal becomes substantially more difficult when bleed times exceed 120 s. The target bleed time established by most US processing plants is 90 s. However, multiple factors affect the actual bleed times achieved at specific broiler slaughter operations. These factors include changes in line speed and blood tunnel configuration.

Scald water temperature levels were set at soft (50°C; 122°F) or hard scald (60°C; 140°F). Soft scalding of broilers is used in commercial slaughter operations that desire the retention of the outer yellow-colored epidermis of defeathered carcasses. However, feather removal is more difficult in soft versus hard scalding. Conversely, the epidermis is removed along with the feathers in hard scalding, which is used by the majority of commercial slaughter plants in the United States, as feather removal is enhanced by scalding at a higher temperature.

Feed was withdrawn from the flock 10 h before processing. Selected broilers were placed in solid-bottom coops and held for 4 h before pro-
cessing. Broilers were processed individually. Each broiler was removed from a coop by hand, weighed, and hung from a shackle line. Each bird was electrically stunned for 15 s using a 25 V DC high-frequency stunner (12–15 mA per bird) followed by a 25 V AC poststunner for 10 s. Each broiler was transferred from the shackle line to a hand-held shackle, decapitated within 30 s of exiting the stunning tunnel, and allowed to bleed for either 60 or 120 s. Previous research has shown that there is no significant difference in blood loss volume between broilers exsanguinated via neck cut versus decapitation [6].

Blood drained from the carcass was collected in a plastic bag for the allotted time. The collection bag was then removed and any remaining blood entered the scalding vessel. Each carcass was then immersion scalded in an individual vessel containing 16 L of potable water for 2 min at either 50 or 60°C. Carcasses were vigorously agitated in the scalding vessel manually by the hand-held shackle to simulate air agitation without incurring loss of scalder water. Fresh scalder water was used for each carcass.

After scalding, carcasses were suspended and allowed to drip for 10 s before picking. A representative sample of approximately 100 g of wet feathers were plucked by hand from the chest, legs, back, and wings of each carcass and placed in a preweighed plastic bag. Weight of wet feathers was determined and 2 L of rinse water was added and the bag was manually agitated for 2 min. The resulting feather rinse PPW was then sieved (500 µm) to recover feathers and the rinse PPW sample for each carcass was collected and placed on ice.

**Experiment 2**

One hundred twenty 42-d-old commercial broilers were used for this experiment. The experiment was conducted on 1 day per week for 3 wk, with 40 birds processed each week. On each of the 3 d of processing, 40 birds from 1 flock were randomly selected from a dump coop at a commercial processing plant and transferred to plastic top-loading coops for transport to the processing laboratory. The broilers (n = 120) were randomly placed into the 4 treatments (n = 30) similar to experiment 1 (Exp1). The birds were then processed as described in Exp1 with some exceptions. (1) Broilers in experiment 2 (Exp2) were processed in groups of 5 birds (24 total groups, 6 groups per treatment). (2) The 5 broilers in each group were scalded in succession in one scalding vessel containing 20 L of potable water, with fresh scalder water being used with each group of 5 birds. (3) Approximately 100 g of representative wet feathers were removed from each broiler’s chest, legs, back, and wings and collectively placed in a 10-L plastic bottle and weighed. Four liters of rinse water was added and the bottle was manually agitated for 2 min.

Bird handling within the experiments was conducted in accordance with the principles and specific guidelines presented in *Guidelines for the Care and Use of Agricultural Animals in Research and Teaching* [7], and experimental protocol was reviewed and approved by the University of Georgia Animal Care and Use Committee.

**Analytical Methods**

The PPW samples collected during Exp1 were analyzed for COD (method 5220D), TS (method 2540B), TSS (method 2540D), TVS (method 2540E), and TKN (method 4500-NorgD) [8]; PPW samples collected during Exp2 were analyzed for COD, TS, and TSS.

**Data Treatment**

**Weight of Feathers.** Each feather collection container was preweighed in grams. After the feathers were collected, the weight of the empty container was subtracted from weight of the collected feathers and container to determine the total weight of feathers collected.

**Feather Data Values.** Wet feathers, on average, equal 21% of a broiler’s live weight [9]. Thus, each broiler’s measured live weight (Exp1) or average broiler live weight in each 5-bird group (Exp2) was multiplied by 0.21 to determine the weight of total wet feathers per broiler if carcasses were plucked clean. During the experiment, approximately 100 g of
wet feathers were collected from each carcass. Load values were normalized to 21% of each broiler’s (Exp1) or average broiler (Exp2) live weight to account for the difference in actual feathers collected and total feathers present on each carcass. Normalization was accomplished by dividing the 21% of live weight value by the actual weight of feathers collected from each carcass (Exp1) or group of 5 carcasses (Exp2). Each concentration (mg/L) and load (g/kg lwt) data point was then multiplied by the resulting normalization value.

**Feather Rinse PPW.** If the potable water background concentration (mg/L) for a parameter was at a detectable level, that background concentration value was subtracted from the data point. If the background sample concentration was below detectable limit, the concentration data point remained as reported. A load value in grams per bird was determined for each data point by multiplying the volume of rinse water by the concentration (mg/L) of that parameter and dividing by 1,000. As the loading value in Exp2 represented a 5-bird group, results were divided by 5. The result of the normalized feather weight in grams was multiplied by the final load value of grams per bird. A load in g/kg lwt was then calculated by dividing the grams per bird value by the kilogram live weight of each broiler (Exp1) or average broiler live weight in each group (Exp2).

### Statistical Analysis

Data were subjected to statistical analysis using the GLM procedure of the SAS/STAT program [10]. Data from the 4 treatments with 6 replications were analyzed by factorial ANOVA (2 × 2). The feather rinse PPW data were first run as ANOVA with an interaction term between the main factors (i.e., bleed time and scald temperature). If the interaction was not significant (P > 0.05), a Student’s t-test was run to analyze each factor independently [10]. Differences in means were regarded as significant at P ≤ 0.05.

### RESULTS AND DISCUSSION

Previously published research documents increase in the concentrations of typical PPW constituents within cumulative slaughter PPW flumes over the last several decades. In 1972, Hamm surveyed 10 southeast United States poultry processing plants and reported average slaughter PPW flume concentrations of 1,919 mg/L for COD, 974 mg/L for TS, and 808 mg/L for TVS [11]. Carawan et al. reported TS and TSS concentrations of slaughter PPW flumes of 894 and 512 mg/L, respectively [4]. Hamza et al. reported that the mean COD from a slaughter PPW flume was 1,449 mg/L [12]. Merka reported an average TSS from slaughter flume PPW from 5 broiler processing plants to be 1,667 mg/L [13]. However, in none of these publications were the reported concentrations converted to mass loadings due to the lack of accurate information available on water volumes used.

Based on statistical analysis of PPW results from Exp1 and Exp2, no interactions were observed between the main effects for any of the wastewater parameters tested. Therefore, the main effects of bleed time and scald temperature were analyzed independently.

**COD: Organic Load**

**Exp1.** The COD mean loading results for feather rinse PPW are summarized in Table 1. No significant difference was observed in mean COD load based on bleed time (P = 0.6712), which averaged 0.908 g/kg lwt. However, scald temperature did produce a significant difference in feather rinse PPW COD loading (P = 0.0207). Results showed that the hard-scald treatment produced a mean COD load of 0.991 g/kg lwt, which was significantly greater than the soft-scald treatment load of 0.824 g/kg lwt. Therefore, a higher hard scalding temperature may result in a significantly greater amount of organic matter being retained in carcass feathers post-scald that are subsequently rinsed from the feathers during picking.

**Exp2.** The COD loading results for Exp2 based on bleed time and scald temperature are summarized in Table 2. No significant difference was observed in the feather rinse PPW means based on bleed time (P = 0.3874) or scald temperature (P = 0.7024), which averaged 1.033 g/kg lwt.

**TS**

**Exp1.** The feather rinse PPW TS results for bleed time and scald temperature are summa-
Table 1. Offal feather rinse wastewater mean load (grams per kilograms of live weight ± SEM) values for 5 wastewater parameters at 2 bleed times (60 and 120 s) and 2 scald temperatures (50 and 60°C) for 24 male broilers (12 carcasses per level) in experiment 1

<table>
<thead>
<tr>
<th>Item</th>
<th>COD¹</th>
<th>TS²</th>
<th>TSS³</th>
<th>TVS⁴</th>
<th>TKN⁵</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bleed time (s)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>60</td>
<td>0.924 ± 0.06</td>
<td>0.603 ± 0.07</td>
<td>0.310 ± 0.02</td>
<td>0.475 ± 0.06</td>
<td>0.089 ± 0.006</td>
</tr>
<tr>
<td>120</td>
<td>0.892 ± 0.04</td>
<td>0.677 ± 0.07</td>
<td>0.272 ± 0.02</td>
<td>0.551 ± 0.05</td>
<td>0.087 ± 0.003</td>
</tr>
<tr>
<td>Scald temperature (°C)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>50</td>
<td>0.824b ± 0.03</td>
<td>0.585 ± 0.05</td>
<td>0.285 ± 0.01</td>
<td>0.512 ± 0.06</td>
<td>0.083 ± 0.003</td>
</tr>
<tr>
<td>60</td>
<td>0.991a ± 0.06</td>
<td>0.695 ± 0.08</td>
<td>0.296 ± 0.03</td>
<td>0.514 ± 0.06</td>
<td>0.093 ± 0.006</td>
</tr>
</tbody>
</table>

¹COD = chemical oxygen demand.  
²TS = total solids.  
³TSS = total suspended solids.  
⁴TVS = total volatile solids.  
⁵TKN = total Kjeldahl nitrogen.

No significant difference was observed between the bleed time ($P = 0.4352$) or scald temperature treatments ($P = 0.2441$). The PPW TS load averaged 0.640 g/kg lwt.

Exp2. Based on the results of mean TS loadings, no significant difference was noted between the bleed time treatments ($P = 0.9083$), which averaged 2.040 g/kg lwt. However, the soft-scald treatment produced a mean TS load of 2.136 g/kg lwt, which was significantly greater ($P = 0.0182$) than the hard-scald treatment at 1.945 g/kg lwt. The TS results for Exp2 bleed time and scald temperature are summarized in Table 2. Based on these results, a lower soft-scalding temperature may result in a significantly greater amount of solids being retained in carcass feathers postscald. In addition, given that the mean COD (i.e., organic) loads were not significantly different between the 2 scald temperatures, the external debris on the commercial flock broilers was substantially inorganic in nature. These inorganic solids are most likely related to the silica and other inorganic components in the fecal material, feed, and dust generated in commercial broiler houses over multiple flocks.

TSS

Exp1. The TSS load (g/kg lwt) results from Exp1 are summarized in Table 1. No significant difference was observed between the bleed time ($P = 0.2229$) or scald temperature treatments ($P = 0.7175$). The feather rinse PPW TSS load averaged 0.291 g/kg lwt. Total solids can be defined in terms of particulate size as the sum of TSS and total dissolved solids (TDS) as represented in the equation $TS = TSS + TDS$ [13]. The mean percentage of TSS and TDS in relationship to

Table 2. Offal feather rinse wastewater mean load (grams per kilograms of live weight ± SEM) values for 3 wastewater parameters at 2 bleed times (60 and 120 s) and 2 scald temperatures (50 and 60°C) for 120 commercial broilers (60 carcasses per level) in experiment 2

<table>
<thead>
<tr>
<th>Item</th>
<th>COD¹</th>
<th>TS²</th>
<th>TSS³</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bleed time (s)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>60</td>
<td>1.100 ± 0.11</td>
<td>2.035 ± 0.06</td>
<td>0.360 ± 0.03</td>
</tr>
<tr>
<td>120</td>
<td>0.966 ± 0.10</td>
<td>2.045 ± 0.06</td>
<td>0.327 ± 0.03</td>
</tr>
<tr>
<td>Scald temperature (°C)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>50</td>
<td>1.003 ± 0.09</td>
<td>2.136b ± 0.05</td>
<td>0.319 ± 0.03</td>
</tr>
<tr>
<td>60</td>
<td>1.063 ± 0.12</td>
<td>1.945b ± 0.05</td>
<td>0.368 ± 0.03</td>
</tr>
</tbody>
</table>

¹COD = chemical oxygen demand.  
²TS = total solids.  
³TSS = total suspended solids.
TS was calculated for all feather rinse PPW samples. The mean percentage for TSS versus TDS for all 24 samples was 46 versus 54%, respectively.

**Exp2.** No significant difference was found between the bleed times ($P = 0.4640$) or the scald temperatures ($P = 0.2806$) in Exp2, which averaged 0.344 g/kg lw. The TSS results for Exp2 are summarized in Table 2. The mean percentage for TSS versus TDS for all 120 samples was 17 versus 83%, respectively.

**TVS**

**Exp1.** The TVS results for Exp1 are summarized in Table 1. No significant difference was found between the bleed time ($P = 0.3473$) or scald temperature treatments ($P = 0.9808$) for TVS, which averaged 0.513 g/kg lw. The TS can be defined in terms of organic content as the sum of TVS (i.e., organic) and total fixed solids (TFS; i.e., inorganic) as represented in the equation $TS = TVS + TFS$ [13]. The mean percentage for TVS versus TFS for all 24 samples was 81 versus 19%, respectively.

**TKN**

**Exp1.** No significant difference was observed between the bleed time ($P = 0.8223$) or scald temperature treatments ($P = 0.1337$) for TKN, which averaged 0.088 g/kg lw. The mean TKN results for Exp1 based on the 2 main effects are summarized in Table 1.

Plumber et al. [14] reported scalder PPW loadings produced by the same Exp1 broilers and Exp2 broiler flocks. For Exp1, bleed time significantly affected COD, TS, TVS, and TKN scalder PPW loadings, but not TSS loading. Scald temperature had no effect on any of the parameters tested on scalder PPW produced in Exp1. For Exp2, bleed time significantly affected COD, TVS, and TKN scalder PPW loadings, but not TS or TSS loading. Scald temperature had no effect on any of the parameters tested on scalder PPW in Exp2 [14].

**Calculating PPW Impacts**

Dry feathers account for approximately 5% of a broiler’s live weight [15, 16]. However, feathers have a high water absorptive capacity and thus retain a substantial volume of water during the scalding process. The moisture content of wet feathers is 75 to 80% after scalding [17], and, on average, wet feathers account for 21% of a broiler’s live weight [9]. Thus a processing plant slaughtering 250,000 broilers each day at an average of 2.0 kg (4.4 lb) per bird live weight, can expect to handle 105,000 kg (231,000 lb) of offal feathers on a wet weight basis. Whereas feathers themselves are somewhat resistant to degradation in PPW, the feces, dirt, and other external debris captured within wet feathers can substantially increase the concentration (mg/L) of organic solids and nutrients in PPW.

The mean carcass feather rinse PPW loads (g/kg lw) produced by this laboratory bench-scale method can be used to calculate the potential economic effect of live production practices (e.g., broiler external cleanliness) based on wastewater treatment costs. For example, the mean feather rinse PPW TS load for the commercial flock (i.e., dirtier) carcasses in Exp2 was 2.030 versus 0.640 g/kg lw for the experimental flock (i.e., cleaner) broilers in Exp1. Thus, on average, an additional 1.390 g/kg lw of TS entered the feather rinse PPW for the commercial flock carcasses. Using the typical value of $0.25/lb of TS for a municipal surcharge fee, the following calculation can be made for a hypothetical poultry processing plant slaughtering 250,000 birds per day, weighing 2.5 kg per bird for 260 processing days per year:

$$\begin{align*}
(250,000 \text{ birds/d}) & \times (2.5 \text{ kg/lwt per bird}) = 625,000 \text{ kg/lwt/d}; \\
(625,000 \text{ kg/lwt/d}) & \times (1.390 \text{ g of TS/kg lw}) = 868,750 \text{ g of TS/d}; \\
868,750 \text{ g of TS/d} & = 1,915 \text{ lb of TS/d}; \\
(1,915 \text{ lb of TS/d}) & \times ($0.25/lb of TS) = $478.75/d; \\
($478.75/d) & \times (260 \text{ processing days/yr}) = $124,475/yr.
\end{align*}$$
Thus, a poultry processor can use the results produced by this model to predict a substantial cost savings in reduced wastewater treatment fees by implementing live production practices that reduce external debris on broilers. In the example calculation provided, the effect in reduced surcharges for TS PPW loading alone could result in an annual savings of almost $125,000.

CONCLUSIONS AND APPLICATIONS

1. Duration of bleed time during laboratory-controlled broiler slaughter did not significantly affect feather rinse PPW mass loading (g/kg bw) values.
2. Hard scalding at 60°C significantly increased COD feather rinse PPW loading (g/kg bw), whereas soft scalding at 50°C significantly increased TS loading during laboratory-controlled broiler slaughter experiments.
3. External debris on commercially raised broilers significantly effects feather rinse PPW TS loadings (g/kg bw) and is dominated by inorganic, fine-soluble TDS particles.
4. Commercial flock broiler mean PPW loadings (g/kg bw) generated by a model of feather flume transport were 1.033 for COD, 2.040 for TS, and 0.344 for TSS.
5. Mean carcass PPW mass loading (g/kg bw) values generated by the laboratory bench-scale model described can be used to calculate economic effect of pollutant reductions practices based on established wastewater treatment costs.

REFERENCES AND NOTES

7. FASS. 2010. Guidelines for the Care and Use of Agricultural Animals in Research and Teaching. 3rd ed. Federation of Animal Science Societies, Champaign, IL.